Report of the Ninth Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer

(Geneva, Switzerland, 14-16 May 2014)
REPORT OF THE
NINTH MEETING OF THE OZONE RESEARCH MANAGERS
OF THE PARTIES TO THE VIENNA CONVENTION FOR THE
PROTECTION OF THE OZONE LAYER
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INTRODUCTION

The 9th meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer was held at the Headquarters of the World Meteorological Organization (WMO) in Geneva, from 14 to 16 May 2014.

The meeting was organized by the Ozone Secretariat of the United Nations Environment Programme (UNEP) in cooperation with the World Meteorological Organization (WMO), in accordance with decision I/6 of the Conference of the Parties to the Vienna Convention for the Protection of the Ozone Layer. A list of participants is provided in Annex A to the present report.

OPENING OF THE MEETING

The meeting started on Wednesday, 14 May 2014.

Opening Statement (Tina Birmpili, Executive Secretary, Ozone Secretariat)

Tina Birmpili, the Executive Secretary of the Ozone Secretariat, welcomed the participants on behalf of the Executive Director of UNEP. She thanked the World Meteorological Organization (WMO) for hosting the meeting, and working with the Secretariat to organize the 9th meeting of the Ozone Research Managers. The Vienna Convention and its Montreal Protocol constitute the international ozone protection regime that was one of the undoubted success stories of international cooperation. She noted that the ozone community needs to change the narrative if the momentum is to be kept alive. In order to be part of an emerging agenda or an agenda that continues to be relevant to the decision makers, including and in particular those who decide on funds, on policy, and research priorities, there is a need to shift the notion that the ozone layer protection is already achieved, and thus the job is done. While it is important to recognize the achievements, it also is important to emphasize the challenges that lie ahead.

Ms Birmpili continued to say that Universal ratification was one of the key elements of the success of the Montreal Protocol, and that the independent assessment of the latest information on scientific, environmental, technical, and economic aspects of ozone layer depletion and protection was another parameter of success. The Parties have taken important policy decisions based on the assessments, and that it is exactly that interface which integrated the science and policy, scientific uncertainty, and policy implementation that made the Montreal Protocol successful. She informed the participants that the outcome of the 9th ORM meeting will be presented to the Conference of the Parties to the Vienna Convention in November this year. The Conference of the Parties will take its decisions to address the recommendations of the ORM, and those decisions will be taken up at the highest political level in the countries for implementation. It is the responsibility of the ORM meeting to make sure that the report of the meeting is drafted in such a way that is policy relevant and comprehensive to the Parties.

Welcome Statement (Deon Terblanche, WMO)

Mr Deon Terblanche, Director of the Atmospheric Research and Environment (ARE) Branch under which the Global Atmospheric Watch (GAW) Programme resides, welcomed all the delegates to the 9th meeting of the WMO/UNEP Ozone Research Managers. He conveyed the greetings and best wishes of the WMO Secretary General, Mr Michel Jarraud. Mr Terblanche mentioned the long fruitful relationship between WMO and UNEP on working toward understanding and protecting the ozone layer. He mentioned that this work remains one of the shining examples of the ability of humanity to achieve great outcomes through collective action. These are valuable reminders of success in a world that has become increasingly complex and hesitant in tackling global challenges. He thanked the ozone managers, who together with their teams of experts, have contributed greatly to the success of the Vienna Convention and its Montreal Protocol.

The record depletion of stratospheric ozone over the Arctic three years ago, the importance of stratospheric ozone to life on Earth, and the increasing awareness of the links between stratospheric ozone and the climate system imply that focus should not be lost now. Observations
from the ground, in the air, and from space, and operated by dedicated and well-trained experts, remain a cornerstone to ongoing success. Echoing the sentiments expressed by Ms Birmpili, he also highlighted how important it is to have comprehensive and comprehensible recommendations in the final report as an outcome to this meeting.

Scientific Assessment of Ozone Depletion and the Interface with ORM Recommendations (Paul Newman, SAP Co-Chair, and Michael Kurylo, 8th ORM Co-Chair)

As Chair of the 8th Meeting of Ozone Research Managers that was held in Geneva Switzerland in May 2011, Mr Michael Kurylo provided an overview on the role of the meetings of Ozone Research Managers and their interface with the three WMO/UNEP Assessments (Scientific, Environmental, and Technology and Economic). He emphasized that the purpose of each ORM meeting is to review ongoing research and monitoring programmes for ozone and UV-B with an emphasis on (i) assessing research (including measurement calibration and archiving) related to the health and environmental effects of ozone modifications, (ii) identifying research and monitoring gaps, (iii) ensuring national and international coordination, and (iv) developing a set of recommendations for future research and expanded cooperation in developed and developing countries. He described the highly complementary, but distinctly different, roles of the ORM reports and the three WMO/UNEP Assessments. Whereas all are required under the Vienna Convention and its Montreal Protocol and serve as communication devices between the research community (striving for better understanding) and decision makers (focused on informed action), the Assessments enable the Parties to evaluate control measurements under the Montreal Protocol. The Assessments constitute neither policy recommendations nor research-planning documents, but provide input for both. The ORM reports, on the other hand, specifically address research and monitoring needs in light of the scientific understanding provided by the Assessments, and do make specific recommendations to the Parties regarding international funding for improved research coordination and networking. He then briefly summarized the 9th ORM agenda items, which include (i) a review of 8th ORM Recommendations and activities under the Vienna Convention Trust Fund, (ii) presentations on the state of the ozone layer including climate links, (iii) updates on international monitoring programmes, (iv) satellite research and monitoring programmes (present and future), (v) regional reports on ozone and UV research and monitoring taking into account the available national reports, and (vi) development of current recommendations in four key areas (research, systematic observations, data archiving and stewardship, and capacity building) derived from all of the information provided and presented.

On behalf of the Scientific Assessment Panel (SAP) Co-Chairs, Mr Paul Newman (NASA Goddard Space Flight Center) informed the group that the Montreal Protocol mandates an assessment of ozone and ozone depletion under Article 6 at least every four years. UNEP initiated the assessment panel process in 1988 pursuant to this article. The SAP leads the assessment process, and the “Scientific Assessment of Ozone Depletion: 2014” is in progress, and will be delivered at the end of 2014.

The assessments are founded upon the results derived from the science community. In order to perform these assessments, the SAP requires:

- High-quality measurements of ozone-depleting substances (ODSs), greenhouse gases (GHGs), and related gases are crucial for supporting the Montreal Protocol.
- High-quality measurements of total ozone are crucial to detecting recovery.
- High-quality measurements of ozone profiles are crucial to detecting recovery in the upper stratosphere.
- Interpreting polar ozone requires observations of total ozone, ozone profiles, and ancillary observations (e.g., winds, temperature, ClO, HCl).
- Cooling of the stratosphere is caused by increasing GHGs. Global observations of stratospheric observations are needed, plus ground observations of the upper stratosphere for calibration and validation.
- Do we have the necessary observations for diagnosing the meteorological changes in the Southern Hemisphere as the ozone hole begins to recover?
• Observations of long-lived species (e.g., SF₆ and CO₂ for age, H₂O for vertical transport) are necessary to diagnose the slow Brewer-Dobson circulation.
• Models of the stratosphere/troposphere system integrate our knowledge of the atmospheres. Model output is fundamental to projecting the future state of the stratosphere.

Election of the Co-Chairs *(Tina Birmpili, Executive Secretary, Ozone Secretariat)*

On the basis of a suggestion put forward by the Ozone Secretariat, the meeting decided to have two Co-Chairs, one from a developed-country Party and another from a developing country Party, to conduct the 9th meeting of the Ozone Research Managers. Having two Co-Chairs from an Article 5 (developing country) Party and a non-Article 5 (developed country) Party was a formula that has been used successfully in the working group meetings of the Montreal Protocol.

Mr Michael Kurylo (United States of America) and Mr Gerrie Coetzee (South Africa) were unanimously elected Co-Chairs of the 9ORM meeting.

Adoption of the 9th ORM Agenda *(9th ORM Co-Chairs)*

The agenda was unanimously adopted as contained in Annex B. The summaries of the presentations given under sessions 1 to 5 are provided below. Full presentations are also available separately.

**SESSION 1: INTRODUCTORY SESSION: THE VIENNA CONVENTION**

**Review of the Recommendations of the Eighth Meeting of the Ozone Research Managers, Geneva, May 2011 (WMO Global Ozone Report No. 53) and the Resultant Decisions of the Ninth Conference of the Parties to the Vienna Convention, Bangkok, November 2011 (Michael Kurylo, 8th ORM Chair)**

As Chair of the 8th Meeting of Ozone Research Managers (Geneva, Switzerland – May 2008) Mr Michael Kurylo reviewed the recommendations from that meeting and the resultant decisions of the 9th Meeting of the Conference of the Parties to the Vienna Convention (Bali, Indonesia – November 2011). The 8th ORM recommendations were formulated against a background of information from the 2010 Scientific Assessment of Ozone Depletion that the complexities of ozone and UV science and their interactions with changing climate require (i) continuation and expansion of systematic measurement and analysis capabilities for tracking the evolution of ozone- and climate-related source gases and parameters, (ii) detection and tracking the stabilization and expected recovery of stratospheric ozone from the influence of ODSs while responding to a changing climate, (iii) attribution of changes in radiation forcing to changes in the ozone profile or to effects of climate change, and (iv) derivation of a global record of ground-level UV radiation. These requirements led to specific recommendations in the areas of research, systematic observations, data archiving, and capacity building that are detailed in the full report of the 8th ORM, which can be obtained at <http://ozone.unep.org/Meeting_Documents/research-mgrs/8orm/8ORM_full_report.pdf>.

These recommendations were presented at the 9th COP and formed the basis by the parties to enact Decision IX/2 (Recommendations Adopted by the Ozone Research Managers at Their Eighth Meeting) (Annex C of this report), which urged the Parties to make every attempt at implementing the 8th ORM recommendations in all four areas. In particular, this Decision encouraged the Parties to:

• Adopt the recommendations in report No. 53 of the World Meteorological Organization Global Ozone Research and Monitoring Project.
• Maintain research capabilities that enable measurements and scientific understanding of ozone depletion and evolution in a changing atmosphere.
• Maintain, expand and integrate systematic ozone-related observations that are critical to understanding and monitoring the long-term changes in atmospheric composition and the associated response in ground level ultraviolet radiation.

• Continue to implement the recommendations of the 8th meeting of the Ozone Research Managers in relation to data archiving and to encourage the reprocessing and salvage of archival data.

• Accord priority to supporting and implementing the various capacity-building activities recommended by the Ozone Research Managers and to encourage the Ozone Research Managers to develop measures that would enable them to assess the effectiveness of capacity-building activities in the future.

With respect to the Trust Fund, the following recommendations were made:

• To urge all parties and relevant international organizations to make voluntary financial and/or in-kind contributions to the Trust Fund.

• To request the Secretariat to continue to invite parties and relevant international organizations annually to make voluntary contributions to the Fund and, with each such invitation to parties, to report on the prior years’ contributions, funded activities and planned future activities.

• To request the Secretariat and invite the World Meteorological Organization to continue their cooperation with regard to activities funded by the Trust Fund.

• To request the Secretariat and invite the World Meteorological Organization to strive for regional balance in the activities supported by the Trust Fund and to encourage complementary funding to maximize Trust Fund resources.

• To request the Secretariat to report to the Conference of the Parties at its tenth meeting on the operation of, contributions to and expenditures from the Trust Fund and on the activities funded by the Trust Fund since its inception.

Activities under the Vienna Convention Trust Fund for Research and Systematic Observation Relevant to the Vienna Convention

The Status of the Trust Fund (Meg Seki, Ozone Secretariat)

In accordance with the request of the Conference of the Parties to the Vienna Convention in decision VI/2, the United Nations Environment Programme (UNEP), in consultation with the World Meteorological Organization (WMO), established an extra-budgetary fund for receiving voluntary contributions from the parties and international organizations for the purpose of funding certain research and observation activities related to the Convention in developing countries and countries with economies in transition. In 2008, the Ozone Secretariat and WMO agreed on a memorandum of understanding (MOU) on the institutional arrangements for making decisions on the allocation of funds in the Trust Fund, and the Parties approved the MOU in the same year. The total funds received by the Trust Fund since 2003 amount to US$277,454 (contributors: Andorra, Czech Republic, Estonia, Finland, France, Kazakhstan, South Africa, Spain, Switzerland, and the United Kingdom); the total expenditure to date is US$175,828; and the existing balance is US$101,828.

The Trust Fund was initially established in February 2003, with a five-year term ending on 31 December 2007. Upon request of the Conference of the Parties in decision VII/2, UNEP extended the life of the Trust Fund to 31 December 2015. The Trust Fund will close at the end of 2015 unless the Parties request that UNEP extend it once again. The Conference of the Parties to the Vienna Convention, during its tenth meeting in November 2014, is expected to consider the status of the Trust Fund and take a decision on the way forward, including whether or not to extend its life beyond 2015.
**Report on Planned Activities under the Trust Fund** (Geir Braathen, WMO)

Mr Geir Braathen started out by underlining the importance and usefulness of the activities carried out so far under the Vienna Convention Trust Fund for Systematic Observations and Research. In particular, training courses, such as the one organised in the Czech Republic in 2011, are well received by the participants.

The WMO/GAW Scientific Advisory Group for Ozone has discussed future needs for activities that can help to improve data quality and knowledge transfer, and the following are suggested for the next 2 to 3 years:

- Transport and installation of a Dobson observation hatch to be moved from Switzerland to Nairobi. Cost estimate: US $15,000.
- Dobson intercomparison for Africa. Cost estimate: US $50,000.
- Dobson intercomparison for South-West Pacific (Australia, New Zealand, Indonesia, Malaysia, Philippines). Cost estimate: US $30,000.
- Dobson intercomparison for South America. Cost estimate: US $50,000.
- Brewer Users’ Group meeting and training course, proposed to be held in Thailand. This activity can be funded partly through the Brewer Trust Fund, with support from the Canadian Government. Cost to the Vienna Convention Trust Fund: US $20,000.

**Discussion on the Way Forward for the Trust Fund** (Meg Seki, UNEP)

The following options for the way forward with the Trust Fund were presented for consideration by the meeting so that suggestions and advice of the ORM could be conveyed to the Conference of the Parties:

- Option 1: To continue the Trust Fund and its operation with business as usual.
- Option 2: To continue the Trust Fund with some changes in its operation:
  (a) Simply fund the participation of Article 5 experts in international meetings relevant to research and monitoring or for fellowships.
  (b) Adjust the procedure to invite contributions only towards specific projects or activities.
  (c) Involve another organization as a co-partner for specific tasks, e.g., identifying co-financiers and fundraising, designing activities and projects, and coordinating activities.
- Option 3: To close down the Trust Fund.

Further details on the Trust Fund issues are provided in document UNEP/OzL/Conv.ResMgr/9/2.

**Appointment of Discussion Leaders and Rapporteurs for the Various Recommendation Areas – Research Needs, Systematic Observations, Data Archiving, Capacity Building**

(9th ORM Co-Chairs)

Discussion leaders and rapporteurs for the recommendation areas were selected as follows:
- Greg Bodeker and John Pyle were chosen to introduce the area of “Research Needs.” Paul Newman and A. R. Ravishankara were chosen as rapporteurs.
- Wolfgang Steinbrecht and Jean-Christopher Lambert were selected to lead the discussion on “Systematic Observations,” with P. K. Bhartia and Neil Larsen as rapporteurs.
- “Data Archiving and Stewardship” would be to be introduced by Martine De Mazière and John Rimmer, with Stephen Montzka and Stoyka Netcheva as rapporteurs.
- Ayité-Lô Ajavon and Geir Braathen took on the task to lead the discussion on “Capacity Building,” with Anne Thompson and Matt Tully as rapporteurs.

SESSION 2: THE STATE OF THE OZONE LAYER AND INTERACTIONS BETWEEN OZONE LAYER DEPLETION AND CLIMATE CHANGE

The Current and Future States of the Ozone Layer (Wolfgang Steinbrecht, DWD)

Ground- and space-based observations show that total ozone columns over most of the globe have levelled off since around 2000, or have even been increasing slightly. The large decline observed from the 1960s to the late 1990s has definitely ended. Space- and ground-based observations also show that ozone in the upper stratosphere has been increasing over the last 10 to 15 years. These data show that the Montreal Protocol for the protection of the ozone layer has successfully curbed the ozone decline.

Model simulations of future ozone indicate that, apart from the expected decline of ozone depleting substances (ODSs), future levels of greenhouse gases (GHGs), especially CO₂, N₂O, and CH₄, will play important roles in the expected recovery of the ozone layer: GHGs warm the troposphere, but they (mostly CO₂, also H₂O) also result in substantial cooling of the stratosphere. This cooling changes the rates of chemical reactions affecting ozone. Tropospheric warming and stratospheric cooling are also expected to increase the speed of the global mean meridional Brewer-Dobson circulation, especially in the second half of the 21st century. Due to these climatic changes, and due to the expected ODS decline, ozone levels are projected to recover to values higher than observed in the 1980s over most of the globe. The tropics are an exception, where ozone columns are projected to remain slightly below 1980s levels due to the increase of the Brewer-Dobson Circulation.

While CO₂ is chemically inert, N₂O and CH₄ are broken down in the stratosphere. Their future levels directly influence ozone through NOₓ and HOₓ chemical cycles. Generally, increased N₂O results in less ozone, while increased CH₄ results in more ozone. Model simulations, based on representative concentration pathway (RCP) scenarios of future CO₂, N₂O, and CH₄ levels, show that projected ozone changes in 2050 to 2100 due to these gases may become comparable in magnitude to past ozone depletion by ODSs. However, there is substantial uncertainty because future emission scenarios are uncertain, and forecasts also differ between models.

Links between Ozone and Climate (Paul Newman and John Pyle, SAP Co-Chairs)

Mr Paul Newman and Mr John Pyle presented material on behalf of the Scientific Assessment Panel (SAP). This presentation covered three different interactions:

1. Atmospheric ozone is affected by climate change through transport (changes in the Brewer-Dobson circulation and stratosphere-troposphere exchange) and temperature-dependent chemical processes.

2. Atmospheric ozone can affect climate – There is new evidence on how stratospheric ozone changes influence tropospheric weather and climate. This includes intensification/migration of the Southern Hemisphere westerlies, changes in the Southern Annular Model, Hadley Cell expansion, precipitation changes, etc.
Climate role of ozone-depleting substances and their replacements – Radiative forcing due to CFCs, HCFCs, and HFCs.

HFCs and N$_2$O (A. R. Ravishankara, SAP Co-Chair)

The talk briefly discussed the roles of HFCs and N$_2$O in the atmosphere in depleting the ozone layer and altering climate. HFCs do not destroy the ozone layer, and they have very small ozone-depleting potentials (ODPs) (<10$^{-4}$) and can be taken to be zero. They degrade to stable chemicals that do not destroy ozone. Hence, it can be inferred that HFCs are safe for the ozone layer!

Some HFCs are potent greenhouse gases (GHGs). They strongly absorb outgoing IR in the window region. Therefore, the longer-lived HFCs are potent GHGs. For example, HFC-134a has a GWP = 1380. Future climate forcing by HFCs can be very large because of the use of high-GWP HFCs. Even though HFCs are not significant for climate forcing today, the use of the current mix of HFCs (with large GWPs) can undo or greatly offset the climate gains made by the Montreal Protocol, if left unabated. It is very important to note that HFCs were introduced mostly because of the Montreal Protocol.

However, there are many ways to reduce the climate influence of high-GWP HFCs. In the process of developing substitutes, care must be taken to avoid other effects, such as being local pollutants (ozone production) and producing toxic chemicals, such as trifluoroacetic acid.

Based on the above discussions, it is clear that there are some key research needs. They include:

1. Continued monitoring of HFCs – monitor “new” HFCs
2. Evaluating new low-GWP substitutes for t, GWP, etc.
3. Evaluating potential effects of substitutes (e.g., TFA formation, tropospheric ozone production)
4. Evaluating alternate technologies for environmental issues

Nitrous oxide (N$_2$O) is both an ozone-layer-depleting gas (ODP = 0.017) and a greenhouse gas (GWP = 310). It is an unintended by-product of various activities essential to humans. Its total emission is reasonably well known, but individual source strengths need improvement.

The major source of N$_2$O is as an “unintentional” by-product of food production. Even though various approaches exist to reduce N$_2$O emissions, it is a difficult problem because of its connection to human food production.

There are many key research needs associated with N$_2$O. They include:

1. Continued monitoring of N$_2$O at the surface
2. Continued measurements of N$_2$O in the stratosphere
3. Obtaining emission estimates for N$_2$O from various sources and understanding their trends

It is worth noting that there are cost effective ways to reduce nitrogen usage and increase food production efficiency to minimize N$_2$O abundances.

Influences of Ozone-Layer Depletion and Climate Change on UV Radiation: Impacts on Human Health and the Environment (Paul Newman, SAP Co-Chair, for Janet Bornman, Nigel Paul, and Min Shao, EEAP Co-Chairs)

This presentation, which was prepared by Janet Bornman, Nigel Paul, and Min Shao (EEAP Co-Chairs), was given by Paul Newman (SAP Co-Chair). Mr Newman started out by showing how the three Assessment Panels complement each other in their contributions to the
Montreal Protocol. The 2014 Environmental Effects Assessment will address negative and positive effects of solar UV radiation on:

- Human health
- Terrestrial ecosystems
- Aquatic ecosystems
- Carbon and other global chemical cycles
- Air quality
- Materials

Mr Newman presented some key findings that will be included in the EEAP Assessment:

- There is yet no statistically significant detectable response of UV radiation to ozone recovery.
- Projections of UV radiation by 2100 show that, due to recovery and even super-recovery (due to greenhouse gases), there will be a decrease of UV radiation in some regions.
  * In the tropics, one expects a small increase in UV, as ozone is projected to be lower due to greenhouse gases.
  * At high latitudes, one expects an increase in cloud cover, which also will lead to a decrease in UV radiation.
- In polluted regions, an increased aerosol loading will lead to decreases in UV radiation, whereas cleaned areas will see increases in UV radiation by year 2100.
- Melting of ice will lead to more UV radiation entering the ocean and lakes.
- The Assessment will also point out that exposure to UV-B radiation has both adverse and beneficial effects on human health.
- It was pointed out that it remains difficult to provide public health messages to guide people on safe sun exposure due to a lack of accuracy of such information for different skin types, and the fact that the time of day and duration of exposure are key factors for harmful or beneficial exposure.
- Models have estimated that skin cancer incidence world-wide would have been 14% greater (2 million people) by 2030 without implementation of the Montreal Protocol and its amendments.

There also will be discussion in the EEAP Assessment on ways in which climate change enhances effects of UV radiation on biogeochemical cycles in terrestrial and aquatic ecosystems. The Assessment will also treat environmental damage to materials, such as building materials, clothing fabrics, and glass windows.

SESSION 3: INTERNATIONAL MONITORING PROGRAMMES

The WMO Global Atmosphere Watch (GAW) Programme (*Liisa Jalkanen, WMO*)

Ms Liisa Jalkanen gave an overview of WMO’s Global Atmosphere Watch Programme (GAW). She explained that the GAW mission is to carry out systematic long-term monitoring of atmospheric chemical and physical parameters globally, and thereby provide input for environmental analyses and assessments. The goal is also to develop our predictive capability as exemplified by the GAW Urban Research Meteorology and Environment (GURME) project and WMO’s Sand and Dust Storm Warning System.
GAW measures atmospheric parameters within six areas:

- Stratospheric ozone
- Greenhouse gases (CO₂, CH₄, N₂O, CFCs)
- Reactive gases (tropospheric ozone, CO, VOC, NOₓ, SO₂)
- Precipitation chemistry
- Aerosols (chemical, physical, AOD)
- UV radiation

Information about the GAW systems, its stations and their measurement programmes can be found in the GAW Station Information System (GAWSIS, http://gaw.empa.ch/gawsis/).

Ms Jalkanen showed the large increase in the community dealing with atmospheric chemistry, as exemplified by the attendance at the first meeting of CO₂ experts at the Scripps Institution of Oceanography, San Diego, California in 1975, which included 14 participants, and the CO₂ expert meeting in Wellington, New Zealand in 2011, which included approximately 80 participants. She also showed the importance of long, continuous time series, contrasting the graph of the first 2 to 3 years of Mauna Loa CO₂ observations with the iconic 50-year time series that shows the steady and exponential growth of CO₂ in the atmosphere.

GAW puts a lot of emphasis on quality assurance (QA) and quality control (QC), and its QA/QC system includes:

- Training station personnel
- Assessment of infrastructures, operations, and the quality of observations at the sites
- Documentation of data submitted to the World Data Centres (WDCs)
- Improvement of the quality and documentation of legacy data at the WDCs

GAW has six data centres, collecting, hosting and distributing data for the different categories of GAW parameters:

- Ozone and UV
- Solar radiation
- Greenhouse gases
- Aerosols
- Precipitation chemistry
- The World Data Centre for Remote Sensing of the Atmosphere

In addition there are central facilities such as central calibration laboratories and regional and world calibration centres.

Training of station personnel is done twice per year at the GAW Training and Education Centre (GAWTEC) near Garmisch-Partenkirchen in Germany. More than 280 persons from 58 countries have been trained at GAWTEC since the beginning of this activity.

Recent assessment and bulletins where GAW has contributed include:

- WMO/UNEP Scientific Assessments of Ozone Depletion (every four years)
- WMO Greenhouse Gas Bulletin (every year)
- WMO Antarctic Ozone Bulletin (bi-weekly during the ozone hole season)
- WMO Aerosol Bulletin (one issue so far)
• Integrated Assessment of Black Carbon and Tropospheric Ozone, UNEP/WMO 2011
• WMO/IGAC Impacts of Megacities on Air Pollution and Climate, 2012
• Precipitation Assessment (Atm. Env., Dec 2013)

There is increasing focus in WMO on megacities and large urban complexes, both for meteorological and air quality research, applications, and services. Activities are aimed at the development of strategies for megacities to deal with weather, climate, and environmental problems, as well as improvement of related services.

More information on GURME can be found at <http://www.mce2.org/wmogurme/>. GAW Programme publications can be found at <http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html>.

The Global Atmosphere Watch Ozone Observing System and Integrated Global Atmospheric Chemistry Observations for Ozone and UV (IGACO-Ozone/UV)

(Geir Braathen, WMO)

Mr Geir Braathen started the presentation by emphasising the importance of long-term series, and used the HCl time series from Jungfraujoch and the ozone time series from Halley and Arosa as examples. He then showed a diagram that includes the various elements of the Global Atmosphere Watch ozone observing system, such as data centres and calibration centres. He then mentioned the WMO Greenhouse Gas Bulletin and the WMO Antarctic Ozone Bulletin as examples of value-added products from the GAW Programme before he described the most recent ozone-relevant GAW reports, such as the guidelines for ozonesonde measurements and the Dobson Handbook. In conjunction with near-real-time data transfer, he showed a diagram with the details of the current flow of ozonesonde data from stations to the various data centres at NILU, WOUDC, NASA (SHADOZ), and ECMWF.

Mr Braathen then showed the gradual and long-term improvement in Dobson measurement quality through a graph produced by the Regional Dobson Calibration Centre for Europe (hosted by the German Weather Service). He went on to describe the IGACO-Ozone/UV activities, with emphasis on the recent work done by the Absorption Cross Sections for Ozone (ACSO) Committee. He presented results from a study carried out at the Regional Brewer Calibration Centre, hosted by the Spanish State Meteorological Agency, which demonstrate that new cross sections measured in a laboratory at the University of Bremen give a much better agreement between Dobson and Brewer spectrophotometers than obtained with existing cross sections.

Finally, Mr Braathen showed a series of graphs and maps that describe a worrying downward trend in the number of stations reporting data to WOUDC. A part of this decline is probably due to station closure, but the rapid decline the last few years is most likely due to delays in data submission. All station operators were therefore urged to submit data to WOUDC in a timely manner.

The Network for the Detection of Atmospheric Composition Change (NDACC)

(Martine De Mazière, IASB-BIRA)

Ms Martine De Mazière informed the group that the international Network for the Detection of Atmospheric Composition Change (NDACC) suffers from a loss of stations, i.e., loss of observations and loss of data submitted to the archive, due to the lack or decrease of funding resources. This loss seems to be more severe in high-latitude stations, and in Europe or for stations operated by European countries. It turns out that, in several countries, it is more difficult to get funding for long-term maintenance of existing stations/data records than for starting a new observing station. We welcome several new stations starting NDACC monitoring activities in Asia, Africa, and South America, often in collaboration with European or U.S. partners.
NDACC has addressed several of the 8th ORM recommendations, in particular: increase of capacity, with new stations and new data products; progress towards standard operating procedures; progress towards improved network consistency, data quality, and data characterization; progress towards improved data archiving, including metadata, timeliness, data versioning, data access, and documentation.

NDACC continuously demonstrates its value for model and satellite data validation, in particular for the identification of satellite drifts and degradation. It has delivered important contributions to the SI2N activity and the WMO 2014 Scientific Assessment of Ozone Depletion.

Global Climate Observing System (GCOS) Including GRUAN
(Greg Bodeker, Bodeker Scientific)

Mr Greg Bodeker’s talk began with an overview of essential climate variables (ECVs) within GCOS, and highlighted that ozone is an ECV. As such, ozone is recognized as a climate variable that is both currently feasible for global implementation, and that has a high impact with respect to the UNFCCC and IPCC requirements. The presentation gave an overview of the 20 GCOS climate-monitoring principles, and the 12 GCOS guidelines for the generation of climate data records for ECVs.

The talk then transitioned to a presentation of the GCOS Reference Upper Air Network (GRUAN). GRUAN is a network for ground-based reference observations for climate in the free atmosphere in the frame of GCOS. At present, 15 stations are participating in GRUAN, but this is envisaged to grown to 35-40 sites across the globe. The three stated goals of GRUAN were presented:

(i) To provide long-term, high-quality climate records
(ii) To constrain and calibrate data from more spatially-comprehensive global observing systems (including satellites and current radiosonde networks)
(iii) To fully characterize the properties of the atmospheric column

The definition of a reference observation was presented, together with a summary of the significant effort that that will be invested in GRUAN to derive robust estimates of the uncertainties on all measurements. Mr Bodeker finished the presentation with a summary of the outcomes of a GRUAN workshop held in June 2012 to define the criteria that would guide the expansion of GRUAN, and he showed analyses of potential optimal locations of measurement sites to detect expected trends in total column ozone through the 21st century.

The Stratosphere-Troposphere Processes and Their Role in Climate Project of WCRP: The Joint SPARC/IO3C/WMO/NDACC Initiative on Past Trends in the Vertical Distribution of Ozone, SI2N (Birgit Hassler, NOAA)

Ms Birgit Hassler presented an overview of the joint SPARC/IO3C/WMO/NDACC Initiative (SI2N) on Past Trends in the Vertical Distribution of Ozone that was started in 2011, and is still ongoing. The initiative aimed to carefully study and compare the existing ozone profile measurements, and then improve them, if necessary. Since 2011, three international SI2N workshops have been held, and a combined special issue has been initialized in the open-access journals *Atmospheric Chemistry and Physics* (ACP), *Atmospheric Measurement Techniques* (AMT) and *Earth System Science Data* (ESSD). To this point, there have been approximately 40 SI2N-related research papers submitted to the special issue (including one of the three planned initiative overview papers), and approximately 5 research papers in other peer-reviewed journals. Five groups were established within the initiative with the following focus topics:

- Long-term satellite records
- Short-term satellite records
- Umkehr (Dobson and Brewer)
• Ground-based systems
• Ozonesondes

These groups tried to update, improve, and possibly reprocess the measurement systems that fall in their category. An additional group dealing with the issues associated with merging different data sets was created when it became clear that there was a need to look into these issues in more detail.

Seven different long-term merged data sets were created, and, within the framework of SI2N, they were compared in detail for the first time:

• Two versions of SBUV data sets based on improved measurements from different NOAA satellites
• One data set that combines SAGE II and OSIRIS measurements
• Two data sets that combine SAGE II and GOMOS measurements
• Two data sets (GOZCARDS and SWOOSH) that combine several different measurement systems

When analyzing these different data sets for long-term ozone changes, it becomes clear that, in addition to the uncertainties of the applied statistical trend model, there is an additional layer of uncertainty added to the data sets due to the applied merging. Trends in the upper stratosphere calculated for the last 16 years for the Northern Hemisphere midlatitudes, the tropics, and the Southern Hemisphere midlatitudes, do not agree well between the different data sets. This is most likely caused primarily by the different merging techniques applied. Based on this, the following learned lessons from the SI2N initiative can be identified:

1. Merged data sets are the only way to determine multi-decadal trends.
2. Errors in merging are similar to decadal stability and significant compared to ozone trends.
3. Careful work is needed to improve and refine approaches and data sets (c.f. temperature).
4. We are getting close to an unambiguous detection of ODS-related increase in ozone.

Therefore, the SI2N recommendations are:

1. Ground-based measurement systems are absolutely essential to validate the merged data sets (long-term measurements; different regions of the globe; not just total column ozone, but ozone profiles, etc.).
2. Merging/continuing records should be a point of consideration for planning future observational systems (satellite and ground-based).

Ground-Based Networks for Measuring Ozone- and Climate-Related Trace Gases and the Current State of the Atmosphere (Stefan Reimann, Empa)

Mr Stefan Reimann gave a presentation about the ground-based measurement networks for halocarbons. Ozone-depleting substances regulated under the Montreal Protocol are largely behaving as expected, and are declining according to their lifetime. Concurrently, emissions are decreasing, also as expected, with the exception of CCl₄. CCl₄ emissions decreased slower than expected. The reason for this behaviour is not clear. Potential reasons could be from ongoing emissions from production, feedstock use, or destruction; old industrial sites; or an incorrectly estimated atmospheric lifetime.
Furthermore, some CFCs were newly detected in the atmosphere. Although they are partly increasing, their concentration is extremely low, and does not affect the ozone layer in their current concentration.

HFC emissions as CO$_2$-equivalents are at the point of becoming more important than emissions from HCFCs and CFCs for climate change. Unsaturated HFCs (so-called HFOs) are being produced by industry, which, due to their low global warming potential (GWP), can lower the effect of HFCs for the climate.

Uncertainties in Projections of Ozone-Depleting Substances and Alternatives

(Guus Velders, RIVM)

The rates at which ozone-depleting substances (ODSs) are removed from the atmosphere, which determine the lifetimes of these ODSs, are key factors for determining the rate of ozone layer recovery in the coming decades. Mr Guus Velders presented a comprehensive uncertainty analysis of future mixing ratios of ODSs, levels of equivalent effective stratospheric chlorine (EESC), ozone depletion potentials, and global warming potentials, using, among other information, the 2013 WCRP/SPARC assessment of lifetimes of ODSs and their uncertainties. The year EESC returns to pre-1980 levels, a metric commonly used in WMO assessments to indicate a level of recovery from ODS-induced ozone depletion, is 2048 for midlatitudes, and 2075 for Antarctic conditions. However, the uncertainty in this return to 1980 levels is significant. The year EESC returns to pre-1980 levels ranges from 2039 to 2064 (95% confidence interval) for midlatitudes, and 2061 to 2105 for the Antarctic spring. The primary contribution to these ranges comes from the uncertainty in the lifetimes (mainly CFC-11 and Halon-1211), with smaller contributions from uncertainties in other modelled parameters (fractional release values, alpha, age-of-air).

HFCs and alternative chemicals and technologies are increasingly used to replace ODSs. Projections of these alternatives and their effects on climate are also affected by the uncertainty in the lifetimes of the HFCs, but the uncertainty in the projection of the demand and mix of alternatives being used has a much larger effect on future climate.

While CFCs were originally used mainly in applications such as spray cans, and were released within a year after production, HFCs are now mainly used in refrigerators and air-conditioners, and are released over years to a decade after production. Their containment in such equipment represents banks, which are building up as production grows. Consequently, increases of HFC banks represent a substantial unseen commitment to further radiative forcing of climate change also after production of the chemicals ceases. Choices of later HFC phase-out dates lead to larger commitments to climate change, unless growing banks of HFCs from millions of dispersed locations are collected and destroyed.

References:

International Ozonesonde Activities (e.g., NOAA South Pole Program, The Southern Hemisphere Additional Ozonesondes Network (SHADOZ))

(Anne Thompson, NASA)

Ms Anne Thompson (NASA Goddard Space Flight Center) informed the group that the Southern Hemisphere Additional Ozonesonde (SHADOZ) Network, begun as an international collaborative activity in 1998, has delivered more than 6,000 ozonesonde-radiosonde profile data sets to the website <http://croc.gsfc.nasa.gov/shadoz>. These data are sent annually to the woudc.org (WOUDC Data Centre). There have been about 20 sponsoring nations and organizations engaged in SHADOZ, with 13 stations operating in 2013-2014: Natal, Paramaribo, San Jose (Costa Rica), San Cristobal, Nairobi, Irene, La Réunion, Watukosek, Kuala Lumpur, Hanoi, Fiji, Samoa, and Hilo (review in Thompson et al., *JGR*, 2012). The frequency of soundings
has declined since the first period of SHADOZ, when more than 400 profiles were recorded each year (1999-2006). In 2011-2013, fewer than 300 launches were made because five stations experienced multi-year gaps. Four of the five gap stations have been re-activated, and more than 350 profiles are anticipated for 2014. With SHADOZ now in its 17th year, two important activities have emerged: (1) incorporation of SHADOZ data into studies of ozone trends in the lower stratosphere and free troposphere; and (2) continuous evaluation of ozone profiles in terms of technical and equipment changes (Smit and ASOPOS, WMO, 2012). The latter has led to engagement in WMO-sponsored activities like the Jülich Ozone Sonde Intercomparison Experiment (JOSIE), and in WMO recommendations for reprocessing of the global ozonesonde data set. Two SHADOZ stations (Hilo and Samoa) have already reprocessed their records; the other stations are underway.

In terms of trends, the decline in stratospheric ozone recorded by SHADOZ sondes and SAGE II (1984-2009) seem to be turning around (Aschmann et al., ACPD, 2014; Gebhardt et al., ACP, 2014). The reason is a slowing down of the acceleration in the Brewer-Dobson circulation. Very large free-tropospheric ozone increases (+25-50% per decade, in winter, over Irene and La Réunion; Thompson et al., ACPD, 2014) have a dynamic component. However, from 6-12 km, origins point to pollution from rapidly developing regions of South America, Africa, and South Asia. Fine features like these are not viewable by satellite, and are beyond the range of emerging geostationary space instruments that are focused on the Northern Hemisphere.

SESSION 4: SATELLITE RESEARCH AND MONITORING

Lessons Learned in Creating Long-Term Ozone Data Sets: Recommendations for the Future (P. K. Bhartia, NASA)

Mr P. K. Bhartia (NASA Goddard Space Flight Center) assessed the quality of data from the satellite ozone-monitoring network, discussed the role of the ground-based network, and made recommendations for the future. He indicated that the quality of total ozone data from satellite BUV instruments is very high, and this programme is robust. However, by comparison, the quality of ozone profile data from satellites is highly variable, and the satellite programmes are much less robust. He suggested that the primary focus of the ground-based ozone monitoring network should be on improving the profiling capability by keeping the ozonesonde network healthy and by developing low-cost methods of doing ozone profiling from the ground that have been proposed recently.

Current and Planned Ozone and Climate Observations from Space

U.S. Satellite Programmes: NASA, NOAA, and Other Agencies (Kenneth Jucks, NASA)

Mr Kenneth Jucks (NASA Headquarters) reported that the U.S. continues to observe both column and altitude-resolved ozone concentrations from satellites. NASA currently operates the Aura satellite, obtaining column ozone from the OMI instrument, tropospheric ozone from the TES instrument, and altitude-resolved ozone via limb observations with the MLS instrument. NASA and NOAA jointly observe column and profile concentrations of ozone with the OMPS sensor suite on the Suomi NPP satellite. NASA and NOAA plan to continue the OMPS observations on the next two JPSS series of polar orbiting operational weather satellites, though the limb-sounding instrument will only be on JPSS-2. NASA also is planning on deploying the SAGE-III instrument for limb sounding of ozone, water vapour, and aerosols on the International Space Station in 2015. The only current or planned instrument that obtains vertically resolved concentrations of other key stratospheric trace gases is the MLS instrument currently on Aura. It obtains concentration profiles of ClO, H₂O, N₂O, HCl, and several other minor gases. Once MLS/Aura cease operation (expected around 2022 at the latest), these capabilities will no longer exist from any other satellite sensor. The only existing avenue to pursue such a sensor within the U.S. is through the NASA Venture Class programme.
European Space Agency Activities (Claus Zehner, ESA/ESRIN)

ESA Earth observation satellites include the Meteorological, Sentinel, and Earth Explorer Missions. ESA is building all these missions in cooperation with EUMETSAT, the European Commission, and on behalf of its member states. The Meteorological missions are operated by EUMETSAT, and include the geostationary Meteosat and polar orbiting MetOp satellite families. The Sentinel satellites are the space segment of the European Copernicus programme, and are/will be operated by ESA and EUMETSAT. Six Sentinel missions are being planned right now, each one consisting of a constellation of two satellites to fulfil operational requirements of the Copernicus services (Sentinel 1A was launched on April 3 2014). The Earth Explorers are research missions designed to address key scientific challenges identified by the science community, while demonstrating breakthrough technology in observing techniques. These missions are operated by ESA, with the missions Cryosat, SMOS, and SWARM currently in orbit. Furthermore, ESA has specific agreements with owners of missions to acquire, process, archive, and distribute data from their satellites – so-called Third Party Missions (e.g., SciSat, Odin).

The ERS-2 GOME and the Envisat SCIAMACHY, MIPAS, and GOMOS instruments provided satellite ozone measurements in the past. The missions SciSat (e.g., ACE) and Odin (e.g., OSIRIS) are providing continued limb/occultation, and the missions MetOp-A and -B (GOME2/IASI) provide continued nadir-viewing ozone measurements. These data sets will be extended in the future by the MetOp-C, MSG-IRS, MetOp-NG, Sentinel 5P, Sentinel 4, and Sentinel 5 missions. This future constellation will insure continuous long-term, nadir-viewing ozone measurement capabilities, but, based on the age of the SciSat and Odin missions, it is clear that there soon will be a limb/occultation satellite mission gap.

ESA has specific programmes ongoing on the preservation and exploitation of its EO archives/data sets. ERS and Envisat Phase F activities especially will improve further the quality of Level 1 and Level 2 data sets, and, within the Long-Term Data Preservation programme, all ESA EO archives (including raw data) will be preserved. Ozone climate data sets are being generated within the ESA Climate Change Initiative (CCI).

The CCI programme started during 2010, with a planned duration of 6 years (two project phases of 3 years each). The objective of CCI is to realise the full potential of the long-term global ESA EO archives as a significant and timely contribution to the Essential Climate Variables (ECV) databases required by the United Nations Framework Convention on Climate Change, and is based on the satellite ECV requirements as specified by GCOS.

During the first phase of the Ozone_cci project (<http://www.esa-ozone-cci.org>), total ozone column, nadir profile, and limb profile data sets have been generated. This was done after a careful review of all existing retrieval algorithms, and by selection of the “best” one for each ECV parameter. These selection/intercomparison activities included very detailed validation against independent reference data, and close interaction with ozone climate modellers (e.g., DLR, University of Cambridge). All data sets are available for free at <http://www.esa-ozone-cci.org/?q=node/160>.

Main achievements include the development of an improved total ozone column algorithm (GOTFIT-V3) that has been applied to GOME, GOME-2, and SCIAMACHY data. The resulting combined data set shows very good agreement (1% range) to ground-based network data (Brewer) and the U.S. SBUV data set. On nadir profiling, the algorithm with best performance in the troposphere has been selected, and on limb profiling, the so-called HARMOZ data set has been generated for the instruments ACE, GOMOS, MIPAS, OSIRIS, SCIAMACHY, and SMR. The HARMOZ data include individual instrument profiles with a common pressure grid and concentration unit, and with pair-wise bias and drift distributions to the other instruments.
Close interaction with users (climate modellers) throughout the project supported product definition (e.g., common NetCDF format, including pair-wise bias/drift information for limb profiles), and provided product assessment on the “fitness for purpose” (climate monitoring).

Independent validation of all data sets (e.g., algorithm selection, error characterisation) is essential, requiring the maintenance of high-quality ground-based networks. As GCOS accuracy requirements for satellite-based ECVs are stringent (e.g., decadal drift of 1% for total ozone columns, 10% accuracy for profiles in the UTLS), the same requirements apply to the reference data.

Consistent error analysis has been applied to all sensors and traceability (e.g., algorithm/validation documentation). So far the project has produced more than 35 peer-reviewed publications.

During the next three years, the Ozone_cci product portfolio will be improved by:

- Extending the time coverage of existing data sets (e.g., full processing of nadir profiles over satellite instrument lifetimes)
- Improving/reprocessing existing retrieval algorithms for nadir UV sensors (improved cloud correction scheme, harmonize columns, and profiles).
- Including data from other instruments (e.g., OMI, IASI)
- Including new products (e.g., tropospheric data products)
- Extending the altitude range of limb products → UTLS and mesosphere
- Linking/merging European data sets to historical U.S. data series (e.g., ongoing cooperation within the CEOS-Atmospheric Composition Constellation with NASA colleagues)

**KNMI Space-Based Measurement Activities (Peter van Velthoven, KNMI)**

Mr Peter van Velthoven (KNMI, the Netherlands) presented the TROPOspheric Monitoring Instrument (TROPOMI), which is a spaceborne nadir-viewing spectrometer with bands in the ultraviolet, the visible, the near infrared, and the shortwave infrared. TROPOMI is the payload for the ESA/Copernicus Sentinel 5 Precursor mission, planned for launch in 2016, with a seven-year design lifetime. The objective of the mission is to provide high-quality and timely information on the global atmospheric composition for climate and air quality applications. TROPOMI will make daily global observations of key atmospheric constituents, including ozone, nitrogen dioxide, sulphur dioxide, carbon monoxide, methane, formaldehyde, and aerosol properties.

The Sentinel-5 Precursor mission will extend the current data records from OMI (Ozone Monitoring Instrument) on NASA’s EOS Aura satellite, and is the link between the current scientific missions and the planned operational Sentinel-4/-5 missions. It can connect the planned atmospheric composition geostationary missions by providing in-flight calibration/validation and intercomparison opportunities. Compared to OMI, TROPOMI has a six-times higher spatial resolution (7x7km), an improved signal-to-noise ratio, and additional near-infrared and shortwave infrared bands, allowing CH₄ and CO retrieval and more accurate cloud corrections. TROPOMI is an initiative from the Netherlands, and is developed in cooperation with ESA. KNMI (Pepijn Veefkind) is the TROPOMI Principal Investigator, and SRON (Ilse Aben) is the Co-Principal Investigator.

**Japanese Satellite Programmes (Takuki Sano, JAXA)**

Mr Takuki Sano (JAXA) started with a brief introduction about the SMILES instruments. He then showed the technical specifications of the instrument, as well as the observation scheme on orbit. SMILES observations onboard the International Space Station covers mainly the Northern Hemisphere.
Mr Sano then explained about two recent results from SMILES data analysis. One of them is the diurnal variation of stratospheric ozone. This is the first time the variation has been observed. The other topic was a possible negative bias in ozonesonde data according to the response time in the sonde component, which has been deduced from a comparison with SMILES data.

Finally, he introduced the history of the level-2 data release and an open-to-public data website inside ISAS/JAXA, <http://darts.isas.jaxa.jp/iss/smiles>, with links to the SMILES website and/or the data.

**Chinese Satellite Programmes (Fuxiang Huang, Chinese Space Agency)**

The Chinese ozone-monitoring instruments on the FY-3 Satellites are TOU (Total Ozone Unit) and SBUS (Solar Backscatter Ultraviolet Sounder). FY-3A, -B, and -C were launched in 2008, 2010, and 2013, respectively. For the present, three TOUs and two SBUSs are in operation, and some of their data are open. Since the launch of FY-3A, there have been a number of data comparisons with ground-based observations and data from American and European satellites in order to validate and evaluate the total ozone and ozone profiles. To improve and maintain the precision of these products, a lot of work has been done on in-orbit calibration. The FY-3 ozone data have been applied in Antarctic ozone-depletion monitoring since 2009 and the 2011 spring Arctic severe ozone-depletion event. The data also have been applied to other monitoring activities, such as ozone-depletion monitoring over the Tibetan Plateau. Within the next four years, China plans to develop some new-generation ozone-monitoring instruments, combining total ozone, nadir profile, and limb profile measurements.

Over the past several decades, China has put great effort into developing ground-based total ozone and UV observations. Operational ozone and UV monitoring at six ground-based observing stations have been running since the 1980s in mainland China, and Taiwan and Hong Kong have been measuring ozone and UV on the ground for even longer. The Zhongshan station in Antarctica began observing total ozone and UV in 1993. Chinese ground-based ozone stations carry out ozone observation using Dobson and Brewer instruments. These data have been shared through the WOUDC websites.

China has set up the China National Environmental Monitoring Center and more than 30 province-level centres, under the Ministry of Environmental Protection of the People’s Republic of China, to monitor surface ozone and other atmospheric pollutant components during the quick development of economics and industry. The China Meteorological Administration operates even stations for background surface ozone measurement located in Mainland China. The Shanghai Meteorological Service launches monthly ozonesondes for ozone profiles. Taiwan and Hong Kong also run operational surface ozone monitoring, and launch ozonesondes for ozone profiles.

The range of ozone research topics in China is broad and varied. Among these activities, the finding of severe summer ozone valley over the Tibetan Plateau by applying satellite ozone data is prominent. The Tibetan Plateau, located in the west of China, is the highest and largest Plateau in the world, and plays a critical role in East Asian climate. The relationship between ozone change and climate change in the Tibetan Plateau is a very good example for understanding global ozone change and the relationship between ozone change and climate. Another hot field of Chinese ozone research is focused on the physical and chemical working processes of surface ozone and other related pollutant components emission.

Mr Huang’s presentation included two recommendations:

- Satellite ozone measurements play a more and more important role in global ozone monitoring and assessment. But there exist remarkable differences in the data from different satellites and different instruments. Many factors account for these differences, but the most important parts may be the differences of instrument manufacturing and retrieval algorithms, as well as other differences such as in-orbit calibration and data treatment. The remarkable difference in satellite data sets has
resulted in disagreement in the assessment of ozone change. To make a long-term, continuous, and consistent global ozone data set, complete and truly international cooperation, including instrument manufacture, retrieval algorithm developing, in-orbit calibration, data validation, and evaluation, is critical.

- Ozone monitoring and change detection over the Tibetan Plateau is very important. But study on this topic is very limited. The Chinese welcome international cooperation on this topic, and they recommend that an assessment of ozone change results over the Tibetan Plateau be included in future report like those of the Antarctic and Arctic.

Summary of the Key Issues in Space-Based Measurements: Identification of Future Needs and Opportunities (Jean-Christopher Lambert, IASB-BIRA)

Research and monitoring relevant to the Vienna Convention and the Montreal Protocol require the following, non-exhaustive list of satellite measurements of atmospheric composition:

- Ozone vertical column and ozone vertical distribution.
- Key species controlling the ozone photochemistry (e.g., nitrogen oxides, HCl, ClO, BrO, and polar stratospheric clouds).
- Ozone-depleting substances regulated by the Montreal Protocol and amendments, their substitutes, and their degradation products.
- Tracers of the coupling between atmospheric chemistry, dynamics, and climate.
- Species needed to improve modelling tools like chemistry-transport models (CTM), general circulation models (GCM), and data assimilation systems (DA).

In the context of the 9th ORM meeting, updated information on current and future satellite programmes was received from the following agencies (in alphabetical order):

- Belgian Institute for Space Aeronomy (BIRA-IASB)
- French Centre National d’Études Spatiales (CNES)
- Canadian Space Agency (CSA)
- German Aerospace Centre (DLR)
- European Space Agency (ESA)
- European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)
- Japan Aerospace Exploration Agency (JAXA)
- Royal Netherlands Meteorological Institute (KNMI)
- U.S. National Aeronautics and Space Administration (NASA)
- U.S. National Oceanic and Atmospheric Administration (NOAA)
- National Satellite Meteorological Center (NSMC) of China Meteorological Administration (CMA)

Pioneered by the U.S. (S)BUV(-2)/TOMS series and the European GOME/SCIAMACHY/OMI instruments, global monitoring of the ozone vertical column and profile continues with three series of operational nadir-viewing polar orbiting missions:


(ii) Three Chinese CMA/NSMC FengYun-3 satellites (FY-3A launched in 2008, FY-3B in 2010, and FY-3C in 2013), with the SBUS and TOU ozone instruments.
OMPS onboard the NOAA/NASA JPSS (NPP-Suomi launched in 2011, JPSS-1 is planned for 2016, JPSS-2 for 2022).

While multi-spectral UV instruments like OMPS and SBUS focus on ozone and aerosols, hyper-spectral UV-visible and IR instruments like GOME-2 and IASI measure a list of ozone-related trace gases as well, like NO$_2$, BrO, HNO$_3$, and OCIO. Similar nadir-viewing facilities are envisaged in the post-EPS era, with the next-generation ozone instruments of China (launch 2018), ESA/EUMETSAT GMES/Copernicus Sentinel-5 (launch 2020), and NASA's GACM (project for 2025). Sentinel-5 Precursor TROPOMI is to be launched by ESA in 2016 as a gap-filler between Envisat SCIAMACHY/Aura OMI and Copernicus Sentinel-5.

A geostationary constellation of air quality and regional climate monitoring satellites (GEO-AQ) will be launched between 2017 and 2022, consisting of:

- The Korean KARI GEMS
- The Japanese JAXA GMAP-Asia
- The European ESA/EUMETSAT GMES/Copernicus Sentinel-4
- The U.S. NASA TEMPO

This constellation, with geostationary focus on midlatitudes, will be complemented by two coordinated Canadian CSA PCW/PHEMOS missions operating from highly elliptical Molniya orbits with pseudo-geostationary focus on the Arctic. Equipped with nadir UV-visible and infrared instruments, the GEO-AQ constellation will offer, at a typical spatial resolution of 8x8 km$^2$ and temporal sampling of 1 hour, access to short-term variations of the atmospheric composition, including tropospheric ozone, its precursors, and aerosols.

There is a serious concern about profiling capabilities at high vertical resolution. The loss of Envisat in 2012 follows the termination of UARS HALOE and MLS, SAGE-II/III, and POAM-III in 2005; Aura HIRDLS in 2009; and ISS JEM SMILES in 2010. This drastic reduction of atmospheric limb and solar occultation profiling capabilities of atmospheric constituents will even turn into a real gap in coming years with the anticipated end of currently aging missions:

- Odin (in operation since 2001)
- SCISAT ACE-FTS/MAESTRO (since 2003)
- Aura MLS (since 2004)

Continuation of high-resolution ozone profiling after OMPS on NPP (launched in 2011) and SAGE-III on ISS (launch in early 2015) is uncertain. JPSS-2 (launch 2022) might be equipped with another OMPS-limb, but this information had not been confirmed when this presentation was prepared. The most serious concern is that, despite recommendations expressed at the two previous ORM meetings, no replacement has been planned for aging limb emission sounders (in the microwave and infrared ranges). Limb mission concept studies are in development, e.g., ALISS (with CATS, STEAMR, and SHOW onboard); the ALTIUS UV-visible-NIR limb scattering instrument for the PROBA micro-satellite; a FTS follower onboard CASS; and an MLS-like instrument on GACM (in 2025?). But no comprehensive replacement of the disappearing facilities has been planned so far. As a consequence, there will be soon no high-resolution profile measurements of HCl, ClO, N$_2$O, HNO$_3$, and other key species. Without such data, unexpected events like the severe 2011 Arctic ozone depletion could not have been analysed, and the underlying processes could not be quantified. Several recent studies have also shown that the unavailability of such data degrades climatological assessments, trend assessments, and the analyses performed by operational data assimilation systems. We are also moving from a period where the ozone layer was threatened by ozone-depleting substances, to a period where growing concentrations of other source gases, especially CO$_2$, N$_2$O, CH$_4$, and H$_2$O will impact the ozone layer more and more; but, again, no profile measurements of these species will be available. A similar concern persists for observations of temperature and dynamical tracers performed by the same limb missions.
Ground-based networks (Brewer and Dobson spectrophotometers, DOAS UV-visible and FTIR spectrometers, lidars, ozonesondes, millimetre-wave radiometers, and ground-level in situ measurements) constitute the primary source of correlative observations for the validation of satellite data. Such networks should be maintained, and even extended, to cover a wider range of atmospheric states and regions of interest. The steady decrease in the number of stations reporting data to WOUDC and NDACC might become a concern if this reduction of facilities continues. The deployment of measurement facilities in the tropics and the Southern Hemisphere is encouraged. For some species and instruments, further effort is needed to improve the station-to-station homogeneity of networks and to consolidate long-term data records, especially in view of data assessments addressing the links between atmospheric composition change and climate change.

With the scientific needs moving towards the study of interactions between ozone and climate change issues, ground-based and satellite measurement systems are facing new challenges and more stringent data quality requirements. Traceability and consistency of quality assurance methods and of quality information from end to end, that is, from the acquisition of binary data by the instrument to the delivery of four-dimensional atmospheric fields by modelling and assimilation systems, is of particular concern. Multi-mission/multi-sensor/multi-agency projects and strategies like the GEO Quality Assurance framework for Earth Observation (QA4EO), the Global Space-based Inter-Calibration System (GSICS), SPARC assessments, ESA’s Climate Change Initiative, NASA’s GOZCARDS, and topical intercomparison campaigns aimed at understanding and reducing discrepancies between different types of observations, are encouraged. These new steps in the integrated exploitation of satellite and ground-based data may require the development of dedicated methods and tools, and should be supported by adequate research activities.

SESSION 5: NATIONAL AND REGIONAL REPORTS ON OZONE RESEARCH AND MONITORING

In this session, each representative of a region presented the regional and national situations with ozone monitoring and research, focusing on the key issues raised by the countries in the region based on the national reports submitted for this meeting (Annex D of this report).

Region 1: Africa (Gerrie Coetzee, South African Weather Service)

The number of Region 1 national reports received for the meeting were few. Reports were received from Algeria, Burkina Faso, Kenya, South Africa, Togo, Egypt, Gambia, and Madagascar.

The concentration of ozone and research and monitoring activities is only invested in a few countries, and Africa remains a very data-sparse continent. In general, the established UNEP Ozone Offices in most countries have reported well on Montreal Protocol implementation issues with data and figures of ODS. They also are actively involved in awareness campaigns and other more general environmental actions.

The specific and noteworthy activities reside with the three countries that manage WMO Global GAW stations: Algeria (Tamanrasset), Kenya (Mt Kenya), and Cape Point (South Africa). These three also have strong regional GAW station representation within their regions. Egypt also has a well-established ground-based network consisting of Dobson and Brewer instruments for monitoring atmospheric ozone and UV monitoring. Routine ozonesonde soundings are only conducted at the Kenya, Nairobi NMS (with MeteoSwiss twinning), and by the South African NMS at its Irene station. From networking and past meetings, it must be mentioned that Morocco has Dobson and Brewer instruments contributing to the monitoring efforts on the continent.

Published science papers, and even more so with African lead authorship, are difficult to find. Thus, there remains a great lack of research capacity on the continent. Satellite activities/interest is limited to only a few satellite data users to support their ground-based research activities.
It has been stated that capacity among many African universities do exist, but capacity building and twinning with developed nations or even neighbouring countries remains a rather wishful aspiration. Some African countries have noted their concern towards some of their leading scientists, who have been empowered through capacity building, but who have not returned to the continent to ensure that their in-house monitoring and research could be sustained. This also relates to earlier ORM meetings and discussions regarding the transfer or relocation of spare instruments from the developed world to data-sparse regions. This is still an extremely slow process, despite the fact that the Trust Fund has these activities noted as one of its priorities. Much more could be done in this respect, and a greater effort is needed to accelerate and take advantage of this large potential. It was noted that Uganda (Kampala) has received a Dobson instrument in such a manner for operational usage.

Lastly, the establishment of air quality monitoring stations in many countries has been on the rise. It must be noted that these networks can contribute to the goal of ozone-related monitoring, if some basic and appropriate instruments also are linked to these stations. From the Renewable Energy Sector, and especially the solar sector, we have seen the establishment of many “state-of-the-art” sun-tracking stations, especially in southern Africa. Africa is a continent of exceptional irradiance exposures, especially UV. A challenge remains to connect to this sector in such a fashion, and to use these high-quality tracking stations as a vehicle to enhance systematic observations, especially in the UV and aerosol fields.

Overall, the situation in Africa remains more or less at concerning past levels, and even sustaining the existing capabilities is difficult to maintain. This is especially true for those long-term and important data sets that have been making value-added contributions to the global initiatives.

**Region 2: Asia (Hidehiko Isobe, JMA, and Hideharu Akiyoshi, NIES)**

**Ground-Based Ozone Observations**
- According to the national reports, the ground-based monitoring network is systematically operated.
- Stations in East and Southeast Asian countries contribute to international programmes (e.g., AGAGE, SOWER); however, Japanese NDACC station operations were stopped in 2011.
- The next regional Dobson intercomparison is planned for 2015.

**Observations from Space**
- Satellite observations of chemical constituents are ongoing in China, but they have stopped in Japan.

**Research Activity**
- Studies in the following areas have progressed:
  * Distribution of natural source ODSs
  * Estimation of the mean age of air
  * Dehydration process in the tropical tropopause layer
  * Future ozone projections and process studies of past events by using Chemistry Climate Models (CCMs) and Chemical Transport Models (CCMs)

**Recommendations and Needs**
- Submission of observation data to the WOUDC should be encouraged.
- Some countries need financial and technical support to improve or start ozone observations.
- An update of the CCM and the development of a CCM coupled to the ocean are needed.
Region 3: South America (Eduardo Luccini, IFIR-CONICET)

Mr Eduardo Luccini started by giving an overview of sites where ozone or UV measurements are performed in different countries in the region; notably, Argentina, Bolivia, Brazil, Chile, and Ecuador. Argentina, Brazil, and Chile also have stations that measure ozone or UV in Antarctica. Maps that show the location of all the stations are found in the respective national reports.

The most recent calibration activities in the region were:

• 2009: Calibration of part of the Brazilian Brewer network
• 2010: Calibration of South American Dobson, UV-Biometers, and surface ozone instruments at the Regional Calibration Center of the Argentine National Weather Service
• 2011: Calibration of the Chilean Brewer instrument
• Intercomparison campaigns were planned for the period 2011-2013, but they were not carried out.

Planned activities include:

• Calibrations: New calibration campaigns for Brewer, Dobson, UV-Biometers, and surface ozone instrument networks will be planned for 2015. It is recommend that these activities be included in the WMO official calibrations agenda, even though funds to support them are still not assured. All regional calibration activities are equally important. An agreement on the priorities is necessary.

• Courses: There is a clear need and desire expressed by all the concerned countries to attend training courses that cover instrument handling and data use. If possible, it is suggested that some of these courses be arranged in Region 3. Even if funds to attend these courses are not yet assured, there is a need for a fluid communication on their realization and schedule.

• Data transfer: Data will continue to be sent when possible to the International Centres. A main concern during the period 2011-2013 has been the changes suffered by WOUDC, and new guidelines on where and how to send data to the International Centres.

Region 4: North America, Central America and the Caribbean

USA (Kenneth Jucks, NASA, and Stephen Montzka, NOAA)

The U.S. has a comprehensive research programme dedicated to understanding changes in ozone, ozone-depleting substances (ODSs), and UV flux changes. While funds for these activities come primarily from NOAA and NASA, the U.S. Environmental Protection Agency (EPA), National Science Foundation (NSF), and Department of Agriculture (USDA) also fund key activities. NASA and NOAA collaborate strongly on ground-based observations of key ODSs and substitute chemicals, using strong and significant international collaborations, to form the basis for the long-term ODS time series. Data for ODSs and ozone provided by these activities enable an assessment of the success or failure of international Protocols on ozone and climate, and are key inputs to the WMO/UNEP Ozone assessments. NASA and NOAA also contribute significantly to the international NDACC and SHADOZ networks for ground-based remote sensing and ozonesondes. NOAA maintains a long-term series of ground-based UV spectroradiometer observations of column ozone, and provides and maintains the calibration standards for the international networks. NOAA, EPA, NSF, and USDA support long-term observations of surface UV fluxes. NASA, in collaboration with agencies such as NOAA and NSF, maintains a significant airborne science programme that is designed to address open and important questions in atmospheric science related to ozone and climate. Recent activities include the NASA-funded SEAC4RS campaign, as well as the Earth Venture ATTREX campaign. The latter developed a strong collaboration with the NSF CONTRAST campaign and the UK NERC-funded CAST
campaign to understand the role of tropical convection and transport on the composition of the stratosphere relative to many key climate processes.

**Canada (Stoyka Netcheva, Environment Canada)**

Ms Stoyka Netcheva presented the current state of Canada’s ozone monitoring programme. The location, the equipment, and measurement frequency for total ozone column and ozone profile measurements were detailed. Products and services based on collected data such as UVI forecast, monitoring, and reporting of the state of the ozone layer and the UV radiation were demonstrated. Environment Canada (EC) and NOAA’s UVI forecast models were described. A comparison of forecasts’ outputs with UV measurements made by Brewer instruments at 10 Canadian stations for 1996-2009 period also was presented. Preliminary results from the work on the improvement of EC’s UVI forecast model were shown, and targeted areas of the effort were specified. Research activities of Canadian universities and their collaborators in the field of stratospheric and tropospheric ozone and factors affecting ozone budget were noted. Several key scientific findings obtained by Canadian researchers were brought to the attention of the meeting. Ms Netcheva also explained the goal of an ongoing initiative to re-evaluate the ozonesonde records in Canada, as well as some preliminary results. The progress from an effort to build a global 3-D ozone model, based on backward and forward trajectories from ozonesondes and MOZAIK records, was demonstrated. Canada’s involvement with WMO in the field of ozone monitoring and research was detailed. Special attention was given to the Brewer Trust Fund, the Brewer travelling standard, the World Brewer Calibration Centre activities, and the status of the reference standard. The transition of the World Ozone and UV Radiation Data Centre’s management, its renewal objectives, new form, and current status of archives was presented. Finally, Ms Netcheva gave a summary of work in progress and the vision of future needs.

**Region 5: South-West Pacific (Matt Tully, BoM)**

**Observational Activities**

A number of long-term Dobson observing sites within the Region have continued their programmes since the last ORM, a number dating back to 1957, including Mauna Loa (NOAA), Brisbane, Aspendale / Melbourne, and Macquarie Island (Australia), and Wellington / Invercargill / Lauder (New Zealand). The Dobson programmes at Samoa, Manila, Singapore, and Darwin have also operated for more than thirty years.

A Brewer has been operated at Bandung (Indonesia) from 1996 to 1998, and from 2006 onwards.

Three very important ozonesonde programmes have continued at Broadmeadows, Lauder, and Macquarie Island, crucial for the Southern Hemisphere midlatitudes (spanning 38° to 55° S). In addition, a number of SHADOZ sites are located at lower latitudes in Region 5: Hilo, Samoa, Sepang Airport, Watukosek, and Suva.

In Antarctica, Region 5 countries Australia and New Zealand also have continued to operate an ozonesonde programme at Davis, and a Dobson at Arrival Heights, respectively. Arrival Heights is among the best-instrumented sites in Antarctica, and measurements of key species ClO, BrO, HCl, HNO₃, and NO₂, as well as ozone, are made.

NDACC sites in Region 5 include Alice Springs, Wollongong, Lauder, and Macquarie Island.

The famous station at Lauder has continued operations since the 8th ORM, with long time series of more than 20 years continuing for instrumentation such as ozonesondes, Dobson, UV spectrometer, ozone lidar, and microwave radiometers.

Long-term *in situ* measurements of ODSs and GHGs have continued at Cape Grim, which is now approaching its fortieth anniversary.
The Australian Bureau of Meteorology continues to operate the Region 5 Dobson Calibration Centre.

**Modelling and Research**

The most prominent chemistry-climate modelling work has been performed by NIWA and Bodeker Scientific; however, a number of other research projects are also underway in Australia and New Zealand. Australian and New Zealand ozone research is now well coordinated through the “Ozone Science Group” supported by the Australian Government Department of Environment.

**Capacity Building**

Indonesia recommended technical support for the calibration and maintenance of instruments to continue observational programmes as a high priority for capacity building.

**Antarctica**

**Antarctica (Steve Colwell, British Antarctic Survey, via WebEx)**

The British Antarctic Survey (BAS) has been measuring stratospheric ozone levels since the International Geophysical Year (IGY) in 1957. It was data from Halley station (75˚S, 26˚W) that led to the discovery of the hole in the ozone layer by BAS scientists in the 1980s.

BAS currently operates a Dobson ozone spectrophotometer and a Système d’Analyse par Observations Zénithales (SAOZ) instrument at Halley station, and a SAOZ at Rothera station (67˚S, 68˚W). The data are processed in near-real time, and sent out on a Global Telecommunication System (GTS) as a Character form for the Representation and EXchange of data (CREX) message. The data are also archived at the World Ozone and Ultraviolet Radiation Data Centre (WOUDC).

BAS maintains a web page that is updated on a weekly basis, and contains information about the Antarctic ozone layer, and links to online resources and the data that have been collected by BAS. The web page can be found at <http://www.antarctica.ac.uk/met/jds/ozone/index.html>.

**Czech Republic Activities in Antarctica (Michal Janouch, CHMI)**

The Solar and Ozone Observatory of the Czech Hydrometeorological Institute, in cooperation with the Argentine Antarctic Institute, installed Brewer ozone spectrophotometer (double MKIII) No. 199 at the Marambio Base – Argentina, Antarctica (B199). This activity is the project of the Ministry of the Environment of the Czech Republic and the State Environmental Fund of the Czech Republic, “Monitoring of the State of the Earth’s Ozone Layer and Solar UV-radiation in Antarctica - The Contribution of the Czech Republic to the Vienna Convention and the Montreal Protocol.” Cooperation with Argentina is the result of close cooperation in matters related to the Antarctic between the Government of the Czech Republic and the Government of the Argentina in 2010. The B199 has been independently calibrated by travelling standard Brewer No. 17 – International Ozone Service, Toronto Canada (IOS) in 2012. The B199 is checked regularly, and maintained each year during austral summer. Mr Janouch discussed and presented information on the data that are available.

**Other Antarctic Activities (Geir Braathen, WMO)**

Mr Braathen gave an overview of Antarctic stations sending data in near-real time for use in the WMO Antarctic Ozone Bulletin. He showed time series from four stations with more than 50-year-long time series, namely Macquarie Island, Halley, Syowa, and Vernadsky (formerly Faraday). Seven stations provide Dobson data, four stations provide Brewer data, seven stations provide ozonesonde data, six stations provide DOAS data, three stations with Russian filter instruments, one with a lidar, and one with an FTIR instrument. Mr Braathen then showed that the apparent decline in total ozone mass deficit since the record large ozone hole in 2006 is partly due to transport of ozone-rich air at higher altitudes (around 25 km) that has masked the ozone
depletion going on in the 15-20 km altitude range. By using the amount of ozone between 100 and 38 hPa, he showed that the interannual variability in the ozone mass deficit becomes considerably smaller than when using a mass deficit based on total ozone as a metric. This shows the importance of maintaining profile measurements of ozone.

**Region 6: Europe**

**Belgium (Jean-Christopher Lambert, IASB-BIRA)**

This presentation highlighted ozone monitoring and research activities undertaken by the Belgian Federal Public Planning Service Science Policy (BELSPO), the Belgian Institute for Space Aeronomy (BIRA-IASB), the Royal Meteorological Institute of Belgium (IRM-KMI), the Free University of Brussels (ULB/SPECAT), and University of Liège (ULg/GIRPAS).

The ground-based monitoring activities include the long-term monitoring of ozone; ODSs and substitutes; GHGs; nitrogen compounds; the budgets of chlorine, fluoride, and bromine compounds; dynamical tracers; aerosols; and ground level UV-B radiation. Ground-based measurements are taken by complementary instrumentation including Brewer and Dobson UV spectrophotometers, balloonborne electrochemical ozonesondes, DOAS UV-visible and FTIR spectrometers, and spectral/broadband UV instruments. Atmospheric composition measurements are taken at several Network for the Detection of Atmospheric Composition Change (NDACC) and WMO Global Atmosphere Watch (GAW) stations, namely:

- **Uccle (Belgium, 50°N)**
- **Harestua (Norway, 60°N)**
- **Jungfraujoch (Swiss Alps, 46°N)**
- **Haute Provence Observatory (France, 44°N)**
- **Bujumbura (Burundi, 3°S)**
- **Reunion Island (21°S)**
- **Belgian Antarctic station Princess Elisabeth (71°S)**

A new FTIR instrument is being installed in Brazil. Many data records cover several decades, e.g.: the ozonesonde programme in Uccle started in 1969; the Dobson and Brewer measurements started in 1971 and 1983, respectively; and the FTIR data record at the Jungfraujoch provides trends of inorganic fluorine and chlorine with respect to levels in the early 1980. UV spectral and broadband measurements are taken continuously at seven sites in Belgium and at Princess Elisabeth base in Antarctica.

The satellite-based monitoring activities include various contributions to international satellite programmes, and, in particular, ERS-2 GOME (1995-2011); Envisat (GOMOS, MIPAS, and SCIAMACHY, 2002-2012); SCISAT ACE-FTS (since 2003); EOS Aura OMI (since 2004); MetOp-A (GOME-2 and IASI, since 2006); and MetOp-B (GOME-2 and IASI, since 2012). Belgium also participates in the SOLSPEC and SOVIM instruments of the SOLAR mission, measuring solar spectral irradiance and its variations from the International Space Station. Belgian institutes are active in the preparation of future missions like the upcoming GMES/Copernicus Sentinel 5 Precursor TROPOMI (to be launched in 2016), and the series of Sentinels 4 (2018+) and 5 (2020+). In response to the urgent need to develop a gap-filler mission to continue high-resolution limb measurements after the era of Envisat, Odin, and Aura, BIRA-IASB has proposed the ALTIUS concept, a lightweight versatile limb sounder instrument designed for operation onboard the PROBA platform, also developed by Belgium. International cooperation is fostered through bodies and initiatives like CEOS, ESA Quality Working Groups, EUMETSAT O3M-SAF, GAW, GMES/Copernicus, IO3C, NDACC, and SPARC initiatives (SI2N, SDI, DA).

Research activities include trend assessments of the ozone column and vertical distribution; ODSs; the stratospheric chlorine, fluoride, and bromine budgets; other ozone-related
substances like NO2; stratospheric aerosols; and UV-B radiation; as well as the study and monitoring of ozone loss in the Arctic; algorithm developments and subsequent satellite data reprocessings in order to meet quality requirements for ozone research in a changing climate; the study of sources, sinks, and transport of trace gases, on the global scale using satellite data, and on the regional scale (polar, midlatitudes, tropics) using ground-based data; studies to better understand and use the information offered by remotely sensed atmospheric data, e.g., the development of multi-dimensional observation operators used in satellite validation and data assimilation. Apart from analysis and interpretation of observational data, various models have been developed and used. These models include chemical transport modelling of the troposphere and stratosphere, calculation of atmospheric trajectories and dispersion, long-term reanalysis of observations through a 4-D variational chemical assimilation system, and prediction of chemical weather. In particular, the BASCOE 4D-var assimilation system is a component of EU’s GMES/Copernicus Atmospheric Core Service (MACC-I/II/III projects).

**Czech Republic (Ladislav Metelka, CHMI)**

Daily observations of total ozone have been performed at the Solar and Ozone Observatory (SOO) of the Czech Hydrometeorological Institute (CHMI) in Hradec Králové since 1961 with a Dobson spectrophotometer. Two Brewers were added in 1994 and 2004, enabling the addition of systematic Umkehr measurements. Measurements of ozone vertical profiles started at the Upper Air Department (UAD) of CHMI in Prague-Libus in 1978 using Brewer-Mast radiosondes; these were replaced by ECC sondes in 1992. The ozonesondes are launched 3 times a week, from January to April. A 50-year-long time series of total ozone encouraged the Czech experts to perform a complex analysis of this unique data series, and to make several model experiments focused on the quality of the measurements and an evaluation of long-term changes of TOZ over Central Europe. Technological equipment for monitoring the ozone layer and solar UV in the Czech Republic were upgraded – a UV calibration unit, solar photometer SPUV-10, 67 ozonesondes, and an ozone tester for their calibration were bought. As for international cooperation, SOO and UAD have been involved in the Match project and EUBrewNet activities, contributed to the activities of the Regional Dobson Calibration Center – Europe (MOHp Hohenpeissenberg, Germany), and to subregional intercomparisons of Brewer spectrophotometers.

**Germany (Ulf Köhler, Deutscher Wetterdienst)**

Regular and long-term ozone monitoring has been fulfilled by a large number of institutes in Germany. Within comprehensive programmes, ground-based long-term observations are provided by DWD (Hohenpeissenberg, Lindenberg), and AWI at its sites in Koldewey (Spitsbergen) and Neumayer (Antarctica); and UV-monitoring and research are conducted by BfS, UBA, DWD, and University of Hannover. The remote sensing of ozone and ozone-relevant species, especially with satellite instruments, has been performed by DLR, IMK-Karlsruhe, and the IUP at the University of Bremen. Modelling and laboratory investigations have been done by a large number of institutes (Forschungszentrum Jülich, MPI-DKRZ Hamburg, DLR, Universities of Köln, Berlin, Mainz, and München, IMK-KIT, IUP, and GEOMAR Kiel).

Observations with ozonesondes, ground-based spectrometers, and satellite data analyses indicate a possible slight recovery of the ozone layer over northern midlatitudes and Antarctica since the mid 1990s. This trend, however, is not significant yet. The potential for extremely low values still exists (see 2011 and 2012 after the high value in 2010), as the concentrations of ODSs are still high. The additional influence of natural factors like the Arctic Oscillation/Northern Atlantic Oscillation, QBO, solar cycle, volcanic aerosol, and the sporadic occurrence of Arctic “ozone holes” can lead to these very low values. The observed ODS decline starting around 2000, however, confirms that the Montreal Protocol is making a difference.

The introduction of new, better ozone cross sections (after Brion-Daumont-Malicet) had to be postponed, when the scientists at the University Bremen (IUP) presented a set of cross sections (after Serdyuchenko) that provide much better consistency between Dobson and Brewer
spectrophotometers. The accurate determination of the corresponding temperature dependencies should be finished before final official adoption of these cross sections.

The World Calibration Center for Ozone Sondes (WCCOS) at FZ Jülich continues to improve and standardize the quality of ozone soundings with the main types of balloon sondes. Under the auspices of WMO/GAW, GAW Report No. 201 “Quality Assurance and Quality Control for Ozonesonde Measurements in GAW for standardization of sonde operation (SOPs)” was published in 2011.

The Regional Dobson Calibration Centre for WMO RA VI Europe (RDCC-E) at the Meteorological Observatory Hohenpeissenberg (MOHp), in close cooperation with the Solar and Ozone Observatory at Hradec Králové (SOO-HK, Czech Republic), has been responsible for the second-level calibration and maintenance service of approximately 25 operational Dobson spectrophotometers in Europe since 1999. In the past 15 years, 31 intercomparisons (24 at MOHp; 3 at LKO, Arosa, Switzerland; 3 at INTA, El Arenosillo, Spain; and 1 at Hradec Králové) were organized, performed, and evaluated under the lead management of RDCC-E to calibrate a total of 93 Dobsons. 28 instruments were upgraded, and 4 Dobsons already have been relocated. In addition, the RDCC-E participated in two Dobson IC’s for the RA I (in Dahab, Egypt in 2004 and Pretoria, South Africa, 2009). These activities, including training courses and support during data examination, done by SOO-HK, have been major contributions to capacity building, and should be continued.

Nordic Countries (Weine Josefsson, SMHI)

Mr Weine Josefsson presented an overview of network and monitoring activity in the Nordic countries and Greenland. In the station-sparse area of Iceland, one long-term total ozone station has been making Dobson observations since 1958. These observations (raw data) have now been digitized and re-processed. The Reykjavik series shows the importance of long-term series when compared to the shorter ones available from other sites.

All Nordic countries operate stations measuring total ozone, and a number of sites also monitor UV (broadband, narrowband, and spectral). There are several NDACC sites measuring column and also vertical profiles of several compounds related to ozone chemistry. Some of the instruments are operated by other countries.

The meteorological services produce and distribute UV-index forecasts to the public. There are also systems to compute near-real-time UV-irradiance (Denmark, Finland, and Sweden).

Finland and Sweden are involved in activities using instruments onboard satellites.

Besides the UV-index, EPA and Radiation Protection Authorities are disseminating information to the public trying to change how people behave in the sun.

The reader is encouraged to refer to the national report of each country for more information regarding future plans, needs, and recommendations.

Poland (Janusz Borkowski, IGF-Polish Academy of Sciences)

Mr Janusz Borkowski described the ozone-monitoring activity being conducted by the Institute of Geophysics Polish Academy of Sciences (IGPAS) and Institute of Meteorology and Water Management (IMWM). Measurements of total ozone are taken at Belsk Observatory (IGPAS) with Dobson and Brewer instruments, and ozone profiles are measured by the Umkehr inverse technique. The ozone soundings are performed at the Legionowo upper-air station (IMWM). Measurements of UV-B radiation are made at both locations. As an example of analysis of the results of monitoring, the long-term variability of the total ozone was characterised. Mr Borkowski also listed the research subjects investigated by the Institute of Geophysics.
Switzerland (Dominique Ruffieux, MeteoSwiss)

In the Swiss presentation, which was prepared by Mr René Stübi and Mr Dominique Ruffieux, the latter discussed the ozone-related monitoring activities at the Arosa and Payerne stations, as well as the support to the Kenyan Nairobi station. Different time series of the ozone column above Arosa and of the ozone profiles measured by sondes and microwave instruments at Payerne also were presented.

The constant effort to improve the quality of the long records was illustrated by the time series of the difference of total ozone of each Brewer compared to the triade mean. These series show a stability of the measurements over the last decade to within ± 0.5%.

Mr Ruffieux also presented the recent achievements of a MeteoSwiss project for improving the Dobson ozone column data quality. The new automated data acquisition system provides more reproducible measurements at a higher frequency, with performance comparable to the Brewer instruments.

Turkey (Serpil Yağan, TSMS)

The Turkish State Meteorological Service (TSMS) is responsible for observing and promoting research activities on measurements of ozone and UV radiation. In addition, a Brewer spectrophotometer is used for ozone measurements in Ankara.

Total ozone measurements have been made using the Brewer since November 2006. Brewer data are sent to the World Ozone and UV Radiation Data Centre. These data are archived and published with the station ID 348 in Toronto.

Calibration of the Brewer Spectrophotometer has been performed since it began operating in 2006. The first Brewer calibration was carried out by International Ozone Services on 7–12 October 2008, and it was financially supported by the WMO. The second Brewer calibration was carried out by Kipp and Zonen on 22–29 September 2010. The third Brewer calibration was carried out by Kipp and Zonen on 23-27 September in 2013.

UV radiation measurements are made at 15 different stations. UV radiometers are used to measure UV radiation at 14 stations in narrow band, and at 1 station in broadband, using 30 instruments. Spectral UV-B measurements using the Brewer #188 MKIII have been made since 2006 in Ankara.

The TSMS and DWD global-model outputs for daily ozone and UV-index forecasts are published on the TSMS website.

United Kingdom (Lynette Clapp, Defra)

Ms Lynette Clapp gave an overview of ozone monitoring and research in the United Kingdom. She started by acknowledging the institutions that fund and carry out ozone related research:

• Defra consortium for Baseline Measurement and Analysis of UK Stratospheric Ozone and UV (Ricardo-AEA, University of Manchester (UoM), University of Reading, Imperial College, and UK Met Office)
• Department of Energy and Climate Change (DECC)
• British Antarctic Survey (BAS)
• University of Cambridge
• National Environment Research Council (NERC)
Ozone measurements in the UK funded by Defra include:

- Dobson instrument in Lerwick, Shetland Islands, North Scotland (operated by Met Office, 1957-)
- Brewer instrument, Reading University, Berkshire, South England (operated by University of Manchester, 2003-)

Ozone measurements in the UK operated by UoM include:

- Brewer instruments (Manchester, North England, and Valentia, Irish Republic)
- SAOZ instrument (Capel Dewi, Aberystwyth, Wales)

The British Antarctic Survey (BAS) performs several measurement programmes in Antarctica:

- **Halley**: Dobson instrument, total ozone, and NO₂ column measurements with a SAOZ spectrometer (from January 2013)
- **Rothera**: Total ozone and NO₂ column measurements with a SAOZ spectrometer
- **Radiosonde programme** at both (funded by the UK Met Office and BAS)
- Support measurements at Vernadsky (Ukraine)
- The UK Met Office lent Dobson #35 to the South African Weather Service in June 2006, and it remains on loan there.

High-frequency, real-time *in situ* measurements of the principal halocarbons and radiatively active trace gases have been made at Mace Head on the West coast of Ireland since 1987. These measurements form a key part of the international Advanced Global Atmospheric Gases Experiment (AGAGE) measurement programme. For about 70% of the time, Mace Head monitors clean westerly air that has travelled across the North Atlantic Ocean. For the remaining time, Mace Head receives substantial regional-scale pollution in air that has travelled from the industrial regions of Europe. The site is therefore ideally situated to record trace-gas concentrations associated with both the Northern Hemisphere background levels and with the more polluted air arising from Europe.

The UK Department for Energy and Climate Change has expanded the atmospheric observation network (UK DECC network) to include three additional sites in the UK: Angus, north of Dundee; Tacolneston, near Norwich; and Ridge Hill, near Hereford. These sites significantly increase the spatial and temporal resolution for the interpretation work, enabling UK emission estimates to be made from atmospheric observations, as well as decreasing uncertainties associated with UK estimates. Analysis of the atmospheric observation data also identifies sources of and trends in ozone formation from different areas, including comparison of observed data with expected trends, to identify any new substances with ozone-depleting or radiative forcing properties.

The solar UV index is measured at nine sites (from 50 to 60°N) across the UK by the Centre for Radiation, Chemical, and Environmental Hazards of Public Health England (PHE). DoH provides support for this UV monitoring work, which provides information for the Global Solar UV Index in association with the World Health Organisation (WHO), WMO, UNEP, and the International Commission on Non-Ionizing Radiation Protection. A tenth site is located at Thule in Greenland, which is operated in conjunction with the Danish Meteorological Institute.

Calibration activities include:

- **The Dobson instrument in Lerwick** is re-calibrated every 4 to 5 years. The last re-calibration of Dobson #32 took place in 2011. The last re-calibration of Dobson #41 took place in 2009, and the instrument is scheduled to go to the 2014 Hohenpeissenberg intercomparison.
• **Brewer #075 in Reading** is re-calibrated every 2 years. The last re-calibration took place in El Arenosillo, Spain in 2013.

• The last re-calibration of **Brewer #172 in Manchester** was at the RBCC-E site in Spain in 2013.

• **The Bentham DM150 in Reading** was last re-calibrated during a five-day intercomparison with the World Standard UV Instrument ‘QASUME’ from Davos, Switzerland in 2013.

• PHE found inconsistencies with the internal calibration of the **UV broadband instruments**, so R-AEA has been invited to the lab to investigate.

In the areas of research projects and collaborations, John Rimmer (UoM) made a successful bid for funds from European COST Office to bring all European Brewer Ozone Spectrophotometer stations together in a formal network. COST Action ES1207 EUBrewNet was launched in April 2013 (http://www.eubrewnet.org/cost1207/). In addition, John Pyle (University of Cambridge) is Co-Chair of the Scientific Assessment Panel.

Regarding future plans, Defra has no plans to provide funding for any additional ozone, UV or ODS monitoring sites in UK, and is keeping future research needs for policy development under review. NERC continues to support the BAS and NCAS national capability to monitor ozone and to model chemistry and climate. Funding support for new research projects on ozone will be considered through usual processes.

Dr Clapp ended her presentation with the following recommendations:

• Maintenance of long time series is essential, especially for trend analysis and ground-truthing of satellite data.

• Additional work to model emissions of trace gases and ozone-depleting substances will be beneficial for assessing emissions inventories.

**Armenia, Belarus, and Russian Federation** *(Yury Borisov, CAO, and Aliaksandr Krasouski, BSU)*

Mr Yuri Borisov (CAO) and Mr Aliaksandr Krasouski (BSU) presented the activities in Armenia, the Republic of Belarus, and the Russian Federation.

**Armenia**

There are two stations in Armenia where total ozone measurements are carried out: Amberd, where total ozone has been measured with a Dobson spectrophotometer since November 2000, and Arabkir, where total ozone has been observed with an M-124 filter ozonometer since 1990.

The measurements at Arabkir are compared to the Dobson measurements at Amberd in order to determine calibration corrections connected with the aging of the ozonometer filters.

Studies of the connection between changes in total ozone, ultraviolet radiation, and the morbidity of the population by skin cancer for different regions of the country have been initiated and are ongoing.

The Dobson data from Amberd are reported regularly to the WMO/GAW World Ozone and UV radiation Data Centre.

Combining forecasts of the total ozone distribution over the Northern Hemisphere from the WMO/GAW ozone mapping programme with forecasts of cloudiness, daily forecast maps of the distribution of UV indices over the territory of Armenia are made with the use of a model for solar irradiation. The estimations and forecasts of UV indices for inhabited areas of Armenia are calculated according to the guidelines given in “UV Index for Public “ (COST Action 713 on UVB
Forecasting), and are included in the weather forecasts for dissemination to the public via mass media.

Future plans in Armenia include:

- Continue with regular measurements of ozone and distribution of the results.
- Efforts for the organisation of regular measurements of ultraviolet radiation will be undertaken.
- The results of modelling of a climatic regime of UV irradiation will be used for development of results begun in the first bullet above, research of the vulnerability of the health of a village and urban population to increase of ultraviolet radiation, and the influence on vulnerability of the height of a location in all regions of Armenia. The research is based on long-term statistics on morbidity of the population of Armenia by skin cancer, and on results of total ozone measurements.

Needs and recommendations from Armenia include:

- To use the capacities of the weather station at Amberd, allowing for the implementation of international projects for monitoring of solar radiation and vertical distribution of ozone, lidar observations, aerosol transfer, and transboundary air pollution in the region of South Caucasus.
- To periodically organize data quality workshops, similar to the WMO/UNEP Dobson Data Quality Workshop in Hradec Králové, Czech Republic, 14-18 February 2011.
- To enable ozone experts from developing countries to receive short-term training in world-renowned scientific centres in order to improve their scientific and technical potential.

**Belarus**

Total ozone measurements in Belarus have been carried out since 1998 at the National Ozone Monitoring Research and Educational Center (NOMREC) in Minsk. The instrument used is a PION ozonometer designed and built at NOMREC.

Since 2006, using PION-UV and M-124-M filter instruments, regular total ozone and UV radiation measurements have been conducted in conjunction with the seasonal Belarusian Antarctic Expeditions in the region of Enderby Land (Antarctica).

NOMREC possesses a full database on total ozone monitoring in the atmosphere over the territory of Belarus for the period 1998-2014. NOMREC also has the database of surface solar UV radiation spectra, as well as doses of various biological effects for the territory of Belarus covering the period 2001-2014.

The network of total ozone measurement sites was enlarged in 2011. Currently, the measurements are also taken at the BSU biological station (Naroch Lake) and at the Gomel State University. As a net ozonometer, a fully automated PION-F double-channel filter photometer is used.

Monitoring of the total column of nitrogen dioxide has been performed at the Minsk Ozone Station since 2007. In 2009-2010, the nitrogen dioxide column values were measured with a new DOAS zenith-sky system.

Ozone profile monitoring has been conducted since 1985 with a lidar instrument at the B. I. Stepanov Institute of Physics, National Academy of Sciences of Belarus.

A submersible PION-F photometer has been designed to study solar UV radiation propagation in the aqueous medium down to a depth of 20 m.
**Russian Federation**

In the Russian Federation, ozone observations are carried out by the Central Aerological Observatory (CAO) in Moscow and the Main Geophysical Observatory (MGO) in St. Petersburg, both under the auspices of the Federal service for hydrometeorology and environmental monitoring (Roshydromet). In addition to a number of stations with M-124 filter instruments, there are two Dobson and five Brewer spectrophotometers, as well as six SAOZ spectrometers. In addition to total ozone measurements, ozone profile measurements are carried out at Salekhard (67°N, 67°E). In addition, microwave radiometers and lidars are used to measure ozone profiles. The first total ozone measurements from the Russian geostationary weather satellite Elektro-L have been conducted.

The Lomonosov Moscow State University has monitored surface UV radiation using the UVB-1 1YES pyranometer since 1989. The Brewer instruments located in Yakutsk, Obninsk, Kislovodsk (since 1989), and Dolgoprudny (2014) have been calibrated to measure the spectral distribution of surface UV radiation.

The MGO of Roshydromet provides calibration of the M-124 filter ozonometers. The reference is provided by Dobson spectrophotometer No. 108, which, in turn, undergoes an intercalibration procedure once every four years at the WMO European Calibration Center in Hohenpeissenberg. Since 1988, the deviation of Dobson No. 108 total ozone measurements from the WMO reference values has not exceeded 1%. The M-124 instruments are calibrated at least every two years. The Brewer spectrophotometers operated in Obninsk, Kislovodsk, and Tomsk, were last calibrated in 2012.

The stability of the total ozone measurement scale is maintained through regular calibration of M-124 ozonometers at MGO, and a monthly ozonometer intercomparison at the stations. Each station has three instruments: operational, back-up, and reserve. MGO provides continuous control of the measurement quality and performance of the M-124 instruments. Ozonometers that suffer a considerable change in the measurement scale are replaced ahead of the scheduled time, and then undergo calibration.

The data from routine total ozone observations from the M-124 network are transmitted to the Hydrometeorological Center of Russia, CAO, and MGO daily. CAO archives the data, performs their primary quality control, and transmits them to the WOUDC. These data, together with that from other countries, are used by WOUDC for operational imaging of total ozone fields (http://woudc.org/). CAO also performs operational mapping of the total ozone distribution over Russia, reveals anomalies, and analyzes their reasons. At MGO, the total ozone data undergo more thorough quality control, which enables an assessment of the instrument performance and data correction. After QA control, the results are transmitted to the WOUDC. WOUDC also regularly receives total ozone and UV data measured with Brewer spectrophotometers at Kislovodsk, Obninsk, and Tomsk. Total ozone and NO$_2$ measurements on the territory of Russia using SAOZ are made at six high-latitude stations: Anadyr (64°N, 177°E), Zhigansk (67°N, 123°E), Irkutsk (52°N, 104°E), Salekhard (67°N, 67°E), Dolgoprudny (56°N, 37°E), and Murmansk (68°N, 33°E).

**The European COST Action EUBrewNet: Towards Consistency in Quality Control, Quality Assurance, and Coordinated Operations of the Brewer Instrument**

*(John Rimmer, University of Manchester)*

The aim of EUBrewNet is to bring together all the Brewer Ozone Spectrophotometers in and around Europe into a formal network with standardised characterisation, calibration, and data-processing procedures. A central database will be set up to allow central processing and quality assessment, and also to provide near-real-time data for ozone, UV, and aerosol optical depth in the UV. Data collection and processing will be automated as far as possible. At the moment, 20 European countries and 4 international partners are involved in the project. The networking, training school, conference, and dissemination instruments are funded through COST Action ES1207. The results of the Action will be published and made available to both the public and
scientific communities. Collaborations and interactions with other countries or agencies are encouraged and welcomed.

SESSION 6: DISCUSSION OF RECOMMENDATIONS

Recommendations arising from the meeting were discussed under four topics. For each topic, selected resource persons made a short introductory presentation for each topic, followed by discussion. Rapporteurs identified for each topic led the drafting of the recommendations on the basis of the discussions. The national reports formed an important basis for the discussions and the recommendations. The resource persons and rapporteurs were as follows:

**Research Needs:** Introduction by Greg Bodeker, New Zealand, and John Pyle, SAP Co-Chair; Rapporteurs – Paul Newman and A. R. Ravishankara, SAP Co-Chairs

**Systematic Observations:** Introduction by Wolfgang Steinbrecht, Germany, and Jean-Christopher Lambert, Belgium; Rapporteurs – P. K. Bhartia, USA, and Niels Larsen, Denmark

**Data Archiving and Stewardship:** Introduction by Martine De Mazière, Belgium, and John Rimmer, UK; Rapporteurs – Stephen Montzka, USA, and Stoyka Netcheva, Canada

**Capacity Building:** Introduction by Ayité-Lô Ajavon, Co-Chair, SAP, and Geir Braathen, WMO; Rapporteurs – Anne Thompson, USA, and Matt Tully, Australia

The final recommendations, provided below, are divided into six categories: overarching goals; research needs; systematic observations; data archiving and stewardship; capacity-building; and the General Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention. The last category of recommendations resulted from a discussion on the accomplishments and the future of the General Trust Fund. Those recommendations will be particularly relevant for the discussions at the tenth meeting of the Conference of the Parties to the Vienna Convention on agenda item 5 (b) on the status of the General Trust Fund.

**Recommendations**

**A. Overarching Goals**

1. **Recognise that the issue of changes in climate and in the stratospheric ozone layer are intimately coupled:** The Montreal Protocol was instituted to protect the Earth’s surface from the harmful UV radiation increases that could arise from the depletion of the ozone layer by ozone-depleting substances. Over the decades, research has clearly shown that ozone layer depletion, and its projected recovery, and changes in climate are intricately linked. Therefore, it is essential to encompass changes in climate in efforts to protect the ozone layer.

2. **Existing observation capabilities for climate and ozone layer variables need to be maintained and enhanced.** Given the strong coupling between ozone layer depletion and changes in climate, the observations of climate and ozone layer variables should be carried out and analysed together whenever possible.

3. **Continue, enhance, and target the Vienna Convention Trust Fund for Research and Systematic Observation to better support the above goals:** In line with the above two goals, it is essential to continue and significantly enhance the Vienna Convention Trust Fund for Monitoring and Research to make it more effective in addressing some of the issues that arise from above. It is also essential to develop a strategic plan for the Fund, and to
request that the UNEP/Ozone Secretariat and WMO set up a small working group to assist them in setting priorities and ensuring implementation.

4. *Dedicate to build capacity to meet the above goals:* Given the above, it is very important to carry out capacity building activities in the Montreal Protocol Article 5 countries to expand the scientific expertise, with the added benefit of expanding the geographical areas for the measurements and data archival of the key variables related to the ozone layer and changing climate.

**B. Research Needs**

Extensive research over the past decade and more has highlighted the role that stratospheric ozone plays as a core component of the global climate system. Stratospheric ozone has responded to, and will continue to respond to, decreases in stratospheric temperatures resulting from accumulation of CO₂ in the stratosphere and to changes in ozone chemistry resulting from anthropogenic emissions of ozone depleting substances (ODSs). Further, the role of ODSs and their substitutes as greenhouse gases (GHGs) brings in yet another important facet to this issue.

The complex coupling of ozone, atmospheric chemistry and transport, and climate changes is still not fully understood. Further research is needed to better understand the underlying processes and to improve model predictions of the expected changes in both ozone and temperature distributions of the middle atmosphere. In support of WMO/UNEP Ozone Assessments, there is a need for coordinated simulations of future ozone changes using chemistry climate models (CCMs) constrained by common boundary conditions. These simulations should include ancillary simulations that include, e.g., fixed GHG concentrations or fixed ODS concentrations to permit an attribution of changes in ozone to these forcings.

Progress has been made on the recommendations made at the 8th Ozone Research Managers meeting, and it includes the following:

- Advances have been made in better quantifying the lifetimes of key ODSs and, importantly, their uncertainties.
- There have been ongoing efforts to further develop CCMs and to push towards the development of fully coupled Earth System Models (ESMs).
- Advances have been made in constructing long-term data records of stratospheric ozone and the trace gases that affect stratospheric ozone.
- Studies of the processes that maintain the stratospheric aerosol layer, which strongly influences ozone chemistry, have advanced.
- The value of including an interactive stratosphere in models of the global climate system has been more clearly elucidated.
- The role of HFCs as a climate-forcing agent has been better quantified and the means by which the climate protection benefits of the Montreal Protocol can be preserved has also been explored.

**Key research needs recommendations arising from the 9th ORM:**

(i) *Chemistry-climate interactions and monitoring the Montreal Protocol*

It is now well established that the future evolution of the stratospheric ozone layer will depend not just on the decline of ODS concentrations, but also on how climate will affect stratospheric temperatures and circulation. Furthermore, the coupling between atmospheric composition and climate is two-way. Past changes in stratospheric ozone are known to have impacted surface climate; future ozone change is projected to affect the climate system.
It is incumbent on the scientific community to monitor the continued effects of the Montreal Protocol. There is a research need for detailed analyses of the wide range of data on ozone, ODS, and related gases so that we can comprehensively assess the impact of the Protocol. Further research, combining state of the art CCMs and reference quality, altitude-resolved data records is needed to explain past changes.

(1) **Ozone in climate models:** There is increasing appreciation that the inclusion of ozone in models of the atmosphere improves the quality of long-term projections of climate change, and also creates new opportunities, e.g., for seasonal predictions. Accordingly, research is required to better understand those surface climate processes affected by changes in the stratosphere, including effects on tropospheric circulation, precipitation, sea ice, ocean-atmosphere exchange, etc.

(2) **The changing Brewer-Dobson Circulation:** Research is needed to resolve the apparent inconsistency between model projections of an increasing strength in the Brewer Dobson Circulation (BDC) and observations of long-lived trace gases in the stratosphere, which, if anything, suggest a slowing of the BDC. Resolving this inconsistency may require new measurements, e.g., of SF$_6$ and CO$_2$ in the middle and upper stratosphere that can be used to infer changes in the strength of the BDC (see also the Systematic Observations section).

(3) **Constructing Data Records:** Improved, long-term data records of stratospheric ozone, other trace gases associated with ozone chemistry (e.g., HNO$_3$, ClO, BrO, H$_2$O, CH$_4$, N$_2$O) and other atmospheric state variables (e.g., temperature) need to be constructed to assess the physical consistency of trends in ozone and temperature, and to aid the interpretation of the causes of long-term changes in ozone. A temperature climate data record of the free troposphere and stratosphere is needed to interpret the interactions between changes in the thermal structure of the atmosphere (which will be forced by changes in greenhouse gas concentrations) and changes in ozone. Such a temperature data record will also support the construction of ozone data records since measurements in ozone mixing ratio often need to be converted to number density and measurements on pressure levels need to be converted to measurements on geopotential height, both of which require temperature time series. These temperature time series must be stable over multiple decades to avoid aliasing false temperature trends into false ozone trends. Inhomogeneities in current meteorological reanalyses suggest that this approach to generating temperature time series for the stratosphere is inadequate. Data records should be constructed according to the principles outlined by GCOS (Global Climate Observing System; GCOS-143).

(4) **Trends in ozone:** Research is required to better quantify trends in vertically resolved ozone data records in different regions of the atmosphere, and in particular over the polar regions where observed ozone trends have been largest. Trends in ozone and associated trace gases need to be analysed in detail to assess whether their observed evolution to date is consistent with our understanding of the process affecting trends and variability. Expectations for the length of measurement series required to confirm the effectiveness of the Montreal Protocol need to be investigated.

**(ii) Processes influencing stratospheric evolution and links to climate**

The stratosphere is a highly coupled chemistry-radiation-dynamics system. Thus, models need to incorporate the fundamental understanding of these processes. In some cases our knowledge base is incomplete. We require more and improved laboratory measurements of kinetic and spectroscopic parameters. Field measurements are required to improve understanding, ranging, for example, from the surface emissions of very short-lived substances to the transport and transformation of species moving between the troposphere and stratosphere (and back again).
(1) **Non-ODS gases**: The role played by gases, other than the ODSs controlled under the Montreal Protocol, in ozone depletion chemistry (e.g., N₂O, CH₄, biogenic bromocarbons) needs to be further investigated. Emissions databases of CH₄ and N₂O need to be improved to permit more realistic modelling of the impact of their emissions on ozone. Changes in atmospheric concentrations of ODS replacements need to be reconciled with known emissions and atmospheric lifetimes of these gases. The effects of changes in tropospheric OH on the lifetimes of short-lived gases that, when transported to the stratosphere, provide a source of chemically active species to the stratosphere, need to be better quantified. Seasonally resolved tropospheric OH climatologies, validated against appropriate measurements (see *Systematic Observations* section), are required to reduce uncertainties in model simulations of the transport of short-lived compounds from the surface to the stratosphere. Knowledge of tropospheric OH concentrations is also required to understand lifetimes of other gases such as CH₄.

(2) **Laboratory measurements**: Laboratory measurements provide the foundation for our satellite retrievals, ground-observations, and model simulations. The quality/precision of O₂ and O₃ cross-sections needs to be improved. The O₂ cross-section has a major impact on the lifetime to species that are photolysed in the stratosphere. The selection and use of improved O₃ absorption cross-sections in ground-based remote sensing measurements of ozone need to be finalised. Furthermore, as new gases (e.g., HFCs) are proposed, it is necessary to conduct accurate laboratory studies of their fundamental loss processes (viz., reactions with OH, UV cross-sections, IR absorption spectra). Improvements in laboratory measurements of ozone absorption lines in the IR are also required for improving ground-based retrievals of other trace gases that are absorbed in the IR. It is also essential that these laboratory data are critically evaluated. Stewardship and curation of the laboratory data are important to have a trustworthy database for modelling, analyses, and understanding. Experts with deep knowledge of chemical kinetic, photochemical, and spectroscopic data need to be involved in the stewardship and curation process.

(3) **Stratospheric aerosols**: Stratospheric aerosols comprising the Junge Layer are important as both surfaces for heterogeneous chemical processes, but also for their radiative impact. Hence, understanding the processes that control the atmospheric distribution of aerosols is fundamental to modelling of the stratosphere. In particular, understanding how SO₂ and carbonyl sulphide (OCS) maintain the Junge layer and how particles evolve in the stratosphere are of key importance. Such research will also support the inclusion of appropriate processes in the models being used to assess aspects of proposed geoengineering actions through intentional enhancement of the stratospheric aerosol layer.

(4) **Stratosphere-troposphere exchange (STE)**: Research is required to improve understanding of the processes controlling the two-way exchange of gases and aerosols between the troposphere and the stratosphere, e.g., the Asian Monsoon circulation that provides an efficient pathway for pollutants from close to the surface, through the tropical tropopause layer, and into the stratosphere. The fidelity of the simulation of STE processes in CCMs must be assured if we are to have confidence in projections of climate driven changes in STE through the 21st century. Targeted field campaigns are required, e.g., to understand tropical processes and the processes active in the upper troposphere and lower stratosphere (UT/LS) that modulate the chemical and dynamical two-way coupling between the stratosphere and the troposphere.

(iii) **UV changes and other impacts of ODS changes**

Recent simulations of ozone changes through the 21st century suggest that increases in surface UV in the tropics, and decreases at middle and high latitudes, could occur. For humans, this poses the risk of elevated skin cancer incidence in the tropics, but also slightly increases the
risk of UV doses that are too low for the production of sufficient Vitamin D at middle and high latitudes. While research on the impacts of changes in UV radiation on various organisms has substantially advanced, various needs for research remain, including:

1. Factors affecting UV: There is a need to disaggregate the factors affecting UV radiation at the surface so that the influence of factors other than ozone (e.g., cloud cover, aerosol abundance, albedo, and temperature) can be better assessed.

2. UV change impacts: The effects of stratospheric ozone change, and the resulting changes in UV radiation, on human health, ecosystems, and materials, require further study. These studies should include quantitative analyses that allow an assessment of the magnitude of specific impacts in relation to UV changes. Research should also account for interactions between the effects of changes in UV and those of climate change, particularly effects that may lead to feedbacks to climate change, for example, through altered carbon cycling or tropospheric chemistry.

3. ODS substitutes: Support studies that investigate the environmental effects of ODS substitutes, and their degradation products, on human health and the environment.

C. Systematic Observations

As stated in Article 3 of the Vienna Convention, systematic observations are critical for monitoring and understanding long-term changes in the ozone layer, as well as changes in atmospheric composition and climate. In order to verify the expected ozone recovery and to understand interactions with changing climate, continuing observations of key trace gases and parameters characterizing the role of chemical and dynamical processes will be required for the next decades.

We are now moving from a period where increasing ozone depleting substances (ODS) were threatening the ozone layer, to a period where growing concentrations of other climate related gases, especially CO₂, N₂O, CH₄, and H₂O will impact the ozone layer more and more. These impacts are complex and are interacting. Not all are fully understood. Future emissions are especially uncertain.

Long-term monitoring of the ozone layer, therefore, has to continue. Monitoring needs to be expanded to important new species and parameters. Key measurement regions include the upper troposphere and lower stratosphere, regions of troposphere to stratosphere exchange in the tropics and monsoon circulations, as well as the polar caps and the upper stratosphere. In particular, measurements of the vertical distribution, especially in the UTLS region and in the upper stratosphere, are of prime importance.

Global observations provide the essential data-basis for our understanding of ozone, ozone depleting substances and UV radiation. Many nations around the world are contributing. These networks also provide the training for atmospheric scientists internationally, including developing countries. Measurements from these networks provide the basis of all research activities and for decision-making. Networks fall into two categories, ground-based networks and space-based networks. The achievements since the 8th ORM are:

- Despite some difficulties, ground- and space-based measurements of ozone, most relevant trace gases, temperature, and stratospheric aerosol have successfully continued over the last years.
- The OMPS limb instrument on the current SUOMI NPP platform and the planned deployment of the SAGE III solar occultation instrument on the International Space Station from 2015 will reduce the imminent gap in atmospheric limb sounding instruments for ozone, aerosol, and water vapour. However, as indicated in the key recommendations below, a severe lack of limb measurement capabilities is expected for many other important gases.
• Refurbishment and relocation of unused Dobson and Brewer instruments to data-poor regions is continuing, albeit at a slow rate of about one instrument per year.

• Additional laboratory spectroscopic studies have now provided the basis for moving towards finalizing recommendations on the best ozone absorption cross-sections in the ultraviolet. Some satellite data sets are already using these new cross sections; application to ground-based observations (especially Dobson and Brewer data) should now be possible until the next ORM.

• Initial measurements of important emerging ODS replacement substances, e.g., HFCs, have been made.

Key systematic observations recommendations arising from the 9th ORM:

(1) Continuation of limb emission and infrared occultation observations from space is necessary for global vertical profiles of many ozone and climate related trace gases. Without such observations, data events like the severe 2011 Arctic ozone depletion cannot be analysed, and the underlying processes cannot be quantified.

(2) Continuation of ground-based stations with long-term records is absolutely necessary to provide a reliable baseline for trend estimation. The steady decrease in the number of stations, especially for profile measurements, is starting to endanger the independent monitoring of trends and the capturing of unexpected events, as well as our ability to validate satellite data records.

(3) Effort should be expanded to maintain regular, long-term monitoring in key regions for troposphere-stratosphere exchange, such as monsoon regions, Southeast Asia, the maritime continent, and the Tibetan plateau. Measurements should also be targeted to data poor areas like South America, Africa, and Asia.

(4) Attention must be given to the continuation of stratospheric aerosol measurements. These data allow the analysis of stratospheric transports, and possible changes in the circulation. They become even more crucial after major volcanic eruptions.

(5) As most ODSs are declining, other source gases, especially N₂O, CH₄, and water vapour, are becoming more important, and will have impacts on the ozone layer. Increased efforts to monitor these gases, understand their changing fluxes, and better assess their impacts will be required.

(6) Measurements of emerging ODS substitutes need to be included in the baseline monitoring programmes. Existing archives could be analysed for historic estimates of atmospheric burdens of such gases.

(7) The important connection between ozone and climate change, and the expected changes in the mean meridional Brewer-Dobson circulation, require monitoring of temperature and trace-gas profiles, especially of dynamical tracers like N₂O and SF₆, and of ozone and water vapour in the UTLS.

(8) To maintain stewardship of long-term surface UV records, existing measurements of surface UV radiation and related parameters should be continued.

(9) As technology and software have matured, new cost effective instruments are becoming available. Efforts should be made to evaluate such instruments for their suitability for deployment in the networks. Where possible, column measurements should be complemented by profile measurements.

(10) Public information services need to be implemented further.

D. Data Archiving and Stewardship

Progress has been made on the recommendations made at the 8th Ozone Research Managers meeting, and it includes the following:
• Submission of level-0 Dobson data – This is an ongoing, but not yet a finalised process.
• Need for comprehensive reporting of national ozone-depleting substance (ODS) production and consumption to improve emission inventories continues to be addressed – Reporting continues successfully for most ODSs, although discrepancies of unknown origin between reported production and atmospheric observations remain for CCl4. Global reporting of non-ODS substitutes (e.g., HFCs to the UNFCCC) is currently insufficient for reconciling global-scale observations. In addition, countries should be encouraged to submit revised production and/or consumption figures from past years, when warranted.
• The need for workshops to provide training on metadata collection and on the processes for data archiving; and the coordination/communications role for both the WMO Permanent Representatives and/or the Ozone Research Managers will be addressed in recommendations for capacity building.

Key data archiving and stewardship recommendations arising from the 9th ORM:

(i) Make arrangements for more cost efficient and effective data archiving

(1) There is a need to develop robust automated data submission with centralised processing and QA schemes to ensure timely submission, or even near-real-time (NRT) submission, to the appropriate data centre. All necessary information to process and re-process data, e.g., calibration histories, should be included in the processing facility. Scientific oversight is required. Satellite overpass data should be included with ground station data in the data centre so that initial quality assessments can be performed in near-real time. Databases should be configured to store multiple versions with full traceability.

(2) It is necessary to digitise historical data for ozone and related species, as well as for ancillary data (e.g., laboratory spectroscopic data, station information, etc.) where available and before the information gets lost, in order to include them in modern database systems.

(3) Encourage data providers to submit to existing databases to avoid proliferation of databases and to avoid loss of data after the end of a campaign or project. Responsibilities for data centres should be clearly established.

(4) Funding agencies need to recognise long-term archiving as resource-intensive and a critical part of any measurement programme. Stewardship and succession must be a consideration. Long-term data preservation (LTDP) must be supported. In particular, Member States of ESA should commit to support the ESA LTDP programme.

(5) Central data archives for satellite data sets (e.g., the DAAC at NASA) should be established by other agencies, and linked via a central portal (e.g., CEOS portal), on a sustainable basis. The WDC-RSAT (World Data Centre for Remote Sensing of the Atmosphere, operated by the DLR in Oberpfaffenhofen, Germany) may play this role in Europe. Satellite overpass data and subsets over network stations should be readily available (e.g., a facility like AVDC and TEMIS should be sustained).

(6) Enhanced linkage among data centres must be targeted. This requires that data centres work together more, and make progress with exchange of metadata and interoperability. Open and user-friendly formats and data access must be encouraged; data that are not open to the community should be uncovered. Different data levels (L0 to L3; merged data sets) may be required for different users. Efforts should be continued to generate homogenous long-term data records from available sources.
It should be a responsibility of the data centres to provide tools to re-format, read, and view the data.

Data publishing with an associated doi, e.g., in Pangeae or ESSD, should be encouraged to provide data to the scientific community and to give recognition to scientists and the funding agencies for providing the data. It may also offer a good solution to the archiving (including traceability) of model output or single data sets.

E. Capacity Building

Capacity building for ozone monitoring and research in developing countries and in countries with economies in transition comes from the general commitments anchored in the Vienna Convention. Enhancement of the GAW ozone-monitoring network in all continents and creation of local scientific communities contributing to global ozone science are the main goals of capacity building. In order to increase the awareness of the importance of compliance with the Montreal Protocol, it is of vital importance that each Party to the Protocol have resident expertise in ozone matters. This can be obtained through transfer of knowledge from the industrialised world to the developing countries. One way to accomplish this is through the establishment of monitoring programmes that will produce observational data of value to the WMO/UNEP Scientific Assessments of Ozone Depletion, carried out periodically under the Montreal Protocol on Substances that Deplete the Ozone Layer. Researchers from developing countries should be encouraged to take part in analysis of data and in scientific publications where their data are used. Many developing countries are located in the tropics, and this is also an area of the globe where there is a lack of observations.

While there has been progress in capacity building since the 8th ORM, much remains to be accomplished. A number of key activities have been undertaken over the last three years that have had significant impact. In particular:

(i) Educational workshops

• The 13th Biennial Brewer Users Group Meeting, 12-16 September 2011 in Beijing, China.
• The 14th WMO-GAW Brewer User's Workshop, 24-28 March 2014 in Santa Cruz, Tenerife.

(ii) One-on-one training

The manager of the Regional Dobson Calibration Centre for South America received training at the World Dobson Calibration Centre in Boulder, Colorado in September/October 2013.

(iii) Twinning

In addition, a number of countries have developed twinning relationships that have built both capacity and scientific relationships over this time period. The following are key examples of quality twinning relationships that can be used as models for further endeavours of this kind:

• Finland – Argentina
• Netherlands – Surinam
• Spain – Algeria
• Spain – Egypt
• Spain – Morocco
• Spain – Argentina
• Switzerland – Kenya
• UK – South Africa
• USA – SHADOZ network (Costa Rica, South Africa, Vietnam, Kenya, Brazil, Surinam, Ecuador, Fiji, Indonesia)

The 9th ORM also recognizes that a number of other organizations (e.g., WMO GAW) support capacity-building activities such as the German GAWTEC (GAW Training and Education Centre). Nevertheless, capacity building is a long-term activity, and many of the recommendations of the 8th ORM are still fully applicable (see section on Capacity Building under Recommendations, Report of the Eighth Meeting of the Ozone Research Managers).

At the 8th ORM, it was noted that surplus equipment exists in many developed countries and could be made available for redeployment. Two Dobson instruments, formerly deployed in Norway have been identified by the WMO/GAW Scientific Advisory Group for Ozone (O3-SAG). They will be relocated to Russia and Sri Lanka, respectively, during 2014 and 2015. Plans are to fund these activities under the Vienna Convention Trust Fund for research and systematic observation (see section below). Four additional Dobson instruments as well as Brewer instruments might become available for relocation over the next few years and the O3-SAG will coordinate the relocation of these instruments.

At the 8th ORM, it was recommended to develop a set of metrics in order to assess the effectiveness of capacity-building activities. It was proposed that these metrics could consist of one or more of the following:

- The number of refereed publications in peer-reviewed journal from scientists in developing economies.
- The quantity and quality of data submitted to the WOUDC or other appropriate archives.
- Increased involvement in the Ozone Assessment through publications used, authors, reviewers, etc.

Extensive work has been carried out on the second bullet point above and this work has revealed that there is a considerable decline in the number of ozone observing stations submitting data to the World Ozone and UV Radiation Data Centre (WOUDC). Work is underway to identify the exact reason for this decline. Although it is assumed that some of the decline is due to station closure, part of the reason could also be due to delays in data submission. Stations are being contacted and urged to submit data in a timely manner.

**Key capacity building recommendations arising from the 9th ORM:**

1. **Provide training courses for station operators in developing countries.** The participants at the 9th ORM expressed the need for more training on measurement techniques, including Dobson, Brewer, and ozonesonde measurements. Such training could be supplemented with on-line materials. This will improve data-taking capabilities and enhance the quality of data records for use in assessment activities. It is important that training include elements of quality assurance and data re-processing when necessary.

2. **Establish fellowships for students from developing countries.** In the framework of Article 4 of the Vienna Convention, the participants at the 9th ORM raised the issue of education and training, and proposed that fellowships be established to allow students from Article 5 countries to study for MSc and PhD degrees at universities in developed countries. These fellowships would not all need to be funded by the Trust Fund, as several developing countries have scholarship programmes, but would require facilitation between relevant universities in non-Article 5 countries and institutes and agencies conducting monitoring and research in Article 5 countries. The relevant involved agencies would be responsible for nominating potential students, who could then return to work on research and monitoring activities following completion of their studies.

3. **Maintaining the quality of the WMO/GAW global ozone observing system through the continuation and expansion of regular calibrations and intercomparisons.** The quality of the
data from the ozone-observing networks depends on such exercises. Campaigns aiming at such calibrations and intercomparisons also include transfer of knowledge from experts in developed countries to station managers in developing countries.

(4) **Ozonesonde intercomparisons and reprocessing of ozonesonde data.** Intercomparisons of sondes have been ongoing since 1996 through the WMO World Calibration Centre for Ozonesondes (Jülich Research Centre, Germany), but no major activity dedicated to chamber tests by the major groups contributing data to WOUDC has taken place since 2000. With re-processing of the global sonde data set underway according to the recommendations of the ASOPOS group, and with several changes in sonde manufacturers since 2010, it is essential that another JOSIE campaign with representatives of major techniques be conducted. This needs to include a training exercise on how to re-process ozonesonde data for participants of stations from emerging countries.

F. **Vienna Convention Trust Fund for Research and Systematic Observation**

There was a detailed discussion on the accomplishments and on the future of the Vienna Convention Trust Fund for research and systematic observation. Although important activities including calibrations, intercomparisons, and a training course have been implemented under the Trust Fund to date, and, despite the fact that these exercises have been useful and successful, the amount of funds in the Trust Fund is not sufficient to make substantial and sustainable improvements to the global ozone observing system. It was agreed that, rather than inviting the parties to contribute funds to the Trust Fund in a general and routine manner, it would be better to ask for support for well-defined and well-budgeted, concrete activities, with clear explanations of their necessity, expected outcomes, and benefits. There was agreement that such an approach will make it clear to the donors what the “return on the investment” will be, and help to raise more funds in the future.

It was proposed and agreed that WMO and the Ozone Secretariat should establish a steering committee for the Trust Fund. This steering committee should consist of members of the Scientific Assessment Panel, individual scientists with expertise in ozone observations, and a representative of WMO and Ozone Secretariat. This steering committee should develop a long-term strategy and implementation objectives and priorities. The objectives should be developed in the light of the four Overarching Goals given above. In addition to the long-term strategy, one also needs a short-term action plan that takes into account the most urgent needs of the global ozone observing system, and which will make the best possible use of the money currently in the Fund.

**Key Trust Fund recommendations arising from the 9th ORM:**

(1) **Long term**

WMO and the Ozone Secretariat should establish a steering committee for the Vienna Convention Trust Fund for research and systematic observation. The committee will develop a long-term strategy, objectives and priorities for the Trust Fund as described above, and advise on the activities under the Trust Fund, including on development of proposals, prioritization and implementation.

(2) **Short term**

The following areas were identified as the priority objectives for the Trust Fund in the near future:

- Capacity building in developing countries
- Inter-calibration of instruments and training of instrument operators
- Increasing the number of ozone observations

The specific projects that will be accorded priority for financing by the Trust Fund in the next 3 years (the 2014-2016 time period) are listed below. Their implementation and results will be
reviewed at the next ORM meeting. The costs given for the projects are approximate, and add to a total of US $255,000. The current amount of available funds in the Trust Fund is US $101,626.

(3) Late 2014

- Relocation of Dobson no. 14 (formerly deployed in Tromsø) to Tomsk, Russia. Cost: US $20,000.

(4) 2015

- Dobson intercomparison campaign for Asia, hosted by the Japanese Meteorological Agency. Cost: US $50,000.
- Relocation of Dobson observation hatch from Arosa, Switzerland to Nairobi. Cost: US $15,000.
- Training course on ozone measurements with the Brewer instrument in conjunction with a Brewer User Group’s Meeting, to be held in Thailand during April or May 2015. Cost of approximately US $40,000 to cover the participation cost of a number of participants from developing countries. Approximately half of this can possibly be covered by funds from the Canadian Brewer Trust Fund.

(5) 2016

- Dobson intercomparison campaign for Australia and Oceania, hosted by the Australian Bureau of Meteorology. Cost: US $30,000.
- Dobson intercomparison campaign for South America, hosted by the National Meteorological Service of Argentina. Cost: US $50,000.

Closure of the Meeting

Statements of appreciation were made by Mr Geir Braathen on behalf of WMO, Ms Tina Birmpili on behalf of UNEP and the Ozone Secretariat as well as the Parties to the Vienna Convention, and Mr Michael Kurylo and Mr Gerrie Coetzee, the Co-Chairs of the 9th ORM.
ANNEX A

WMO/UNEP NINTH MEETING OF THE OZONE RESEARCH MANAGERS OF THE PARTIES TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER
(Geneva, 14-16 May 2014)

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Group Photo of Participants at the Ninth Meeting of the Ozone Research Managers of the Parties to the Vienna Convention for the Protection of the Ozone Layer
Geneva, Switzerland, 14-16 May 2014
AGENDA

Wednesday, 14 May 2014

08:00 hrs onwards  Registration

09:00 – 09:30 hrs  Opening of the Meeting
   - Opening Statement (Tina Birmpili, Executive Secretary, Ozone Secretariat)
   - Welcome Statement (Deon Terblanche, WMO)
   - Scientific Assessment of Ozone Depletion and the Interface with ORM Recommendations (Paul Newman, SAP Co-Chair, and Michael Kurylo, 8th ORM Chair)

09:30 – 09:40 hrs  Election of the 9th ORM Co-Chairs (Tina Birmpili, Executive Secretary, Ozone Secretariat)

09:40 – 09:50 hrs  Adoption of the 9th ORM Agenda (9th ORM Co-Chairs)

SESSION 1: INTRODUCTORY SESSION: THE VIENNA CONVENTION

09:50 – 10:10 hrs  Review of the Recommendations of the Eighth Meeting of the Ozone Research Managers, Geneva, May 2011 (WMO Global Ozone Report No. 53) and the Resultant Decisions of the Ninth Conference of the Parties to the Vienna Convention, Bangkok, November 2011 (Michael Kurylo, 8th ORM Chair)

10:10 – 10:40 hrs  Activities under the Vienna Convention Trust Fund for Research and Systematic Observation Relevant to the Vienna Convention
   - The Status of the Trust Fund, (Meg Seki, Ozone Secretariat)
   - Report on Planned Activities under the Trust Fund (Geir Braathen, WMO)
   - Discussion on the Way Forward for the Trust Fund

10:40 – 11:00 hrs  Appointment of Discussion Leaders and Rapporteurs for the Various Recommendation Areas – Research Needs, Systematic Observations, Data Archiving, Capacity Building (9th ORM Co-Chairs)

11:00 – 11:10 hrs  Q&A / Discussion

11:10 – 11:30 hrs  COFFEE/TEA
**Wednesday, 14 May 2014 (continued)**

**SESSION 2: THE STATE OF THE OZONE LAYER AND INTERACTIONS BETWEEN OZONE LAYER DEPLETION AND CLIMATE CHANGE**

11:30 – 12:00 hrs  The Current and Future States of the Ozone Layer (Wolfgang Steinbrecht, DWD)

12:00 – 12:20 hrs  Links between Ozone and Climate (Paul Newman and John Pyle, SAP Co-Chairs)

12:20 – 12:40 hrs  HFCs and N₂O (A.R. Ravishankara, SAP Co-Chair)

**12:40 – 14:00 hrs  LUNCH**

14:00 – 14:20 hrs  Influences of Ozone-Layer Depletion and Climate Change on UV Radiation: Impacts on Human Health and the Environment (Paul Newman, SAP Co-Chair, for Janet Bornman, Nigel Paul, and Min Shao, EEAP Co-Chairs)

14:20 – 14:40 hrs  Q&A / Discussion

**SESSION 3: INTERNATIONAL MONITORING PROGRAMMES**

14:40 – 15:00 hrs  The WMO Global Atmosphere Watch (GAW) Programme (Liisa Jalkanen, WMO)

15:00 – 15:20 hrs  The Global Atmosphere Watch Ozone Observing System and Integrated Global Atmospheric Chemistry Observations for Ozone and UV (IGACO-Ozone/UV) (Geir Braathen, WMO)

15:20 – 15:40 hrs  The Network for the Detection of Atmospheric Composition Change (NDACC) (Martine De Mazière, IASB-BIRA)

**15:40 – 16:00  COFFEE/TEA**

16:00 – 16:20 hrs  Global Climate Observing System (GCOS) Including GRUAN (Greg Bodeker, Bodeker Scientific)

16:20 – 16:35 hrs  The Stratosphere-Troposphere Processes and Their Role in Climate Project of WCRP: The Joint SPARC/IO3C/WMO/NDACC Initiative on Past Trends in the Vertical Distribution of Ozone, Si²N (Birgit Hassler, NOAA)

16:35 – 16:50 hrs  Ground-Based Networks for Measuring Ozone- and Climate-Related Trace Gases and the Current State of the Atmosphere (Stefan Reimann, Empa)

16:50 – 17:10 hrs  Uncertainties in Projections of Ozone-Depleting Substances and Alternatives (Guus Velders, RIVM)

17:10 – 17:50 hrs  Q&A / Discussion: Initial Framing of Recommendations

18:00 – 20:00 hrs  Cocktail Reception in the WMO Attic, 9th Floor
Thursday, 15 May 2014

SESSION 3: INTERNATIONAL MONITORING PROGRAMMES (CONTINUED)

09:00 – 09:20 hrs  International Ozonesonde Activities (e.g., NOAA South Pole Program, The Southern Hemisphere Additional Ozonesondes Network (SHADOZ)) (Anne Thompson, NASA)

SESSION 4: SATELLITE RESEARCH AND MONITORING

09:20 – 09:50 hrs  Lessons Learned in Creating Long-Term Ozone Data Sets: Recommendations for the Future (P. K. Bhartia, NASA)

09:50 – 11:00 hrs  Current and Planned Ozone and Climate Observations from Space
   - U.S. Satellite Programmes: NASA, NOAA, and Other Agencies (Kenneth Jucks, NASA)
   - European Space Agency Activities (Claus Zehner, ESA/ESRIN)
   - KNMI Space-Based Measurement Activities (Peter van Velthoven, KNMI)

11:00 – 11:20 hrs  COFFEE/TEA

11:20 – 11:45 hrs  Current and Planned Ozone and Climate Observations from Space (continued)
   - Japanese Satellite Programmes (Takuki Sano, JAXA)
   - Chinese Satellite Programmes (Fuxiang Huang, Chinese Space Agency)

11:45 – 12:15 hrs  Summary of the Key Issues in Space-Based Measurements: Identification of Future Needs and Opportunities (Jean-Christopher Lambert, IASB-BIRA)

SESSION 5: NATIONAL AND REGIONAL REPORTS ON OZONE RESEARCH AND MONITORING

In this session, each representative of a region will present the regional and national situations with ozone monitoring and research, focusing on the key issues raised by the countries in the region based on the national reports submitted for this meeting. In particular, representatives are requested to highlight activities associated with the 8th ORM recommendations.

12:15 – 12:30 hrs  Region 1: Africa (Gerrie Coetzee, South African Weather Service)

12:30 – 12:45 hrs  Region 2: Asia (Hidehiko Isobe, JMA, and Hideharu Akiyoshi, NIES)

12:45 – 13:00 hrs  Region 3: South America (Eduardo Luccini, IFIR-CONICET)

13:00 – 14:00 hrs  LUNCH

14:00 – 14:55 hrs  Region 4: North America, Central America, and the Caribbean
   - USA (Kenneth Jucks, NASA, and Stephen Montzka, NOAA)
   - Canada (Stoyka Netcheva, Environment Canada)

14:55 – 15:10 hrs  Region 5: South-West Pacific (Matt Tully, BoM)

15:10 – 15:30 hrs  Antarctica
   - Antarctica (Steve Colwell, British Antarctic Survey, via WebEx)
   - Czech Republic Activities in Antarctica (Michal Janouch, CHMI)
   - Other Antarctic Activities (Geir Braathen, WMO)

15:30 – 15:50  COFFEE/TEA
Thursday, 15 May 2014 (continued)

15:50 – 17:40 hrs Region 6: Europe
- Belgium (Jean-Christopher Lambert, BIRA-IASB)
- Czech Republic (Ladislav Metelka, CHMI)
- Germany (Ulf Köhler, DWD)
- Nordic Countries (Weine Josefsson, SMHI)
- Poland (Janusz Borkowski, IGF-Polish Academy of Sciences)
- Switzerland (Dominique Ruffieux, MeteoSwiss)
- Turkey (Serpil Yağan, TSMS)
- UK (Lynette Clapp, Defra)
- Armenia, Belarus, and Russian Federation (Yury Borisov, CAO, and Aliaksandr Krasouski, BSU)

17:40 – 18:30 hrs Discussion: Identification of Needs and Gaps
Breakout Groups Meet to Frame Initial Recommendations

Friday, 16 May 2014

08:45 – 09:00 hrs The European COST Action EUBrewNet: Towards Consistency in Quality Control, Quality Assurance, and Coordinated Operations of the Brewer Instrument (John Rimmer, University of Manchester)

SESSION 6: DISCUSSION OF RECOMMENDATIONS

In this session, recommendations arising from the meeting will be discussed and agreed. Under each topic of recommendations, a short introductory presentation (10-15 min.) will be made, followed by discussions on the topic.

09:00 – 09:45 hrs Research Needs: Presentation of Initial Draft by Greg Bodeker and John Pyle, (Paul Newman and A.R. Ravishankara, Rapporteurs)

09:45 – 10:30 hrs Systematic Observations: Presentation of Initial Draft by Wolfgang Steinbrecht and Jean-Christopher Lambert, (P.K. Bhartia and Niels Larsen, Rapporteurs)

10:30 – 11:15 hrs Data Archiving and Stewardship: Presentation of Initial Draft by Martine De Mazière and John Rimmer, (Stephen Montzka and Stoyka Netcheva, Rapporteurs)

11:15 – 11:45 hrs COFFEE/TEA

11:45 – 12:30 hrs Capacity Building: Presentation of Initial Draft by Ayité-Lô Ajavon and Geir Braathen (Anne Thompson and Matt Tully, Rapporteurs)

12:30 – 13:00 hrs Discussion of Draft Recommendations

13:00 – 14:30 hrs LUNCH

14:30 – 16:30 hrs Further Discussion and Adoption of Recommendations and Report

16:30 – 16:50 hrs COFFEE/TEA

16:50 – 17:30 hrs Other Matters

17:30 hrs Closure of the Meeting
IX/1: Status of ratification of the Vienna Convention, the Montreal Protocol and the London, Copenhagen, Montreal and Beijing amendments to the Montreal Protocol

1. To note with satisfaction the large number of countries that have ratified the Vienna Convention for the Protection of the Ozone Layer and the Montreal Protocol on Substances that Deplete the Ozone Layer;

2. To note that, as at 1 November 2011, 196 parties had ratified the London Amendment to the Montreal Protocol, 194 parties had ratified the Copenhagen Amendment to the Montreal Protocol, 185 parties had ratified the Montreal Amendment to the Montreal Protocol and 171 parties had ratified the Beijing Amendment to the Montreal Protocol;

3. To urge all States that have not yet done so to ratify, approve or accede to the amendments to the Montreal Protocol, taking into account that universal participation is necessary to ensure the protection of the ozone layer;

IX/2: Eighth meeting of the Ozone Research Managers and the Trust Fund for Research and Systematic Observation relevant to the Vienna Convention

Recalling that, pursuant to the objective defined in decision I/6 of the Conference of the Parties to the Vienna Convention for the Protection of the Ozone Layer, the ozone research managers review ongoing national and international research and monitoring programmes with a view to ensuring the proper coordination of those programmes and identifying gaps that need to be addressed,

Recognizing that it is necessary and important to continue to monitor changes in the ozone layer and to understand the scale of the impact on the ozone layer of increasing concentrations of greenhouse gases and the implementation of the Vienna Convention on the Protection of the Ozone Layer,

Recalling decision VI/2, by which the Conference of the Parties established the Vienna Convention Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention for the Protection of the Ozone Layer,

Noting with appreciation the contributions to the Trust Fund by several parties and the joint efforts of the World Meteorological Organization and the Ozone Secretariat in the implementation of the activities funded by the Trust Fund,

Noting that the Ozone Research Managers at their eighth meeting stated that although there had been progress in building capacity since their seventh meeting in 2008, much remained to be accomplished,

1. To take note with appreciation of the report of the eighth meeting of the Ozone Research Managers;

2. To encourage parties:
   (a) To adopt the recommendations in report No. 53 of the World Meteorological Organization Global Ozone Research and Monitoring Project;
(b) To maintain research capabilities that enable measurements and scientific understanding of ozone depletion and evolution in a changing atmosphere including:

(i) Improvement and validation of coupled chemistry-climate and earth system models to take better account of ozone parameters and other atmospheric processes;

(ii) Continued and increased exploitation of long-term measurements and data for scientific process studies;

(iii) Support for fundamental laboratory studies to estimate photochemical reaction rates and to refine and update older measurements;

(c) To maintain, expand and integrate systematic ozone-related observations that are critical to understanding and monitoring the long term changes in atmospheric composition and the associated response in ground level ultraviolet radiation;

(d) To continue to implement the recommendations of the seventh meeting of the Ozone Research Managers in relation to data archiving and to encourage the reprocessing and salvage of archival data;

(e) To accord priority to supporting and implementing the following capacity-building activities recommended by the Ozone Research Managers:

(i) Development of a mechanism under the auspices of the World Meteorological Organization Global Atmosphere Watch to enable countries to donate good-quality, operational equipment through the World Meteorological Organization for deployment to developing countries as a means of enhancing the global operational network of ozone-observing and UV-observing stations, including tasking the scientific advisory committees for ozone and ultraviolet radiation of Global Atmosphere Watch with assessing the overall global needs for the distribution of the equipment, noting the need to ensure training of experts from developing countries in this technology;

(ii) Provision of financial support from the Trust Fund to support the participation of professional and technical persons from developing countries in the following workshops:

   a. Second Dobson workshop planned for 2013 as a follow-up to the successful workshop held in the Czech Republic in 2011;

   b. Ozone-observing and UV-observing workshop organized in conjunction with the 2012 quadrennial ozone symposium in Toronto, Canada;

3. To encourage the Ozone Research Managers to develop measures that would enable them to assess the effectiveness of capacity-building activities in the future;

4. In relation to the Trust Fund:

   (a) To urge all parties and relevant international organizations to make voluntary financial and/or in kind contributions to the Trust Fund;

   (b) To request the Secretariat to continue to invite parties and relevant international organizations annually to make voluntary contributions to the Fund and, with each such invitation to parties, to report on the prior years’ contributions, funded activities and planned future activities;

   (c) To request the Secretariat and invite the World Meteorological Organization to continue their cooperation with regard to activities funded by the Trust Fund;
(d) Also to request the Secretariat and invite the World Meteorological Organization to strive for regional balance in the activities supported by the Trust Fund and to encourage complementary funding to maximize Trust Fund resources;

(e) To request the Secretariat to report to the Conference of the Parties at its tenth meeting on the operation of, contributions to and expenditures from the Trust Fund and on the activities funded by the Trust Fund since its inception;

5. To encourage the national ozone focal points to distribute information on, and coordinate, monitoring and scientific activities in their countries where relevant;

IX/3: Financial matters: Financial reports and budgets

Recalling decision VIII/4 on financial matters,


Recognizing that voluntary contributions are an essential complement for the effective implementation of the Vienna Convention,

Welcoming the continued excellent management by the Secretariat of the finances of the Trust Fund for the Vienna Convention for the Protection of the Ozone Layer,

1. To take note with appreciation of the financial statement of the Trust Fund for the biennium 2010–2011 ended 31 December 2010 and the report on the actual expenditures for 2010 as compared to the approvals for that year;

2. To approve the 2012 budget for the Trust Fund in the amount of $723,063, the budget for 2013 in the amount of $735,622 and the budget for 2014 in the amount of $1,280,311 as set out in Annex I to the report of the Ninth Meeting of the Conference of the Parties to the Vienna Convention and the Twenty-Third Meeting of the Parties to the Montreal Protocol;¹

3. To authorize the Secretariat to draw down the amounts of $120,063 in 2012, $132,622 in 2013 and $677,311 in 2014, respectively, from the Fund balance for the purpose of reducing that balance;

4. To ensure, as a consequence of the drawdowns referred to in paragraph 3, that the contributions to be paid by the parties amount to $603,000 for each of the years 2012, 2013 and 2014 as set out in Annex II to the report of the Ninth Meeting of the Conference of the Parties to the Vienna Convention and the Twenty-Third Meeting of the Parties to the Montreal Protocol;

5. To urge all parties to pay their outstanding contributions as well as their future contributions promptly and in full;

IX/4: Tenth meeting of the Conference of the Parties to the Vienna Convention

To convene the Tenth Meeting of the Conference of the Parties to the Vienna Convention back to back with the Twenty-Sixth Meeting of the Parties to the Montreal Protocol.

¹ UNEP/OzL.Conv.9/7-UNEP/OzL.Pro.23/11.
## NATIONAL REPORTS AVAILABLE TO THE MEETING

<table>
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<tr>
<th>Country</th>
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<td>Algeria</td>
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<td>Viet Nam</td>
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<td>Iran, Islamic Republic of</td>
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INTRODUCTION

Dans le cadre du renforcement du programme de surveillance et suivi de la composition chimique de l'atmosphère, l'OMM a initié en 1989 le projet de la VAG qui unit actuellement un réseau d'une trentaine de stations dans le monde. Pour consolider ce réseau avec de nouvelles stations d'échelle globale, l'OMM a sélectionné en 1991 six nouveaux sites dans les pays en voie de développement dont la station algérienne couplée en deux sites Tamanrasset/Assekrem fait partie.

<table>
<thead>
<tr>
<th>Coordonnées géographiques des deux sites</th>
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<tbody>
<tr>
<td>Latitude</td>
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<tr>
<td>Tamanrasset</td>
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<tr>
<td>Assekrem</td>
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La région de Tamanrasset fait partie du Hoggar central, elle s'étend sur une superficie de plus 500000 Km² et sa population est estimée à 200000 habitants répartie à travers une dizaine d'agglomérations, elle est caractérisée par un climat aride influencé par les régimes soudano-saharien et méditerranéen avec une faible pluviométrie, une température élevée en été, une forte évaporation et un fort ensoleillement. Le site de mesure de la VAG se trouve dans le centre de la ville de Tamanrasset capitale du Hoggar. L'Assekrem est une région touristique semi-aride éloignée de la ville de Tamanrasset d'environ 50 Km. Le nombre de ses fidèles habitants dépasse rarement une dizaine d'individus sauf à l'exception des visites touristiques. Vu son éloignement, le site est loin de toute source locale ou proche de pollution. Les polluants régissant dans le lieu sont souvent produits extérieurement et amenés par les vents. C'est pour cette raison que son endroit a été retenu par l'OMM pour pratiquer des mesures spécifiques de pollution de fond.
**ACTIVITÉS DES OBSERVATIONS**

Les tâches assurées dans le programme des mesures effectuées dans le cadre de la VAG sont indiquées sur le logigramme suivant, il faut juste préciser qu’il existe des observations manuelles et automatiques.

Le tableau suivant précise avec plus de détails les informations concernant les différents instruments ou capteurs utilisés pour l’élaboration des mesures manuelles ou automatiques dans les deux sites de la VAG de Tamanrasset et l’Assekrem ainsi que leurs mois de début, leurs fréquences temporellement respectées et les unités des grandeurs préservées dans les fichiers bruts des données.
<table>
<thead>
<tr>
<th>Mesure</th>
<th>DONNÉE</th>
<th>Instrument</th>
<th>Début</th>
<th>Fréquence</th>
<th>Unité</th>
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<td>Ozone total</td>
<td>Épaisseur</td>
<td>Dobson #11</td>
<td>Mai 1994</td>
<td>3 fois par jour</td>
<td>DU</td>
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<td>Rayonnement direct</td>
<td>Irradiation</td>
<td>Phérioriômetre</td>
<td>Septembre 1994</td>
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<td>Rayonnement direct</td>
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<td>3 min puis 1 min</td>
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<td>Irradiation</td>
<td>Pyranomètre</td>
<td>Octobre 1994</td>
<td>3 min puis 1 min</td>
<td>W/m²</td>
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<td>Rayonnement diffus</td>
<td>Irradiation</td>
<td>Pyranomètre</td>
<td>Octobre 1994</td>
<td>3 min puis 1 min</td>
<td>W/m²</td>
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<td>Rayonnement infrarouge</td>
<td>Irradiation</td>
<td>Pyrgéomètre</td>
<td>Octobre 1994</td>
<td>3 min puis 1 min</td>
<td>W/m²</td>
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<td>Trouble atmosphérique</td>
<td>Trouble</td>
<td>Photomètre</td>
<td>Janvier 1995</td>
<td>3 fois par jour</td>
<td>Sans unité</td>
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<td>Gaz à effet de serre</td>
<td>Concentration</td>
<td>Échantillonneur</td>
<td>Septembre 1995</td>
<td>1 fois par semaine</td>
<td>ppm ppb</td>
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<td>Rayonnement ultraviolet</td>
<td>Irradiation</td>
<td>Pyranomètre</td>
<td>Janvier 1997</td>
<td>5 min</td>
<td>W/m²</td>
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<tr>
<td>Ozone en surface</td>
<td>Concentration</td>
<td>Analyseur TECO</td>
<td>Mars 1997</td>
<td>1 min</td>
<td>ppb</td>
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<td>Rayonnement atmosphérique</td>
<td>Irradiation</td>
<td>Pyranomètre</td>
<td>Mars 2000</td>
<td>1 min</td>
<td>W/m²</td>
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<td>Aerosol Optical Depth</td>
<td>Épaisseur optique</td>
<td>Photomètre</td>
<td>Septembre 2006</td>
<td>Entre 10 et 15 min</td>
<td>Sans unité</td>
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<td>Ozone total</td>
<td>Épaisseur Brewer #201</td>
<td>Cimel</td>
<td>Octobre 2011</td>
<td>En continu</td>
<td>DU</td>
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<td>Rayonnement ultraviolet</td>
<td>Irradiation</td>
<td>Radiomètre</td>
<td>Octobre 2011</td>
<td>1 min</td>
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</table>

**ENVOIS DES DONNÉES**

Après leurs contrôles, traitements et sauvegardes, les données des différentes mesures de la VAG sont régulièrement expédiées soit par courrier, transmises par internet ou envoyées par FTP périodiquement aux centres mondiaux respectifs de collecte et d’archivage des fichiers.

<table>
<thead>
<tr>
<th>Envois et archivage des données</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Données</strong></td>
</tr>
<tr>
<td>Trouble</td>
</tr>
<tr>
<td>AOD</td>
</tr>
<tr>
<td>Ozone en surface</td>
</tr>
<tr>
<td>Ozone total</td>
</tr>
<tr>
<td>Gaz à effet de serre</td>
</tr>
</tbody>
</table>
**MESURES EFFECTUÉES**

**L’OZONE TROPOSPHERIQUE (Assekrem)**

Le rôle principal de l’analyseur qui n’est rien d’autre qu’un photomètre UV est de déterminer la concentration de l’ozone troposphérique en mesurant une atténuation de la lumière due à la présence du polluant. Le TECO repose donc essentiellement sur le principe de l’absorption du rayonnement ultraviolet qui traverse l’échantillon d’air par les molécules d’ozone. Les concentrations mesurées sont affichées en ppb en temps réel sur l’analyseur et en même temps stockées sur le disque dur du PC.

![Ligne d’échantillonnage](image1.png) ![Analyseur TECO](image2.png)


**L’OZONE STRATOSPHERIQUE (Tamanrasset)**

La mesure de l’ozone total s’effectue à l’aide du spectrophotomètre Dobson #11. L’observation manuelle consiste à effectuer deux genres d’observations, du soleil direct et du zénith. La mesure du soleil direct qui permet d’avoir l’épaisseur de la couche d’ozone peut s’effectuer en présence de nuages autour du soleil à condition que l’ombre soit apparent puisque l’extinction des radiations ultravioletttes par les nuages fins qui est très minime.

Un nouveau appareil de mesures automatiques qui est le Brewer #201 (Mk III) a été mis en exploitation depuis l’année 2011, cet instrument fournit directement et de façon continue l’épaisseur de la couche d’ozone. Le spectrophotomètre de Tamanrasset rentre dans un réseau d’autres instruments de mesure continue de l’ozone stratosphérique principalement celui de l’Espagne qui est le pays de coopération dirigée par le service météorologique AEMET. Le Brewer #201 de Tamanrasset est maintenant intégré dans le réseau Iberonesia (www.iberonisa.net/brewer) géré par le centre RBCC-E (www.rbcc-e.org) situé au centre de recherche atmosphérique d’IZANA (AEMET- Espagne).
Trois mesures de la couche d'ozone sont effectuées par jour par le Dobson #11 : L'horaire de la mesure dépend de la saison, l'observation doit être effectuée lorsque le soleil est loin du zénith. À Tamanrasset, les mesures sont réalisées en moyenne aux heures suivantes :

<table>
<thead>
<tr>
<th></th>
<th>Matin</th>
<th>Midi</th>
<th>Après midi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hiver</strong></td>
<td>09 h 30 à 10 h 00 TU</td>
<td>12 h 00 à 12 h 15 TU</td>
<td>14 h 00 à 14 h 15 TU</td>
</tr>
<tr>
<td><strong>Eté</strong></td>
<td>09 h 00 à 09 h 30 TU</td>
<td>12 h 30 à 12 h 45 TU</td>
<td>15 h 00 à 15 h 30 TU</td>
</tr>
</tbody>
</table>

Chaque fin du mois, un étalonnage interne du Dobson #11 est effectué pour permettre de suivre l'état de fonctionnement de l'appareil et de déduire les corrections éventuelles qu'il faut apporter aux coefficients de calcul de la colonne d'ozone du mois suivant. Cette vérification concerne essentiellement la comparaison de la lampe à mercure si elle continue de délivrer les longueurs d'onde appropriées pour l'absorption efficace de l'UVB et la lampe standard qui contrôle la stabilité de l'instrument respectivement avec les deux lampes étalons. L'instrument et après son transfert de l'université de Bordeaux (France), a été étalonné trois fois à l'étranger dans le cadre des campagnes régionales organisées par l'OMM :

- En 1993 au laboratoire CMDL à Boulder (Etats-Unis).
- En Mars 2000 à Prétoria (Afrique du sud)
- En Mars 2004 à Dahab (Egypte).

L'aperçu de l'image suivante donnée par le site internet [www.iberonesia.net/brewer](http://www.iberonesia.net/brewer) qui montre une évolution diurne de la colonne de l'ozone total en confirmant ses faibles variations à Tamanrasset peut être obtenu journalement en temps réel pour s'assurer de la bonne continuité des mesures effectuées par le Brewer #201.
L’avantage de ce nouvel instrument de mesure de la colonne de l’ozone est d’avoir des observations continues de l’épaisseur de la couche sur le spectre de l’irradiation ultraviolette. Avec le nombre de données journalières qui est suffisant, on peut aussi lisser beaucoup plus l’évolution fréquentielle dans le temps et déduire comment l’ozone stratosphérique se distribue statistiquement. Comme on peut aussi déterminer la corrélation qui existe avec les données du même paramètre observées manuellement et rattraper les lacunes des fichiers Dobson #11. Le Brewer #201 fournit donc une masse considérable d’informations concernant la colonne d’ozone, ces observations avec les calculs de la colonne de l’ozone par le biais des irradiations UV mesurées à l’Assekrem vont permettre de franchir un grand pas dans la connaissance de l’évolution de l’ozone stratosphérique au Hoggar.

**ANALYSE DES RÉSULTATS**

**Evolution diurne de l’ozone total**

Les observations tri-horaires de l’ozone total par le Dobson #11 ont été recensées depuis 1994 entre les épaisseurs extrêmes absolues de 214 DU observée à 09 h TU et 320 DU à 12 h TU. La couche de l’ozone s’élargie plus à midi a une valeur normale de 268.6 DU qui n’a pas dépassé la variation de plus ou moins 2.2 DU tout le long des mesures.

<table>
<thead>
<tr>
<th>Ozone total tri-horaire en DU mesuré par Dobson à Tamanrasset</th>
<th>Période : 1994 à 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>Moyenne</td>
</tr>
<tr>
<td>09 h TU</td>
<td>12 h TU</td>
</tr>
<tr>
<td>214.0</td>
<td>217.0</td>
</tr>
<tr>
<td>268.5</td>
<td>269.1</td>
</tr>
<tr>
<td>315.0</td>
<td>320.0</td>
</tr>
</tbody>
</table>

Les données de l’ozone total issues des mesures Brewer #201 livrent plus de précisions sur la variation diurne grâce à la masse étendue des indications fournies par le spectrophotomètre. Les observations effectuées durant les deux années précédentes confirment les résultats du Dobson #11 puisqu’elles révèlent le constat d’un maximum de l’épaisseur de la couche d’ozone entre 11 h TU et 12 h TU, la courbe horaire de l’ozone total de Janvier 2012 à Décembre 2013 est parfaitement symétrique durant la période journalière étalée de 07 h TU à 15 h TU.
En utilisant toutes les données acquises, on relevé qu’il existe une forte dépendance statistique entre les épaisseurs de l’ozone total observées chaque trois heures, la grande valeur du coefficient de corrélation linéaire ($R = 96\%$) a été marquée entre les variables de 12 h TU et 15 h TU. La même constatation est faite pour l’ozone en surface avec la note que la corrélation est plus faible entre les mesures de 09 h TU et 15 h TU.

**Corrélations linéaires & leurs équations de droite**

<table>
<thead>
<tr>
<th></th>
<th>Ozone total</th>
<th>Ozone en surface</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 h TU</td>
<td>15 h TU</td>
</tr>
<tr>
<td>09 h TU</td>
<td>$R = 96%$</td>
<td>$R = 95%$</td>
</tr>
<tr>
<td>$a$</td>
<td>0.9804</td>
<td>0.9542</td>
</tr>
<tr>
<td>$b$</td>
<td>6.0885</td>
<td>11.863</td>
</tr>
<tr>
<td>12 h TU</td>
<td>$R = 96%$</td>
<td></td>
</tr>
<tr>
<td>$a$</td>
<td>0.9452</td>
<td></td>
</tr>
<tr>
<td>$b$</td>
<td>13.501</td>
<td></td>
</tr>
</tbody>
</table>

**Evolution journalière de l’ozone total**

Les courbes suivantes montrent lissiblement que les moyennes quotidiennes de l’ozone stratosphérique mesuré à Tamanrasset par les deux méthodes (manuelles et automatiques) ont traversé les mêmes allures d’évolution pendant les années 2012 et 2013, souvent les deux variables ont des grandeurs très proches. L’écart de 1.6 DU qui existe entre les moyennes d’ozone total du Brewer #201 (270.3 DU) et du Dobson #11 (268.7 DU) est jugé très faible. Ce résultat conforte les mesures de l’ozone stratosphérique à Tamanrasset et conclut que le spectrophotomètre Dobson #11 qui est un instrument très robuste, est en bon état de fonctionnement puisque le Brewer #201 a été étalonné que récemment en Juin 2013 en Espagne. Une corrélation est jugée intéressante d’être établie entre les deux types de mesures en comparant communément les deux types de fichiers correspondants.

Le petit écart de 1 DU à 2 DU qui peut exister entre les deux types de mesures est instrumentalement tout à fait acceptable mais il faut qu’il soit régulier dans le temps afin de se rendre compte de tout changement qui peut apparaître sur les données.
Chaque instrument possède ses propres caractéristiques électroniques, et même si on dispose de deux spectrophotomètres de types pareilles Brewer à Tamanrasset, leurs valeurs observables ne seront jamais identiques et c’est très difficile techniquement de savoir lequel des instruments donne des informations moins précises que si on soumet les deux appareils dans des mêmes conditions de mesures, cette procédure les instrumentistes l’appellent étalonnage et seul l’étalon qui est un équipement de mesure de référence peut donner les mesures les plus fiables.

Le nuage de points confirme les constatations faites précédemment, la corrélation linéaire entre les deux types de variables des mesures de l’ozone stratosphérique est encourageante, le coefficient de la relation qui est proche de 99 % peut avoir un seuil proche de 100 % si les deux instruments continuent à être stables techniquement pour donner des grandeurs efficaces de l’épaisseur de la couche.

**CORRELATION LINEAIRE Ozone Dobson en fonction Ozone Brewer, Période : 2012 à 2013**

\[ y = 1.0099x - 4.657 \]

\[ R = 98.82\% \]

**Evolution saisonnière de l’ozone total**

Le tableau des valeurs mensuelles extrêmes absolues des épaisseurs de l’ozone total observées depuis l’année 1994 montre que le minima de 214 DU a été observé durant le mois de décembre 2009 et le maxima de 320 DU en février 2011.
L’évolution mensuelle de l’ozone stratosphérique à Tamanrasset durant les deux dernières décennies est maximale en saison d’été particulièrement en Juillet et minimale en période d’hiver principalement en Décembre. La couche d’ozone admet une épaisseur supérieure à la moyenne successivement entre les mois d’avril et de septembre.

La température maximale moyenne de Tamanrasset possède une variation saisonnière de même sens de croissance de l’évolution du minimum moyen de l’ozone total sur le même lieu de mesure à l’exception de la faible variation de l’ozone total entre avril et mai. La corrélation entre les deux variables mensuelles est de 96 %.

Il existe aussi une forte approche entre les moyennes mensuelles de l’épaisseur de l’ozone stratosphérique et l’énergie du rayonnement ultraviolet (280 nm à 330 nm) mesuré sur le même site de Tamanrasset surtout durant la période de Juin à Décembre.
Les courbes saisonnières de l'épaisseur maximale moyenne de l'ozone stratosphérique et le trouble AOD maximal moyen à la longueur de 500 nm (mesures dans le cadre du projet SALAM) ont évolué dans le même sens de croissance pendant les huit dernières années à l’exception des évolutions entre les mois de Juin et de Juillet.

La même constatation peut être faite aussi saisonnièrement entre les épaisseurs minimales moyennes de l'ozone total et les valeurs maximales moyennes du trouble atmosphérique à 500 nm pour le même site de mesure à l’exception des évolutions entre les mois de Juin et d’Août. Les courbes mensuelles des deux paramètres sont confondues durant la phase de Septembre à Décembre.
Comparaison de l’ozone total de Tamanrasset avec celui d’Izaña (Espagne)

Il s’agit de comparer l’évolution saisonnière de l’ozone stratosphérique entre la région de Tamanrasset situé en pleine Sahara et le lieu d’Izaña localisé dans une ile durant la période des deux années de 2012 et 2013. En moyenne, l’ozone total observé près de l’océan est plus grand de 14 DU de celui mesuré dans le désert. Durant les mois de juillet et août, les deux Brewer ont collecté les mêmes épaisseurs. Le maximum à Tamanrasset est relevé en Juillet alors qu’à Izaña il est observé en Avril, Le minimum à Tamanrasset est observé en Février alors qu’à Izaña il est mesuré en Décembre. On ajoute que le Brewer #157 est considéré comme un instrument de référence.

![Graphique de l’évolution de l’ozone total à Tamanrasset et Izaña de 2012 à 2013](image)

**Evolution annuelle de l’ozone total**


![Graphique de l’évolution annuelle de l’ozone stratosphérique à Tamanrasset de 1995 à 2013](image)

Les valeurs extrêmes absolues enregistrées des épaisseurs de l’ozone stratosphérique à Tamanrasset sont un minimum de 214 DU observé durant l’année 2009 et un maximum de 320 DU en 2011.
Evolution horaire de l’ozone en surface

Les mesures automatiques de l’ozone troposphérique qui ne dépendent pas de la présence du soleil ont des concentrations en croissance nocturnement de 20 h TU de la veille à 06 h TU du matin et en évolution contraire jusqu’à 14 h TU, cette variation est l’opposé de celle marquée habituellement par la température.

Durant la période de 20 h TU à 06 h TU du matin citée ci-dessus, il existe une forte corrélation entre les valeurs horaires des concentrations de l’ozone en surface avec celles de l’inverse de la température moyenne.
**Evolution saisonnière de l’ozone en surface**

Saisonnièrement, l’ozone total réagit relativement comme un gaz à effet de serre en enregistrant une concentration élevée en printemps (Avril) et un minimum durant la saison d’automne alors que le maxima est observé en Juillet. Les concentrations sont au-dessous de la moyenne durant le mois de Juin et la phase de Septembre à Décembre.

Les extrêmes absolu de l’ozone en surface qui sont très écartées de la valeur moyenne de 39 ppb ont atteint 9 ppb entre les dates du 18 et 19 Mars 2008 et 119 ppb pendant la journée du 23 du même mois et la même année où durant la veille, la force maximale du vent a atteint son record observé à l’Assekrem de 158 Km/h.

<table>
<thead>
<tr>
<th>Années de 1998 à 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minima</td>
</tr>
<tr>
<td>Maxima</td>
</tr>
</tbody>
</table>

**Evolution annuelle de l’ozone en surface**

Comme on l’a vu pour l’ozone total, l’ozone en surface a évolué annuellement dans le sens contraire en marquant des concentrations au-dessus de la moyenne durant la dernière décennie en traversant des variations relativement faibles.
Les valeurs extrêmes absolues observées annuellement sont très séparées par rapport à la moyenne, les extremums sont 9 ppb et 119 ppb mesurés en 2008 comme on l’a souligné précédemment.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Minima</td>
<td>Maxima</td>
</tr>
<tr>
<td>98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13</td>
<td>83 61 59 84 53 70 89 97 68 83 119 78 77 80 79 80</td>
</tr>
</tbody>
</table>

La représentation graphique suivante qui simplifie les évolutions interannuelles des deux variables de l’ozone depuis l’année 2008, montre que l’ozone que ce soit total ou en surface a connu une baisse considérable durant l’année 2002. De 1998 à 2003 et bien que les échelles soient différentes, les deux courbes sont plus voisines qui n’est pas le cas pour la période de la dernière décennie où les variables sont plus dispersées, mais dans les deux cas de périodes on retient que souvent le sens d’évolution est le même.

**Evolution fréquentielle de l’ozone**

On remarque que l’ozone troposphérique possède une évolution fréquentielle d’une allure plus symétrique par rapport à celle enregistrée pour l’ozone stratosphérique. Des fréquences totales de 43 % et de 56 % ont concerné respectivement les épaississe de l’ozone total comprises entre 262 DU et 280 DU et les concentrations de l’ozone en surface variables entre 31.5 ppb et 42.5 ppb.
**LES GAZ À EFFET DE SERRE**

Un prélèvement d’air est effectué hebdomadairement sur deux flacons à l’aide de l’échantillonneur Martin § Kitzis (modèle Maks) reçu du CMDL. L’échantillonnage s’effectue à l’extérieur loin de tout obstacle. L’air est aspiré à l’aide d’une petite pompe à travers un tube étalé verticalement de préférence en présence du vent pour faciliter le mouvement des masses d’air dans l’entourage de l’appareil.

**Flacon de gaz**  **Echantillonneur Marks**

Les résultats obtenus après les analyses régulières faites par le laboratoire CMDL ont montré que la région de l’Assekrem n’est pas épargnée par le phénomène de l’augmentation des concentrations des GES comme c’est le cas des gaz principaux du dioxyde de carbone et le méthane qui ont atteint respectivement des concentrations mensuelles moyennes de 381.6 ppm en avril et 1799.7 ppb en Juin.

<table>
<thead>
<tr>
<th>Gaz</th>
<th>Unité</th>
<th>CO₂</th>
<th>CH₄</th>
<th>CO</th>
<th>H₂</th>
<th>N₂O</th>
<th>SF₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Janvier</td>
<td></td>
<td>378.0</td>
<td>1812.1</td>
<td>109.5</td>
<td>526.0</td>
<td>319.4</td>
<td>5.71</td>
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<tr>
<td>Février</td>
<td></td>
<td>379.7</td>
<td>1812.4</td>
<td>116.1</td>
<td>529.3</td>
<td>319.5</td>
<td>5.75</td>
</tr>
<tr>
<td>Mars</td>
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<td>379.9</td>
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<td>121.9</td>
<td>531.5</td>
<td>319.3</td>
<td>5.69</td>
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<tr>
<td>Avril</td>
<td></td>
<td>381.6</td>
<td>1809.1</td>
<td>120.6</td>
<td>543.6</td>
<td>319.6</td>
<td>5.83</td>
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<tr>
<td>Mai</td>
<td></td>
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<td>1803.3</td>
<td>111.8</td>
<td>541.1</td>
<td>319.0</td>
<td>5.81</td>
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<tr>
<td>Juin</td>
<td></td>
<td>380.7</td>
<td>1799.7</td>
<td>94.9</td>
<td>540.7</td>
<td>319.9</td>
<td>5.92</td>
</tr>
<tr>
<td>Juillet</td>
<td></td>
<td>378.6</td>
<td>1802.1</td>
<td>91.9</td>
<td>536.8</td>
<td>320.0</td>
<td>5.99</td>
</tr>
<tr>
<td>Août</td>
<td></td>
<td>375.6</td>
<td>1804.1</td>
<td>92.5</td>
<td>532.5</td>
<td>319.9</td>
<td>5.94</td>
</tr>
<tr>
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<td></td>
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<td>87.3</td>
<td>528.8</td>
<td>319.9</td>
<td>5.94</td>
</tr>
<tr>
<td>Octobre</td>
<td></td>
<td>374.7</td>
<td>1805.4</td>
<td>84.1</td>
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<td>320.1</td>
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<td>6.10</td>
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<td>1817.4</td>
<td>104.7</td>
<td>519.1</td>
<td>320.1</td>
<td>5.97</td>
</tr>
</tbody>
</table>

Les concentrations moyennes saisonnières des GES

Les concentrations moyennes annuelles de quelques GES sont en croissance continue d’une année à une autre comme c’est le cas du gaz carbonique, méthane, le protoxyde d’azote et l’hexafluorure de soufre qui ont atteint respectivement des concentrations maximales de 395.6 ppm, 1846.1 ppb, 326.6 ppb et 8.1 ppt durant l’année 2013.

**Minimum, Maximum**
**CONCENTRATIONS MOYENNES ANNUELLES DES GES**

<table>
<thead>
<tr>
<th>Gaz</th>
<th>CO₂</th>
<th>CH₄</th>
<th>CO</th>
<th>H₂</th>
<th>N₂O</th>
<th>SF₆</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unité</td>
<td>ppm</td>
<td>ppb</td>
<td>ppb</td>
<td>ppb</td>
<td>ppb</td>
<td>ppt</td>
</tr>
<tr>
<td>1996</td>
<td>361.8</td>
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<td>101.1</td>
<td>534.5</td>
<td>313.1</td>
<td>3.97</td>
</tr>
<tr>
<td>1997</td>
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<td>1780.1</td>
<td>106.7</td>
<td>530.8</td>
<td>313.5</td>
<td>4.10</td>
</tr>
<tr>
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<td>546.3</td>
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<td>4.32</td>
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<tr>
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<td>1801.0</td>
<td>104.0</td>
<td>539.4</td>
<td>314.8</td>
<td>4.50</td>
</tr>
<tr>
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<td>1801.9</td>
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<td>316.1</td>
<td>4.72</td>
</tr>
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<td>1801.4</td>
<td>101.0</td>
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<td>4.90</td>
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<td>317.7</td>
<td>5.11</td>
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<tr>
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<td>1805.9</td>
<td>106.6</td>
<td>540.3</td>
<td>318.3</td>
<td>5.32</td>
</tr>
<tr>
<td>2004</td>
<td>377.6</td>
<td>1801.5</td>
<td>101.3</td>
<td>538.5</td>
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<td>325.4</td>
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<td><strong>1846.1</strong></td>
<td><strong>92.1</strong></td>
<td>522.0</td>
<td><strong>326.6</strong></td>
<td><strong>8.10</strong></td>
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</table>

**CONCLUSION**

Les mesures de l’ozone dans le site couplé de Tamanrasset/Assekrem sont d’un grand intérêt pour la communauté scientifique car leurs données peuvent servir pour la validation des modèles numériques des systèmes satellites puisque la station de la VAG se trouve sur un endroit stratégique représentatif de la région du Nord-Africain. Avec l’ozone total qui peut être déterminé à l’Assekrem en fonction des irradiations de l’ultraviolet, non seulement on peut comparer son épaisseur avec les concentrations de l’ozone en surface mais l’objectif est de connaître le comportement des variations de l’ozone stratosphérique dans deux niveaux distincts d’altitudes (Assekrem et Tamanrasset). Dans ce cas même l’ozone troposphérique peut être estimé à Tamanrasset si on arrive dans le futur à trouver une relation du paramètre avec la colonne de l’ozone à l’Assekrem puisque les deux lieux de Tamanrasset et l’Assekrem sont proches et bénéficient souvent des mêmes conditions climatiques, la continuité des mesures de l’ozone au Hoggar est d’un apport scientifique majeur.

**BESOINS ET RECOMMANDATIONS**

L’approvisionnement de la station VAG par les consommables et surtout les pièces de rechange est très indispensable, la panne brusque d’une petite pompe peut causer l’arrêt total d’un équipement comme ça été le cas pour les mesures continues du monoxyde de carbone à l’Assekrem interrompues depuis décembre 2013, deux équipements de mesures qui sont l’analyseur des aérosols et le compteur de particules ont connu le même sort respectivement en 2004 et 2007 après des années d’observations. Les instruments de mesures que ce soient de l’ozone ou autres sont très sensibles, si on veut que les mesures spécifiques de l’ozone continuent à Tamanrasset/Assekrem, on doit doter les stations de mesures par un complément nécessaire de pièces de rechanges et programmer régulièrement des compagnes d’étalonnage.
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
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<tbody>
<tr>
<td>AEMET</td>
<td>Agence Espagnole de la Météorologie</td>
</tr>
<tr>
<td>AOD</td>
<td>Aerosol Optical Depth</td>
</tr>
<tr>
<td>BSRN</td>
<td>Baseline Surface Radiation Network</td>
</tr>
<tr>
<td>CH₄</td>
<td>Méthane</td>
</tr>
<tr>
<td>CMDL</td>
<td>Climatological Monitoring and Diagnostics Laboratory</td>
</tr>
<tr>
<td>CO</td>
<td>Monoxyde de carbone</td>
</tr>
<tr>
<td>CO₂</td>
<td>Gaz carbonique</td>
</tr>
<tr>
<td>DMRS</td>
<td>Direction Météorologique Régionale Sud</td>
</tr>
<tr>
<td>DU</td>
<td>Dobson Unit</td>
</tr>
<tr>
<td>EMPA</td>
<td>Eidgenössische Materialprüfungs und Forschungsanstalt</td>
</tr>
<tr>
<td>GES</td>
<td>Gaz à Effet de Serre</td>
</tr>
<tr>
<td>GLO</td>
<td>Grandes Longueurs d’Ondes</td>
</tr>
<tr>
<td>h</td>
<td>Heure</td>
</tr>
<tr>
<td>H₂</td>
<td>Hydrogène</td>
</tr>
<tr>
<td>Km</td>
<td>Kilomètre</td>
</tr>
<tr>
<td>min</td>
<td>Minute</td>
</tr>
<tr>
<td>Mk</td>
<td>Mark</td>
</tr>
<tr>
<td>nm</td>
<td>Nanomètre</td>
</tr>
<tr>
<td>N₂O</td>
<td>Protoxyde d’azote</td>
</tr>
<tr>
<td>NASA</td>
<td>Administration Américaine pour l’Aéronautique et l’Espace</td>
</tr>
<tr>
<td>NCDC</td>
<td>National Climatic Data Center</td>
</tr>
<tr>
<td>NOAA</td>
<td>Administration Nationale des Océans et de l’Atmosphère</td>
</tr>
<tr>
<td>OMM</td>
<td>Organisation Mondiale de la Météorologie</td>
</tr>
<tr>
<td>ONM</td>
<td>Office National de la Météorologie</td>
</tr>
<tr>
<td>ppb</td>
<td>Partie Par Billion</td>
</tr>
<tr>
<td>ppm</td>
<td>Partie Par Million</td>
</tr>
<tr>
<td>RBCCE</td>
<td>Centre Régional de Calibration des Brewer de l’Europe</td>
</tr>
<tr>
<td>SALAM</td>
<td>Saharan Air Layer Analysis and Monitoring</td>
</tr>
<tr>
<td>SF₆</td>
<td>Hexafluorure de soufre</td>
</tr>
<tr>
<td>TU</td>
<td>Temps Universel</td>
</tr>
<tr>
<td>UV</td>
<td>Ultra-Violet</td>
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<tr>
<td>UVB</td>
<td>Ultra-Violet-B</td>
</tr>
<tr>
<td>VAG</td>
<td>Veille de l’Atmosphère Globale</td>
</tr>
<tr>
<td>WDCGG</td>
<td>World Data Center for Greenhouse Gases</td>
</tr>
<tr>
<td>W/m²</td>
<td>Watts par mètre carré</td>
</tr>
<tr>
<td>WOUDC</td>
<td>World Ozone and UV Data Center</td>
</tr>
<tr>
<td>WRDC</td>
<td>World Radiation Data Center</td>
</tr>
</tbody>
</table>
ARGENTINA - National Report

Geophysical overview

- The Argentine continental territory has suffered at least 10 events of overpass of the springtime Antarctic Ozone Hole during the period 2011-2014, some of them lasting several days.

- The UVB radiation levels registered at the Antarctic Argentine stations under Antarctic Ozone Hole periods are comparable to maximum mid-latitude levels over the Hemisphere, with clear-sky UV Index values between 8 and 10.

- The northwestern Andean Plateau presents the highest UV radiation levels in the world, with monthly averaged UV Index (including cloudiness) above 18 in December-January and maximum clear-sky UV Index over 20 in densely populated zones.

- There is growing evidence of ozone-depleted associated climate change over the Argentine territory, particularly a wetting of the Central-Northeast Pampas due to increased precipitation in the last decades in summer season.

- ACCOMPLISHMENT OF THE 8TH ORM RECOMMENDATIONS

The major issues related to the 8th ORM recommendations for developing countries during the period 2011-2014 have been accomplished or efforts have been devoted to accomplish them. Economic and logistic support for national and international projects continues. Results of research on top field subjects like Antarctic Ozone Hole, effects of the ozone depletion and UV radiation on productivity areas, and ozone depletion - climate change interaction have been published. Update of the public information of the daily forecasted UV Index map is on the way.

Researchers and technical personal had participated in training and data management courses. However, it is possible that information about training courses and scientific workshops devoted specifically to developing countries, and particularly to Region III South America, had not arrived to the most interested peoples and institutions in Argentina. More fluid communication is necessary between WMO and the international institutions with the ORM contact in Argentina to receive and disseminate in the country all the available information on ozone and UV related international activities and support.

Monitoring and raw data archiving have been assured, and long-term final calibrated databases are being elaborated. However, there is presently a main concern due to the delay or interruption of the calibration activities in the principal monitoring institutions, even though they were planned, as can be seen in next sections of this report.

1. MONITORING

The following map details the geographical location of the principal sites in Argentina where atmospheric ozone and/or solar UV radiation and related parameters are measured (cartographic source: Instituto Geográfico Nacional Argentino, http://www.ign.gob.ar/):
The following are the detailed measurement activities at the principal monitoring institutions:

- **Servicio Meteorológico Nacional** (SMN - Argentine National Weather Service)

Contact: MSc. Gerardo Carbajal Benítez
Servicio Meteorológico Nacional. Av. de los Constituyentes 3454, C1427BLS, Ciudad Autónoma de Buenos Aires. Phone: 54-11-51676767 int. 18306. Email: gcarbajal@smn.gov.ar.

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Measured Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Quiaca</td>
<td>22.11°S, 65.57°W, 3459m. a.s.l.</td>
<td>Total O₃ Column X</td>
</tr>
<tr>
<td>Pilar</td>
<td>31.66°S, 63.88°W, 338 m. a.s.l.</td>
<td>Surface O₃ X</td>
</tr>
<tr>
<td>Mendoza</td>
<td>32.88°S, 68.87°W, 704m. a.s.l.</td>
<td>Vertical O₃ Profile X</td>
</tr>
<tr>
<td>Rosario</td>
<td>32.96°S, 60.62°W, 25m. a.s.l.</td>
<td>Broadband Surface UV X</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td>34.61°S, 58.41°W, 25m. a.s.l.</td>
<td>X</td>
</tr>
<tr>
<td>Comodoro Rivadavia</td>
<td>45.78°S, 67.50°W, 46m. a.s.l.</td>
<td>X</td>
</tr>
<tr>
<td>San Julián</td>
<td>49.32°S, 67.75°W, 62m. a.s.l.</td>
<td>X</td>
</tr>
<tr>
<td>Ushuaia</td>
<td>54.80°S, 68.27°W, 14m. a.s.l.</td>
<td>X X X</td>
</tr>
<tr>
<td>Marambio</td>
<td>64.23°S, 56.72°W, 300m. a.s.l.</td>
<td>X X X</td>
</tr>
</tbody>
</table>

SMN is the WMO South-American Regional Calibration Center for Dobson Spectrophotometers, for UV-Biometers and for surface ozone TECO instruments. Ozone and UV-Biometer calibration campaigns were planned initially for year 2012, afterwards for year 2013, but they were still not accomplished.

- Projects in collaboration with: World Meteorological Organization, Finnish Meteorological Institute, Instituto Nacional de Meteorología (INM, Spain), Instituto Nacional de Tecnología Aeroespacial (INTA, Spain), Argentine Antarctic Institute, Argentine CITEDEF Institute.
- Instituto Antártico Argentino (IAA - Argentine Antarctic Institute)

Contact: Ing. Eduardo Calvino, Téc. Héctor A. Ochoa
Dirección Nacional del Antártico - Instituto Antártico Argentino. Dpto. Ciencias de la Atmósfera
Cerrito 1248 - C1010AAZ - Capital Federal. Argentina. Phone: 54-11-4812-0071/72. Email: edcalvino@dna.gov.ar, haochoa@dna.gov.ar

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Instruments and Measured Parameters</th>
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<tr>
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<td>Total O&lt;sub&gt;3&lt;/sub&gt; Column</td>
<td>Surface O&lt;sub&gt;3&lt;/sub&gt;</td>
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<td>Marambio</td>
<td>64.23°S, 56.72°W, 300m. a.s.l.</td>
<td>X</td>
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<tr>
<td>San Martin</td>
<td>68.13°S, 67.13°W, 40m. a.s.l.</td>
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<tr>
<td>Belgrano II</td>
<td>77.86°S, 34.62°W, 250m. a.s.l.</td>
<td>X</td>
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- Projects in collaboration with: Servicio Meteorológico Nacional (Argentina), Instituto de Física Atmosférica de Roma (IFAR, Italia), Instituto Nacional de Técnica Aeroespacial (INTA, España), el Instituto Nacional de Meteorología (INM, España), Instituto Meteorológico Finlandés (IMF, Finlandia), Observatorio Solar y de Ozono del Instituto Hidrometeorológico de la República Checa.

- Instituto Nacional de Genética y Biología Molecular (INGEBI - Argentine National Institute of Genetics and Molecular Biology)

Contact: Ing. Susana B. Díaz
Instituto de Investigaciones en Ingeniería Genética y Biología Molecular. Vuelta de Obligado 2490
- C1428ADN Buenos Aires – Argentina. Tel.: (54-11) 4783-2871 - Fax: (54-11) 4786-8578 - e-mail: ingebi@dna.uba.ar, diazsusana@gmail.com

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Instrument (Narrowband UV and PAR surface irradiances)</th>
<th>Last calibration and present state</th>
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<tbody>
<tr>
<td>San Salvador de Jujuy</td>
<td>24.17°S, 65.02°W, 1300 m. a.s.l.</td>
<td>GUV-511</td>
<td>2011 - Out of service since 2012</td>
</tr>
<tr>
<td>Buenos Aires</td>
<td>34.58°S, 58.47°W, Sea level</td>
<td>GUV-511</td>
<td>2011</td>
</tr>
<tr>
<td>San Carlos de Bariloche</td>
<td>41.01°S, 71.42°W, 700 m. a.s.l.</td>
<td>GUV-511</td>
<td>2011</td>
</tr>
<tr>
<td>Trelew</td>
<td>43.25°S, 65.31°W, Sea level</td>
<td>GUV-511</td>
<td>2011</td>
</tr>
<tr>
<td>Ushuaia</td>
<td>54.83°S, 68.30°W, Sea level</td>
<td>GUV-511</td>
<td>2007 - working only for short discontinuous periods</td>
</tr>
</tbody>
</table>

- Projects in collaboration with: National Science Foundation (NSF, USA), Centro Austral de Investigaciones Científicas (CAdIC, Argentina), Dirección Nacional de Antártico (DNA, Argentina) y Dirección Nacional de Meteorología (INM, Spain), Instituto Nacional de Tecnología Aeroespacial (INTA, Spain), Programa Nacional para Investigaciones Antárticas (PNRA, Italy).
- Centro Austral de Investigaciones Científicas (CADIC - Austral Center for Scientific Research) - Tierra del Fuego

Contact: Ing. Susana B. Díaz
Instituto de Investigaciones en Ingeniería Genética y Biología Molecular. Vueltas de Obligado 2490 - C1428ADN Buenos Aires – Argentina. Tel.: (54-11) 4783-2871 - Fax: (54-11) 4786-8578 - e-mail: ingebi@dna.uba.ar, diazsusana@gmail.com

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
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<th>Instrument</th>
<th>Last calibration and present state</th>
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<tbody>
<tr>
<td>Ushuaia</td>
<td>54.83°S, 68.30°W, Sea level</td>
<td>Spectral solar irradiance (range: 280-620 nm)</td>
<td>SUV-100 spectroradiometer</td>
<td>2008 (every 15 days with secondary lamps) – Out of service since 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total O₃ Column, NOₓ</td>
<td>EVA 4</td>
<td>2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Narrowband UV and PAR solar irradiance</td>
<td>GUV-511</td>
<td>2007 - working only for short discontinuous periods</td>
</tr>
<tr>
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<td></td>
<td>Narrowband UV and PAR solar irradiance</td>
<td>NILU-UV</td>
<td>2011</td>
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<tr>
<td></td>
<td></td>
<td>Total O₃ Column Spectral solar irradiance (range: 280-325 nm)</td>
<td>Brewer MKIV spectroradiometer</td>
<td>Under reparation – Out of service since 2010</td>
</tr>
</tbody>
</table>

- Projects in collaboration with: National Science Foundation (NSF, USA), Instituto de Investigaciones en Ingeniería Genética y Biología Molecular (INGEBI, Argentina), Dirección Nacional de Antártico (DNA, Argentina) y Dirección Nacional de Meteorología (INM, Spain), Instituto Nacional de Tecnología Aeroespacial (INTA, Spain), Programa Nacional para Investigaciones Antárticas (PNRA, Italy).

- Estación Fotobiológica “Playa Union” (Photo-Biological Station “Playa Union”) - Chubut

Contact: Dr. Walter Helbling
Estación de Fotobiología Playa Unión. Casilla de Correos N°15 (9103), Rawson, Chubut, Argentina. Tel: 54–280-4498019. Email: whelbling@efpu.org.ar, efpu@efpu.org.ar

<table>
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<th>Instrument</th>
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<tr>
<td>Playa Union</td>
<td>43.30°S, 65.03°W, 10m. a.s.l.</td>
<td>Surface broadband UVB, UVA and PAR solar irradiance</td>
<td>ELDONET surface spectroradiometer</td>
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<td></td>
<td></td>
<td>Resolution: 1nm. Range: 190-1100 nm</td>
<td>Ocean Optics spectroradiometer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Underwater broadband UVB, UVA and PAR solar irradiance</td>
<td>ELDONET subsmerible spectroradiometer</td>
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<tr>
<td></td>
<td></td>
<td>Underwater solar irradiance</td>
<td>Ocean Optics subsmerible radiometer</td>
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<td></td>
<td></td>
<td>- Weather station</td>
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<tr>
<td></td>
<td></td>
<td>- Laboratory equipment for biological-sample analysis</td>
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</tr>
</tbody>
</table>

- Projects in collaboration with: Universidad de Concepción (Chile), Universidade de Sao Paulo, Fundação Universidade Federal do Rio Grande e Instituto Nacional de Pesquisas
Espacais (Brasil), CONICET, Estación de Fotobiología Playa Unión, Instituto Nacional de Investigación y Desarrollo Pesquero (Argentina), University of South Florida (USA), Centro de Procesamiento de Imágenes y Fundación La Salle (Venezuela), Interamerican Institute for Global Change Research (IAI), National Natural Science Foundation of China.

- Centro de Investigaciones Laser y Aplicaciones (CEILAP - Center for Laser Research and its Applications)

**Contacts:** Dr. Eduardo Quei, equel@citedef.gob.ar; eduardojuquel@gmail.com
Dr. Elian Wolfram, ewolfram@gmail.com
Dr. Jacyo Salvador, jacosalvador@gmail.com
Dr. Bioing. Marcelo Raponi, mraponi@citedef.gob.ar


<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Instrument</th>
<th>Measurement</th>
<th>Institution</th>
</tr>
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<tr>
<td>Rio Gallegos</td>
<td>51.60°S, 69.32°W, 15m. a.s.l.</td>
<td>DIAL LiDAR</td>
<td>Ozone profile between 15-45 km</td>
<td>CEILAP/Argentina</td>
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<tr>
<td></td>
<td></td>
<td>YES UVB-1</td>
<td>UV erythemal irradiance</td>
<td>CEILAP/Argentina</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAOZ UV-Vis. Spectrometer</td>
<td>Ozone and NO₂ total column</td>
<td>SAOZ Network/France</td>
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<td></td>
<td></td>
<td>Pyranometer</td>
<td>Total solar radiation</td>
<td>CEILAP/Argentina</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GUV 541</td>
<td>Spectral bands at 305, 313, 320, 340 and 380 nm</td>
<td>CEILAP/Argentina</td>
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<tr>
<td></td>
<td></td>
<td>Brewer Spectrophotometer S/N 124</td>
<td>Total ozone, NO₂ and spectral UV every 0.5 nm</td>
<td>INPE/Brasil</td>
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<td></td>
<td></td>
<td>Millimetric waves radiometer</td>
<td>Upper stratospheric-mesospheric ozone profiles</td>
<td>Nagoya University/Japan</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>between 35 and 80 km</td>
<td></td>
</tr>
</tbody>
</table>

- Projects in collaboration with: Network for the Detection of Atmospheric Composition Change (NDACC/NOAA), Laboratorio de Ozono y Radiación Ultravioleta de la Universidad de Magallanes, Punta Arenas - Chile, Japan International Cooperation Agency.

- Instituto de Física de Rosario (IFIR - Institute of Physics of Rosario)

**Contact:** Dr. Rubén Piacentini

Grupo de Radiación Solar – IFIR (CONICET/UNR). 27 de febrero 210bis (Ocampo y Esmeralda), 2000, Rosario. Argentina. Phone: 54-341-4853200. E-mail: ruben.piacentini@gmail.com

<table>
<thead>
<tr>
<th>Station</th>
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<th>Measured Parameters</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosario</td>
<td>32.96°S, 60.62°W, 25m. a.s.l.</td>
<td>UV erythemal irradiance</td>
<td>YES UVB-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total solar irradiance</td>
<td>Kipp &amp; Zonet CM5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Broadband Total UV</td>
<td>Kahl TUVR</td>
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<td>Broadband UBV</td>
<td>EKO UBV</td>
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<td></td>
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<td>Broadband UVA</td>
<td>EKO UVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface air quality: CO, NOx and O₃</td>
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</tbody>
</table>
• Projects in collaboration with: CEILAP (Argentina), Universidad Federal de Pernambuco (Brasil), Japan International Cooperation Agency.

- **Instituto de Investigaciones Físico-Químicas (Institute for Physical-Chemical Investigations) - Córdoba**

  **Contact:** Dra. Beatriz M. Toselli  
  Departamento de Físico Química – INFIQC. Facultad de Ciencias Químicas, Universidad Nacional de Córdoba. Ciudad Universitaria, 5000 Córdoba. Argentina. Email: toselli@fcq.unc.edu.ar

<table>
<thead>
<tr>
<th>Station</th>
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<th>Instrument</th>
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<tr>
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<td>UV erythemal irradiance</td>
<td>2 instruments YES UVB-1</td>
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<td></td>
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<td>Total solar irradiance</td>
<td>YES TSP-700</td>
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<tr>
<td></td>
<td></td>
<td>Spectroradiometer (300 - 870 nm)</td>
<td>Ocean Optics USB-4000</td>
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<td></td>
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<td>Aerosols with size &lt;10 µm and &lt;2.5 µm</td>
<td>SKC Deployable particulate sampler</td>
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<tr>
<td></td>
<td></td>
<td>Aerosols size distribution for 0&lt; size &lt;10 µm</td>
<td>SIOUTAS-SKC</td>
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<tr>
<td></td>
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<td><strong>Real time size distribution for 0.5 µm &lt; size &lt; 10 µm</strong></td>
<td>Met One 212-1</td>
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</table>

• Projects in collaboration with: National Center for Atmospheric Research (USA).

- **Instituto de Ecología “Fundación Miguel Lillo” (Institute of Ecology “Fundación Miguel Lillo”) - Tucumán**

  **Contact:** Dr. Juan A. González, Dr. Fernando Eduardo Prado  
  Instituto de Ecología - Fundacion Miguel Lillo. Miguel Lillo 251, 4000, Tucumán, Argentina. E-mail: lirios@cgec.org.ar, fepra@csnat.unt.edu.ar

<table>
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<td></td>
<td>PAR and Total solar irradiance</td>
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</tbody>
</table>

• Projects in collaboration with: other Argentine institutions.

- **Instituto de Biodiversidad y Medioambiente (INIBIOMA - Institute of Bio-diversity and Environment) - Rio Negro**

  **Contact:** Dra. María Gabriela Perotti, Dra. María C. Diéguez, Dra. A. Patricia Perez  
  INIBIOMA-Centro regional Universitario Bariloche. Universidad Nacional del Comahue. Quintral 1250, 8400 Bariloche, Argentina. Phone: 54-2944-428505. Email: perottigaby@yahoo.com, dieguezmrc@gmail.com, perezfotolab@gmail.com

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<td><strong>Narrowband UV channels</strong></td>
<td><strong>GU4500</strong></td>
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<td>Underwater broadband UV irradiance</td>
<td>Ocean Optics submersible spectrometer</td>
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<td>During 2011 a new equipment will be installed:</td>
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<tr>
<td>- Automatic weather station</td>
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<td>- CO₂ monitoring instrument</td>
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<td>- Aerosols monitoring instrument</td>
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<tr>
<td>- Atmospheric Mercury monitoring instrument</td>
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</tr>
</tbody>
</table>

- Projects in collaboration with: other Argentine institutions, BBVA Foundation (Spain), European Union Program “Global mercury observation system”.

2. REGIONAL CALIBRATION ACTIVITIES

Last calibration activities of the South-American WMO Network instruments have taken place during 2010 at the Regional Calibration Center for South America - Buenos Aires Central Station of the Argentine National Weather Service. In September 2010 the IV Regional Intercomparison of surface ozone measurement instruments and in November 2010 the calibrations of both the Dobson ozone spectrometers and the UV erythemal solar irradiance instruments (UV-Biometers) were developed. So, there is a concerning delay for the next calibration campaigns, which should have been accomplished initially in 2012, then in 2013 but they were still not carried out. The Argentine institutions have made the corresponding plans for these calibration campaigns, but there is an evident international fund and/or logistic restriction to support presently these tasks. Then, in some simpler cases such as working with UV-Biometers or surface ozone, we are analyzing the possibility to dispose local reference instruments appropriately calibrated at the international centers to assure accomplish our own Regional calibration campaigns. Obviously, this is not possible in the case of ozone Dobson spectrophotometers.

3. THEORY AND MODELING

- Programa para el Estudio de Procesos Atmosféricos en el Cambio Global (PEPACG - Program for the Study of Atmospheric Processes Related to the Global Change)

Contact: Dr. Pablo O. Canziani
Equipo Interdisciplinario Para el Estudio de Procesos Atmosféricos en el Cambio Global (PEPACG-UCACyT), Pontificia Universidad Católica Argentina, Alicia Moreau de Justo 1600, C1107AFF, Capital Federal, Argentina. Phone: 54-11-4349-0200 int. 2107. E-mail: canziani@uca.edu.ar, pocanziani@gmail.com

PEPACG carries on research focused on the understanding of the climate dynamics and climatology of the regional coupled troposphere-stratosphere-ozone layer climate system and the impacts of the observed changes, due to both ozone depletion and climate change, including local/regional climate change drivers, on social and productive systems of Argentina. When international collaboration arises such studies are extended, in collaboration with local institutions, to Chile and Uruguay. Doctoral and MSc. theses have been completed or are under way covering different aspects of these issues, e.g. UV radiation impacts on grape sugar content in the wine producing region of Mendoza Province.

Modelling work now includes the use of WRF and PRECIS. Modeling of UV radiative transfer in the atmosphere is still limited to 1-D codes using principally the Discrete Ordinates algorithm with semi-spherical correction in the direct component, which is useful for cases of homogeneous-layers composition of the atmosphere.
A Special WCRP Workshop on the Climatic Effects of Ozone Depletion in the Southern Hemisphere: Assessing the evidence and identifying gaps in the current knowledge, was held at the UCA with over 50 participants from North America, Europe, Asia and Australia/NZ convened in March 2013 to discuss our current understanding and propose a series of areas of interest for future research dealing with the climate impacts of ozone depletion and the upcoming recovery, following the application of the Montreal Protocol and Amendments. Among important issues discussed is the need to improve and continue monitoring activities of the stratosphere and ozone layer during the coming decades to understand the new state of the ozone layer during the recovery process and its links with climate change, the need to significantly improve models which couple the troposphere-stratosphere-ozone layer, which are not currently properly reproducing such major issues as oceanic and sea-ice response to the coupled effects of ozone and climate change.

Areas of study in the period 2011-2014 included: - Dynamic Climatology of the Tropopause over Argentina. - Sudden climate perturbations in the Southern Hemisphere's troposphere and stratosphere. - Cirrus, Tropopause and interchanges troposphere-stratosphere over Argentina. - Climate and ozone impacts on grape production.

4. DISSEMINATION OF RESULTS

Data Reporting

The SMN sends total ozone measurements as well as the ozonesonde data routinely to the WOUDC. The database is currently being transformed to the required CSV format. Surface ozone retrievals are submitted to the corresponding center in Japan.

Information to the public

The SMN continues providing a daily national UV Index forecast map for clear and cloudy conditions both in its web page (http://www.smn.gov.ar) as well as to the massive diffusion media. The UV Index of the SMN web page is presently in update process and it will be totally renewed during next months of year 2014.

All mentioned institutions often provide information to the media. During the ozone hole season SMN, CADIC and PE-PACG send to the media frequent reports describing the ozone hole evolution, using satellite retrievals and ground-based information. Conferences within congress and other open to the public were given in the different specialties in the period 2011-2014.

Each November, the Argentine Dermatological Society carries out the National Campaign for prevention of the skin cancer.

5. RELEVANT SCIENTIFIC PAPERS 2011-2014


Casati P. Analysis of UV-B regulated miRNAs and their targets in maize leaves. Plant Signaling and Behaviour; 8, 10. 2013.


6. FUTURE PLANS

The main concern is to maintain the operability and quality of the monitoring available infrastructure through the appropriate services and frequent calibrations of the instruments, facts that have suffered certain delay during the period 2011-2014.
In view that the main problems concerning the ozone depletion and its consequences will affect particularly the Argentine territory and its neighborhood for many years, future research activities will be a continuation and extension of current investigations. Then, future plans and recommendations are basically similar to those of the 8th ORM (2011). Among the principal subjects:

- Evolution of the total ozone column over the region. Trends of ozone and UV levels. Dynamics, chemistry and inter-annual variation of the Antarctic ozone hole.
- Study of the influence of the near vortex and ozone hole incursions over Patagonia
- Study the relationship between tropospheric and stratospheric dynamic and climatic behavior and the links with ozone change.
- Ozone and climate change interactions.
- The chemistry and dynamics of stratosphere-troposphere exchange.
- Cirrus clouds, the tropopause, and ozone.
- Effects of the UV radiation on the human health in the region. Biological effects of the UV radiation, especially on crops in the region.
- Studies of solar radiation and its components and biological effects in Antarctic Peninsula.

7. NEEDS AND RECOMMENDATIONS

It is possible that information about training courses and scientific workshops devoted specifically to developing countries, and particularly to Region III South America, had not arrived to the most interested peoples and institutions in Argentina. More fluid communication is necessary between WMO and the international institutions with the ORM contact in Argentina to receive and disseminate in the country all the available information on ozone and UV related international activities and support.

We emphasize that the first need at present for Argentina is to maintain their current monitoring networks in qualified operation. The coordination between the international support institutions and the Argentine monitoring networks has worked very well in the past, but the delay of the recent years in making the appropriate calibration campaigns is a warning for possible decline in the quality of monitoring and research activities. Argentina is aware of the importance of their data in view of the strategic geographical location to study the atmospheric ozone problem, and the authorities of their monitoring institutions are searching for alternative solutions to maintain their databases within high quality standards, but coordination and support from the international scientific and funding institutions is primordial to avoid a critical situation.

Other scientific concerns are still common to previous reports and must consider the strategic geographical location of Argentina to study and to understand the consequences of this global environmental problem:

- Antarctica and the Southern Cone of South-America must be still for many years considered the most critical region in the world related to ozone depletion and its consequences.
- The Antarctic Ozone Hole must be continuously monitored by all means for many years. Permanent ground-based and satellite-based instruments are an essential complement for this task.
- There is growing evidence that the ozone layer is both acting in response to current climate variability and change as well as affecting climate over the Southern Hemisphere. Such coupled studies are an important component of understanding needed to assess climate variability and climate change processes. Hence it is important to strength all atmospheric measurements relevant to both processes. This also requires a strong support in capacity
building at the technician and research levels to continue both with monitoring and relevant research as proposed by SPARC-WCRP and its links with the various WCRP initiatives.

- It is essential that research activities be enhanced regionally and globally in the double-pronged aspect of ozone depletion and change within the framework of Climate Change due to the many joint aspects and couplings that are now starting to be known. Hence it is essential to sustain national and international projects regarding these as relevant issues.

- Until the recovery of the ozone layer does not become evident and sustained in time and as long as the international scientific community does not have a clear and fully developed picture of the linkages between the ozone layer, the stratosphere and the troposphere, within the scope of climate change and variability such research must be supported, nationally, regionally and internationally.

This report was prepared by Dr. Eduardo Luccini and Dr. Pablo Canziani, based on the infrastructure, activities and achievements of the Argentine institutions and research groups involved in Vienna-Convention-related monitoring and research activities. We gratefully acknowledge all the experts and institutions that provided the information to elaborate this Report.

*****
ARMENIA

OBSERVATIONAL ACTIVITIES

The GAW regional station #410 Amberd from 2000 carries out the regularly measurements of total ozone. The station is equipped by Dobson spectrophotometer D-044 (Fig.1).
Location: 40.38N, 44.25E, 2070 a.s.l.

The begun in 1990 measurements of total ozone on the local network ozone-observing station Arabkir in city Yerevan are continued. The station is equipped by filter ozonometer M-124.
Location: 40.20N, 44.50E, 1113 a.s.l.

Some results of carried out on Dobson-station measurements are presented on Fig.2.

Figure 1. GAW regional station #410 Amberd.

Figure 2. Dynamics of total ozone over Armenia during 2000-2013.

Profile measurements of ozone and other gases/variables relevant to ozone loss - not made.
UV measurements - not made.
Calibration activities - the calibration of Dobson spectrophotometer D-044 in European RDCC in Hohenpeissenberg in 2010 was executed.

RESULTS FROM OBSERVATIONS AND ANALYSIS

The results of measurements showed, that during 2007-2013 the average increase of total ozone is observed
• on 1.3% per year for annual values,
• on 0.2% per year for spring months,
• on 0.8% per year for summer months,
• on 1.6% per year for autumn months,
• on 3.2% per year for winter months.
These data can be interpreted as testifying to gradual recovery of ozone layer in middle latitudes of north hemisphere of Earth. This can be attributed to the reduction of emissions of ODS due to the Montreal Protocol.

THEORY, MODELLING, AND OTHER RESEARCH

Using the constructed early computer model of solar radiation transfer in atmosphere and of its distribution on the territory of Armenia and estimations of climatic parameters of solar radiation on the territory of Armenia [2] are created the references books [3], [4].

The comparative analysis of modern results of total ozone measurement at stations "Arabkir" (ozonometer M-124) and "Amberd" (Dobson spectrophotometer) with the purpose to find correction of algorithm of calibration of filter-ozonometers, connected with aging of filters, is continued.

The studies of connection between changes of total ozone, ultraviolet radiation and the morbidity of population by skin cancer for different regions of country, the begun in [1], are continued.

RECOMENDATIONS OF 8ORM:

DISSEMINATION OF RESULTS

Data reporting

Monthly results of measurements of total ozone at station Amberd are regularly submitted in the WOUDC.

On the basis of results of measurements of total ozone on stations Amberd and Arabkir is continued the creation of local computer bank.

Information to the public

Using the forecasts of total ozone distribution above northern hemisphere from WMO/GAW ozone mapping program and forecasts of cloudiness with use of the model of solar irradiation are developed the daily maps of forecasts of distribution of UV Indexes on the territory of Armenia. The estimations and forecasts of UV indexes for mostly inhabited areas of Armenia are calculated according to "UV Index for Public" (COST-713 Action UVB Forecasting) and are included in the weather forecasts for dissemination to the public via mass media.

Relevant scientific papers


PROJECTS AND COLLABORATION

On created on the Dobson-station Amberd the first-level station EMEP are continued works for measurements of concentrations of pollution in precipitations and of solid particles in air, also of SO₂, NO₃, and surface ozone O₃.

FUTURE PLANS

Regular measurements of ozone with distribution of the received results will be continued.

Efforts for the organisation of regular measurements of ultra-violet radiation will be undertaken.
The results of modeling of a climatic regime of UV irradiation will be used for development of results begun in [1] research of vulnerability of health of the village and urban population to increase of ultraviolet radiation and the influence on vulnerability of height of location in all regions of territory of Armenia. The research is based on long-term statistics on morbidity of the population of Armenia by skin cancer and on results of total ozone measurements.

NEEDS AND RECOMMENDATIONS

Needs: to use the capacities of weather station Amberd, which allow implementation of international projects for monitoring of solar radiation and vertical distribution of ozone, lidar observations, aerosol transfer and transboundary air pollution in region of South Caucasus.

The recommendations:
• periodically to organize DQ Workshops, similar WMO/UNEP Dobson Data Quality Workshop Hradec Kralove, Czech Republic, February 14-18, 2011.
• enabling for ozone-experts from developing countries of short-term practice in leading scientific centres of the world for improving of their scientific and technical potential.
1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

The Australian Government’s Bureau of Meteorology (BoM) has primary responsibility for monitoring total column ozone.

- The BoM Dobson network consists of stations located at Brisbane, Darwin, Macquarie Island, Melbourne, and Perth (Perth is operated in conjunction with NOAA). Brisbane, Macquarie Island and Melbourne have records stretching back to 1957.

A number of universities also undertake some total ozone monitoring:
- A Brewer spectrophotometer operated by the University of Tasmania (operating costs financed by the BoM).
- Two Mk IV Brewer spectrophotometers operated by the Queensland University of Technology.
- Remote sensing FTIR operated by the University of Wollongong (the measurements are made as part of the Network for the Detection of Atmospheric Composition Change, NDACC).

NIWA operates a zenith viewing spectrometer at Macquarie Island for NO$_2$ column and profile information as part of NDACC.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Regular ozonesonde measurements are taken by the BoM at:
- Macquarie Island (weekly flights since 1994)
- Melbourne (weekly flights, with a program having operated from various locations around Melbourne since 1965).
- Davis station, Antarctica, in conjunction with the Australian Antarctic Division (AAD), since 2003. Flights are currently conducted weekly from May to November and monthly from December to April. Since early 2014, the Chinese Academy of Meteorological Sciences (CAMS) has been collaborating in this programme, which now also involves information exchange and research associated with atmospheric chemistry measurements at China’s Zhongshan station (near Davis). In conjunction with some of these ozonesonde flights, the AAD has operated a Rayleigh/Mie/Raman lidar at Davis to measure temperature and aerosol loading in the stratosphere (the lidar operated from 2001-2012 and is anticipated to collect further data from 2016).

Coarse vertical resolution profiles from Dobson Umkehr measurements have been made at BoM Dobson network sites dating back to 1962. Umkehr observations are still made at Brisbane, Darwin and Perth. (Stone et al., in preparation for AMT).

1.3 UV measurements

1.3.1 Broadband measurements
The Australian Radiation and Nuclear Safety Agency (ARPANSA) has maintained a network of UV detectors in capital cities around Australia since 1989. In 1996 the instruments were changed over to Solar Light UVB 501 broadband biometers. Kingston, Tasmania was added in 2007 and more recently Canberra was added as a new site (December 2010). Biometers have also been collecting data at Macquarie Island since 2001 and the Australian Antarctic stations Mawson, since 2002, and both Davis and Casey since 1996. The sites in Antarctica are currently being upgraded with new biometers. The biometers are intercompared at Yallambie before placement in the field. Spectral measurements with traceable calibrations at Antarctic mainland stations commenced in 2010 at Davis and Mawson. In 2011 a Bentham spectral system was installed at Davis for at least two summers with the aim of providing a longer duration series of calibrated spectral measurements, with the aim to subsequently extend this to both Mawson and Casey as well.

The Queensland University of Technology uses Solar Light 501 UV biometers in Brisbane to provide a live UV Index update to the public, as well as operating a national network of Yankee UVB pyranometers, located in Brisbane, Townsville, Canberra and Hobart.

### 1.3.2 Narrowband filter instruments

N/A

### 1.3.3 Spectroradiometers

The BoM owns and operates two NIWA-designed spectroradiometers at Alice Springs and Melbourne.

ARPANSA currently uses a Bentham spectroradiometer based at the Melbourne site to simultaneously measure solar UVR and transfer a traceable calibration to the biometers before installation. This instrument commenced measurements in December 2008 and has been operating continuously since then. ARPANSA also currently measures solar UVR using a Bentham spectroradiometer at Davis Station in the Antarctic.

### 1.4 Calibration activities

The BoM holds the RA V Dobson standard and operates the Regional Dobson Calibration Centre (RDCC) for Australia. The regional standard Dobson is inter-compared regularly with the world standard Dobson, most recently in Boulder in August 2013. ARPANSA meets the WMO’s instrument specifications and characterization as a health advisory agency that provides the daily UV levels. CSIRO/BoM ODS measurements employ calibration standards supplied by the Scripps Institution for Oceanography (USA) and the data are regular compared to data collected at Cape Grim by NOAA (USA), U. East Anglia (UK) and NIES (Japan).

### 1.5 Ozone Depleting Substances

Australian activities in ODS research are focused on *in situ* observations at the WMO Baseline Station at Cape Grim, Tasmania (funded and managed by the Australian Bureau of Meteorology), at the CSIRO laboratory at Aspendale, Victoria, and on air samples collected for the Cape Grim Air Archive and from the CSIRO Australian and global flask sampling networks. Australian activities also include ODS modeling, and all ODS observational and modeling research involve collaborations with AGAGE (Advanced Global Atmospheric Gases Experiment) and other colleagues in the USA, Europe and Japan.
ODSs monitored and modeled in the Australian program include species from all the major ODS groups – CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), halons, chlorocarbons, bromocarbons and nitrous oxide.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozonesonde and Dobson data from the Bureau network are available through the WOUDC and are frequently used for purposes such as satellite calibrations and trend analysis.

The Melbourne Dobson record from 1978-2012 was analysed in Tully, Klekociuk and Rhodes (2013) who found total ozone has been closely tracking mid-latitude EESC over this period.

Analyses of ozonesonde data from Davis station (Antarctica) are used in the following areas;

- Near real-time analyses of ozone in the Southern Hemisphere winter (WMO Antarctic Ozone Bulletins; see http://www.wmo.ch/pages/prog/arep/gaw/ozone/index.html)
- Satellite and instrument validation (e.g. Dupuy et al., 2008).

Gies et al 2013 studied a low ozone event observed over southern Australia in August 2011, which led to anomalously high UV exposure for this time of year.

A clear-sky UV Index Climatology (1979-2007) has been developed and is available at: http://www.bom.gov.au/jsp/ncc/climate_averages/uv-index/index.jsp. (Lemus-Deschamps and Making 2011).

Australian ODS research made a major contribution to the WMO/UNEP Scientific Assessment of Ozone Depletion: 2010 and is currently making a major contribution to the 2014 Assessment.

ODS contributions to Equivalent Effective Stratospheric Chlorine (EESC) and global radiative forcing (RF) have been derived from Cape Grim and other global AGAGE stations, from the Cape Grim Air Archive and from Antarctic firn air (Rigby et al., 2013, 2014; Fraser et al., 2014a).

Global and Australian regional estimates of HCFC-22 and CCl₄ emissions have been derived for these important ODSs from Cape Grim and global AGAGE data (Xiao et al., 2010a; Saikawa et al., 2012; Fraser et al., 2014b).

Global emissions of the four major halons in the atmosphere have been derived from Cape Grim Air Archive data (Newland et al., 2013).

Several new ODSs, some of which are growing in the background atmosphere, have been identified in the Cape Grim Air Archive and their emissions and lifetimes have been estimated (Laube et al., 2014).
AGAGE data, including Cape Grim, have been used to derive a revised estimate of the sources and sinks of atmospheric methyl chloride, the most abundant natural ODS in the atmosphere (Xiao et al., 2010b).

Cape Grim and AGAGE global in situ nitrous oxide (N₂O) data and N₂O data from the CSIRO global monitoring network have been used to substantially advance the understanding of the sources and sinks of this important ODS and the cause of its long-term increase in the background atmosphere (nitrogenous fertilizers) (Nevison et al., 2010; Park et al., 2012; Thompson et al., 2013, 2014a,b,c).

3. THEORY, MODELLING, AND OTHER RESEARCH

Using the UK Chemistry and Aerosols (UKCA) model within the Australian Community Climate and Earth-Simulation System (ACCESS) framework, researchers at the University of Melbourne and CSIRO, along with collaborators at the New Zealand National Institute of Water and Atmospheric Research (NIWA) are developing the capability of a fully coupled atmosphere-chemistry (and eventually ocean) model. The model is being used to simulate the stratospheric ozone layer chemistry and dynamics with the goal of a better understanding of the impacts of the development and recovery of the Antarctic Ozone Hole on the climate of the Southern Hemisphere.

- Specific simulations are being performed for the 1st Chemistry-Climate Model Initiative (CCMI-1). This work operates under project q90 of the National Computational Infrastructure, and Project 4012 of the Australian Antarctic Science (AAS) scheme (https://secure3.aad.gov.au/proms/public/projects/report_project_public.cfm?season=1213&project_no=4012).
- AAS Project 4012 (Polar Feedbacks of Ozone Recovery on Climate in the Southern Hemisphere) is using the model output to investigate the influence of ozone zonal asymmetries on Antarctic surface climate.

Siddaway et al. (2013) examined the timing of the return to pre-ozone hole conditions in spring and summer ozone recovery using model simulations from the 2nd Chemistry-Climate Model Validation activity (CCMVal-2), finding that recovery is slower in the later months.

Arblaster, Meehl and Karoly (Arblaster et al. 2011) have studied the impact of ozone depletion and recovery on Southern Hemisphere climate.

Satellite and surface measurements have been used to investigate ozone and UV changes over Australia and skin cancer incidence (Lemus-Deschamps and Makin, 2011; Makin 2011).

Using ground-based and satellite instruments, Innis and Klekociuk (2006) and Alexander et al. (2011, 2013) have quantified the effects of planetary waves and orographic gravity waves, respectively, on the formation of Polar Stratospheric Clouds.

ClO data from microwave measurements made at Scott base have been used to examine the chlorine dimer ozone loss kinetics (Kremser, Schofield et al., 2011).

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Ozonesonde and Dobson data from all Bureau of Meteorology stations are archived at the World Ozone and UV Data Centre (Woudc).
Measurements of column amounts from the FTIR system at Wollongong are reported via the Network for Detection of Atmospheric Composition Change (NDACC) database (see http://www.ndsc.ncep.noaa.gov/data/), as are spectral UV data from Alice Springs.

Cape Grim and AGAGE global ODS data, and N₂O data from the CSIRO global flask monitoring network are regularly archived at the WMO World Data Center for Greenhouse Gases (WDCGG) in Japan: http://ds.data.jma.go.jp/qmd/wdgg/

4.2 Information to the public

A UV forecast is issued daily by the Bureau of Meteorology. The UV forecast is important because approximately 380,000 Australians are diagnosed with skin cancer every year. The UV forecast is released to the public by the Bureau of Meteorology regional office in each state and it is provided to the media as part of the weather report (Deschamps et al., 2006). It is also available at http://www.bom.gov.au/uv/index.shtml, and it is extensively used in Australia’s SunSmart promotional and educational campaigns. (This system currently uses GFS ozone forecasts and ACCESS meteorological fields as input to the UV radiation code to forecast UV Index. Aerosols and UV surface albedo effects are also included).

ARPANSA provide measured real-time UV levels which are updated every minute. A plot of the UV levels for Australian sites is available on the ARPANSA web site at http://www.arpansa.gov.au/uvindex/realtime/index.cfm. Historical UV index data since 2004 is also available on the ARPANSA web site at http://www.arpansa.gov.au/uvindex/monthly/ausmonthlyindex.htm.

The Queensland University of Technology’s Aus Sun Research Lab maintains a website giving five-minute updates of the UV Index in Brisbane: http://www.uv.hlth.qut.edu.au/community/uvindex.jsp.


Ozone analyses and forecasts are used by a number of groups to issue statements on the development of the ozone hole each year.

During spring of each year, CSIRO provides a weekly update on the status of the ozone hole, based primarily on satellite data from OMI and TOMS, which is posted on the Department of Environment website and publicly available.

4.3 Relevant scientific papers (those published since 2011 or otherwise referenced in this report)


5. PROJECTS AND COLLABORATION

Information on Australian activities related to ozone and UV is shared through the *Australian Ozone Science Group*, co-ordinated by the Australian Government Department of Environment, which has led to increased co-operation between agencies and institutions.

A number of Australian scientists contributed as lead-authors, co-authors, contributors or reviewers of the 2010 and 2014 Scientific Assessment of Ozone Depletion, supported by the Department of Environment. David Karoly is a member of the Scientific Steering committee for the 2014 Scientific Assessment of Ozone Depletion, again supported by the Department of Environment.

The Bureau of Meteorology has ongoing collaboration projects with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) on UV Index validation against surface measurements and with SunSmart (Cancer Council Australia) on the use of the UV Index to promote sun protection; and

The BoM/AAD ozonesonde and AAD lidar measurements at Davis station in Antarctica have contributed to the International Polar Year cluster project ORACLE-O3, and the CONCORDIA/SI and MATCH campaigns.

ARPANSA has an ongoing collaborative project with the Australian Antarctic Division entitled Determination of the ultraviolet radiation environment at the Australian Antarctic Stations using broadband and spectral instrumentation (AAS 4115).

6. FUTURE PLANS

- Chemistry-climate simulations using the ACCESS model will be archived for the CCMI-1 project.
- The historic Umkehr Dobson record is to be reanalysed for the Australian region (BoM – University of Melbourne).
- The BoM is planning to purchase a number of new instruments to operate alongside network Dobsons as well as continuing to develop new UV spectral radiometers.

7. NEEDS AND RECOMMENDATIONS

Support for ongoing long term observational programs.
Belarus

As a result of the government reorganization, the Ministry of Education of Belarus is now in charge of ozone monitoring procedures, whereas the international cooperation is assigned to the Ministry of Environmental Protection and Natural Resources.

Following Belarus' accession to the Customs Union, all legislative acts (laws, decisions, instructions) regarding ODS circulation, certification, and custom charges have been formulated and submitted to the authorities of Russian Federation and Kazakhstan aiming to be unified in future. The relevant changes and additions to the ozone layer protection laws should be adopted by our legislative body this summer.

1. MONITORING ACTIVITIES

Belarus continues to design instrumentation as well as develop monitoring, calibration procedures and the archiving of stratospheric & tropospheric ozone, nitrogen dioxide, aerosols, surface UV radiation data and vertical lidar profiles of stratospheric & tropospheric ozone and aerosols.

1.1. Measurements of total ozone (TO) and UV radiation

The monitoring of TO has been maintained in the Republic of Belarus since 1998. Main measurements are taken at the Minsk Ozone Station (Minsk, 27.469E, 53.833N) having № 354 in the WMO international network.

During the period of 1998 to 2002, TO measurements were performed employing the “direct-sun” and “zenith-sky” procedures by means of an ozonometer PION designed at NOMREC.

Since 2006, column ozone values have been retrieved using the Stamnes procedure from spectral irradiance measurements made with the spectroradiometer PION-UV.

The network of TO measurements sites has been enlarging since 2011. Currently, the measurements are also taken at the BSU biological station (the Naroch lake) and at the Gomel state university. As a net ozonometer, one uses a fully automated PION-F double-channel filter photometer.

Since 2006, applying PION-UV and M124-M instruments, the regular TO and UV radiation measurements have been conducted at the time of seasonal Belarusian Antarctic Expeditions in the region of Enderby Land (Antarctica).

NOMREC possesses a full database on TO monitoring in the atmosphere over the territory of Belarus for the period of 1998 – 2014. Also, NOMREC has the database of surface solar UV radiation spectra as well as doses of various biological effects for the territory of Belarus covering the period of 2001-2014.
1.2. Total nitrogen dioxide measurements

Monitoring of nitrogen dioxide has been performed at the Minsk Ozone Station since 2007. In 2009-2010, the nitrogen dioxide column values were measured with a new DOAS zenith-sky system constructed on the base of the Oriel-260 spectrometer. The measurement procedure included the nitrogen dioxide column retrieval technique elaborated at the Obukhov Institute of the Atmosphere Physics (Russia).

A new MAX-DOAS measurement device on the base of Oriel-257 spectrometer has been used for a number of short-term intercomparison measurement campaigns for retrieval of vertical nitrogen dioxide concentration profiles in several sites in Belarus (Minsk, Naroch National Park), Germany (during the calibration procedure in Max Planck Institute for Chemistry, Mainz), and Antarctica.

1.3. Surface ozone monitoring

Measurements of surface ozone concentration have been carried out since 2004 at the Minsk Ozone Station and Berezina National Park EMEP station employing DOAS instrument TRIO-1 which has passed standard certifications in the Belarus State Institute of Metrology. The absolute error did not exceed ±1.45 ppb in the ozone concentration range of 0-200 ppb.

For surface ozone monitoring, a TEI 49C ozone analyser has also been employed particularly for calibration. A compact device to measure the surface ozone concentration is originated at NOMREC and based on a new type of semiconductor nickel oxide sensor.

![Fig. 1: Falls in surface ozone concentrations](image)

At the location of the Minsk Ozone Station, one has observed the effect of non-periodic short-term deep surface ozone falls (for a few minutes time, see fig. 1). The phenomenon has been detected by instruments of the various types. The fall depth depends on the instrument time constant. The problem needs further analysis and discussion.

Department of Hydrometeorology has recently created a complex network of observational sites for the atmospheric air quality on the territory of Belarus. Ozone, some of its precursors as well as aerosol particles are among atmosphere pollutants being controlled at the sites. In particular, Minsk has 4 such points located in city
areas differing in air pollution level.

1.4. Profile measurements of ozone and aerosols

The atmosphere monitoring has been conducted at B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus since 1985. In 2007-2014, two wavelength (355 and 532 nm) lidar measurements of stratospheric aerosol parameters were performed as well as ozone concentration profiles (266 nm).

A type of lidar system was developed using the transmitter at the wavelength 281.7 nm on the base of solid-state stimulated Raman scattering converter. The system provides measurements of ozone concentration in a layer of 1 – 10 km.

1.5. Calibration activity

Spectral irradiance calibrations of PION-UV and other instruments in a spectral range of 285-450 nm were regularly carried out at the NOMREC site with a 300 W tungsten band-lamp certified by the Russian National Standard Agency. Total ozone instruments were calibrated using a WMO regional standard (Dobson N108 spectrophotometer) in Voeikov Main Geophysical Observatory (MGO), St. Petersburg, Russia. The last calibration was performed in July, 2013.

On a regular basis, one also uses a special technique originated specifically at NOMREC for checking and recalibration of total ozone instruments at the operational sites.

In summer 2013, the MAX-DOAS measuring system of NO₂ profiles participated in the MAD-CAT intercalibration and intercomparison campaign at the Max Planck Institute for Chemistry, Mainz, Germany.

2. OBSERVATION RESULTS AND ANALYSIS

In accordance with the analysis of total ozone data at Minsk (53.83 N, 27.47 E) for the periods of 1979-1992 and 1996-2012, besides a reduction in multi-year averages of monthly average values of total ozone, one has revealed a shift in the annual total ozone maximum from April to March (fig. 2). This is due to the changing of circulation processes in the atmosphere.

Substantial efforts have been taken to assign this fact to the circulation processes in the northern hemisphere. Analysis has shown that this dependence is most clearly revealed if comparing to the circulation processes described by Dzezrdzeevsky. Matching a number of days with different types of meridional circulation and TO average monthly values demonstrates an existing for several years link between these quantities. One may assume that the shift in the annual maximum is due to the changes in troposphere circulation, that is intensification of the meridional northern circulation in March and intensification of the meridional southern circulation in April (fig. 3).
Fig. 2: Multi-year averages of monthly average values of total ozone for the periods of 1979-1992, and 1996-2012.

Fig. 3: Average monthly values of TO and a number of days with the meridional northern circulation in March for the periods of 1979-1992 and 1996-2012.
3. SCIENTIFIC ACTIVITIES

3.1. Engineering development

The work is continued to modernize an M124 filter ozonometer. As a result, we have a final modification of M124.

A double-channel filter photometer PION-F has been devised to measure levels and doses of the biologically active surface solar UV radiation (CIE bioeffect). Both instruments can be used at the sites where previous generation of M124 devices was exploited. NOMREC can organize modernization and recalibration of the existing observational M124 network in cooperation with Voeikov MGO (St. Petersburg, Russia).

The construction of the PION-F has no moving elements. PION-F is designed for all-weather application in a completely automated mode. Systems of the photometer spectral selection are similar to the M124 filter systems, but radiation registration is realized from a hemisphere in two measuring channels simultaneously. To enhance sensitivity of the system and reduce a stray exposure, a solar-blind PMT has been used in the device.

An automated complex system including a base unit of the biologically active UV radiation meter, a sensor of the total radiation, and a FAR sensor has been created on the basis of the PION-F photometer.

A submersible device has been specifically engineered to study solar UV radiation propagation in the aqueous medium up to a depth of 20 m. The instrument is equipped with a surface unit enabling to measure both radiation levels at different depths and water transparency.

A MAX-DOAS measuring system of atmospheric NO$_2$ slant column densities is designed on the basis of an Oriel-257 spectrometer.

A small-sized model of a tropospheric lidar and the mobile monitoring system of ice and snow cover condition have been developed.

Within the framework of the National Antarctic program, two filter ozonometers M124-M and the spectroradiometer PION-UV have been specifically modified to be used in polar areas of the Earth.

3.2. Theory and modelling

Some developments have been made advancing the measurement procedure as well as the Stamnes ozone retrieval technique.

Following the analysis of possibilities for various techniques of TO measurement, one has defined that the errors of direct-sun measurements are comparable to those of zenith measurements in the order of magnitude at large solar zenith angles. Meanwhile, stability of zenith measurements if considering the atmospheric variations is essentially higher. Moreover, the best ratio between signal levels and stability of the TO retrieval algorithm is achieved while registering a signal by a cosine input device in the specially selected spectral intervals.

Also, some efforts have been undertaken in the field of modelling studies of stratospheric ozone layer processes. In particular, a mesoscale atmospheric model has been used to simulate dynamical processes of local ozone anomalies formation, evolution, and decay. Apart from that, a project is currently underway dealing with...
ozone-climate connections, namely, the ozone mechanism of solar activity influences on mesosphere-stratosphere-troposphere coupling.

4. DISSEMINATION OF RESULTS

The data derived by the NOMREC along with the data collected at the B.I. Stepanov Institute of Physics are submitted to and archived in the database of the National Environmental Monitoring System (NEMS). At the moment we still have problems with submitting our data to WOUDC.

4.1. Information to the Public

Mapping and UV Index forecast generated specifically for different regions have been realized since 2006.

The UV Index short-term forecast made for the Belarus territory is submitted to the National news agency BelTA on a daily basis.

These data are also available on the NOMREC site at http://ozone.bsu.by and on the official site of the National Hydrometeorological Agency of Belarus at http://www.pogoda.by.

4.2. Projects and collaboration

Presently, we have four active projects at NOMREC:

1. Within the NEMS Ozone Monitoring Program, we have plans to expand our network to six observation stations in Belarus instead of existing three ones to meet the recommendations of the 8th ORM.

2. As part of the National Space Research Program of Belarus, we implement the project on ozone-climate interactions.

3. Within the National Environmental Program, we have a special project aimed at estimating a climatic average of stratospheric and surface ozone.

4. A separate research project on atmospheric modelling for the purposes of numerical weather prediction, regional climate forecasting and stratosphere-troposphere interactions.

At B.I. Stepanov Institute of Physics, two project are currently implemented dealing with lidar development for measurements of ozone and aerosols in the troposphere and the stratosphere, respectively.

Furthermore, B.I. Stepanov Institute of Physics and NOMREC have corresponding projects in the National Antarctic Program of Belarus related to atmospheric research. A permanent ozone station in Antarctica is about to be established in the nearest future.

Also, it is planned to intensify research activities in the field of ozone-climate connections in the framework of the National Climatic Program of Belarus starting the next year.
5. REFERENCES


BELGIUM

1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

1.1.1 The Royal Meteorological Institute (RMI)

The RMI performs Daily Ozone column measurements with two automated Brewer spectrophotometers. One (nr 16) is a single monochromator, in use since 1983 and the other one (nr 178) is a double monochromator installed in 2001. Both instruments are operational in Uccle (Belgium).

Measurements with a Dobson spectrophotometer (nr 40) which started in 1971, continued until end of May 2009. As RMI has two Brewer instruments and a long overlap period with the Dobson instrument, the Dobson measurements were stopped. In agreement with WMO-GAW the instrument is now loaned to the University of Kiev (Ukraine) and is operational there.

The observations mentioned above take place at Uccle (50°48’N, 4°21’E, 100 m asl, complementary NDACC station see (http://www.ndacc.org) and station 053 in the WOUDC list).

In addition RMI started in January 2011 observations at the Belgian Antarctic station Princess Elisabeth with Brewer instrument 100, which was put at our disposal by KNMI in the Netherlands. The new Antarctic station is located at 71 deg south, 23 deg East, 1397m asl. It obtained nr 499 in the WOUDC list, and will be operational during the manned periods in the austral summer.

1.1.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

BIRA-IASB performs ground-based monitoring of the total column of ozone, of ozone depleting substances and of other ozone relevant species (halogens, NOy, BrO, HCFC, CFC…) for budget, process and long-term trend studies, at the following 8 stations:

- The International Scientific Station of the Jungfraujoch, Switzerland (46.55°N, 7.98°E, 3580 m asl, NDACC Alpine station) (see also 1.1.3): long-term time series of many constituents by FTIR and SAOZ UV-Visible DOAS instruments. The time series of FTIR column data starts in the early eighties, while the SAOZ time series of the O_3 and NO_2 column start in 1990. In the second half of 2010, an additional MAXDOAS Instrument was installed by BIRA-IASB at the Jungfraujoch; it monitors the stratospheric vertical distribution of BrO, NO_2 and ozone as well as tropospheric abundances of NO_2, H_2O, O_3, H_2CO and aerosols.
- Harestua, Norway (60.2°N, 10.8°E, 596 m asl, NDACC Arctic station): UV-Visible DOAS instruments, measuring since 1994 the column of O_3, NO_2, OClO, and BrO.
- The Observatoire de Haute Provence (OHP), France (43.94°N, 5.71°E, 650 m asl, NDACC Alpine station): UV-Visible DOAS instruments measuring the column of O_3, NO_2, and BrO since summer 1998. The UV-Visible DOAS instrument was upgraded with an off-axis capability (MAXDOAS) in 2000 and since then measures also tropospheric abundances of NO_2 and H_2CO.
- Ile de la Réunion (20.9°S, 55.5°E, 10 m asl, NDACC Southern Hemisphere tropical station): FTIR observations (total column abundances and vertical distributions of O_3, halogenated and nitrogenated source and reservoir gases, and more) started in summer 2002. Initially FTIR observations were made on a campaign basis, in Sept-Oct. 2002, August to November 2004, and May to November 2007. Since May 2009, the instrument (Bruker 120M) is operated on a continuous basis. During the first FTIR campaign in 2002, simultaneous measurements at sea level and at high altitude (2200 m asl) were performed, allowing inferring columns in the boundary layer/low troposphere, via a differential approach.

The FTIR observations with this instrument were stopped in December 2011, which was replaced with a new more performant FTIR instrument (see below).

From August 2004 to July 2005, a UV-Visible MAXDOAS instrument measuring O_3, NO_2, BrO, H_2CO columns and tropospheric abundances, was operated at the same site.
• Ile de la Réunion (20.9°S, 55.5°E, 10 m asl, NDACC Southern Hemisphere tropical station): in September 2011, BIRA-IASB installed a new more performant FTIR instrument (Bruker 125HR) enabling high-precision measurements of greenhouse gases (CO₂ and CH₄) as well. This instrument has been operational since September 2011 and it is being switched regularly between the TCCON Mode (for doing greenhouse gas measurements in the near-infrared) and the NDACC mode (for doing measurements of ozone and related key species). The instrument got the official certification of being affiliated to the Total carbon Column Observing Network (TCCON) in summer 2012. As the evolution of the stratospheric ozone layer is influenced by climate changes, these measurements are relevant indirectly for understanding ozone in the future.

• Ile de la Réunion (20.9°S, 55.5°E, 10 m asl, NDACC Southern Hemisphere tropical station): in February 2013, another Bruker 125HR FTIR spectrometer was installed at the new NDACC observatory at the Maido site (2200 m asl) for making solar absorption observations in the mid-infrared, in the NDACC mode (for doing measurements of ozone and related key species).

• Xianghe, P.R. China (40°N, 115°E): BIRA-IASB initiated a ground-based monitoring activity in China at the occasion of the Olympic Games organized in Beijing during summer 2008. To this aim a state-of-the-art UV-visible MAXDOAS system was developed at BIRA-IASB and installed at a few hundred meters from the Olympic station on the roof of the Institute of Atmospheric Physics (IAP) of the Chinese Academy of Science (CAS) in Beijing. The measurement campaign lasted from July 2008 until April 2009 and was a success. It was then decided to further develop the cooperation with IAP by setting up a long-term monitoring activity taking benefit of the existing IAP infrastructure at the sub-urban monitoring site of Xianghe, situated approximately 50 km East of Beijing. This area is not strongly affected by local emissions but still largely under the influence of pollutants transported from three surrounding major cities: Beijing, Tianjin and Tangshan. The BIRA-IASB MAXDOAS instrument was installed in Xianghe in February 2010 and since then continuously operated, with the local support from IAP. Four years of observations are now available allowing for the study of a number of trace gases (NO₂, O₃, H₂CO, SO₂, HONO, BrO, CHOCHO, and H₂O) and aerosols in the troposphere and/or the stratosphere. These measurements are being exploited in support of various projects, serving in particular the validation of tropospheric measurements from recent satellite sensors (GOME-2, OMI, and SCIAMACHY) and various modeling projects dealing with the determination of trace gas emissions in China.

• Bujumbura, Burundi (3°S, 21°E): BIRA-IASB set up a UV-visible MAXDOAS spectrometer and CIMEL sun photometer at the University campus of Bujumbura in November 2013, for the observation of O₃, NO₂, HCHO, glyoxal, SO₂, BrO, H₂O and aerosols. The first months of data are available.

• Uccle, Brussels, Belgium (50.8°N, 4.35°E, 100 m asl, NDACC Northern Hemisphere Mid-latitude station): In April 2011, BIRA-IASB started ground-based monitoring using a commercial Mini-MAXDOAS instrument from Hoffmann Messtechnik GmbH. This system provides measurements of tropospheric NO₂ and aerosols with a time resolution of approximately 20 minutes. It is used in support of the Copernicus Atmospheric Service and for satellite validation purposes.

BIRA-IASB is involved in several satellite missions measuring the total column of ozone and of ozone relevant species (halogens, NOy, BrO, HCFC, CFC…) for budget, process and long-term trend studies:

• Global Ozone Monitoring Experiment (GOME), aboard ESA’s ERS-2 platform, measured the column of O₃, NO₂, BrO and OCIO from July 1995 till the switch-off of the platform in June 2011. BIRA-IASB is a co proposer of the instrument, plays a key role in scientific developments, evolution and geophysical validation of the operational GOME Data Processor for total ozone and NO₂ established at DLR (Germany) on behalf of ESA (Lambert et al. 1999, 2000; Spurr et al. 2004; Van Roozendael et al. 2007; Balis et al. 2007; Loyola et al. 2009; Lerot et al. 2010; Van Roozendael et al. 2012; Lerot et al. 2014; Koukouli et al. 2014). OIP Sensor Systems, a
Belgian company specialised in defence, security and space, built the GOME Polarization Monitoring Devices (PMDs).

- Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY), a tri-national contribution to ESA’s Envisat satellite by Belgium, Germany and The Netherlands, measured the column of O₃, NO₂, BrO, SO₂, OCIO and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB is a Co-PI of the instrument, has followed the technical development of the instrument, is involved in the development and evolution of retrieval algorithms, and is a Co-chair of the SCIAMACHY Validation and Interpretation Group (SCIAVALIG). OIP Sensor Systems, a Belgian company specialised in defence, security and space, built the SCIAMACHY Polarization Monitoring Devices (PMDs).

- Ozone Monitoring Instrument (OMI), aboard NASA’s EOS-Aura polar platform, measures since 2004 the column of O₃, NO₂, BrO, SO₂, OCIO and other trace gases. BIRA-IASB has been active in the development and geophysical validation of ozone, NO₂ and BrO data products from OMI.

- Global Ozone Monitoring Experiment -2 (EUMETSAT GOME-2), aboard EUMETSAT MetOp-A platform since October 2006 and MetOp-B platform since September 2012, measures the column of O₃, NO₂, BrO, SO₂, OCIO and other trace gases. Partner of the EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3M-SAF), BIRA-IASB plays a key role in scientific developments, evolution and geophysical validation of the operational GOME-2 Data Processor for the column of ozone, NO₂, BrO, H₂CO and SO₂ established at DLR (Germany) as part of the O3M-SAF (Loyola et al. 2011; Lerot et al. 2010b; Lerot et al. 2014; Koukouli et al. 2014).

- Infrared Atmospheric Sounding Interferometer (IASI), on board of EUMETSAT MetOp-A (since 2006) and MetOp-B (since 2012) platforms. BIRA-IASB is involved in the development of a N₂O data product. N₂O releases NOₓ in the stratosphere, which is an Ozone Depleting Substance (ODS). The steady growth of N₂O makes it a threat to the stratospheric ozone layer in the future. In addition, BIRA-IASB is developing a methane product from IASI.

1.1.3 Université Libre de Bruxelles (ULB)

- The Atmospheric Spectroscopy group (Service de Chimie Quantique et Photophysique) at ULB is heavily involved in the IASI/MetOp satellite mission, being member of its Science Working Group (ISSWG-2), under auspice of CNES and EUMETSAT. IASI is a sounder that measures the thermal infrared radiation of the Earth/atmosphere in nadir geometry (Hilton et al., 2012), at fairly high spatial (12 km diameter circular pixel on-ground) and spectral (0.5 cm⁻¹) resolutions (Clerbaux et al 2009). IASI is part of the EPS system, and is scheduled to operate up to 2020 at least. The first IASI instrument onboard the European MetOp-A was launched platform in late 2006 and declared operational in July 2007. The second instrument was launched in 2012. Both are currently in operation. As compared to UV sounders but also precursor infrared sounders (IMG and TES), IASI has the advantage of high spatial and temporal sampling, providing global measurements twice daily, once in the morning and once in the evening. The small pixel allows capturing fine concentration variations of several trace gases (Clarisse et al., 2013). The ULB group has set-up, in collaboration with the French LATMOS, a near-real time processing chain for IASI. Of particular relevance here are:
  - Ozone total columns distributions, which are retrieved global twice a day, in near-real time using FORLI-O3. The product has already undergone validation against ground-based measurements and GOME-2 FORLI-O3 should be implemented in 2015-2016 in the EUMETSAT Central Application Facility and is expected to become the operational processing chain for IASI O3. FORLI-O3 will also be the reference algorithm for the work to be performed under the O3-CCI project.
  - Nitric acid total columns distributions, which have an important role in regulating the ozone hole, and a sensitive species to monitor its development.
  - Aerosols from various types, including volcanic ash and sulfuric acid droplets (Clarisse et al., 2013)
In addition a series of column measurements for tropospheric species, strongly involved in the ozone budget by being ozone precursors, are provided. These include in particular CO (e.g. Worden et al., 2013) and volatile organic compounds (Duflot et al., 2013; Razavi et al. 2011; Stavrakou et al., 2011 and 2012).

### 1.1.4 University of Liège

ULg is responsible for the operation and maintenance of the FTIR spectrometer installed at the Jungfraujoch station, Switzerland (46.5°N, 8.0°E, 3580 m asl; http://www.ndacc.org). High-resolution infrared solar spectra are recorded year-round at that site since the mid-1980s. The observational dataset acquired there is unique worldwide in terms of time period covered and measurement density. Systematic analysis of the spectra allows the determination and extension of long-term total column time series of numerous species relevant to ozone, i.e. ozone itself, reservoirs of the NOy (NO, NO2, HNO3, ClONO2) and Cly (HCl and ClONO2) families, chlorinated source gases monitored by the Montreal Protocol (CFC-11, -12, HCFC-22, -142b, CCl4). See Table 1 for a complete list of the current FTIR target species at the Jungfraujoch.

ULg is further involved in the Canadian ACE satellite mission (Bernath et al., 2005), which includes an FTIR instrument on operation from space since early 2004. ULg contributes to the validation of the ACE-FTS data and to their scientific exploitation.

### 1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

#### 1.2.1 The Royal Meteorological Institute (RMI)

The vertical distribution of ozone at Uccle is measured three times per week by the means of balloon soundings with ozone sondes since 1969. These measurements provide ozone profiles of very high vertical resolution (a few hundred metres). ECC ozone sensors are used since 1997. Ozone profile data in the period 1969-1997 were obtained with Brewer-Mast sensors. Special care is taken to ensure the homogeneity of the time series, not only between the two types of ozone sensors, but also between every single sensor.

#### 1.2.2 University of Liège (ULg)

In addition to total column determinations, analysis of the FTIR spectra with dedicated state-of-the-art algorithms provides information on the vertical distributions of most of the target species, allowing studying and characterizing the state and evolution of the stratosphere and troposphere at northern mid-latitudes. Derived geophysical parameters then consist in total and partial column abundances above the site, including related uncertainty evaluations. Table 1 provides the current list of atmospheric gases routinely studied at the Jungfraujoch. Ozone is among the target gases as well as halogenated or nitrogenated species (sources and reservoirs) involved in ozone depletion. In addition, numerous greenhouse gases are also monitored.
Table 1. Molecules currently studied in FTIR solar spectra recorded at the Jungfraujoch

<table>
<thead>
<tr>
<th>Reference gas:</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor constituents:</td>
<td>CO₂, N₂O, CH₄, CO, O₃</td>
</tr>
<tr>
<td>Trace constituents:</td>
<td></td>
</tr>
<tr>
<td>Halogenated species:</td>
<td>HCl, ClONO₂, HF, COF₂, CCl₂F₂, CHClF₂, CCl₃F, CH₃CCl₂F, CCl₄, CF₄, SF₆</td>
</tr>
<tr>
<td>Nitrogenated species:</td>
<td>NO, NO₂, HNO₃, ClONO₂</td>
</tr>
<tr>
<td>Others:</td>
<td>H₂O, C₂H₆, C₂H₂, C₂H₄, HCN, OCS, H₂CO, H₂CO₂, CH₃OH</td>
</tr>
<tr>
<td></td>
<td>Isotopologues of CO, CH₄, H₂O, O₃</td>
</tr>
</tbody>
</table>

1.2.3 The Belgian Institute for Space Aeronomy (BIRA-IASB)

BIRA-IASB performs ground-based monitoring of the vertical distribution of ozone, of ozone depleting substances and of other ozone relevant species (halogens, NOy, BrO, HCFC, CFC…) for budget, process and long-term trend studies, at the following 6 stations:

- The International Scientific Station of the Jungfraujoch, Switzerland (46.55°N, 7.98°E, 3580 m asl, NDACC Alpine station): time series of FTIR observations (led by ULg) starting in the early eighties. BIRA-IASB contributes to the exploitation of the FTIR data for the study of vertical ozone trends. BIRA is also responsible for the operation of a UV-Visible MAXDOAS instrument installed in the second half of 2010, from which profiles of stratospheric NO₂ and BrO are retrieved. This MAXDOAS instrument monitors the stratospheric vertical distribution of BrO, NO₂ and ozone as well as tropospheric abundances of NO₂, H₂O, O₃, H₂CO and aerosols.

- Harestua, Norway (60.2°N, 10.8°E, 596 m asl, NDACC Arctic station): UV-Visible DOAS instruments operating since 1994, from which the vertical distribution of stratospheric NO₂ and BrO is retrieved.

- The Observatoire de Haute Provence (OHP), France (43.94°N, 5.71°E, 650 m asl, NDACC Alpine station): UV-Visible DOAS instruments operating since summer 1998, from which the vertical distribution of stratospheric NO₂ and BrO is retrieved.

- Xianghe, China (40°N, 115°E): UV-visible MAXDOAS instrument operating since February 2010, from which the vertical distribution of stratospheric NO₂ and BrO is retrieved.

- Bujumbura, Burundi (3°S, 21°E): UV-visible MAXDOAS instrument operating since November 2013, from which the vertical distribution of stratospheric NO₂ and BrO is retrieved.

- Ile de la Réunion (20.9°S, 55.5°E, 10 m asl, NDACC Southern Hemisphere tropical station): From the FTIR observations at high spectral resolution, one can derive some limited information about the vertical distribution of the observed species. In particular, for ozone, one can derive 5 independent partial columns between the ground and the upper stratosphere.

BIRA-IASB is involved in several satellite missions measuring the vertical distribution of ozone, of ozone depleting substances and of other ozone relevant species (halogens, NOy, BrO, HCFC, CFC…) for budget, process and long-term trend studies:

- Global Ozone Monitoring Experiment (GOME), aboard ESA’s ERS-2 platform, measured solar backscattered ultraviolet radiances from 1996 till the switch-off of the platform in June 2011. Form these radiance measurements several institutes retrieve the vertical distribution of ozone in the stratosphere and troposphere. BIRA-IASB is a co-proposer of the instrument,

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1 Species typed in italic are primarily present in the stratosphere, while the others are tropospheric ... source gases.
contributes to the evolution of several ozone profile retrieval algorithms through Round-Robin audits and plays a key role in their geophysical validation. OIP Sensor Systems, a Belgian company specialised in defence, security and space, built the GOME Polarization Monitoring Devices (PMDs).

- **Scanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY)**, a tri-national contribution to ESA’s Envisat satellite by Belgium, Germany and The Netherlands, measured the vertical profile of O₃, NO₂, BrO and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB is a Co-PI of the instrument, has followed the technical development of the instrument, is involved in the development and evolution of retrieval algorithms, and is a Co-chair of the SCIAMACHY Validation and Interpretation Group (SCIAVALIG). OIP Sensor Systems, a Belgian company specialised in defence, security and space, built the SCIAMACHY Polarization Monitoring Devices (PMDs).

- **Global Ozone Monitoring by Occultation of Stars (GOMOS)**, on board of ESA’s Envisat, measured the vertical profile of O₃, NO₂, NO₃, OClO and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB is a co-proposer of the instrument, an expert support laboratory (ESL) certified by ESA, and has been active in the development and validation of O₃, NO₂, OClO and temperature data products.

- **Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)**, on board of ESA’s Envisat, measured the vertical profile of O₃, NO₂, HNO₃, N₂O, CO, CH₄, H₂O, CFCs, HCFCs and other trace gases from August 2002 till the loss of contact with Envisat in April 2012. BIRA-IASB has been active in the geophysical validation of O₃, temperature, NOy, N₂O, CO, CH₄, HCFC and CFC data products.

- **Atmospheric Chemistry Experiment – Fourier Transform Spectrometer (ACE-FTS)** on board of CSA’s SCISAT-1 launched in 2003, measures via the solar occultation technique the vertical distribution of many ozone related trace gases and parameters. BIRA-IASB has been active in the development and geophysical validation of ozone, CH₄, CO, N₂O, NOy, HCl, HCFCs and CFCs and temperature data products. Inside the ACE-FTS instrument is a visible/near infrared imager with two filtered channels at 0.525 and 1.02 µm, chosen to match two of the wavelengths monitored by the SAGE II satellite instrument. Made by the Belgian company Fill Factory of Mechelen, the imagers provide an important diagnostic for pointing and for detecting the presence of clouds in the field of view of the instrument.

- **Global Ozone Monitoring Experiment-2 (EUMETSAT GOME-2)**, aboard EUMETSAT MetOp-A platform since October 2006 and MetOp-B platform since September 2012, measures solar backscattered ultraviolet radiances, from which several institutes retrieve the vertical distribution of ozone in the stratosphere and troposphere. BIRA-IASB contributes to the evolution of several ozone profile retrieval algorithms through Round-Robin audits and plays a key role in their geophysical validation.

- **Infrared Atmospheric Sounding Interferometer (IASI)** operating on board of MetOp-A since 2006 and MetOp-B since 2012. BIRA-IASB has contributed to the validation of the CO and HNO₃ vertical profile data. It has developed an algorithm for retrieving vertical profiles of the mineral dust aerosol. It is working on a CH₄ vertical profile product. To improve the sensitivity at the surface, it is working on synergetic SWIR/TIR retrievals of CH₄ – with GOSAT data as test case.

- **Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere (ALTIUS)**: national development of a limb viewing satellite instrument responding to the requirements resulting from the 7th and 8th ORM Meetings in 2008 and 2011, respectively (WMO GORMP Report No. 51 and No. 53): “Satellite observations of high vertical resolution profiles using limb viewing for O₃ and key molecules are required in order to more accurately understand the changes in O₃ as CFCs decline and climate change occurs.” ALTIUS has now entered phase B1 (see below in Section 6: Future plans).
1.2.4 Université Libre de Bruxelles (ULB)

Contribution to satellite missions:

- The Atmospheric Spectroscopy group (Service de Chimie Quantique et Photophysique) at ULB tackles several chemistry-related activities around the IASI/MetOp satellite mission. The researchers take active part in the IASI Sounder Science Working Group (ISSWG-2), under auspice of CNES and EUMETSAT, for IASI and preparation of IAS on EPS-SG. In addition to providing information on total columns (see above), IASI has also profiling capabilities at least equal if not superior to most instrument currently in operation. With the FORLI processing chain set-up at ULB, the following products are available in near-real-time:
  - Ozone vertical profiles, which are retrieved in 40 layers of 1km thickness starting from the ground, with 3-4 independent pieces of information. Upper stratospheric, UTLS and tropospheric contributions are well decorrelated. The maximum sensitivity of IASI to the ozone profile extends from the mid-troposphere to the lower stratosphere, and the product is thus of high relevance for monitoring the vertical structure of the ozone hole, the contribution of tropospheric ozone to climate, as well as the impact of ozone in the lowest layers on air quality.
  - Nitric acid vertical profiles. The vertical information is low but the retrieval of vertical profiles improves on the columns measurements by accounting for changes in tropopause height. Vertical profiles are available in NRT. The maximum sensitivity is in the upper troposphere. A partial de-correlation between tropospheric and stratospheric HNO3 is possible in the best cases.

- In addition to IASI, the ULB researchers are involved SCISAT-1 ACE-FTS Science Team, although their active contribution has decreased in the last years due to their large involvement in IASI. They have contributed to several profile studies with ACE-FTS.

1.3 UV measurements

1.3.1 Broadband measurements
Nihil

1.3.2 Narrowband filter instruments
Nihil

1.3.3 Spectroradiometers

1.3.3.1 The Royal Meteorological Institute (RMI)
UV spectral irradiance measurements at Uccle: both Brewer spectrophotometers are also used to monitor the UV-B radiation intensities. They perform several scans per day (number depending on the time the sun is above the horizon).

Since January 2011, also the Brewer in Antarctica performs UV spectral measurements during its operational period the austral summer.

1.3.3.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)
BIRA-IASB operates a UV-monitoring network of 6 stations in Belgium: Mol, Mont Rigi, Oostende, Redu, Uccle, and Virton. This network monitors global solar spectral irradiance, broadband data, filter radiometer data, sunshine duration, as well as associated cloud and meteorological parameters.
In December 2012, BIRA-IASB deployed also its UV-B and UV-A and pyranometer sensors for the measurement of the global solar irradiation in the UV and visible wavelength ranges at the Belgian Princess Elisabeth station in Antarctica (71°S, 23°E, 1300 m asl).

All the measured data sets in Belgium and Antarctica are available publicly on http://uvindex.aeronomie.be.

### 1.4 Calibration / Validation activities

#### 1.4.1 The Royal Meteorological Institute (RMI)

Before the transfer to Ukraine, the Dobson instrument nr 40 was refurbished and calibrated at the Regional Calibration Centre of WMO in Hohenpeißenberg in 2009-2010. It turned out that the instrument has been very stable since the last calibration. Therefore no reprocessing of the data set at Uccle was necessary.

The Brewer instruments 016 and 178 were compared with the travelling reference instrument nr 017 in 2006 and 2008. In 2010 the instruments were calibrated in Uccle together with Brewer #100 (before it was sent to Antarctica) against Brewer reference instrument 158. The cosine response of Brewer 178 was measured in co-operation with BIRA in 2011. In 2012 Brewers 016 and 178 were calibrated against reference instrument 158. In 2014 a new calibration campaign is planned (this time also including the instrument operated in Antarctica). The results of these calibrations were taken into account for the new ozone observations and also the older data were recalculated.

The ozone sondes are carefully prepared and calibrated with a reference instrument in the laboratory before launch. A correction procedure is applied to minimise the inhomogeneity that could have been introduced at the change of the sonde type in 1997. We also took part in the Ozone Sonde Data Quality Assessment (O3S-DQA) activity, a part of the SPARC-IGACO-IOC (SI2N) Assessment on "Past Changes in the Vertical Distribution of Ozone". The goal of the O3S-DQA activity is to create a world-wide, homogenized set of ozone sonde data which includes an uncertainty estimate for every single measurement. The idea is to define Standard Operating Procedures and corrections for the ozone sonde measurements and to convert all measurements to these by means of transfer functions. The Uccle dataset (from 1997 onwards) was corrected according to those standard operating procedures and algorithms and an uncertainty analysis have been applied to those data.

The UV-B calibration of the Brewer instruments was checked with 1000W lamps in 2006, 2008, 2010 and 2012 during the calibration visits. In 2004 the special comparative observations were performed with a travelling reference UV instrument of the Joint Research Centre (JRC in Ispra) in the frame of the Qasume project (Gröbner et al, 2004). All the 1000W calibrations were consistent within the expected errors.

#### 1.4.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

The ground-based FTIR, zenith-sky DOAS and MAXDOAS UV-visible instruments are all contributing to the NDACC. As such, they comply with the various NDACC protocols for instrument certification, measurement, data intercomparisons, data submission and data use.

The MAXDOAS instruments have participated to several calibration/intercomparison campaigns, e.g., the recent CINDI campaign in Cabau (NL) in summer 2009 (Roscoe et al., 2010).

The calibration of the FTIR instruments at La Réunion is verified on a daily basis by doing HBr (for NDACC) and HCl (for TCCON) cell measurements. We also participate in the data processing standardisation procedures that are on-going in the frame of the NDACC Infrared Working Group and the TCCON network.

BIRA-IASB coordinates cal/val activities for GOME, GOMOS, MIPAS, SCIAMACHY, ACE-FTS, OMI and GOME-2.

BIRA-IASB contributes to the international development of a global data quality strategy for the GEOSS, an effort led by CEOS WGCV in response to GEO Tasks DA-06-02 and DA-09-01. It is involved in the board establishing the Quality Assurance framework for Earth Observation (QA4EO,
At European level it is active in the system engineering for the Copernicus (formerly GMES) Atmospheric Service (GAS), where it ensures coordination and harmonisation of the data quality strategy between, on one hand, the GMES/Copernicus pioneering projects ESA GSE PROMOTE and EC FP6 GEMS, and on the other hand, the EC FP7 projects establishing the GMES/Copernicus atmospheric core service (MACC-I/II), the GMES air quality downstream service (PASODOBLE) and the GMES/Copernicus volcanic observatory (EVOSS).

BIRA-IASB coordinates the EU FP7 project Demonstration Network Of ground-based Remote Sensing Observations (NORS) in support of the Copernicus Atmospheric Service (Nov. 1, 2011 – Oct. 31, 2014). The project aims at providing NDACC data on a rapid delivery basis (less than 1 month after acquisition) for the validation of the MACC-II products (and in the future the operational phase of the Copernicus Atmospheric Service products). A Web-based server at nors-server.aeronomie.be automatically generates validation reports on a daily basis. This service is used extensively for the validation of the MACC-II stratospheric ozone service products. The intention is to extend the validation tools to the validation of satellite data.

In the EU FP7 project QA4ECV (2014-2017), BIRA-IASB coordinates the development, implementation and application of a Quality Assurance system for atmospheric Essential Climate Variables (ECVs). This project aims at developing a robust generic system for the QA of satellite and in-situ retrieval algorithms and multi-decadal data records that can be applied virtually to all ECVs in a prototype for future sustainable services in the frame of the GMES/Copernicus Climate Change Service. Multi-use tools and SI/community reference standards are being developed. More details on http://www.qa4ecv.eu/

1.4.3 University of Liège (ULg)

Calibration of the Jungfraujoch FTIRs is performed according to NDACC recommendations, in order to characterize the instrument performance and stability. This is done by regularly recording HBr cell measurements. Also, N₂ (whose vertical distribution and concentration are well known) absorption features are further used to check the instrumental consistency, in particular for time periods for which regular cell measurements are unavailable.

1.4.4 Université Libre de Bruxelles (ULB)

The ULB has become participant in the O3MSAF activities in CDOP2, from 2012. In this framework, it plays a key role in the implementation of algorithms (including for ozone) at the EUMETSAT Central Application Facility, and on the quality assurance of the retrieved products. For ozone this includes comparison with the processing chain operating in parallel at ULB, and collaboration with validation partners.

The ULB will strengthen its calibration/validation activities within the O3-CCI project for which the generation of a consistent long-term time series of ozone profile is the major requirement. This will be further reinforced by dedicated calibration activities in the frame of the EU-QA4ECV project.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 The Royal Meteorological Institute (RMI)

Research evolution of total atmospheric ozone and its distribution versus altitude at northern mid-latitudes, in particular above Belgium revealed a mean temporal decrease in ‘good’ ozone in the stratosphere and an increase in ‘bad’ ozone in the troposphere. With the help of model calculations it was shown that both changes are primarily of anthropogenic origin. Further observations in Uccle (Brussels) showed that observed levels of harmful UV-B irradiance at ground level anti-correlate with levels of stratospheric ozone. Initiatives have been taken to warn the general public about health risks resulting from excessive exposure to the sun in summertime.

The figure below shows the time evolution of the ozone column over Uccle based on the combined data of the Dobson (1971-1989) and the Brewer Instruments (1990-now). The ozone column decreased with 3% per decade in the period 1980-1997 and then there is possible sign of recovery.
afterwards, although the period is too short to draw firm conclusions. The ozone soundings have shown us that the decrease occurs in the lower stratosphere, especially during winter and early spring. In the troposphere, on the contrary, the ozone concentrations tend to increase due to photochemical reactions in polluted air.

The first ozone measurements at the Antarctic Station princess Elisabeth (January and February 2011) are reported to the WOUDC.

![Figure 1: running annual mean of total ozone (in Dobson Units) from Dobson and Brewer spectrophotometers at Uccle, together with a stepwise regression. The times of major volcanic eruptions, affecting the ozone layer are also indicated.](image)

The ozone sonde stations at Uccle (Belgium) and De Bilt (Netherlands), separated by only 175 km, offer a unique opportunity to test the influence of different ozone sonde types and different correction strategies, as well as to detect the presence of inhomogeneities in the ozone sonde time series resulting from changes in sounding equipment (solution, radio sonde, ozone sonde, interface, sounding software, etc.). In particular, we highlighted a 2.5 year period (beginning of 2007 to mid-2009) of anomalous high tropospheric ozone values measured by ozone sondes at Uccle and compare these with the observations from De Bilt. Because the ozone deviations were only observed in the free troposphere where ozone concentrations are relatively low, and not in the boundary layer or the stratosphere, this issue is directly related to the sensitivity of ozone sondes. Therefore, the effect of every instrumental change, even though small, during this 2.5 year anomalous period was analysed considering a change in the radio sounding equipment, different ozone sonde batches, operational differences at the stations, differences on ascent and descent during the anomalous period; an environmental cause is also examined.

Unfortunately, one single, specific cause for the observed high tropospheric ozone values at Uccle could not be identified. There are two explanations consistent with the observations and not ruled out by the analysis: 1) the majority of the ozone sondes used at Uccle between March 2007 and August 2009 needed longer conditioning of their sensors and, therefore, behaved more accurately at low ozone concentrations during their descent or when used a second time, and 2) an
environmental origin arising from a local difference in the air mass between Uccle and De Bilt and between the ascent and descent.

2.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

2.2.1 Trend studies of ozone and ozone-depleting substances

- BIRA-IASB studies trends in the vertical profile of O₃ above Europe, in various layers in the atmosphere, based on NDACC FTIR observations (Vigouroux, C. et al., 2008; contribution to WMO Scientific Assessment of Ozone Depletion: 2010.). An updated trend analysis up to end of 2013 and including also stations outside Europe was carried out in the frame of the SPARC/IO3C/WMO-IGACO/NDACC (SI²N) initiative on past changes in the vertical distribution of ozone. It will be published in the SI²N Special Issue of ACP/AMT/ESSD (Vigouroux et al., 2014, http://www.atmos-chem-phys.net/special_issue284.html) and included in the 2014 WMO Scientific Assessment of Ozone Depletion.

- Characterisation and documentation of the long-term stability of ozone data records is a prerequisite to accurate ozone trend studies. In support to the SPARC/IO3C/WMO-IGACO/NDACC (SI²N) initiative on past changes in the vertical distribution of ozone, BIRA-IASB investigates the accuracy, mutual consistency and potential drifts of about fourteen satellite ozone profilers having provided, all together, ozone profile data records from 1984 to 2013. The study is based on the integrated use of GAW-contributing ground-based network data as a reference (WOUDC, NDACC, SHADOZ). BIRA-IASB also ensures the coordination of the SI²N overview paper reporting on data quality aspects. The results will be published in the SI²N Special Issue of ACP/AMT/ESSD (Hubert et al., 2014; Lambert et al., 2014, http://www.atmos-chem-phys.net/special_issue284.html) and contribute to the preparation of the 2014 WMO Scientific Assessment of Ozone Depletion.

- BIRA-IASB coordinates ESA’s CCI Ozone project, in which it contributes to the refinement of total ozone retrieval algorithms in view of producing homogenised total ozone data records from all European UV-visible nadir satellites: GOME, SCIAMACHY, GOME-2A, OMI, GOME-2B... A homogenised total ozone data record from GOME, SCIAMACHY and GOME-2A has been produced and published (Lerot et al., 2014), enabling accurate total ozone trend studies over 1995-2013 to be published in the coming year.

- BIRA-IASB studied trends of stratospheric BrO at several NDACC stations and verified the consistency with the observed trends from SCIAMACHY. BrO is decreasing since 2001 at a rate of about -1%/year (Hendrick et al., 2008 and 2009).

- BIRA-IASB has contributed with HCl and HF measurements at La Réunion to a study of the inorganic chlorine and fluorine trends on a global scale, involving all NDACC Infrared Working Group members (Kohlhepp et al., 2012).

2.3 University of Liège (ULg)

The Jungfraujoch FTIR observational data set from ULg now covers 30 years. It is the longest available worldwide and hence is particularly appropriate for trend determination investigations. We summarize here below a selection of relevant and recent results.

Since the mid-1980s, ULg has maintained the consistent monitoring of the vertical column abundances of HCl and ClONO₂, which are the main inorganic Cly reservoirs in the stratosphere. Their sum shows that the rate of increase of Cly has progressively slowed down during the early-1990s, and stabilised in 1996-1997, in response to the amended production regulations on O₃-depleting substances by the Montreal Protocol. Since then, the Cly loading has shown a slow but statistically significant decrease (-1.1%/yr.) over the 1997-2007 time period, which is commensurate with the organic chlorine decrease in the troposphere when accounting for a mixing time of about 3-4 years. However, more recent Jungfraujoch data show an unexpected and significant increase in HCl over 2008-2011, with a rate of change of + (2.0±0.5) %/yr. (2σ). This is confirmed in sign and amplitude by ACE-FTS occultation measurements at northern mid-latitudes (Mahieu et al., 2013).
The check of the evolution of anthropogenic chlorine-bearing source gases such as CFC-11, CFC-12 and CCl4 demonstrates the efficiency of the amended Montreal Protocol. Significant rates of decrease are determined for these three first source gases. In contrast, HCFC-22 and HCFC-142b whose (partial) regulation started later on are still on the rise (+4.3 ± 0.1 %/yr. for HCFC-22; +6.5±0.5 %/yr. for HCFC-142b; 2σ over 2000-2012).

Recent trend values computed over the 1995-2010 time interval indicate very small or non-significant (at 2σ) recovery of stratospheric ozone for the three stratospheric partial column time series accessible to the FTIR technique (altitude ranges from 12 to 20 km, 20 to 28 and 28 to 48 km). Trend derived from the total column data set amounts to (+0.10 ± 0.06) %/yr.

Measured rates of increase of the major radiatively active gases that are to be controlled under the Kyoto Protocol are: for CO2, an average of 0.49 %/year over the 1984-2010 period; for CH4, a series of contrasted changes, with in particular a trend of 0.36 %/yr. in 1995-1999, 0%/yr. in 2000-2004 and a re-increase since then (0.2 %/yr. in 2005-2012); for N2O, an average of 0.28%/year from 1984 to 2009; for SF6, a substantial increase of still more than 4 %/yr. over 2004-2010; for CF4, a continuous accumulation close to 1%/yr. since the early 2000s (Mahieu et al., 2014).

2.4 Université Libre de Bruxelles (ULB)

In the last years The ULB has been involved in the monitoring of global ozone distributions using IASI, both in terms of columns and vertical profiles. Time series are available from 2008 onwards. The ozone products – columns and profiles – have first been analysed and compared to other available means (for total columns see Anton et al. 2011 and for profiles e.g. Dufour et al., 2012). Biases have been identified (e.g. in the UTLS wrt to ozone sondes or on the total column wrt to the UV sounding instruments) but the reasons for them is not yet clearly understood and will need further investigations. In the last years the comparisons have been extended to the study of the Polar Regions, for the stratosphere and the troposphere (Scannell et al., 2012, Gazeaux et al., 2013, Pommier et al., 2012)

The first trends of the Antarctic ozone hole have been obtained and the ability of IASI to capture the vertical structure of the ozone hole has been looked at (Scannell et al., 2012). The time series of O3 at various altitudes over the stratosphere and the troposphere have been investigated over 6-years, as discussed in section 3.4.5 below (Wespès et al., in preparation).

Many efforts were devoted to tropospheric O3, including the study of transport, and the relation with precursor emissions (Wespès et al., 2012, Parrington et al., 2013; Safieddine et al., 2013).

3. THEORY, MODELLING, AND OTHER RESEARCH

3.1 The Royal Meteorological Institute (RMI)

The Brewer data have been analysed for aerosol information in the UV. These AOD data at 320 nm are available now (Cheymol and De Backer, 2003). Special measurements with Brewer 178 (and later also with Brewer 100 in Antarctica) were started to measure also the AOD at 340 nm (De Bock et al, 2010).

RMI is also partner in the BACCHUS project. The aim of the RMI contribution is to run the Canadian regional model for Chemical composition (including ozone) over Europe.

3.1.1 Satellite data validation and characterisation

RMI is partner in the Ozone SAF (Science application facility) of EUMETSAT. The main task here is the validation of the ozone profiles retrieved from satellite observations.

3.1.2 Trend studies

A study on the effect of trends in ozone and aerosol content of the atmosphere on the trend of UV radiation received at the Earth’s surface is undertaken in the frame of the BELSPO project AGACC-II.
3.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

3.2.1 Modelling

- Complete 3D modelling of the stratosphere, including transport, chemistry, aerosol microphysics and a heterogeneous chemistry module.
- Chemical 4D variational data assimilation (BASCOE), in particular of stratospheric O$_3$ and related species (http://bascoe.oma.be).
- Development and maintenance of the MACC-II Stratospheric Ozone Service (http://macc.aeronomie.be), delivering in NRT global analyses of stratospheric ozone and related key species.
- 1D box model for process studies, and for interpretation of UV-Visible DOAS observations.
- Studies based on 3D model IMAGES for the troposphere and UT/LS boundary region
- Development of inverse tropospheric modelling methods, to identify emissions (e.g., for CO, NOx, tropospheric ozone precursors, …)

3.2.2 Laboratory experiments

- Spectroscopic studies in support of remote sensing experiments (optical spectroscopy, ion chemistry for mass spectrometry applications…)
- Spectroscopic studies in support of investigations concerning global warming issues.
- Radiometric calibration for UV monitoring instruments.
- Studies of reaction pathways and kinetics of atmospheric species, using mass spectrometry.

3.2.3 Instrument developments

- MAXDOAS instruments and associated data analysis algorithms; The MAXDOAS technique has the capability of determining vertical distributions in the troposphere and low stratosphere.
- Optimisation of the FTIR observations for achieving higher-quality measurements, in particular improved solar tracking technique; adaptation to combined NDACC and TCCON measurements.

3.2.4 Ground-based data retrieval algorithm developments

- Use of inversion algorithms (using the Optimal Estimation Method) for ground-based DOAS and FTIR remote sensing spectral data, for the retrieval of the vertical distribution of absorbing atmospheric constituents. The algorithms allow the retrieval of vertical profile information from the ground-based DOAS and FTIR spectra, at low vertical resolution (worse than 5 km), for e.g., NO$_2$, O$_3$, HNO$_3$, HCl, … For the FTIR data this approach has been optimised for some target species in the EC project UFTIR (Feb. 1, 2003 – July 31, 2005) coordinated by BIRA-IASB. Tikhonov regularisation and Information Operator Approach have also been implemented as alternative inversion algorithms for FTIR measurements; in some cases, these approaches improve the robustness of the retrievals.
- In the frame of the NDACC Infrared Working Group (IRWG), in the period 2006-2013 when a BIRA-IASB member was Co-chair, work has been done to homogenize the retrieval strategies across the network.
- In the frame of NORS and the NDACC IRWG, a large effort has been carried out to develop harmonised error budget evaluations for the FTIR data products and to implement tools for their evaluation in the standard FTIR processing code SFIT-4. SFIT-4 is now in its test version.
3.2.5 Satellite data retrieval algorithm developments

- Development, validation and implementation of satellite data retrieval algorithms for ERS-2 GOME, Envisat SCIAMACHY, MetOp-A GOME-2 and MetOp-B GOME-2 total O$_3$, NO$_2$, BrO, HCHO, SO$_2$...; data processing and dissemination.
- Development, validation and implementation of satellite data retrieval algorithms for aerosols and trace gases from GOMOS.
- Development of retrieval algorithms for IASI/MetOp for aerosols and CH$_4$.

3.2.6 Satellite data validation and characterisation

- Continuous contributions to the geophysical validation of satellite data for O$_3$, NO$_2$, CH$_4$, CO, N$_2$O... (GOME, SCIAMACHY, GOMOS, MIPAS, ACE-FTS...) using independent ground-based network data, collected from NDACC, WOUDC and SHADOZ. These activities will be extended to upcoming missions like the Copernicus Sentinel-4 and Sentinel-5 (UVN and IASI-NG instruments) and their precursor Sentinel-5p TROPOMI.
- A multi-purpose simulator of global measurement systems for atmospheric composition has been built at BIRA-IASB: OSSSMOSE (Observing System of Systems Simulator for Multi-mission Synergies Exploration). This versatile environment provides realistic simulations of the output of real and hypothetical global observing systems and of their data comparison. It combines various state-of-the-art components, such as multi-dimensional observation operators mapping in 2D/3D the real sensitivity of a measurement system to atmospheric gradients, cycles and trends. OSSSMOSE can be used to investigate and quantify smoothing and sampling properties of ozone measurement systems and of their data comparison, and it has been applied with success to the validation of Envisat and MetOp to close the error budget of data comparisons (e.g., Cortesi et al., 2007; Lambert et al., 2012; Verhoelst et al., 2012). It can also be used for optimisation studies and gap analysis of measurement systems.
- Development of climatologies of some stratospheric species like BrO and NO$_2$.

3.3 University of Liège (ULg)

Most of the research activities reported in the previous Ozone Research Managers Report (2002, 2005, 2011) are continuing.

3.1.1 Satellite data validation and characterisation

ULg has been involved in numerous satellite validation studies over recent years (e.g. SCIAMACHY, MIPAS, and MOPITT). In particular, ULg has been strongly involved in the calibration/validation of ACE data products (O$_3$, N$_2$O...), leading the validation for HCl, HF, CCl$_2$F$_2$ and CCl$_3$F.

3.3.2 Instrument developments

Since more than two years, a remote control system has been in control of the Jungfraujoch Bruker instrument, allowing to complement the observations performed locally and to maximize the observation time. The system is perfectly working despite the challenging harsh meteorological conditions encountered at the Jungfraujoch; it has already undergone numerous evolutions to improve reliability and determination of the instrument status.

In parallel, we have been developing a new acquisition system that, along with total integration inside the remote control system, will provide improved signal to noise ratio and instrument throughout as well as the capacity to implement new digital processing methods, leading to enhanced spectrum quality, improved line shape and therefore better vertical distribution determinations.
3.3.3 Trend studies
Numerous relevant long-term trend studies have been performed over the period under review here, on the basis of Jungfraujoch ground-based data (see e.g. section 2.2) or using satellite products (inorganic chlorine and fluorine, organic chlorine and fluorine, source gases relevant to ozone (N₂O, CH₄)...

3.4 Université Libre de Bruxelles (ULB)

3.4.1 Laboratory experiments
The “Service de Chimie Quantique et Photophysique” has established expertise in the measurement of accurate absorption line parameters (positions, intensities and widths) for atmospheric trace gases in the infrared (far-, mid- and near-) and visible ranges, using high-resolution Fourier transform spectroscopy. Analysis of spectra is carried out using software written in the laboratory. The contribution of ULB to international spectroscopic databases remains at the forefront.

3.4.2 Retrieval algorithm developments
The group has acquired a leading position for the atmospheric radiative transfer modelling in the thermal infrared and also for the development of atmospheric trace gases retrieval methods. It owns and maintains sophisticated algorithms, for research and operational applications in atmospheric chemistry and physics. They include:

- The Atmosphit line-by-line radiative transfer model, which allows simulation of spectra recorded under various geometries and/or with different instruments. Accurate and versatile, it has been used in most studies prior to IASI launch, and for IASI local analyses. A module using an advanced doubling-adding method to account for multiple scattering was coupled to Atmosphit, allowing simultaneous retrieval of gas and aerosol properties.

- The FORLI series of software specific to IASI (Hurtmans et al., 2012). These rely on fast radiative transfer calculations using look-up-table (LUT) approaches. The LUT compile absorbance spectra, pre-calculated on a given spectral range and on well-defined temperature/pressure/humidity grids. FORLI versions are currently in place for O₃, HNO₃ of particular for stratospheric sounding, and in addition NH₃ and CO. The FORLI series allow NRT processing of the huge IASI data flow to provide global distribution of concentrations twice daily. FORLI-CO, FORLI-O3 and FORLI-HNO3 will become the operational processor for IASI after their implementation at EUMETSAT-CAF following the agreement signed under the O3MSAF-CDOP2

- Radiance indexing schemes for IASI, which are used to track a reactive species, among which SO₂, CH₃OH, HCOOH, and aerosols, including volcanic ash (e.g. Clarisse et al., 2012 and 2013; Van Damme et al., in preparation).

3.4.3 Satellite data retrievals

- Development, upgrade and maintenance of a NRT IASI processing chain. Processing starts with the receiving of the calibrated L1C radiances from Eumetcast, which are transformed in suitable format and quality-flagged using available ancillary information (e.g. cloud coverage). The retrievals are performed on a cluster of PCs, which currently has 190 CPU’s and 24TB of storage capabilities. Retrieved products from FORLI include O₃, HNO₃, CO and NH₃ profiles on the global scale (cloud-free data). Additional products from the offline processing are based on the calculation of hyperspectral radiance indices for several reactive species, which are converted to columns using appropriate look-up-tables.
### 3.4.4 Satellite data validation and characterisation

- Contribution to the validation activities of IASI and ACE-FTS chemistry products, in particular CO and O₃ but also (on-going) NH₃, HNO₃, CH₃OH.
- Continued cross-comparisons between satellites, in particular CO and O₃
- Contribution to the validation activities of IASI chemistry products, in particular CO and O₃ but also (on-going) SO₂, NH₃, HNO₃, CH₃OH.
- Continued cross-comparisons between satellites, in particular CO and O₃

### 3.4.5 Trend studies

- The time series of O₃ at various altitudes over the stratosphere and the troposphere have been investigated by fitting constant, annual and semi-annual terms, solar flux (SF) and quasi biennial oscillation (QBO) proxies to the IASI time series (Wespès et al., in preparation). The ozone time development estimation (“trends”) has been quantified based on the six full years of the IASI observation in four selected layers. The results suggest interestingly a significant positive trend in the upper stratosphere possibly pointing out a recovery of upper stratospheric ozone while a significant negative trend is observed in the troposphere in the mid-latitudes of the N.H. during the summer, probably linked to decreased emissions of ozone precursor.

![Figure 2: Five years’ time series of ozone vmrs from IASI, looked at separately in the stratosphere, the UTLS and the troposphere (Wespès et al., in preparation)](image)

- First time-series of HNO₃ in the troposphere and the stratosphere have been gathered and first analyses performed
- Time series of SO₂ and volcanic ash from volcanic eruptions have been obtained (Clarisse et al., 2012).
• First time series for CO columns from IASI and contribution to a decadal record by combination to MOPITT data (Worden et al., 2013). These activities will be strengthened in the frame of the EU-FP7 QA4ECV project.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

4.1.1 The Royal Meteorological Institute (RMI)
The ozone data (columns and profiles) are regularly deposited in the WOUDC of WMO. Uccle is also affiliated to NDACC. Therefore the data are also made available in that network. In near real time the data are also distributed via NILU, where the data can be used for campaigns (e.g. Match campaigns to determine ozone losses in the polar and sub polar winter atmosphere, see Streibel et al, 2005). The data are also stored and used in databases for the validation of satellite data (ENVISAT and EUMETSAT). Total ozone values are exchanged daily with the WMO ozone mapping centres in Canada and Greece for the production of daily ozone maps. The ozone profiles corrected according to the recommendations of the O3S-DQA activity are also distributed to this panel.

4.1.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)
NDACC FTIR and UV-visible (MAX)DOAS data are submitted on a regular basis to the NDACC Data Host Facility (DHF) established at NOAA NCEP (http://ndacc.org) Key data and results will be reported in the WMO Scientific Assessment of Ozone Depletion: 2014 and the SI2N joint special issue of ACP, AMT and ESSD.

Spectral UV data are available from http://ulisse.busoc.be/

4.1.3 University of Liège (ULg)
Time series of NDACC-relevant molecules (e.g., HCl, ClONO2, HF, COF2, HNO3, NO2, NO, O3, CFC-12, HCFC-22) from 1989 onwards are being archived routinely at the NOAA Data Host Facility (Washington, DC, USA), with the ozone data mirrored to the WOUDC archive in Toronto. Pre-1989 data are available upon request. More and more data are now also available in hdf file archives which provide the available vertical information on the retrieved products.

In addition, important results deduced from Jungfraujoch observations have been included in successive editions of the scientific assessment of ozone depletion (UNEP/WMO), with ULg scientists involved as co-author or contributors in all recent volumes. This remains true for the upcoming report (WMO2014).

4.1.4 Université Libre de Bruxelles (ULB)
• Dissemination in scientific literature
• IASI CO distributions of profiles are distributed in NRT to ECMWF in the frame of GMES atmosphere service MACC (http://www.gmes-atmosphere.eu/) (Inness et al., 2013). The data are also archived at the French ETHER datacenter (http://ether.ipsl.jussieu.fr) and available upon request. O3 distributions have been distributed for preliminary validation to a series of research groups. They are now similarly available upon request.
• Future operational dissemination of the IASI CO, O3, HNO3 and SO2 products from IASI will occur within the O3SAF (data to processed at EUMETSAT-CAF and disseminated through EUMETCAST system). This will start in 2015 with CO and SO2, followed by O3 and HNO3 in (tentative years) 2016.
• Archives of O3 profiles will be generated in the frame of the O3-CCI and made available to the community.
• Spectroscopic information obtained by the “Service de Chimie Quantique et Photophysique” is disseminated through various channels.

4.2 Information to the public

4.2.1 The Royal Meteorological Institute (RMI)
Daily UV forecasts are produced and disseminated with the weather forecasts. They are also available at the internet (www.meteo.be).
Ozone and UV data of Uccle were also used in yearly reports on the environment (successive MIRA reports).

4.2.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)
Relevant information is available on different web pages hosted by BIRA-IASB:
• UV radiation and indexes monitoring: http://uvindex.aeronomie.be
• NORS leaflet: http://nors.aeronomie.be
• AGACC brochure: http://agacc.aeronomie.be
• NDACC Satellite Working Group website, with catalogues and relevant information on atmospheric composition satellites: http://accsatellites.aeronomie.be

BIRA-IASB publishes press releases on ozone related subjects and activities, including:
• The Franco-Belgian space instrument SOLAR / SOLSPEC celebrates its five years in space (04.04.2013)
• Live UV index in Antarctica (31.01.2013)
• New Belgian instruments for solar measurement in Antarctica (07.12.2012)
• Official inauguration of measurement station in the Indian Ocean (29.10.2012)
• European Metop-B satellite launched (21.09.2012)
• Ozone layer stabilized, but large depletion in the polar regions continues to occur (16.09.2012)

BIRA-IASB contributes to WMO Antarctic Ozone Bulletins and WMO Arctic Ozone Bulletins (http://www.wmo.int/pages/prog/arep/gaw/ozone).

BIRA-IASB disseminates relevant information to the public through lessons and seminars in most of the major Belgian universities, through large public events like the Annual Open Doors organised at BIRA-IASB premises, through participation in public exhibitions at the Planetarium in Brussels and the Euro Space Centre in Redu.

4.3 Relevant scientific papers

4.3.1 The Royal Meteorological Institute (RMI)
Papers since 2011 (after those included in the previous report) are mentioned. Authors affiliated to RMI are in bold.
Peer reviewed:


Proceedings:

WMO, GAW Report No. 201, Quality Assurance and Quality Control for Ozonesonde Measurements in GAW, prepared by Prepared by Herman G.J. Smit and the Panel for the Assessment of Standard Operating Procedures for Ozonesondes (ASOPOS), September, 2011. (report)

Andy Delcloo and Olaf Tuinder, Validation of GOME-2 ozone profiles, using balloon sounding data, EUMETSAT Meteorological Satellite conference, 4-9 September, 2011, Oslo, Norway.(proceeding)

Andy Delcloo, Daniel Hurtmans, P-F Coheur, C Clerbaux, Validation of IASI ozone profiles, using balloon sounding data, EUMETSAT Meteorological Satellite conference, 4-9 September, 2011, Oslo, Norway.(proceeding)


4.3.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

Peer-reviewed papers and books (Ordered alphabetically, publications from 2009 to 2013, authors from BIRA-IASB in bold):


Lambert, J.-C., MACC Validation Protocol, Peer-reviewed Technical Note, EC FP7 Monitoring Atmospheric Composition and Climate (MACC), FP7-MACC-MAN-3-4, Version 1, 47 p., 11 October 2010.


4.3.3 University of Liège (ULg)

(Peer review publications from 2007 onwards, ordered alphabetically. A list including all types of publication is available from the ULg electronic repository via this link)


4.3.4 Université Libre de Bruxelles (ULB)

Relevant peer-reviewed papers (Ordered alphabetically, publications from 2011 to 2013)


5. PROJECTS AND COLLABORATION

5.1 Participation in national and international other collaborations projects

5.1.1 The Royal Meteorological Institute (RMI)

- Belgian federal research programme Scientific Support for Sustainable Development: AGACC and AGACC-II: Advanced exploitation of ground based measurements for atmospheric

- COST Action ES0604 on Water Vapor and climate (WAVACS)
- COST Action ES1207: A European Brewer Network
- Satellite validation projects of ESA and Eumetsat.
- Prodex Project Bacchus (2010-2013)
- Belgian federal science policy: Belatmos project for monitoring of atmospheric composition at the Belgian Antarctic Base (2008-2012)
- Solar Terrestrial centre of Excellence (recurrent support of the ozone research programme)
- Participation in the validation team of the Ozone monitoring SAF of EUMETSAT

5.1.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

- IPCC assessments, WMO Stratospheric Ozone assessments and SPARC/IO3C/IGACO/NDACC (SI2N) vertical ozone trend assessments.
- 7th Framework Programme of the European Commission MACC, MACC-II, PASODOBLE, SHIVA, EVOSS, NORS, QA4ECV.
- ‘Chemistry and climate related studies using the IASI remote sensor’ for preparing the scientific research aspects of the IASI mission on board METOP-A’
- Involved in a dozen science and processing teams of satellite missions, e.g. SCIAMACHY SSAG, SCIIVALIG, and SADDU.
- ESA’s Envisat Atmospheric Chemistry Validation Team; ESA’s Quality Working Groups; ESA Multi-TASTE (2008-2012) and Multi-TASTE Phase F (2014) validation support to Envisat atmospheric data evolution.
- ESA Climate Change Initiative Aerosol project (http://www.esa-aerosol-cci.org/) for which the second phase starts in spring 2014
- ESA Sentinel-5 Precursor Level 2 Processor Component Development project (2012-2015)

5.1.3 University of Liège (ULg)

- Atmospheric Composition, Chemistry and Climate (A3C), PRODEX contract, 2010-2013.
- Contract FNRS FRFC (Observations and study of the variability and evolution of the free atmosphere from the Jungfraujoch International Scientific Station)
• F.R.S. – FNRS research project, Improvement of the FTIR spectroscopy instrumental technique in the framework of continued observations and characterization of the Earth atmosphere from the Jungfraujoch, 2013-2016.

• Project: GAW-CH (FTIR measurements at the Jungfraujoch 2010-2013)
• Project GAW-CH 3 (FTIR measurements at the Jungfraujoch 2014-2017)
• Project: EC-GEOMON (Global Earth Observation and Monitoring; 2007-2011)
• Project EC-NORS (Demonstration Network of Ground-based remote sensing observations in support to GMES atmospheric service; 2011-2014)

5.1.4 Université Libre de Bruxelles (ULB)
• Support to Aviation Control Services (SACS+), ESA, 2009-2012
• European Volcano Observatory Space Services (EVOSS), EU-FP7, 2009-2013
• Atmospheric Composition, Chemistry and Climate (A3C), ESA/Prodex, 2010-2013
• Effects of Climate Change on Air Pollution and Response Strategies for European Ecosystems (ECLAIRE), EU-FP7, 2011-2015
• Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (O3MSAF), EUMETSAT, 2012-2017
• Support to aviation Control Service 2 (SACS2), ESA, 2012-2013
• The synergetic SWIR and IR retrievals of near-surface concentrations of CH4 and CO for Earth and Planetary atmospheres (SIROCCO), ESA, 2012-2013
• IASI.Flow: Infrared Atmospheric Sounding with IASI and Follow-on missions, ESA-Prodex, 2014-2015
• B-O3MSAF, Belgian Contribution to the O3MSAF activities, ESA-Prodex, 2014-2015
• EU-FP7 PANDA, PArtnership with chiNa on space DAta, 2014-2017
• EU-FP7 QA4ECV, Quality Assurance system for Essential Climate Variables, 2014-2018.

5.2 Representation in international organisations

5.2.1 The Royal Meteorological Institute (RMI)
• EUMETSAT Scientific and Technical Group, Policy Advisory Committee and Council
• Domain Committee ESSEM van COST [http://www.cost.eu/domains_actions/essem](http://www.cost.eu/domains_actions/essem)
• Management Committee of COST ES1207: A European Brewer Network
• Brewer sub-committee of WMO-GAW
• EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring (Steering Group member)
• Participant in the SI2N O3S-DQA activity

5.2.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)
• International Ozone Commission (IO3C) of the IAMAS-IUGG.
• WMO GAW NDACC Steering Committee: Co-chair (since Nov. 2013), Co-chair of the Satellite WG (since 1999), Co-chair of UV-Visible WG (since 2003), and Co-chair of the IR WG (since 2006 until mid-2013)
• WMO GAW UV-SAG.
• WCRP SPARC.
• Committee on Earth Observation Satellites (CEOS): Participation in Working Group on Cal/Val (WGCV) and in Atmospheric Composition Constellation (ACC).
• Working Group on Cal/Val Infrastructure.
• Science Advisory Group of GOME and GOME-2, GOMOS, SCIAMACHY, and OMI.
• ESA Council, EUMETSAT Council.
• International Committee on Space Research (COSPAR).
• Member of the Science Team of the Canadian ACE/SciSAT mission, of the EOS-Aura OMI International Science Team…
• EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring.
• Mission Advisory Groups of S-5p TROPOMI, Sentinel 4 and Sentinel 5.
• Member of the MACC-II, PASODOBLE, NORS and QA4ECV Management Board.

5.2.3 University of Liège (ULg)
• ACE science team
• ISSJG (International Scientific Station Jungfraujoch and Gornergrat) Astronomic Commission
• NDACC steering committee
• NDACC-Infrared working group
• PI contribution to Task Group 3 of ACCENT-TROPOSAT 2 (strategies for the validation of tropospheric products from satellites)

5.2.4 Université Libre de Bruxelles (ULB)
• Member of the Scientific committee of the “IASI Conference” series
• Member of the IASI Sounder Science Working Group–II
• Member of the ACE Science Team

6. FUTURE PLANS

6.1 The Royal Meteorological Institute (RMI)
• Continuation of the observations at Uccle (ozone column, ozone profile, Spectral UVB, aerosol) and at the Antarctic station (Ozone column, Spectral UVB and aerosol).
• Installation of a Ceilometer LIDAR in Uccle to monitor the aerosol backscatter in the troposphere.
• Analysis of the data obtained at the Belgian Antarctic station.
• Participation in the validation and quality assurance of satellite observations (O$_3$MSAF CDOP-2 of EUMETSAT and Ozone CCI of ESA).
• A thorough re-evaluation of ozone trends from the balloon ozone profile measurements, using several statistical techniques, is planned in the near future.
6.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

Ground-based measurements of ozone and other gases/variables relevant to ozone loss

• Initiative for Belgian-Brazilian networking, starting with the installation of an FTIR instrument at Porto Velho (Rondonia, Brazil), for NDACC and TCCON observations. The installation is planned in June 2014.

• Contribution to a 1-year intercomparison campaign (2014-2015) aiming at filling gaps in the TCCON Network, through the demonstration of smaller and cheaper, portable, spectrometers

• Extension of the BIRA-IASB NDACC-related monitoring activities at Reunion Island with the installation of a new UV-visible MAXDOAS instrument, planned for November 2014.

• Preparation of a large scale Sentinel-5 Precursor Cal/Val campaign in Bucharest, Romania planned to take place in summer 2016. This campaign will also include a formal NDACC UV-Vis Intercomparison exercise, and will be supported by instrumented aircraft observations.

• Development of a centralised and automated processing system for UV-visible MAXDOAS observations to be hosted at the ESA Cal/Val facilities, in support of multi-mission programmes.

Satellite-based measurements of ozone and other gases/variables relevant to ozone loss

• As a direct response to the recommendations from the 7th and 8th Ozone Research Managers Meetings, BIRA-IASB has developed the instrument concept of Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere (ALTIUS). This future instrument consists of a limb viewing atmospheric sounder designed to operate on board a micro-satellite like the PROBA platform. This instrument would combine the technique of limb scattering observation with an imaging capacity when operating on the day side. At the terminator and in the eclipse phase, the spectrometer would be used in solar and stellar occultation modes respectively. This instrument is designed to infer from UV-visible-NIR radiance measurements from the upper troposphere to the mesosphere the vertical distribution of ozone, NO\textsubscript{2}, BrO, CH\textsubscript{4}, H\textsubscript{2}O, OClO, aerosols and PSCs… BIRA-IASB is the PI of this instrument, which has now entered Phase B1 of its development.

• Tropospheric Monitoring Instrument (TROPOMI) to be launched in early 2016 as part of ESA’s Copernicus Sentinel-5 Precursor mission. This instrument will provide measurements of the troposphere down to the boundary layer and quantify emissions and transport of anthropogenic and natural trace gases and aerosols, which impact air quality and climate. BIRA-IASB is one of the key TROPOMI level-2 algorithm developers, being responsible for the prototyping of three important products: ozone, SO\textsubscript{2}, and HCHO.

• Continued participation and/or coordination of validation and quality assurance of satellite observations in the context of the EUMETSAT O3MSAF CDOP-2/3, ESA Multi-TASTE Phase F, ESA Ozone_cci, SCIAMACHY Quality Working Group Phase-F, and EU FP7 QA4ECV.

6.3 University of Liège (ULg)

The ULg group has accumulated a solid experience in the high resolution FTIR spectroscopy under high altitude harsh climatic conditions, including remote control operation. Based on this experience, in agreement with our long term development plans and fully in accordance the recommendations in the 7th Ozone Research Managers Meeting, ULg has obtained the authorizations (and is now seeking for the necessary funding) to install a remote controlled FTIR facility on the Atacama plateau (about 5100m ait), probably on the ESO APEX or ALMA premises. This location is ideal to characterize the composition of tropical air masses above South America, being a very dry site, free of air and electromagnetic pollution and providing abundant clear sky conditions. The local topology of the site is also ideal for satellite data validation and calibration of an otherwise FTIR uncovered area. It is also accessible for heavy equipment transportation. Of course, our plans include the continuation of the NDACC observations at the Jungfraujoch station and the application of the new acquisition system to all of our instruments.
6.4 Université Libre de Bruxelles (ULB)

On the remote sensing side, IASI-related activities will be strengthened. The NRT FORLI processing chain will be upgraded and is planned to be implemented shortly at the EUMETSAT CAF (Central Application Facility) for wider dissemination of the L2 products to the community. This should be done within the O3M-SAF. The group will pursue its activities around the preparation of future sounders, including the IAS on EPS-SG and IRS on MTG.

The group will foster activities with IASI in the context of chemistry and climate, including \( \text{O}_3-\text{HNO}_3 \) correlations in the troposphere; link to \( \text{O}_3 \) and precursor emissions in the troposphere, STE, \( \text{O}_3 \) long-wave radiative effect. The group will contribute to various international efforts for providing long-term quality-assured information on essential climate variables, e.g. in the frame of the O3-CCI and QA4ECV projects.

6.5 Princess Elisabeth Research Station

At the occasion of the International Polar Year 2007, the Belgian government decided to build a new scientific summer station at Utsteinen, East Antarctica and committed the International Polar Foundation to design and build this new base.

A Brewer ozone spectrophotometer was installed mid-January 2011 and was able to measure until 14 February 2011. It measured the total column amount of ozone and the UV radiation in the UV-A and UV-B bands. It was successfully set up for the first time. It was mounted on the northern roof of the station. It needs sun and regular maintenance for operation and was therefore de-installed at the end of the season. First analyses of the data show that it made very good and interesting measurements of total ozone and the UV index at Utsteinen.

7. NEEDS AND RECOMMENDATIONS

There is a need to secure financial support for laboratory spectroscopic activities supporting investigations of the terrestrial atmosphere.


8.1 Research Needs

8.1.1 The Royal Meteorological Institute (RMI)

In response to “Coupled chemistry-climate models (CCMs) are becoming more mature, but it is clear that more effort must be devoted to model development and validation.” (p 31, WMO report of the 8th session No. 53):

- At RMI a coupling between the chemical transport model CHIMERE and the numerical weather prediction model (Alladin) was performed.
- Within the BACCHUS project RMI works on the adaptation of the Canadian coupled transport/chemical GEMBACH model to Europe.

Chemistry Climate:

- At the Princess Elisabeth station in Antarctica, the RMI has installed different instruments aiming at characterising the polar aerosol and cloud properties (p 32, 8th WMO report). RMI will introduce a project, led by the KULeuven and in collaboration with partners from the modelling community, to exploit these measurements and compare them with model output.
Ultraviolet and Environmental Effects:

- An example of a support study that allow quantitative disaggregation of the factors affecting UV radiation at the surface (p 32, WMO report of the 8th session No. 53) is the study on the different contributions to the variations in UV intensities reaching the ground (see De Backer, 2009), which is currently updated (De Bock et al., 2014, in preparation)

8.1.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

Chemistry Climate:

- BIRA-IASB coordinates the Data Assimilation activity of the international programme Stratosphere/Troposphere Processes and their Role in Climate (SPARC).
- BIRA-IASB continuously improves its 4D-variational data assimilation system BASCOE and the chemical transport model associated with it, which includes detailed microphysics description. BASCOE is part of the GMES/Copernicus (MACC-I/II) Stratospheric Ozone Service.
- BIRA-IASB is the European leader of the BACCHUS project, and works on the adaptation of the Canadian coupled transport/chemical GEMBACH model to Europe.
- BIRA-IASB coordinates ESA’s CCI Ozone project (Phase I 2010-2013, Phase II 2014-2016) which aims at improving ozone data products from European satellites in order to provide harmonised ozone data records suitable for climate change studies. This project includes specific effort on the improvement of ozone profile data in the upper troposphere and lower stratosphere, to improve our evolving understanding of the coupling and exchange in this particular altitude region.

Underpinnings for Observations and Models
BIRA-IASB contributes to the ACSO effort on ozone absorption cross-sections.

8.2 Systematic Observations

8.2.1 The Royal Meteorological Institute (RMI)

Ground-based networks

- The balloonsonde measurements at Uccle (3 times a week) are maintained, and with respect to the specific suggestions (p. 34, WMO report of the 8th session No. 53), we note that:
  - The ozonesondes almost always reach the 30 km altitude
  - The simultaneously obtained water vapour profiles are archived and are available. As a matter of fact, the RMI published a study based on the corrected upper-tropospheric humidity profiles gathered with sondes (Van Malderen and De Backer, 2010).
- The two Brewer instruments at Uccle, measuring ozone and total UV, are maintained and are calibrated every 2 years.
- A Brewer instrument was installed in Antarctica, providing direct observations of polar ozone processes (p 33, WMO report of the 8th session No. 53).
- RMI actively participates in the COST action ES1207 EUBREWNET, which aims at creating an homogenized network of Brewer instruments (both in operating procedures and data processing) at the European level, in response to the fact that there are multiple calibration sites around the world within the Global UV Monitoring System that are not tied together sufficiently (p 35, WMO report of the 8th session No. 53).
Satellite Networks

RMI is a partner in the EUMETSAT O3SAF, and is responsible for the validation of the operational ozonesonde profiles and aerosol products of the GOME2 instruments on board of the meteorological satellites.

Consistency and Complementary of Data Sets and Re-Evaluation of Data Records

- RMI is a partner in ESA’s CCI Ozone project (Phase I 2010-2013, Phase II 2014-2016) which includes re-evaluation of ozone column/profile data records from European and American satellites in order to provide harmonised ozone data records suitable for climate change studies.
- RMI participates in the SI2N initiative with systematic data quality studies of past records on vertical ozone trends, in particular in the Ozonesonde Data Quality Assessment Working Group, and with studies of ozone variabilities and trends, using those ozonesonde data.

8.2.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)

Ground-based networks

- As recommended in the 8ORM report, efforts have been made to maintain operation of existing instrumentation, and to increase the use of more sophisticated instrumentation, mainly FTIR spectrometers and (MAX)DOAS UV-visible instruments. BIRA-IASB has continued operation of its FTIR and (MAX)DOAS UV-visible instruments which contribute to the NDACC and TCCON global monitoring networks. The instrument deployed previously in Beijing was moved to Xianghe, approximately 50 km East of Beijing.
- As recommended, BIRA-IASB has also deployed additional ground-based instruments in the Tropics: NDACC/TCCON certified FTIR instruments on Reunion Island (Indian Ocean), and NDACC certified (MAX)DOAS UV-visible instruments on Reunion Island and in Bujumbura (Burundi). Deployment of a new NDACC/TCCON FTIR instrument at Porto Velho in the Brazilian Amazonian forest is envisaged for summer 2014.
- In response to the need to give attention to systematic water-vapour-profile measurements, as it is a strong driver for decadal climate variability, BIRA-IASB has improved its retrieval algorithm for water vapour profile from FTIR spectrometers.

Satellite networks

- The work performed at BIRA-IASB on GOME/SCIAMACHY/OMI/GOME-2 total ozone retrieval algorithms is a response to the requirement to continue the key baseline set of solar backscatter UV observations. In particular, the development of the GODFIT direct fitting algorithm has led to improvements needed to expand capabilities at high latitudes and high solar-zenith angles (Lerot et al., 2014).
- In response to the need to give special attention to N₂O, as this gas is becoming one of the most important substances that can lead to ozone destruction, BIRA-IASB is involved in the development of a N₂O data product fromIASI.
- In anticipation of the upcoming gap in limb viewing satellites, BIRA-IASB has proposed the new satellite mission ALTIUS, a limb scattering and occultation satellite instrument addressing directly the 7ORM and 8ORM requirements for limb viewing observations of high vertical resolution profiles of ozone and key ozone related parameters that are critical for understanding the science behind changes in ozone in the context of changing climate. This instrument concept combines the technique of limb scattering observation with an imaging capacity when operating on the day side. At the terminator and in the eclipse phase, the spectrometer would be used in solar and stellar occultation modes respectively. This instrument is designed to infer from UV-visible-NIR radiance measurements from the upper troposphere to the mesosphere the vertical distribution of ozone, NO₂, BrO, CH₄, H₂O, OCIO, aerosols and PSCs… The mission has entered Phase B1 of its development.
Consistency and Complementary of Data Sets and Re-Evaluation of Data Records

- Work has been done at BIRA-IASB, in collaboration with ULg, about the consistency between data from different observational techniques, in particular for NO2 and HCHO from FTIR and UV-visible DOAS instruments.

- BIRA-IASB coordinates ESA’s CCI Ozone project (Phase I 2010-2013, Phase II 2014-2016) which includes re-evaluation of ozone column/profile data records from European and American satellites in order to provide harmonised ozone data records suitable for climate change studies.

- BIRA-IASB participates in the SI2N initiative with systematic data quality studies of past records on vertical ozone trends, and with studies of ozone variabilities and trends, using ground-based and satellite data.

- In response to the need to further develop methods and tools for a better-integrated use of complementary data with different scale, resolution etc., BIRA-IASB has developed the multi-purpose simulator of global measurement systems for atmospheric composition OSSSMOSE (Observing System of Systems Simulator for Multi-mission Synergies Exploration). This versatile environment combines various state-of-the-art components, such as multi-dimensional observation operators mapping in 2D/3D the real sensitivity of a measurement system to atmospheric gradients, cycles and trends. OSSSMOSE provides realistic simulations of the output of real and hypothetic global observing systems and of their data comparison. It can be used to investigate and quantify smoothing and sampling properties of ozone measurement systems and of their data comparison and it has been applied with success to the validation of Envisat and MetOp to close the error budget of data comparisons (e.g., Cortesi et al., 2007; Lambert et al., 2012; Verhoelst et al., 2012). It can also be used for optimisation studies and gap analysis of measurement systems.

8.2.3 University of Liège (ULg)

In accordance with the recommendation to expand the ground-based networks in accordance with scientific needs (p. 33 WMO report of the 8th session No. 53), ULg considers installing an FTIR instrument in Chile. Having obtained the authorizations and finalized the technical preparations to install a remote controlled FTIR facility on the Atacama plateau (about 5100m alt), probably on the ESO APEX or ALMA premises, ULg is now looking for the funding needed to buy the instrumentation and operate it on a regular basis.

Approaches allowing monitoring new relevant species with FTIR instruments have recently been developed and are now routinely applied. This is true for CCl4, CF4 and HCFC-142b.

Water vapor became another target of our long-term FTIR monitoring activities. Water vapor profiles are now regularly archived in hddf at the NDACC database.

8.2.4 Université Libre de Bruxelles (ULB)

Satellite networks

- Satellite retrieval techniques have been improved, as well as data dissemination to a variety of users

- Retrievals of aerosols from infrared nadir observations, including sulphates, have started.

- Efforts to harmonize datasets from various satellite sounders have started and this will be strengthen further in the coming years within European and International consortia

- Several studies focusing on the link between chemistry and climate have been undertaken.

8.3 Spectroscopic standards

At ULB the participation to international reference spectroscopic databases has been pursued.
8.4 Data Archiving

8.4.1 The Royal Meteorological Institute (RMI)
- The RMI archives the data regularly in the well-established network databases as WOUDC and NDACC.
- The RMI also submitted homogenized ozonesonde data to the database set up within the O3SDQA Working Group and will submit Brewer data to the database that will be created within the framework of the COST action ES1207 EUBREWNET.
- The raw data and metadata is also stored locally so that reprocessing of historical data is easily established.
- RMI is also partner is a national project aiming at setting up a metadata database which will be compliant with the EU INSPIRE Directive.

8.4.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)
- BIRA-IASB archives continuously the data acquired by its NDACC certified instruments into the NDACC Data Host facility (http://ndacc.org).
- In the frame of the EU FP7 NORS project, data archiving of NDACC observations has been accelerated for a set of pilot stations: for the NORS target species, data are now submitted within 1 day to 1 month after acquisition. In the future, procedures and tools that have been developed for this purpose will be extended to other NDACC key species.
- BIRA-IASB has also been the driver for the development, implementation and improvement of the GEOMS HDF formatting guidelines, in use in international data archives like the NDACC Data Host Facility and the Aura Validation Data Centre.
- BIRA-IASB has developed tools for the complete evaluation of the error budget associated with the FTIR data products. The uncertainty components are now systematically submitted in the HDF FTIR data files. Similar developments are on-going for UV-Vis data products.

8.4.3 University of Liège (ULg)
- ULg performs regular data archiving at NDACC
- As a participant to NORS, ULg is contributing to rapid delivery of data to NDACC (O₃, NO₂, CH₄ and CO), typically within 15 days after data acquisition

8.5 Capacity Building

8.5.1 The Royal Meteorological Institute (RMI)
The relocation of the unused Dobson instrument from Uccle to Kyev is explicitly mentioned on p 38 of the WMO report of the 8th session No. 53.

8.5.2 The Belgian Institute for Space Aeronomy (BIRA-IASB)
In the EU FP7 NORS project, coordinated by BIRA-IASB, there is a work package dedicated to capacity building. This includes: exporting knowledge and expertise acquired in NORS to new and NDACC candidate stations outside of Europe (of the order of 10 stations outside of Europe are being developed in this WP), and linking with the satellite community via representation at CEOS meetings. The non-European stations in this WP that are managed by BIRA-IASB are the stations at Xianghe (P.R. China) and Bujumbura (Burundi).
9. CO-ORDINATES OF BELGIAN INSTITUTES AND LEADING SCIENTISTS INVOLVED IN 
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Dr. Alexander Mangold (Measurements on the Princess Elisabeth Station Antarctica, MC member
of COST action ES1207 EUBREWWNET)
Dr. Roeland Van Malderen (Analysis of ozone time series, MC member of COST action ES1207
EUBREWWNET)
Dr. ir. Andy Delcloo (Validation of satellite ozone data, Member of project team of O3M SAF of
EUMETSAT)
Ms. Veerle De Bock (Retrieval of aerosol optical parameters from Brewer observations, MC
member and workgroup leader in COST action ES1207 EUBREWWNET))
Dr. Joris Van Bever (Modelling of chemical composition of the atmosphere within Bacchus)
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Dr. Jean-Christopher Lambert (Member of the International Ozone Commission, satellite and ground-based remote sensing of the atmospheric composition, synergistic exploitation of atmospheric composition data, data quality strategy, multi-mission satellite validation, member of EUMETSAT O3M-SAF project team, Co-chair of the NDACC Satellite Working Group, Vice-chair of the CEOS Working Group on Cal/Val / Atmospheric Composition Subgroup)

Dr. Michel Van Roozendael (Satellite and ground-based remote sensing measurements of the atmospheric composition, implementation and testing of retrieval algorithms to invert radiance observations into geophysical data, remote-sensing instrument developments, data validation, member of EUMETSAT O3M-SAF project team, coordinator of the ESA CCI O3 project, Co-chair of the NDACC UVVIS Working Group)

Dr. Quentin Errera (stratospheric modelling, chemical data assimilation, reanalysis of long-term atmospheric data records, leader of the SPARC Data Assimilation activity)

Dr. S. Chabrillat (stratospheric modelling, chemical data assimilation, chemical weather, Stratospheric Ozone Service of the GMES/Copernicus Core Atmosphere Service project MACC)

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BRAZIL - NATIONAL REPORT

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1. OBSERVATIONAL ACTIVITIES

The ozone layer observations by National Institute for Space Research (INPE) are made using a network of ground based spectrophotometers Dobson and Brewer types. We currently operate two Dobson at Natal and Cachoeira Paulista, and six Brewer in the sites: Natal, Cuiabá, Cachoeira Paulista, Santa Maria, La Paz (Bolivia) and Brazilian Antarctic Station Comte. Ferraz (table 1). In addition, ozone concentrations are also measured by the ECC sounding technique on balloons by participation in the SHADOZ Project (The Southern Hemisphere Additional Ozonesonde Network - http://croc.gsfc.nasa.gov/shadoz). A long term measurement program at Brazil has been operational since 1974. Special field campaigns have also been made at other sites, especially in Antarctica, Punta Arenas (Chile) and Rio Gallegos (Argentina). Biomass burning effects are observed by satellite and airplane for INPE. More recently, instruments to measure the UV-B radiation have been added to the network.

Table 1 – INPE’s NETWORK SPECTROPHOTOMETERS DOBSON AND BREWER

<table>
<thead>
<tr>
<th>SITE</th>
<th>LAT. (SOUTH)</th>
<th>LONG. (WEST)</th>
<th>DOBSON NUMBER</th>
<th>BREWER NUMBER</th>
<th>PERIOD and TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>NATAL, BRAZIL</td>
<td>5.84°</td>
<td>35.21°</td>
<td>093</td>
<td>110</td>
<td>1994-1998 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>073</td>
<td>1996-2004 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>056</td>
<td>2002-2004 Mark IV</td>
</tr>
<tr>
<td>Cuiabá, BRAZIL</td>
<td>15.3°</td>
<td>56.1°</td>
<td>-</td>
<td>081</td>
<td>1991-1997 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>110</td>
<td>1996-2004 Mark IV</td>
</tr>
<tr>
<td>La Paz, BOLIVIA</td>
<td>16.54°</td>
<td>68.08°</td>
<td>-</td>
<td>110</td>
<td>1996-2004 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2002-2004 Mark IV</td>
<td></td>
</tr>
<tr>
<td>Cachoeira Paulista, BRAZIL</td>
<td>22.88°</td>
<td>45.08°</td>
<td>114</td>
<td>124</td>
<td>1997 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2000-2006 Mark IV</td>
<td></td>
</tr>
<tr>
<td>Sao José dos Campos, BRAZIL</td>
<td>23.2°</td>
<td>45.86°</td>
<td>-</td>
<td>056</td>
<td>2000-2006 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>167</td>
<td>2003-2006 Mark III</td>
</tr>
<tr>
<td>Santa Maria, BRAZIL</td>
<td>29.26°</td>
<td>53.48°</td>
<td>-</td>
<td>056</td>
<td>1998-2006 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>056</td>
<td>2000-2002 Mark IV</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>124</td>
<td>2010-2012 Mark IV</td>
</tr>
<tr>
<td>Rio Gallegos, ARGENTINA</td>
<td>53.20°</td>
<td>70.90°</td>
<td>-</td>
<td>068</td>
<td>1992-2000 Mark IV</td>
</tr>
<tr>
<td>Punta Arenas, CHILE</td>
<td>62.1°</td>
<td>58.4°</td>
<td>-</td>
<td>068</td>
<td>Spring 2002-2010</td>
</tr>
</tbody>
</table>

Figure 1. Map of INPE’s NETWORK Spectrophotometers Dobson and Brewer.
1.1 Calibration activities

Five Brewer spectrophotometers were calibrated by International Ozone Services Inc. (IOS) in 2004, 2007 and 2009.

INPE participated in international calibration in 1994, in Spain, where the Natal Dobson (093) was shipped with our expert. In 1997, the expert Bob Evans, from NOAA, checked the Natal Dobson, on a visit to Natal, but did no adjustments in the instrument. Buenos Aires WMO Intercomparison was made in 2001, 2003, 2006 and 2010 with the participation of our two Dobson instruments.

Three GUV was calibrated in 2001, in São José dos Campos, Brazil, using standard instrument of Biospherical Instruments Inc. The GUV 9285 is operating in Natal, the GUV 9255, in Cachoeira Paulista and the GUV 9285, in Brazilian Antarctic Station. Nowadays, only one GUV is operational in São José dos Campos.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

2.1 Ozone Total Column Observations

2.1.1 Dobson spectrophotometers

Ground based ozone total column has been measured continuously at low latitude sites, using Dobson spectrophotometer at Natal (6° S, 35° W) and Cachoeira Paulista (23° S, 38° W). The ozone data from 1974 to 2012 for the two Dobson spectrophotometers are presented in the figure 2.

The ozone total column varies between 240 and 290 DU and shows large year variability. In the period from 1974 to 2000, the average is 266.5 DU with standard deviation about 10.5 at Natal and 269.3 DU with 12.9 of standard deviation at Cachoeira Paulista. In the period from 2000 to 2012, the average is 264.6 DU with standard deviation about 12.0 at Natal and average 265.3 DU with 14.0 of standard deviation at Cachoeira Paulista.

Figure 2. The figure shows 38 years data set of Dobson, obtained at Cachoeira Paulista and Natal, Brazil. The data are presented as monthly average (black line) and running mean of the 11 days (red line).
2.1.2 Brewer spectrophotometers

From data collected by ground and satellite installed equipments: instruments Brewer Spectrophotometer, TOMS (Total Ozone Mapping Spectrometer) and OMI (Ozone Monitoring Instrument), comparisons were made (TOMS-BREWER and OMI-BREWER) between these data. With the good correlation between these instruments, a single data series was created, in which were made and analyzed monthly averages between the periods from 1979 to 2011, showing the behavior of the ozone total column over the South of Brazil, Southern Space Observatory (Observatório Espacial do Sul - OES/CRS/CCR/INPE-MCTI, 29,42°S; 53,87°W), in São Martinho da Serra city (Crespo, N.M. et all, 2012), shown in figure 3.

![Figure 3](image.png)

**Figure 3.** The figure shows a new 38 years data set of the Brewer, TOMS and OMI, for Southern Space Observatory (Observatório Espacial do Sul), São Martinho da Serra, RS, Brazil (29,42°S; 53,87°W).

Table 2. Values obtained from the comparison between the instruments TOMS-Brewer and OMI-BREWER: number of points used (N), correlation coefficient ($R^2$), MBE (Mean Bias Error) and MABE (Mean Absolute Bias Error).

<table>
<thead>
<tr>
<th></th>
<th>TOMS - BREWER</th>
<th>OMI - BREWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>2164</td>
<td>1184</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0,88</td>
<td>0,94</td>
</tr>
<tr>
<td>MBE (%)</td>
<td>0,23±3,55</td>
<td>-0,85±2,38</td>
</tr>
<tr>
<td>MABE (%)</td>
<td>2,67±2,35</td>
<td>1,85±1,72</td>
</tr>
</tbody>
</table>

For other latitudes, ozone data were not validated because the Brewers need calibration. A reanalysis of the data will be presented in


2.1.3 Ozonesondes


2.1.4 Ozone Climatology

We present a regional and seasonal climatology, at Natal, of SHADOZ ozone profiles in the troposphere and tropical tropopause layer (TTL) based on measurements taken during the first five years of Aura, 2005–2009, results published in Thompson, A. M., et al. (2012), Southern Hemisphere Additional Ozonesondes (SHADOZ) ozone climatology (2005–2009): Tropospheric and tropical tropopause layer (TTL) profiles with comparisons to OMI-based ozone products, J. Geophys. Res., 117, D23301, doi:10.1029/2011JD016911. Thompson, A. M. et all (2012) present "a regional and seasonal climatology of SHADOZ ozone profiles in the troposphere and tropical tropopause layer (TTL) based on measurements taken during the first five years of Aura, 2005–2009. In all, 15 stations operated during that period. A west-to-east progression of decreasing convective influence and increasing pollution leads to distinct tropospheric ozone profiles in three regions: (1) western Pacific/eastern Indian Ocean; (2) equatorial Americas (San Cristóbal, Alajuela, Paramaribo); (3) Atlantic and Africa. Comparisons in total ozone column from soundings, Ozone Monitoring Instrument (OMI, on Aura, 2004-) satellite and ground-based instrumentation are presented. Most stations show better agreement with OMI than they did for EP/TOMS comparisons (1998–2004; Earth-Probe/Total Ozone Mapping Spectrometer), partly due to a revised above-burst ozone climatology. Possible station biases in the stratospheric segment of the ozone measurement noted in the first 7 years of SHADOZ ozone profiles are re-examined. High stratospheric bias observed during the TOMS period appears to persist at one station. Comparisons of SHADOZ tropospheric ozone and the daily Trajectory-enhanced Tropospheric Ozone Residual (TTOR) product (based on OMI/MLS) show that the satellite-derived column amount averages 25% low. Correlations between TTOR and the SHADOZ sondes are quite good (typical $r^2 = 0.5–0.8$), however, which may account for why some published residual-based OMI products capture tropospheric interannual variability fairly realistically. On the other hand, no clear explanations emerge for why TTOR-sonde discrepancies vary over a wide range at most SHADOZ sites."

Figure 4. Map of SHADOZ stations that operated during the early Aura era, July 2004–2010. Malindi (ceased in 2006) is not included here. See operating period and technical summary for individual stations in Table 3. Technical details of SHADOZ sondes used at each site during 1998–2004, within the Earth-Probe/TOMS period, are given in Thompson et al. [2003a, 2007]. Tahiti operated in 1998–1999.
### Table 3. SHADOZ Station Locations Used in This Study, With Years of Record and Sample Number (SN) Analyzed for 2005–2009.

<table>
<thead>
<tr>
<th>Site</th>
<th>Latitude, Longitude</th>
<th>Years of SHADOZ Data</th>
<th>SN, 2005–2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotonoua</td>
<td>07N, 15E</td>
<td>2005–2007</td>
<td>100</td>
</tr>
<tr>
<td>Irenea</td>
<td>25S, 28E</td>
<td>1999–2007</td>
<td>64</td>
</tr>
<tr>
<td>Nairobi</td>
<td>01S, 35E</td>
<td>1999–2010</td>
<td>189</td>
</tr>
<tr>
<td>La Réunion</td>
<td>21S, 55E</td>
<td>1998–2010</td>
<td>158</td>
</tr>
<tr>
<td>Kuala Lumpur</td>
<td>2.7N, 102E</td>
<td>1998–2010</td>
<td>114</td>
</tr>
<tr>
<td>Watukosek</td>
<td>7.5S, 112.6E</td>
<td>1998–2010</td>
<td>65</td>
</tr>
<tr>
<td>Fiji</td>
<td>18S, 178E</td>
<td>1998–2008</td>
<td>44</td>
</tr>
<tr>
<td>Paramaribo</td>
<td>05N, 55W</td>
<td>1999–2009</td>
<td>140</td>
</tr>
<tr>
<td>Alajuela/Heredia</td>
<td>10N, 84W</td>
<td>2006–2010</td>
<td>192</td>
</tr>
<tr>
<td>Natal (Brazil)</td>
<td>06S, 35W</td>
<td>1998–2010</td>
<td>173</td>
</tr>
<tr>
<td>Ascension Is.</td>
<td>08S, 15W</td>
<td>1998–2010</td>
<td>207</td>
</tr>
</tbody>
</table>


### Table 4. Profile Characteristics of Ozone for Tropical SHADOZ Stations (Within ± 18 Degrees)

<table>
<thead>
<tr>
<th>Site</th>
<th>Minimum Ozone Mixing Ratio (km)</th>
<th>FT Mean O3 Mixing Ratio (5 km - 12 km)</th>
<th>TTL Mean O3 Mixing Ratio (14 km–18.5 km)</th>
<th>Ozonopause (km), LRT (km)</th>
<th>Mean GWI, GW Max. ±</th>
<th>Altitude of Ozonopause ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kuala Lumpur</td>
<td>13</td>
<td>35.8</td>
<td>120</td>
<td>16.6, 16.9</td>
<td>19.4, 17.0</td>
<td>10.9, 18.2</td>
</tr>
<tr>
<td>Watukosek</td>
<td>14</td>
<td>30.8</td>
<td>95.6</td>
<td>17.0, 16.9</td>
<td>18.5, 18.1</td>
<td>12.6, 18.1</td>
</tr>
<tr>
<td>Fiji</td>
<td>13</td>
<td>40.1</td>
<td>140</td>
<td>16.6, 16.9</td>
<td>12.6, 18.1</td>
<td>16.5, 17.1</td>
</tr>
<tr>
<td>Am. Samoa</td>
<td>12</td>
<td>35.7</td>
<td>135</td>
<td>16.5, 17.1</td>
<td>16.6 ± 1.1</td>
<td>16.1, 18.1</td>
</tr>
</tbody>
</table>

**Eastern Indian/Western Pacific Oceans**

**Equatorial Americas**

<table>
<thead>
<tr>
<th>Site</th>
<th>Minimum Ozone Mixing Ratio (km)</th>
<th>FT Mean O3 Mixing Ratio (5 km - 12 km)</th>
<th>TTL Mean O3 Mixing Ratio (14 km–18.5 km)</th>
<th>Ozonopause (km), LRT (km)</th>
<th>Mean GWI, GW Max. ±</th>
<th>Altitude of Ozonopause ±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natal</td>
<td>11</td>
<td>58.6</td>
<td>140</td>
<td>16.2, 17.0</td>
<td>16.9 ± 1.6</td>
<td>15.9 ± 1.6, 16.2, 18.1</td>
</tr>
<tr>
<td>Ascension</td>
<td>11</td>
<td>63.9</td>
<td>134</td>
<td>16.2, 17.1</td>
<td>8.35, 18.0</td>
<td>15.5 ± 1.9, 16.9</td>
</tr>
<tr>
<td>Cotonoua</td>
<td>11</td>
<td>72.5</td>
<td>155</td>
<td>15.5, 16.9</td>
<td>16.6, 18.0</td>
<td>15.5 ± 1.9, 16.9</td>
</tr>
<tr>
<td>Nairobi</td>
<td>11</td>
<td>55.3</td>
<td>134</td>
<td>16.4, 17.0</td>
<td>16.6, 18.0</td>
<td>16.3 ± 1.6, 17.0</td>
</tr>
</tbody>
</table>

a Altitude corresponding to 100 ppbv ozonopause as in Figures 5; data from 2005–2009.
b From ozonopause definition of Sivakumar et al. [2011] based on 1998–2008 data. Mean difference between their ozonopause and LRT averages 0.25 km, with five of 7 tropical sites having ozonopause higher than LRT.
c GWI = Gravity Wave Index, based on 1998–2007 soundings [Thompson et al., 2011a].
d Sivakumar et al. [2011] categorizes Fiji as a Sub-tropical site.
Figure 5. Displays annual cycles of ozone in the troposphere, TTL (Tropical Tropopause Layer) and LS for the Natal SHADOZ stations, based on contouring mean monthly-averaged ozone profiles for the years 2005–2009. Thompson, A. M. et al. (2012).

Figure 6. Average ozone, temperature, water vapor profiles over Natal SHADOZ station. The minimum corresponds to the 25th percentile for each parameter; the maximum corresponds to the 75th percentile. The asterisk locates local minimum O3 mixing ratio in the UT and TTL, from which location of most prevalent convective outflow inferred. Horizontal dashed line indicates ozonopause (Table 4).
Figure 7. (a) Zonal view of stratospheric column O3, in Dobson Units (DU, ±15) determined from integrated stratospheric O3 of 2005–2009 soundings. (Cotonou not shown due to small number of samples to 10 hPa). Bars indicate 1±15 standard deviation. For two subtropical stations, Hilo and Réunion, a column >170 DU may result from intrusion of mid-latitude air parcels. Lack of distinct zonal variation signifies the absence of a wave-one in the stratosphere [cf. Thompson et al., 2007, Figure 6]. (b) Zonal view of integrated column O3 between 115 and 42 hPa (15–20 km).

Figure 8. Time-series of OMI overpass ozone total column (solid line) with integrated total ozone (red) from all soundings in 2005–2009 that reached 20 hPa. Above burst addition to total ozone is from the most recent SBUV/SAGE/MLS climatology [McPeters and Labow, 2012]. The latter is similar to McPeters et al. [2007] but differs 5–10 DU typically from the SBUV add-on used in earlier EP/TOMS comparisons [McPeters et al., 1997; Thompson et al., 2003a, 2007]. Where available, total O3 from co-located Dobson, Brewer or SAOZ instruments (blue triangle) is given. The lower panel includes sonde-OMI difference and the ground-based-sonde.
2.1.5 Influence of Antarctic Ozone Hole over South of Brazil

The Antarctic Ozone Hole is a cyclical phenomenon which occurs over the Antarctic region from August to December each year. The polar vortex turns it into a restricted characteristic dynamics for this region. However, from time to time, some air masses with low ozone concentration could escape and reach regions of lower latitudes. Pinheiro et al. (2011 and 2012) and Peres (2013) analyzed the influence of the Antarctic Ozone Hole over the South of Brazil in the years from 2008 to 2011, and from 1979 to 2011, respectively. To verify these events, ozone total column from Brewer Spectrophotometers MKIV #081 (from 1992 to 2000), MKII #056 (from 2000 to 2002) and MKIII #167 (from 2002 to nowadays) installed at Southern Space Observatory (29.42°S, 53.87°W), in São Martinho da Serra, South of Brazil, and TOMS and OMI Spectrometer overpass data for the same coordinates were used. In addition to ozone data, potential vorticity maps using GrADS (Grid Analysis and Display System) generated with the NCEP reanalysis data and air mass backward trajectories, using the HYSPLIT model of NOAA, were analyzed. Ozone total column for the days with low ozone were compared with monthly climatological average from 1979 to 2011. Considering only the days with ozone lower than climatological means minus 1.5 standard deviation, increased absolute potential vorticity and backward trajectories indicating the origin of polar air masses, 66 events were observed in the period analyzed, with an average decreased about 8.66 ± 3.13 % when compared with climatological means.

Table 5. Distribution of the events of influence of the Antarctic Ozone Hole over South of Brazil, occurred from 1979 to 2011, during August, September, October and November, at Southern Space Observatory (29.42°S; 53.87°W; 488,7m). (Results from Peres, 2013)

<table>
<thead>
<tr>
<th>Month</th>
<th>Number of Events</th>
<th>Percentage of Events (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>August</td>
<td>9</td>
<td>13.6</td>
</tr>
<tr>
<td>September</td>
<td>20</td>
<td>30.3</td>
</tr>
<tr>
<td>October</td>
<td>30</td>
<td>45.5</td>
</tr>
<tr>
<td>November</td>
<td>7</td>
<td>10.6</td>
</tr>
</tbody>
</table>

In Figure 10 is shown an event example (Peres et al., 2012) of the influence of Antarctic Ozone Hole over South of Brazil occurred at October 13th and 14th, 2012, with total ozone column about 252.6 DU, a reduction of 13.7 % in comparison with October climatological mean 292.7 ± 9.85 DU. The stratosphere dynamic is shown by potential vorticity maps at isentropic level of 620 K
potential temperature, Figure 11, (a) for October 13\(^{th}\), 2012 and (b) for October 14\(^{th}\), 2012. From 13\(^{th}\) to 14\(^{th}\), it can be seen an increase at absolute potential vorticity over South of Brazil. The backward trajectory by NOAA HYSPLIT Model for October 14\(^{th}\), 2012, Figure 11 (c), showed the polar origin of the ozone poor air mass over South of Brazil. Finally, in Figure 11(d), OMI image for October 13\(^{th}\), 2012, is shown.

**Figure 10.** Ozone total column (DU) from October, 11\(^{th}\) to 18\(^{th}\), 2012, at Southern Space Observatory, South of Brazil. The lines represent climatological mean and its value minus 1.5 the standard deviation for October.

**Figure 11.** Potential Vorticity and wind for October (a) 13\(^{th}\) and (b) 14\(^{th}\), 2012, (c) backward trajectory by HYSPLIT model at 620K for October 14\(^{th}\), 2012, and (d) OMI satellite image for October 13\(^{th}\), 2012. (Peres et all., 2012)
2.1.6 Ozone and UV Forecast

The forecast of Ozone Layer Concentration and UV radiation can be obtained from INPE/CPTEC site (http://satelite.cptec.inpe.br/uv), which used satellite data NOAA 16, sensor SBUV/2.

![Figure 12](Image) Example of Ozone forecast by INPE/CPTEC for 04/14/2014.

4. DISSEMINATION OF RESULTS

4.1 Data Reporting

The Brewer data have been submitted to WOUDC since 2004 and Dobson data since 1978.

4.2 Information to the public

The Ozone e UV forecasts are in web sites: [www.crn2.inpe.br/lavat](http://www.crn2.inpe.br/lavat) and [http://satelite.cptec.inpe.br/uv](http://satelite.cptec.inpe.br/uv).
4.3 Relevant scientific papers


Peres, L. V. Secondary Effects of Antarctic Ozone Hole over South of Brazil, Master Degree Dissertation on Meteorology, Federal University of Santa Maria, 2013 (in Portuguese).

5. PROJECTS AND COLLABORATION

The Project in the Brazilian Antarctic Program: **INCT- Antarctic Environmental Research**, Project Antarctic Atmosphere and Environmental Impacts in South America, operated through the knowledge and monitoring of Antarctic atmosphere and its environmental impacts on South America.

Objectives of the Area:

1. To monitor and evaluate:
   - The regions of movement of Antarctic Cold Fronts as far as South America, especially Brazil;
   - The greenhouse effect perceived in Antarctica;
   - The chemical changes of the atmosphere and their influence on the climate, involving: the interaction Sun - Earth, the temperature of the mesosphere and the hole in the ozone layer;

2. To offer supporting information to numerical models of climate and weather forecasting.

   Collaboration with the Centro de Investigaciones en Láseres y Aplicaciones, CEILAP-UNIDEF (MINDEF-CONICET),
   Collaboration with the San Andres University, La Paz, Bolivia
   Collaboration with the Magallanes University, Punta Arenas, Chile
   Collaboration with the Magallanes University, Punta Arenas, Chile
   Collaboration with the Takushok University, Tokyo-Japan
   Collaboration with the Federal University of Santa Maria, Santa Maria, Brazil.

**FUTURE PLANS**
The current monitoring networks are to be maintained operational. However, there is no special plan or project for building new capacities to conduct ozone or UV radiation. Some projects, such
as projects focusing on climate change, may include instruments installation and research related to ozone and UV.

7. NEEDS AND RECOMMENDATIONS

It is very important the support for the annual calibrations and maintenance of the Brewer. The last calibration of the Brazilian Brewers was in 2009. All instruments needed calibrations as soon as possible. Financial support for trips techniques and participation in Ozone and UV Meetings, Congresses and Symposium are also needed.
BURKINA FASO

1. **Background**
Burkina Faso is a landlocked country of 105,869 square miles, located in the heart of Western Africa, approximately 600 miles from the Atlantic Ocean. Ouagadougou, the capital city, has about one million inhabitants. The country borders Benin, Côte d'Ivoire, Ghana, Mali, Niger and Togo. With 13.4 million inhabitants and a density of 13.1 inhabitants per mile², Burkina Faso is one of the most populated states in western Africa. Per capita income is about $US 1000. Industry is mainly agricultural. Burkina Faso exports cotton, cattle and out-of-season vegetables to Europe. Weather is dry for much of the year with summer temperatures often reaching 45 deg C. Principal cities are Bobo Dioulasso, Koudougou and Fada Ngourma.

2. **Status of Ratification**

The country ratified both the London and Copenhagen Amendments in 1995, and subsequently ratified the Montreal and Beijing Amendments in 2002.

3. **Institutional And Regulatory Framework**

**General legislative framework**
Burkina Faso ratified the Convention of Vienna and the Montreal Protocol on 20th July 1989. The legal basis for subsequent legislation controlling the import and use of ODS goes back to a ministerial edict (no. 91-069/PRES) promulgated on 25th November 1991 and the corresponding decree through which it was enforced (no. 91-0434/MICM) issued on 27th November 1991. The legal basis for ODS legislation was subsequently strengthened by the Law no. 005/97/ADP promulgated on 30th January 1997. This document defined atmospheric pollution as the presence in the air of substances or particles that prejudice health, public safety or the environment, or by the presence in the atmosphere of substances which (among other things) contribute to Global Warming or Ozone Depletion.

**Establishment and Role of National Ozone Unit (Bureau National Ozone (BNO))**

The BNO was established in 1994 as an entity within the Department of Anti-pollution and Health which answers to the General department for the Preservation of the Environment within the Ministry of Environment. The objective of the BNO is to reduce ODS consumption according to the limits set in the Montreal Protocol for substances listed in Annexes A and C. To achieve this goal, the following specific tasks have been assigned to the BNO:

- To study the import and consumption of ODS
- To communicate data on the import and consumption of ODS to the MP Secretariat
- To organize training, information and awareness raising programmes to sensitize the general public to the problem of ozone depletion.
- To create a refrigerant recovery and recycling Centre.

**ODS legislation**

Legislation specific to ODS was enacted via a ministerial decree issued on 11th March 1997. This required that a Prior Approval for Import be obtained for the import of any ODS or piece of equipment containing ODS. A Notice to Importers was issued on the same day (97-005/MCIA/SG) by the Ministry of Commerce covering the import of any substance appearing in Annex A of the Montreal Protocol and its amendments or any equipment containing these substances.
The control of ODS import and export on a day-to-day basis is achieved through close cooperation between the Bureau National Ozone (BNO), the Individual Client Centre, and the Customs Service.

The legislation from 1997 required that importers wishing to import shipments of ODS submit an application to the “Centre des guichets uniques” who then established the bona fides of the importer and referred the application to the BNO, who would decide if and how much ODS the importer could bring into Burkina Faso. A positive response from the BNO would result in the issuing of the Prior Approval for Import (API - referred to above). The BNO issued permits in accordance with a phased reduction in ODS imports which succeeded in meeting the 50% cut in base consumption required for 2005.

The mechanism described above no longer applies as import of most ODS became illegal in January 2006 (see below). Further documentation is required under normal customs rules for any shipment of goods valued at over 500,000 CFA (769 euros). Any shipment of goods valued at 3 million CFA or more (4,614 euros) must be inspected by an accredited goods inspection company. The following describes the current legislative framework governing trade in ODS and ODS-containing equipment.

**ODS Legislation via the Union Economique et Monétaire Ouest Africaine (UEMOA)**

The UEMOA comprises Togo, Cote d’Ivoire, Benin, Senegal, Mali, Gambia in addition to Burkina Faso. The ODS control mechanism described above became redundant from January 1st 2006 when the UEMOA member states jointly agreed to ban the import and export of all Annexes A, B and E ODS (CFCs, halons, Carbon Tetrachloride, Methyl Chloroform and Methyl Bromide) and equipment containing these ODS apart from equipment required for urgent medical purposes. This was enacted via Regulation No. 04/2005/CM/UEMOA “Harmonisation of regulations concerning the import, trade and re-export of ODS and ODS containing equipment”. This was agreed by the Council of Ministers of the member states in July 2005. It prescribes a tight regime of control which is aimed at preventing the movement of ODS between member states. Some of the relevant articles of the legislation are:

Art 3: Import of ODS and equipment containing ODS will become illegal when this regulation comes into force.

Art 4: Production of ODS and export from the territory of member states is forbidden

Art 5: Application of the provisions of the MP and its amendments in respect of the import from non-member state of ODS or equipment containing ODS is the responsibility of the Ministry in charge of Commerce of the State to which the shipment is destined. The Ministry of Commerce of this state must provide prior authorisation.

Art 7: The BNO of each member state is charged with registering the importers and distributors of ODS and equipment containing it.

Art 8: A Community Ozone Committee (CCO) is created within UEMOA and charged with putting into effect the provisions of the MP relating to ODS

Art 9: A list of ODS and the equipment containing them can be modified through regulations issued by the UEMOA council of ministers following notification by the CCO

Art 10: All contravention of the provisions of the present regulation exposes those carrying out the contravention to the legal sanctions provided by the relevant member state
Art 12: The present regulation enters into force on 1st January 2006 and will be published in the official bulletin of the UEMOA

4. Research

Capacity building for ozone monitoring and research

Many stations that used to observe the thickness of the ozone layer with Dobson spectrophotometers have switched over to the more automatic Brewer spectrophotometer. After some years of overlapping measurements, the Dobson instruments are no longer needed at these sites and can be relocated to sites in developing countries. Such relocation is a very cost effective way of transferring knowledge and observing capacity to developing countries since the instrument is obtained at no cost.

In Vision

Many ozone- and UV-monitoring stations are located in developing countries and countries with economies in transition (CEITs).

There are an insufficient number of regional centres for research, calibration, and validation, especially in developing countries.

Burkina Faso is a land lock Country in West African Sahara. Despite of the limited means the country makes many efforts in various areas to ensure equality between actual peoples needs and the situation in the future. So Burkina Faso is party of most of Multilateral Environment Agreement like Vienna Convention and its Montreal Protocol, the Kyoto Protocol on Climate Change. In this last domain the country acquire measurement station in the frame of climate change and mitigation plan, implemented by our Meteorological department. In the new concept on country integrated management of the MEAs Burkina Faso vested interest to establish an ozone monitoring station in accordance with the discussion and recommendations of Ozone Research Managers Meetings under the Vienna Convention for the protection of the Ozone Layer; To that end the country wish to be considered on voluntary basis by likely donors (USA, Canada that help sine Burkina on implementing the national ozone programme) in receiving a proper working second hands equipment either a Dobson or a Brewer Spectrophotometer from its previous quoted partners . A twinning arrangement with one or two developed countries can also be foreseen

The aim of acquiring a monitoring station would be to join WMO’s GAW network and contribute to the world’s ozone data collected and archived by world data centres such us WOUDC? at the same time to built a capacity in Burkina Faso for atmospheric Science and research. Further with the initiative Burkina Faso will be able to conduct research programs that will help understand the behavior in this part of the world which is the West Africa below the Sahara Occidental. Therefore Burkina Faso will be a very useful place to monitor these parameters to prove the ground truth for the world in order to verify data from other means.

5. Measurements

Gases and other parameters to be measured would include: Total column ozone, trace gases, UV levels.

6. Location of measurement site

The monitoring instrument will be placed back to back in a suitable and appropriate place in the meteorological devote to that end. The meteorological will be request to gather data and maintain the station.

The physics and atmospheric chemistry labs of University of Ouagadougou, the National Ozone unit and the national meteorological department jointly will be responsible for measurements and
maintenance of the instruments. The department of physics of atmospheric chemistry has students at graduate and postgraduate level. Especially there is an enthusiasm for postgraduate students to join atmospheric research. There are trained laboratory technician in the department to handle instruments. If they are provided with necessary additional training they will be able to maintain the instruments. Since university is planning to expand on monitoring and research there will be an interest on these types of instruments and data. There is also postgraduate programme on environment sciences at the university and the students in these programs will be using the instruments for their research. The Ozone Unit is keen to provide necessary input for this project and the technical help is also available with the unit through their technical staff. Therefore, instrument will be put in to useful work and sustainability will be ensured. The data will be sent to the data centres and taking the measurements Personnel to be involved and their responsibilities.

Implementation Period

Continue implementation of monitoring and maintenance Conduct periodic training and maintenance Organize participation in the GAW calibration exercises and other relevant activities as appropriate.

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CAMBODIA

Introduction
Cambodia is a Party to the Montreal Protocol having acceded to the Vienna Convention and the Montreal Protocol in 27 June 2001 and the fourth amendments on 31 January 2007. Cambodia is a developing country and has been classified as an Article 5(1) country.

This ODS Phase-out Management Plan including Country Program, Terminal Phase out Management Plan and HCFC Phase-out Management Plan have been prepared and implemented by Cambodia National Ozone Unit of the Ministry of Environment on behalf of the Royal Government of Cambodia. It is a consensus approved by the National Steering Committee and by the Senior Minister, Minister of Environment on behalf of the Royal Government of Cambodia. The plans; especially, HCFC Phase-out Management Plan explains the policies and programs that the Royal Government of Cambodia has both adopted and intends to adopt to ensure Cambodia’s compliance with the Montreal Protocol on ODS phase-out schedule. Many of these activities presume that financial and technical assistance for Cambodia’s efforts will be provided from the Multilateral Fund.

Recently Cambodia’s Hydro-Chlorofluorocarbon Phase-out Management Plan (HPMP) of Ozone Depleting Substances was prepared and submitted for consideration at the 61st Meeting of the Executive Committee of the Multilateral Fund and was approved at the same meeting in November 2010. Cambodia’s consumption of HCFCs in 2008 was 165 metric tonnes. Thus, Cambodia was faced with a challenge to freeze this consumption by 2013 and phase-down this consumption by new control schedule of Montreal Protocol 10% by 2015 and 35% by 2020 and 67.5% by 2025, and finally the 97.5% reduction from the base line by 2030 for Annex-C Group-I substances (HCFCs).

1. Monitoring activities

Use of CFC and HCFC in sectors
Cambodia is not an ODS producing country, but as an ODS import-dependent country. Based on the historical data reported to the Ozone Secretariat, only HCFC-22 has been imported into Cambodia. Given that there is no manufacturing sector in Cambodia; HCFC-22 imported into the country has been solely used for servicing sector of refrigeration and air-conditioning equipment. Cambodia neither uses HCFC-141b nor imported pre-blended polyol for the foam sector as all foam products are imported from other countries, especially those from the Southeast Asia region. Cambodia uses CFC and HCFCs only in the installation and servicing of refrigeration and air-conditioning equipment.

Based on data survey for end-users in 2008, Cambodia used about 164 MT of HCFC-22 and 1.2 MT of HCFC-123. The HCFCs were used in sub-sectors such as air conditioning, chiller, commercial refrigeration and transportation refrigeration. There are also HFC-blended refrigerants (R-404A, R-407C, and R410A) being used. The survey in 2009 did not find any use of HCFC in foam-blowing, fire-fighting, or solvent applications.

Based on data of importation in 2013; there are about 20 companies were registered (included old and new companies) and applied for imported permission from NOU/MoE; and there also the importation of HFCs refrigerant, air conditioning equipment contained HCFC-22 air conditioning equipment contained HFC-410a as blend refrigerant and others RAC equipment were imported by those companies into Cambodia. However, the trend of the importation of the R22 based equipment has been reduced, while the R410a has increased in the recent year since 2011 when we start implement HPMP.

There are 20 companies that have previously registered with Ministry of Environment as importers of ozone depleting substances in Cambodia, but only four importers have been applied for the quota for the 2014 importation, which all the companies are based in Phnom
Penh. The source of imported HCFCs in 2009 was mainly from China, India, and Singapore. There was some amount that was supplied through cross-border trade with Thailand and Vietnam. Breakdown consumption of HCFCs by substance during 2008-2012 as reported to the Ozone Secretariat is shown in Table 1.

Table 1 shows the Article 7 data for HCFCs that Cambodia had reported to the Ozone Secretariat during 2008-2012.

<table>
<thead>
<tr>
<th>Year</th>
<th>HCFC-22 (MT)</th>
<th>Total (MT)</th>
<th>Consumption of Annex C-I (ODP Tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>143.27</td>
<td>143.27</td>
<td>7.9</td>
</tr>
<tr>
<td>2009</td>
<td>311.17</td>
<td>311.17</td>
<td>17.1</td>
</tr>
<tr>
<td>2010</td>
<td>233.24</td>
<td>233.24</td>
<td>12.8</td>
</tr>
<tr>
<td>2011</td>
<td>249.21</td>
<td>249.21</td>
<td>13.7</td>
</tr>
<tr>
<td>2012</td>
<td>183.96</td>
<td>183.96</td>
<td>10.12</td>
</tr>
</tbody>
</table>

Remark: Official data of the Article 7 data report of 2013 will be submitted to the Ozone Secretariat.

Table 1 shows the import of HCFC-22 from 2008-2012 as compiled by the Cambodian NOU. Besides HCFC-22, there is no record of other HCFCs being imported into Cambodia though the survey indicated that 1.2 MT of HCFC-123 had been used in 2008. The import of HCFC-22 has steadily increased in line with the country economic development until 2011 and dropped down in the 2012 while starting implement of the HPMP.

**Production**

Cambodia does not produce any ODS and all ODS must be imported. The total amount of ODS imported to Cambodia is used only to meet its local demand. There is no known branch/subsidiary of foreign fluorochemical manufacturers in the country.

For the HFCF consumption, there is no manufacturing of HCFC-dependent RAC equipment such as air conditioners in Cambodia. All RAC equipment is imported into Cambodia.

**Exports**

Export of ODS including HCFCs is controlled under the Sub-Decree. There is no record of export of HCFCs from Cambodia to other countries.

**Levels of HCFCs in blends and as feedstock, as applicable;**

There is no HCFC used as feedstock in Cambodia nor is there any record of import of HCFC in blends. The data survey did not find any use of HCFC blends by the servicing workshops. The NOU also has not issued any import license for HCFC blends.

**Levels of HCFC consumption**

Based on the end-user data survey, Cambodia used about 164 MT of HCFC-22 and 1.2 MT of HCFC-123 in 2008. There are also HFC-blended refrigerants (R-404A, R-407C, and R410A) being used. The survey revealed that HCFCs were used in the following sub-sectors: air conditioning, chiller, commercial refrigeration and transportation refrigeration as shown in Table below:
Estimated HCFC use in different sub-sectors (MT)

<table>
<thead>
<tr>
<th>Sub-sectors</th>
<th>HCFC-22</th>
<th>HCFC-123</th>
<th>Total</th>
<th>Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air conditioning</td>
<td>143.0</td>
<td></td>
<td>143.0</td>
<td>87%</td>
</tr>
<tr>
<td>Chiller</td>
<td>15.0</td>
<td>1.2</td>
<td>16.2</td>
<td>10%</td>
</tr>
<tr>
<td>Commercial refrigeration</td>
<td>4.0</td>
<td></td>
<td>4.0</td>
<td>2%</td>
</tr>
<tr>
<td>Transportation refrigeration</td>
<td>2.0</td>
<td></td>
<td>2.0</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>164.0</strong></td>
<td><strong>1.2</strong></td>
<td><strong>165.2</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Most of HCFC used in Cambodia are used in Phnom Penh (66%), followed by Siem Reap (14%) and Battambang Mean Chey (7%). These 3 provinces are the major cities where most hotels, casinos, restaurants, apartments, office buildings, and other establishments are located. The remaining consumption (13%) is used in other provinces.

Information on Ozone issues to the public
The National Ozone Unit under the Institutional Strengthening Program being assisted by UNEP. The NOU has raised awareness on ozone related issues, published awareness materials for distributing to the public, relevant institutions and stakeholders. In addition, the National Ozone Unit conducted the Inter-ministerial Meeting, awareness workshops for the participants from relevant institutions and stakeholders attended these workshops.

2. Research on stratospheric ozone
As Cambodia is one of the developing and low volume consumption country; therefore, the research on stratospheric ozone have not been conducted; therefore, the data on the stratospheric ozone is not available, we join the meeting as we would like to learn the process of the monitoring and analysis of ozone layer depleting as well as how the scientist have been done, while we expected that we can do some works on such research in the future.

3. Future plan
Since Cambodia is the one of the developing countries; therefore, Cambodia are very keen to participate in the research program in other countries as well as to set up the instrument to monitor the ozone level that can effect to human health, crop, etc,. As the instrument are very technical and costly; therefore, Cambodia need to have support from international communities. In this regard, Cambodia would like to take any steps/projects related to ground ozone Monitoring in Cambodia.

4. Need and recommendation
- There is the need to install the equipment to monitor the ground ozone monitoring in place
- Training on the scientific, technical training and more international collaboration
- Need the financial support for exchange visit among the countries in the region at the monitoring station to improve the knowledge and experiences.

Finally, we would like to express our sincere thanks to WMO/UNEP to give an opportunity for Cambodia delegate to participate in the meeting and to show up the national report on the implementation of the Montreal Protocol related issues in Cambodia and we hope that we will get more other support on this activity in the near future.

References
- HCFC Phase Out Management Plan for Cambodia
- Terminal Phase out Management Plan for Cambodia
- Country Program for Montreal Protocol Implementation
Canada’s Ozone Science Program

Stoyka Netcheva
Air Quality Research Division
Atmospheric Science and Technology Directorate
Environment Canada

9th Ozone Research Manager's Meeting
May 14-16 2014
Outline

• Current state of ozone monitoring in Canada
• Products and Services
• Research activities not covered by ozone monitoring
• Key scientific findings for the reporting period
• International engagement
• Concluding remarks
Canada’s Ozone Monitoring Program

• Column measurements
  – Arctic sites: Alert, Eureka, Resolute with 3 instruments
  – mid-latitude sites: Churchill, Goose Bay, Edmonton, Saturna Island, Kelowna, Richmond and Toronto

• Weekly profile measurements at 8 sites
  – Arctic sites: Alert, Eureka, Resolute
  – mid-latitude sites: Churchill, Goose Bay, Edmonton, Yarmouth, Kelowna and Toronto

intly with USA-NOAA operating Brewers at Mauna Loa, Hawaii and South Pole

Brewers are operated by Canadian Universities at several stations for research purposes
Daily products delivered to the public: UV Index forecast by Meteorological Services of Canada

- Developed in 1992 as a health protection tool for Canadians to measure the strength of the ultraviolet radiation they are exposed to.
- Standardized by the World Health Organization (WHO) and used by 100 countries around the world.
Brewers application: UV Index forecast validation

Brewers are used for EC and NOAA UV Index forecast validation. EC and NOAA forecast methods (FM) plotted against collocated Brewer measurements. Blue open circles show EC forecasts, and red plus signs show NOAA forecasts. Four major weather types are represented: cloud-free sky (type 1), light clouds (type 2), heavy clouds (type 3), and rain (type 4).

From He et al., JAMC, 2013

UVI attenuation: clouds, albedo, altitude improvement
7 day clear-sky and cloud affected forecast
Sample results from stratospheric ozone assimilation

Comparison of column ozone short-term forecasts (after assimilation) and Brewer measurements in Dobson Units for Toronto (Jan-Feb 2009)

Ozone field at ~10 hPa without and with assimilation of satellite ozone data (18UTC, 31 Aug 2008)

Implementation of near-real time global assimilation of stratospheric ozone for the purpose of improving UV index forecasts and providing ozone boundary conditions for regional air quality forecasts (to be completed in 2015).

Rochon, Stroud, Menard, DeGrandpre, EC
Brewer applications: UV in the Arctic

Brewer UV from 3 Arctic Brewer sites (Resolute, Eureka, Alert) are used in NOAA Arctic Report Card, BAMS State of Climate report, and other publications.

In the spring of 2011, they reported UV levels that are 60% higher than normal.

Seasonal variation of the noontime UV Index at Eureka. The top (first) panel compares noontime UVI measurements performed in 2011 (red dots) with the average noontime UVI (blue line), the range between the 10th and 90th percentile (dark shading), and the range of historical minima and maxima (light shading). The second panel shows the 2011 UVI anomaly in absolute terms, calculated as the difference between measurements and the average. The third panel shows the relative UVI anomaly calculated as the percentage departure from the climatological mean. The fourth panel shows a similar anomaly analysis for total ozone derived from satellite measurements. Vertical broken lines indicate the times of the vernal equinox, summer solstice, and autumnal equinox, respectively.

Form Bernhard et al., ACP, 2013
Near Real Time monitoring

March 17, 2014

Total ozone deviations from normal in %

The tropopause pressure

High (low) tropopause corresponds to low (high) ozone

Temperature at 50 hPa

Ozonesonde from Payerne, Switzerland.

High tropopause causes ozone deficiency below 18 km.
Near Real Time Monitoring

![Graph showing total ozone from Brewer, Dobson and sondes at the South Pole.](image)

**Figure 56.** Total ozone above the South Pole as measured by a Brewer spectrophotometer, which belongs to Environment Canada, ozonesondes (orange circles) launched by NOAA, a Dobson spectrophotometer operated by NOAA and by the OMI instrument on board the AURA satellite. Due to the late sunrise at the South Pole after the polar night, the satellite retrievals start only on 24 September, the Dobson measurements start on 7 October and the Brewer measurements start on 10 October. The grey curve shows the 1992-2012 median as derived from MSR and TMC data based on satellite overpasses. The light grey shaded area shows the range of values during the 1992-2012 time period.
Canadian ozonesonde network
Re-evaluation Results: reduced uncertainty

**Tropospheric changes:** increases of up to 5% after 1979; up to 20% before 1980 (Brewer-Mast sondes), reducing with altitude.

**Stratospheric changes:** decreases of up to 6% before 1980, less below 25km. Increases of ~1% in 1980s, ~2-3% in 1990s; little change in 2000s.

<table>
<thead>
<tr>
<th></th>
<th>Mean K</th>
<th>Std Dev</th>
<th>Trend</th>
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<tr>
<td><strong>BM data</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Original</td>
<td>1.27</td>
<td>0.303</td>
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<td>Renormalized</td>
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<tr>
<td>Response correction</td>
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<td><strong>ECC data</strong></td>
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<td></td>
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<tr>
<td>Original</td>
<td>0.97</td>
<td>0.101</td>
<td>-2.6 +/- 0.6 %/decade</td>
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<tr>
<td>All corrections</td>
<td>0.99</td>
<td>0.087</td>
<td>0.6 +/- 0.5 %/decade</td>
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</tbody>
</table>
Global 3D data set

Ozone data from sparse measurements projected using meteorological winds (air parcel trajectories).

More detail, longer record than satellites.

From Tarasick, PAHA WS

Trajectory-mapped ozone data from commercial aircraft (MOZAIC)

And from ozonesondes
Canadian Middle Atmosphere chemistry-climate Model

- Compared to the full record of available ground-based observations, the CMAM chemistry-climate model, constrained to observed meteorology, is able to reproduce a large degree of the variation in total column ozone.

- The model also shows good agreement with available satellite observations of the stratospheric partial column, though the satellite record is discontinuous.

- To reconcile the near-constant total column since 1980, with the stratospheric decrease since 1980, the model calculates an increase in tropospheric ozone.

From Shepherd et al. Nature Geosc. 2014
Following the eruption of Mt. Pinatubo, little ozone enhanced ozone depletion was seen in the Southern Hemisphere mid-latitude.

Corresponding model simulation with ODSs held at 1960 levels (blue line) shows enhanced transport of ozone in Southern Hemisphere.

Plotting the difference between the two CMAM runs, giving the ozone destruction due to ODSs, clearly shows enhanced ozone destruction in both hemispheres following Mt. Pinatubo.

From Shepherd et al. Nature Geosc. 2014
Canadian Network for the Detection of Atmospheric Change (CANDAC)
(PI J. Drummond)

The Polar Environment Atmospheric Research Laboratory (PEARL)
- PEARL based measurements to validate Canadian SCISAT/ACE and Odin/OSIRIS ozone measurements
- stratospheric ozone loss in spring 2011
- anomalous dynamics and chemistry during the final stratospheric warming
- partial and total column measurements of trace gases, trends in halogen containing species and other atmospheric constituents and parameters controlling the ozone budget
- stratospheric and tropospheric ozone research under new PAHA project (Probing the Atmosphere of the High Arctic): Composition Measurements (CM) - Ozone and Related Species (CM-O3)

Toronto
- FTIR measurements of stratospheric composition to identify mid-latitude polar vortex intrusions over Toronto

Large Measurement Campaigns: national and international scale

- PEARL, Canadian universities (Dal, UofT, others): measurements of ozone and related species using IR and UV/VIS spectrometers
  - Springtime validation campaigns for Canadian SCISAT/ACE and Odin/OSIRIS,
  - MATCH - Determination of Stratospheric Polar Ozone Losses

- BORTAS (Quantifying the impact of BORereal forest fires on Tropospheric oxidants over the Atlantic using Aircraft and Satellites) – international study with many collaborators
International Engagement

• Support capacity building initiative of WMO through Brewer Trust Fund ($30,000 U.S. per year)

• Provide experts to WMO Experts’ Committees
  – GAW SAG-Ozone
  – GAW SAG-UV
  – GAW Data Centre Managers

• Maintain the WMO World Brewer Ozone Calibration Centre

• Maintain and provide the Global Brewer Travelling Standard Instrument to WMO

• Operate the World Meteorological Organization (WMO) World Ozone and Ultraviolet Data Centre (www.woudc.org)
World’s Brewer Calibration Centre activities 2011-2014

• Absolute calibration of Triad instruments took place in October 2013
• Established Triad of double monochromator instruments
• Comparison between 2 Triads is in progress
• USA-NOAA #109 calibrated against Triad in May 2013
• 2 instruments of Japan Meteorological Agency calibrated in March 2014
• Traveling standard #017 used to calibrate 115 instruments in 43 countries through WMO
• Inter-comparison of a Triad instrument with the Standard of Regional Calibration Centre Europe in progress
• Comparison between Dobson and Brewer measurements at Mauna Loa, Hawaii in progress
Pandora Spectrometer and Brewer Triads

- Sun and sky spectrometer – measures solar spectra
- Designed for satellite validation and pollution monitoring
- Operation and software design are similar to these for the Brewer spectrophotometer (commands, schedules)
- Automated, established algorithms, data available in real time
- Specifications:
  - Czerny-Turner spectrometer with backthinned CCD detector (Avantes)
  - 270-530 nm at 0.6 nm spectral resolution, 4 pixels oversampling
  - Wavelength independent FOV of 1.5° (FWHM)
  - T stabilized spectrometer (enclosed insulation under improvement)
  - High temporal resolution (<30 seconds per measurement)
  - Simultaneous measurements of various trace gases incl. O₃, NO₂, SO₂, BrO, HCHO, water vapour
  - Small size and portability (20 kg)
  - Cost: ~$40k
- Two instruments were deployed in 2013 (McKay and Toronto)
- Continue comparison with Brewer Triad instruments in Toronto.

The Pandora-Brewer difference

There is a 0% to 4% systematic difference between Brewer and Pandora total ozone caused likely by the difference in ozone absorption coefficients and their temperature dependence.
The triad update - 2014

The old and new triads agree within 1%, but there are some systematic differences likely due to stray light. The long-term instrument stability is a challenge.

The biases between individual Brewer triad instruments and the “baseline.” The baseline was established using high-frequency Pandora measurements adjusted for the Pandora-Brewer bias: The biases between Pandora and the new triad due to different ozone cross-sections were removed on a daily basis.

The error bars represent 95% confidence limits for 5-day mean differences.
MLO Brewer and Dobson observations

Brewer ozone retrievals are not sensitive to SO$_2$, while Dobson overestimates ozone in presence of SO$_2$

The whiskers represent 10$^{th}$ and 90$^{th}$ percentiles, the box edges represent the 25$^{th}$ and 75$^{th}$ percentiles, the centre is drawn at the median value. Dobson measurements (direct sun or blue zenith) are taken once a day near local noon. Dobson data were provided by NOAA.

Dobson measurement was at 13:00 HAST

From V. Fioletov EC
Renewal objectives:

- Enhance the data submission mechanism and infrastructure
- Effective and efficient data management approach
- Modernize data access mechanisms
- Improve accessibility and usability of the website
### WOUDC managed by Meteorological Services of Canada - update on data records

**May 12th, 2014 Report**

<table>
<thead>
<tr>
<th>Data Category</th>
<th>Platforms</th>
<th>Number of Files</th>
<th>Temporal Range</th>
<th>Number of New Platforms</th>
<th>Data Increase Since Last Report – May 2011 (%)</th>
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<tr>
<td>Lidar</td>
<td>2</td>
<td>~700</td>
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<td>Ozonesonde</td>
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<td>1962-2014</td>
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<td>Total Column (Daily)</td>
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<td>1926-2014</td>
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<td>Total Column (Hourly)</td>
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<td>~69000</td>
<td>1984-2014</td>
<td>4</td>
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<td>Umkehr</td>
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<td>~10000</td>
<td>1951-2014</td>
<td>0</td>
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</table>
Concluding remarks

• Arctic ozone levels continue to be difficult to forecast
• Research is on-going in improving ozone in numerical forecast through chemical data assimilation
• OSIRIS and SCISAT are beyond their design life
• New real-time products can be instituted when the necessary data and related product becomes available
• Research is on-going in enhancing our understanding of the relationship between ozone and climate
CHILE

Geographical Location
Chile is located in Southern South America, from 17°30’ S in the north to 56°30’ S (Cape Horn), bordering the South Pacific Ocean. Chile stretches over 4,300 km (2,700 mi) along the southwestern coast of South America From north to south, Chile extends 4,270 km (2,653 mi), and yet it only averages 177 km (110 mi) east to west.

OBSERVATIONAL ACTIVITIES
Continuous monitoring of UV radiation in major cities is mainly operated and maintained by the Meteorological National Service of Chile (DMC). Observations of total column ozone are carried out only in one station, in southern Chile (Punta Arenas), operated and maintained by the University of Magallanes (Umag). Ozone profile measurements, two stations are operating: in Isla de Pascua (Eastern Island) since 1995 and in Punta Arenas between 2009 and 2012 were carried out continuous observations with ECC ozonesonde, by difficulties of funds to buy inputs this activity has been suspended, but during 2014 the ozone profile observations will started again.

Ozone Column measurements

<table>
<thead>
<tr>
<th>Station</th>
<th>Instruments</th>
<th>Institution</th>
<th>LAT.</th>
<th>LONG.</th>
<th>Period of observations</th>
<th>Calibrations</th>
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<td>70°54’W</td>
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<tr>
<td>Punta Arenas</td>
<td>Brewer MKIV 124</td>
<td>University of Magallanes (Chile)- INPE (Brazil)</td>
<td>53°18’S</td>
<td>70°54’W</td>
<td>Aug.2007-Nov.2007</td>
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<tr>
<td>Punta Arenas</td>
<td>Brewer MKII 180</td>
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<td>2007-2009</td>
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Ozone Profile measurements

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<th>Station</th>
<th>Type</th>
<th>Institution</th>
<th>LAT.</th>
<th>LONG.</th>
<th>Period of observations</th>
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<td>Umkehr</td>
<td>University of Magallanes</td>
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<td>70°54’W</td>
<td>2002 – today</td>
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<td>Punta Arenas</td>
<td>Ozone sondes ECC-Z LMG6</td>
<td>University of Magallanes</td>
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<td>70°54’W</td>
<td>2009 – today</td>
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<td>Eastern Island</td>
<td>Ozone sondes ECC</td>
<td>DMC</td>
<td>27°09’S</td>
<td>109°27’W</td>
<td>1994- today</td>
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DMC: Dirección Meteorológica de Chile (National Meteorological Service)
UV measurements

Broadband measurements

<table>
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<tr>
<th>Station</th>
<th>Instruments</th>
<th>Institution</th>
<th>LAT.</th>
<th>LONG.</th>
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<tr>
<td>Arica</td>
<td>Solar Light 501</td>
<td>University of Atacama</td>
<td>13° 28'S</td>
<td>70° 20'W</td>
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<td>Santiago</td>
<td>Solar Light 501</td>
<td>University of Santiago</td>
<td>33°26'S</td>
<td>70°40'W</td>
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<td>Puerto Natales</td>
<td>Solar Light 501</td>
<td>University of Magallanes</td>
<td>51° 43'S</td>
<td>72° 31'W</td>
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<td>Punta Arenas</td>
<td>Solar Light 501</td>
<td>University of Magallanes</td>
<td>53°18'S</td>
<td>70°54'W</td>
<td>1997 - today</td>
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<td>Puerto Porvenir</td>
<td>Solar Light 501</td>
<td>University of Magallanes</td>
<td>53° 17'S</td>
<td>70°22'W</td>
<td>1997- 2002</td>
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<tr>
<td>Puerto Williams</td>
<td>Solar Light 501</td>
<td>University of Magallanes</td>
<td>54° 55'S</td>
<td>67° 37'W</td>
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<td>Bernardo O’Higgins</td>
<td>Solar Light 501</td>
<td>University of Magallanes</td>
<td>63°19'S</td>
<td>56°54'W</td>
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DMC UV Network

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<th>TYPE</th>
<th>LAT</th>
<th>LONG</th>
<th>ELEV</th>
<th>PERIOD OF OBSERVATIONS</th>
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<tr>
<td>Arica</td>
<td>Pyranometer YES UV–B</td>
<td>18° 28' S</td>
<td>70° 19’ W</td>
<td>23m</td>
<td>2006 – today</td>
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<tr>
<td>Iquique</td>
<td>Pyranometer YES UV–B</td>
<td>20° 33' S</td>
<td>70° 07’ W</td>
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<td>Maria Elena</td>
<td>Pyranometer YES UV–B</td>
<td>22° 21’ S</td>
<td>69° 40’ W</td>
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<td>San Pedro de Atacama</td>
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<td>68° 12’ W</td>
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<td>Antofagasta</td>
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<td>70° 26’ W</td>
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<td>Isla de Pascua</td>
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<td>27° 09’ S</td>
<td>109° 26’ W</td>
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<td>El Tololo</td>
<td>Pyranometer YES UV–B Kip –Zonen /Li-Cor</td>
<td>30° 10’ S</td>
<td>70° 48’ W</td>
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<td>Valparaiso</td>
<td>Biometer Solar Light</td>
<td>32° 56’ S</td>
<td>71° 28’ W</td>
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<td>Farellones</td>
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<td>33° 21’ S</td>
<td>70° 17’ W</td>
<td>2746m</td>
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<tr>
<td>Valle Nevado</td>
<td>Pyranometer YES UV–B</td>
<td>33° 21’ S</td>
<td>70° 15’ W</td>
<td>3015m</td>
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<tr>
<td>Santiago- Pudahuel</td>
<td>Pyranometer YES UV–B</td>
<td>33° 23’ S</td>
<td>70° 47’ W</td>
<td>475m</td>
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<td>70° 40’ W</td>
<td>520m</td>
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<tr>
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<td>STATION</td>
<td>TYPE</td>
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<td>LONG.</td>
<td>ELEV</td>
<td>PERIOD OF OBSERVATIONS</td>
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<td>-----------</td>
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<tr>
<td>Talca</td>
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<td>35° 25’ S</td>
<td>71° 40’ W</td>
<td>100m</td>
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<td>Concepción</td>
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<td>73° 03’ W</td>
<td>8m</td>
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<td>Valdivia – UACH</td>
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<td>39° 48’ S</td>
<td>73° 14’ W</td>
<td>9m</td>
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</tr>
<tr>
<td>Valdivia – Cecs</td>
<td>Pyranometer YES UV–B</td>
<td>39° 49’ S</td>
<td>73° 15’ W</td>
<td>18m</td>
<td>2010 – today</td>
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<tr>
<td>Puerto Montt</td>
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<td>73° 05’ W</td>
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<td>Coyhaique</td>
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<td>45° 35’S</td>
<td>72° 07’ W</td>
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<td>Punta Arenas</td>
<td>Pyranometer YES UV–B</td>
<td>53° 00’ S</td>
<td>70° 51’ W</td>
<td>37m</td>
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<tr>
<td>Centro Meteorológico Antártico Presidente Eduardo Frei</td>
<td>Pyranometer YES UV–B</td>
<td>62° 25’ S</td>
<td>58° 53’ W</td>
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**Narrowband filter instruments**

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<th>LAT.</th>
<th>LON.</th>
<th>Period of observations</th>
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<td>Santiago</td>
<td>GUV 511</td>
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<td>Punta Arenas</td>
<td>GUV 511</td>
<td>University Magallanes</td>
<td>53°18’S</td>
<td>70°54’W</td>
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<td>Punta Arenas</td>
<td>NILU UV</td>
<td>University Magallanes</td>
<td>53°18’S</td>
<td>70°54’W</td>
<td>2010 – today</td>
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<td>Base Prof. Julio Escudero</td>
<td>NILU UV</td>
<td>University Magallanes</td>
<td>62°12’S</td>
<td>58°57’W</td>
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**Spectroradiometers**

<table>
<thead>
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<th>Instruments</th>
<th>Institution</th>
<th>LAT.</th>
<th>LON.</th>
<th>Period of observations</th>
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<td>DMC-University Austral</td>
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<td>University of Magallanes</td>
<td>53°18’S</td>
<td>70°54’W</td>
<td>2002–today</td>
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**Calibration activities**

a) **DMC-network**: The instruments of the DMC were compared and calibrated in Antofagasta, 2012.

b) **BREWER 180 (Punta Arenas)**: The last calibration carry out for International Ozone Services Inc. (IOS) did the ozone and UV calibration and service of Chilean Brewer Spectrophotometer #180 was during period Nov. 09 – 12, 2009 at Punta Arenas, Chile.

c) **Biometers network (University of Magallanes)**: The Solar Light instruments of the group of the University of Magallanes are calibrated each two year using the Brewer 180 located in Punta Arenas.

**RESULTS FROM OBSERVATIONS AND ANALYSIS**

Results of Studies at Punta Arenas Chile (Lat. 53S, Long. 70W).

The Brewer observations have been operational at Punta Arenas from May 1992 until today. The Figure 1 was constructed using TOMS data(1978-1992), Brewer #068 (1992-2000) and Brewer #180 (since year 2002). This Figure shows the variation of the ozone column with monthly mean. A simple linear fit shows a slight increase in the total ozone column at Punta Arenas, and the recovery of the ozone column values to pre 80 should occur approximately between 2033-2040.

![Figure 1. Ozone over Punta Arenas Chile 1978-2013 obtained with TOMS and Brewer spectroradiometer (# 068 and # 180).](image-url)
The number of days in which the Antarctic Ozone Hole (AOH) has been over South cone region varies year to year. Figure 2 shows the number of events of low ozone to Punta Arenas. The criteria for defining an event of low ozone is that ozone column (daily average) must be lower than the reference (mean monthly climatological values for Punta Arenas from TOMS overpass data for the period 1978-1987), minus twice the standard deviation of the mean (mean monthly - 2\(\sigma\)). The number of days per year is shown in part (a), these data show a cyclical variability of about 10 years. Last three years shows significant minimum, if these values remain low during next years it would be a sign of recovery of total column ozone to pre-80 values.

Figure 2. Number of days per year under the climatological (1978-1987) average minus two standard deviations, period 1992-2012

**DISSEMINATION OF RESULTS**

**Data reporting**
- Data from Brewer 180 being sent to the WOUDC until 2011.
- Data of ozone profiles obtained in Punta Arenas being prepared and sent to the WOUDC.

**Information to the public**
- The National Meteorological Service (DMC) gives UV-Index forecast for all stations show in DMC network.
- Since 1999 the Ozone Laboratory and RUV of the University of Magallanes provides a UV-Index daily forecast during spring and summer time (TEMIS).
FUTURE PLANS

The research group of the University of Magallanes will continue ozone observations. Collaboration with other groups will be intensified, especially with the CEILAP group in Rio Gallegos and the GAW station located at Ushuaia (Argentina).

NEEDS AND RECOMMENDATIONS

- Financial support for supplies for ozonesonde of Punta Arenas is a priority, because the UVO3Patagonia project, funded by the International Agency of Japan will end in September 2011.
- The experience of the intercomparasion and calibration activities (Brewer and GUV) in Punta Arenas was very successful, it would be important to replicate with more instruments.

Recommendations 7ORM

1) Provide resources for sustainable, long-term operation of regional centers for research, calibration, and validation in developed and, especially, in developing countries. Several regional centers for Dobson and Brewer instrument calibration have been established. It is of vital importance that these centers receive sufficient support to arrange regular calibration exercises for the instruments in their respective regions.

In Chile there is no center calibration of ozone and ultraviolet instruments, closest activities are carried out in Buenos Aires (Argentina)

The latest calibration of the Brewer spectrophotometer #180 were made by International Ozone Service Inc. in 2011, it was supported by WMO

By:

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2Laboratory for Atmospheric Sciences, University of Magallanes, Punta Arenas, Chile
1. Development of space-based ozone monitoring capacity.

Since 2008, China has launched 3 polar-orbit meteorological satellites FY-3 carrying two ozone monitoring instruments: TOU (Total Ozone Unit) and SBUS (Solar Backscatter Ultraviolet Sounder). The FY-3A, B and C were launched in 2008, 2010 and 2013 respectively. Most of the global ozone data are open for global users by website.

2. Ground-based ozone and UV monitoring

China Meteorological Administration (CMA) started operational ozone and UV monitoring since 1980s. CMA is now running 7 ground-based ozone and UV observing stations and 2 additional UV observing stations in mainland China. Taiwan and Hong Kong have been measuring the ozone and UV on the ground for even longer. Chinese ground-based ozone and UV monitoring stations are listed in Table 1. Measurements have been shared through the WOUDC websites.

<table>
<thead>
<tr>
<th>Type of observation</th>
<th>Station</th>
<th>Org.</th>
<th>Instrument</th>
<th>No.</th>
<th>Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total ozone</td>
<td>Xianghe</td>
<td>CMA</td>
<td>Dobson</td>
<td>#075</td>
<td>1979-2013</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>#216</td>
<td></td>
</tr>
<tr>
<td>Total ozone</td>
<td>Kunming</td>
<td>CMA</td>
<td>Dobson</td>
<td>#003</td>
<td>1980-2010</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>#198</td>
<td></td>
</tr>
<tr>
<td>Total ozone/UV</td>
<td>Waliguan</td>
<td>CMA</td>
<td>Brower</td>
<td>#54</td>
<td>1991-</td>
</tr>
<tr>
<td>Total ozone/UV</td>
<td>Longfengsha</td>
<td>CMA</td>
<td>Brower</td>
<td>#76</td>
<td>1993-</td>
</tr>
</tbody>
</table>
3. Surface ozone monitoring and ozone sonde observation

Surface ozone and other atmospheric pollutant components monitoring system of mainland China has been operated by the China National Environmental Monitoring Center and more than 30 province-level centers under the Ministry of Environmental Protection of the People’s Republic of China. CMA is running 1 global and 6 regional atmospheric background stations to monitor surface ozone operationally. Chinese atmospheric background stations are listed in Table 2. Operational ozone sonde for ozone profile are launched in Lhasa and Beijing stations. Taiwan and Hong Kong also run operational surface ozone monitoring and ozonesonde for ozone profiles.

<table>
<thead>
<tr>
<th>Level</th>
<th>Station</th>
<th>Org.</th>
<th>start</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>Waliguan</td>
<td>CMA</td>
<td>1991-</td>
</tr>
<tr>
<td>Regional</td>
<td>shangdianzi</td>
<td>CMA</td>
<td>1985-</td>
</tr>
<tr>
<td>Regional</td>
<td>Linan</td>
<td>CMA</td>
<td>1985-</td>
</tr>
<tr>
<td>Regional</td>
<td>Longfengshan</td>
<td>CMA</td>
<td>1985-</td>
</tr>
</tbody>
</table>
4. Results from observations and Analysis

- We carried out a lot of data validation and comparison research for the FY-3 ozone data after the launch of satellites. Figure 1 shows the comparison of NOAA-18 SBUV/2, GOME-2 and FY-3A TOU zonal mean of total ozone. Figure 2 shows the relative bias and root mean square of FY-3A TOU total ozone data compared with data of OMI and ground-based measurements. Figure 3 shows the relative difference percentage of FY-3B SBUV ozone profile compared with these of NOAA-16,17 and 18 SBUV/2.

Fig 1. Comparison of NOAA-18 SBUV/2, GOME-2 and FY-3A TOU zonal mean of total ozone.
Fig2. Comparison of the FY-3A TOU total ozone with OMI and ground-based measurements.

Figure 3 shows the relative difference percentage of FY-3B SBUS ozone profile compared with these of NOAA-16, 17 and 18 SBUV/2.
FY-3 ozone data were applied in monitoring the Antarctic and Arctic ozone depletion. The FY-3A TOU total ozone data were used to monitor the Antarctic ozone depletion during 2009-2012. Figure 4 shows the distribution of October 2009-2012 averaged total ozone in Antarctic. The FY-3B SBUS and TOU and NOAA-16,17,18 and 19 SBUV/2 data were applied in monitoring the 2011 spring Arctic severe ozone depletion. Figure 5 shows the movement of the area of ozone reducing heading towards the north middle latitude during March 28-31, 2011.

Fig 4. Distribution of averaged October 2009-2012 total ozone in Antarctic with
the FY-3A TOU total ozone data (in DU).

As revealed in Figure 5, the ozone depletion region moved from the North Pole to middle latitude including western Europe and central Russia. Total ozone levels for these regions were 230-250 DU, with some sections falling below 220 DU, posed a threat both to the people’s health safety and environment.

- Considering the total ozone loss, figure 6 shows a comparison of ozone profiles during the ozone depletion on March 14, and prior to depletion on March 1 and post depletion on April 8, 2011 at 71.11°N, 77.09°E. The comparison shows 80-90% total ozone loss is resulted from the stratosphere ozone reduction.
Fig 6. Comparison of ozone profiles during depletion, prior to depletion and post depletion on March 14, March 1 and April 8, 2011 (in DU) (From Liu et al., 2011).

Wang et al., carried out surface ozone measurements in the background atmosphere of Hang Kong 1994-2007 to study the influence of primary pollutants on surface ozone(Wang et al., 2009). Figure 7 shows the surface ozone changing trends in the site.

Fig 7. Monthly mean ozone mixing ratios and the linear fit line at Hok Tsui,
To discover the origins and transport pathways of air masses in the background atmosphere of Southern China, Wang et al examined the results of cluster analysis of the hourly trajectories for the period. Figure 8 shows the four groups and the percentage occurrence of each, with shaded areas as the mean NO2 column concentration obtained from GOME and SCIAMACHY for 1996-2007.

Fig 8. Four major types of 10-day backward trajectories at Hok Tsui. The percentage of each type during the 1994-2007 is shown in parentheses. The NO2 column data from GOME and SCIAMACHY (averaged over 1996-2007) are shown in the shaded areas. The boxes in dashed lines are potential sources for ozone at Hok Tsui: (1) NCP: North China Plain, (2)YRD: Yangtze River Delta, (3)PRD: Pearl River Delta, (4)Kr-Jp: Korea
and Japan. TW: Taiwan, SA: Southeast Asia (from Wang et al., 2009).

Ma et al. studied the influence of airmass transport events on the variability of surface ozone concentration at Xianggelila Regional Atmospheric Background Station, southwest of China (Ma et al., 2014). In situ measurements of O3, CO, and meteorological parameters were made from Dec 2007 to Nov 2009 at the site. It is found that both O3 and CO peaked in spring while the valleys of O3 and CO occurred in summer and winter, respectively. A normalized indicator of transport events (marked as “Y”) of transport events on the basis of the monthly normalized O3, CO and water vapor is proposed to evaluate the occurrence of O3 transport events from the upper, O3-rich atmosphere. Corresponding to the different frequency of the transport events in four seasons, the responses of surface O3, CO and water vapor for different trajectory pressure levels and Y indicator are examined. The numbers of hours with both Y higher than a given value and trajectory pressure level lower than a given level are calculated for each season and shown in figure 9. Corresponding to the different frequency of the transport events in four seasons, the responses of surface O3, CO and water vapor for different trajectory pressure levels and Y indicator are examined. Figure 10 shows the trends of surface O3, CO and water vapor respond to the distribution patterns of the trajectory pressure levels and Y values in spring, fall and winter.
Fig 9. Hours with both trajectory pressure lower than and Y value bigger values in four seasons. Note that X-aris is in logarithmic coordinate.

Fig 10. Distributions of the values of O3, CO, and water vapor above specific trajectory pressure and Y indicator. Y-axis denotes trajectory pressure (hpa) and X-axis denotes Y indicator. Units of color bar of O3 and CO are ppb; of
water vapor is gkg⁻¹. (from Ma et al., 2014)

5. Theory, Modelling and Other Research

- Huang et al studied the solar cycle signal of tropospheric ozone over the Tibetan Plateau using TOR tropospheric ozone data from 1979 to 1992 and solar flux F10.7 index data (Huang et al., 2009). Figure 11 shows the distribution of tropospheric ozone over the Tibetan Plateau in four seasons from 1979-1992. Figure 12 shows the changing trends of tropospheric ozone and solar irradiance flux.

Fig 11. Distribution of TOR over the Tibetan Plateau in four seasons from 1979-1992 (From Huang et al., 2009).

Fig 12. The changing trends of tropospheric ozone responds to the F10.7 solar irradiance during 1979-1992 (From Huang et al., 2009).
Zou studied the seasonal variation in total ozone over the Tibetan Plateau using Nimbus-7 ozone data (Zou, 1996). Low ozone concentration are found over the large scale topographies of the Tibetan Plateau, the Rocky Mountains and the Andes Mountains. The phenomenon is the strongest over Tibet. Total ozone is lowest in Tibet is lowest in October and highest in March. However relative to zone mean total ozone, the largest ozone deficiency over Tibet occurs in May, while smallest occurs during November-January months. The ozone deficiencies are negatively correlated to the heat flux from the surface to the air in Tibet, with correlation coefficient -0.97. The ozone trend over Tibet, deduced from TOMS 1978-1991 year round data, is $-0.79 \pm 0.82$ DU/year ($-2.7 \pm 2.8\%$/decade), with the monthly trends ranging from $-0.17$DU/year ($-0.6\%$/decade) to $-1.79$DU/year ($-6.0\%$/ decade). Figure 13 shows the climate averaged ozone deviation over the Tibet in JJA (June-July-August) during 1979-1991. Figure 14 shows negative zonal deviations over the Tibet for different month.

![Figure 13](image)

**Fig 13.** The climate averaged ozone deviation over the Tibet in JJA during 1979-1991. (From Zou 1996)
Fig 14. Seasonal variations of total ozone (solid line) and zonal ozone deviation (dotted line) in Tibet. (From Zou 1996)

- Bian et al found a large area with extremely low ozone occurred over the Tibetan Plateau during December 14-17, 2003 using TOMS data (Bian et al., 2006). Figure 15 shows the location of low ozone regions over the Tibetan Plateau during Dec 14-17, 2003.

Fig 15. Distribution of total ozone from TOMS corrected by bias 4% during December 16, 2003 (From Bian et al., 2006)
Peking University and other research organizations, have done some research on emissions and monitoring of ODS and the substitutes. In most cities, the ambient mixing ratios of HCFCs and HFCs were significantly higher than the background values (P < 0.01). Compared with the results of previous research conducted in 2001 and other single-city studies, the levels of CFC-11, CFC-12 and CFC-113 have decreased since then, while the levels of HCFCs and HFCs have increased rapidly. Under the examined business-as-usual (BAU) scenario, the cumulative emissions of HFC-23 in China over the period 2013–2050 are projected to be 609 Gg. Figure 16 shows the geographical distributions of HCFC-22 and HFC-134a mixing ratios. Regions with high mixing ratios of HCFC-22 and HFC-134a are North China Plain (NCP), Yangtze River Delta (YRD) and Pearl River Delta (PRD). All of these regions are highly populated areas with a relatively high rate of car ownership, and HFC-134a mainly comes from mobile airconditioners.
Fig 16. Map showing the geographical distribution of ambient mixing ratios of (a) HCFC-22 and (b) HFX-134a in China. The larger the pink circle, the higher the mixing ratio. The red hollow circles display the regions with high mixing ratios. (from Fang, et al., 2012).

- Fang etc. (2014) did forecast of HFC-23 emissions in China. Under the examined business-as-usual (BAU) scenario, the cumulative emissions of HFC-23 in China over the period 2013–2050 are projected to be 609 Gg. On the other hand, the potential reduction is very high.
Fig 17. Projected HFC-23 production, incineration and emissions in China for the period 2013–2050 under the BAU scenario (upper panel) and projections of annual HFC-23 emissions in China under three scenarios (lower panel). The historical emissions for the period 1980–2012 are also shown for a full depiction of HFC-23 emission evolution in China. Global HFC-23 emissions for 2036–2050 were linearly extrapolated based on HFC-23 emission components for the period 2031–2035 in the projection by Miller and Kuijpers (2011).

Li et al (Li et al, 2014) published a research results related to industrial Nitrous Oxide Emissions. It is shown that from 1990 to 2012, industrial N2O emissions in China grew by some 37-fold from 5.07 to 174 Gg (N2O), with total accumulated emissions of 1.26 Tg, and (2) from 2012 to 2020, the projected emissions are expected to continue
projects in China, which is equivalent to 89.6 Tg of CO₂ eq and growing rapidly from 174 to 561 Gg under current policies and assuming no additional mitigation measures. The total accumulated mitigation potential for this forecast period is about 1.54 Tg, the equivalent of reducing all the 2011 greenhouse gases from Australia or halocarbon ozone-depleting substances from China.

![Fig 18. Comparison of industrial N₂O emission in China with global emissions and emissions in major groups.](image)

- Wu etc (2014). studied the atmospheric concentrations of TFA in China, where an annular denuder and filter pack collection system were deployed at a highly urbanized site in Beijing. It found that the atmospheric concentrations of Trifluoroacetic acid (TFA) in Beijing, China was also reported. The annual mean atmospheric concentration of TFA was 1580 ± 558 pg/m³. Using a deposition model, the annual TFA deposition flux was estimated to be 619 ± 264 μg m⁻² year⁻¹.

6. Relevant scientific papers

Bian J, G Wang, H Chen, et al., 2006, ozone mini-hole occurring over the


Fang Xuekun, Jing Wu, Jianhua Xu, Daikuan Huang, Yehong Shi, Dan Wan, Hai Wu, Min Shao, Jianxin Hu*, Ambient mixing ratios of chlorofluorocarbons, hydrochlorofluorocarbons and hydrofluorocarbons in 46 Chinese cities, Atmospheric Environment 54, 387-392

Fang Xuekun, Benjamin R. Miller, Shenshen Su, Jing Wu, Jianbo Zhang, and Jianxin Hu, Historical emissions of HFC-23 (CHF3) in China and projections upon policy options by 2050, DOI: 10.1021/es404995f

Han J, Li Li, S Su, Jing Wu, Xuekun Fang, Shenglan Jia, Jianbo Zhang, Jianxin Hu; Estimated HCFC-142b emissions in China: 2000–2050; Chin. Sci. Bull. DOI 10.1007/s11434-014-0337-z


Li L, Jianhua Xu, Jianxin Hu, and Jiarui Han; Reducing nitrous oxide emissions to mitigate climate change and protect the ozone layer; Environ. Sci. Technol., DOI: 10.1021/es404728s


Wu J, Jonathan W. Martin, Zihan Zhai, Keding Lu, Li Li, Xuekun Fang, Hangbiao Jin, Jianxin Hu, and Jianbo Zhang, Airborne Trifluoroacetic Acid and Its Fraction from the Degradation of HFC-134a in Beijing, China, dx.doi.org/10.1021/es4050264


Wu J, X Fang, W Xu, et al., 2013, Chlorofluorocarbons, hydrochlorofluorocarbons, and hydrofluorocarbons in the atmosphere of four Chinese cities, Atmospheric Environment, 75, 83-91


Yao B, Vollmer MK, Xia L et al., 2012, A study of four-year HCFC-22 and HCFC-142b in-situ measurements at the Shangdianzi regional background station in China. Atmospheric Environment, 63, P43–49


7. Recommendations

- Collaboration of monitoring and research on ozone change and its influence on climate change over the Tibetan Plaeau is critical for better understanding global ozone change. We suggest the assessment of ozone change over the Tibetan Plateau will be included in future assessment reports.

- International cooperation in the field of satellite ozone remote sensing, including new technique improvement, retrieval algorithm theories, in-orbit calibration, data validation and evaluation, which will be helpful for establishing long-term, consistent and high quality ozone datasets, should be continued and encouraged.

- More open data share of tropospheric and surface ozone is encouraged.

- Collaborative studies of improving precision of satellite remote sensing data is encouraged and continued.

- More needs to be carried out to understand sources of CTC and other new substances may be impact to ozone layer.
The international cooperation and assists for improvement the research level and quality are appreciated for developing countries.
CUBA - National Report

Juan Carlos Peláez Chávez, Cuban Meteorological Institute

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14-16 May 2014, Geneva, Switzerland
OBSERVATIONAL ACTIVITIES

Program of measurements of the total amount of atmospheric ozone and ultraviolet solar radiation (UV-B)

Total Ozone

- The measurements of total amount of ozone at Havana Ozone Station continues from February 2011 until present without interruptions and Dobson No.67 was calibrated last time in the IV Regional Dobson Intercomparison in Buenos Aires, Argentina between Nov and Dec 2010 where the instrument was subjected to a deep revision.

- On the other hand results of measurements are sent daily to the [http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_allmap_g.htm](http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_allmap_g.htm).

- We have assisted and supported the colleagues at the Solar Radiation Observatory of the National Autonomous University of Mexico to restart total ozone measurements with Dobson spectrophotometer #98 after being repaired at NOAA/ESRL/GMD in charge of Robert Evans. Currently the instrument is operational and the station of Mexico City is reporting daily to [http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_allmap_g.htm](http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_allmap_g.htm).

UV Measurements

- Due to problems with the radiometer (Biometer 501 No.2853 No.285 manufactured by Solar Light) for UV solar radiation measurements and UV index determination at Havana station these measurements are interrupted since April 2012.

- In any case, partly compensating the lack of ground measurements, an analysis was made of the behavior of the UV index for Havana based on information from OMI (aura_omil2ovp_omuvb_vO3_havana.txt). The statistical analysis of these data were the subject of a bachelor degree thesis at Havana University, no significant trend was found for UV solar radiation for the period 2004-2013 at Havana station.
RESULTS FROM OBSERVATIONS AND ANALYSIS

The study of ground measurements at Havana station and those from the OMI instrument over the same location, and at Camaguey station, located Eastward on the National Territory show, in agreement with former reports, the following results.

The total ozone distribution over the National Territory is well defined by an annual cycle with maxima in the summer months and minima in the winter months. The amplitude of this cycle is of about 40 Dobson Units and its mean value is 275 Dobson Units.

Regarding the spatial distribution over the National Territory, the total ozone content shows a small latitudinal gradient of about 2 DU between the Eastern and the Western regions in the winter season. In the summer this gradient turns bigger reaching 10 DU in May. The small values in latitude are explained by the disposition of our territory, which practically spans over a single latitude (rigorously just a range no larger than 3.5 degrees). As previously pointed out, the most relevant feature is the wide annual cycle of the TOC.

In addition to the annual cycle, TOC also shows two other seasonal cycles. It is known the variation of ozone following the quasi-biannual oscillation of stratospheric wind, with its greater value precisely over the Equatorial region. At our territory’s location, this signal is less visible, but still existent (Bojkov and Fioletov, 1996).
FUTURE PLANS

- We hope, that in the course of this year, and the next, thanks to the collaboration with the Solar Radiation Observatory of the National Autonomous University of Mexico and the National Meteorological Service of Mexico, we will be able to count with the necessary equipment to start a program of UV solar radiation monitoring at two locations on Cuba’s National territory.

- Present the actual TOZ and UV-Index values at the portal of the Cuban Meteorological Institute for public information.

RECOMMENDATIONS

- It would be very useful if workshops (The Dobson Data Quality Workshop) were held like the one at Hradec Kralove (Czech Republic) in 2011.
In the Czech Republic (CR) the ozone and UV monitoring and research activities are mostly carried out at the facilities of the Czech Hydrometeorological Institute (CHMI). In the recent years the scientists from the Institute of Atmospheric Physics of the Czech Academy of Sciences, Prague (IAP-CAS) were involved in investigation of the relation between ozone and processes in the upper atmosphere.

### 1. OBSERVATIONAL ACTIVITIES

Long-term monitoring of the ozone layer started in CR more than five decades ago in 1961 as a contribution to the initiative of the International Geophysical Year and later to the GAW Programme of WMO. In 1994 measurements of UV spectral and erythemal radiation have been implemented at the Solar and Ozone Observatory (SOO-HK) to couple monitoring of both important environmental parameters. Currently these activities become more integrated into the projects and in-situ infrastructure of the European Union. Significant attention is paid to the scientific presentation of the outputs and to the public information.

#### 1.1 Column ozone measurements

Uninterrupted daily observations of total ozone (TOZ) by the Dobson D074 and Brewer MK-III B098 (single) and MK-IV B184 (double) spectrophotometers have been performed at SOO-HK in Hradec Kralove since 1961 and 1994, respectively. The TOZ measurements are regularly deposited into the World Ozone and UV Data Center (WOUDC) in Toronto as free available data sets and to the Total Ozone Mapping Center operated by Environment Canada for daily mapping of geographical distribution of TOZ. The transfer of the data goes through the GTS-WIS telecommunication system of WMO in Buffer-CREX codes.

Since 2010 the Brewer MK-III spectrophotometer B199 of CHMI has been operated at the station Marambio Base in Antarctica under the bilateral cooperation of CR and Argentina. This international project is supported by the Ministry of the Environment of the Czech Republic as a contribution of CR to the monitoring of the ozone layer in the area of the “ozone hole”.

#### 1.2 Profile measurements of ozone

Monitoring of ozone profiles by the electrochemical ozone sondes is continued at the Upper Air Department (UAD-PR) of CHMI in Prague. Since 1992 the measurements have been performed using the ECC sondes and the VAISALA DigiCORA facility. The balloon-born sondes are launched three times a week from January to April. The observations are submitted to the WOUDC and also to the data bases of the Network for the Detection of Atmospheric Composition Change (NDACC).

Regular daily measurements of vertical distribution of ozone up to about 50 km by the Umkehr inverse technique are performed at SOO-HK by the Brewer spectrophotometers. A special software package was developed by experts from SOO-HK and NOAA Boulder that is used for operation of the instruments and data processing.
1.3 UV measurements

1.3.1 Broadband measurements

The UV-Biometers are still operated at 4 CHMI stations (Hradec Králové, Košetice, Kuchařovice and Labská Bouda) that are located in typical climate and geographical regions of CR. The 10-minute erythemal irradiances (EUV) are collected in the near-real-time at SOO-HK and presented together with the actual TOZ and UV-Index values at the web portal of CHMI http://portal.chmi.cz//files/portal/docs/meteo/ozon/o3uvb.html.

1.3.2 Narrowband filter instruments

Since January 2013 the narrowband spectral measurements of the solar radiation have been carried out at SOO-HK using the 10-channel SPUV-10 filter sun photometer (Yankee Env. Systems, Inc. USA, http://www.yesinc.com/products/radvis.html). The instrument measures irradiances at 10 selected wavelengths from UV to IR parts of the solar spectrum (316.6; 331.7; 367.3; 413.4; 495.8; 613.4; 672.0; 869.4; 938.3; 1023.6 nm). These make calculation of atmospheric parameters related to ozone (APD, NOx, water amount, SO2) possible. The photometer is operated simultaneously with Brewers and spectral irradiances are processed by the libRadtran software package, see e.g.: http://www.libradtran.org/doku.php?id=start.

1.3.3 Spectroradiometers

Spectral measurements of UV solar radiation (298-325 nm) are performed with both Brewer spectrophotometers at SOO-HK and at the Marambio station. The high-quality and evaluated scans are submitted also to the European UV Data Base (EUVDB) at FMI, Helsinki. The Brewer MKIII operated at SOO-HK is used as the national reference for calibration of the operational UV-Biometers.

1.4 Calibration activities

The Dobson D074 instrument is regularly compared towards the regional standard D064 at the Regional Dobson Calibration Center – Europe (RDCC-E), Hohenpsissenberg. The spectrophotometer is maintained as the secondary reference for Europe. The Brewers are calibrated every two years by the travel reference B017 that represents the calibration scale of the World Triad maintained by EC, Canada. In the recent years the calibrations were realized at SOO-HK as the regional intercomparisons of Brewers operated in the region of Central Europe.

The ozone sondes are properly calibrated in the pre-launch preparation procedures defined by the SOPs. New ozone tester Model TSC-1 Ozonizer from the Science Pump Corporation has been installed in 2012 and is being used at UAD-PR.

Calibration of all spectrophotometers and UV-Biometers are now performed by the UV calibration unit (dark box, precise power supply and sets of the PTB standard lamps) that has been installed at SOO-HK. In the future the calibration activities are to expand in cooperation with the Czech Metrological Institute in the frame of the European Metrology Research Programme EMRP that is currently under preparation.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

In the recent years the systematic monitoring of TOZ, the thickness of the ozone layer, at SOO-HK exceeded 50 years. This encouraged the Czech experts to perform a complex analysis of this unique data series and to make several model experiments focused on quality of measurements and evaluation of long-term changes of TOZ over Central Europe.
The particular analyses have reached the following results that are summarized in the papers presented in the list of publications in this Report.

2.1 Data sets
The original daily averages of TOZ (DS and ZS) taken by the Dobson \(X_D\) and Brewers \(X_B\) were homogenized with respect to the international calibrations of the instruments. A combined \(X_{DB}\) data series of \(X_D\) (1961-1993) and \(X_B\) (1994-2010) was created. Because of the seasonal differences between \(X_D\) and \(X_B\) observations due to the temperature sensitivity of the ozone cross sections and by stray-light effects the \(X_D\) data series was converted to the Brewer calibration scale by a regression transfer function developed for the D074 and B098 instruments and the location of SOO-HK. The converted data \(X_{CONV}\) were then merged with the \(X_B\) into the \(X_{MERG}\) data series. Finally the daily values of total ozone \(X_{REAN}\) were filled-in with the help of the ERA-40 and ERA-Interim re-analyses into the \(X_{MERG}\) data set on days with missing observations. In this way a completed \(X_{ALL}\) data series of all days of the period 1961-2010 was created. All the above data sets have been deposited into the open data portal PANGAEA: http://doi.pangaea.de/10.1594/PANGAEA.779819 and further analyzed.

2.2 Trend analyses
The data series of TOZ were used to estimate tendencies of differences of total ozone between the post-Pinatubo (the “recovery” era) and the pre-ozone-hole (the reference) periods. As the differences indicated a discrepant annual course they were investigated for typical seasons – winter/spring (XII-IV), spring/summer (V-VIII) and fall (IX-XI). The results showed that:

- The most pronounced and the earliest depletion of the ozone layer over Central Europe occurred in the XII-IV months with the minimum (- 10%) in the mid 90s. This ozone decrease was followed by a similar ozone reduction (-7%) in the V-VIII season. In the IX-XI months the changes did not reached statistically significant levels – see Fig. 1.
- While in the season XII-IV the ozone depletion is followed by its recovery in the recent years, the summer values (V-VIII) remain persistent on the reduced levels.
- Significant differences of seasonal tendencies estimated by linear approximations have been found in the post-Pinatubo era if particular data series are taken for the analysis.
- The calibration-consistent data series \(X_D, X_{MERG}, X_{ALL}\) confirm the above seasonally different changes. The \(X_{DB}\) (combined Dobson and Brewer calibration scale) shows a remarkable lower gradient in XII-IV and continuing negative tendency in the V-VIII season. This confirms an instrumental (calibration) signal in the statistical data set \(X_{DB}\) that can influence evaluation of recovery of the ozone layer in the current and forthcoming years.
- The data series \(X_{ALL}\) or \(X_{MERG}\) have been found to be the most representative for more sophisticated analyses of the long-term changes of TOZ. If the linear approximation is taken for estimation of the tendencies then recovery of the ozone layer over Central Europe can be expected about 2020 in the winter/spring season. But no positive tendencies are evident for the summer season.

2.3 Homogenization and changes of ozone vertical profiles
The ozone sonde observations performed at UAD-PR in Prague (winter-spring months I-IV) of the period 1983-2011 were revised and homogenized by means of correction factors calculated from parallel total ozone measurements taken at SOO-HK and using the updated Standard Operation Procedures (SOPs) defined for the GAW Programme. The ozone profiles were then used both for calculation of ozone effective temperature \(T_{eff}\) applied in the transfer function \(X_D\) to \(X_B\) and for estimation of changes of ozone concentrations on particular levels / altitudes. Comparison of average profiles showed significant changes of vertical distribution of ozone manly in the 80’s (Fig. 2). While amount of ozone in troposphere increased by about 100 % a significant ozone decrease (-25 %) was found in the lower
stratosphere. But after the Pinatubo minimum ozone partial pressure has increased here up to -10 %. In the recent decade the ozone concentrations are almost stable on all levels up to cca 30 km.

Difference between the Umkehr observations of ozone vertical distribution (UMK) measured by the Brewer spectrophotometers at SOO-HK and ozone sonde profiles from UAD-PR was also investigated. The comparison included 158 UMK and ozone sonde profiles that were performed on the same days of very good weather condition. The results showed the best agreement (less than 2 D.U.) in the layers 5 and 6 that are located at the altitude of the ozone maximum. In the layers 2, 3 (close to the tropopause) and 7, 8 (close to end of the ozone sonde flights) the differences were substantially higher. The UMK observations were processed by the UMK-04 algorithm using the apriori “sonde” and “climate” profiles. It has been found that the “climate” profile gives better results. Comparison of simultaneous UMK profiles measured by the B098 (single monochromator equipped with the NiSO4- UV filter) and by the B184 (double monochromator) instruments shows a very good agreement. This confirms capability of both spectrophotometers to produce UMK measurements of equivalent quality.

Fig. 1 Relative differences $\Delta X_{\text{ALL}}$ between yearly seasonal total ozone averages and the reference pre-ozone-hole values in the particular seasons XII-IV, V-VIII, IX-XI smoothed by robust locally weighted regression, Hradec Králové (1961-2010).
3. THEORY, MODELLING, AND OTHER RESEARCH

3.1 Modelling of TOZ changes by the Extreme Values Model (EVM)

The EVM model was used to evaluate and quantify contribution of extreme high (EHOs) and low (ELOs) total ozone values to long-term changes of the ozone layer at SOO-HK. The first application of the EVM was performed using the original Dobson observations $X_D$ (ref). Then the model was running with the merged $X_{MERG}$ data. Together with impacts of the EHOs and ELOs “fingerprints” of EESC (vortex losses) and of selected geophysical proxies (circulation indices ENSO, NAO-, NAO+, volcanic eruptions) were identified. The basic results that are documented in Fig. 3 can be summarized as follows.

- Frequency of the ELOs was decreasing from the mid 70s to the mid 90s and then it has become stable. This can be explained by higher occurrence of the ozone “mini-holes” of the dynamical origin passing through the region in the spring and summer months. The lower values in 1992 and 1993 are evidently linked to the Pinatubo eruption.
- Occurrence of the EHOs has decreased during the period concerned. But this change appeared after the mid 80s – in the ozone-hole period, when the ozone layer was attenuated globally. In the last two decades the numbers of EHOs is almost stable. This could be related to decreasing of amount of ozone in Arctic air masses that penetrated to the mid-latitudes after the brake-down of the vortex. Such situations are registered only sporadically in the current years.
- Annual and seasonal trends estimated from the data series with and without the extreme values show an important influence of the EHOs and ELOs extreme values on the long-term trends.
As the occurrence of the extreme values are usually related to exceptional circulation/dynamical situations the above contribution of EHOs and ELOs to trends can be attributed mostly to natural external processes than to EESC.

Assessment of the relation between the EHOs and ELOs and the circulation and geophysical phenomena are documented in Fig. 3 by marks attributed to the individual parameters. It is evident that the frequency of EHOs decreases with increasing of ENSO and NAO- indices. On the contrary, when the NAO+, volcanic activity and ozone losses in the vortex are high numbers of ELOs increase and numbers of EHOs decrease.

The above findings confirm a significant contribution of the natural processes to changes of the ozone layer over Central Europe that are at least comparable with the chemical losses of stratospheric ozone.

Fig. 3 Yearly frequencies of days with extreme low (ELOs) and high (EHOs) values of total ozone. $X_D$ (blue line) and $X_{MERG}$ (red line), Hradec Králové (1965-2005). Points: ENSO (blue), NAO- (red), NAO+ (orange), volcanic eruptions (pink), vortex losses(gray). Full marks – significant, crosses – not significant.

3.2 Modelling of TOZ changes by the Neural Networks Model (NNM)

The NNM technique comes out from creation of non-linear regressions between estimated parameters – predictands and input proxies – predictors. Construction of the NNM model that was used for estimation of the monthly averages of total ozone $X_{ALL}$ (predictands) has been developed using the Intelligent Problem Solver (IPS) of the programme Statistica Neural Networks. Before its final design and application the model was tested by a large set of potential predictors that included:

- Upper Troposphere / Lower Stratosphere (UT/LS) parameters (divergency, relative vorticity, potential vorticity, specific humidity, relative humidity, zonal wind, meridional wind, vertical velocity, geopotential high, temperature, all in 10 standard pressure levels (300, 250, 200, 150, 100, 70, 50, 30, 20 a 10 hPa and tropopause pressure and temperature.
- The external (forcing) parameters (the EESC reference data set from WMO 2010, the Aerosol Optical Depth (AOD) data set for the belt of 50 N in three stratospheric layers (15-20, 20-25, 25-30 km) and variability of their vertical profiles, solar activity SOLAR by the radio flux on 2800 MHz from the observatories Ottawa and Penticton and by the sunspot number).
- Parameters of the climate dynamics (NAO, circulation indices NINO1+2, NINO3, NINO4 a NINO3.4, zonal wind in Pacific (Singapore) as a parameter of the Quasi Biennial Oscillation (QBO).
Parameters of the annual course (the Sine and Cosine functions characterizing position of particular months in the annual course).

Altogether 219 possible predictors were tested and their importance evaluated during the tuning process. Finally the time evolution of impacts of particular predictors on changes of TOZ was estimated.). The results viewed in (Fig. 4) show that:

- The 11-year solar cycle is evident but it influences total ozone only by about ±1% without long-term effects.
- Impacts of the AOD loading due to the recent major volcanic eruptions (El Chichon 1982 and Pinatubo 1991) are well pronounced (-3%) but the effects disappeared relatively fast.
- Impact of the UT/LS parameters seems to be almost simultaneous with the solar activity by the mid 80s. Then a rapid increase of their impact (-2% ozone depletion) is evident with a stable character in the current years.
- Increasing amount of EESC caused reduction of ozone till the mid 90s when it reached its maximum (about -5%). Decreasing trend of the EESC concentrations in the atmosphere then caused reduction of its impact by a half to -2.5% in the recent years.
- If the episodic impact of the volcanic eruptions is avoided then the most significant reduction of total ozone in the 20-th century was caused by about 2/3 due to the chemical processes and by 1/3 due to changes of the dynamics and thermo-dynamics in the UT/LS. In the recent 15 years the influence of EESC is getting clearly weaker while the impact of the UT/LS processes is not changing remarkably. The chemical ozone reduction is thus losing its dominant influence on the ozone layer over the region.
- It is apparent that the solar activity affects total ozone in the 11-year cycle but without an annual course. The AOD contributed significantly in the mentioned volcanic episodes in 1982 and 1991 mainly in the winter months. The UT/LS predictors are the substantial contributors to the changes of total ozone after 1985. The influence of EESC reaches maximum in spring and early summer. Its increase is evident in the 80s and then weakening in the first decade of the 21-st century.
- Comparison of the time evolution of the influence of the UT/LS predictors with EESC in particular months indicates that in the winter months the influences are comparable. But in spring and in summer the impact of EESC was clearly dominating. The slower recovery of ozone in the summer months in the recent 15 years (Fig. 1) is thus apparently related to slower decrease of EESC in this season while in the winter months lowering of the EESC concentrations together with changes of some UT/LS parameters accelerate the ozone increase.
3.3 Prognoses of TOZ by the NNM model

The NNM was used to estimate the future evolution of the ozone layer over Central Europe in coming decades because of the decrease of EESC as the key parameter. The particular predictors were therefore taken as follows. Solar activity constant on the level of 1961-2010 without the 11-year cycle, AOD constant on the zero level (clear stratosphere), UT/LS predictors constant as the monthly medians of the period 1961-1985 (no climate change), EESC values according the WMO2010 of the period 1961-2100.

The simulated changes of total ozone are viewed in Fig. 5 as differences between the modeled monthly averages of TOZ and the measured values $X_{ALL}$ of the reference period 1961-1980. It is evident from the graph that a rapid and strong influence of the EESC concentrations appeared in the 80s, mainly in spring and beginning of summer while in winter it was remarkably lower. The impact peaked around 1995 and later on it has been slowly decreasing. While in December and January the influence is low in the present in the summer months it is still significant and decreasing very slowly with expected ozone recovery about 2030-2050. Because the variability of UT/LS predictors was not taken in the model, the expected climate change could influence the above estimations. The increasing contribution of the UT/LS parameters then can reach and even exceed the impact of the EESC and stabilize the ozone layer below its pre-ozone-hole level. Contribution of the UT/LS processes

Fig. 4 Time evolution of the relative effect of particular predictors on the values of total ozone with respect to the pre-ozone-hole period 1961-1980, Hradec Králové, 1961-2010. Thin curves – data smoothed by the centered 13-month running means (the annual course removed). Thick curves – data smoothed by the robust locally weighted regression (influence of UT/LS and EESC with the smoothing parameter $\alpha=0.13$, AOD and solar activity SOLAR with the smoothing parameter $\alpha=0.02$).
to the ozone recovery in the regional scale therefore should be assessed using the regional outputs from the climate-models. But these are still not available.

![Image](image-url)

*Fig. 5 Estimated long-term evolution of the impact of EESC on total ozone in the area of Central Europe simulated by the Neural Network Model - relative differences in percents towards the “pre-ozone-hole” period 1961-1980.*

### 3.4 Other research

The research activities performed by the team of IAP-CAST show that the trends in stratospheric and mesospheric temperatures have somewhat changed in the mid-1990s in accord with the change of ozone trends. The change in ozone trend resulted in levelling-off of stratospheric temperature trends, in leveling-off or maybe even reversal changes of mesospheric temperature from negative to slightly positive, and in change of the mesopause region temperature trends from none to somewhat negative once. A high dependence of annual variation of ozone has been also found. This finding can contribute to interpretation of observed trends in winds in the stratosphere. The update of investigations confirmed continuation of change of the laminae trends from negative to positive in the mid-1990s. Some influence of the 11-year solar cycle on the Brewer-Dobson circulation was found, which might have an impact on the overall state of circulation system in the stratosphere.

### 4. DISSEMINATION OF RESULTS

#### 4.1 Data reporting
The CHMII facilities continue deposition of the ozone observations mainly to the WOUDC Toronto and the high quality UV spectral irradiances into the European UV Data Base (EUVDB) at FMI, Helsinki. The daily representative values of TOZ are submitted to the World Ozone Mapping Centre of the Environment Canada via the GTS/VIS telecommunication system using the CREX-BUFER codes. The ozone sonde observations are submitted to WOUDC and NDSC data base via FTP accounts and to the partners in the MATCH campaigns via NILU database.

4.2 Information to the public
For a long time the actual values of total ozone and the UV-Index in the territory of CR and their comparison with the long-term averages are presented daily in mass media and at the web portal of CHMII: http://portal.chmi.cz/files/portal/docs/meteo/ozon/o3uvb.html. In this way the public have the full on-line access to the fresh pieces of information related to the condition of the ozone layer and harmful UV irradiances. Actual data of total ozone from the Marambio station are presented at the web page of the project.

Public presentations of the complex information on the condition of the ozone layer in the global scale and over the territory of CR were given by the Czech research teams to the public, scientific community and students at joint meetings in the recent years. These were organized by the Ministry of the Environment of CR at universities and in the conference facilities usually in relation with celebration of the International Day for the Preservation of the Ozone Layer. The chief goals and implementation of the Vienna Convention and the Montreal Protocol were presented and discussed at the meetings, as well.

4.3 Relevant scientific papers
Except of many oral and poster presentations given at the scientific meetings including the Quadrennial Ozone Symposium 2012 the following per-reviewed papers were published in the scientific journals.


5. PROJECTS AND COLLABORATION

In the recent years the researchers of the Czech institutions participated or still contribute to the following research and development projects and collaborations.


- “Upgrade of technological facilities for monitoring of the ozone layer and UV solar radiation in the territory of the Czech Republic”. Development project supported by the Ministry of the Environment of CR No.:03431021, 2011-2013. The UV calibration unit as a national etalon for calibration of the UV monitoring instruments and the SPUV-10 solar photometer for measurements aerosol optical depth (AOD) in the UV, VIS and NIR wavelength regions of the solar spectrum were installed and their operation started at SOO-HK. 67 ozone sondes and the ozone tester for their calibration were bought and launched at UAD-PR. Terminated.


- COST-ES1207 “A EUropean BREWer NETwork – EUBREWNET”: Research and development project implemented by the European Union (2013-2017). Creation of a joint infrastructure for operation of the Brewer spectrophotometers in Europe is the main goal of the project. Experts from CHMI-SOO-HK are involved mostly in creation and implementation of the operational software and calibration procedures of the instruments. Continued.


- WMO/GAW/RDCC-E: “The Regional Dobson Calibration Centre – Europe”. Bilateral cooperation between the German Weather Service, Meteorological Observatory


6. FUTURE PLANS

With respect to the recommendations of the previous ORMs the ozone and related research and development activities carried out in CR will be focused on the following topics and goals.

- The ozone and UV monitoring programme implemented by CHMI including the international data transfer and public presentation of the outputs to be performed in its current structure and scope.
- The research and development projects specified above that have not expired to be continued.
- CHMI facilities to continue assistance to the ozone segment of the GAW programme mainly through the activities and actions organized by the Regional Dobson Calibration Centre - Europe in the area of calibration of instruments, re-location of the unused spectrophotometers and training of their operators.
- Cooperation with the European central facilities on metrological standardization of the Dobson instruments under the Joint Research Project proposed by the PMOD Davos to the European Metrology Research Programme (EMRP).
- CHMI experts to further investigate relation between ozone changes and the climate change in the region of Central Europe.
- To expand utilization of solar spectral observations carried out at SOO-HK for calculation of other atmospheric parameters related to ozone and UV.

7. RECOMMENDATIONS addressed to the 9-th ORMM

- The relocation of unused instruments for monitoring of total ozone (Dobson) and possibly also UV (Brewer) is an important part of the capacity building. Though each campaign usually has specific features, general rules on ownership, financial support for transport of instruments, training of operators and installation at the site should be defined and fixed under the umbrella of WMO and UNEP. This will make preparation and realization of such actions faster, simple and more efficient.
- Because of the recent rearrangements in the World Ozone and UV Data Center, Toronto the activities and personal capacity of the WOUDC, as a key data facility of GAW, has decreased. An urgent attention should be paid to its revitalization by WMO and Environment Canada.
- Though the EUBREWNET project is focused mainly on the European area many of its outputs will get features for their general implementation in the global network. These are to be fostered by the WMO facilities (RBCC-E) and expert groups (SAG-O3).
- Collection of the historical primary (0-level) data and the calibration metadata from the Dobson stations was recommended to the 8-ORM. This actual topic of the highest priority of WOUDC remains for coming years.
Monitoring of the State of the Earth’s Ozone Layer and Solar UV-radiation in Antarctica - the Contribution of the Czech Republic to the Vienna Convention and the Montreal Protocol

OBSERVATIONAL ACTIVITIES 2010 - 2014

Measurements of ozone and UV-radiation
Four years ago the Solar and Ozone Observatory of the Czech Hydrometeorological Institute in cooperation with the Argentine Antarctic Institute installed the Brewer ozone spectrophotometer (double MKIII) No. 199 at the Marambio Base - Argentina, Antarctica. The Brewer spectrophotometer No.199 (B199) is a fully automated instrument (Fig.1).

Fig.1: The Brewer No.199 and travelling standard the Brewer No. 17 (International Ozone Service, Toronto Canada at the Marambio Base in January 2012.

This activity is the project of the Ministry of the Environment of the Czech Republic and the State Environmental Fund of the Czech Republic "Monitoring of the State of the Earth’s Ozone Layer and Solar UV-radiation in Antarctica - the Contribution of the Czech Republic to the Vienna Convention and the Montreal Protocol",
Cooperation with Argentina is the result of close cooperation in matters relating to the Antarctic between the Government of the Czech Republic and the Government of the Argentine Government in 2010.

The aims of the present work is to improve scientific knowledge for global assessments on ozone depletion and climate change for the Montreal protocol to the Vienna Convention, better understanding of processes in the upper troposphere and lower stratosphere through modelling and data analysis and studies of the long-term variability in extratropical large scale transport are also being performed to improve long-term predictions of mid and high latitude ozone and UV radiation.

**Calibration activities**
The B199 has been independently calibrated by travelling standard the Brewer No. 17 - International Ozone Service, Toronto Canada (IOS) in 2012, Fig. 2. The B199 is regularly checked and maintained each year during austral summer.

![Fig.2: The results of calibration between the Brewer No.199 and travelling standard the Brewer No. 17 (International Ozone Service, Toronto Canada at the Marambio Base in January 2012.](image)

**RESULTS FROM OBSERVATIONS AND ANALYSIS**
The project consists of three parts.

Part A: The introduction of regular measurements of total ozone and UV-spectral radiation in the area of the north-eastern part of the Antarctic Peninsula (Marambio Base – Argentina) and on-line transmission of data.

Part B: The use of measurements of total ozone and vertical profile of ozone - Umkehr for the operational assessment of the state of the ozone layer and validation of satellite measurements.
Part C: The use of spectral measurements of UV radiation for operational evaluation of the field UV-index in the Antarctic for validation of satellite measurements.

The result of the correlation between Aura-OMI and B199 total ozone measurements (Direct Sun) is presented in Figure 3.

Fig 3: Correlation between daily means Aura-OMI and Brewer (Direct Sun) measurements (March 2010 – February 2014, N = 493, R=0.991).

THEORY, MODELLING, AND OTHER RESEARCH DISSEMINATION OF RESULTS

Data reporting
Ozone observation will be in the next years regularly submitted to the World Ozone and Ultraviolet Data Centre (WOUDC), in Toronto and also to other partner institutions within projects - e.g. Argentine Antarctic Institute and World Meteorological Organisation (GAW – Antarctic Ozone Bulletin), Fig. 4.

Information to the public
During this time over 7 conferences open to the public were given in the different disciplines in the period 2008-2010. Actual data of total ozone are presented NRT on the web page of the project: http://www.antarktida-ozon.cz.
Total ozone is observed at the Argentina GAW station Marambio (64.2°S, 56.6°W) with a Dobson and Brewer MKII spectrophotometer. The measurements started up after the winter on 16 August. Ozone profiles are observed with ozonesondes. Soundings are carried out once to twice per week. Six ozonesondes were launched in June, six in July and nine in August. So far in September nine sondes have been launched. The lowest total ozone value observed so far this year with the Brewer instrument was 152 DU on 21 September (see Figure 19). Also the day after suffered very low ozone with 154 DU. This value is confirmed by the ozonesonde launched on that day. Also with the ozonesonde one deduces a total ozone column of 154 DU on 22 September (Figure 20). During the same time period the 12-20 km partial ozone column has dropped from about 140 DU to 39 DU on 22 September, i.e. a reduction of 72%.

Fig. 4: The example of the Antarctic Ozone Bulletin 2013.
Relevant scientific papers


PROJECTS AND COLLABORATION

- With the Argentine Antarctic Institute
- With the WOUDC, WMO – Antarctic Bulletin
- With the UNEP

FUTURE PLANS

- Continuing of measurements at the Marambio Base and publishing of the results.
- Calibration of the spectrophotometer, Brewer No.199 and Brewer No. 17 – IOS in 2015.

NEEDS AND RECOMMENDATIONS

- Real-time ground base data and continuing validation with the satellite from Antarctica – GTS/WIS and WMO – Antarctic Bulletins.

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1. OBSERVATIONAL ACTIVITIES

The Danish Meteorological Institute (DMI), in collaboration with the Danish Environmental Protection Agency, conducts permanent measurements of the stratospheric ozone layer. Daily ground-based measurements of the ozone layer thickness as well as weekly balloon-based measurements of the vertical ozone profiles are performed in Denmark and Greenland. The measurements are reported to international databases. In addition, the measurements are incorporated in validation of satellite measurements. Balloon-based measurements of the ozone layer are often conducted as part of larger international projects such as Match-campaigns.

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss.

Daily observations of total ozone are performed by the DMI in Denmark and Greenland:

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>Instrument</th>
<th>Start of observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copenhagen</td>
<td>56°N, 12°E</td>
<td>Brewer Mark IV</td>
<td>May 1992</td>
</tr>
<tr>
<td>Sondre Stromfjord</td>
<td>67°N, 51°W</td>
<td>Brewer Mark II</td>
<td>September 1990</td>
</tr>
<tr>
<td>(Kangerlussuaq)</td>
<td></td>
<td>Brewer Mark III</td>
<td>February 2010</td>
</tr>
<tr>
<td>Thule Air Base</td>
<td>77°, 69°W</td>
<td>SAOZ 1024 diode array</td>
<td>September 1990</td>
</tr>
<tr>
<td>(Pituffik)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

Weekly ozone soundings have been performed using balloon-borne EEC sensors from Scoresbysund (Illoqqortoormiut, 71°N, 22°W) since January 1993. Ozone soundings have also been performed on campaign basis from Thule Air Base each winter since January 1992 and occasionally from Copenhagen.

1.3 UV measurements

1.3.1 Broadband measurements

A Yankee Environmental Systems model UVB-1 radiometer has been operated by DMI in Copenhagen since 1996. A custom UV radiometer (erythemally weighted UV and total UV-A) has been in operation in Thule (Pituffik) since 1993. The latter instrument is owned by the Health Protection Agency in the U.K. (former National Radiological Protection Board) and the UV-B part of the instrument is similar to the Solar Light model 500.

1.3.2 Narrowband filter instruments

A narrowband filter instrument – Biospherical Inc., model GUV2511 – has been operated on the east coast of Greenland at Scoresbysund (Illoqqortoormiut) by DMI since 2008.

1.3.3 Spectroradiometers

At Sondre Stromfjord (Kangerlussuaq) the Brewer MkII instrument has measured spectral UV-B (290-325nm) since late 1990 and the Brewer MkIII instrument since February 2010.
2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Summer (June, July, August) average column ozone measurements, based on NASA TOMS Nimbus 7 version 8 (years 1979-1991) and DMI Brewer (years 1992-2013) from Sondre Stromfjord (Kangerlussuaq), Greenland, are shown in left-hand side in the figure below.

Likewise summer (June, July, August) average column ozone measurements, based on NASA TOMS Nimbus 7 version 8 (years 1979-1991) and DMI Brewer (years 1992-2013) from Copenhagen, Denmark, are shown in the right-hand side of the figure. Neither of the two data sets shows significant trends since 1992.

Below is shown the 20-year long record of weekly ozone soundings from Scoresbysund (Illoqqortoormiut). Shown are the vertical profiles of ozone partial pressure (mPa).
3. THEORY, MODELLING, AND OTHER RESEARCH

DMI has participated in major European Arctic and tropic campaigns since the beginning of the 1990's including EASOE, SESAME, THESEO, THESEO-2000-SOLVE, VINTERSOL, HIBISCUS, and Scout-AMMA, as well as a long series of EU-projects. The research is based on a broad spectrum of accessible observations and analyses of meteorological conditions in the stratosphere. DMI participates in the EC-Earth climate model development, in particular regarding an improved representation of the stratosphere, and studies are performed on the downward influence from the stratosphere on tropospheric climate. Using the personal exposure data combined with satellite and ground station data DMI has participated in the development of more accurate models to assess the impact of climate change on future UVR exposure to European populations.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

The measurements are reported to databases under Network for the Detection of Atmospheric Composition Change (NDACC) and World Ozone and UV-radiation Data Center (WOUDC) under the WMO-programme Global Atmosphere Watch (GAW).

4.2 Information to the public

UV-index forecasts, based on Danish total ozone measurements, were initiated at DMI in summer 1992. This public service runs permanently, made public on the Internet and in several media. DMI is responsible for the Near Real Time UV-index processing as part of the EUMETSAT Satellite Application Facility on Ozone and Atmospheric Chemistry Monitoring and provides daily global maps of clear sky UV-indices. DMI has initiated a UV service for Greenland in collaboration with the Greenland Department for Health. DMI’s ozone measurements are made available on the Internet (www.dmi.dk) together with a yearly updated status report (in Danish language).

4.3 Relevant scientific papers


B. Christiansen, Stratospheric bimodality: Can the equatorial QBO explain the regime behavior of the NH winter vortex?, J. Climate, 23(14), 3953-3966, 2010.


5. PROJECTS AND COLLABORATION

Thule (Pituffik), Sondre Stromfjord (Kangerlussuaq), and Scoresbysund (Ittoqqortoormiit) are
Arctic stations within the Network for the Detection of Atmospheric Composition Change. In addition to
the DMI instrumentation, aerosol lidars are operated at these stations by the University of Rome (Italy)
and SRI International (USA), respectively, together with an FTIR spectrometer at Thule, operated by
National Center for Atmospheric Research (USA). DMI also collaborates with Laboratoire
Atmosphères, Milieux, Observations Spatiales (LATMOS) (France) for daily total ozone
measurements by a SAOZ instrument at Scoresbysund. DMI participates from Thule and
Scoresbysund in the yearly Match-campaigns, coordinated by the Alfred Wegener Institute in
Germany, with ozone soundings in the Arctic to quantify the chemical ozone depletion. DMI ozone
measurements have been used for validation of the Suomi-NPP.

Aerosol robots (Aeronet) from NASA are installed in Thule, Sondre Stromfjord, Scoresbysund
and Narsarsuaq in Greenland.

Within the EU-project COMBINE, DMI has been involved in modelling aspects of the
stratosphere-troposphere coupling, investigating the importance of a well-resolved stratospheric
representation for modelling the tropospheric climate. DMI participated in the EU-project ICEPURE
investigating the adverse and beneficial health effects of ultraviolet radiation (UVR) exposure.

The DMI participates in EUMETSAT’s Satellite Application Facility on Ozone and Atmospheric
Chemistry Monitoring, developing operational UV-index products, based on satellite measurements of
the ozone layer.

6. FUTURE PLANS

National funding for ozone and UV monitoring in Denmark and Greenland is secured until the
end of 2015. After this period the funding situation will be renegotiated.

Research efforts will be directed towards improved understanding of the role of stratospheric
changes for tropospheric climate including the dynamical coupling between the troposphere and the
stratosphere. It is intended to include a stratospheric representation in new developments of the EC-
Earth model complex.

7. NEEDS AND RECOMMENDATIONS

It is considered important to monitor the recovery of the ozone layer at high latitudes during
changing stratospheric climatic conditions (decreasing temperatures, perhaps increased water vapour
concentrations and other changes in chemical composition, changes in stratospheric dynamics).
Maintaining and running stratospheric monitoring stations in the Arctic and elsewhere is becoming an
increasingly heavy burden on national funding sources and possibilities for direct funding of ground-
based monitoring activities and data provision should be considered to be included in major
international programmes such as the European Copernicus.
DOMINICAN REPUBLIC

The Dominican Republic has ratified the Montreal Protocol on Substances that Deplete the Ozone Layer and the amendments thereto: London (ratified in June 1998); Copenhagen (ratified in June 1998); Montreal (ratified in May 2005) and Beijing (ratified in October 2008). The Dominican Republic has therefore developed activities to protect the ozone layer, both within specific projects and through the work of the Ozone Unit, following the guidelines set out under the Montreal Protocol for the gradual elimination of substances that deplete the ozone layer.

The implementation of investment and non-investment projects is financed by the Multilateral Fund for the Implementation of the Montreal Protocol and carried out through its implementing agencies, namely the United Nations Development Programme (UNDP); the United Nations Environment Programme (UNEP); World Bank; and the United Nations Industrial Development Organization (UNIDO).

The Dominican Republic is currently implementing the HCFC phase-out plan with UNDP as the implementing agency. This project, financed by the Montreal Protocol, provides for innovative direct collaboration with the private sector, which is directly responsible for the implementation of industrial reconversion activities for polyurethane foams. Furthermore, activities will be implemented jointly with the refrigeration and air conditioning services sector in order to achieve the established targets.

At a more technical level, the most widely used group of ozone-depleting substances controlled under the Montreal Protocol includes HCFC-141b and HCFC-22, listed in annex C, group 1, of the Protocol. HCFC-141b, which has an ozone-depleting potential (ODP) of 0.11, is used primarily in the manufacture of polyurethane foam (rigid foam for thermal insulation and integral skin foams for the car manufacturing industry) and, in significantly lower quantities, as a solvent for cleaning refrigeration systems. HCFC-22, which has an ODP of 0.055, is primarily used in the Dominican Republic as a refrigeration gas in the maintenance of commercial refrigeration and air conditioning equipment. Other types of HCFC listed in annex C, group 1, of the Montreal Protocol may also be used in the manufacturing and servicing sectors in expanded polyurethane foams, solvents, sterilizing solutions and fire extinguishers.

In accordance with decision XIX/6 of the Montreal Protocol, which significantly accelerated the phase-out of HCFCs, baseline consumption was calculated as the average consumption for the years 2009 and 2010. The first control measure was the freezing of consumption at the baseline level in 2013; the second is a reduction of 10 percent by 2015; the third is a reduction of 35 percent by 2020; and the fourth is a reduction of 62.5 percent by 2025. The final stage of compliance seeks to eliminate HCFC consumption by 1 January 2030, allowing an annual average of 2.5 percent for maintenance services during the period 2030–2040.

In the Dominican Republic, the use of HCFCs can be broken down as follows:

- Pure HCFC-141b, used to flush refrigeration equipment.
- HCFC-141b in imported polyols for foam manufacturing.

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1 http://www.multilateralfund.org/
2 http://www.undp.org/energyandenvironment/
3 For the purposes of the Montreal Protocol, national consumption is calculated as national production plus imports minus exports. The Dominican Republic is neither a producer nor an exporter of HCFCs.
• Pure HCFC-22, used in the maintenance of refrigeration and air conditioning equipment and refrigerated vehicles.
• Pure HCFC-123, used in operational industrial refrigeration systems.

The Ozone Unit, the official title of which is PRONAOZ, falls under the Ministry of the Environment and Natural Resources. Under the Montreal Protocol, it is the government organization responsible for the implementation of national activities designed to preserve the ozone layer and works in coordination with other institutions and organizations. The principal responsibilities of PRONAOZ within the context of the Montreal Protocol are as follows:

• The formulation and application of general and specific policies relating to the environment and the preservation of the ozone layer.
• Responsibility for the collection of information and production of statistics relating to material advances in the preservation of the ozone layer.
• Raising awareness in the general population with regard to the preservation of the ozone layer, global warming and the measures which the country is taking in response.
• Managing the preparation of projects designed to fulfil the commitment made by the country to the phased reduction in the use of ozone-depleting substances and HCFCs, in accordance with national policies and the regulations laid down by the Multilateral Fund, to present to the Executive Committee of the Multilateral Fund for the Implementation of the Montreal Protocol; approving such projects and presenting them to the Executive Committee.
• Overseeing management and control systems for consumption data relating to ozone-depleting substances.

When the tasks listed in the previous section relate specifically to the Montreal Protocol, they are carried out by PRONAOZ. The Ozone Unit acts as a national focal point for the coordination of projects designed to eliminate ozone-depleting substances.

From a geopolitical perspective, the Dominican Republic is strategically located in the Caribbean and we therefore believe that we may be one of the countries in the region that requires financial support from the funds designated for the strengthening of data acquisition relating to ultraviolet rays in accordance with decision VCVI/2, adopted at the Sixth Conference of the Parties to the Vienna Convention in November 2002. Paragraph 2 of that decision requested UNEP, in consultation with World Meteorological Organization, to establish an extrabudgetary fund for the purpose of financing activities on research and systematic observations relevant to the Vienna Convention in developing countries and countries with economies in transition. The decision also established the primary aim of that fund as “[providing] complementary support for the continued maintenance and calibration of the existing World Meteorological Organization Global Atmospheric Watch4 ground-based stations for monitoring column ozone, ozone profiles and ultraviolet radiation in the developing countries and in the countries with economies in transition, to address balanced global coverage” and, at the same time, to consider “[supporting] other activities identified by the Ozone Research Managers and in consultation with the co-chairs of the United Nations Environment Programme Scientific Assessment and Environmental Effects Assessment Panels, for the improvement of the observation network and relevant research”.

4 “Global Atmospheric Watch” in English.
The country has some 120 meteorological stations, covering an area of 48,442 square kilometres, of which a sample of 10 stations situated in areas which could provide data on the most important regions of the country, such as tourist areas and border zones, could be used (see map in annex I). That activity would improve service to the community and tourists, and would increase the operational capacity of the National Ozone Programme to act as a specialized technical organism mandated to monitor the effects of the depletion of the ozone layer and fulfil the commitments entered into by the country under the Montreal Protocol.

In addition to the fact that such evaluations would enable the parties to assess the control measures taken under the Montreal Protocol and would serve as a means of communication between the scientific research community and decision makers, it would also facilitate the making of specific recommendations to the parties with regard to the provision of funds to improve research coordination and the establishment of networks.

The National Ozone Programme is responsible for the execution of the activities planned under this programme and the initiative would be implemented in coordination with the National Meteorological Office (ONAMET). The fact that the aim of such meetings is “to review ongoing national and international research and monitoring programmes with a view to ensuring proper coordination and identifying gaps that need to be addressed” should be borne in mind, as should the importance of science as the basis for the decisions of the parties, the importance of monitoring and research to better understand atmospheric processes and changes, including the impact of the implementation of the new HCFC adjustments, and the fact that it is clear that the changes in stratospheric ozone will have an impact on the climate of the planet. The climatic effects of the reduction in ozone-depleting substances as a result of the Montreal Protocol have also been proven to be highly significant in comparison with those of the Kyoto Protocol.

In conclusion, the Dominican Republic remains committed to national and international action to preserve the ozone layer.
ECUADOR

Geophysical Overview
The entire territory of the Republic of Ecuador is located amid the tropical region and features a vast zone with a complex topographic situation on its highland cities. The Ministry of Public Health has expressed major concern for high level of UV radiation, which easily reaches over 17 Perth index points, on certain Andean cities.

Consequently, Pan American Health Organization (PAHO/WHO) has requested Ecuadorian authorities to enable an UV public warning system for certain cities and public awareness campaigns on health risks for UV over exposure.

ACTIVITIES RELATED TO 8TH ORM RECOMMENDATIONS

The National Institute for Meteorology and Hydrology Affairs (INAMHI) has provided assistance to NOAA - Climate Monitoring and Diagnostics Laboratory, to operate radiosondes / ozonesondes at the San Cristobal Regional Station in WMO RA III.

Since 2013 INAMHI has deployed seven Automatic Weather Stations (AWS), equipped with UV radiation sensors. During 2014 INAMHI aims to revamp its solar radiation research capabilities by installing and integrating into the national weather observation grid, our first Brewer Spectrophotometer. Also, during 2014, it is expected for Ecuador to install three additional UV-AWS, and to develop an UV basic forecast program.

Finally, by 2015, Ecuador aims to strengthen its local capacities by implementing 20 additional UV-AWS on highland main populated areas, to improve solar radiation calibration procedures and training on proper equipment for its metrology laboratories.

1. MONITORING.
Map shows the geographical location in which a Weather automatic station was installed with UV and Global Radiation sensors, Brewer Spectrophotometer and ozone radiosonde station:
Green: operative UV-AWS  
Yellow: expected UV-AWS  
Red: Brewer Spectrophotometer  
Cyan: Ozone Radiosonde Station.

<table>
<thead>
<tr>
<th>Estation name</th>
<th>Latitude</th>
<th>longitude</th>
<th>Altitude (m.a.s.l.)</th>
<th>Instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedernales</td>
<td>00° 03’ 49.7” N</td>
<td>80° 03’ 00.8” W</td>
<td>25</td>
<td>Operative UV-AWS</td>
</tr>
<tr>
<td>Santa Elena</td>
<td>02° 14’ 00.6” S</td>
<td>80° 52’ 30.3” W</td>
<td>44</td>
<td>Operative UV-AWS</td>
</tr>
<tr>
<td>Pichilingue</td>
<td>01° 04’ 27.5” S</td>
<td>78° 29’ 34.5” W</td>
<td>81</td>
<td>Operative UV-AWS</td>
</tr>
<tr>
<td>La Argelia</td>
<td>04° 01’ 11.0” S</td>
<td>79° 12’ 04.0” W</td>
<td>2.160</td>
<td>Operative UV-AWS</td>
</tr>
<tr>
<td>Cuenca</td>
<td>02° 53’ 50.1” S</td>
<td>79° 00’ 12.1” W</td>
<td>2.587</td>
<td>Operative UV-AWS</td>
</tr>
<tr>
<td>Izobamba</td>
<td>00° 21’ 57” S</td>
<td>78° 33’ 10.0” W</td>
<td>3.058</td>
<td>Brewer Spectrometer, UV-AWS</td>
</tr>
<tr>
<td>El Puyo</td>
<td>01° 30’ 27” S</td>
<td>77° 56’ 38” W</td>
<td>960</td>
<td>Operative UV-AWS</td>
</tr>
<tr>
<td>Riobamba</td>
<td>01° 39’ 00” S</td>
<td>78° 39’ 00” W</td>
<td>2.760</td>
<td>Expected UV-AWS</td>
</tr>
<tr>
<td>Rumipamba</td>
<td>00° 01’ 05” S</td>
<td>78° 35’ 32” W</td>
<td>2.680</td>
<td>Expected UV-AWS</td>
</tr>
<tr>
<td>San Gabriel</td>
<td>00° 36’ 15” N</td>
<td>77° 49’ 10” W</td>
<td>2.960</td>
<td>Expected UV-AWS</td>
</tr>
<tr>
<td>San Cristobal</td>
<td>00° 54’ 00” N</td>
<td>89° 36’ 00” W</td>
<td>6</td>
<td>Ozone Radiosonde</td>
</tr>
</tbody>
</table>
• **Projects:**
  - Ultraviolet National Network and UV Forecasting. Started on May 2012, supported by the National Authority on Science, Technology and Innovation (SENESCYT), with technological advice by the Atmospheric Physics Laboratory within the San Andrés University, La Paz, Bolivia.

• It is also relevant to mention the Ecuadorian Civil Aerospace Agency (EXA) and Quito’s Environmental Agency, which operates UV-AWS, generating local and national data.

2. **FUTURE PLANS.**
On 2012 INAMHI was categorized as a Public Research Institute, and its mandate has shifted from a service to a scientific background. Since then it has embarked upon several research projects, such as UV National Monitoring Network, Meteorological Radars Grid, Atmospheric Modeling on Forecasting and Climate Change, climate facts on tropical disease proliferation on subtropical areas, etc.

3. **RECOMMENDATIONS.**
Ecuador has identified an essential requirement on institutional strengthening, R&D technical assistance regarding: monitoring solar radiation, air chemistry, to identify and allocate scholarship opportunities for Ecuadorian public servants to boost our institutional capacities related to meteorological research.

Finally, Ecuador remains enthusiastic for the opportunity to log its newly acquire scientific capabilities and data emanating from our meteorological monitoring grid, within the World Ozone Monitoring Network, bidding for INAMHI to be considered among active participants for this thematic area.

Marcelo Ayabaca
12/05/2014
EGYPT, Arab Republic of

1. INTRODUCTION

Egypt lies in the northern corner of Africa. It is bounded by the international frontiers of the Mediterranean Sea in the North, the Red Sea in the East, Libya in the west and Sudan in the south. The total area of Egypt is about 1.02 million Km² and the Capital is: Cairo. Egypt is geographically divided into four main divisions:

- The Nile Valley and Delta (approx. 33,000 Km²): It extends from the North Valley to the Mediterranean Sea and is divided into Upper Egypt and Lower Egypt, extending from Wadi Halfa to the south of Cairo and from North Cairo to the Mediterranean Sea. The River Nile in the north is divided into two branches, Damietta and Rachid embracing the highly fertile agricultural lands of the Delta.

- The Western Desert (approx. 680,000 Km²): Extends from the Nile Valley in the East to the Libyan borders in the west, and from the Mediterranean in the north to the Egyptian southern borders. It is divided into: The Northern Section, it includes the coastal plain, the northern plateau and the Great Depression, the Natroun Valley and Baharia Oasis. The Southern Section, it includes Farafra, Kharga, Dakhla, and El-Owainat in the far south.

- The Eastern Desert (approx. 325,000 Km²): It extends from the Nile Valley in the West to the Red Sea, Suez gulf, and Suez Canal in the East, and from Lake Manzala on the Mediterranean in the North to Egypt's southern borders with Sudan in the south. The Eastern Desert is marked with the Eastern Mountains that range along the Red Sea with peaks that rise to about 3000 feet above the sea level. This desert is a store of Egyptian natural resources including various ores such as gold, coal, and oil.

- Sinai Peninsula (approx. 61,000 Km²): Sinai has a triangular shape having its base at the Mediterranean in the North and its apex in the South at Ras Mohammed, the Gulf of Aqaba to the East and the Gulf of Suez and Suez Canal to the west. It is topographically divided into three main sections. The southern section, it involves extremely tough terrain that is composed of high-rise granite mountains. Mount Catherine rises about 2640 meters above sea level, thus making it the highest mountaintop in Egypt. The Central section, it comprises the area bounded by the Mediterranean to the North, At-Teeh plateau to the south, it is a plain area having abundant water resources derived from rainwater flowing from southern heights to the central plateau.

2. CLIMATE

The Egyptian climate is influenced by the factors of location, topography, and general system for pressure and water surfaces. These aspects affect Egypt's climate dividing it into several regions. Egypt lies in the dry equatorial region except its northern areas located within the moderate warm region with a climate similar to that of the Mediterranean region. It is warm and dry in the summer and moderate with limited rainfall increasing at the coast in winter. The annual average day and nighttime temperatures in Lower and Upper Egypt is 20 and 25, and 7 and 17 respectively.

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2 Mawaheb Abou El-Azm, Mounir W. Labib and Ahmed Abou El-Soud, “Control Measures to Reduce Pollutant’s Levels in the Greater Cairo Area”, [Air and Waste Management Association, Paper # 424, USA, 2008.](#)
Table 1 summarizes monthly-average meteorological parameters for GC over the past 30 years. Through most of the year, wind speed is fairly consistent from the north (ENE to NNW) sector. However, during winter and spring (Nov. – Mar.), somewhat higher average winds are seen in the WSW sector. These often represent desert wind storms (Khamaseen winds) which transport dust from the deserts to the west and produce elevated PM concentrations in GC. Table 1, presents a quick and approximate data for the meteorological elements of the GC area.

Table 1. Monthly-average meteorological data in the greater Cairo (GC) area for the past 30 years

<table>
<thead>
<tr>
<th>Month</th>
<th>Relative Humidity (%)</th>
<th>Visual Distance (Km)</th>
<th>Cloud Cover</th>
<th>Temperature (°C)</th>
<th>Wind Speed and Direction a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>%</td>
<td>Cloud Base (m)</td>
<td>Max</td>
</tr>
<tr>
<td>January</td>
<td>58</td>
<td>9</td>
<td>50</td>
<td>1845</td>
<td>18.1</td>
</tr>
<tr>
<td>February</td>
<td>56</td>
<td>9</td>
<td>50</td>
<td>1756</td>
<td>19.5</td>
</tr>
<tr>
<td>March</td>
<td>51</td>
<td>9</td>
<td>50</td>
<td>2164</td>
<td>23.4</td>
</tr>
<tr>
<td>April</td>
<td>45</td>
<td>9</td>
<td>50</td>
<td>3068</td>
<td>28.1</td>
</tr>
<tr>
<td>May</td>
<td>45</td>
<td>9</td>
<td>50</td>
<td>3677</td>
<td>31.8</td>
</tr>
<tr>
<td>June</td>
<td>49</td>
<td>9</td>
<td>50</td>
<td>1454</td>
<td>34.3</td>
</tr>
<tr>
<td>July</td>
<td>57</td>
<td>9</td>
<td>50</td>
<td>875</td>
<td>34.2</td>
</tr>
<tr>
<td>August</td>
<td>61</td>
<td>9</td>
<td>50</td>
<td>731</td>
<td>33.6</td>
</tr>
<tr>
<td>September</td>
<td>61</td>
<td>9</td>
<td>38</td>
<td>827</td>
<td>32.3</td>
</tr>
<tr>
<td>October</td>
<td>60</td>
<td>9</td>
<td>38</td>
<td>1628</td>
<td>30.0</td>
</tr>
<tr>
<td>November</td>
<td>58</td>
<td>9</td>
<td>38</td>
<td>1663</td>
<td>24.4</td>
</tr>
<tr>
<td>December</td>
<td>59</td>
<td>8</td>
<td>38</td>
<td>2472</td>
<td>20.3</td>
</tr>
</tbody>
</table>

a A double asterisk (**) indicates a “most probable” value while a single asterisk indicates a less probable value.

Meteorological data (temperature, relative humidity, and wind speed and direction) from Cairo International Airport are available on an hourly basis from the U.S. NOAA National Climatic Data Center. Data from other locations may be obtained upon request to Egyptian agencies. Studies conducted by Lowenthal et al. (2001) and Abu-Allaban et al. (2007) showed that PM10 concentrations in GC were higher in fall than in winter, 1999 or during summer, 2002. Surface meteorological data were examined to try to explain differences between fall and winter of 19993. Seasonal-average temperature and vector-averaged wind speed and direction were calculated for four sites in GC. The average winter temperature ranged from 13.7 to 15.4 oC while the average fall temperature ranged from 19.4 to 20.6 oC. Thus, the seasonal variation was approximately 5 oC. The seasonal vector-averaged wind direction ranged from 312 to 6 degrees, i.e., from the north, in both seasons at the four measurement locations. The seasonal variation in concentration was thus unrelated to wind direction. The seasonal vector-averaged wind speed ranged from 1.2 to 2.8 mph in winter and from 0.72 to 1.86 mph in fall. The average ratio of winter to fall wind speed was 1.8±0.8. The lower wind speeds during fall along with increased emissions from agricultural burning may explain the higher PM concentrations during that season because lower ventilation

associated with low wind speeds may allow for buildup of pollutants in the vicinity of the sources in Cairo.

3. **OZONE ACTIVITIES AT EGYPT**

In Egypt, Systematic monitoring of atmospheric ozone, UV solar radiation and related research activities are conducted by Egyptian Meteorological Authority (EMA). All the observations data are performed by ozone and UV solar radiation experts at the regional ozone center in EMA to end up with high quality ozone and UV measurements. After that the data are stored in the central data base of EMA. The atmospheric ozone and UV solar radiation observations contribute to the regular monitoring of the atmosphere and climate in Egypt and to international activities and projects, mainly to the GAW Programme.

4. **OZONE NETWORK AND MEASUREMENTS**

Egyptian Meteorological Authority has been involved in the long-term monitoring of the ozone layer for more than 40 years. Measurements of the total ozone amount and ozone vertical profile by the Umkehr method at Cairo (30.08°N, 31.28°E) by means of the Dobson spectrophotometer No.96 started in 1967, long before the depletion of the ozone layer became great challenge for research community and the policy makers. At 1973 Cairo became a Regional Ozone Center (ROC) for ozone stations at North Africa and Middle East.

After discovering the ozone depletion, in 1984 EMA established another ozone observatory at Aswan (23.97°N, 32.78°E) measuring of the total ozone amount and ozone vertical profile closed to the tropics region by means of the Dobson spectrophotometer No.69.

Since the ozone became an important subject for research community and the policy makers, EMA established another two ozone observatories in both Matrouh and Hurghada in 1998 and 2000 respectively to end up with ozone monitoring network cover the Egyptian sky. In Matrouh, measurements of total ozone and ozone vertical profile by means of Brewer spectrophotometer No.143 while in Hurghada by means of Dobson spectrophotometer No.59. For more details see table: 2.

<table>
<thead>
<tr>
<th>Table 2. The Egyptian Ozone Stations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cairo</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>WMO No.</td>
</tr>
<tr>
<td>Ozone ID.</td>
</tr>
<tr>
<td>Latitude</td>
</tr>
<tr>
<td>Longitude</td>
</tr>
<tr>
<td>Height (m)</td>
</tr>
<tr>
<td>Instrument</td>
</tr>
<tr>
<td>Elements</td>
</tr>
</tbody>
</table>

---

5. EGYPTIAN OZONE MONITORING AND ITS OBSERVATIONAL ACTIVITIES

The ozone monitoring network at Egypt consists of 4-ozone stations are:

1. **Cairo Ozone station:**
   - Measure the total ozone amount and its vertical distribution by the Umkehr Method since 1968.
   - Different type of total ozone amount observations such as Direct sun (DS) and zenith sky (ZB) or cloud sky (ZC) are taken daily for more than 7–times at different zenith angles, using BP-scale.

2. **Aswan Ozone station:**
   - Measure the total ozone amount and its vertical distribution by the Umkehr Method since 1984.
   - Different type of total ozone amount observations such as Direct sun (DS) and zenith sky (ZB) or cloud sky (ZC) are taken daily for more than 7–times at different zenith angles, using BP-scale.

3. **Matrouh Ozone station:**
   - Measure the total amount of ozone, the total amount of SO2 and UV-B since 1998 by means of the Brewer mark II No. 143.
   - Daily regular Adjustments of ETC by using mercury and standard lamps (HG, SL) tests.
   - DS and ZS for O3 and SO2 and UV-B observations are taken daily for more than 10-time at different zenith angles, using BP-scale.

4. **Hurghada Ozone station:**
   - Measure the total ozone amount and its vertical distribution by the Umkehr Method have been started since 2000.
   - Different type of total ozone amount observations such as Direct sun (DS) and zenith sky (ZB) or cloud sky (ZC) are taken daily for more than 7–times at different zenith angles, using BP-scale.
5. **Cairo Regional Ozone Center (ROC) duties:**
   - Responsible for all the data and instruments at all Egyptian ozone stations.
   - Collecting ozone data from all stations in Egypt.
   - Re-calculation of the data of all ozone stations by “DOBSON” software package.
   - Maintenance and Calibration of all ozone instruments.
   - Training Dobson and Brewer Operators.
   - Re-processing of historical data sets and maintenance of total Ozone database.
   - Updating the zenith polynomials correction.
   - All ozone data are regularly submitted to WOUDC (World Ozone and Ultraviolet Radiation Data Centre) in Toronto, Canada.
   - ROC researchers promote the main activities of ozone research.

6. **VERTICAL DISTRIBUTION OF OZONE**

   Vertical distribution of ozone in the atmosphere is measured by both Dobson and Brewer Spectrophotometers (Umkehr method) at Aswan, Matrouh and Hurghada. The N-values are stored in the ozone database at EMA and they are also deposited in the WOUDC, Toronto, Canada for final processes.

7. **SURFACE OZONE**

   EMA measures surface ozone outside urban regions, at Hurghada which is an official WMO Global Atmospheric Watch (GAW) station. Also EMA measures surface ozone at Sidi Branni (31.37°N, 25.53°E). South Valley University (SVU) in cooperation with EMA has been measured surface ozone at Qena city.

8. **CALIBRATION ACTIVITIES**

   - The Dobson spectrophotometers have been regularly calibrated using Mercury and Standard lamps to adjust ETC, R-N tables and Q-table. In this way their intercomparisons stability can be checked and evaluated.
   - Dobson spectrophotometers No.96 has been participated in different international intercomparisons which took place at Poland in 1974, at Boulder Colorado (USA) in 1977, at Arosa Observatory (Swiss Meteorological Institute) in 1986, at Greece in 1997, at Germany 2001, at Dahab (Egypt) in 2004, and at Hohenpeissenberg Observatory (Germany) in 2011.
   - Dobson spectrophotometers No.69 has been participated in different international intercomparisons which took place at Boulder Colorado (USA) in 1984, at Hradec Kralove Observatory (Czech Republic) in 1993, at Arosa Observatory (Swiss Meteorological Institute) in 1999, at Dahab (Egypt) in 2004, and at Hohenpeissenberg Observatory (Germany) in 2010.
   - Dobson spectrophotometers No.59 has been participated in different international intercomparisons which took place at Hohenpeissenberg Observatory (Germany) in 2010, at Dahab (Egypt) in 2004, and at Hohenpeissenberg Observatory (Germany) in 2009.
   - The Brewer spectrophotometer mark II No.64 was calibrated against the reference instrument Brewer No.17 maintained by the International Ozone Corporation (Canada) at the Matrouh observatory in 2005 and 2008.
9. ULTRAVIOLET RADIATION

EMA measures the broadband UV solar radiation due to its biological effect at different sites. Also EMA in cooperation with University of South valley have been measured the broadband UV radiation at Qena since 2000. The present network for monitoring the UV and UVB radiation at Aswan, Qena, Cairo, Rafaah (31.22ºN, 34.20ºE) is shown in table (3).

Table (3): The Egyptian UV and UV-B radiation Stations

<table>
<thead>
<tr>
<th></th>
<th>Aswan</th>
<th>Qena</th>
<th>Cairo</th>
<th>Rafaah</th>
<th>Matrouh</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV</td>
<td>Epply Radiometer</td>
<td>Epply Radiometer</td>
<td>Epply Radiometer</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>UV-B</td>
<td>UVB-1 Pyranometer</td>
<td>UVB-1 Pyranometer</td>
<td>UVB-1 Pyranometer</td>
<td>UVB-1 Pyranometer</td>
<td>Brewer MII</td>
</tr>
</tbody>
</table>

10. COLLABORATION - NATIONAL AND INTERNATIONAL

Ozone and related research are conducted sporadically within the country, mostly at a few academic institutions such as Cairo University, EL Azhar University and South Valley University.

- ROC researchers promote the main activities in ozone research.
- EMA in co-operation with WMO carries out a training program for operators of ozone Arab countries.

Egyptian Meteorological Authority must also acknowledge its many international collaborators with specific references to international programs as:

- The World Meteorological Organization (WMO) for her support to attend international intercomparisons and training courses. Also for the financial support to organize the intercomparison of the Dobson ozone instruments operated in the Africa region at Dahab from 22/2-12/3/2004.n which 21 specialists and 11 instruments from 10 countries.
- USA NOAA ESRL, Boulder for maintenance the ozone instruments.
- WOUDC, Toronto, Canada for the scientific cooperation.
- Training assistance from the CZECH SOO-HK, in Hradec Kralove
- Germany also DWD (European Dobson Calibration facility).
- The state Meteorological Agency of Spain (AEMET) for offering the Brewer training course.
11. RESULTS AND ANALYSIS

11.1 Variation of ozone over Egypt

Figure (1) shows that the Maximum values of total ozone amount appear at spring months over Matrouh and Cairo but appear at summer months over Aswan and Hurghada due to the photochemical effect (near to tropical region).

![Annual variation of ozone at Egyptian ozone observatories](image1)

**Fig.(1). Annual variation of ozone at Egyptian ozone observatories**

Monthly variation and trend of ozone for five years over Egyptian ozone observatories are represent by figure 2. The figure shows that the linear trend is negative at all station.

![Monthly variation and trend at Egyptian ozone observatories](image2)

**Fig.(2). Monthly variation and trend of ozone at Egyptian ozone stations**
11.2 Variation of damage UV at northwest of Egypt

Monthly variation of total ozone amount and the total integral effect of the UV (weighted Erythema UV) radiation coming to the ground level during the day (dose) at Matrouh shown in figure (3). It shows that ozone varies seasonally with a maximum in spring and DUV varies seasonally with a maximum in summer.

Fig. (3). Monthly variation of ozone and weighted Erythema UV at Matrouh

11.3 UV index at northwest of Egyptian

Hourly UV radiation was determined for the entire period evaluated in this study. Figure (4) shows the hourly variation of dangerous UV with its Index over coastal northwest of Egypt (Matrouh).

The amount of UVB light at ground level is determined by the solar elevation, the amount of ozone in the atmosphere and the cloudiness of the sky. When the sun raises higher in the sky the amount of atmosphere its rays have to pass through before striking the ground lessens. Therefore UVB protection is critical in the hours around solar noon. A person being out in the sun during midday hours more than ten minutes if you are without protection. A person should wear protective clothing and use a sunscreen, a hat with a brim and sunglasses.
12. MONTREAL PROTOCOL (MP)

12.1 Background

The Montreal Protocol on Substances That Deplete the Ozone Layer (a protocol to the Vienna Convention for the Protection of the Ozone Layer) is an international treaty designed to protect the ozone layer by phasing out the production of numerous substances believed to be responsible for ozone depletion.

Due to its widespread adoption and implementation it has been hailed as an example of exceptional international co-operation with Kofi Annan quoted as saying that "perhaps the single most successful international agreement to date has been the Montreal Protocol". It has been ratified by 196 states.

12.2 Terms and purposes

The treaty is structured around several groups of halogenated hydrocarbons that have been shown to play a role in ozone depletion. All of these ozone-depleting substances contain either chlorine or bromine (substances containing only fluorine do not harm the ozone layer). For a table of ozone-depleting substances see:

For each group, the treaty provides a timetable on which the production of those substances must be phased out and eventually eliminated.

12.3 Multilateral Fund (MLF)

The Multilateral Fund for the Implementation of the Montreal Protocol provides funds to help developing countries to phase out the use of ozone-depleting substances.

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5 The Ozone Hole-The Montreal Protocol on Substances that Deplete the Ozone Layer
6 http://ozone.unep.org/Ratification_status/
7 The full terms are available from http://ozone.unep.org/Publications/MP_Handbook/Section_1.1_The_Montreal_Protocol
The Multilateral Fund was the first financial mechanism to be created under an international treaty. It embodies the principle agreed at the United Nations Conference on Environment and Development in 1992 that countries have a common but differentiated responsibility to protect and manage the global commons.

The Fund is managed by an executive committee with an equal representation of seven industrialized and seven Article 5 countries, which are elected annually by a Meeting of the Parties. The Committee reports annually to the Meeting of the Parties on its operations.

Up to 20 percent of the contributions of contributing parties can also be delivered through their bilateral agencies in the form of eligible projects and activities.

The fund is replenished on a three-year basis by the donors. Pledges amount to US$ 2.1 billion over the period 1991 to 2005. Funds are used, for example, to finance the conversion of existing manufacturing processes, train personnel, pay royalties and patent rights on new technologies, and establish national ozone offices.

12.4 Ozone Depleting Substances (ODS's)

Ozone layer is a natural filter and a shield that surround the Earth to protect all creatures from the harmful part of Ultra Violet – B rays that threaten man's health and safety.

The source of threat is the result of actions and technology developed by man with the development of civil life and the development of new chemical substances. This led to the emission of gases from substances that cause the depletion to the ozone layer.

Since the Montreal Protocol came into effect, the atmospheric concentrations of the most important chlorofluorocarbons and related chlorinated hydrocarbons have either leveled off or decreased. Halon concentrations have continued to increase, as the halons presently stored in fire extinguishers are released, but their rate of increase has slowed and their abundances are expected to begin to decline by about 2020. Also, the concentration of the HCFCs increased drastically at least partly because for many uses CFCs (e.g. used as solvents or refrigerating agents) were substituted with HCFCs. While there have been reports of attempts by individuals to circumvent the ban, e.g. by smuggling CFCs from undeveloped to developed nations, the overall level of compliance has been high. In consequence, the Montreal Protocol has often been called the most successful international environmental agreement to date. In a 2001 report, NASA found the ozone thinning over Antarctica had remained the same thickness for the previous three years, however in 2003 the ozone hole grew to its second largest size. The most recent (2006) scientific evaluation of the effects of the Montreal Protocol states, "The Montreal Protocol is working: There is clear evidence of a decrease in the atmospheric burden of ozone-depleting substances and some early signs of stratospheric ozone recovery."

Unfortunately, the hydrochlorofluorocarbons, or HCFCs, and hydrofluorocarbons, or HFCs, are now thought to contribute to anthropogenic global warming. On a molecule-for-molecule basis, these compounds are up to 10,000 times more potent greenhouse gases than carbon dioxide. The Montreal Protocol currently calls for a complete phase-out of HCFCs by 2030, but does not place any restriction on HFCs. Since the CFCs themselves are equally powerful as greenhouse gases, the mere substitution of HFCs for CFCs does not significantly increase the rate of anthropogenic global warming, but over time a steady increase in their use could increase the danger that human activity will change the climate.
Policy experts have advocated for increased efforts to link ozone protection efforts to climate protection efforts. Policy decisions in one arena affect the costs and effectiveness of environmental improvements in the other.

13. GLOBAL WARMING POTENTIALS (GWP) OF ODS’S

The global warming potential (GWP) represents how much a given mass of a chemical contributes to global warming over a given time period compared to the same mass of carbon dioxide. Carbon dioxide's GWP is defined as 1.0. A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless. Why are there three values given for the GWP and atmospheric lifetime?

All GWP values represent global warming potential over a 100-year time horizon. Dashes indicate that the source did not include a GWP value for the given compound. The first value in each of the second and third columns is from the Scientific Assessment of Ozone Depletion, 2002. The second and third values in each of these columns are from the Intergovernmental Panel on Climate Change IPCC) Second, Third & Fourth Assessment Reports.

For more specific information on how many of these chemicals are used as substitutes for ozone-depleting substances, the Significant New Alternatives Policy (SNAP) Program's web site presents useful information about it.

The substances subject to restrictions in the Kyoto protocol either are rapidly increasing their concentrations in Earth's atmosphere or have a large GWP.

The GWP depends on the following factors:

- the absorption of infrared radiation by a given species
- the spectral location of its absorbing wavelengths
- the atmospheric lifetime of the species

Thus, a high GWP correlates with a large infrared absorption and a long atmospheric lifetime. The dependence of GWP on the wavelength of absorption is more complicated. Even if a gas absorbs radiation efficiently at a certain wavelength, this may not affect its GWP much if the atmosphere already absorbs most radiation at that wavelength. A gas has the most effect if it absorbs in a "window" of wavelengths where the atmosphere is fairly transparent. Because the GWP of a greenhouse gas depends directly on its infrared spectrum, the use of infrared spectroscopy to study greenhouse gases is centrally important in the effort to understand the impact of human activities on global climate change.

13.1 Calculating the global warming potential

Just as radioactive forcing provides a simplified means of comparing the various factors that are believed to influence the climate system to one another, Global Warming Potentials (GWPs) are one type of simplified index based upon radioactive properties that can be used to estimate the potential future impacts of emissions of different gases upon the climate system in a relative sense.

GWP is based on a number of factors, including the radioactive efficiency (infrared-absorbing ability) of each gas relative to that of carbon dioxide, as well as the decay rate of each gas (the amount removed from the atmosphere over a given number of years) relative to that of carbon dioxide.

---

The radioactive forcing capacity (RF) is the amount of energy per unit area, per unit time, absorbed by the greenhouse gas that would otherwise be lost to space.

The Intergovernmental Panel on Climate Change (IPCC) provides the generally accepted values for GWP, which changed slightly between 1996 and 2001 Third Assessment Report (TAR). The GWP is defined as the ratio of the time-integrated radioactive forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas. Since all GWP calculations are a comparison to CO$_2$ which is non-linear, all GWP values are affected.

14. MONTREAL PROTOCOL PROJECTS IN EGYPT:

Montreal Protocol projects in Egypt can be summarized in different sectors. Different projects were conducted to minimize and stop using of these ODS, these projects can be summarized in the following:

14.1 Foam Projects in Egypt

Table 4. Presents all projects conducted in Egypt in the foam sector, including the Ozone Depleting Potential ODP (Tons) and the Global Warming Potential (GWP) in CO$_{2e}$ metric tons

<table>
<thead>
<tr>
<th>Project Code</th>
<th>Project Title</th>
<th>ODS</th>
<th>ODP (Tons)</th>
<th>GWP (CO$_{2e}$ MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGY/FOA/08/INV/05</td>
<td>Phase-out of CFC-11 in manufacture of flexible polyurethane foam at Misr Foam Co.</td>
<td>CFC-11</td>
<td>121.0</td>
<td>566,280.0</td>
</tr>
<tr>
<td>EGY/FOA/08/INV/06</td>
<td>Phase-out of CFC-11 in the manufacturing of molded, flexible, semi-rigid and rigid polyurethane foam at Taki-Vita factory</td>
<td>CFC-11</td>
<td>50.0</td>
<td>234,000.0</td>
</tr>
<tr>
<td>EGY/FOA/08/INV/07</td>
<td>Phase-out of CFC-11 in the manufacture of molded polyurethane foams at Technopol Egypt SAE</td>
<td>CFC-11</td>
<td>55.0</td>
<td>257,400.0</td>
</tr>
<tr>
<td>EGY/FOA/09/INV/10</td>
<td>Elimination of CFC-12 in the manufacture of extruded polystyrene foam at Al-Sharif Plastic Factories</td>
<td>CFC-12</td>
<td>75.0</td>
<td>804,000.0</td>
</tr>
<tr>
<td>EGY/FOA/09/INV/12</td>
<td>Phase-out of CFC-11 in manufacture of molded foam at Misr Foam Co.</td>
<td>CFC-11</td>
<td>28.0</td>
<td>131,040.0</td>
</tr>
<tr>
<td>EGY/FOA/10/INV/15</td>
<td>Elimination of CFC-11 in the manufacture of molded flexible polyurethane foam at Modern Building Carpentry Co. (Mobica)</td>
<td>CFC-11</td>
<td>20.0</td>
<td>93,600.0</td>
</tr>
<tr>
<td>EGY/FOA/10/INV/17</td>
<td>Elimination of CFC-11 in the manufacture of molded rigid polyurethane foam at Cairo Light Industries Co. (Olympic Electric)</td>
<td>CFC-11</td>
<td>75.0</td>
<td>351,000.0</td>
</tr>
<tr>
<td>EGY/FOA/11/INV/18</td>
<td>Conversion to CFC-11 free technology in the manufacture of rigid polyurethane foam (PUF) at Specialized Engineering Contracting Co.</td>
<td>CFC-11</td>
<td>15.0</td>
<td>70,200.0</td>
</tr>
<tr>
<td>EGY/FOA/11/INV/19</td>
<td>Conversion to CFC-11 free technology in the manufacture of flexible polyurethane foam at Alex Foam (formerly Dekheila Chemical Industries Co.)</td>
<td>CFC-11</td>
<td>130.0</td>
<td>608,400.0</td>
</tr>
<tr>
<td>EGY/FOA/11/INV/20</td>
<td>Conversion to CFC-11 free technology in the manufacture of flexible polyurethane foam (PUF) at Horse Foam Co.</td>
<td>CFC-11</td>
<td>120.0</td>
<td>561,600.0</td>
</tr>
<tr>
<td>Project Code</td>
<td>Project Title</td>
<td>ODS</td>
<td>ODP (Tons)</td>
<td>GWP (CO2e MT)</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------</td>
<td>------------</td>
<td>---------------</td>
</tr>
<tr>
<td>EGY/FOA/1 2/INV/22</td>
<td>Conversion to CFC free-technology in the manufacture of flexible polyurethane foam at Foam Industrial and Hyma</td>
<td>CFC-11</td>
<td>170.0</td>
<td>795,600.0</td>
</tr>
<tr>
<td>EGY/FOA/1 2/INV/26</td>
<td>Conversion to CFC free-technology in the manufacture of rigid molded and miscellaneous PUF at 5 plants: Tiba Air, Egat Company, Solar Energy Company, Ismailia Aluminum Company, and Fu Tech Company</td>
<td>CFC-11</td>
<td>44.2</td>
<td>206,856.0</td>
</tr>
<tr>
<td>EGY/FOA/1 2/INV/27</td>
<td>Conversion to CFC free-technology at Scib Chemical Company</td>
<td>CFC-11</td>
<td>12.4</td>
<td>58,032.0</td>
</tr>
<tr>
<td>EGY/FOA/1 2/INV/28</td>
<td>Conversion to CFC free-technology at El Fateh</td>
<td>CFC-11</td>
<td>59.0</td>
<td>276,120.0</td>
</tr>
<tr>
<td>EGY/FOA/1 2/INV/29</td>
<td>Conversion to CFC free-technology at Industrial Engineering Company for Construction and Development (Icon)</td>
<td>CFC-11</td>
<td>51.0</td>
<td>238,680.0</td>
</tr>
<tr>
<td>EGY/FOA/1 5/INV/36</td>
<td>Conversion to CFC-free technology in the manufacturing of rigid PUF at seven enterprises: GMC, Petrojet, Modern Products, Cairo General Contractors Co., Egyptian Solar Energy, Tawifika, Helwan</td>
<td>CFC-11</td>
<td>69.0</td>
<td>322,920.0</td>
</tr>
<tr>
<td>EGY/FOA/1 8/INV/48</td>
<td>Conversion to CFC free technology in the manufacture of flexible molded PUF and integral skin foam at El Shabrawi</td>
<td>CFC-11</td>
<td>16.0</td>
<td>74,880.0</td>
</tr>
<tr>
<td>EGY/FOA/2 2/INV/64</td>
<td>Phase-out of the remaining ODS consumption in the foam sector (11 enterprises)</td>
<td>CFC-11</td>
<td>319.0</td>
<td>1,492,920.0</td>
</tr>
<tr>
<td>EGY/FOA/1 0/INV/16</td>
<td>Elimination of CFC-12 in the manufacture of extruded polystyrene foam in Advanced Chemical Engineering Systems (Advechems)</td>
<td>CFC-12</td>
<td>183.3</td>
<td>1,964,976.0</td>
</tr>
</tbody>
</table>

### 14.2 Refrigeration Projects in Egypt

Table 5. presents all projects conducted in Egypt in the refrigeration sector, including the Ozone Depleting Potential (ODP) (Tons) and the Global Warming Potential (GWP) in CO2e metric tons.
<table>
<thead>
<tr>
<th>Project Code</th>
<th>Project Title</th>
<th>ODS</th>
<th>ODP (Tons)</th>
<th>GWP (CO2e MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGY/REF/20/INV/58</td>
<td>Elimination of CFC-11 and CFC-12 in the manufacture of commercial refrigeration equipment at El-Mohandes</td>
<td>CFC-11</td>
<td>13.0</td>
<td>60,840.0</td>
</tr>
<tr>
<td>EGY/REF/29/TAS/75</td>
<td>Implementation of the RMP: establishing a national recovery and recycling network</td>
<td>CFC-12</td>
<td>100.0</td>
<td>1,072,000.0</td>
</tr>
<tr>
<td>EGY/REF/13/INV/32</td>
<td>ODS phase-out at Delta Industrial Co.</td>
<td>CFC-11</td>
<td>117.0</td>
<td>547,560.0</td>
</tr>
<tr>
<td>EGY/REF/15/INV/41</td>
<td>Phasing out ODS at Societe Mondiale pour Refroidissement (Alaska) domestic refrigeration plant</td>
<td>CFC-11</td>
<td>55.0</td>
<td>423,500.0</td>
</tr>
<tr>
<td>EGY/REF/13/INV/33</td>
<td>ODS phase-out at Electrostar for Refrigeration Co.</td>
<td>CFC-11</td>
<td>51.0</td>
<td>392,700.0</td>
</tr>
<tr>
<td>EGY/REF/13/INV/35</td>
<td>ODS phase-out at Kiriazi Refrigeration Manufacturing Co.</td>
<td>CFC-11</td>
<td>137.0</td>
<td>1,054,900.0</td>
</tr>
<tr>
<td>EGY/REF/15/INV/38</td>
<td>Phasing out ODS at Helwan Company for Metallic Appliances domestic refrigeration plant</td>
<td>CFC-11</td>
<td>7.5</td>
<td>57,750.0</td>
</tr>
<tr>
<td>EGY/REF/15/INV/40</td>
<td>Phasing out ODS at Islamic Company for Industrialization (Siltal) domestic refrigeration plant</td>
<td>CFC-11</td>
<td>26.0</td>
<td>200,200.0</td>
</tr>
<tr>
<td>EGY/REF/15/INV/42</td>
<td>Phasing out ODS at International Co. for Refrigeration and Appliances (Iberna) domestic refrigeration plant</td>
<td>CFC-11</td>
<td>19.0</td>
<td>146,300.0</td>
</tr>
<tr>
<td>EGY/REF/15/INV/43</td>
<td>Phasing out ODS at El Nasr Company for Electric and Electronic Apparatus (Philips) domestic refrigeration plant</td>
<td>CFC-11</td>
<td>22.5</td>
<td>173,250.0</td>
</tr>
<tr>
<td>EGY/REF/15/INV/39</td>
<td>Phasing out ODS at Super Bosh Factory domestic refrigeration plant</td>
<td>CFC-11</td>
<td>13.0</td>
<td>100,100.0</td>
</tr>
</tbody>
</table>

14.3 Halon Management Bank in Egypt

Table 6. Presents the Halon Management Bank in Egypt, including the Ozone Depleting Potential ODP (Tons) and the Global Warming Potential (GWP) in CO2e metric tons

<table>
<thead>
<tr>
<th>Project Code</th>
<th>Project Title</th>
<th>ODS</th>
<th>ODP (Tons)</th>
<th>GWP (CO2e MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGY/HAL/32/TAS/81</td>
<td>Halon management bank programme</td>
<td>Halon-1211</td>
<td>251.3</td>
<td>467,480.0</td>
</tr>
</tbody>
</table>

14.4 Methyl Bromide Project in Egypt

Table 7. presents the Methyl Bromide project in Egypt, including the Ozone Depleting Potential ODP (Tons) and the Global Warming Potential (GWP) in CO2e metric tons

<table>
<thead>
<tr>
<th>Project Code</th>
<th>Project Title</th>
<th>ODS</th>
<th>ODP (Tons)</th>
<th>GWP (CO2e MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGY/FUM/38/INV/86</td>
<td>National phase-out of methyl bromide in horticulture and commodities fumigation</td>
<td>MB - CH3Br</td>
<td>309.3</td>
<td>1,546.7</td>
</tr>
</tbody>
</table>
14.5 Medical aerosol Project in Egypt

Table 8. Presents the Meter Dose Inhaler (MDI) project in Egypt, including the Ozone Depleting Potential ODP (Tons) and the Global Warming Potential (GWP) in CO$_2$e metric tons

<table>
<thead>
<tr>
<th>Project Code</th>
<th>Project Title</th>
<th>ODS</th>
<th>ODP (Tons)</th>
<th>GWP (CO$_2$e MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGY/PHA/46/INV/91</td>
<td>National CFC phase-out plan (first tranche)</td>
<td>CFC</td>
<td>237.5</td>
<td>2,088,100.0</td>
</tr>
</tbody>
</table>

14.6 Overall Montreal Project in Egypt

Table 9. Presents the overall Montreal Projects in Egypt, including the Ozone Depleting Potential ODP (Tons) and the Global Warming Potential (GWP) in CO$_2$e metric tons

<table>
<thead>
<tr>
<th>Sector</th>
<th>Total ODP (Ton)</th>
<th>Total GWP (CO$_2$e Metric Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOAM</td>
<td>1,612.9</td>
<td>9,108,504.0</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>786.0</td>
<td>5,390,820.0</td>
</tr>
<tr>
<td>Halons</td>
<td>251.3</td>
<td>467,480.0</td>
</tr>
<tr>
<td>Methyl Bromide</td>
<td>309.3</td>
<td>1,546.7</td>
</tr>
<tr>
<td>MDI</td>
<td>237.5</td>
<td>2,088,100.0</td>
</tr>
</tbody>
</table>

Figure 5. ODP Tons of all Montreal Projects in Egypt
Figure 6. GWP of all Montreal Projects in Egypt (CO$_2$ metric tons)

![GWP Graph]

Egypt Consumption of ODS's from 1995 - 2012 comparison with Base Line

Figure 7. Consumption of CFCs

![CFC Consumption Graph]
15. **NEEDS AND RECOMMENDATIONS**

- Providing a continued maintenance and calibration of instruments such as Dobson, Brewer spectrophotometers and UV sensor with the support of WMO is important.
- It is highly appreciated to get fanatical support to start measuring ozone vertical distribution by ozonesonde in both Aswan and Matrouh upper air stations. Because it is very important to study the tropospheric ozone budget and its impact in climate change.
- It is recommended to take care of problems on operation of instruments and stability of data quality persist at some strategic ozone stations located mainly in developing countries in the tropics and in the Southern Hemisphere. To solve the situation the WMO/GAW and the UNEP Programs should reinforce their key role in the capacity building and in maintenance of the global ozone and UV monitoring infrastructure.
- We in need to involve and connect brewer No.143 by the south Europe Brewer net.
- Participate in a scientific research program for ozone and climate change modeling.
- It is recommended to support awareness programs to increase the use of ODS alternative substances with low or negligible global warming potential.

**BY: Ahmed A. Gahein and Wafik M. Sharobiem**
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&
Ezzat Lewis H. Agaiby and Onsy Alfy Karras
Egyptian Environmental Affairs Agency (EEAA)
1. GROUND BASED OBSERVATIONS

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss
The discovery of the Antarctic "ozone hole" in the mid 1980’s initiated several ozone monitoring activities also at northern high latitudes. In Finland, ozone column monitoring has been carried out by the Finnish Meteorological Institute at Sodankylä (67.4°N, 26.6°E) since 1988 and at Jokioinen (60.5°N, 23.3°E) since 1994. At both stations an automated system based on Brewer spectrophotometer is continuously operated. Since November 2012 this monitoring programme has taken place in close cooperation with the COST Action ES1207: A EUropean BREWer NETwork – EUBREWNET.

At Sodankylä Arctic research centre (FMI-ARC) wintertime ozone columns are also monitored with a SAOZ spectrophotometer which is operated in cooperation with CNRS-Paris already since 1990. The SAOZ measurements also provide NO₂ and OClO column amounts. This instrument works at large solar zenith angles and is thus capable of measurements during the wintertime at high latitudes. Multiyear ozone measurements from both stations have shown large inter-annual variations, in addition significant ozone loss has been observed in the Arctic stratospheric vortex during several years since early 1990’s.

Total ozone columns have been measured during 2012–2013 in Helsinki using a NASA owned Pandora spectrometer. Measurements will be continued again in 2014 in Helsinki and a new FMI Pandora instrument will be implemented to Kuopio.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss
Ozone soundings have been carried out since 1989 at Sodankylä where balloon ozone sensor measurements are carried out regularly throughout the year, while in Jokioinen these measurements are conducted during winter and spring when chemical ozone depletion is expected.

Another long-term initiative at FMI-ARC related to stratospheric ozone is the measurements of polar stratospheric cloud (PSC) properties. PSCs play an essential role in chlorine activation and subsequent ozone depletion. PSCs are generally divided in two types based on their optical parameters, type II are large particles of primarily water ice, type I are typically smaller particles of nitric acid trihydrate or supercooled ternary solution droplets. At Sodankylä these stratospheric cloud particles have been observed during stratospheric campaigns since 1991/1992 by lidar and since 1994 by aerosol backscatter sondes.

At Sodankylä, since December 2002, stratospheric humidity is monitored in winter months using Cryogenically cooled Frost point Hygrometer (CFH) and FLASH-B hygrometers developed at the Central Aerological Observatory of RosHydromet. Already earlier, in January 1996 an Arctic dehydration event was recorded and investigated at Sodankylä using NOAA/CMDL hygrosonde, a predecessor of CFH.

The national meteorological institutes in Finland (FMI) and Argentina (SMN) started a joint ozone research program in 1987, including regular ozonesonde measurements at Marambio (64.1°S, 56.4°W), Antarctica. In 1988 routine ozone soundings were started at Marambio. Recently FMI and SMN have started Aerosol optical depth and radionuclide measurements at Marambio.

1.3 UV measurements

1.3.1 Broadband measurements
FMI operates SL501 broadband instruments at six sites in Finland. These instruments provide online information on the erythemal irradiance that is published through the internet along with the UV-Index forecast.
1.3.2 Narrowband filter instruments
FMI cooperates with Argentina and Spain on Antarctic ozone and UV. In 1999 the collaboration was extended to include UV radiation research. The established UV monitoring network consists of NILU-UV instruments in Marambio, Belgrano and Ushuaia, and a travelling reference. Continuous multifilter UV time series are available from Sodankylä since 2002. One NILU-UV radiometer has been used to measure UV radiation of a reference field within a large field experiment of FUVIRC (Finnish Ultraviolet International Research Center) and one measure at the roof of the sounding station. One NILU-UV, in Helsinki, has been acquired for campaign use.

1.3.3 Spectroradiometers
FMI has monitored the spectral UV irradiance with Brewer instruments in Jokioinen (Mark III since 1995) and Sodankylä (Mark II since 1990). A second Brewer spectroradiometer, Mark III, has been installed in Sodankylä in 2012. Additionally, a Bentham DM150 has been acquired for campaign use, as well as, more recently, one diode array spectroradiometer SP-J1009 for monitoring the spectral irradiance on a vertical surface following the solar azimuth, and another for monitoring the direct spectral irradiance at Jokioinen. In 2012, a portable ASD field spectrometer was acquired.

1.4 Calibration activities
FMI is operating dark room UV calibration facilities both in Jokioinen and Sodankylä. FMI has participated in several UV measurement comparison campaigns, where it has been established that the quality of Finnish Brewer measurements is high and steady. The Brewer instrument of Jokioinen served as one of the core instruments of the QUASUME project (Quality Assurance of Spectral Ultraviolet Measurements in Europe). The European reference spectroradiometer developed in the project and now hosted by the WMO World Calibration Center for UV radiation in Davos is invited for auditing visits to both observatories on a regular basis. FMI is also responsible for the calibration of the Antarctic NILU-UV travelling reference instrument and for its data quality assurance. Brewer total ozone measurements in Jokioinen and Sodankylä are calibrated by annual visits of a travelling Brewer standard instrument or by visiting the Regional Brewer Calibration Center for Europe (RBCC-E) at Tenerife.

1.5. Measurement and validation campaigns
The Arctic research center at FMI has become an important site for ozone validation campaigns. In 2006 and 2007 major ozone campaigns were organised in Sodankylä by NASA, ESA and FMI, aiming to achieve < 1% total ozone measurement accuracy in both ground based and satellite based platforms. Sub-percent accuracy is needed for reliable monitoring of the effects of Montreal protocol. FMI Arctic Research Centre (FMI-ARC) also participated in the EUMETSAT EPS campaign in 2007, which involved ozone soundings and groundbased measurements.

FMI has also hosted international intercomparison campaigns of lightweight hygrosondes in 2004 and 2010. The LAPBIAT Atmospheric Sounding Campaign in January-March 2010 involved a large set of stratospheric measurements by applying various measurement techniques. In 2011 FMI organised the CEOS Nordic Ozone Intercomparison campaign. The goal of the campaign was to characterize Brewer and Dobson spectrophotometer accuracy. FMI stations at Sodankylä and Jokioinen have participated in ozonesonde Match campaigns during each Arctic winter, including winter 2013/2014.

2. SATELLITE OBSERVATIONS AND DATA PRODUCTS
FMI has a strong participation in several satellite instruments that are targeted for monitoring ozone in the atmosphere (GOMOS/Envisat, OSIRIS/Odin, OMI/EOS-Aura, GOME-2/METOP-A, METOP-B). The GOMOS stellar occultation instrument onboard the ESA’s Envisat satellite operated from March 2002 to April 2012. High vertical resolution ozone profiles that cover the altitude range from upper troposphere to lower thermosphere during years 2002-2012 have been analysed at FMI. FMI participates in ensuring the GOMOS data quality and in improving the data processing as a member of the ESA’s GOMOS quality working group. The full reprocessing of GOMOS data was performed by ESA in 2012. Recently the algorithm for processing GOMOS bright limb data have been developed at FMI and daytime GOMOS ozone profiles are made available through the ESA SPIN project.
The GOMOS data 2002–2012 have been used to continue SAGE II solar occultation time series of ozone 1984–2005 in the stratosphere. The trend analysis of the time series shows that negative ozone trend observed in 1984 – 1997 has changed to positive at mid-latitudes and tropics. In particular positive ozone trend is now seen around 40 km. These results are part of the international SI2N project (Past changes in vertical distribution of ozone) and will be included in WMO 2014 ozone assessment. In addition, GOMOS data plays an important role in the ESA’s climate change initiative for developing essential climate variable (ECV) of ozone. FMI participates in developing the ECV dataset of high resolution ozone profiles using GOMOS data. The OSIRIS instrument onboard the Swedish small satellite Odin has measured ozone profiles since 2001. The work is ongoing to combine OSIRIS, GOMOS and SAGE II observations to study the changes of ozone in high latitudes.

The Dutch-Finnish OMI instrument onboard the NASA’s EOS-Aura satellite has measured total ozone columns since 2004. FMI is hosting the OMI UV surface irradiance processing and archiving facility which includes level 2 data, gridded level 2 data and level 3 data. The improvement and validation of the UV products are continued. In addition, local maps of total ozone columns and UV irradiance together with other atmospheric constituents covering Central and Northern Europe are processed at FMI. These Very Fast Delivery (VFD) products exploit the Direct Broadcast antenna at Sodankylä, Northern Finland. These products are available in the Internet (omivfd.fmi.fi) within 15 min after the overpass of the satellite. Presently similar real time ozone products are being developed for OMPS instrument on-board NASA/NOAA Suomi NPP satellite.

FMI is responsible of developing, distributing and archiving of the UV-radiation product of GOME-2. This is done within the EUMETSAT’s Satellite Application Facility project of ozone and atmospheric chemistry, O3M-SAF (http://o3msaf.fmi.fi).

3. RESULTS FROM OBSERVATIONS AND ANALYSIS

FMI has developed quality control (QC) and quality assurance (QA) practices that are suitable for many kinds of UV instruments. At FMI, at the moment, only Brewer UV measurements are considered to have a sufficient quality for assessment of long-term changes. The QC/QA procedures of the Brewers include daily maintenance, laboratory characterizations, calculation of long-term spectral responsivity, data processing and quality assessment. Methods for the cosine correction, the temperature correction and calculation of long-term changes in spectral responsivity were implemented. The Sodankylä spectral time series is among the longest in Europe. No statistically significant spectral UV changes were found for the SZA interval 63°-65° at Sodankylä during 1990-2011. However, record high UV levels were observed in summer 2011 at both Jokioinen and Sodankylä, were the UV index 7 and 6, correspondingly, were measured for the first time. The ratio of UV-B irradiance at 305 nm to UV-A irradiance at 324 nm exceeded the 1990-2010 average by 16% in summer 2011. At Jokioinen, however, the 18-year time series shows a positive trend of nearly 5% per decade in the monthly sum of erythemal UV radiation in July, the main holiday season in the country.

The UV albedo of Arctic snow has been quantified in Sodankylä, also in relation to UV absorbing aerosols, including volcanic ash, dust and soot, deposited on snow. The effective snow grain size is the main factor to determine snow albedo, but various environmental parameters can influence the spectral UV albedo, too, and the UV absorbing impurities may decrease albedo the more the shorter the wavelength.

Ozonesonde observations have been conducted in Sodankylä since 1989. These data along with the data from other Arctic stations have been analysed. It was seen that during the recent decades the largest ozone changes in the stratosphere and troposphere have occurred in the late winter/spring period. The observed negative trend in the stratosphere prior to 1996-1997 can be attributed to the combined effect of chemical and dynamical changes, while the observed increase since then is primarily due to the dynamical changes. In the troposphere, trends have been positive regardless of the chosen time period. This may be related to the long-term changes in Arctic oscillation as it regulates the transport of ozone and its precursors from industrialized regions towards the pole and it may also modulate stratosphere-troposphere exchange. Continuation of ozonesonde observations is planned to detect possible changes in high-latitude tropospheric and stratospheric ozone.
Water vapour changes in the UTLS have a large impact on the climate system. Yet the accurate measurements of the UTLS water vapour remain a technological challenge. FMI has hosted two major field campaigns of comparison of light-weight instruments capable of water vapour measurements in the upper troposphere and lower stratosphere. The campaigns has led to a better understanding of the accuracy of the in situ instruments and contributed to significant improvement of the technology. In addition, the data has provided a unique opportunity to study meteorological and microphysical processes in the lower stratosphere and upper troposphere, including processes related to PSC formation and redistribution of water vapour in the Arctic lower stratosphere.

Recently, changes in the vertical distribution of ozone have been analysed with the combined analysis of GOMOS and SAGE-II data. Several studies have been dedicated to the evolution of ozone and other trace gases during sudden stratospheric warmings, to influence of planetary waves on shaping ozone profiles, and to influence of energetic particle precipitation on the chemical composition of the middle atmosphere.

4. THEORY, MODELLING, AND OTHER RESEARCH

The modelling activities related to middle atmospheric ozone includes the use of a global 3D chemistry transport model of the stratosphere and mesosphere (FinROSE-ctm), a climate model covering the middle atmosphere (MAECHAM) and a model of the ionosphere (Sodankylä Ion Chemistry model). The modelling work includes both studies of long term trends of stratospheric ozone and water vapour utilizing reanalysed meteorological data (ECMWF reanalysis data) as well as process studies (PSC, chlorine activation, ozone loss rates). It has been shown, using both chemistry transport models and observations, that in the Northern Hemisphere the amount of springtime ozone has a large impact on the surface UV radiation, which extends into the following summer. The studies are also focused on impacts of ozone depletion and recovery on surface climate, which are shown to be significant in the Southern Hemisphere. These results add to the increasing number of evidence that the stratosphere plays an important role in climate change and call for a better representation of the stratosphere in models used for climate studies, in particular for a wider use of chemistry-climate models (CCMs), which include stratospheric ozone chemistry. FMI participated in the preparation of the SPARC assessment of CCMs (CCMVal-2, http://www.atmosp.physics.utoronto.ca/SPARC/ccmval_final/index.php). Furthermore, FMI contributes to the ozone assessment 2014.

The scientific use of satellite measurements is increasingly important. In addition, the impact of solar proton events on the stratosphere and mesosphere is studied. In this study the unique night time ozone profile measurements of GOMOS are used. GOMOS data are also used for studying turbulence and gravity waves in the stratosphere.

FMI has developed models for reconstruction of the past UV time series as well as for assessment of the future UV levels. These data are essential for assessment of the long-term changes in surface UV. FMI has participated in multidisciplinary research projects that aim at better understanding of the effects of increased UV exposures on human health, terrestrial and aquatic ecosystems, or materials.

FMI coordinates the research project UVEMA exploring the Effects of UV radiation on MAterials. The study focuses on rubber compounds, natural fibre composites and carbon fibres provided by the industrial partners of the project. A program of long-term outdoor material testing has been set up at seven European sites, including Jokioinen Observatory and Arctic Research Centre at Sodankylä. Prevailing UV radiation and weather conditions are being monitored alongside with the program at each station. Exposed material samples will be investigated in respect of various properties: colour, quality/coarseness of the surface and compression/flexural/tensile strength. As an outcome, more reliable estimates for the useful life-time of the materials are to be gained.
5. DISSEMINATION OF RESULTS

5.1 Data reporting
FMI has participated in the Global Atmospheric Watch (GAW) programme since 1994. Within the program, FMI maintains the Pallas-Sodankylä GAW station and conducts an extensive research programme related to atmospheric aerosols. Within this twin GAW station surface and boundary layer measurements are done in FMI clean air site of Pallas while upper air measurements, UV and Ozone monitoring takes place at Sodankylä (fmiarc.fmi.fi). In upper air research Sodankylä functions as an auxiliary station in the global Network of Detection of Atmospheric Composition Change (NDACC). The total ozone values are reported to the WOUDC on a daily basis both from Jokioinen and from Sodankylä.

FMI maintains the European UV Database (EUVDB). EUVDB is a regional WMO database containing some two million UV spectra (uvdb.fmi.fi/uvdb/). The UV spectra of the two Finnish Brewer instruments are submitted to EUVDB. The UV time series of FMI are used to yearly update the UV-radiation chapter of the NOAA Arctic Report Card: http://www.arctic.noaa.gov/reportcard/.

Regular ozone soundings have been performed at Marambio since 1988, the ozone data is sent to two international databases at the World Ozone and Ultraviolet Data Centre (WOUDC, Toronto, www.woudc.org) and the Norsk institutt for luftforskning (NILU, Oslo, www.nilu.no/nadir/). Furthermore, the UV measurements are available at polarvortex.org. Both the ozone and UV measurements are used in scientific publications, and form a significant contribution to the WMO ozone bulletins (www.wmo.ch).

5.2 Information to the public
FMI provides a 2-day global forecast of the UV Index (http://www.fmi.fi/uvi). The forecast, which is published on the internet, includes contour maps of the local solar noon maximum clear sky maximum UV Index. Additionally, local clear sky UVI forecasts are provided for several sites in Finland and globally. The Finnish broadband UVI measurements are also incorporated in near-real-time on the web page. Several newspapers, radio channels and TV publish the forecasted or measured values during April to August. FMI has actively participated in increasing the awareness of general public on the health effects of UV radiation. Ozone depletion has a large public interest due to related health (UV) and environmental issues. The unprecedented stratospheric conditions and severe ozone loss in the spring of 2011 triggered a wide interest in the Finnish media.

Figure 1. Ozone sounding at Sodankylä in February 2014. The ozone soundings have been made on regular basis in an effort to study Arctic stratospheric and tropospheric ozone changes. Results of the ozone soundings have been made publicly available through the FMI web site.
The major scientific results are published in international refereed journals and are also presented at relevant international conferences. Popularized information is distributed through press releases and interviews. Information about research activities, remote sensing projects as well as measurements and analysis results are available through FMI web pages, http://www.fmi.fi. FMI-ARC observations and analyses are available at http://fmiarc.fmi.fi.

5.3 Recent relevant scientific papers (2011–2014)

- von Hobe, M., Bekki, S., Borrmann, S., Cairo, F., D’Amato, F., Di Donfrancesco, G., Döhrbrack, A., Ebersoldt, A., Ebert, M., Emde, C., Engel, I., Ern, M., Frey, W., Genco, S., Griessbach, S., Grooß, J.-U., 281


6. PROJECTS AND COLLABORATION

The major national funding organisations are the Academy of Finland and Tekes, the Finnish Funding Agency for Innovation. Both of them have partially funded the ozone research in Finland in addition to FMI. FMI collaborates with Finnish universities on atmospheric modelling and developing data retrieval methods and assimilation techniques for the satellite instruments.

A list of projects related to UV and ozone research:
- MIDAT 2010–2013 (Middle atmosphere dynamics and chemistry in climate change)
- ASTREX (Advanced Analyses of Stratosphere- Troposphere Exchange)
- UTLS WaVa (Arctic upper troposphere lower stratosphere water vapour)
- COOL (Aerosol intervention technologies to cool the climate: costs, benefits, side effects, and governance)
- FUVIRC (Finnish Ultraviolet International Research Center, http://fmiarc.fmi.fi/fuvirc/fuvirc_hs)
- UVEMA (Effects of UV radiation on Materials, uvema.fmi.fi/)
- MACC-II (EU project, FMI participating in task related to UV-radiation)
- O3M-SAF (EUMETSAT’s Satellite application facility on ozone and atmospheric chemistry)
- IGACO-O3/UV secretariat (WMO and GAW-ozone)
- ACSO (Absorption cross sections of ozone, IGACO-O3/UV activity)
- Ozone_cci (ESA Climate Change Initiative)
- EUBREWNET (EUropean BREWer NETwork, COST Action ES1207 for the years 2012-2017 whose main objective is to establish a coherent network of European Brewer Spectrophotometer stations to harmonise and develop approaches, practices and protocols to achieve consistency in quality control, quality assurance and coordinated operations.)
- SI2N (Past changes in vertical distribution of ozone, SPARC, IO3C, IGACO-O3, NDACC initiative)
- PP-TROPOMI (Processor prototype studies for TROPOMI, Tekes funded)
- SPIN (ESA funded project, GOMOS ozone data and time series)

FMI has participated in several EU funded Arctic and Antarctic research projects including tasks such as stratospheric modelling and measurement campaigns. Sodankylä has participated in all major European stratospheric ozone campaigns.

FMI is coordinating the EUMETSAT Satellite Application Facility on Ozone Monitoring (O3M SAF, o3saf.fmi.fi). O3M SAF is one of the SAFs in EUMETSAT SAF network. SAFs are specialised development and processing centres within the EUMETSAT Application Ground Segment (www.eumetsat.int). O3M SAF is developed in co-operation with Koninklijk Nederlands Meteorologisch Instituut (KNMI), Deutsche Zentrum fur Luft- and Raumfahrt (DLR), Deutscher Wetterdienst (DWD), Aristotle University of Thessaloniki (LAP), Hellenic National Meteorological Service (HNMS), Danish Meteorological Institute (DMI), Meteo-France (M-F) and Koninklijk Meteorologisch Instituut (KMI).

The purpose of the O3M SAF is to produce a set of near real-time and offline products and validation services. Near real-time products are GOME-2 total ozone and ozone profiles, NO2 and UV fields. Offline products derived from GOME-2 data are total and/or tropospheric column amounts of ozone, NO2, BrO, SO2, HCHO, H2O, OClO, ozone profiles, aerosol index and UV fields including cloudiness and albedo. The ozone and UV data is validated against ground-based observations of total ozone and UV as well as balloon borne, microwave and lidar observations of the vertical distribution of ozone. An important part of the O3M SAF activities has been related to scientific work to develop radiative transfer calculation methods and other algorithms used for satellite ozone and related data retrieval.

The Satellite Data Centre of FMI-ARC started in 2002. The activities include a processing facility for the GOMOS/Envisat ozone instrument. The FMI-ARC data centre also process part of the OSIRIS/Odin ozone data. Data reception and processing from the EOS-Aura satellite is also going on for Very Fast Delivery products of the total ozone, SO2, aerosol index and UV irradiance.
products, available within 15 min after the overpass of the satellite. The Centre is also responsible of reception of OMI data used in near real time $O_3$ and UV-products.

IGACO (International Global Atmospheric Chemistry Observations) is a strategy which aims for bringing together ground-based, aircraft and satellite observations of 13 chemical species in the atmosphere. The implementation of IGACO-O3/UV has been organized through the Global Atmospheric Watch (GAW) programme of WMO. Everyday work is coordinated by WMO jointly with a secretariat hosted by the Finnish Meteorological Institute with a Memorandum of Understanding with the WMO. The implementation plan of IGACO-O3/UV was published in 2008 (http://www.igaco-o3.fi/linked/en/IGACO-O3_UV_Implementation_Plan.pdf). During the last years IGACO-O3/UV has concentrated on two activities: ACSO (Absorption Cross Sections of Ozone, http://igaco-o3.fmi.fi/ACSO) and SI2N (SPARC-IO3C-IGACO-O3-NDACC initiative on Past Changes on Vertical Distribution of Ozone, http://igaco-o3.fmi.fi/VDO/).

7. FUTURE PLANS
Although the basic processes related to stratospheric ozone are now believed to be fairly well understood, there remain important research topics related to ozone and UV, such as the interaction between ozone depletion/recovery and climate change and the effects of UV-irradiance on nature, human health, agriculture, and on materials. According to the present understanding the recovery of the ozone layer will take several decades, but the scenarios contain many uncertainties, among which man’s behaviour is not the smallest. To verify the existing and coming scenarios it is imperative that the research and monitoring activities will be continued and developed.
Research on the stratospheric ozone layer in France
- Courtesy translation -

Research on the stratospheric ozone layer in France is mainly performed by the following laboratories:

- LATMOS [http://www2.latmos.ipsl.fr/index.php/en]
- LACy [http://lacy.univ-reunion.fr/home/]
- Laboratoire d’Aérologie [http://www.aero.obs-mip.fr/]
- CNRM [http://www.cnrm.meteo.fr/]

Moreover, Sophie Godin-Beekmann (Observatoire de Versailles Saint-Quentin-en-Yvelines) is the Secretary of International Ozone Commission (IO3C).

It focuses on the following topics:

**1. Monitoring of ozone long term evolution at global scale**

The surveillance of the ozone layer is based on measurements performed within ground-based observation networks (e.g. NDACC – Network for the Detection of Atmospheric Composition Changes and GAW - Global Atmosphere Watch), on board aircrafts (e.g. IAGOS – In situ Aircraft for a Global Observing System) or satellite (e.g. GOMOS instrument aboard the ENVISAT platform).

LATMOS and LACy contribute to NDACC through (1) lidar measurements of ozone, temperature and aerosol vertical distribution in the stratosphere and (2) UV-Visible spectrometer measurements of ozone and nitrogen dioxide integrated contents. Measurements are performed at several key NDACC stations: Observatoire de Haute Provence (France), Dumont d’Urville (Antarctica), Réunion Island (France), Alomar (Norway) and within the SAOZ network that includes 13 UV-Visible spectrometers implemented in stations located in France, Siberia, Brasil and Antarctica. Measurement time series of more than 30 years for some of them provide a detailed picture of the long term evolution of ozone and associated parameters. They enable the quantification of ozone decreasing trends up to the end of the 1990s and show its stabilization thereafter with signs of increase at some stations (Figure 1).

![Figure 1: Total ozone trends at Observatoire de Haute-Provence for the two periods (1983-1996 et 1997-2011), using two methods for the evaluation of the long term evolution of ozone depleting substances in the stratosphere (Piecewise linear trend and Equivalent Effective Stratospheric Chlorine), from Nair et al., 2013.](image)

Laboratoire d’Aérologie, together with the Forschungszentrum Jülich (Germany), is responsible for the MOZAIC and IAGOS airborne observations of ozone in the upper troposphere and lower stratosphere (UTLS). MOZAIC observations (August 1994 - today) are airborne in-situ measurements for ozone, water vapor, carbon monoxide, and total nitrogen oxides (NOx). Data acquisition is automatically performed during round-trip international flights (ascent, descent and cruise phases) from Europe to America, Africa, Middle East, and Asia. IAGOS observations (July 2011 - today) include ozone, water vapor, carbon monoxide, and cloud droplets (number and size). The time series of MOZAIC-IAGOS ozone measurements allow the quantification of ozone long-term trends in the critical UTLS region.

2. Evaluation of ozone chemical destruction in the springtime in the polar regions
The study of ozone destruction in the polar regions is performed by LATMOS, using satellite or ground-based measurements of ozone, together with chemical transport models (e.g. REPROBUS or MIMOSA-CHIM) developed at the laboratory. Of particular importance was the study of the record ozone depletion in the Arctic spring 2011. Very unusual meteorological conditions in the Arctic characterized by a cold and prolonged polar vortex induced a chemical ozone destruction that was similar to the destruction observed in the 1980s in Antarctica (Figure 2).

![Figure 2: Ozone loss at around 18 km altitude simulated by the MIMOSA-CHIM chemical transport model for various Arctic winters in the period 1997 – 2011, from Kuttipurath et al., 2012².](image)

3. Simulation of the stratospheric ozone recovery and impact of climate change
The study of the ozone recovery is performed by LATMOS and CNRM using the global chemistry-climate models LMDz-REPROBUS, a component of the IPSL Earth system model, and CNRM-ACM. Several simulations were made based on different scenarios for the evolution of stratospheric halogen content and greenhouse gases emissions. The performance of the models were also tested by comparing hindcast simulations with observations, in the frame of a large scale chemistry climate model evaluation exercise (CCMVal project) organised for the last WMO UNEP international report on the state of the ozone layer (WMO, 2011)³.

4. Next international report on the state of the ozone layer, to be published in 2014
The following French researchers are contributing to this report:

- Slimane Bekki (LATMOS): editor of chapter 3 (Polar Ozone)
- Cathy Clerbaux (LATMOS): co-author of chapter 1 (Ozone-Depleting Substances)
- Sophie Godin-Beekmann (OVSQ): lead author of chapter 3 (Polar Ozone)
- Kathy Law (LATMOS): co-author of chapter 5 (Scenarios, Information, and Options for Policymakers).

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GAMBIA, Republic of the

The Ozone Unit of the National Environment Agency of the Gambia is supervised by the Technical Services Network Directorate of its Ozone related activities including the monitoring of Ozone Depleting Substances. For Gambia to play a more important role in the monitoring of atmospheric Ozone its research capabilities needs to be boosted so that atmospheric Ozone can be monitored from ground stations. For this to be a reality the Ozone Unit will have to forge a link with local and international organizations to acquire the necessary skills and inputs to establish such research stations.

The Ozone Unit is indeed planning to collaborate with the United Nations Environment Programme (UNEP), the United Nations Industrial Development Organizations (UNIDO) World Metrological Organization (WMO) and the United Nations Environment programme to set up Ozone monitoring centers. In a bid to fully filling this aspiration the Ozone Unit has set up an National Ozone Committee on Ozone Depleting Substances (NACODS) to ensure that Ozone related issues are monitored country wide and new innovations and developments initiated to contribute to the international data base on atmospheric Ozone monitoring.

OZONE MONITORING CURRENT STATUS

The Gambia at the moment does not have a scientific Ozone Monitoring center or centers that can monitor the Ozone Layer from the ground none the less for the Ozone office to attain its aims and objectives and to fully integrate with the international community on the monitoring of the Ozone Layer it is important the country gets fully equipped Ozone Monitoring centers in all the major regions.

We monitor imports of Ozone Depleting Substances by collecting Data from importers and refrigeration technicians country wide.

The Data is reported to the Ozone Secretariat, the Ozone Action and the Multilateral Fund Secretariat.

FUTURE OZONE MONITORING PLANS

The national Committee on Ozone Depleting Substance in collaboration with the National Ozone Unit has plans to set up Ozone monitoring centers to enable the unit carry out monitoring programmes of the Ozone Layer and Gases that are vented into the atmosphere.

The Ozone Unit plans to seek for funding to build the capacities of Ozone Unit Staff and other stake holders like refrigeration technicians to be able operationalize Ozone Monitoring centers.

The Unit plans to conduct study tours to countries or parties that already have successful monitoring mechanism to learn from their experts on the monitoring of stratospheric Ozone Layer

In a bid to building the capacity of our Local Expertise we plan to cooperate internationally with developed countries to transfer their technologies to not only Gambia but countries with the West African region.

**FUTURE RECOMMENDATIONS**

Funding of major and sustainable research on atmospheric Ozone is hindered by limitation in funds, so we are recommending that some funding is sought for article five countries to enable them carry our scientific research on Stratospheric Ozone.

Stratospheric research data is almost nonexistent in the West Africa Sub Region, therefore the United Nations Environment programme needs to come up with an incentive to organize sub regional training programmes on how to get research centers to facilitating the collection of Atmospheric Data.

For international organizations like World Metrological Organization identify successful Ozone Research Centers to enable third world countries visit such countries to learn from them their initiatives in the field of stratospheric research.

**CONCLUSION**

Securing funds to purchase computers and build the capacity of local staff and other stakeholders to facilitating sustainable Stratospheric Ozone Monitoring and yearly reporting to the Ozone Secretariat of the United Nations Environment Programme.
Still a large number of institutions in Germany have been very active in ozone and UV research and monitoring. Table 1 as a summary shows a compilation of these institutes and their activities. Generally, universities and research centers (MPI, DLR, KIT, FZ-Jülich, AWI) are more research oriented, government agencies (DWD, BfS, UBA) are focused on long-term monitoring. Germany is a key player for several satellite instruments (GOME, SCIAMACHY, MIPAS, GOME-2/MetOp-A, GOME-2/MetOp-B). Ground based long-term observations in Germany are provided primarily by DWD (Hohenpeissenberg and Lindenberg stations) and by AWI in the Arctic and Antarctic (Ny-Ålesund/Koldewey and Neumayer stations). UV-monitoring is carried out by BfS, UBA and DWD. Germany is also supporting crucial international quality-assurance and quality-control activities by hosting the World Calibration Centre for Ozone Sondes (WCCOS) and the WMO RAVI Regional Dobson Calibration Center (RDCC-E, in cooperation with the Czech Republic).

### Table 1 German Institutes involved in ozone/UV research (R), development (D), modeling (MD), monitoring (MT), quality assessment /quality control (QA/QC)

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<td>Karlsruhe, Garmisch-Partenkirchen (IfU)</td>
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<td>MIPAS, FTIR, ENVISAT, LIDAR, CARIBIC</td>
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1. OBSERVATIONAL ACTIVITIES

German agencies are major players in long-term ground-based monitoring and in ongoing satellite measurements of ozone and related trace gases.

Table 2. Operational ground-based network for long-term measurements of ozone and UV

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<th>Type of observation</th>
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IUP Bremen is the lead PI for the SCIAMACHY instrument on ENVISAT (2002-2012), and GOME (1995-2011), both for instrument and algorithm development, as well as advanced data processing. Scientific data processing for GOME-2 (since 2006) are done as well by IUP.

The Institute für Meteorologie und Klimaforschung (IMK) of the Karlsruhe Institute for Technology (KIT) operates ozone analyzers aboard the CARIBIC observatory (www.caribic.de) which is based on a 1.5 ton automated measurement container deployed monthly on 4 consecutive long distance flights. A precise large scale UTLS climatology has been established and is continued. CARIBIC is part of IAGOS (www.iagos.org) which combines the MOZAIC approach (packag-
es aboard a large number of aircraft for ozone and other trace gases and aerosol) with the CARIBIC approach (a large automated flying atmospheric chemistry observatory). IAGOS is being fostered by the German Ministry of Education and research as a European Infrastructure. IAGOS-CORE and IAGOS-CARIBIC form, especially at times when satellite capabilities have been reduced, an increasingly important pillar in global scale observations.

**Germany's Meteorological Service (DWD)** is running a comprehensive ground-based measurement program at the Observatories Hohenpeissenberg and Lindenberg, monitoring the ozone vertical distribution and total ozone columns on a regular and long-term basis. Special efforts are put into high quality and long-term consistency. The time series cover more than four decades for column ozone and ozone profiles (Dobson since 1964 (Potsdam/Lindenberg) and 1967 (Hohenpeissenberg) and Brewer since 1983, balloon-sonde since 1967, and more than 25 years for stratospheric LIDAR observations up to 48km (since 1987). Data are regularly submitted to the data centers at Toronto (WOUDC), NDACC, NILU and Thessaloniki. In addition to the operational UV-network of the BfS, DWD continues to measure UV-B radiation for research and development purposes.

The **German Aerospace Centre (DLR-EOC)** provides the operational satellite total ozone and tropospheric ozone data for the sensors GOME, SCIAMACHY, GOME-2/MetOp-A, and GOME-2/MetOp-B. In the same way DLR-EOC is leading the development of the operational systems for the TROPOMI/Sentinel-5-Precursor mission. Ozone as well as trace gas measurements (total NO2, tropospheric NO2, SO2, BrO, H2O, HCHO) and cloud information from GOME-2 are free available two hours after sensing. The following figure 1 shows the ozone measured by the GOME-2 sensors on September 29th, 2013. DLR/DFD is providing much of the ground-processing for several satellite missions and also hosts the World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT).

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**Fig. 1:** Ozone hole as measured by the GOME-2 sensors operated in tandem on-board the MetOp-A and MetOp-B satellites. Plot by D. Loyola, DLR.

The **Alfred Wegener Institute for Polar and Marine Research (AWI)** operates two fully equipped polar stations in the Arctic (Koldewey/Ny-Ålesund), and Antarctic (Neumayer) and temporarily onboard RV POLARSTERN. Regular vertical ozone balloon soundings at Neumayer continue the very long Antarctic sounding record that started at the former Georg Forster station in 1985 (see Fig. 2). A full suite of NDACC measurements is running at the primary station Koldew-
This includes ozone-soundings by ECC-sondes, Lidar, microwave, DOAS, FTIR and UV-spectrometers. In addition, the same radiation measurements as at Neumayer-Station are performed as part of the BSRN.

Column measurements of ozone and other gases/variables relevant to ozone loss are performed with FTIR and DOAS at the German-French station AWIPEV in Ny-Ålesund/Spitsbergen. (AWI together with U. Bremen). Profile measurements of ozone and other gases/variables are done with ozone soundings at Neumayer Station (Antarctica) and at the German-French station AWIPEV in Ny-Ålesund/Spitsbergen, where also a Microwave (U. Bremen) is operated.

While ENVISAT was lost in April 2012, processing of new MIPAS/ENVISAT data versions is still going on. Data products generated at KIT-IMK include global fields of ozone, temperature, tropospheric source gases and their decomposition products (e.g. H2O, CH4, N2O, CFC-11, CFC-12, HCFC-22, COCl, SF6, SO2, OCS), chlorine radicals and reservoirs (ClO, ClONO2, HOCI), nitrogen reactants and reservoirs (NO, NO2, HNO3, N2O5, ClONO2, HNO4, BrONO2), odd hydrogen reservoirs (HOCl, H2O2), pollutants relevant to upper tropospheric ozone chemistry (CO, C2H6, C2H2, HCN, formic acid, acetone, PAN), and cloud particle properties of PSCs relevant for the polar ozone loss.

Trends of chlorine reservoir species, HCl and ClONO2, and of HF were derived by KIT-IMK from ground-based FTIR data of 17 NDACC sites, and were compared with model data (Kohlhepp et. al., ACP 2012). For the period of 2000 to 2009 a decrease of HCl and ClONO2 was observed at all sites. The latitudinal dependence is also discussed in the paper. Together with our colleagues from AEMET (Spain), a long-term time series of ozone was derived from Izana FTIR observations. Furthermore, a detailed error characterisation and comparison with data from other techniques and finally, a trend study is given (Garcia et al., AMT 2012 & Garcia et al., AMTD 2014).

1.1. Calibration activities

The Forschungszentrum Jülich hosts the World Calibration Centre for Ozone Sondes (WCCOS). WCCOS is part of the quality assurance plan for balloon borne ozone sondes that are in routine use in the GAW observation network of the WMO. Since its inception in 1995, WCCOS provides an experimental chamber that simulates conditions in the atmosphere as a balloon ascends from the surface to the stratosphere. The Jülich Ozone Sonde Intercomparison Experiments (JOSIE) have evaluated and improved the performance of the ozone sondes.

Previous JOSIE-intercomparisons have clearly demonstrated that even small differences of sensing techniques, sensor types or operating procedures can introduce significant inhomogeneities in the long term ozone sounding records between different sounding stations or within each station individually. To resolve these artifacts a group of ozone sonde experts under the lead of the WCCOS started in 2012 in the context of the SPARC/IGACO-O3/IOC initiative on “Understanding past changes in the vertical distribution of ozone” the “Ozone Sonde Data Quality Assessment (O3S-DQA)” activity with the primary goal of homogenizing selected long term ozone sonde data sets of the global ozone sounding networks. We aim to reduce uncertainties between long term
sounding records from 10-20% down to 5-10% through the use of generic transfer functions. It is expected to finalize the activity by 2015 by providing a well documented and homogenized ozone sonde data set that can be used for long term ozone trend determination and satellite validation purposes.

The Regional Dobson Calibration Centre for WMO RA VI Europe (RDCC-E) at the Meteorological Observatory Hohenpeissenberg (MOHp) is closely co-operating with the Solar and Ozone Observatory at Hradec Kralove (SOO-HK, Czech Republic). It has been responsible for second level calibration and maintenance service of now approximately 20 operational Dobson spectrophotometers in Europe since 1999, including the Antarctic Dobsons at Halley Bay (British Antarctic Survey BAS) and Vernadsky (Ukraine). The support of the establishment of the Regional Dobson Calibration Centre for WMO RA I Africa, to be run by the South African Weather Service has been continued. The refurbishment of European Dobsons being out of operation and their re-location mostly outside of RA VI became more and more important.

The success of the calibration activities in the global Dobson calibration system can be seen in Fig. 3. A majority of the Dobsons to be calibrated match with the reference instrument during the initial comparison with 1%.

![Fig. 3: Relative difference between field Dobson and reference instrument during initial calibration. Plot by U. Köhler, DWD Hohenpeissenberg.](image)

"Antarctic-Dobsons" (British Antarctic Survey)
MIPAS/ENVISAT data products, particularly O3, CH4 and CFCs, were extensively validated by comparison with independent measurements. For MIPAS-ozone the instrumental drift has been quantified in order to be able to calculate drift-corrected trends (Figure 4).

Fig. 4: This figure shows the trend in stratospheric ozone - between 10 and 50km - as derived from MIPAS measurements for the time period of July 2002 to April 2012. Hatched areas denote trends which are less than twice as large as their error and, thus, less significant than to the 2-sigma level.

A more detailed description of this figure is given under 2. Results from Observations and Analysis in the section MIPAS results obtained by the Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research (KIT-IMK).
1.2. UV-measurements

The working group of G. Seckmeyer of the Institute of Meteorology and Climatology from the Leibniz University Hannover recently developed a new non-scanning multidirectional spectroradiometer instrument for simultaneous measurements of spectral sky radiance. The instrument is a non-scanning MultiDirectional Spectroradiometer (MUDIS), which can measure the spectral sky radiance as a function of zenith and azimuth angle with a high spectral and temporal resolution. The instrument is based on a hyperspectral imager and measures spectral sky radiance in the wavelength range of 250–600 nm at 113 different directions simultaneously (Riechelmann et al. (2013)).

The newly developed spectroradiometers are versatile Instruments with a wide range of application possibilities. Some of these are for example: vitamin D weighted Exposure determination, Solar Energy Applications, Derivation of trace gases by DOAS techniques, investigation of aging of materials (e.g. on facades), Radiance and plant growth applications and more.

For the determination of vitamin D weighted exposure a novel method by integrating the incident solar spectral radiance over all relevant parts of the human body has been developed (Seckmeyer et al., 2013). Earlier investigations are based on the irradiance on surfaces, whereas the new method takes into account the complex geometry of the radiation field and the geometry of the human body. Seckmeyer et al. (2013) assumed that sufficient vitamin D can be produced within the human body in one minute for a completely uncovered body in vertical posture in summer at midlatitudes (e.g. Rome, June 21, noon, UV index of 10) and calculated the exposure times needed in other situations or seasons to gain enough vitamin D. The results showed that at the winter solstice (December 21, noon, cloudy) at least in central Europe sufficient vitamin D cannot be obtained with realistic clothing, even if the exposure were extended to all daylight hours.

To determine the erythemally weighted irradiance, dosimeters could be used. The Institute compared the doses of erythemally weighted irradiances derived from polysulphone (PS) and electronic ultraviolet (EUV) dosimeters with measurements obtained using a reference spectroradiometer. The results of the Investigation published in Seckmeyer et al. 2012 concluded that while UV dosimeters are useful for their design purpose, namely to estimate personal UV exposures, they should not be regarded as an inexpensive replacement for meteorological grade instruments.

A further instrument developed by the working group of Herr Seckmeyer is the hemispherical sky imager (HSI) system. The system contains a commercial compact CCD (charge coupled device) camera equipped with a fish-eye lens. This system is capable of measuring sky luminance with high spatial and temporal resolution of more than a million pixels and every 20 seconds respectively. In addition radiance data are derived from images of the HSI system as well. The results are presented in Tohsing et al. (2013) and Tohsing et al. (2014). Furthermore long term cloud monitoring is performed.

Within the network of atmospheric composition change an intercomparison of UV spectroradiometers is planned at the Leibniz University of Hannover, Germany in summer 2014. The participants will likely come from Germany, France, Austria and Chile.
Dr. Koepke’s radiation group at the Meteorological Institute of the Ludwig-Maximilians-University (MIM-LMU) has been performing regular UV-very-observations in Munich and on the Zugspitze (UFS Zugspitze) in close co-operation with Prof. Blumthaler from the University Innsbruck (Austria) since 2004. The following two figures 5a and b show the climatology of the corresponding UV-Index at both locations.

Fig. 5a and b: IV-Index at the stations Munich (left panel) and Zugspitze (right panel)

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

AWI has been instrumental in coordinating Match balloon-sonde campaigns for the observation of polar ozone losses. Whenever meteorological conditions were suitable for ozone loss Match campaigns have been carried out for 20 years. They are a major component of European and world-wide ozone research. They document the long-term evolution of polar ozone loss over the Arctic. The unusually cold Arctic winter vortex of 2010/2011 has resulted in the largest ozone loss ever measured above the Arctic (Fig. 6), comparable to a normal Antarctic winter. Substantial ozone loss but less than expected ozone loss was observed in the most recent winter 2013/14.

AWI in collaboration with the University Bremen and the GEOMAR have shown the existence of a pronounced minimum in the tropospheric column of ozone over the West Pacific (see Fig. 7), the main source region for stratospheric air. Modelling based on this finding and a single
measurement of OH available in air from this area suggest a corresponding minimum of the tropospheric column of OH. This has the potential to amplify the impact of surface emissions on the stratospheric composition. Specifically, the role of emissions of biogenic halogenated species for the stratospheric halogen budget and the role of increasing emissions of SO2 in South East Asia or from minor volcanic eruptions for the increasing stratospheric aerosol loading, and hence stratospheric ozone chemistry, need to be reassessed in light of these findings. This is also important since climate change will further modify OH abundances and emissions of halogenated species. The study is based on ozone sonde measurements carried out during a cruise (“TransBrom”) with the RV Sonne roughly along 140–150° E in October 2009 and corroborating ozone and OH measurements from satellites, aircraft campaigns and FTIR instruments. Model calculations with the GEOS-Chem Chemistry and Transport Model (CTM) and the ATLAS CTM were used to simulate the tropospheric OH distribution over the West Pacific and the transport pathways to the stratosphere. The potential effect of the OH minimum on species transported into the stratosphere has been shown via modeling the transport and chemistry of CH2Br2 and SO2 (Fig. 8a-c).

Fig. 7: “West pacific ozone profiles”: Ozone profiles measured in three different marine regions: the tropical Atlantic, the tropical West Pacific and the West Pacific outside the tropics. The red curve shows that ozone is consistently at or below the detection limit throughout the troposphere over the tropical West Pacific. In the other regions the ozone concentrations are in a range typical for the troposphere. Graphic: Markus Rex, Alfred Wegener Institute.

Fig. 8a-c: “Ozone and OH holes”: Location and extent of low ozone concentrations and thus of the OH hole over the West Pacific. Fig. 8a shows the region of origin of the air in the stratosphere, Fig. 8b ozone sonde measurements (dots) and satellite measurements (coloured map) of the total amount of ozone in the tropospheric column of air and Fig. 8c the total amount of OH in the tropospheric column of air calculated with a model. Graphic: Markus Rex, Alfred Wegener Institute.
Stratospheric chlorine trend measurements at the IMK and IfU sites (ground-based), as well as balloon-borne measurements from Frankfurt and Heidelberg Universities, indicate declining chlorine since the mid 1990ies. This shows the success of the Montréal protocol. The data from University of Heidelberg and University of Frankfort show that Bromine has also started to decline in recent years (see Fig. 9).

![Fig. 9: Total stratosph. BrO from balloon-borne BrO observations (squares) and annual means from ground-based measurements at Harestua (60°N) and Lauder (45°S). The stratospheric data are compared to bromine (ppt) measured at the Earth’s surface, with varying amounts of very short lived Bromine species added (blue lines). By K. Pfeilsticker IUP Heidelberg.](image-url)
Ozone trend analyses Hohenpeissenberg (Dobson, see Fig. 10) reveal increasing stratospheric ozone since the late 1990s. Ozone increase in the upper stratosphere (not shown) is a first sign of a beginning ozone recovery, but this is not so clear for the total ozone column and the lower stratosphere. There, dynamical factors like the Arctic Oscillation (AO) contribute majorly to the recently enhanced levels. As Figs. 6 (and also Fig. 8 and 9) indicate, 2010 was a year with much higher total ozone than observed in the last 15 to 20 years. This substantial increase in just one year can be attributed to the phase of the QBO in early 2010, and to the extreme negative phase of the AO in much of 2010 (compare Fig. 4). In contrast to 2010 the years 2011 and 2012 showed again very low values partly coming from an again reversed AO index and in addition in 2011 an ozone hole occurred over the North Pole. This ozone poor airmass reached the mid-latitudes after the break of the polar vortex in spring and early summer (see also Fig. 10 and 11).

Recent analysis of ten years of SCIAMACHY and MIPAS limb ozone profiles show an increase in upper stratospheric ozone since 2002 which are consistent with the decline in stratospheric halogen related to the Montreal Protocol phasing out ozone depleting substances. In certain regions of the atmosphere, however, a continuous decline in ozone is observed (~10 hPa in the tropics) which are likely related to changes in NOy and tropical upwelling. Since 2000 total ozone in the northern extratropics show large interannual variability but overall little changes after a brief period from the middle 1990s until 2000 where total ozone level strongly increased (Fig. 11). Multiple linear regressions accounting for different factors contributing to ozone changes clearly indicate that the long-term decline up to the middle 1990s has stopped in the extratropics in both hemispheres proving the success of the Montreal Protocol.

Fig. 10: Observed annual mean total ozone at Hohenpeissenberg, and multiple linear regression analysis of the magnitude of contributing factors. Top: Black: Observations at Hohenpeissenberg (47.8°N, 11°E). Gray: Multiple linear regression result. Red: Ozone variation attributed to Effective Equivalent Stratospheric Chlorine (EESC). Lower graphs: Ozone variation attributed to the QBO (magenta), to the Arctic Oscillation (AO, blue), to enhanced stratospheric aerosol (green), and to the 11-year solar cycle (orange). Plot by W. Steinbrecht, DWD.
Fig. 11: Evolution of total ozone anomalies since 2002-1979. Plot is based on the merged SBUV/TOMS/OMI MOD V8 data record (1978-1996) and merged GOME1/SCIAMACHY/GOME2 (GSG) record. Anomalies were calculated from area weighted monthly mean zonal mean data in 5° latitude steps, by removing the seasonal mean from the period 1980-2008 (Plot by M. Weber, IUP Bremen).

Fig. 12: Timeseries of annual mean ozone from the GOME/SCIAMACHY/GOME-2 dataset along with the SBUV MOD V8.6 merged ozone and World Ozone and UV Data Center (WOUDC) ground data. Annual means are shown for various latitude bands from NH middle latitudes (30°N-60°N), tropics (25°S-25°N), to SH middle latitudes (30°S-60°S) in the lower three panels. The global mean (60°S-60°N) is shown in the top panel. Indicated in the plots are the expected change in ozone from the effect of the equivalent effective stratospheric chlorine (EESC). Tropical ozone does not show a significant long-term trend with respect to EESC changes, but solar cycle (11 years) variability is evident. The EESC curves indicate a modest (anthropogenic) recovery of ozone of roughly 2-3 DU at middle latitudes in the last ten years. However, year-to-year changes can amount to up to ±15 DU (Plot by M. Weber, IUP Bremen).
The interannual variability in extratropical total ozone is related to variability in the Brewer-Dobson circulation (Fig. 12). The variability in atmospheric dynamics resulted in extreme events like the above average total ozone levels throughout 2010 in the northern hemisphere, the substantial Arctic ozone loss in 2011, and below average ozone hole above Antarctica in 2002.

The following MIPAS results were obtained by the Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research (KIT-IMK):

Large Arctic ozone loss during the exceptionally cold winter 2010/2011 was observed by MIPAS/ENVISAT (Sinnhuber et al., 2011). Bohlinger et al. (2014) investigated the possibility that the cold Arctic winters in the stratosphere may be getting colder as a result of increases in greenhouse gases.

MIPAS SF6-based age-of-air measurements indicate decadal changes in the meridional circulation. The data hint at an overall increased tropical upwelling, together with changes in the mixing barriers. These circulation changes were also shown to affect the distribution of CFCs in the stratosphere: While a decrease of stratospheric CFC mixing ratios is clearly observed, stratospheric trends measured by MIPAS were found to differ from age-of-air corrected tropospheric trends inferred from in-situ measurements. This can only be explained by decadal changes in atmospheric age-of-air spectra or vertical mixing patterns. Also the explanation of MIPAS ozone trends requires circulation changes: otherwise the ozone trend distribution patterns cannot be understood satisfactorily.

In order to avoid artefacts in MIPAS ozone trends, special emphasis was laid on performing the trend analysis on the basis of drift-corrected data. The result of this analysis is shown in Fig. 4, where hatched areas denote significance levels of less than 2 sigma. A hemispheric asymmetry is clearly visible. Larger areas of significant positive trends (red tiles) were found in the southern hemisphere. In the northern hemisphere positive trends appear at higher altitudes, while some negative trends are present at altitudes around 20 to 30 km. In the tropics positive ozone trends were found just above the tropopause, while there are two areas of negative trends around 25 and 35 km. This is contradictory to recent literature, especially model runs, which predict negative trends just above the tropical tropopause due to increased upwelling in this region. Supposedly changes in global circulation can help to explain these differences.

MIPAS/ENVISAT measurements of sulphur compounds (SO2, COS) help to understand stratospheric sulphur chemistry, which is, due to its link to aerosol formation, also relevant for stratospheric ozone. Further, MIPAS measurements have helped to better understand the kinetics of the HOCl formation from HO2 and ClO. Another important focus of science with MIPAS data is the perturbation of ozone chemistry by air noxified/hoxified/cloxified by particle precipitation. While during solar proton events, particle-induced chemistry was observed to happen also in the stratosphere, normally NOx is generated in the thermosphere and subsides into the polar winter stratosphere, where it provides a substantial fraction of the total polar NOx.

Balloonborne observations with the MIPAS instrument have given first observations of the chlorine monoxide dimmer (ClOOCl) in the polar stratosphere and its role for polar ozone loss chemistry (Wetzel et al., 2010, Wetzel et al., 2012). Simultaneous observations of HNO3 with PSC particles emphasize the role of non-spherical particles for denitrification (Woiwode et al., 2014).

Ozone-hole monitoring (DLR)

Since 2007 near-real-time ozone observations from the GOME-2 instrument aboard MetOp have been operationally assimilated into the three dimensional chemical-transport model ROSE/DLR. These daily analyses of the global total ozone column allow for a synoptic view on the current total column ozone distribution and variability. This is especially important where direct observational data is missing, e.g. during the polar night. Figure 15 shows the daily ozone-hole size derived from the assimilated fields. Monthly means are derived to facilitate the comparison between different years (figure 14).

As part of the MACC II (Monitoring Atmospheric Composition and Climate: http://www.copernicus-atmosphere.eu/) project, the 4Dvar chemical data assimilation system SACADA performs full chemical analyses and forecasts of the stratospheric composition. Currently, total column observations of the abovementioned instrument MetOp/GOME-2 and ozone pro-
files AURA/MLS are assimilated on an operational daily basis (figure 13). Beside ozone, the MLS assimilation includes HCl, HNO3, N2O and H2O. The GOME-2 based analyses have been recently compared to other stratospheric MACC analyses (Lefever et al., 2014). The study showed the importance of profile information for good quality ozone analyses. All forecasts and analyses are available at the WDC/RSAT.

**Figure 13:** Assimilated ozone field based on MLS/AURA observations.

**Figure 14:** The satellite-based ozone analyses are used to continuously monitor the inter-annual variability of the Antarctic ozone hole. The bullet figures depicts the evolution of the Antarctic ozone hole by the September mean for the years 2011, 2012 and 2013.
Sampling of stratospheric air has been continued at the University of Frankfurt in an effort to monitor stratospheric chemical composition and to determine mean age, which serves as a proxy for the strength of the stratospheric circulation (Brewer-Dobson circulation). Based on these observations the long term evolution of total chlorine in the stratosphere has been calculated (Fig. 16., updated from (Engel et al., 2002)) and updated for the scientific assessment report to be pub-

Figure 15: Daily ozone-hole size based on GOME-2 observations.

Fig.16: temporal evolution of total chlorine in the mid-latitude stratosphere, based on tropospheric trends and age of the air (see (Engel et al., 2002) and the upcoming scientific assessment for details).
lished in 2014. The data show that total chlorine has reached its maximum at all stratospheric levels now and is declining steadily.

Further studies by University Frankfurt included the budgets of chlorine, bromine and iodine species in the troposphere (Laube and Engel, 2008; Brinckmann et al., 2012; Sala et al., 2014; Tegtmeier et al., 2013) and the stratosphere (Laube et al., 2008; Laube et al., 2010), as well as emissions of halogen species in the troposphere, chemical transformation during the transport to the stratosphere and chemistry of the stratosphere (Hamer et al., 2013; Hossaini et al., 2013; Montzka and Reimann et al., 2011; Wetzel et al., 2010)

**Studies of stratospheric transport and its possible climate-related change.**

A key aspect for the future evolution of the stratosphere is the impact of global change on stratospheric composition, temperatures and dynamics. University Frankfurt has contributed to this issue with studies of dynamical processes and their possible changes in the past decade. In particular we investigated the long term trend in mean age using observations of age tracer CO$_2$ and SF$_6$ (Engel et al., 2009; Ray et al., 2010) from balloons and of a variety of tracers from airborne observations (Boenisch et al., 2011). These observations all indicate that the assumption of single trend in mean age (and thus overall stratospheric transport) is overly simplified (Birner and Bönisch, 2011). Rather there is increasing evidence that a strengthening of the circulation is more restricted to the lower part of the stratosphere.
3. THEORY, MODELLING, AND OTHER RESEARCH

In particular, chemistry-climate models (CCMs) are used in Germany to simulate and understand the recent changes and trends of the stratospheric ozone, and to predict the future evolution of the ozone layer. German activities are well interfaced to international programs like the SPARC/IGAC Climate-Modelling Initiative (CCMI), which has been co-led by DLR staff. EMAC, a CCM has been established; a consortium is led by DLR with partners from MPI for Chemistry and the University in Mainz, MPI for Meteorology in Hamburg, FU Berlin, and KIT. Coordinated model simulations and analyses have been performed. EMAC has been used to simulate the decadal trends from the 1960s to 2100; results contributed significantly to the recent UNEP/WMO Scientific Assessments of Ozone including the upcoming report which is now written. As an example, the Figure 17 shows spring-to-fall ratio of observed polar cap total ozone (>50o) as a function of the absolute extra-tropical winter mean eddy heat flux (September to March in the Northern Hemisphere (NH) and March to September in the Southern Hemisphere (SH)) derived from ECMWF ERA-Interim data (left side). Data from the SH are shown as triangles (September over March ozone ratios) and from the NH as solid circles (March over September ratios). Selected polar total ozone distributions for selected years are shown at the top-left. Respective results performed by CCM simulations are presented on the right (updated from Weber et al., 2011).

![Figure 17](image)

**Fig. 17: Description see text**

**MACC GRG model intercomparison (DLR)**

The global chemical data assimilation systems BASCOE and SACADA are run in parallel to the MOZART-IFS chemical forecasting system at ECMWF (MACC o-suite) providing independent stratospheric analyses. We here report on offline experiments using chemistry-only runs by MOZART, BASCOE and SACADA chemistry modules. By analyzing the performance of the three different chemistry schemes, it is hoped that we can learn for the future development of the C-IFS with full stratospheric chemistry. While results are consistent for most chemical species, significant differences are found for the intermediate reservoir gases leading to ozone changes of up to 20% at 10 hPa after 30 days of integration. In the upper stratosphere, differences probably due to different photolysis rates are even higher (figure 18). With respect to ozone depletion, the model’s polar stratosphere is dominated by the parameterizations of liquid and solid particles at low temperatures. In middle and low latitudes, the three reaction systems simulate significantly different gas phase partitioning. An update of the SACADA reaction system to better comply with BASCOE’s reduces some differences. But model-model deviations are still significant.
Assimilation of radiosonde data (DLR)

Satellite observations have been a reliable source of profile data on stratospheric trace gases for almost two decades. Thanks to improvements in data assimilation, the global distribution can now be derived at the instrument’s error level, daily and with high reliability (e.g. Lefever et al., 2014). However, data gaps and instrument failure are common and can severely hamper assimilation results. What is more, the coming years will see a decline of profile resolving instruments. Therefore, Observing system simulation experiments (OSSEs) have been performed to investigate the impact of ozonesonde observations on a data assimilation system during a simulated satellite data gap in February 2003. Using the 4D-Var data assimilation system SACADA, the relative influence of launch rates and station coverage has been analyzed. Different network and sounding configurations were evaluated. Analysis skill and linear pattern correlation with respect to ERA-Interim reference data were assessed for the 20 km altitude level that is representative for the lower stratosphere (see figures 19 and 20). First-guess and analysis minus observation error statistics allowed optimization of a priori error settings. In this way, the assimilation of simulated and real-world ozone soundings could be appropriately calibrated. In summary, it is found that, during satellite data gaps, ozonesonde data can have a significant positive impact on the mean analysis skill depending both on the number of observations and the network layout. Based on the existing GAW system, a better layout with 28 stations and three soundings bi-weekly, proved clearly superior to VINTERSOL/MATCH. The positive gain in skill reached 0.26 compared to a free-running model.

Figure 18: Ozone differences on July 30th, 2011, for MOZART-BASCOE, MOZART-SACADA and BASCOE-SACADA mixing ratios after 30 days of simulation at 0°E.

Figure 19: Ozone mixing ratios (ppmv) at 20 km altitude on 28 February 2003 for (left) the free-running model experiment (no assimilation), (middle) with assimilation of VINTERSOL ozonesoundings and (right) from ERA-Interim re-analysis (Baier et al., 2013).
AWI is developing and employing the ATLAS CTM, which has been used for e.g modeling polar ozone depletion or transport pathways from the troposphere to the stratosphere. AWI is developing SWIFT, a fast but accurate ozone chemistry scheme intended for use in Earth System and Climate Models, like the models used in the IPCC reports, which use prescribed ozone so far. This enables the inclusion of interactions of ozone and climate in this sort of models, which is not feasible due to computational constraints so far.

IUP Bremen is the PI institute for the SCIAMACHY instrument aboard the ENVISAT satellite. Research is made in the field of ozone and ozone relevant trace gas and aerosol retrievals, but also some modeling and analysis on time-scales ranging from ozone episodes to decadal changes. Scientific support includes validation and for the GOME-2, and SCIAMACHY projects, and the generation of consistent long-term data sets. IUP Bremen has also provided new ozone absorption cross-sections at high spectral resolution (~0.03nm) and covering atmospheric temperatures between 193 and 293 K and the wavelength range 230-1050 nm (Fig. 21).

**Figure 20:** The Pearson’s pattern correlation difference for February 2003 showing the overall improvement due to ozonesonde assimilation at 20 km altitude. Contour lines show significant correlation changes only.

**Fig. 21:** New laboratory ozone absorption cross-section shown in the Huggins band. Indicated are also the operational Brewer and Dobson wavelengths. (Plot from Serdyuchenko, IUP).
The working group Physics of the Middle Atmosphere at the Institut für Meteorologie of Freie Universität Berlin (head: Prof. Dr. Ulrike Langematz) uses the EMAC chemistry-climate model as well as observations to study the effects of changes in anthropogenic emissions of ozone depleting substances (ODSs) and greenhouse gases (GHGs) on stratospheric ozone. Another focus is the role of solar variability at different time-scales (27 days, 11 years, Maunder minimum) on stratospheric ozone and climate. A selection of results is presented below.

**Future Arctic Temperature and Ozone: The Role of Stratospheric Composition Changes**

(Langematz et al., 2014)

Multi-decadal simulations with the EMAC chemistry climate model were analyzed to examine the role of changing concentrations of ozone depleting substances (ODSs) and greenhouse gases (GHGs) on Arctic springtime ozone. The focus is on potential changes in the meteorological conditions relevant for Arctic ozone depletion. It is found that with rising GHG levels (as projected in the IPCC SRES A1B-scenario) the lower Arctic stratosphere will cool significantly in early winter, while no significant temperature signal is identified later in winter or spring. A seasonal shift of the lowest polar minimum temperatures from late to early winter in the second part of the 21st century occurs. However, Arctic lower stratosphere temperatures do not seem to decline to new record minima. The future Arctic lower stratosphere vortex will have a longer lifetime, as a result of an earlier formation in autumn. No extended vortex persistence is found in spring due to enhanced dynamical warming by tropospheric wave forcing. Because of the dominant early winter cooling, largest accumulated areas of polar stratospheric clouds (APSC) are projected for the middle of the 21st century. A further increase of APSC towards the end of the 21st century is prevented by increased dynamical polar warming. EMAC suggests that within the next few decades there is a chance of low Arctic springtime ozone in individual years, however there is no indication of a formation of regular Arctic ozone holes comparable to the Antarctic. Towards the end of the 21st century, when ODS concentrations will be close to pre-1960 levels, further rising GHG levels will lead to an increase of Arctic springtime ozone.

**Figure 22: Evolution of the Arctic average total ozone column in the REF (top panel) and NCC (bottom panel) simulations in March. Shown are deviations from the 1970-1982 mean [DU]. Dashed black lines indicate the dates of maximum Arctic Cly loading at 50 hPa and of its return to 1980 values. (from Langematz et al., 2014).**

The EMAC model projections of the future Arctic average total ozone column in Arctic spring (Figure 22, top) show that due to the regulation of ODS emissions by the Montreal protocol ozone will recover to 1970/1980s levels by the middle of the 21st century, when halogens will have strongly decreased. Due to the effects of rising GHGs (REF simulation) Arctic ozone will reach higher values by the end of the 21st century than in the past, in contrast to a hypothetical simulation with GHGs fixed at 1960 levels (non climate change NCC simulation).
Chemical contribution to future tropical ozone change in the lower stratosphere
(Meul et al., 2014)

The future evolution of tropical ozone in a changing climate was investigated by analysing time slice simulations made with the chemistry–climate model EMAC. Between the present and the end of the 21st century a significant increase in ozone is found globally for the upper stratosphere and the extratropical lower stratosphere, while in the tropical lower stratosphere ozone decreases significantly by up to 30% (Figure 23). Previous studies have shown that this decrease is connected to changes in tropical upwelling. Here the dominant role of transport for the future ozone decrease is confirmed, but it is found that in addition changes in chemical ozone production and destruction do contribute to the ozone changes in the tropical lower stratosphere. Between 50 and 30 hPa the dynamically induced ozone decrease of up to 22% is amplified by 11–19% due to a reduced ozone production. This is counteracted by a decrease in the ozone loss causing an ozone increase by 15–28%. At 70 hPa the large ozone decrease due to transport (~52%) is reduced by an enhanced photochemical ozone production (+28%) but slightly increased (~5%) due to an enhanced ozone loss. It is found that the increase in the ozone production in the lowermost stratosphere is mainly due to a transport induced decrease in the overlying ozone column while at higher altitudes the ozone production decreases as a consequence of a chemically induced increase in the overlying ozone column. The ozone increase that is attributed to changes in ozone loss between 50 and 30 hPa is mainly caused by a slowing of the ClOx and NOx loss cycles. The enhanced ozone destruction below 70 hPa can be attributed to an increased efficiency of the HOx loss cycle. The role of ozone transport in determining the ozone trend in this region is found to depend on the changes in the net production as a reduced net production also reduces the amount of ozone that can be transported within an air parcel.

Figure 23. Latitude-height section of the change in the annual zonal mean ozone mixing ratio between the year 2000 and 2095 in ppmv (red/blue shading indicates positive/negative changes). Statistically significant changes on the 99% confidence level are coloured. Black contours indicate the relative ozone change in %, the contour interval is 10%.

Chemistry climate model simulations of the effect of the 27 day solar rotational cycle on ozone
(Kubin et al., 2011)

The results from two simulations with the coupled chemistry climate model (CCM) ECHAM5/MESSy (EMAC) were analyzed for the effect of solar variability at the 27 day rotational time scale on ozone. One simulation is forced with constant spectral irradiances at the top of the atmosphere and the other one with daily varying irradiances using data of 1 year for solar maximum conditions. Consistent changes are applied to the photolysis scheme of the model. The model results show the main features of observed correlations between ozone and solar irradiance variability with a maximum positive correlation in the upper stratosphere and an anticorrelation in...
the mesosphere. The relative sensitivity of upper stratospheric ozone to changes in the solar ultraviolet flux is estimated to be 0.3 to 0.4% per 1% change in 205 nm flux. During periods of strong 27 day variability, a similar upper stratospheric ozone sensitivity is derived. However, when the daily solar irradiance variability is weak and dominated by the 13.5 day period, the ozone sensitivity is reduced in the subtropics. The modeled temperature response is consistent with the ozone signal. When averaged over one rotational cycle, the ozone and temperature response to a neglect of the 27 day cycle is weak and statistically insignificant in the stratosphere but of non negligible magnitude and statistically significant in the equatorial mesosphere. Our results suggest that ignoring daily solar flux variations on the 27 day time scale in transient CCM simulations does not lead to a significant degradation of the time mean ozone response in the stratosphere, while in the tropical mesosphere, significant errors of up to 3% may occur.
4. DISSEMINATION OF RESULTS

4.1 Data reporting and providing

Data are regularly submitted to the data centers at Toronto, Thessaloniki, NILU and NDACC.

World Data Center for Remote Sensing of the Atmosphere

An important source for data is the World Data Center for Remote Sensing of the Atmosphere, WDC-RSAT. It offers scientists and the general public free access (in the sense of a “one-stop shop”) to a continuously growing collection of atmosphere-related satellite-based data sets (ranging from raw to value added data), information products and services. Focus is on atmospheric trace gases, aerosols, dynamics, radiation, and cloud physical parameters. Complementary information and data on surface parameters (e.g. vegetation index, surface temperatures) is also provided. This is achieved either by giving access to data stored at the data center or by acting as a portal containing links to other providers.

The WDC-RSAT is the most recent data center in the WMO-WDC family. In the context of IGACO within the WMO program Global Atmosphere Watch (GAW) and in line with the WMO-GAW Strategic Plan 2008-2015, WDC-RSAT especially concerns itself with linking different GAW-relevant data sets both, with each other and with models. In this context WDC-RSAT will also handle non-satellite based data which are relevant within the context of validation. As a contribution to WIGOS and in cooperation with the German Environmental Research Station Schneefernerhaus (UFS), WDC-RSAT is developing techniques providing WMO-GAW global stations with satellite based data and information products and to allow for computing-on-demand applications. Strategies and techniques to properly validate data sets, including for example data assimilation methods, are developed and tested. Aspects of the atmosphere’s variability at different temporal and spatial scales are addressed.

WDC-RSAT implemented an interactive map viewer (assessable at http://wdc.dlr.de “Map Viewer”) which supports visualization and download of L3 and L4 data set obtained from satellite observations (e.g. MetOp/GOME-2) as well as from model analysis. The viewer is particularly designed to support the navigation through the four-dimensional space of model results (latitude / longitude / altitude / time) and the typically three-dimensional space of satellite observations (latitude / longitude / time). Examples see in Figures 24, 25 and 26.

![Map Viewer](http://wdc.dlr.de)

**Figure 24:** Ozone total column observations from MetOp-A/GOME-2 for 1st of February 2014 (L3 product). WDC-RSAT map viewer is assessable at http://wdc.dlr.de “Map Viewer”.

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Figure 25: Activated chlorine at 56 hPa derived from ROSE/DLR model analysis for 1st of February 2013 (L4 product).

Figure 26: Chemically induced ozone change (ppb/day) at 56 hPa derived from ROSE/DLR model analysis for 1st of February 2013 (L4 product).
4.2 Information to the public

A noteworthy German contribution to WMO’s World Data Centers is the World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT). WDC-RSAT is hosted by the Cluster for Applied Remote Sensing at the German Aerospace Centre (DLR-CAF). WDC-RSAT offers scientists and the general public free access to a continuously growing collection of atmosphere-related satellite-based data sets and services. WDC-RSAT provides support for many Projects, e.g. the EU-funded MACC project. See http://wdc.dlr.de/ for more information.

The German Aerospace Centre (DLR-EOC) provides free access to satellite (GOME, GOME-2) atmospheric composition data and related services, see http://atmos.eoc.dlr.de/gome2 for more information.

BfS and DWD provide the public with UV-information including daily forecasts of the UV-index and warnings. The daily UV-forecasts for clear sky and cloudy conditions are available for free on a global scale:

http://kunden.dwd.de/uvi/
http://www.bfs.de/de/uv/uv2/uv_messnetz/uvi/prognose.html

AWI:


Press release about tropospheric “ozone hole” in the tropical West Pacific causing an OH minimum (3 April 2014, http://www.awi.de/de/aktuelles_und_presse/pressemitteilungen/detail/item/pm_rex_englisch/?cHash=59a96f88d0c51b566b34370f5bd4b)

Some of these press releases were widely picked up by the media resulting in hundreds of reports in online and print media as well as radio and tv broadcasts.

KIT-IMK trace gas climatologies from MIPAS/ENVISAT are part of the SPARC Data Initiative and accessible via

MIPAS ozone data have been selected by the Climate Change Initiative by ESA and are distributed as a harmonized data set via
http://www.esa-ozone-cci.org/?q=node/161. The original data are available directly from IMK
4.3 Relevant scientific papers


Birner, T., and Bönisch, H.: Residual circulation trajectories and transit times into the extratropical lowermost stratosphere, Atmos. Chem. Phys., 11, 817-827, 10.5194/acp-11-817-2011, 2011.


Brinckmann, S., Engel, A., Boenisch, H., Quack, B., and Atlas, E.: Short-lived brominated hydrocarbons - observations in the source regions and the tropical tropopause layer, Atmospheric Chemistry and Physics, 12, 1213-1228, 10.5194/acp-12-1213-2012, 2012.


Woiwode, W., Grooß, J.-U., Oelhaf, H., Molleker, S., Bormann, S., Ebersoldt, A., Frey, W., Gulde, T., Khaykin, S., Maucher, G., Piesch, C., and Orphal, J.: Denitrification by large NAT particles: the impact of reduced settling velocities and hints on particle characteristics, Atmos. Chem. Phys. Discuss., 14, 5893-5927, doi:10.5194/acpd-14-5893-2014, 2014.


5. PROJECTS AND COLLABORATION

Germany continues its contribution to the preparation of the WMO ozone assessments. For the actual assessment, again several lead and co-authors, and many contributing authors came from German institutes.

German institutions also participate in a number of international and EU funded research projects, special measurement campaigns and modeling studies, such as CAWSES, SCOUT-O3, GEMS, GMES, MACC, SHIVA and RECONCILE. They play a major role in EUMETSAT and ESA projects.

The German Aerospace Centre (DLR-EOC) is responsible for the operational GOME-2 total and tropospheric ozone products, trace gas measurements (total NO2, tropospheric NO2, SO2, BrO, H2O, HCHO) and cloud information in the framework of EUMETSAT O3M-SAF project.

DLR is a key partner of ESA CCI ozone project coordinated by the BIRA (Belgium). DLR-IMF leads the team responsible for the total ozone products, DLR-PA leads the climate research group and DLR-DFD leads the system engineering team. As part of the CCI work the second version of the GOME-type Total Ozone Essential Climate Variable was created (GTO-ECV) covering the time period 1996 to 2011. There is an excellent agreement between GTO-ECV and the latest SBUV ozone data provided by NASA, see the figure 27 below.

Fig. 27: Differences in total ozone monthly zonal mean anomaly from GTO-ECV (ESA CCI), SBUV (NASA) and ground-based measurements. Courtesy D. Loyola, DLR.
German scientist are currently part of the science panel for the UNEP/WMO Scientific Assessment of Ozone Depletion: 2014 (Steinbrecht and Dameris are Lead-Authors)

Active participation in the ESA Climate Change Initiative, in particular the “Ozone_CCI” project (DLR)

Several ongoing national and European funded projects (e.g., DFG-research group SHARP, BMBF MiKlip project STRATO, and the EU-project StratoClim) with significant parts related to investigations of the stratospheric ozone layer (DLR)

14 active Arctic and 2 Antarctic Match campaigns, coordinated by AWI, and additional 3 passive Arctic Match analyses, funded by the EU and national institutes, have been carried out since the winter 1991/92, most recently in the past northern hemisphere winter 2013/2014. These campaigns have been instrumental for our current understanding of chemical ozone loss in the Arctic.

AWI participated in the EU project RECONCILE which addressed central questions regarding polar ozone depletion, with the objective to quantify some of the most relevant yet still uncertain physical and chemical processes. It improved prognostic modelling capabilities to realistically predict the response of the ozone layer to climate change.

AWI participated in the EU project SHIVA which focused on certain ozone depleting substances (ODSs). By combining measurements from land, ship, aircraft, and space-based platforms, with sophisticated numerical models, SHIVA aimed to better predict the rate, timing and climate-sensitivity of ozone-layer recovery, and identify potential risks to that recovery.

Since 1 December 2013 AWI coordinates the EU project StratoClim (budget ~12 million Euros, 28 partners from 11 European countries) which aims to strengthen our understanding of the role of stratospheric aerosols, ozone and water vapour on climate. Within that project an airborne campaign is planned in the Bay of Bengal in 2016 and a station on the West Pacific Island Palau will be built up including measurements with ozon sondes and a FTIR for at least 2 years.

The decline of anthropogenic chlorine in the stratosphere within the 21st century will increase the relative importance of naturally emitted, halogenated trace gases (VSLS) from the ocean on stratospheric ozone destruction. VSLS play a significant role in present day ozone depletion, in particular in combination with enhanced stratospheric sulfate aerosol concentrations. There is a need to better understand possible changes and feedbacks in a future climate especially under elevated sulfur levels in the stratosphere (Fig. 28). The questions how much of the observed stratospheric halogen and sulfur aerosol abundances originate from natural sources, in particular from oceanic emissions, and how this will change will be addressed in ongoing and future work.
In order to accomplish this goal, the GEOMAR Helmholtz-Centre for Ocean Research Kiel contributed and still contributes to national and EU projects, including SHIVA, HALOCAT, SOPRAN, SOLAS, CCMVal, CCM, SPARC; SSiRC. Research groups (Chemical Oceanography, Maritime Meteorology) at the institute measure brominated and iodinated trace gas concentrations in the ocean and atmosphere, calculate emissions from the ocean into the marine boundary layer along large-scale ship transects, investigate the oceanic sources, and model the transport of the short lived halogenated and sulphuric trace gases into the stratosphere. Lagrangian transport calculations initialized by high-resolution observational emissions demonstrate the importance of deep convective transport in the West Pacific for VSLS entrainment into the stratosphere (Tegtmeier et al., 2013; Marandino et al., 2013). In cooperation with the University of Hamburg, biogeochemical ocean models aim at simulating the oceanic concentrations of several of the compounds. Past and future emission scenarios of halogenated substances from the oceans, which are likely to increase due to climate change and increased anthropogenic sources, are investigated (Ziska et al., 2013; Hepach et al. 2014).

Scientists from GEOMAR have led several cruises in recent years into the tropical Atlantic and Pacific oceans, where the major input of trace gases into the stratosphere occurs. In the next two years cruises will follow into the Pacific and Indian Ocean, the results from which will be incorporated into the models to determine stratospheric input. Observations of VSLS are sparse and need to be extended in spatial and temporal resolution.

KIT-IMK scientists are member of ESA's MIPAS Quality Working Group, the ACE-FTS Science team and various science teams of international space experiments. Further, they are involved in a number of SPARC activities (WAVAS, SDI, Stratospheric Sulphur, CCM, SPARC/IO3C/IGACO-O3/NDACC) and participate to ESA's Climate Change Initiative, where the IMK ozone product is preferred over the official ESA data product. IMK contributes to the STRATOCLIM EC project, the DFG Research Unit SHARP, and the BMBF research programme ROMIC.

Since 2009, J. Orphal from IMK Karlsruhe has been Chair of the “Absorption Cross Sections of Ozone” International Committee at WMO (WMO/IO3C/IGACO-O3). He has been leading an international initiative to review and recommend improved ozone absorption cross-sections. A new standard has not been established yet due to new findings published by Redondas et al., 2014. The planned implementation (at least for LDAR, Dobson and Brewer) has been shifted until new investigations confirm, that the new coefficient sets (from the IUP Bremen) provide a better consistence between the instrument types than the originally recommended coefficient sets (after Daumont-Brion-Malicet). A final report originally planned to be published in 2011 is therefore still pending.

The Hohenpeissenberg Observatory participated in the ESA project CEOS Intercalibration of Ground-Based Spectrometers and Lidars from 2009 to 2012.

The following list comprises the projects and cooperations of the working group

**Physics of the Middle Atmosphere at the Institut für Meteorologie of Freie Universität Berlin**

**Planetary Evolution and Life**
(Atmospheric composition on Early Earth)
Funding agency: HGF-Allianz
Research alliance with 13 national and international partners

**SHARP**

*Stratospheric Change and its Role for Climate Prediction (SHARP)*
Funding agency: DFG (Research unit)
Coordination
Duration: 6 Years, 2009 – 2015
Research alliance with 7 national partners
STRATO

*The role of the stratosphere for decadal climate prediction*
Funding agency: BMBF (FONA Programm „Mittelfristige Klimaprognosen“ (MiKlip))
Duration: 01.09.2011 – 31.08.2014
Research alliance with DLR (Prof. M. Dameris) and GEOMAR Kiel (Prof. K. Matthes)

FAST-O3

*FAST-O3: Fast stratospheric ozone chemistry for global climate models*
Funding agency: BMBF (FONA Programm „Mittelfristige Klimaprognosen“ (MiKlip))
Duration: 01.09.2011 – 31.08.2014
Volume: 125.000 Euro
Research alliance with AWI Potsdam (Dr. M. Rex)

ISOLAA

*Sea-Ice and Stratospheric Ozone – Links and Impacts in the Arctic and Antarctic*
Funding agency: DFG (Schwerpunktprogramm 1158 „Antarktisforschung mit vergleichenden Untersuchungen in den arktischen Eisgebieten“)
Duration: 3 Years, from 01.12.2012
Research alliance with GEOMAR Kiel (Prof. R. Greatbatch)

SOLIC

*Quantification of Uncertainties of Solar Induced Climate Variability*
Funding agency: BMBF (Programm „Role of the Middle Atmosphere in Climate“ (ROMIC))
Duration: 3 Years, start in March 2014
Research alliance with GEOMAR Kiel (Prof. K. Matthes) and KIT Karlsruhe (Dr. M. Sinnhuber)

StratoClim

*Stratospheric and upper tropospheric processes for better climate predictions*
Funding agency: EU (ENV.2013.6.1-2)
Duration: 4 Years, from December 2013
Research alliance with 21 European partners

Contribution to *WMO/UNEP Assessment of Stratospheric Ozone 2014* by Ulrike Langematz (Review Editor of Chapter 2, Contributor to Chapter 3)

6. FUTURE PLANS

Generally, German ozone observations and research activities are expected to continue along the indicated lines. Funding is expected to continue from national and European sources and projects, however, with a generally decreasing trend.

The German Aerospace Centre (DLR-EOC) is leading the development of the operational system for processing the TROPOMI/Sentinel-5-Precursor data (to be launched early 2016) in close collaboration with leading scientists from the institutes KNMI (The Netherlands), SRON (The Netherlands), IUP Bremen, MPIC Mainz, BIRA (Belgium), and RAL (UK). In the same way, DLR-EOC will play a key role in the processing of the Sentinel 4 and Sentinel 5 data.

Within the EU project StratoClim AWI and Uni Bremen together with international collaborators will build up a station on the West Pacific island Palau and will perform measurements with ozonesondes, FTIR and a multi-wavelength cloud/aerosol lidar for about 2 years.

The new airborne imaging infra-red spectrometer GLORIA provides two-dimensional and three-dimensional (through tomography) distributions of a large number of trace gases in the lower stratosphere and UTLS. GLORIA was operated already very successfully on two aircraft cam-
campaigns and will be used in future missions with the German research aircraft HALO. KIT-IMK is coordinating together with many German partners the HALO campaign POLSTRACC (The Polar Stratosphere in a Changing Climate), currently scheduled for winter 2015/2016.

German modeling activities will continue to focus on the expected evolution of ozone (recovery, super-recovery, tropical decline), but also on the important links with climate change (tropospheric warming, stratospheric cooling, changes in wave driving, possible acceleration of the Brewer Dobson circulation).

7. NEEDS AND RECOMMENDATIONS

- Continuing high-quality measurements of total ozone and ozone profiles by satellites on the global scale and by ground-based systems have to be insured for the next decades. The high-quality data of long-term records of ozone and UV especially from selected stations (e.g. super sites) are a crucial precondition to follow the expected recovery of the ozone layer from man-made halogens, and to understand the substantial cooling of the stratosphere and warming of the troposphere that are expected over the next decades from man-made climate change. Therefore the maintenance of the ground network (Dobson, Brewer, sondes, Lidar) has to be fostered.

- New limb/occultation satellite mission is needed as number of limb satellites will decline. This might cause gaps and results in a loss of satellite date with vertical resolution.

- The complex coupling of ozone, atmospheric chemistry, transports and climate changes is still not fully understood. Further research is needed to better understand the underlying processes and to improve model predictions of the expected substantial changes in both ozone and temperature distributions of the middle atmosphere.

- In this context, there is a need for better and more consistent long-term temperature data in the stratosphere.

- Quality Assurance/Quality Control activities like calibration centres must be supported to maintain the high quality standards of the ground stations. This is necessary for satellite validation, for ozone monitoring, and for trend analyses.

- The current process of final determination and implementation of new ozone cross-section/absorption coefficients should get highest priority to obtain consistency between the various instruments either ground-based or satellite-borne.

- Availability of space-borne infrared limb emission instruments after MIPAS (i.e. 2014) is essential for future ozone research.
INDONESIA

INTRODUCTION
Atmospheric structure of Indonesia is expected very complicated because of it's dynamically effect. Strong convection significantly influences the composition of the atmosphere. Minor constituents that affect the atmospheric dynamics and thermal distributions are found in abundance. Particularly Indonesian Maritime Continent is the region where trace gas distributions in the troposphere is strongly influenced by deep convection, frequent lightning and biomass burning. Quantitative studies of these processes have been very limited so far in this region because of the lack of simultaneously in situ measurements of the key species, atmospheric ozone measurements and research in the equatorial region. This is also to realize the importance of developing countries in the tropics to play more important role in the global initiatives to achieve a better understanding of the atmospheric changes and its effects on the environment linked to ozone changes.

OBSERVATIONAL ACTIVITIES
To perform ozone observation, National Institute of Aeronautics and Space (LAPAN) works in collaboration with other National Institutions: NASA, NOAA, NASDA and some of Japanese Universities.

Surface ozone measurement
Surface Ozone measurement conducted at 4 (four) locations which are Bandung, Watukosek, Biak and Pontianak. The surface ozone monitor used in this observation are Dylec model 1006-AHJ and model 1150, produced under a license of Dasibi Inc. The air containing the ozone is pumped into sample cell where the measurement is done by using ultraviolet absorption technique. The result is represented in units of ppbv with the resolution of 1 ppbv and recorded on a strip chart or sent directly to PC that is operated as data logger. The cycle time of measurement is about 12 seconds (Anonym, 1985). This instrument was operated automatically 24 hours every day.
Those location are marked as: Bandung (6.9 °S, 107.5 °E) West Java, 740 m asl, representing polluted city; Biak (1°S, 136 °E) Papua, 50 m asl, representing unpolluted area; Pontianak (0.05 °N , 109.33 °E), West Kalimantan, representing unpolluted area that sometimes influenced by pollution comes from biomass burning / forest fire; and Watukosek (7.5°S, 112.6°E), East Java, 50 m asl representing growing urban area.

Column measurements of ozone and other gases/variables relevant to ozone loss
Brewer spectrophotometer MK-IV (#092) was operated at Watukosek in 1994-2000. Compilation of data was sent to NASDA. After 2000 Watukosek Brewer spectrophotometer is not operated.
In 1996, LAPAN install Brewer spectrophotometer MK-IV (#116) in Bandung and operated until 1998. In 2006 Brewer in Bandung was re-operated after being calibrated under the assistance by MWO in September 2006.
Variables relevant to the ozone loss has also been studied and still continue by analyzing the Ozone Depleting Substances (ODS) data derived from AURA-MLS satellites to investigate condition and its trend in Indonesian region.
Profile measurements of ozone and other gases/variables relevant to ozone loss

Balloon-borne measurements are taken place at Watukosek, East Java. These activities are conducted to observe the vertical profile of the species.

Ozonesondes measurement

Vertical ozone measurement is conducted regularly at Watukosek by using balloon borne equipment. The system is set up of an airborne system - ozonesonde payload type RSII-KC79D provided by Meisei Co., ground observation system tracking telemetry signal automatically and data processing system (also data acquisition system) based on personal computer. The important ozonesonde unit is made up of an ozone detector and the dedicated electronics. Ozone data which is converted into audio signal is sent sequentially with meteorological signals information, i.e. temperature, pressure and references (Anonym, 1979). This payloads were carried aloft using meteorological hydrogen filled rubber balloon (usually 3000 grams) and a protective parachute.

Ozone detector is based on Komhyr's carbon iodine ozone-sensor. The operating principle is based on the reaction of ozone to a potassium iodide solution wherein free iodine is liberated. The liberated iodide is measured quantitatively by a coulometrical method (Kobayashi and Toyama, 1966). According to Kobayashi, error of the measurement is estimated to be within +2%.

Since 1998, Watukosek was officially accepted as ozonesonde station under consolidation of the Southern Hemisphere Additional OZonesondes (SHADOZ) network. Ozonesonde soundings have been conducted on a weekly basis, using ECC ozonesondes. Ozonosonde launches are in collaboration between NASA/NOAA, Kyoto University and the Hokkaido University, Japan.

Water Vapor Measurements

Since 2001, together with ozone soundings, water vapor soundings have been conducted. Soundings have been conducted annually (usually in December or January) using cryogenic chilled-mirror hygrometers that are flown in combination with ozonesondes. Water vapor soundings are in collaboration between LAPAN, Kyoto University, Hokkaido University and CIRES-University of Colorado/NASA/NOAA. This activities are part of SOWER (Sounding Ozone and Water vapor in Equatorial Region) Campaign.

UV measurements

The UV measurements are performed by LAPAN, by using in situ measurement and analyzing data derived from satellite. According to the model simulations released by the 2010 Scientific Assessment of Ozone Depletion there is an indication of future increases of UV levels in the tropics. For humans, this poses the risk of more skin cancer in the tropics. Therefore the UV measurement and dissemination of the information to the public is urgently needed in the near future.

Recently AWS (Automatic Weather Station) also used to measure UV Index. More detailed research has been carried out by adding the location of the research and analysis data derived from AURA-OMI to determine UV conditions in general and in the certain region of Indonesia.

Broadband measurements

Narrowband filter instruments

Bandung and Watukosek station is used to measure UV. The UV Sensor measures UV-B irradiances of the UV spectrum (280 nm - 315 nm).

Spectroradiometers

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Calibration activities
Pre-launch calibration of ozonesonde takes place in a regular basis. Vaisala is precalibrated at NOAA/CIRES University of Colorado/NASA. Brewer instrument was installed by LAPAN in Bandung (Brewer spectrophotometer MK-IV #116). The instrument was installed in early 1995 and last visited in 2001, but had been out of service for the past 4-5 years. The instrument was found to need a new power supply, micro-board and UV filter in front of photomultiplier tube to get it back into service. This calibration was completed in September 2006 at LAPAN site in Bandung, Indonesia by Ken Lamb, (IOS) with the support from the Vienna Convention Trust Fund through the World Meteorological Organization (WMO). In November 2010 calibration and maintenance of Brewer #116, Bandung and Brewer #092, Watukosek were also has been done.

RESULTS FROM OBSERVATIONS AND ANALYSIS

Fig.1. Profiles of ozone concentration observed at Watukosek derived from ten years observation.

Fig.2. The compilation data from 1993 to 2003. These profiles are used as standard profiles for vertical ozone concentration and temperature.
Profiles of ozone concentration and temperature observed at Watukosek in figure 1 and figure 2 has been used as standard profile, (Komala, N. et al, 2006).

Fig 3. The time series of tropospheric column ozone derived from Watukosek ozonesonde data.
The time series of tropospheric column ozone derived from Watukosek ozonesonde data in fig 3 shows an interesting peak in end of the dry season. The peak value is comparable to those of the 1994 and 1997 events.

Fig 4. Watukosek total column ozone data derived from AURA-OMI data.
In Fig 4, total column ozone in Watukosek in late 2004, 2006 and 2010 show higher ozone due to the longer dry season and forest fire effect.

Fig 5. Bandung total ozone as measured by Brewer #116 and derived from AURA-OMI
In Bandung total ozone as measured by Brewer #116 and derived from AURA-OMI. The comparison of total ozone between direct sun, zenith-sky Brewer 116 and OMI data. The direct sun total ozone represented in black line and dot, zenith-sky total ozone is represented by red line and circle, whereas OMI data is represented by green line and dot as shown in Fig 5.

![Image](Time_series_of_total_ozone(DU)_in_Indonesia.png)

**Fig 6.** The trend of long term ozone in Indonesian region derived from SBUV, TOMS and OMI AURA.

The total ozone distribution over Indonesia is defined by an annual cycle with maxima in the dry season and minima in the wet season. The amplitude of this cycle is of about 20 Dobson Units and ranged in between 230 Dobson Unit and 280 DU. Trend of long term ozone in Indonesian region derived from SBUV, TOMS and OMI AURA with the equation of $y = -0.2726 x + 800.18$, $R^2 = 0.09$ $r = -0.3$, ozone decrease is 0.27 DU/year as shown in Fig 6.

![Image](Indonesia_annual_variation.png)

**Fig 7.** Indonesia located in Northern equator to Southern equator, annual variation of total ozone show slightly different annual variation pattern

Total ozone annual variation in Indonesia which is located in Northern equator to Southern equator: In North equator, maximum ozone detected in August and January shows minimum. In equatorial region annual variation of total ozone show maximum in August ~
September and minimum in January while in Southern equatorial annual variation of total ozone reach maximum in October and minimum in January.

**UV measurements**

The UV measurements are performed by LAPAN, located at Bandung and Watukosek. The UV Sensor measures UV-B irradiances of the UV spectrum in the wavelength of 280 nm ~ 315 nm. The UV Index measurement also conducted in Bandung by using AWS (Automatic Weather Station).

![UV Index seasonal variation](image1)

**Fig 8.** Diurnal variation of UV index (left) and comparison of annual pattern of UVI from AWS and AURA-OMI in Bandung (right).

Diurnal variation of UV index in Bandung averaged from 2007 to 2010 AWS UVI data in DJF, MAM, JJA and SON in Fig 8 (left) show that peak of diurnal variation of UVI detected in noon time with UVI of higher than 9. Comparison of annual pattern of Bandung UVI derived from AWS and AURA-OMI in Fig 8 (right) show that the UVI annual variation varied between 8 to 12.

![UV Index annual variation](image2)

![UV Index in Indonesia](image3)

**Fig 9.** Time series of UVI in Indonesia and annual variation pattern

Time series of UVI in Indonesia derived from OMI-AURA data in 2004-2013 indicate that UVI in Indonesia show higher and extreme value. The annual variation of UVI in Indonesia show maximum in March and minimum in June with range of UV index between 9 to 14.
THEORY, MODELING AND OTHER RESEARCH

The Ozone Standard Profile was constructed by using the long term observation data of the ozonesonde launchings from Watukosek (surface ~ 20 km). This Watukosek standard profile is used to validate Watukosek ozone profile based on MOZART (Model of Ozone And Related Tracers) output. There is an on-going research on the relationship between ozone, ODS, UV radiation and climate with the goal of the improvement in modeling.

Fig 10. Comparison of the Watukosek ozone mixing ratio and the output from Mozart (red curve).

Fig 11. Contour of Watukosek Ozone Mixing Ratio profile 1993~2010 (left) and Watukosek OMR and temperature profile 1993~2010 with standard deviation (right), as a result of statistical model of Watukosek ozone and temperature.
Study of ClO in Indonesia indicate that peak of ClO profile in Indonesia was at 2.1 hPa (30.6 km) and ClO concentration varies between 0.20 ppbV to 0.31 ppbv. Seasonal variation of ClO profile show peak at 2.1 hPa (30.6 km) with maximum concentration of 0.31 ppbV in June-July-August (JJA months), while minimum concentration of 0.23 ppbV detected in December-January-February (DJF months).

Time series of ClO and ozone at 2.1 hPa (30. km) where ClO concentration reached maximum. In this altitude, ozone in Indonesia show 4 to 6.2 ppmV and ClO ranged between 0.15 to 0.35 ppbV. We can find the tendency of ozone minimum when ClO reach maximum, especially in January and July each year. Detailed study of chemistry and dynamic process affected the ClO concentration in the atmosphere and its influence to the ozone variation is urgently needed.
DISSEMINATION OF RESULTS

Data reporting

The ozone profile data collected in Watukosek is sent to Hokkaido University, in Sapporo, Japan. The data from Hokkaido University is then transferred to the SHADOZ (Southern Hemispheric Additional Ozonesondes) archives data: http://croc.gsfc.nasa.gov/shadoz/java.html.

Bandung Brewer Spectrophotometer data is sent to WOUDC, Canada, ftp://ftp.tor.ec.gc.ca

Information to the public

Vertical ozone profile data is made available after every launch on the SHADOZ website for the scientific community.

Relevant scientific papers


- Komala, N., S. Saraspriya, K. Kita, and T. Ogawa, Tropospheric ozone behavior observed in Indonesia, Atmospheric Environment, 30, 1851-1856, 1996.

PROJECTS AND COLLABORATION

The major international collaborations are with Hokkaido University, Kyoto University, CIRES-University of Colorado-NOAA/NASA.

LAPAN has participated in projects:

Southern Hemisphere ADDitional OZonosondes, SHADOZ, financed by NASA, from January 1998 until now still continue

Sounding of Ozone and Water vapor at Equatorial Region (SOWER), financed by Hokkaido University, Kyoto University, CIRES-University of Colorado-NOAA/NASA, from January 2004

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until now still continue, through this project we launch regularly ozone and water vapor sondes at Biak (campaign is conducted every January).

FUTURE PLANS
Future research activities will be a continuation and extension of current investigations such as:
Continue monitoring vertical ozone profiles under the SHADOZ program, to obtain ozone climatology,
Continue to monitor ozone total with Brewer and to start with an UV network in Indonesia (measurement of UV Index).
Research on evolution of total ozone column over Indonesian region, can determine trend of ozone and UV levels.
Continue monitoring of the water vapor profiles in Biak under SOWER program,
Start to measure ODS and improve its analysis data derived from satellite
Collaboration research concerning ozone modeling and impact of higher UV-B radiation and ozone layer in Indonesia, dynamics, chemistry and inter-annual variation of equatorial ozone
Continuing and improve the Surface ozone measurements,
To improve dissemination of the data of ozone, UV Index and ODS to the Indonesian community by spread the information and establishing integrated Indonesia own web page.

NEEDS AND RECOMMENDATION
- Permanent ground-based and satellite-based instruments are an essential complement for this research.
- The current monitoring networks must be continue and maintained in qualified operation. The long term research is necessary to determine the future evolution of ozone
- Requires a strong support in capacity building at the technician and research levels to continue both with monitoring and relevant research
- The new monitoring activities of ODS in Indonesia to provide relevant information including long-term monitoring
- Needed financial support for travel to meetings, seminars and workshops abroad.
- Ozone and UV (measurement of UV index) network in Indonesia must be continue and maintained.
- Since tropical region where we stand, UV levels are high, collaboration research concerning ozone modeling and impact of higher UV-B radiation and ozone layer in Indonesia are also needed as a consequence of the equatorial region country..
- Still needed assistance for calibration and maintenance of instrumentations which can not be done in Indonesia due to the lack of budget spare part and experts.
1. Observational Activities

This report contains the updated information on the ozone and UV observation and research activities, which have been pursued in Iran through the past two years since the 7th meeting of the WMO/UNEP Ozone Research Managers.

For the past three decades, the Meteorological Organization (MO) and Geophysics Institute of the University of Tehran have been taking over and performing UV-B and ozone monitoring and research activities in Iran.

Research and monitoring activities are based mainly on and through continuous cooperation and exchange of information between these centers and other research entities, i.e. the universities and related research institutes.

In spite of long history of atmospheric observation and research, the country still lacks sufficient capacity to effectively realize its objectives in the field of ozone and UV observation and networking, which forms only part of the country's atmospheric research and monitoring platform.

1.1. Column measurements of ozone and other gases/variables relevant to ozone loss.

There are three stations in which the ozone measurement facilities are installed and in use. The following stations are operating under the supervision of the Meteorological Organization (MO) and the Geophysics Institute of the University of University of Tehran:

1) Esfahan
2) Geophysics
3) Firouzkooh

Data on the above stations are provided in the Table 1.

<table>
<thead>
<tr>
<th>Station</th>
<th>Type</th>
<th>Coordination</th>
<th>Measurement Facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Synoptic</td>
<td>Upper Atmospheric</td>
<td>Latitude</td>
</tr>
<tr>
<td>Esfahan</td>
<td>Yes</td>
<td>Yes</td>
<td>32° 37'N</td>
</tr>
<tr>
<td>Geophysics</td>
<td>Yes</td>
<td>No</td>
<td>35° 44’N</td>
</tr>
<tr>
<td>Firouzkooh</td>
<td>Yes</td>
<td>No</td>
<td>35° 43’N</td>
</tr>
</tbody>
</table>
Spatial distribution of the stations in Iran, related to above table that measures ozone column is shown in the figure 1.

**Figure 1. The locations of different stations in Iran with measurements of ozone column contents**

**Esfahan Ozone Station:**

This station is recognized by an international 336 codes and is connected to the global networking system. Total ozone is being measured using Dobson system since January 2000. Since April 2000, Brewer equipment was installed and has been operating at Esfahan station. This system measures total ozone in vertical column in an area of 1 cm² by attracting solar and sky radiation. In addition, the system measures UV-B, SO2, and NO2. Esfahan station is recognized by an OIFM code and measures on a daily basis the upper atmospheric conditions between 11 to 12 GMT. This station is also equipped with Radiosonde (RS80) and Hydrogen balloon (toex 600gr) in order to study the Upper Atmosphere.

**Geophysics institute station:**

The institute is mainly responsible for total ozone monitoring, data recording and processing, networking with World Ozone and Ultraviolet Radiation Data Center (WOUDC) and conducting networking, training and public awareness campaigns on stratospheric and surface ozone. The center is equipped with a Dobson photo-spectrometer and ancillary data processing and analysis hardware and software systems. The institute has been in cooperation with Tehran Municipality in air pollution monitoring activities through the established network of pollutants monitoring stations. As of 2000, total ozone has been measured using Dobson system for 30 minutes (from 8am to 7pm). Results of the
measurements are regularly calibrated using satellite data. The data recorded at the above stations is being reported to the WOUDC and are available through the center’s web pages.

**Firoozkooh Station:**

Of the above station, Firoozkooh has not reportedly been active in the field of stratospheric ozone measurements for the past two years. Surface ozone outside urban area has been measured at Firooz-Kooh. The station is a reference station and official connected to the World Meteorological Organization’s (WMO) Global Atmospheric Watch (GAW).

Esfahan and Geophysics stations are mainly involved in the ozone and UV observation in surface ozone measurement activities.

### 1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

(e.g. ozonesondes, ozone lidar)

Profile measurement of ozone needs employment of special equipment, which are not available at the existing station. In order to study the Upper Atmosphere, radiosonde (RS80) and hydrogen balloon (Totex 600gr) are in use at Esfahan station. Data recorded by these instruments then is transmitted to the global telecommunication system using a switching system. Esfahan station is connected to the global network of ozone observation and reports the data back to the WOUDC on a regular basis.

### 1.3 UV measurements

UV-B is only being measured at Esfahan. UV is measured at the wavelengths between 320 and 330 nm including UV-B. there are several other locations reported as high risk spots in terms of exposure to UV. UV monitoring in these high risk spots are of utmost importance and need establishment and use of new UV measurement equipment and facilities.

### 1.4 Calibration Activities

Data recorded by the stations is regularly checked for their validation and consistency. In the case of data inconsistency the equipment are sent to the WMO for calibration. Currently monitoring equipment at Geophysics and Esfahan stations are not calibrated and are not properly in operation.

Equipment installed at the Firooz-kooh station was damaged and not in use for the last seven years. In order to maintain the continuity of ozone data series, the station will need to fix the damaged apparatus and to improve its measurement system. This station only records surface ozone data. An strategy is in place to change the station' systems to European standards.
Calibration of equipment in Geophysics station has been last made in February 2006 in Japan. In an agreement with the Japanese atmospheric research center, the Dobson apparatus at Geophysics station will be calibration, data collected by the Geophysics equipment has 3% deviation from the satellite data recorded for the same period, which is considerably acceptable.

The ozone and UV-B radiation measurement equipment at Esfahan Station has not been recently calibrated. From May 2013 onwards, the machine is not working and needs to be calibrated. So far, despite the correspondence with the respective international organizations, unfortunately no action has been performed yet.

2. Results from Observations and analysis using data of Esfahan station.

![Figure 2. Daily variation of total ozone for the Long-Term duration over Esfahan station (the average data has been calculated for the period from 2000 to May 2013 in every month)](image-url)
Figure 3. Daily variation of UV-B for the Long-Term duration over Esfahan station (the average data has been calculated for the period from 2000 to May 2013 in every month)

3. Theory, Modeling and other research

Two research units are active and affiliated to Meteorological Organization as follows:

- Esfahan Ozone and Atmospheric Chemistry Research Center;
- Atmospheric Chemistry and Air Pollution Research Group of the Meteorological Science Research Center

These centers are linked to the Esfahan and Forooz-Kooh stations and provide necessary research programs of assistance for the Centers.

Computer software is available at the Iranian Geophysics Center and Esfahan station for processing and modeling of the atmospheric ozone and photo-chemicals. These facilities have only been utilized for data processing and analysis. Models developed thus far have only for the simulation and analysis of air pollution in urban areas and so far no model has been developed specially applicable for ozone and UV analyses.
The first Iran-Korea joint workshop on climate modeling, Co-hosted by climatological Research Institute (CRI) and Meteorological Research Institute (MERI) was held on November 16-17 2005. The program consisted of invited and contributed oral presentations from both countries and issues related to the subjects of the workshop were discussed in full. The workshop covered theoretical and applied topics of climate modeling as follows:

- Long-Term Forecasting
- Climate Change and Variability
- Extreme Events
- Application of climate Information
- Tele connections
- Paleoclimatology

4. Dissemination of results

4.1 Data reporting

Firooz-Kooh and Esfahan stations are reference stations connected to the global network of atmospheric watch. Total and vertical ozone data in WMO format are being regularly reported to the World Ozone and Ultraviolet Data Center in Canada (WOUDC). The data recorded by the stations also being archived at the related centers. Data on Ozone and UV recorded at Esfahan station is reported to WOUDC in Canada once every two months. The Firooz-kooh data is reported to the same center on a monthly basis.

4.2 Information to the public

As its routine procedure, the Geophysics institute provides assistances to the graduate and post graduate students through their MSc and PhD research programs on air pollution and atmospheric research. These assistances are in the form of long term meteorological data series and processed information. Reports of the student’s theses are normally available for use by other researchers. The Long-Term Ozone Observation Data are also available at the web-sites of the Geophysics Institute. Information is also provided at the above web-site for the public use. (URLs for the web-sites are: http://geophysics.ut.ac.ir/En/ for Geophysics Institute).

4.3 relevant scientific papers

5. Projects and Collaboration

The following research programs have been completed by the Geophysics research institute:

- The correlation between Total Ozone and troposphere/Stratosphere parameters(1991)
Correlation between Total Ozone and ground-base UV (1999)
Trend analysis of Surface Ozone data collected at Geophysics Synoptic Station in 2002 (2007)
Total Ozone change analysis with respect to the periodic solar activities (1983)
Analysis of interaction between the Total Ozone recorded at a random Meteorological station and regional weather systems (1999)
Comparative analysis of Ozone change through an eleven-year period of activities (1994)
Study of relation between Ozone and Humidity
Investigation of Ozone pollution in the earth (2003)
The study of Stratospheric / Tropospheric exchange by means of ground Ozone measurement (1978)
Temporal and spatial variability of Total Ozone in Central plateau of Iran revealed by ground-based instruments (2007)
Analysis of correlation between total ozone and upper air meteorological parameters in the Middle East (2010)
Investigation of total ozone seasonal distribution over Iran area for 2007-2008 (2013)

The Geophysics Institute and Meteorological Organization are in continuous cooperation with other academic and non-academic research units for the study of atmospheric phenomena.

6. Future Plans
The Meteorological Organization and Geophysics Institute are in demand for improvement of their research, Observation and data recording and reporting systems through regular UV Monitoring and analysis as well as public awareness campaigns.
There is a strong for scientific research on environmental impacts of increased UV due to the ozone depletion in different parts of country covering effects of UV radiation on:
- Human health
- Terrestrial and aquatic ecosystems
- Biogeochemical cycle
- Air quality
- Materials

Development and improvement of “data networking system” is considered by the Meteorological Organization as an important component of the existing Ozone/UV monitoring system. Atmospheric Modeling is another area of interest that requires professional training and advanced hardware and software facilities.

A new atmospheric research center is also under construction in Esfahan for purpose that will need advanced equipment and networking systems.

7- Needs and Recommendations
- Development of advanced research programs on the UV/Ozone analysis and impacts;
- Development of National UV Observation and Monitoring Network
- Organization of regional and national training workshops for officials and experts from relevant UV/Ozone monitoring organizations and public seminars on Ozone/UV changes and its effects on terrestrial life;
- Thematic meetings on UV/Ozone Observation and monitoring will be needed to be included in the UNEP/ROAP networking system. This can be accomplished back to back to the annual network meetings;
- Capacity Building and provision of necessary advanced equipment and facilities to the existing stations including;
  A) Equipping Geophysics station with the following instruments:
     1) Sky Radiometer (POM-02)
     2) Sky Radiometer (POM-01L)
     3) Grating Sunphotometer (PGS-100)
     4) Multichannel Data Logger (PMMS-100)
     5) Brewer Spectrophotometer
     6) Automation of existing Dobson Photo-Spectrometer for improved and precise measurements;
  B) Renovation of Firooz-Kooh station;
  C) Development of new UV monitoring stations in high risk UV spots;
  D) Provision of upper-atmospheric observation and research facilities to Esfahan and Firooz-Kooh station
  E) Provision of technical assistance and training to the centers for advanced atmospheric research and modeling;
- Systematic calibration of surface and upper-atmospheric Ozone measurement instruments at existing station;
**IRAQ**

**Existing and planned ozone research and monitoring activates in Iraq**

Monitoring activities of the Iraqi national ozone unit about the ozone layer depleting substances

Iraq representing by the national ozone unit is implementing activities and preparing a good future plan to avoid importing and using prohibited ODS's this activities includes:

* Identifying imported refrigerants using refrigerants identifiers, the testing applied by the NOU and the authority of quality measurements and standardization;

National ozone unit monitor's the local market and educate local importers and traders to avoid importing, using and trading prohibited ODS's

* One of the national phase out plan in Iraq implemented by the national ozone unit and the project management unit is continuing the awareness and training programs for the technicians in the refrigeration maintenance workshops for the use of the environmental alternative of the ozone depleting substances in the training centers

* One of the activities implemented is using alternatives for methyl bromide in the agriculture sector and pre-shipment quarantine

* Coordination between the national ozone unit and the authority of quality measurements and standardization is to involve the testing companies to identify the incoming shipments of refrigerants and the equipments using this refrigerants before interring Iraq

* Issuing licensing system and enforcement legislations to control ozone depleting substances and forming high level committee to adopt and enforce these legislations from the ministry of environment, ministry of trade ,customs and authority of quality measurements and standardization.
* Forming a national committee to update and develop refrigeration and air-conditioning curricula for engineering colleges, institutes and vocational schools for the best application to use refrigerants and use of the environmental friendly alternatives.

* Ozone unit is forwarding to complete national phase out plan projects such as refrigeration manufacturing project such as light industries company changing to refrigerant 600a

* For the foam manufacturing sector the project of replacing the production line for naser company for ozone friendly alternatives

* For future plans is implementing project for small refrigeration manufacturing companies using ozone friendly refrigerants in production of water coolers

Chief Chemists
Raad K. Hasan
Iraqi National Ozone Unit
The contributing institutions are:

<table>
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<tr>
<th>INSTITUTION</th>
<th>Short name</th>
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<tbody>
<tr>
<td>CETEMPS/Dipartimento di Scienze Fisiche e Chimiche, Universita' degli Studi dell’Aquila, L’Aquila</td>
<td>CETEMPS/UNIAQ</td>
</tr>
<tr>
<td>Università degli Studi di Urbino “Carlo Bo”, Urbino.</td>
<td>UNIURB</td>
</tr>
<tr>
<td>Dipartimento di Fisica, Università di Roma “La Sapienza”, Roma.</td>
<td>UNIRM</td>
</tr>
<tr>
<td>ARPA Valle d’Aosta (Regional Environmental Protection Agency).</td>
<td>ARPAVDA</td>
</tr>
<tr>
<td>CMCC, INGV, Roma.</td>
<td>CMCC/INGV</td>
</tr>
</tbody>
</table>

1. OBSERVATIONAL ACTIVITIES

Column measurements of ozone and other gases/variables relevant to ozone loss.

CETEMPS/UNIAQ: The ozone total columns observed on routine basis at L’Aquila (683 m asl, 43.38°N, 13.31°E) are derived from the balloon ozone-sonde profiles

UNIURB: In situ continuous measurements of Ozone Depleting Substances by Gas Chromatography-Mass Spectrometry at the CNR Atmospheric Research Station “O. Vittori” at Monte Cimone (Northern Apennines, Italy (2165 m asl, 44°11’ N, 10°42’ E) and weekly measurements of the same gases at the ABC-Pyramid Atmospheric Research Observatory (Nepal, 27.95 N, 86.82 E) located in the Himalayas, Khumbu valley, at 5079 m a.s.l.

UNIRM: Total ozone and total nitrogen dioxide observations have been collected since 1992 at Rome (Lat. 41.9°N, Long. 12.5°E, 75m a.s.l) and at Ispra (Lat. 45.8°N, Long. 8.63°E, 240m a.s.l) by using two Brewer MKIV spectrophotometers. Brewer MKIV 067 is located at the Physics Dept. of Sapienza University of Rome. Brewer MMIV 066, located at the Environment Institute of the Joint Research Centre, Ispra (Va) until January 2007, was moved to the alpine station of ARPA (Aosta Valley Regional Environmental Protection Agency) at Saint-Christophe, Aosta (Italy), at approximately 100 km east from Ispra. Aerosol optical depth (AOD) retrievals in the UV and visible regions are now available.

ARPAVDA: Total ozone and total nitrogen dioxide measurements have been collected since 2007 in Saint-Christophe (45.74°N, 7.36°E, 570 m a.s.l.), Aosta, using the Brewer MKIV spectrophotometer #66. This instrument, owned by Sapienza – University of Rome, was moved from the Joint Research Center, Ispra (VA), where it has been measuring since 1992. The spectrophotometer is now being operated by ARPA Valle d’Aosta. Estimates of the total ozone content every 30 minutes are available since 2006, retrieved from the Bentham spectroradiometer. The results have been successfully compared with those obtained by the Brewer #66 and OMI satellite data.
Profile measurements of ozone and other gases/variables relevant to ozone loss

CETEMPS/UNIAQ: The ozone profiles (balloon-sonde) have been collected since 1994. From 2004 this activity has achieved a routine pace: about 1.5/2 ozone profiles (from ground up to 10hPa altitude) per month (This activity is also part of the commitments included in a Convention between University of L’Aquila/CETEMPS - Centre of Excellence for the integration of remote sensing techniques and modelling for the forecast of severe weather- and Italian Government/Ministry of Environment. The Italian Ministry of Environment (Ministero dell’Ambiente e della tutela del Territorio) provides the needed resources for the acquisition of the ozone-sondes, the maintenance of the radio-sonde system.). The ozone profiles database has been available for several calibration/validation campaigns.

UV measurements

CETEMPS/UNIAQ: Broadband measurements
UV-A and UV-B (Yanke Environmental Systems) instruments have been operating since 2004.

UNIRM: Spectral UV irradiance (from 290 to 325nm at 0.5 nm stepwidth) have been measured by Brewer spectrophotometer #067 operational since 1992.

ARPAVDA: Three UV broadband radiometers (2 KIPP&ZONEN UV-S-AE-T, double band A/E, and 1 Yankee YES UVB-1) have been operating since 2004 at three different sites (Saint-Christophe, 570 m asl, La Thuile, 1640 m asl, and Plateau Rosa, 3500 m asl) to account for the altitude and snow effect.

Calibration activities

UNIRM: The absolute calibration of Brewer 067 is made by the IOS inc. (International Ozone Service) almost every year. Furthermore, UV measurements are intercompared with the travelling standard spectroradiometer B5503 from PMOD/WRC (Physikalisch-10 Meteorologisches Observatorium Davos, World Radiation Center) every two years. The YES radiometer participated into the broadband radiometer inter-comparison at PMOD/WRC at Davos (Switzerland) in August 2006.

ARPAVDA: The ozone calibration of Brewer #66 is performed by the IOS inc. (International Ozone Service) almost every two years. UV measurements of the Brewer spectrophotometer and Bentham spectroradiometer are intercompared with the travelling standard QASUME from the PMOD/WRC (Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center) every two year.

The Bentham spectroradiometer is calibrated every month by a local operator by means of 2/3 calibration lamps (portable field calibrators, 200W, from Schreder CMS). The lamps are calibrated by the PMOD/WRC and represent a calibration triad. Cross-calibration between the spectroradiometer and the spectrophotometer are regularly performed. The broadband radiometers spectral response function and cosine response are measured every year in a specialized laboratory (Scheder CMS, Austria).

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

CETEMPS/UNIVAQ: Ozone trend analyses: The extended ozone profile database (2004-20013) has got the quality-standards for being used in a preliminary analysis concerning the possible trends of the ozone content in the different atmospheric region. In summary, such studies show that: there is not any significant trend in the lower troposphere; the same in the higher troposphere and in the lower stratosphere (the se data have a larger standard deviation). In the middle stratosphere [20-25 km], it is evident a small decreasing in the ozone content (about 7 ± 5 DU/decade) which is consistent with other kind of observations (i.e., IPCC’s Special Report on Safeguarding the Ozone Layer and the Global Climate System, 2005)

UNIRM: Surface UV radiation: A climatological characterization based on the time series of UV index was carried out. The mean of maximum UV index is (7.2 ± 0.2) at Ispra and (8.9 ± 0.4) at Rome under clear sky conditions. High exposure category (6< UV index < 7) is more frequent at Rome (32%) than at Ispra (26%). Very high UV indexes (≥ 8) occur only at Rome.

ARPAVDA: Surface UV radiation: The UV indexes are measured in the three stations. Extreme UV indexes occur in the Alps of Valle d’Aosta: close by 9 at Aosta and La Thuile, during summer, and higher than 12 at Plateau
Rosa, because of the coupled effect of altitude (3500 m asl) and snow cover (perennial snow is always present on the glacier).

3. THEORY, MODELLING, AND OTHER RESEARCH

CETEMPS/UNIVAQ: Stratospheric and tropospheric Ozone: Research and assessment studies on stratospheric ozone have been made using a global chemistry-transport model (ULAQ-CTM) and a chemistry-climate coupled model (ULAQ-CCM), both including an interactive module for calculation of aerosol formation and growth. Both models have been validated with satellite and aircraft data and then used for future projections of the ozone layer and changes of the ozone radiative forcing on climate. The above models have also been adapted and used for studies of tropospheric ozone and its precursors, as well as for future trends of tropospheric O3. CETEMPS/UNIAQ modelling activities have also contributed to the UNEP/WMO/IPCC: Scientific Assessment of Ozone Depletion: 2006; Chapter 5: Climate-Ozone Connections, Review Ed. D. Albitron, 49 pp., Geneva, Switzerland, 2007; and to UNEP/WMO/IPCC: Scientific Assessment of Ozone Depletion: 2006; Chapter 6: The Ozone Layer in the 21st Century.

UNIRM: Comparison with Ozone and UV satellite data: The daily mean ozone values from Brewer spectrophotometer #067 showed a good agreement with OMI ozone data retrieved by means of both OMI-TOMS 5 (bias=-1.8%) and OMI-DOAS (bias=-0.7%) algorithms. The comparisons between satellite-based and ground-based UV data showed that, on average, OMI UV products exceed ground-based UV measurements by more than 20%. This may be attributed to the fact that the satellite instrument does not effectively probe the boundary layer, where the extinction by the aerosols can be important, mainly in an urban site as Rome.

ARPNAVDA: Radiative transfer models (e.g. LibRadtran) are routinely used for the forecasts of the UV index in cloudless conditions and for quality control.

CMCC/INGV: Global Modeling of Stratospheric Ozone: MAECHAM general circulation models of the troposphere, stratosphere and mesosphere, as well as with one of its version coupled to a stratospheric ozone chemistry model [the MAECHAM4CHEM chemistry climate model (CCM), and its further evolution, the ECHAM5/MESy1]. CCMs include the full representations of dynamical, radiative, and chemical processes in the atmosphere and their interactions. We have been part of the MAECHAM4CHEM model team that has contributed to the coordinated simulations of past ozone evolution and scenarios of future ozone projection of the last ozone assessment. Analysis of various aspects of the modelling of stratospheric ozone with comprehensive global numerical models Modelling of shortwave radiative transfer in Atmospheric Global Models: The spectral resolution of the shortwave radiation parameterization used in the Middle Atmosphere (MA) ECHAM5 model has been improved.

4. DISSEMINATION OF RESULTS

Data reporting

CETEMPS/UNIVAQ: The multi-annual UV and ozone profile data can be freely used on request at CETEMPS. Model data for international data centers. Contributions to the forthcoming 2014 WMO/UNEP scientific assessment of the understanding of the depletion of the stratospheric ozone layer.

UNIRM: Daily total ozone are submitted to international datacenters at the end of every year.

ARPNAVDA: Every measurement is published in real time on the website of ARPA. Daily total ozone and B-files are submitted daily to the WOUDC.

CMCC/INGV: Preparation of numerical data from the MAECHAM4CHEM model for submission to the British Atmosphere Data Centre (BADC) data center, within the procedures for the last ozone assessment (WMO, 2007).

Information to the public

CETEMPS/UNIVAQ: An annual report concerning the stratospheric ozone and surface UV levels is yearly compiled within the existing Convention between CETEMPS/UNIAQ and Italian Government/Ministry of
Environment. The observational procedures and their scientific content are widely exploited along continuous on-site visiting activities (secondary schools, university students, foreign scientists) and press releases.

5. PROJECTS AND COLLABORATION
CETEMPS/UNIVAQ, UNIURB, UNIRM, ARPAVDA and CMCC/INGV are involved in several National and International projects.

This report has been compiled in April 2014.

Document compiled by Vincenzo Rizi, Marco Iarlori and Guido Visconti, CETEMPS/Dipartimento di Scienze Fisiche e Chimiche, Università degli Studi dell’Aquila, L’Aquila.
1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone and other gases/variables relevant to ozone loss

Total column ozone and Umkehr measurements are carried out by the Japan Meteorological Agency (JMA) at four sites in Japan (Sapporo, Tsukuba, Naha, and Minamitorishima) and at Syowa Station in Antarctica (Table 1). A Brewer spectrophotometer is used for measurements at Minamitorishima, whereas Dobson spectrophotometers are used at the other observation sites.

<table>
<thead>
<tr>
<th>Observation site</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m)</th>
<th>WMO station number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sapporo</td>
<td>43° 04’ N</td>
<td>141° 20’ E</td>
<td>26</td>
<td>47412</td>
</tr>
<tr>
<td>Tsukuba</td>
<td>36° 03’ N</td>
<td>140° 08’ E</td>
<td>31</td>
<td>47646</td>
</tr>
<tr>
<td>Naha</td>
<td>26° 12’ N</td>
<td>127° 41’ E</td>
<td>28</td>
<td>47936</td>
</tr>
<tr>
<td>Minamitorishima</td>
<td>24° 17’ N</td>
<td>153° 59’ E</td>
<td>9</td>
<td>47991</td>
</tr>
<tr>
<td>Syowa</td>
<td>69° 00’ S</td>
<td>39° 35’ E</td>
<td>22</td>
<td>89532</td>
</tr>
</tbody>
</table>

Concentrations of ozone-depleting substances and other atmospheric constituents are monitored by the Center for Global Environmental Research (CGER) of the National Institute for Environmental Studies (NIES) and by JMA. The monitoring sites are listed in Table 2. CGER/NIES monitors halocarbons (CFCs, CCl4, CH3CCl3, and HCFCs), HFCs, surface ozone, CO2, CH4, CO, N2O, SF6, NOx, H2, the O2/N2 ratio, and aerosols at remote sites (Hateruma and Ochiishi). JMA measures surface concentrations of ozone-depleting substances (CFCs, CCl4, and CH3CCl3) and other atmospheric constituents (surface ozone, CO2, N2O, CH4, and CO) at Ryori, a Global Atmosphere Watch (GAW) Regional Station in northern Japan. Monitoring of concentrations of surface ozone, CO2, CH4, and CO is also carried out at Minamitorishima (a GAW Global Station) and Yonagunijima (a GAW Regional Station in the Ryukyu Islands).
The Japanese Ministry of the Environment (MOE) monitors concentrations of halocarbons (CFCs, CCl₄, CH₂CCl₃, halons, HCFCs, and CH₃Br) and HFCs at remote sites (around Wakkanai and Nemuro) and at an urban site (Kawasaki).

Table 2. Locations of monitoring sites for ozone-depleting substances and other minor atmospheric constituents

<table>
<thead>
<tr>
<th>Monitoring site</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m)</th>
<th>Since</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ochiishi</td>
<td>43° 10’ N</td>
<td>145° 30’ E</td>
<td>45</td>
<td>Oct 1995</td>
<td>CGER/NIES</td>
</tr>
<tr>
<td>Hateruma</td>
<td>24° 03’ N</td>
<td>123° 49’ E</td>
<td>10</td>
<td>Oct 1993</td>
<td>CGER/NIES</td>
</tr>
<tr>
<td>Ryori</td>
<td>39° 02’ N</td>
<td>141° 49’ E</td>
<td>260</td>
<td>Jan 1976</td>
<td>JMA</td>
</tr>
<tr>
<td>Minamitorishima</td>
<td>24° 17’ N</td>
<td>153° 59’ E</td>
<td>8</td>
<td>Mar 1993</td>
<td>JMA</td>
</tr>
<tr>
<td>Yonagunijima</td>
<td>24° 28’ N</td>
<td>123° 01’ E</td>
<td>30</td>
<td>Jan 1997</td>
<td>JMA</td>
</tr>
<tr>
<td>Syowa</td>
<td>69° 00’ S</td>
<td>39° 35’ E</td>
<td>18</td>
<td>Jan 1997</td>
<td>JMA</td>
</tr>
</tbody>
</table>

JMA also monitors CFCs, CO₂, N₂O, and CH₄ concentrations in both the atmosphere and seawater of the western Pacific on board research vessels *Ryofu Maru* and *Keifu Maru*.

1.2 Profile measurements of ozone and other gases/variables relevant to ozone loss

1.2.1 Ground-based and sonde measurements

From October 1990 to March 2011, CGER/NIES measured vertical profiles of stratospheric ozone at Tsukuba with an ozone laser radar (ozone lidar); these data were registered in the Network for the Detection of Atmospheric Composition Change (NDACC) database. CGER/NIES also measured vertical profiles of ozone with millimetre-wave radiometers from September 1995 to March 2011 at Tsukuba and from March 1999 to March 2011 at Rikubetsu.

JMA has been monitoring vertical ozone distributions weekly by ozone sonde at three sites in Japan (Naha, Sapporo, and Tsukuba) and at Syowa Station in Antarctica. The ECC type ozone sonde succeeded the KC type in October 2008 at Naha, in November 2009 at Sapporo and Tsukuba, and in March 2010 at Syowa. The KC sonde was developed by JMA and has been used in Japan since
the 1960s.

### 1.2.2 Airborne measurements

In February 2011, JMA began taking monthly (approx.) airborne in situ measurements (flask sampling) of CO₂, CH₄, CO and N₂O concentrations at an altitude of about 6 km along the flight path from mainland Japan to Minamitorishima.

### 1.2.3 Satellite measurements

The Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) was developed for deployment in the Japanese Experiment Module (JEM) on the International Space Station (ISS) through cooperation of the Japan Aerospace Exploration Agency (JAXA) and the Japanese National Institute of Information and Communications Technology. On 11 September 2009 (all dates are JST), SMILES was successfully transported to the ISS in the H-II Transfer Vehicle, launched by an H-IIB rocket. It was attached to the JEM on 25 September and began atmospheric observations on 12 October. The mission objectives are (1) to demonstrate the viability in the outer space environment of a 4-K mechanical cooler and superconducting mixers for submillimetre-wave limb-emission sounding in frequency bands 624.32–626.32 GHz and 649.12–650.32 GHz and (2) to take global measurements of atmospheric concentrations of minor constituents (e.g., O₃, HCl, ClO, HO₂, HOCl, BrO, O₃ isotopes, HNO₃, and CH₃CN) in the middle atmosphere to gain a better understanding of the factors and processes, including climate change, that control the amounts of stratospheric ozone.

Unfortunately, SMILES observations have been suspended since 21 April 2010 owing to the failure of a critical component in the submillimetre local oscillator. Until operations were suspended, SMILES measured concentrations of minor species in the stratosphere and mesosphere for about six months from October 2009 to April 2010. Processing of SMILES data provides global and vertical distributions of about 10 minor atmospheric constituents related to ozone chemistry; these
data are now distributed by ISAS/JAXA from DARTS (Data ARchives and Transmission System; http://darts.isas.jaxa.jp/iss/smiles/) for use by the scientific community. An important outcome of the SMILES observations is that they have revealed the global pattern of diurnal ozone variations throughout the stratosphere. The peak-to-peak difference of the stratospheric ozone mixing ratio reaches 8% over the course of a day, suggesting the need for care when merging ozone data from satellite measurements made at different local time (Sakazaki et al., 2013).

1.3 UV measurements

1.3.1 Broadband measurements
CGER/NIES has used broadband radiometers to monitor surface UV-A and UV-B radiation at five observation sites in Japan since 2000. CGER/NIES calculates the UV Index from the observed data and makes it available to the public hourly via the Internet.

1.3.2 Spectroradiometers
JMA monitors surface UV-B radiation with Brewer spectrophotometers at Sapporo, Tsukuba, and Naha in Japan and at Syowa Station in Antarctica. Observations commenced in 1990 at Tsukuba and in 1991 at the other sites.

1.4 Calibration activities
JMA has operated the Quality Assurance/Science Activity Centre (QA/SAC) and the Regional Dobson Calibration Centre (RDCC) under the GAW programme of the World Meteorological Organization (WMO) to contribute to improving the quality of ozone observations in WMO Regional Associations II (Asia) and V (South-west Pacific). The Regional Standard Dobson instrument (D116) is calibrated against the World Standard instrument (D083) every three years. The most recent calibration was in 2013 at Boulder, Colorado, USA. Through the QA/SAC, a JMA expert visited the ozone observatory in Manila in April 2010 to calibrate the Dobson spectrophotometer
there and provide training in measurement and maintenance of the instruments used there to monitor the ozone layer. JMA supported installation of automated observation systems for Dobson instruments at NOAA/ESRL, Boulder, Colorado (May 2009); Mauna Loa, Hawaii (June 2010); the Bureau of Meteorology, Melbourne, Australia (August 2010); the National Meteorological Service, Buenos Aires, Argentina (November 2010); and NIWA, Lauder, New Zealand (January 2012).

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Trend analyses for total ozone concentrations at three sites (Sapporo, Tsukuba, and Naha), eliminating solar activity and QBO, have shown an overall decrease of total ozone during the 1980s, but, in spite of large year-to-year variations, these analyses indicate either no significant change or slight increasing trends since the mid-1990s. Vertical ozone profiles from Umkehr and sonde measurements in 2012 show reduced ozone levels at altitudes of about 25 km at all three sites, above 35 km at Sapporo and Tsukuba, at about 45 km at Naha, and between 10 and 20 km at Sapporo compared with those in 1979. In contrast, increasing trends of ozone levels from 1998 to 2012 have been identified at altitudes of 13 km, and between 20 and 27 km at Sapporo, and below 24 km altitude at Tsukuba and Naha.

Erythemal UV measurements have been observed at three sites in Japan (Tsukuba, Naha, and Sapporo) since the early 1990s. At Sapporo and Tsukuba, the increasing trends in erythemal irradiance have been observed since the early 1990s. Especially, the yearly sums of erythemal irradiance at Tsukuba during the last three years of observation (2011–2013) are higher than those measured during the period of 1990-2010. On the other hand, no change of erythemal radiation was observed at Naha after the 2000s. Since the decline of total ozone at Sapporo and Tsukuba ceased around the mid-1990s, the increase of erythemal UV radiation since 1990 cannot be attributed to a reduction of ozone levels.

The duration of solar exposure required for vitamin D₃ synthesis in the human body has been estimated by numerical simulation using observed UV data at JMA’s three UV monitoring sites.
(Sapporo, Tsukuba, and Naha). The numerical simulation for Tsukuba at noon in July under a cloudless sky indicated that 3.5 min of solar exposure is required to produce 5.5 \( \mu \text{g} \) of vitamin D\(_3\) per 600 cm\(^2\) skin, which is the minimum requirement for human health. In contrast, the simulation for Sapporo in December at noon under a cloudless sky showed that it took 76 min to produce the same quantity of vitamin D\(_3\).

3. THEORY, MODELLING, AND OTHER RESEARCH

The Center for Climate System Research (CCSR, now the Division of Climate System Research within the Atmosphere and Ocean Research Institute), the University of Tokyo and NIES developed a chemistry–climate model (CCSR/NIES CCM). JMA’s Meteorological Research Institute (MRI) independently developed another chemistry–climate model (MRI-CCM). Both the CCSR/NIES and MRI groups participated in the second round of the Chemistry–Climate Model Validation Activity (CCMVal-2) of the Stratospheric Processes and their Role in Climate (SPARC) programme, and contributed to comparisons between and improvement of CCMs, leading to a better understanding of the individual strengths of these models. The CCSR/NIES and MRI CCMs were used to simulate the recent past and future evolution and global distribution of the stratospheric ozone layer by using concentrations of greenhouse gases and ozone depletion substances as recommended by CCMVal-2. The results of the simulations were published in the SPARC-CCMVal Report (2010). Scientific papers based on the outcome of the simulations were published in a special issue of CHEMCLIM1-Modeling of chemistry and climate (Mc2) in the *Journal of Geophysical Research* in 2010 and in the WMO Ozone Assessment Report in 2010.

NIES is developing a new version of its CCM with T42 horizontal resolution, constructed on the MIROC 3.2 AGCM, which was used for future projections of climate for the IPCC Fourth Assessment Report. This model has a new radiation code that greatly reduces the problem in the previous model of cold bias in the tropical upper troposphere/lower stratosphere. The new CCM incorporates more stratospheric water vapour than the previous version and better represents
observed data. The new CCM is also used as a three-dimensional chemical transport model (CTM) in which temperature and wind velocity data are assimilated into the calculated fields in the model by using a nudging method. The model simulates the global distribution of chemical species observed by SMILES, global patterns of diurnal ozone variation throughout the stratosphere, longitude-dependent ozone concentrations, and ozone chemical forcing at times of sudden stratospheric warming. The CCM and CTM are used for simulations recommended by the Chemistry Climate Model Initiative (CCMI), which is superseding the CCMVal, in order to investigate the individual and combined effects of changes in ozone depletion substances and greenhouse gases on past and future ozone changes. For these simulations, NIES focuses on chemical processes in the stratosphere and their effects on stratospheric and tropospheric climate. The CTM was also used to simulate a low-ozone event in southern South America in November 2009.

JMA’s MRI has developed both a CTM and CCM to study stratospheric ozone. A prominent feature of the MRI-CCM is that QBO, which plays a crucial role in inter-annual variations in the stratosphere, is spontaneously reproduced for wind and ozone in the tropical stratosphere by a T42L68 version that has about 300 km of horizontal resolution and 500 m of vertical resolution in the stratosphere. The MRI-CCM has been used at JMA to simulate ozone distributions by incorporating total ozone data from Ozone Monitoring Instruments (OMI) and has produced ozone forecasts for several days. At present, JMA is investigating the incorporation of ozone data from the Ozone Mapping & Profiler Suite (OMPS) of instruments. The ozone distributions so calculated can be used to monitor variations in total and stratospheric ozone, and to provide a UV forecast service. The MRI-CCM is also used to investigate the effect of the ozone layer on climate and for predictions of the future state of the ozone layer.

A new version of the model developed in 2011, MRI-CCM Version 2 (MRI-CCM2), includes detailed tropospheric ozone chemistry. The chemistry module of MRI-CCM2 is also an important component of the MRI earth-system model (MRI-ESM1), which participated in the fifth phase of the Coupled Model Intercomparison Project. MRI-ESM1 has been developed as an extension of the
atmosphere–ocean coupled general circulation model, MRI-CGCM3, by adding chemical and biogeochemical processes. This model is also used to perform some of the CCMI-recommended simulations.

University of Tokyo, NIES, and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) developed a CCM in 2011 (Watanabe et al., 2011). The CCM was developed by extending the upper boundary of the CHASER model from the lower stratosphere to the mesosphere and includes stratospheric chemistry and PSC processes. This model, known as MIROC-ESM-CHEM, also performs some of the CCMI-recommended simulations, focusing on chemistry–climate processes in the troposphere.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

NIES and the Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University have established stations at Tsukuba and Rikubetsu equipped with NDACC instruments, including lidars, millimetre-wave radiometers, and FTIR spectrometers. Some of the activities of these organizations have been incorporated in NDACC measurements in Japan.

Observational data acquired at JMA’s stations are submitted monthly to the World Ozone and UV Data Centre (WOUDC) in Toronto, Canada. Provisional total ozone data are also delivered daily on the Character Form for the Representation and Exchange of Data (CREX) through the WMO Global Telecommunication System (GTS), and used at the WMO Ozone Mapping Centre in Thessaloniki, Greece, to map the total ozone distribution over the Northern Hemisphere. Total ozone and ozone sonde data acquired at Syowa Station during the Antarctic winter and spring are submitted weekly to the WMO Secretariat for incorporation in Antarctic Ozone Bulletins.

4.2 Information provided to the general public

An annual report on the state of the ozone layer, surface UV-B radiation, and atmospheric
concentrations of ozone-depleting substances is published by the Japanese MOE. Data summaries of JMA’s total ozone, ozone sonde, and UV-B measurements are published monthly on the Internet. An annual report that includes detailed trend analyses of ozone over Japan and the globe is also published for both government and public use. Since 2005, JMA has been providing an Internet-based UV forecast service (in the form of an hourly UV-index map) based on UV-B observations and ozone forecast modelling techniques. Analytical UV maps and quasi-real-time UV observations are also posted hourly on the website. MRI-CCM UV forecasts will be replaced by MRI-CCM2 forecasts in the near future.

The MOE supports research on preservation of the environment in Japan and around the world (including ozone layer depletion) through the Environment Research and Technology Development Fund (ERTDF); their results are published in Annual Summary Reports.

5. PROJECTS AND COLLABORATION

A project named *Studies on the Variability of Stratospheric Processes and Uncertainties in the Future Projection of Stratospheric Ozone* was jointly undertaken as a ERTDF project by NIES, CCSR, Hokkaido University, and Miyagi University of Education. This project used soundings of vertical water vapour profiles in the tropical western Pacific to show that lower stratospheric water vapour at 19–21 km altitude was high and increasing in the 1990s, low between 2000 and 2003, and then increased to return to the level of the late 1990s in the mid-2000s. High-quality measurements were also made of O₂, N₂ isotopes, CO₂, and SF₆ that for the first time allowed identification of gravitational separation in the stratosphere. The results suggested that there has been little change in the age of air in the middle stratosphere of the Northern Hemisphere mid-latitudes since 1975. As part of the project, numerical experiments were also conducted using the CCSR/NIES CCM to investigate the stratospheric response to future increases of greenhouse gases and the impact of long-term variations of the size of the ozone hole.

NIES has started a new ERTDF project named *Effects of Additional CFC Regulation on Fragility of*
Ozone Layer under Future Global Warming. This project investigates the possibility of large-scale ozone depletion in the Arctic, as observed in 2011, by using 100-year CCM simulations in which the concentrations of ozone-depleting substances and greenhouse gases are fixed to past or near-future concentrations. Because the Arctic ozone exhibits large year-to-year variability, 100-year simulations employing different combinations of ozone-depleting substances and greenhouse gases will lead to a better understanding of the fragility of the ozone layer under the influence of future global warming.

JMA's Aerological Observatory has developed an automated Dobson measuring system (described at the JMA web site; http://gaw.kishou.go.jp/wcc/dobson/windobson.html) that reduces the burden on equipment operators and improves data quality. JMA has provided technical support to some foreign organizations interested in using this system.

6. FUTURE PLANS

Ongoing monitoring of levels of ozone, water vapour, and other species near the tropical tropopause will continue to improve our understanding of the role of the tropical transition layer in chemistry–climate interactions. Precise measurements of the concentrations of trace gases in the stratosphere will continue to provide key information on physical, chemical, and dynamic processes in the stratosphere. For example, precise monitoring of trace gases in the middle atmosphere enables identification of variability in the mean age of air and evaluation of the ability of current models to reproduce changes in dynamic atmospheric processes.

Development and improvement of CCM and CTM numerical models will continue, which will allow better prediction of future changes to the ozone layer and improve our understanding of the mechanisms of chemistry–climate interactions. A regular CCM update based on the newest global circulation model will be necessary for ongoing research on chemistry-climate interactions. For example, a new CCM is being constructed based on the MIROC 5 GCM that was used for future climate projections for the IPCC Fifth Assessment Report. Because MIROC 5 GCM simulates
sea-surface temperature distributions better than MIROC3.2 GCM, it provides better climate simulations than those of MIROC 3.2 GCM; thus, the new CCM might provide better chemistry-climate projections using the same chemical module as that of MIROC 3.2 CCM.

7. NEEDS AND RECOMMENDATIONS

Processing and reporting to WOUDC of a long record of unprocessed Brewer Umkehr data from Minamitorishima are needed. For Brewer instruments, a method for selection of cloud-free “good” data from unattended observations is needed, as are side-by-side comparisons with Dobson instruments.

Systematic observations to evaluate the changing state of the ozone layer, including detection of ozone layer recovery, should be continued in cooperation with international monitoring networks such as NDACC and the WMO/GAW programme.

Because of the strong connection between the stratosphere and the mesosphere, much more knowledge about chemical, dynamical and radiative processes in the upper middle atmosphere is needed. For example, reliable observation data for ozone and other chemicals in the upper middle atmosphere are needed, especially for HOx-related species such as OH and HO₂. The depletion and recovery of stratospheric ozone is dependent on climate change and changes of air quality, which, in turn, are dependent on levels of stratospheric ozone; these interdependencies need to be assessed. For example, there is a need to study the influence of super-recovery of the ozone layer in response to continuous increases of greenhouse gases on both climate and air quality in the troposphere. Re-evaluation of chemical reaction data, including photochemical data for use in stratospheric modelling, is urgently required to resolve discrepancies between observations and model calculations. CCMs need to be improved to more accurately simulate the effect on the atmosphere of variations of solar flux. Modelling of dynamical and chemical processes in the mesosphere and lower thermosphere is also necessary.

Finally, a systematic calibration program and well-coordinated monitoring network should be
established to detect variations and long-term trends in ground-level UV radiation.

References


KENYA, Republic of

1. INTRODUCTION
Kenya is a signatory to the international conventions and treaties on climate change and environmental protection. Consequently, the country is actively participating and contributing to the success of the World Meteorological Organization (WMO) programme through the Kenya Meteorological Service (KMS). The Service operates several air pollution observation stations that monitor, among other pollutants, ozone at the surface, troposphere and the stratosphere.

Realizing the importance of developing countries in the tropics to play a major role in the global initiatives to achieve a better understanding of the atmospheric changes and the effects on the environment linked to ozone changes, Kenya initiated its active involvement in the World Meteorological Organization (WMO) Global Ozone Observing System (GO3OS) with the launching of its total ozone monitoring programme in 1984. The ozone monitoring programme has since expanded to the current surface and vertical profile observations.

2. OZONE MONITORING ACTIVITIES

2.1. CURRENT STATUS
Kenya monitors ozone in four stations namely:

- Mount Kenya Global Atmosphere Watch (GAW) station
- Nairobi Regional GAW station
- Jomo Kenyatta International Airport Urban air Pollution Monitoring Station.
- Chiromo Urban air Pollution Monitoring Station.

2.1.1. Mount Kenya GAW station
Mount Kenya Global Atmosphere Watch station (MKN) is located at high altitude (3678m a.s.l, Longitude: 37.297° East, Latitude: 0.062° South,) in equatorial Africa. It is in a data-sparse region of the world and provides a unique opportunity to monitor background air as well as to conduct research in a pristine continental environment. It, therefore, samples air of the tropical mid-troposphere as well as the atmospheric boundary layer. This is done continuously (24 hour observations) in collaboration with International Twinning Partner (MeteoSwiss, Swiss Federal Laboratory for Material Testing and Research (EMPA))

The station monitors the effect of biomass burning on the regional build-up of tropospheric ozone, and discerning if any trends in stratospheric ozone are evident in Equatorial Africa. The station doubles as a global monitoring and research station.

The stations is equipped with one ozone analyzer (TEI 49C). The instrument was initially calibrated at WCC-Empa. Consistent measurements of surface ozone started in May 2002 at MKN. Data is regularly checked for consistency with time series plots, and submitted to QA/SAC Switzerland. QA/SAC continues to work with the station operators to transfer the responsibility of data evaluation to Kenya Meteorological Service (KMS) staff. Ozone data is submitted to the World Data Centre for Surface Ozone (WDCGG) in Japan Meteorological Agency (JMA).
2.1.2 Nairobi Regional GAW station

It is located close to the equator (Altitude: 1795m asl, Latitude: 1.30 S, Longitude: 36.75 E) in Eastern Africa, and corresponds to a unique site location for the detection of ozone in tropical region.

Nairobi regional GAW station monitors the total column of ozone using Dobson spectrophotometer number 18 since 2005. However, these measurements commenced at the University of Nairobi in 1984 until 2005 when the instrument was transferred to Kenya Meteorological Service.

The station also monitors the vertical profile of ozone since 1996. It uses a Lightweight, balloon-borne instrument mated to a conventional meteorological radiosonde. It has an electrochemical concentration cell (ECC) that senses ozone as it reacts with a dilute solution of potassium iodide to produce a weak electrical current proportional to the ozone concentration of the sampled air. During its ascent through the atmosphere, the ozonesonde transmits ozone and standard meteorological quantities to the ground receiving station. These measurements are performed ones per week.

The station commenced monitoring of surface ozone in July 2012. These observations are made every five seconds using Thermal Scientific Model 49i.

2.1.3 Jomo Kenyatta International Airport Urban air Pollution Monitoring Station.

Air quality monitoring in most developing countries is not routinely conducted, and in some urban areas such information does not even exist, though signs of deteriorating air quality and health problems related to air pollution are visible.

In bridging this gap, Kenya installed an Urban Pollution Monitoring Station (UPMS) at the Jomo Kenyatta International Airport (JKIA). The UPMS monitors Ozone (O₃), Carbon monoxide (CO), Sulfur dioxide (SO₂) and aerosols or particulate matter (PM10). This installation was in line with a feasibility that identified a suitable site downwind of run way 06 (RWYO6). The station commenced its operation in July 2012.

2.1.4 Chiromo Urban air Pollution Monitoring Station

The Urban air Pollution Monitoring Station was established at the University of Nairobi in 2009 by Kenya Meteorological Service. It measures surface ozone using TEI 49C instrument.

2.2 PLANNED OZONE MONITORING ACTIVITIES

Kenya plans to implement the National Flagship Programmes under Kenya’s Vision 2030 which include establishment of climate monitoring stations for air pollution monitoring and climate change detection. Indeed, two stations have been established at the University of Nairobi and Jomo Kenyatta International Airport that measures surface ozone among other pollutants. Kenya Meteorological Service plans to establish new station across the country that will monitor both the profile and total ozone. However, establishment of new stations may take long time to realize due to financial limitation. There is therefore need to secure financial support from the relevant institutions.
3. RESEARCH ON OZONE

3.1 EXISTING RESEARCH
Kenya currently does not have any major ozone research project in progress. However, several researches on ozone are being conducted by University students at both under graduate and post graduate level and private researchers.

Figure 1 below shows annual total column of ozone at Nairobi regional GAW station situated at an altitude of 1795m asl (Latitude: 1.30 S, Longitude: 36.75 E). Preliminary investigations indicate a decreasing trend of ozone from 1996 to 2013. However, further investigation is recommended to confirm this trend since the instrument (Dobson Spectrophotometer No. 18) was relocated from University of Nairobi to Kenya Meteorological Headquarters in year 2005. The annual mean and standard deviation are 256.2 DU and 6.9 respectively.

![Annual Total Column Ozone](image)

**Fig: 1. Annual total column of ozone in Nairobi, Kenya**

The mean monthly total column of ozone is indicated in figure 2 below. The figure shows a seasonal variation of ozone. There is a slight peak during the long rains in March-May and a major peak in August-October just before the commencement of the short rains. Minimum values are realized in December-February with corresponding maximum values in August-October. The difference in ozone amount is attributed with stratospheric ozone fluctuations due to the variation of the height of the tropopause (Muthama, 1989). The mean monthly standard deviation is 5.9.

Statistical analysis of ozone profiles over Nairobi split into 3 layers reveals strong yearly variation in the free troposphere and the tropopause region, while ozone in the stratosphere appears to be relatively constant throughout the year. Total ozone measurements by Dobson instrument confirm maximum total ozone content during the short-rains season and a minimum in the warm-dry season (Ayoma et al, 2002).
As a first output of this analysis indicate that the relative ozone variability in the “stratosphere” is weak, thus indicative of small changes in the ozone concentration in the stratosphere over Nairobi during the last 8 years. On the contrary in the “free troposphere” and “tropopause” regions observation showed significant changes: up to 40% of peak to peak variation with a well-defined yearly cycle. This tropospheric ozone variability is higher than expected and may partially be attributed to turbulent air motions (Ilyas, 1991).
Since Mount Kenya GAW station is at high attitude (3678m a.s.l), the site experiences thermally induced wind systems that disturb free tropospheric conditions. A study to investigate the suitability of the station showed that throughout the whole year the station is influenced by thermally induced wind systems and the atmospheric boundary layer (Henne et al. 2008).

Ozone showed a weaker annual cycle with a minimum in November and a broad summer maximum. Inter-annual variations were explained with differences in southern African biomass burning and transport towards MKN. Although biomass burning had little direct influence on the measurements at MKN it introduces inter-annual variability in the background concentrations of the southern hemisphere that subsequently reaches Kenya.

3.2 PLANNED RESEARCH ON OZONE
Preliminary analysis indicates that total column of ozone in Kenya has been decreasing as indicted in figure 1. Further analysis is urgently necessary to confirm this negative trend. However, there is no major ozone research project to determine the status of ozone level in country. This is occasioned by lack of a center for research on ozone-climate interactions due to the huge funds for the establishment of the center.

4. IMPLEMENTATION OF 80RM RECOMMENDATIONS

4.1 RESEARCH NEEDS
Minimum implementation of the recommendations on research from 80RM has been realized. Awareness to conduct research on ozone has been enhanced through seminars and workshops. This has led to publication of a few international journals.

4.1.1 Recommendations on Research Needs
The following recommendations will enhance research activities in Kenya.
- Establishment in Africa of a regional center for research on ozone-climate interactions.
- There are inadequate computing facilities especially for research that involve Global models. Twinning with more advanced research centers should be encouraged.
- Support investigations to resolve the differences between tropical total-ozone column trend estimates, and those trends computed from satellite profiles.
- There is few ozone observing stations in the tropics especially in Equatorial Africa. Governments in this region should be sensitized on the need to establish more ozone monitoring stations.
- Budgetary constraints. The funds allocated for research are inadequate leading to few being conducted. External sourcing of research fund would be highly welcomed.

4.2 SYSTEMATIC OBSERVATION
Systematic observations are critical to understanding and monitoring long-term changes in atmospheric composition. Kenya has been monitoring both total column and vertical profile of ozone since 1984 and 1996 respectively. Kenya has been keen in maintenance of existing facilities and expansion of observing stations. These networks are maintained above a critical level of data quality.
Archived data reports of ozonesondes include the simultaneous water vapour profiles measured by meteorological radiosondes and the data is available for ozone research and monitoring from the relevant world data center.

In the expansion and improvement of ground-based networks the country has established two urban air pollution monitoring stations that monitor ozone, among other air pollutants. In year 2011, Kenya commenced measurements of methane (CH₄) at Mount Kenya GAW station which is both GHGs and ODSs. CH₄ is measured by a Picarro G1301 instrument.

4.2.1 Recommendations on Systematic Observation
Recommendations that will enhance systematic observation in the country are;
- There is poor spatial distribution of ozone observing stations in the tropics especially in Equatorial Africa. Governments in this region to be sensitized on the need to establish more ozone monitoring stations. This would require both infrastructure and equipment support in order to establish new stations.
- Redistribution of instruments from instrument-rich sites to those areas that are poorly populated with instruments to be fast-tracked.

4.3 DATA ARCHIVING
The government provides funding for archiving all raw data from ozone monitoring stations. However, effort is underway to facilitate submission of the data to the WOUDC. The ozone data is archived in such a manner that they can be made easily accessible to scientists and the general public within a reasonable period of time.

4.3.1 Recommendations on Data Archiving
- Participation in regular workshops that provide training on metadata collection and processes for archiving data may support the effort to improve these activities within the ozone and research community.
- It is acknowledged that obtaining data of high quality is costly and time-consuming but is nonetheless an essential task and so data providers should be adequately funded and recognized for their efforts in providing this data to global archives for the furtherance of ozone and UV science.

4.4 CAPACITY BUILDING
The instruments used in ozone measurement require sophisticated calibration and maintenance, much of which is unavailable in Kenya without international intervention. At present, there are insufficient number of regional centres for research, calibration, and training in developed and, especially, in developing countries. To fill this gap, Kenya has established a regional and bilateral cooperation and collaboration (twinning) with Swiss Federal Laboratories for Material Testing and Research (EMPA).

EMPA provide resources and opportunities for scientific and technical training, at and beyond the instrument-operation level, thereby allowing instrument operators and other scientific personnel in Kenya to use their data, other available data, and models in both regional and international research areas. EMPA conducts a biennial system and performance audit of surface ozone and carbon monoxide at the global GAW station, Mount Kenya.
The WMO-GAW Training and Education Centre (GAWTEC) established in Germany has been successful in providing training in measurements and instrument calibration to all our staff involved in ozone measurements.

4.4.1 Recommendations on Capacity Building

- Following the success of the 2011 Czech workshop, a second Dobson Workshop was to be held in 2013 though it never took place. It is therefore proposed that this workshop be held toward the end of year 2014.
- Resources for the exchange programs and visits of personnel from monitoring stations from developed to developing countries should be increased in order to ensure technology and knowledge transfer and sustained measurement programs.
- Balloon sonde networks provide critical high-resolution vertical profiles of ozone, water vapour, and temperature, and therefore provide critical data for understanding the interactions between atmospheric composition and a changing climate. It is therefore important to develop training programs for the operators of these networks so that they can produce high quality, uniform data across the globe.
- Establishment of regional centers for research, calibration, and validation in developing countries to be encouraged.

5. CONCLUSION

The scientific community and in particular the Ozone Secretariat, to facilitate the investigations to resolve the differences between tropical total-ozone column trend estimates, and those trends computed from satellite profiles. This can be realized and especially in developing nation, through initiation of research projects involving sub-regional researchers from several countries. Much work needs to be carried out to understand many aspects of the ozone evolution and change, including ozone-climate relationships, UV relationships, etc. The international cooperation and assistance for improvement of the research level and quality are appreciated especially for African countries.

6. REFERENCES


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KYRGYZSTAN

1. Introduction

For more than 35 years the monitoring of ozone, solar UV radiation, tropospheric aerosol and main greenhouse gases in the central part of Euro-Asian continent is made only at the “Issyk-Kul” station (42.6°N, 77°E, 1650 m a.s.l.).

During a long time the Kyrgyzstan carries out investigations on ozone and concerned problems in the Central Asian region in two directions mainly:

• a complex monitoring of ozone and main greenhouse gases;
• a monitoring of solar UV radiation, and of tropospheric aerosol.

The station is located in the mountains of the Northern Tien Shan, has very favorable conditions for investigations of the above-mentioned problems due to a high transparency of an atmosphere, a lot of sunny days in a year and an absence of sources of anthropogenic pollution. It is unique in the central part of the Eurasian continent.

2. Monitoring

Investigations of atmospheric ozone in Kyrgyzstan began at the Kyrgyz National University in 1979. Different variants of spectral multiwave methods of measurement of the total content of ozone (TO) and stratospheric nitrogen dioxide were developed. For realization of these methods the different devices were made and the scientific station "Issyk-Kul" was created.

During the next years the monitoring of a content of a stratospheric nitrogen dioxide (N02), an integrated content of carbon oxide (CO2), water vapor (H2O) in the atmosphere, and a spectral transparency of the atmosphere in a visible spectrum range of a solar radiation with an estimation of effective parameters of troposphere aerosol was organized at this station. For validation of ozone measurements in various years, a comparison of the measurements by the ozonometer at the station with measurements by the national etalon device of Russia (Dobson spectrophotometer #107) and the data of measurements by the satellite device TOMS were carried out.

Since January 2000, a monitoring of intensity of solar UV radiation at the Earth’s surface in 5 bands of a solar spectrum in width of 2 nm being centralized on wave lengths 305; 312; 320; 340 and 380 nm was carried out by the device MICROTOPS II. The device registers radiation of a solar disk plus scattered radiation within a solid angle of 2.5 degrees.

The global of erythemally weighted solar UV-B irradiance (UV-er) irradiance are regular measured since May 2003 with Model 501 UV-Biometer (Solar Light Co).

The measurements of surface ozone concentration in Issyk-Kul station started in August 2003 and carried out with the help of the UV ozone analyzer TEI 49C. The fence of air is carried out at height of 5 m above a surface of the ground.

3. Research

Mean monthly total ozone (TO) values in the atmosphere over the central part of Eurasia for 1980 - 2008 are given in Figure 1. These values are obtained by averaging mean measured daily TO (curve 1) values. A determination error for mean monthly total ozone TO is less than ± 0.5%. The same Figure 1 presents the smoothed total ozone values (curve 2) and linear trend line 3.

Fig.1. Seasonal (1), annual (2) variation total ozone and linear trend (3) at Issyk-Kul GAW station.
The results of mean daily TO values obtained during ground-based measurements with
the values of TO satellite measurements made by the TOMS installed on board the NIMBUS-7
comparison. For the whole period of comparison the data of both measurements correlated with
each other with the correlation coefficients \( r = 0.95 \). The value of \( r \) in separate years changes
from 0.92 to 0.98.

As it was shown the results of long-term observations at the Issyk-Kul station, the 20 - 30%
amplitude of total ozone variations was relative to mean annual values of TO with oscillations
from 60 DU (1987) to 110 DU (1980, 1986 and 1991). Maxima in TO seasonal variations are
observed in February-April and minima in August-November. Here during the whole observation
period the changes of maxima in March were 40% and changes of minima in October were only
6%. For Issyk-Kul mean for the observation period annual TO seasonal variation, with the
account to a total ozone decrease in 1990 - 1998, is in good agreement with the mean seasonal
variation of total ozone during a year 1973 - 1990 averaged for Central Asia (42 N). During the
whole observation period at Issyk-Kul station means annual ozone content in the atmosphere
decreased to about 10.5% (34 DU) with an average rate -(0.39 \pm 0.03)% a year.

During the whole measurement period almost regular quasibiennial oscillations of smoothed TO
values with an amplitude of 15 DU. were observed. In 1980 - 1983 and 1991 -1992 a
disturbance of these oscillations regularity took place. In 1980 - 1983 and 1991 – 1992 TO
decreases were maximal and the TO decrease rates were equal to - (2.1±0.1) and - (4.5±0.1) %
a year, correspondingly. This is considered to be connected with the El Chichon and Pinatubo
eruptions.

In different time intervals the real trend of inter-annual ozone change may significantly differ
from the linear trend for all period of observations. After short period (1993-1998) of restoration
of ozone layer with the mean rate of 0.6% per year, further ozone layer depletion with the rate
of 1.5% per year took place during the following period.

It is seen from Figure 2, that during some time periods along with usual seasonal total ozone
variations considerable "gaps" - negative anomalies of different duration (from several days to
several months) - were observed at the station. Their appearance and, consequently, a possible
increase of UV radiation fluxes deserve special attention. In their essence these anomalies are
regional, local "micro holes" in ozone layer similar and equal in size to the anomalies observed
over Europe in 1980s.

The data of several ozonometric stations located in the Eurasian centre showed that during
1980 - 1995 the negative anomalies were observed at all stations. Almost simultaneously, the
anomalies were observed in the first half of the 1990s at the Issyk-Kul, Alma-Ata and
Karaganda stations. The first two stations are distanced from each other by ~70 km, and the
latter is almost 800 km away from them. In the spring of 1993, the ozone negative anomaly in
this region was about 1000 km in length and southern boundary was registered in Dushanbe.

A correlation of variations of mean monthly and mean annually total ozone (TO) content over
the mountainous regions of Central Asia for two observation periods of 2009 and 2010 at the
Issyk-Kul station is given in Fig. 2. The horizontal lines indicate means for 12 months. As it is
shown in Figure 3, for 2009, the TO content is 0.309 atm-cm, while for the later of the second
period (2010) obtained a value equal to the TO content -0.326 atm cm and ozone in the
atmosphere over Kyrgyzstan increased by approximately 3.3% in 2010 compared with 2009.

From Fig. 2 it is seen that the main characteristics of intra-annual variations of TO content
preserved - a maximum of TO content occurs in spring, at least - in the autumn, with
preservation of phase seasonal variation.
Fig. 2. Intra-annual fluctuations mean (points) monthly TO content and linear trend. Mean total ozone in the atmosphere above the “Issyk-Kul” station for 12-months (horizontal lines) in 2008 - 2010.

The variations of mean monthly intensities of the ozone surface in the Issyk-Kul from May 2003 to 2008 are given in Fig. 3.

Fig. 3. The variations of mean monthly intensities of the ozone surface

The variations of mean monthly intensities of the ozone surface in the Issyk Kul from 2009 to 2010 are given in Fig 4. It is seen, that in 2010 compared to 2009 mean annual concentration of COS increased from 39,1 ppb (in 2009) to 41.7 ppb (in 2010), i.e. by 6,4%.

Fig.4. Intra-annual variation of mean monthly (points) and mean over 12 months (lines) of surface ozone concentrations in the area of the station of Issyk-Kul in 2008-2010.
Figure 5 shows, along with the measured values of TO, the trend in form of a polynomial of 4 degree, calculated by least squares method from measured data. In Figure 5 you can see that starting (at "Issyk-Kul" st.) from the year 2006, there has been a positive trend in ozone.

![Ozone Trend](image)

**Fig. 5. TO 4th group polynomial trend**

Figure 6 shows that, from 2006, there is a positive trend in the annual average (seasonal fluctuations are excluded) values of TO that is illustrated by a 4th order polynomial trend (solid line). In 2008, the TO had 299 u.d. value and in 2011 the average TO was 311 u.d., i.e. from 2008 to 2011 the annual average TO value increased for 13 u.d..

![Atmospheric Ozone Variations](image)

**Fig. 6. Anti-aliased (smooth) interannual variations of TO and 4th order polynomial trend (solid line)**
It should also be noted, as can be seen from Figure 6, that during the observation period the speed of TO decrease (negative trend) in different intervals of time changed within wide limits. The four intervals should be pointed out: the first from 1980 to 1985, the second - 1989-1993, the third - 1998-2002 and the fourth - 2004-2006, where the decline was especially noticeable.

One of the causes of TO changes, together with anthropogenic ozone-depleting emissions, are emissions from volcanoes that contain fluorine-, sulfur-compounds which destroy the ozone layer getting to the stratosphere. Occurrence of ozone holes at the Poles affects the established circulation processes in the atmosphere, which ultimately leads to disruptions in quasibiennial fluctuations. Correlation of these processes is demonstrated in Figure 7, which shows variations of TO and the years of Antarctic and Arctic ozone holes.

Fig. 7. Interannual variations of TO and the years of ozone holes

The observed positive trend in the rate of change of TO from 2006-2008, is likely due to reduced emissions of ozone-depleting substances of human nature due to the operation of the Vienna Convention for the protection of the ozone layer and the Montreal Protocol on substances that deplete the ozone layer.

The variations of mean monthly intensities of erythemally weighted solar UV-B irradiance (UV-er) in the Issyk Kul are given in Fig. 8.

Fig. 8. Mean monthly total solar-weighted erythemal UV-radiation over the Issyk-Kul lake: model calculation (blue line); measured values (red dots); trend (dashed line).
For the period of 1990 – 2003, the values of total intensity of erythematos weighed UV-B radiation (295-315 nm) reaching the ground in the area of Issyk-Kul lake, were estimated using a three-layered model. In this model the measurements results of ozone and aerosol optical depth in UV range were used. For the period of June, 2003 - February, 2004 the calculated values of total intensity of UV-B radiation were compared to measurements results of UV-B radiation using the UV-Biometer 501.

The calculations have shown that at decreasing total ozone in the region of the Northern Tien Shan since 1990 to 2003 at a rate of (0.23 ±0.05)%/yr the intensity of the global solar UV-er irradiation increased with a rate of (0.38 ±0.07)%/yr.

When comparing the UV-er current mean monthly values with average long-term values, positive deviations of the UV-er were registered: (15-20) % in Feb.1993, April 1997, Feb. 1999, May 2000, Dec. 2000, Nov. 2001, January and March 2002. On some days in spring-summer positive anomalies reached (40-65) %. The increments in mentioned UV-er were observed when local ozone holes were located over the Northern Tien Shan.

The variations of mean monthly intensities of the direct solar UV radiation on the ground surface at local noon in the Issyk-Kul from January 2001 to December 2003 are given in Figure 9 for 4 wavelengths: 305, 312, 320 and 340 nm. Dotted lines are trends. A growth of total ozone for the past several years over the Northern Tien Shan with a rate of (2.5 ±0.14)%/yr is about 5 times higher than the rate of total ozone growth (observed in 1993-1997) caused by a decrease of the stratospheric aerosol burden induced by the Mt. Pinatubo eruption. This total ozone increase was accompanied by a decrease of the UV radiation intensity for $\lambda = 305, 312, 320$ and 340 nm on the Earth's surface with rates of 7.8; 4.6; 3.3 and 1.4%/yr, accordingly.

![Fig. 9. Time series of the local noon direct solar UV radiation, from March 01 to December 03; dotted line represents trends - change in the data with the seasonal cycle removed. The measurements have shown that in 2001-2003 the ozone changes are in a steady correlation with the intensity of the direct solar UV radiation ($\lambda = 305$ nm) only. Thus an increase UV-er irradiance over the Northern Tien Shan the last years occurred mainly due to the depletion of the ozone layer.](image)

Fig. 10 shows a seasonal trend of variations of UV-B radiation and an increase of the mean annually UV-B radiation in 2010 by 2.4% compared with 2009 in the Issyk-Kul.
**Fig. 10.** Intra-annual fluctuations in the local noon (points) the intensity of solar UV-B radiation in the area of the Issyk-Kul Lake in 2008 and 2010.

Mean monthly values of water vapor total content in the atmospheric column of the Eurasia central part are given in Figure 9 for the period of 1980 – 2006.

![Figure 9 showing intra-annual fluctuations](image)

**Fig. 11.** Seasonal (1), annual (2) variation of water vapor and linear trend (3) at Issyk-Kul GAW station.

A total amplitude of seasonal variations of W from winter to summer at Issyk-Kul station has changed within wide ranges from 1.53 g·cm\(^{-2}\) in 1985 to 2.39 g·cm\(^{-2}\) in 1988 (Figure 11). The mean amplitude for the whole observation period was (1.91±0.23) g·cm\(^{-2}\).

The mean monthly of the stratospheric nitrogen dioxide (NO\(_2\)) slant column content from April 1983 to December 2010 are presented on Figure 12. The NO\(_2\) seasonal variations have 35-45% amplitudes.

Between 1983 and 2010, the total content of NO\(_2\) vertical column (Y * 10\(^{15}\) mol/cm\(^2\), hereinafter referred to as a convenience factor of 10\(^{16}\), as a rule, falls) was measured during sunrise and sunset: 5121 morning and 5076 evening observing sessions, each of which consisted of approximately 170-200 individual measurements. The results are shown in Fig. 13.

![Figure 12 showing total NO\(_2\) content](image)

**Fig. 12** A total of the nitrogen dioxide (NO\(_2\)) in 1983-2010.

The results of measurements of CO\(_2\) and troposphere aerosol at Issyk-Kul station are presented in Fig.13 and 14.
4. Applications

The results of measurements of ozone obtained on Issyk-Kul station are transferred regularly to the World Data Centers: in Ozone (Toronto, Canada #347-WOUDC), in Greenhouse Gases (Tokyo, Japan ISK242N00-WDCGG), in aerosol (USA) and on NDSC network of stations (www.empa.ch/gaw/gawsis).

5. Future plans

In account of the COP Decision VIII/2, item 4. and Recommendations of the 8th meeting of the Ozone Research Managers, the priority at the above mentioned stations in Kyrgyzstan for the nearest future will be given to investigations of interaction between ozone and climate, between
stratospheric aerosol and climate, and influence of sulfuric acid stratospheric aerosol on ozone. To implement these tasks, it is necessary to carry out the following:

- to continue monitoring of ozone, NO2, CO2, H2O, UV-er on the ground surface, and surface ozone at the station of Issyk Kul.
- to establish the devices for measurement of other greenhouse gases (CH4, N20), tracer gases (SO2, CO), total and scattered solar UV radiation at the Earth's surface.

6. Need of support

For solution of above mentioned tasks, improvement and expansion of the base monitoring of ozone and stratospheric aerosol in the Central Asian region, Kyrgyzstan as a developing country needs a financial and technical support from General Trust Fund for Financing Activities on Research and Systematic Observations Relevant to the Vienna Convention and other international organizations.

For validation of ozone measurements in different years, a last comparison of the measurements by the ozonometer at the station with measurements by the national etalon device of Russia (Dobson spectrophotometer #107) and with the data of measurements by the satellite device TOMS was carried out in 1991.

Kyrgyzstan kindly requests to render assistance and financial support for calibration of scientific equipment on "Issyk-Kul" scientific research station. According to scientific standards, calibration of spectrophotometers must be conducted every five years, but because of lack of funds, Kyrgyz scientists were not able to implement it.

It is important to note that scientific research station "Issyk-Kul" for measurements of the ozone and green-house gases is the only station located at the great area - between Ural mountains chain and Pacific Ocean. The target technical and financial support of "Issyk-Kul" station will allow to continue scientific research of stratospheric ozone and green-house gases over Central Asian region, as well as to contribute to the global program of researches of the ozone layer.
MADAGASCAR

L’actuel rapport résume et récapitule les grandes lignes des réalisations et perspectives au niveau de la recherche sur la protection de la couche d’Ozone et de la mise en œuvre des activités contenues dans le Programme de Pays (PP) à Madagascar.

I. DESCRIPTION ET CONTEXTE

Madagascar a ratifié la Convention de Vienne pour la protection de la couche d’Ozone le 11 Janvier 1995 et le Protocole de Montréal relatif à des Substances qui Appauvrisent la couche d’Ozone (SAO) le 02 Mai 1996. Le 23 Octobre 2001, il a ratifié les Amendements de Londres, de Copenhague, de Montréal et de Beijing.

Comme la plupart des pays de l’article 05 du Protocole de Montréal, Madagascar étant pays importateur des substances réglementées par ledit Protocole, il ne produit ni de substances ni d’équipements ou appareils contenant des Substances Appauvrissant la couche d’Ozone (SAO).

Toutefois, Le pays respecte et adopte le programme d’action arrêté au niveau international concernant la mise en œuvre dans tous les pays Parties au Protocole de Montréal.

A cet effet, le pays a élaboré et mis en œuvre son Programme de Pays (PP) sur la protection de la couche d’Ozone. Quatre Plans/Projets ont été, jusqu’ici, mis en œuvre conformément à ce Programme Ozone de Pays (PP) :

- Les projets sur le « Renforcement institutionnel de Madagascar aux fins d’application du Protocole de Montréal relatif à des Substances qui Appauvrissent la couche d’Ozone»,
- Les Projets I et II sur le Plan de Gestion des Réfrigérants (PGR et PGR A),
- Le Plan de Gestion de l’Elimination Finale (PGEF) des Chlorofluorocarbones (CFCs),
- Le Plan de Gestion de l’Elimination des Hydrochlorofluorocarbones (HCFCs) ou PGEH.

Ainsi, dans le cadre des activités de suivi des SAO, Madagascar, à travers le Bureau National Ozone (BNO) a terminé en 2013 la mise en œuvre de la première tranche de la première phase du PGEH. Actuellement, nous sommes en train de mettre en œuvre le plan d’action contenu dans la deuxième tranche (2013-2015) de la première phase du PGEH.

En matière de suivi et de recherche sur la couche d’ozone, Madagascar dispose des institutions spécialisées en la matière. Toutefois, faute de matériels techniques spécifiques nécessaires pour ces activités, des données sont encore manquantes sur ce volet.

II. CADRE INSTITUTIONNEL


Le Ministère du Commerce et la Direction Générale des Douanes collaborent étroitement avec le Bureau National Ozone dans la stricte application des dispositions de la réglementation nationale qui régit l’importation et l’utilisation des Substances qui Appauvrissent la couche d’Ozone et les équipements frigorifiques.

En matière de suivi et de recherche sur la couche d’ozone, Le Bureau national Ozone collabore avec les établissements de recherche suivants : la Direction Générale de la Météorologie (DGM), le Centre National de Recherche sur l’Environnement (CNRE) et l’Institut National des Sciences et de la Technologie nucléaire (INSTN).
III. APPROCHE ET PERSPECTIVES

III-1 Activités de suivi sur les SAO et sur la couche d’ozone

a) Suivi sur les substances Appauvrissant la couche d’Ozone (SAO)

La première partie du Programme de Pays (de 1999 à 2010) a été réalisée par Madagascar avec succès à travers les projets d’Appui Institutionnel (PAI), le Plan de Gestion de Réfrigérants (PGF), le Plan de Gestion des Réfrigérants Actualisé (PGR A) et le Plan de Gestion de l’Elimination Finale des CFCs (PGEF/TPMP).

Depuis 2010, Madagascar a commencé la mise en œuvre de la deuxième partie du programme de pays à travers le déroulement des différentes phases du Plan de Gestion de l’Elimination des Hydrochlorofluorocarbones ou PGEH/HPMP.

Dans ce PGEH, il a été prévu entre autres la réalisation d’une étude approfondie sur les Hydrochlorofluorocarbones (HCFCs) et les Substances de remplacement et dont l’objectif étant de réduire d’une manière graduelle et progressive l’émission et la consommation desdites Substances suivant le calendrier d’élaboration de la consommation en HCFCs pour les Pays de l’Article 5 du Protocole de Montréal. Cette étude a porté sur les centres d’intérêt suivants :

En gros, cette étude approfondie, portant sur les HCFC, a donné les résultats suivants :

A Madagascar, le HCFC22 importé est utilisé surtout dans le domaine de la maintenance. Il est très demandé dans tous les domaines : industriels, commerciaux et les conditionnements d’air. Le R22 couvre un large éventail d’applications dans le domaine du froid qu’il s’avère difficile de déterminer un seul et unique réfrigérant de substitution.

Dans l’industrie, il est devenu le fluide indispensable pour les Chambres froides négatives et positives, le tunnel de congélation, la fabrique de glace. Dans le secteur commercial, on l’utilise pour les vitrines frigorifiques, les chambres froides de stockage. Il est notamment utilisé en conditionnement d’air, les climatiseurs domestiques.

Le tableau suivant donne la récapitulation des volumes d’importations en fluides frigorigènes, de 2010 à 2012

<table>
<thead>
<tr>
<th>DESIGNATION</th>
<th>QANTITE FLUIDES FRIGORIGENES EN KG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HCFC</td>
</tr>
<tr>
<td>TYPE</td>
<td>R22</td>
</tr>
<tr>
<td>FLUIDES</td>
<td></td>
</tr>
<tr>
<td>ANNEE 2010</td>
<td>306 012</td>
</tr>
<tr>
<td>ANNEE 2011</td>
<td>300 124</td>
</tr>
<tr>
<td>ANNEE 2012</td>
<td>289 354</td>
</tr>
<tr>
<td>TOTAL</td>
<td>895 490</td>
</tr>
</tbody>
</table>
Ce Tableau nous montre la quantité des fluides frigorigènes importés par Madagascar depuis 2011 (Source BNO). En trois ans, on a importé 895 tonnes de HCFC 22, 96 tonnes de HFC 134A, 24 tonnes de HFC 404A et 16 tonnes de HFC 410A. Il y a aussi des fluides frigorigènes naturels comme le NH3 0.971 tonne, le R290 (Propane) 0.208 tonne et le R600A (isobutane) 0.25 tonne.

Le HFC 407C et le 410A sont utilisés comme des fluides de substitution au HCFC 22 en conditionnement d’air. Ils sont utilisés surtout dans la maintenance des équipements de climatisations. On peut remarquer la montée de l’importation de l’R410A, de zéros à 16 tonnes depuis 2010. Cela est dû à l’importation des climatiseurs fonctionnant avec ce fluide (R410A), depuis la mise en application du PGEH.

Le HFC 134A sert à la réparation des équipements domestiques tels que les frigidaires et congélateurs. Seul le HFC 404A peut être utilisé comme fluide de substitution au HCFC 22 dans le secteur industriel et commercial.

Concernant les fluides naturels tels que le R600A et R290, ils sont utilisés respectivement comme fluide de substitution au CFC 12 dans les équipements domestiques et le HCFC 22 dans le domaine de climatisation. Leurs utilisations sont très minimes mais commencent à se développer davantage.

Quant au NH3 (ammoniac), après vérification auprès de la Société importatrice, on trouve que ce fluide est commandé pour être utilisé dans une autre application autre que l’installation frigorifique.

b) Observation sur la couche d’ozone

Malgré l’existence de la Direction Générale de la Météorologie, qui est l’organe apte à mener cette mission, la pratique de l’observation de la couche d’ozone n’existe pas encore à Madagascar.

Faute de matériels spécifiques, ce département se focalise sur la collecte et le traitement des données relatives aux prévisions météorologiques, telles que la température, l’humidité, la pression et le vent.

Au total, on recense 25 stations météo réparties dans tout le pays.

III-2 Plan de recherche sur la couche d’ozone

Ce volet n’est pas aussi disponible à Madagascar, malgré l’existence des centres de recherche tels que le Centre National de Recherche pour l’Environnement (CNRE) et l’Institut National des Sciences et de la Technologie Nucléaire (INSTN).

La raison réside toujours dans l’absence des matériels spécifiques nécessaires pour conduire ces recherches.

IV. BESOIN ET RECOMMANDATION

Dans le cadre de l’activité de suivi de l’élimination progressive des SAO, en l’occurrence le HCFC ; ainsi que la vulgarisation des substances alternatives aux SAO, Madagascar ne dispose pas encore des mesures incitatives mises en place qui peuvent pousser les utilisateurs à utiliser ces alternatives. Ces mesures peuvent se traduire sous forme de subvention temporaire, pour compenser l’investissement obligatoire que doivent faire les importateurs et les utilisateurs concernés.

Une allocation financière additionnelle est en effet souhaitable dans le cadre du PGEH, pour accompagner avec succès l’élimination progressive des SAO.

En ce qui concerne les activités de suivi et de recherche sur la couche d’ozone, pour combler le vide, Madagascar suggère la dotation en matériels techniques spécifiques des organes de recherche existant formellement, ainsi qu’aux renforcements de capacité de leurs techniciens.
Ce volet recherche sur la couche d’ozone est d’autant plus que nécessaire dans la mesure où les résultats de ces recherches pourraient contribuer à la prévention du cancer de la peau dont le taux d’atteinte ne cesse pas d’augmenter à Madagascar.

Voilà brossé, en quelques paragraphes, le résumé des activités de suivi et de recherches sur les SAO et la couche d’ozone effectuées à Madagascar durant ces dernières années.

Présenté par :
Mr RALISON PAUL OLIVIER
Directeur de l’Intégration de la dimension environnementale
Ministère de l’Environnement et des Forêts de Madagascar
Monitoring Activities:

- **Ozone Layer Protection Regulation 2004-**
  - Prohibitions on Importations
  - Prohibitions on the Importation of Certain Goods
  - Exemptions in relation to imports
  - Prohibitions on Exportation
  - Prohibitions on Manufacture
  - Prohibitions on Sales
  - Exemptions in relation to sales
  - Prohibition on releasing a controlled substance to atmosphere

- **Enforcement** - violation of not more than $10,000 (US Dollars) for each day violated these regulations. Also for a no permit violation, a fee of no more than $500 each is applied.

- **License/Permit System**
  - Permit application is filled out by any importers that is planning to imports ODS goods (HCFCs) with National Ozone Unit (NOU).
  - Application is reviewed and importers are given a permit once approved.
  - Permit is valid for a year, after a year it is required to be renewed.

- **Monitoring with Customs**
  - When importers ODS good arrived on island, Custom notify NOU to verify if importers have permit.
  - NOU officers accompany Custom officers and inspect containers of goods to verify gases in tanks if what is inside is actually as it is labeled on the tanks. This is done by using the Refrigerant identifiers.

- **Data collection of all ODS**
  - After every year, data from Custom office is collected by the NOU for submission to the Ozone Secretariat office.
  - Data is based on how much of gases are imported to the country annually.
  - Data collected is compared with Custom and importers for accuracy.
➢ Data is submitted online to Ozone Secretariat for review to be in compliance with country's required annual baseline
**MONGOLIA**

**Introduction**

This report includes briefing of the observation and research studies of ozone layer protection in Mongolia. The measurement of ozone from ground based stations in Mongolia has started since 2010.

The total column ozone from rocket was measured in between 1988 to 1992.

For the recent years the total column ozone was measured with data from Nimbus satellite from 1979 to 1992 and Aqua and Terra satellites from 2007 to 2013.

**Ozone layer observation and research**

- **The measurement from ground based station**

  The ground based measurement station O3-42M was established in Ulaanbaatar, Mongolia in 2010 with the support of France.

  - **At ozone sounding level**

    There is no available ozone sounding for studying the ozone layer level.

  - **The observations from rocket**

    In cooperation with Russia, the measurement station from rocket was operated during 1988 to 1992 in Sainshand city of Dornogobi Province.

    Sainshand city (coordination of N 44°53'28.38", E 110°08'11.32") is located in the southern gobi region in Mongolia.

    With the M-124 ozonometer from Russia the total ozone was measured. The status of tropopause was determined with the aerologic data at the same time. The measurement from rocket had operated until 1992.

    - The satellite observation and remote sensing

      In Mongolia, the measurements from ground based station did not provide much information, and it was experimented on satellite data. Data from the TOMS on the Nimbus 7 satellite were obtained from NASA database and were used to measure the total ozone distribution in between 1979 and 1992.
In addition, data from MODIS sensor on the Aqua and Terra satellites were used to measure the total ozone distribution in Mongolia.

Further it is possible to monitor with the satellites data.

**The research conducting authorities**

- Institute of Meteorology and Hydrology, Mongolia
- Information and Computing Center, Ministry of Environment and Green Development of Mongolia
- National Ozone Authority, Ministry of Environment and Green Development of Mongolia

**Data and methodology used in the research**

Data from the TOMS on the Nimbus 7 satellite were used to measure the total amount of ozone in Mongolia. The MODIS sensor provides high radiometric sensitivity in 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. These MODIS instruments will offer an unprecedented look at terrestrial, atmospheric, and ocean phenomenology for a wide and diverse community of users throughout the world.

![Figure 1. Total Ozone Distribution over the Mongolia, by Dobson Unit](image)

The measured total ozone is reported in Dobson Units (DU), and the value is in between 0 to 500.

Value = scale factor \( \times 0.1 \)
Results of ozone research

Reliable observations and research of ground based measurements and ozone zone being unavailable in Mongolia, the earlier research studies were done with data from aircrafts. In recent years, data from satellites were used to measure the ozone level above Mongolia.

Spatial and temporal distribution of ozone

The progress of monthly data rocket measurements from Sainshand station in 1989 is shown on figure 2.

The content of total ozone was instable, and the difference between the days in any month was greater.

Figure 2. The progress of monthly data measurements /Sainshand station, 1989/

According to the monthly average total ozone, the ozone content was higher during winter and spring in Gobi regions and lower in summer and autumn.

Figure 3. The monthly average content of the total ozone / Sainshand /
According to TOMS satellite data coverage in Mongolia / the northern latitude of 35.5°-55.5° and the eastern longitude of 80°-130°/, its average shows that the total ozone decreased during 1979 to 1999. But it was predicted that it might increase in the last 5 years.

According to the measurements of Sainshand station, the average value for the last 4 years predicted that there might be increase. At the same time, the satellite data showed the similar results.

According to the variation of multi annual contents of the total ozone, it decreased continuously, and its lowest value reached in 1993 to 1994.

When the total ozone content is compared to the tropopause height, the ozone content increases with the decrease of tropopause height.
The total ozone content is higher when tropopause temperature is lower.

In the research, the result of data from the following satellite is included.

The average value from satellite data of 1978-1993, by Dobson Unit is shown in the figure 8.
Due to dissimilar existence of high mountains such as Altai, Khangai and Khentii, steppe and gobi region the total ozone distribution has its evident characteristic. It is very important to analyze carefully the spatial and temporal distribution of total ozone over Mongolia. This is very significant for understanding the regional climatic feature of Mongolia.

From Fig. 9 we can see distribution of total ozone of Mongolia presents latitudinal distribution generally.

From long time change trends of November 1978 to April 1993 of total ozone (Fig.9), both latitudinal and longitudinal averages of total ozone have slow decreasing
trend. The maximum decrease of latitudinal average appears in 1987 and in 1985. The longitudinal average varies smoothly and steadily.

Long term change trends of seasonal total ozone in Sainshand indicates that the most obvious decrease of total ozone occurs in winter (January), then summer (July) the relevant low changes occurs in autumn (October) and the spring (April). It is shown in Fig.10.

**Figure 10. The seasonal trend of latitudinal average of total ozone over Mongolia**

MODIS data from Aqua and Terra satellites have been extracted and processed daily since 2008 in Mongolia. With these provided data, the total ozone content in Mongolia between 2008 and 2013 were studied.

The trend of the total ozone content over Mongolian territory and Sainshand area by the average value of January, April, July and October between 2008 and 2013 is shown in figures 11-14.
Figure 11. The average ozone content in January

Figure 12. The average ozone content in April
According to the research on seasonal average in 2008 to 2013, the result showed ozone level is decreasing in every season over Mongolian territory.

**Conclusion**

Since 1988, the observation and measurement of ozone from rockets had started in Mongolia. We have the opportunities to monitor the ozone level with the satellite data under our available financial and economic conditions.
We attempted to describe the progress of monthly, annual and multi annual ozone contents over Mongolian territory comparing the results from the total ozone and aerologic measurements of Sainshand station between 1988 and 1992 and the rocket data.

It clearly showed that the ozone content in the stratosphere was instable, and it changed daily. The ozone content over Mongolian territory was higher in winter and spring, lower in summer and autumn. According to the satellites data from 1979 to 1999 and from 2008 to 2013, the total ozone level appeared to be decreasing.

Reference


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National report The Netherlands

Systematic observations:

Surface networks

- Brewer measurements in the Netherlands
  The Brewer measurements at the station “De Bilt” by KNMI with Brewer #189 have been continued. Brewer #189 has been operated continuously since 1 October 2006. It replaced Brewer #100 which provided observations since 1 January 1994. “De Bilt” has the longest record of ozone measured with an MKIII instrument in the WOUDC database.

- Brewer measurements in Suriname
  Measurements at the station “Paramaribo” with Brewer #159 have been continued. After careful cleaning, the dataset has now been submitted to WOUDC and NDACC. (The variability in the ozone data in this tropical station is low, and interference by clouds is a significant problem at this site.)

- Ozone soundings in the Netherlands
  The ozone sounding program at station “De Bilt” by KNMI has been continued, with at least one launch per week, and more when special events occurred.

- Ozone soundings in Surinam
  The ozone sounding program in Paramaribo has been continued with one launch per week. Paramaribo station is part of the SHADOZ network. The observations at Paramaribo are performed by staff of the Meteorological Service of Surinam.

- UV-monitoring in the Netherlands
  RIVM continued the spectral UV-monitoring in Bilthoven in the Netherlands. The overall UV-data record in 2013 spans 20 years (1994-2013). The solar UV-spectrum at the ground is recorded each 12 minutes from sun rise to sun set. More than 20000 spectra are recorded each year. The spectral data are automatically processed with the QC (quality control) and data-analysis software package SHICrivm and the calculated solar UV-index (or zonkracht in Dutch) is presented in real time on the RIVM website (www.rivm.nl/zonkracht (in Dutch) and www.rivm.nl/UVindex (in English)).

- Ozone lidar measurements Lauder, New-Zealand
  RIVM has continued the operation of the stratospheric ozone lidar at the NDACC station in Lauder, New-Zealand where first measurements started in 1994. Measurements were taken by the RIVM stratospheric ozone lidar on 44 nights in 2012 and 32 nights in 2013. On a single measurement night, usually various measurements are done. Profiles up to July 2011 have been submitted to international databases, including NDACC.

Concerns:
Driven by the need for budget-reduction, the operational strategy of the lidar was altered in July 2011. Unfortunately, the implemented changes have introduced problems in the data processing chain and for the post-change period no data have been submitted to the databases yet. Given the limited budget, the necessary software (and possibly hardware) adjustments may take considerable time to implement. A second worry comes from the aging of the system. The lidar has been in operation in Lauder for almost 20 years. While laser and computer have been replaced once since, most parts are close to 25 years old. Many electronic parts are no longer replaceable (no longer built) and failure of those would require a large system update. This is not feasible with the current funding status. Continuity of the measurements is therefore at stake, and measurements may stop abruptly on a failure.

**Satellite networks**

The Netherlands is involved in satellite ozone measurements from several instruments: GOME, SCIAMACHY, OMI, GOME-2 and TROPOMI. These are UV-visible satellite spectrometers, from which ozone and several other trace gases, like NO2, SO2, HCHO, are determined. The OMI and GOME-2 instruments are operational. The TROPOMI instrument is presently being manufactured.

SCIAMACHY was contributed by Germany, the Netherlands, and Belgium to ESA’s Envisat satellite. SRON is the Dutch co-PI of SCIAMACHY. OMI is a contribution from the Netherlands and Finland to NASA’s EOS-Aura satellite. KNMI has the PI-role for OMI. TROPOMI is the successor instrument of OMI and SCIAMACHY. TROPOMI is developed by the Netherlands and ESA, and will fly on the ESA Sentinel-5 Precursor mission, to be launched end of 2015. KNMI has the PI-role of TROPOMI, with SRON as the co-PI.

**Ozone data processing and users**

At KNMI near-real time and off-line data processing of satellite ozone columns and ozone profiles is taking place; see Table 1. Also data assimilated products are made. Most of the products are being delivered to users via the web portal [www.temis.nl](http://www.temis.nl). The OMI ozone products are being delivered via the GSFC Data and Information Services Center (DISC). GOME-2 data processing at KNMI is performed in the framework of the Ozone and Atmospheric Chemistry Monitoring Satellite Application Facility (O3MSAF) of EUMETSAT. Data delivery of near-real-time ozone profile products is done via EUMETCast broadcasting. Figure 1 gives an example of GOME-2 profiles derived for the Antarctic in 2008.
Figure 1: Vertical structure of the Antarctic ozone hole in 2008 observed by GOME-2 (from Van Peet et al., 2008).

There are many users of the satellite ozone data; for example, SCIAMACHY and OMI ozone column data is being delivered in near-real-time to ECMWF for assimilation in the model. The EU MACC project is also a user of KNMI satellite ozone data.

Table 1: Near-real-time and offline satellite ozone products made by KNMI.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Product</th>
<th>Period</th>
<th>Data delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIAMACHY</td>
<td>Ozone column</td>
<td>2002 – 2012</td>
<td><a href="http://www.temis.nl">http://www.temis.nl</a></td>
</tr>
<tr>
<td>OMI</td>
<td>Ozone column, Ozone profile, Assimilated ozone column</td>
<td>2004 – now</td>
<td><a href="http://www.temis.nl">http://www.temis.nl</a></td>
</tr>
</tbody>
</table>

Assessment contributions and outreach

Netherlands scientists (Jos de Laat, Ronald van der A and Guus Velders) have contributed to several chapters of the 2014 UNEP/WMO Scientific assessment report. The Netherlands satellite observations are regularly used in the Antarctic Ozone bulletins given out by WMO.
At the occasion of World Ozone Day, 16 September 2013 a brochure in Dutch was compiled informing policy makers and the general public about the latest developments regarding the ozone layer, UV and associated health impacts in the Netherlands (http://www.knmi.nl/knmi_publicaties/bescherming_ozonlaag_2013/).

Other selected contributions

Studies of exceptional ozone layer events in the Arctic and Antarctic

The ozone observations from OMI have been used by Manney et al. (2011) to analyse the unprecedented ozone loss in the Arctic in March 2011 illustrated in figure 2. They demonstrated that the chemical ozone destruction in the Arctic vortex in spring 2011 was comparable to that in the Antarctic ozone hole. It is the first time that this was observed since observations have started. A likely cause were the unusually cold temperatures in the Arctic stratospheric vortex, which led to strongly enhanced chlorine activation and ozone loss.

Figure 2: The distribution of ozone in the Arctic on 26 March 2011 as observed by OMI.

The 2010 Antarctic ozone hole was on the other hand characterized by an anomalously small amount of ozone loss. Satellite observations showed that this was mainly due to
reduced ozone depletion in the 20-25 km height range. At lower heights ozone loss was not exceptional. De Laat and Van Weele (2011) showed that the reduced chemical ozone loss in 2010 was due downward transport of relatively humid air as a consequence of the occurrence of a minor Sudden Stratospheric Warming (SSW). This is illustrated in figure 3. The moist air air from the middle stratosphere did not descend much deeper than about 20 km and therefore ozone destruction below that altitude was left unaffected and similar to other years without SSWs.

Figure 3: The time evolution of the temperature anomaly in K (upper panel) and humidity anomaly in ppmv (lower panel) in the Antarctic in 2010 relative to 2005-2009, as observed by the MLS instrument.

Re-evaluation of ozone data-records
A major effort has been the multi-sensor re-analysis of total ozone performed with the TM3-DAM model (Van der A et al, 2010). This effort created a single coherent total ozone dataset from all available ozone column data measured by polar orbiting satellites in the near-ultraviolet Huggins band in the last thirty years. Fourteen total ozone satellite retrieval datasets from the instruments TOMS (on the satellites Nimbus-7 and Earth Probe), SBUV (Nimbus-7, NOAA-9, NOAA-11 and NOAA-16), GOME (ERS-2), SCIAMACHY (Envisat), OMI (EOS-Aura), and GOME-2 (Metop-A) were used. It is used to document the evolution of the Antarctic ozone hole (figure 4). Currently an update and extension of this MSR is underway.

Figure 4: Thirty-year time series of the Antarctic ozone hole, derived from the multi-sensor reanalysis data set of Van der A et al. (2010).

Knibbe et al. (2014) have used the MSR to investigate what explains the temporal variability of total ozone. The two-dimensionality of the MSR allowed them to derive the spatial patterns of regression coefficients and their explanatory power. They did this for both purely statistical as well as physically based regressions. Physically based parameters included EESC, the 10.7 cm solar flux, EP fluxes, QBO, ENSO, day length, PV at 150hPa and geopotential height at 500 hPa. Figure 5 shows that the physical and statistical regression have similar spatial performance distributions. Both show somewhat reduced performance in zonal bands located near the Antarctic vortex edge and at about 10° S in the tropics, and furthermore in a region extending from North Africa to China.
ESA Ozone_cci project

Netherlands scientists (Ronald van der A, Jacob van Peet, Michiel van Weele) have contributed to several deliverables of the ESA Ozone_cci project. Ozone_cci is one of the projects of the ESA Climate Change Initiative to generate climate records for many of the essential climate variables. Ozone_cci aims at generating new high-quality satellite data sets that are essential to assess the fate of atmospheric ozone and better understand its link with anthropogenic activities.

During Phase-1 (2011-2013) Ronald van der A and Jacob van Peet contributed to Ozone_cci through the provision of improved (assimilated and non-assimilated) nadir satellite-based ozone profiles. Ronald van der A and Michiel van Weele also (co-)authored the user requirement and product specification documents. Michiel van Weele contributed to the Climate Assessment Report with a comparison of the ozone profile records for the ‘Golden year’ 2008 provided by the instruments and models participating in Ozone_cci (Figure 6). The analysis includes two CCM simulations which were nudged to ERA Interim meteorological reanalysis fields for the year 2008 while the CTM used ERA Interim reanalyses as its meteorological driver.

The presented analysis puts a focus on the stratospheric altitude range [250-0.5 hPa] (12-50 km). The figure shows the present-day achieved consistency against the multi-model mean for each of the individual L3 instrument records for the year 2008 as well as with for the merged L3 limb product and the L4 assimilated nadir profiles. The differences between the models are of same order as the differences between the instruments. No single instrument-model combination was found to perform better than other combinations.

Phase-2 of Ozone_cci starts in 2014 and, like Phase 1, will last for three years.
Figure 6: Comparison of the ozone profiles of the harmonized climate records for the month of March 2008 against each other and against models relative to the multi-model mean of the three models. The limb instrument data records include the gridded zonal-mean ozone records from Envisat-instruments (MIPAS, SCIAMACHY, and GOMOS).
and Odin instruments (OSIRIS, and SMR). The nadir instrument data records include the gridded (L3) and assimilated (L4) zonal-mean ozone records from MetOp-GOME-2 for the same month. The models include the CTM TM5 run by KNMI as well as two CCMs (EMAC and UCAM) nudged to ERA Interim meteorology for the year 2008..

Studies of the future impact of ozone-depleting substances

Preserving Montreal Protocol Climate Benefits by Limiting HFCs

The Montreal Protocol is perhaps the most successful international environmental treaty, responsible for global phaseout of the consumption and production of ozone-depleting substances (ODSs), e.g., chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs). Hydrofluorocarbons (HFCs), which do not destroy stratospheric ozone, were considered long-term substitutes for ODSs and are not controlled by the Montreal Protocol. Because most HFCs are potent greenhouse gases (GHGs), they are included in the Kyoto Protocol. But climate benefits provided by this protocol are limited as they apply only to developed countries and over a short time (2008–2012). In Velders et al. (2012) we described, with no impending global controls on HFCs, inclusion of HFCs under the Montreal Protocol offers a path, starting in the short term, to preserve the climate benefits already achieved by this protocol (see Figure 7).

![Figure 7. Projected radiative forcing by ODSs, HFCs, low-GWP substitutes, and CO₂. The blue hatched region indicates what would have occurred in the absence of the]
Montreal Protocol, with 2 to 3% annual production increases in ODSs. Added to the radiative forcing from ODSs are the contributions from HFCs from an upper-range scenario. Also shown are the radiative forcing from alternative scenarios in which substitution is made with chemicals having shorter lifetimes (lower GWPs). From Velders et al. (2012).

The contribution of HFCs to global temperature change

There is growing international interest in mitigating climate change during the early part of this century by reducing emissions of short-lived climate pollutants (SLCPs), in addition to reducing emissions of CO₂. The SLCPs include methane (CH₄), black carbon aerosols (BC), tropospheric ozone (O₃) and hydrofluorocarbons (HFCs). Recent studies have estimated that by mitigating emissions of CH₄, BC, and O₃ using available technologies, about 0.5 to 0.6°C warming can be avoided by mid-21st century. In Xu et al. (2013) we showed that avoiding production and use of high-GWP (global warming potential) HFCs by using technologically feasible low-GWP substitutes to meet the increasing global demand can avoid as much as another 0.5°C warming by the end of this century. This combined mitigation of SLCPs would cut the cumulative warming since 2005 by 50% at 2050 and by 60% at 2100 from the CO₂-only mitigation scenarios, significantly reducing the rate of warming and lowering the probability of exceeding the 2°C warming threshold during this century.

Uncertainty analyses of ozone depleting substances

The rates at which ozone-depleting substances (ODSs) are removed from the atmosphere, which determine the lifetimes of these ODSs, are key factors for determining the rate of ozone layer recovery in the coming decades. In Velders and Daniel (2014) we presented a comprehensive uncertainty analysis of future mixing ratios of ODSs, levels of equivalent effective stratospheric chlorine (EESC), ozone depletion potentials, and global warming potentials, using, among other information, the 2013 WCRP/SPARC assessment of lifetimes of ODSs and their uncertainties. The year EESC returns to pre-1980 levels, a metric commonly used to indicate a level of recovery from ODS-induced ozone depletion, is 2048 for mid-latitudes and 2075 for Antarctic conditions based on the lifetimes from the SPARC assessment, which is about 2 and 4 yr, respectively, later than based on the lifetimes from the WMO assessment of 2011. However, the uncertainty in this return to 1980 levels is much larger than the shift due to this change in lifetimes (Figure 8). The year EESC returns to pre-1980 levels ranges from 2039 to 2064 (95% confidence interval) for mid-latitudes and 2061 to 2105 for the Antarctic spring. The primary contribution to these ranges comes from the uncertainty in the lifetimes, with smaller contributions from uncertainties in other modelled parameters (Figure 9).
Figure 8. Normalized EESC (1980 value set to 1) from 1960 to 2100 for mid-latitude conditions using the lifetimes from SPARC (2013) and with uncertainties applied to all parameters. Shown are the median values and 95% confidence interval based on the possible (orange) and most likely (red) uncertainty ranges in lifetimes. The years EESC returns to pre-1980 levels for the median EESC values is indicated with thin dashed lines. The EESC curves corresponding to the zero-emission scenario are shown for reference. From Velders and Daniel (2014).
Figure 9. Uncertainties (difference from the median, 95% confidence interval) in the years of return to pre-1980-levels for mid-latitude conditions resulting from uncertainties in all considered model input parameters. The year of return in the base run is 2048 for mid-latitudes and 2075 for Antarctic spring conditions. From Velders and Daniel (2014).

**UV monitoring and modelling in the Netherlands**

RIVM continued the spectral UV-monitoring in Bilthoven in the Netherlands. Figure 10 provides examples of diurnal dataplots for two summer days in 2013. All measured data are used to calculate yearly sums of UV-radiation received on a horizontal plane. The solar UV-index measured at groundlevel is determined primarily by the solar height, the total ozone column and clouds, and to a lesser extent by variations in aerosol concentrations. From the measured UV-data yearly sums are calculated and a standard procedure is used to correct for cloud effects. Thus, we obtain the measured yearly sum of UV-radiation received at ground level and in addition derive a cloud-corrected yearly sum (see Figure 11 lower and upper curves respectively) to enable a separation of trends and variations caused by ozone, and trends and changes caused by ozone and clouds combined.
Figure 10. Solar UV-index (=zonkracht) measured at RIVM on two summer days in 2013. Figures as provided real time on the RIVM web site.

Figure 11. Observed UV-trends and variations in the Netherlands in the past decades using RIVM’s UV-monitoring data (triangles) and a comparison with modelled UV-radiation levels using a combination of ozone sources (techniques described by den Outer et al 2010). The upper curve is corrected for cloud effects and thus shows the ozone related changes and variations. The lower line gives UV-radiation levels as received at the ground and thus includes both ozone and cloud effects. The yearly sum is calculated for the skin cancer weighted UV (SCUPh).

Maximum clear sky UV-sums are found in the mid-nineties of the last century, with the highest yearly sum in 1995 (see Figure 11). Since that period ozone values slightly
increased and consequently clear sky UV-radiation levels decreased slightly. When looking at the yearly UV-sum received at the ground, including ozone and cloud variations (Figure 11 lower curve), the highest yearly sum was also found in 1995. However, 2003 and 2009 closely follow 1995, and we see that for these years a lower reduction by clouds compensated the slightly higher ozone values.

Ground based measurements of UV were used in validation studies of approaches to calculate UV-radiation at the ground from satellite observations, and a new study was initiated and published to systematically compare ground based UV-measurements with satellite derived UV-budgets derived from satellite observations. Focus in this publication was on cloud effect retrievals (den Outer et al., 2012).

Comparing observed UV-trends with scenario studies on ozone depletion

In addition to the measurements RIVM has developed the Assessment Model for Ultraviolet radiation and Risks (AMOUR) to estimate long term effects of ozone depletion on both UV-radiation and skin cancer risks in relation to various scenarios for the production and emissions of ozone depleting substances.

If we compare the observed UV-trends with different scenarios for ozone depletion calculated with RIVM’s AMOUR-model we get the results shown in Figure 12. To avoid the year to year variability in Figure 12 the observed UV-data (modelled and measured) were taken as three year running means. The success of the Montreal protocol (and its amendments) is clearly seen in the clear sky UV-trends (Figure 12, left), which appear to follow the Copenhagen amendment scenario closely. Including the cloud effects (right panel) provides more scattering, but also in that case the large increases expected if no countermeasures to protect the ozone layer would have been taken (red line) are not reached in the past decade.

Figure 12. Observed UV-changes in yearly doses for the Netherlands (blue lines and dots) compared with UV-changes in relation to three ozone depletion scenario’s using RIVM’s assessment model AMOUR: scenario without countermeasures (red), original 1987 Montreal protocol (orange) and the Copenhagen amendments. The blue lines represent the three year running mean for modeled UV, and the dots for measured UV. The left panel provides ozone related changes and excludes the cloud variability, the right panel includes cloud-effects in the modelled and measured UV.
Skin cancer risks avoided by the Montreal Protocol (and its amendments)

The AMOUR-model was used to estimate worldwide skin cancer risks avoided by the global compliance to the Montreal protocol and its amendments. Led by RIVM researchers a collaborative European study was published with a fully globalised version of the AMOUR-model (van Dijk et al., 2013). Ozone depletion scenarios were obtained from two coupled climate-chemistry models and a no-countermeasure scenario was compared to the scenario with global compliance to the Montreal protocol (and amendments). In the year 2030 (see Figure 13) globally around 2 million cases of skin cancer are avoided by the Montreal Protocol. This excess number would rapidly rise thereafter in view of the long latency periods for the induction of skin cancer and the further increase in the UV-budgets if no countermeasures to protect the ozone layer would have been adopted. Despite the success of the Montreal Protocol to limit future excess skin cancer risks due to increases in ambient UV-radiation it is noted that even with full compliance the majority of excess skin cancer cases due to ozone depletion will not be reached until the mid of the 21st century. Thus, by the time that the ozone layer is expected to have recovered the consequences in terms of excess skin cancer rates will be at its maximum. It is likely however that, with full compliance to the Montreal protocol, the future skin cancer risks will increase much more due to behavioral changes than due to ozone depletion. At present skin cancer risks have increased much more than expected based on ozone depletion and ageing of the populations in large parts of the world. Changes in clothing habits and sun seeking holidays since the fifties of the previous century are likely primary causes for the observed increases in skin cancer incidence. A further increase (another doubling) is expected in the next decades, however the effects of ozone depletion will probably be limited to a few percent if full compliance with the Montreal protocol is achieved. A much worse situation would have occurred if no countermeasures would have been adopted. Nevertheless, protection of the skin to high UV-exposure levels remains important to limit future skin cancer risks.

Figure 13. Total numbers of new cases of skin cancer per million people per year avoided by the Montreal protocol in the year 2030 (taken from van Dijk et al., 2013).
Applications of the lidar measurements in Lauder (NZ)

The ozone lidar data from Lauder have been used for satellite validation, amongst others in the VALID-2 and Multi-TASTE projects. Several publications using this dataset are in preparation (Nair et al., Hubert et al., van Gijsel et al.) and have been published (Nair et al., 2012; Eckert et al., 2013).

In 2011 and 2012 two validation campaigns were performed with the NDACC traveling standard instrument from NASA GSFC.

In the 2012 intercomparison campaign with the GSFC system, some minor issues were identified during comparison of the ozone profiles, which will be corrected for (Figure 14).

Work has also been done to retrieve temperature profiles in addition to the ozone profiles from the lidar data. Initial validation with the NDACC traveling standard (NASA GSFC mobile lidar) has indicated during the intercomparison campaigns in 2011 and 2012 that

Figure 14. Ozone profile measurements on April 13th 2012 by an ECCsonde (green), microwave radiometer (blue-gray), RIVM stratospheric ozone lidar (blue and ocean-blue) and the GSFC mobile lidar (red and plum).
the retrieval is feasible and agreement with the lidar and sonde is good (see Figure 15). Further fine-tuning is needed, but it looks promising.

4/13/2012

Figure 15. Temperature profile observations on April 13th 2012 by a frost-point-hygrometer sonde (green), the GSFC mobile lidar (different retrieval versions: coral, pink, red, plum and orange) and the RIVM stratospheric ozone lidar (blue and dark teal).

References


New Zealand National Report

for the 9th WMO/UNEP Ozone Research Managers Meeting

14-16 May 2014, Geneva, Switzerland

Richard Querel and Olaf Morgenstern, NIWA, Lauder, New Zealand.

Introduction

In New Zealand, ozone- and UV-related research takes place at the National Institute of Water and Atmospheric Research (NIWA), at Bodeker Scientific, and in several of our Universities. Many relevant observations are taken at Lauder, near Alexandra. This station is a global station in WMO’s Global Atmosphere Watch Programme, and also is part of the Network for the Detection of Atmospheric Composition Change (NDACC). Ozone, as well as a number of parameters related to ozone depletion, are measured with a variety of techniques such as Dobson spectrophotometry, UV-visible spectroscopy, infrared spectroscopy, microwave radiometry, electrochemical ozonesondes flown on balloons, ozone and aerosol lidars, and frostpoint hygrometers. Solar UV radiation is measured at a number of sites. There also are measurement activities outside of New Zealand, such as in Antarctica and Pacific Islands. Specific work in support of environmental conventions also is taking place. Due to its location in the Southern Hemisphere and proximity to Antarctica, New Zealand is particularly interested in the climate effects of stratospheric ozone depletion. The newly approved “Deep South” National Science Challenge is a newly funded 10-year research programme with the aim of better understanding how changes in the Antarctic region affect New Zealand; the effect of ozone depletion and recovery on climate will form part of this programme.

Projects and Collaborations:

National Projects

Ozone and related research in New Zealand is undertaken primarily through the New Zealand Regional Atmosphere programme, which includes various measurement activities of ozone and associated species, primarily at Lauder, New Zealand, and Arrival Heights, Antarctica, measurement of physical variables such as UV, as well as global chemistry-climate modelling. UV measurements at Lauder are part of a larger research effort, spanning the physical and medical sciences communities, on the impact of UV on human health (both positive and negative effects), materials, and the biosphere. This research is informing health organizations such as the New Zealand Cancer Society.

International Projects

Ozone research in New Zealand is undertaken in close collaboration with many international partners and contributes to a wide range of international projects. Selected current international projects are:

NDACC (Network for the Detection of Atmospheric Composition Change), for which Lauder is the primary southern mid-latitude site, has been the principal focus of ozone-related work by NIWA at Lauder for more than three decades. NIWA reports a variety of profile, total column, and surface in-situ measurements of ozone and associated species to NDACC, taken at its primary locations at Lauder, NZ, and Arrival Heights, Antarctica, and also UV/Vis measurements of total-column NO2
from Macquarie Island, Australia, taken in collaboration with the Bureau of Meteorology, and Mauna Loa, Hawaii, in collaboration with NOAA.

IGAC/SPARC CCMI (Chemistry Climate Modelling Initiative): Contributing CCM simulations to the CCMI archive and participating in process oriented validation of CCMs. CCMI is the latest in a series of chemistry-climate modelling activities involving NIWA; previously, NIWA contributed to CCMVal-1 (informing the 2006 WMO Ozone Assessment), CCMVal-2 (informing the 2010 Ozone Assessment), and ACCMIP (informing the 5th Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, on tropospheric composition change). Unlike these predecessor activities, the aim of CCMI is to perform and assess whole-atmosphere chemistry-climate model simulations that will inform upcoming ozone, tropospheric air quality, and climate assessments, all with the same class of model. NIWA is participating in the development of the MetOffice Unified Model which, in different versions, has been used for all of these purposes, and is also working with Australian partners on their contribution to CCMI, using the ACCESS model.

Figure 1: Zonal-mean total column ozone (Dobson Units) in the NIWA chemistry-climate model. (top) 10-year mean for present-day conditions (contours: TOMS/SBUV climatology). (bottom 3 panels) Annual-mean ozone column in all forcings, fixed-ozone depleting substances, and fixed greenhouse gases simulations.
GRUAN (GCOS Reference Upper Air Network): Measurements of ozone, water vapour and meteorological parameters using ozonesondes and high-standard radiosondes. This is done on contract with NOAA and the New Zealand MetService. In support of this activity, NIWA has changed aspects of the method of conducting ozonesonde flights, has brought in a Global Positioning System (GPS) instrument which produces, as a by-product, total-column water vapour, and is using improved radiosondes giving more accurate readings of temperature and pressure.

BSRN (Baseline Surface Radiation Network): Various measurements of radiation, particularly of UV, are supplied to this international network.

SAGE-III Validation: Validation campaign, planned for 2015, of ozone and aerosol soundings, to validate the SAGE-III instrument on board the International Space Station, on contract with NASA.

**National collaborators**

NIWA

Richard Querel, Lauder: Ozone measurements project manager; GRUAN

Olaf Morgenstern, Lauder: Programme Leader – New Zealand Regional Atmosphere; Chemistry-climate modelling

Guang Zeng, Lauder: Chemistry-climate modelling

Alan Thomas & Hamish Chisolm, Lauder: Ozonesonde project, Dobson measurements

Dan Smale, Lauder: TEI and FTIR in situ ozone measurements

Sylvia Nichol, Wellington: Dobson measurements

Hisako Shiona, Christchurch: Dobson measurements, ozonesonde project, chemistry-climate modelling.

Adrian McDonald, University of Canterbury: Stratospheric ozone and dynamics, model analysis.

Tony Reeder, University of Otago: Effects of UV overexposure in humans.

Martin Allen, Univ Canterbury: UV dosimetry

Barbara Hegan, Cancer Society: UV Public health advisory

Karin Kreher, Bodeker Scientific: UV/Vis measurements of atmospheric composition

Greg Bodeker, Bodeker Scientific: GRUAN, simplified ozone chemistry

Robert Scragg & Alistair Stewart, Univ Auckland: UV, vitamin D and Health

Kathy Nield & Neil Swift, Callaghan Institute/MSL: Irradiance calibration issues

Martin Allen, Univ Canterbury: Dosimeters

Zim Sherman, Scienterra, Timaru: Dosimeters
Australian collaborations

Peter Gies, Australian Radiation Protection and Nuclear Safety Authority: UV and behavioural studies

David Griffith & Nicholas Jones, University of Wollongong: Collaboration on FTS measurements, especially related to biomass burning

Bruce Forgan, Bureau of Meteorology: Spectral and broadband radiation and aerosols

David Karoly, U Melbourne: Collaboration on coupled chemistry climate modelling

Andrew Klekociuk, Australian Antarctic Division: Collaboration on coupled chemistry-climate modelling.

Janet Bornman (Curtin, Australia), United Nations UNEP: Environmental Effects of UV radiation

Robyn Lucas (ANU): UNEP also UV Workshop

Peter Gies (ARPANSA), Michael Kimlin (QUT): UV Workshop

USA and Canada collaborations

NOAA

Dale Hurst, GMD: Funder and co-investigator on frost point hygrometer flights at Lauder, provision of surface ozone instruments, data sharing and interpretation

Patrick Disterhoft, CSD, CUCF: Global variability of UV (Mauna Loa and Boulder), Calibration of spectroradiometers

Robert Evans & Irina Petropavlovskikh, GMD: Dobson total-column ozone measurements

GMD = Global Monitoring Division (was CMDL); CSD = Chemical Sciences Division (was aeronomy laboratory); CUCF = Colorado Ultraviolet Calibration Facility

NASA

Richard McPeters, GSFC: Provision of Total Ozone Mapping Spectrometer (TOMS) satellite-based total column ozone measurements

Jay Herman, GSFC: Validation of satellite derived UV, UV units

Larry Thomason, LaRC: Provision of Stratospheric Aerosol and Gas Experiment (SAGE) satellite-based measurements of trace gases and aerosols. Lead investigator of the SAGE-III campaign.

Michael Kurylo, NDACC: NDACC data archival, meta data

Qing Liang, Margaret Hurwitz, Paul Newman, GSFC: Chemistry-climate modelling

GSFC = Goddard Space Flight Center; LaRC = Langley Research Center; NDACC = Network for the Detection of Atmospheric Composition Change
USA Universities

Wei Gao & Marek Uliasz, Colorado State University/USDA: Global variability of UV, USDA radiation suite; collaboration on dispersion modelling

Alan Parrish, University of Massachusetts: Co-investigator on microwave radiometers for ozone profiling

Darryn Waugh, Johns Hopkins University: Collaboration on chemistry-climate modelling

USDA = United States Department of Agriculture

Other USA and Canada

Gerald Nedoluha, Naval Research Laboratories (NRL): Co-investigator on microwave radiometers

R Booth & G Bernhard, Biospherical Instruments: Validation of UV from spectrometers

Sasha Madronich, NCAR: TUV Radiative transfer model, aerosol studies, UNEP

Sancy Leachman, Utah: UV dosimeters and health

Tracy Petrie, Oregon: UV dosimeters and health

Charles N. Long, Pacific Northwest National Laboratory (PNNL): Radiation Studies

Vitali Filetov, Environment Canada: UVI

NCAR = National Center for Atmospheric Research

United Kingdom collaborations

Martyn Chipperfield, University of Leeds: Collaboration in chemical modelling

Neal Butchart & Fiona O’Connor, UK Met Office: Collaboration on chemistry-climate modelling

John Pyle, University of Cambridge: Chemistry-climate modelling

Ann Webb (and several others), Univ Manchester: Rationalising UV units for CIE

Collaborations with rest of Europe

Jordi Badosa, Laboratoire de Meteorologie Dynamique (LMD), Ecole Polytechnique, Palaiseau, France: Radiation Studies

Josep Calbo, Departament de Fisica, Universitat de Girona (UdG), Girona, Spain: Radiation Studies


Ulrich Platt, University of Heidelberg, Germany: Development of instruments and techniques, data sharing and interpretation
Martin Dameris & Hella Garny: DLR-Institut für Physik der Atmosphäre, Germany: Collaboration on chemistry-climate modelling

Mario Blumthaler: Medical University of Innsbruck, Austria: Inter-comparisons and sky radiances

Dietrich Häder: University of Erlangen, Germany: Global variability of UV Eldonet instrument network

Günther Seckmeyer: University of Hannover, Germany: Sky imagery and pollution effects

Michiel van Roozendael, Belgium Institute of Space Aeronomy: Maintain UV/Visible trace gas standards and development of new techniques (NDACC)

Martine de Mazière, BIRA, Belgium: Interpretation of FTS measurements and validation of satellite data

Alkis Bais (Thessaloniki, Greece): UNEP

Lars Olof Björn, Lund Univ, Sweden: UNEP FAQs

Collaborations with Africa

Piet Aucamp (Private consultant, South Africa): UNEP FAQs

Caradee Guy, Univ Natal: UV dosimeters

Collaborations with Southeast Asia and Japan

Hideaki Nakajima, National Institute for Environmental Studies, Japan: Provision of Improved Limb Atmospheric Spectrometer (ILAS) satellite-based measurements of trace gases

Tetsu Nagai, Meteorological Research Institute of Japan: Aerosol lidar

Osamu Uchino, National Institute of Environmental Studies, Japan: Aerosol lidar

Yoshihiro Kondo: University of Tokyo, Japan: Spectral irradiance & actinic flux in polluted sites, aerosol studies

Collaborations with South America

Francesco Zaratti, Univ San Andreas, La Paz, Bolivia: Dissemination of UVI information

Sergio Cabrera, Univ de Chile, Santiago, Chile: Dissemination of UVI information

Ruben Piacentini, CONICET, Rosario, Argentina: Dissemination of UVI information

Hector Guillen, Soc Photobiology, Arequipa, Peru: Dissemination of UVI information

Susana Diaz, CONECIT, Buenos Aires, Argentina: UVI/WMO
Ozone Research in New Zealand

Of the more than 70 active NDACC measurement sites in the world, only three are equipped with a full complement of standard ozone measuring instruments: ozonesondes, Dobson spectrophotometer, UV/vis spectrometer, lidar, FTIR, microwave radiometer, as well as surface in situ observations. New Zealand is home to one of these sites (Lauder): the only one in the Southern Hemisphere.

Long time series measurements are key to identifying trends; the Lauder measurement site hosts several on-going multi-decadal data sets relevant to ozone research, including:

- Stratospheric NO2 since 1981 (33 years)
- Ozonesondes since 1986 (28 years)
- Dobson Ozone since 1987 (27 years)
- UV Spectrometers since 1989 (25 years)
- Ozone lidar since 1994 (20 years)
- Microwave radiometers since 1994 (20 years)
- TEI in situ ozone analyser since 2004 (10 years)

Electrochemical cell ozonesondes have been launched weekly since 1986 at Lauder, New Zealand (45°S, 170°E, 370 meters above sea level), a rural and clean background site representative of Southern mid-latitudes. With this data it is possible to assess the impact of dynamical and chemical changes and climate variability on ozone changes from the surface to the lower stratosphere at Lauder.

Figure 2: Time series of ozonesondes from Lauder which have been launched weekly since 1986.
The stratospheric NO$_2$ time series from Lauder is the longest in the world: 1981 – present.

![LONG TERM NO$_2$ MEASUREMENTS OVER LAUDER, NZ (45° S, 170° E)](image)

Figure 3: NO$_2$ time series from the UV/Vis spectrometers at Lauder since 1981.

The Dobson spectrophotometer at Lauder has been measuring since 1987 and is one of several NOAA instruments measuring at locations around the world.

![Dobson Total Column Ozone above Lauder: Year averages based on monthly averages](image)

Figure 4: Total column ozone from Dobson spectrophotometer measurements at Lauder. Plotted are the yearly averages based on monthly averages. Note the possible trend reversal beginning from 1999.
Figure 5: Daily column ozone data from Lauder as compared to the long term average (1979-2013). Shown in the plot are measurements from a Dobson spectrometer, estimates of ozone from the UV4 spectrometer, along with modelled estimates from the NIWA combined total column ozone data base.

Bodeker Scientific has received funding from the New Zealand Antarctic Research Institute to develop a stratospheric ozone module for an interactive simple climate model that can be used to make ensemble projections of the development of the ozone layer through the 21st century that incorporates the effects of changes in CO$_2$ and ozone depleting substances on ozone, and feedbacks of ozone on the climate system by virtue of its radiative forcing.

Due to funding constraints, maintenance of the Bodeker Scientific global total column ozone database$^{[1]}$ and the vertically resolved ozone database$^{[2]}$ has ceased, as have the analyses from these databases, for example various metrics of Antarctic ozone depletion$^{[3]}$.

$^{[1]}$ http://www.bodekerscientific.com/data/total-column-ozone
$^{[2]}$ http://www.bodekerscientific.com/data/monthly-mean-global-vertically-resolved-ozone
Future Plans

- All ozone measuring instrumentation at Lauder and Arrival Heights are fully operational and recording data.
- Ozonesonde launches at Lauder will proceed under the current 1 per week schedule.
- A proposal has been submitted to upgrade the Dobson instrument installed at Arrival Heights. This will involve transportation back to Lauder where it will have automation hardware installed along with a pre- and post-upgrade calibration/validation run with respect to the Lauder Dobson unit.
- An intercomparison study of Lauder ozone instrumentation is underway.

Needs and Recommendations

The following needs and recommendations require attention:

- Particularly in the tropics, there is some disagreement between different datasets, and w.r.t. model results, regarding the trends since 2000 of total column ozone. Detection of ozone recovery in this region would benefit from resolving these discrepancies.
- The budget for carbon tetrachloride remains unbalanced. Further measurements in more locations, close to potential sources, of this important ozone-depleting substance, would be useful.
- The effects of stratospheric change on surface climate change, and the mechanisms involved, need to be better quantified. There is now largely a consensus in the literature that seasonally past ozone depletion has been the dominant driver of climate change in the Southern Hemisphere, and future ozone recovery will remain an important driver of climate change, but large uncertainties remain about the regional impacts of both.
- In particular, the links, if any, between ozone depletion and expanding sea ice around Antarctica remain poorly understood and are generally not captured by general circulation models. This casts doubt on climate projections of the Southern Hemisphere.
- Changes in ozone in the upper troposphere and lower stratosphere, especially in the tropics, need to be better quantified and the effects of changes in ozone in this region of the atmosphere on the temperature structure of the atmosphere need to be better quantified.
- An ongoing debate about ‘optimal’ levels of UV exposure indicates that further research on vitamin D production and its health effects would be useful.
- A better quantification of natural sources of bromine in the troposphere is needed. Particularly, a possible intensification of the aquaculture of kelp, either for food production and carbon capture, would cause a potentially significant increase in the production of bromocarbons, which can affect the stratospheric ozone layer. This risk needs to be understood.

- Continuing support for long-term, high quality measurement sites.
Relevant scientific publications since 2011. NZ authors are in bold:


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anthropogenic emissions of CO and C2H6, ATMOS. CHEM. PHYS., 12,16, 7543-7555,
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Ozone monitoring and related research activities in Norway involve several institutions and there is no distinct separation between research, development, monitoring and quality control. This report presents Norwegian ozone related activities that have been carried out the last years.

1. OBSERVATIONAL ACTIVITIES

In 1990 the Norwegian Environment Agency (the former Norwegian Pollution Control Authority) established the programme “Monitoring of the atmospheric ozone layer”, which included measurements of total ozone at selected sites in Norway. Some years later, in 1994/95, the network was expanded and “The Norwegian UV network” was established. It consists of nine 5-channel GUV instruments located at sites between 58°N and 79°N. In addition the network included ozone lidar measurements until 2011. The measurements are undertaken by the Norwegian Radiation Protection Authority and the Norwegian Institute for Air Research on behalf of the Norwegian Environment Agency. Table 1 gives an overview of the location of the various stations, the type of measurements, and the institutions/institutes responsible for the daily operation of the instruments. The measurement sites are marked in Figure 1: Blue circles represent sites where both quality assured total ozone and UV measurements are performed, whereas green circles represent sites with UV measurements only.

<table>
<thead>
<tr>
<th>Station</th>
<th>Location</th>
<th>UV</th>
<th>Total ozone</th>
<th>Ozone lidar</th>
<th>Institute</th>
</tr>
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<tbody>
<tr>
<td>Grimstad</td>
<td>58°N, 08°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>Norwegian Radiation Protection Authority</td>
<td></td>
</tr>
<tr>
<td>Oslo</td>
<td>60°N, 10°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>University of Oslo/ Norwegian Institute for Air Research</td>
<td></td>
</tr>
<tr>
<td>Østerås</td>
<td>60°N, 10°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>Norwegian Radiation Protection Authority</td>
<td></td>
</tr>
<tr>
<td>Bergen</td>
<td>60°N, 05°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>Norwegian Radiation Protection Authority</td>
<td></td>
</tr>
<tr>
<td>Finse</td>
<td>60°N, 07°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>Norwegian Radiation Protection Authority</td>
<td></td>
</tr>
<tr>
<td>Kise</td>
<td>60°N, 10°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>Norwegian Radiation Protection Authority</td>
<td></td>
</tr>
<tr>
<td>Trondheim</td>
<td>63°N, 10°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>Norwegian Radiation Protection Authority</td>
<td></td>
</tr>
<tr>
<td>Andøya</td>
<td>69°N, 16°E</td>
<td>GUV</td>
<td>Brewer, GUV</td>
<td>Norwegian Institute for Air Research /Andøya Rocket Range</td>
<td></td>
</tr>
<tr>
<td>Ny-Ålesund</td>
<td>79°N, 12°E</td>
<td>GUV</td>
<td>SAOZ, GUV</td>
<td>Norwegian Institute for Air Research</td>
<td></td>
</tr>
<tr>
<td>Antarctica</td>
<td>72°S, 02°E</td>
<td>NILU-UV</td>
<td>NILU-UV</td>
<td>Norwegian Institute for Air Research</td>
<td></td>
</tr>
</tbody>
</table>

1.1 Column measurements of ozone

Total ozone measurements using the Dobson spectrophotometer D56 were performed on a regular basis in Oslo from 1978 to 1998. In Tromsø, Dobson measurements with D14 started back in 1939 and systematic measurements were performed until 1972. After a break of 12 years, the Tromsø Dobson measurements started up again in 1985 and lasted until 1999. Quality-assured Dobson D8 measurements were also performed in Ny-Ålesund, Svalbard, from 1995 to 2007. In 2007 the measurements terminated due to technical failure.
Since the summer 1990 Brewer instrument no. 42 has been in operation at the University of Oslo (Blindern). In 1994 Brewer measurements (with B104) started up in Tromsø, but after the termination of other ozone-related activities at the Auroral Observatory in Tromsø in 1999, the instrument was moved to Andøya, 130 km southwest of Tromsø. Today daily total ozone values from Oslo and Andøya are primarily based on measurements with these Brewer spectrometers. The ozone values are derived from direct sun measurements when available. On overcast days and days where the solar zenith angle is large, the ozone values are calculated from the global irradiance (GI) method (Stamnes et al., 1991). Except for the period from 1973 to 1984, total ozone has been measured on a regular basis in Tromsø/Andøya since 1939, which makes this time series the second longest in the world. The Andøya site is no longer included in the national ozone monitoring programme, but financial funding from the Norwegian Ministry of Climate and Environment will ensure measurements in the future.

NILU - The Norwegian Institute for Air Research is also measuring total ozone in Svalbard. Since 1991 there has been a DOAS instrument (type SAOZ) in Ny-Ålesund measuring total columns of ozone and NO₂. These NO₂ and ozone measurements are a part of the Network for the Detection of Atmospheric Composition Change (NDACC). During summer a GUV instruments is used to derive total ozone in Ny-Ålesund.

1.2 Ozone profile measurements

Together with the Andøya Rocket Range, NILU operated an ozone lidar at ALOMAR (Andøya) from 1995 until 2011. Unfortunately the ozone lidar measurements were excluded from the national monitoring programme in 2011 due to lack of financial support. The lidar is still operated by Andøya Rocket Range, but there is currently no funding for data analysis.

The lidar instrument is approved as a complementary site of the NDACC, and data were submitted to the NDACC database until 2011. The ozone lidar is also used to measure polar stratospheric clouds and stratospheric temperature profiles. The lidar is run on a routine basis during clear sky conditions, providing ozone profiles in the height range 8 to 50 km.

1.3 UV measurements

In total nine Norwegian sites are included in the UV network. The instruments, GUV from Biospherical Instruments Inc, are designed to measure UV irradiances in 4 channels. Using a technique developed by Dahlback (1996), it is possible to derive total ozone abundance, cloud cover information, complete UV spectra from 290 to 400 nm, and biologically weighted UV doses for any action spectrum in the UV wavelength region.

Spectral UV irradiances (global scans) are measured regularly with the Brewer instruments at the Department of Physics, University of Oslo, and at Andøya (ALOMAR).

In January 2007 NILU started measurements with a filter instrument (the NILU-UV radiometer) at the Norwegian research station Troll in Antarctica, financed by the Norwegian Research Council. The instrument is calibrated every month against relative calibration lamps in order to keep track of instrument drift.

1.4 Measurements of Ozone-Depleting Substances (ODSs)

NILU is running an ADS-GCMS and a Medusa-GCMS at the Zeppelin Observatory, Svalbard, which provides high quality measurements of more than 20 ODSs regulated through the Montreal Protocol (Myhre et al, 2013). This is a part of the national programme for monitoring of greenhouse gases, financed by the Norwegian Environment Agency. Several CFCs are also measured at the Troll Observatory in Antarctica (www.nilu.no/Miljøovervåkning/Trollobservatoriet/tabid/213/Default.aspx).

1.5 Calibration activities

1.5.1 The Brewer instruments

The Brewer instruments in Oslo and at Andøya have has been in operation for more than 20 years. Every year The International Ozone Services, Canada, calibrates the Brewer instruments...
at both sites, and the instruments are also regularly calibrated against standard lamps in order to check their stability. The calibrations show that the Brewer instruments have been stable during the years of observations. Also, total ozone measurements from the Oslo Brewer instrument agreed well with the Dobson measurements performed during the period of overlapping measurements from 1991 to 1998.

1.5.2 The GUV instruments

As a part of the Norwegian FARIN project a major international UV instrument intercomparison was arranged back in 2005. Altogether 51 UV radiometers from various nations participated, among them 39 multiband filter radiometers (MBFR’s). The instruments were also characterized on site. In addition to measurements of spectral responses, measurements against QTH lamps and cosine responses were performed for a selection of instruments. The main results have been published by Johnsen et al. (2008).

All the 9 GUV instruments in the Norwegian UV network are yearly calibrated against a reference GUV hosted at the Norwegian Radiation Protection Authority (GUV 9273). Every year drift correction factors are calculated for the GUV instruments prior to final publications of ozone and UVI.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Results from the national programme “Monitoring of the atmospheric ozone layer and natural ultraviolet radiation” are published by the Norwegian Environment Agency and NILU every year. Below are trend results from the last report (Svendby et al., 2013).

2.1 Ozone observations in Oslo

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter (Dec–Feb)</td>
<td>-6.2 (2.4)</td>
<td>-0.9 (3.0)</td>
</tr>
<tr>
<td>Spring (Mar–May)</td>
<td>-8.4 (1.4)</td>
<td>-0.8 (2.5)</td>
</tr>
<tr>
<td>Summer (Jun–Aug)</td>
<td>-3.4 (1.1)</td>
<td>-1.6 (1.3)</td>
</tr>
<tr>
<td>Fall (Sep–Nov)</td>
<td>-4.3 (1.0)</td>
<td>2.3 (1.6)</td>
</tr>
<tr>
<td>Annual (Jan–Dec)</td>
<td>-5.8 (1.0)</td>
<td>-0.5 (1.4)</td>
</tr>
</tbody>
</table>

In order to detect possible ozone reductions and trends over Oslo total ozone values from 1979 to 2012 have been investigated. For the period 1979 to 1998 data from the Dobson instrument has been applied, whereas for the period 1998 to 2012 the Brewer measurements have been used. The results of the trend analysis are summarized in Table 2. The second column indicates that a large ozone decrease occurred during the 1980s and first half of the 1990s. For the period 1979-1997 there was a significant decline in total ozone for all seasons. For the winter and spring the decrease was as large as -6.2 %/decade and -8.4 %/decade, respectively. The negative ozone trend was less evident for the summer, but nevertheless it was significant to a 2σ level.

For the period 1998-2012 the picture is different. As seen from the last column in Table 2 none of the trend results were significant to a 2σ level. For the summer months there was an ozone decline of -1.6%/decade for the period 1998-2012, whereas the ozone trend was correspondingly positive (+2.3%/decade) for the fall. The total ozone was very low most of 2011 and the winter 2012, which strongly affected the 1998-2012 trend results. For example, the ozone winter trend for the period 1998-2010 was as large as +4.5%/decade. When 2011 and 2012 was included in the trend analysis the positive winter trend turned to a negative value of -0.9%/decade. This clearly demonstrates how trend results can be affected by extreme values in the start and/or end of a short regression period. As seen from Table 2 the annual ozone trend from 1998 to 2012 is close to zero.

2.2 Ozone observations at Andøya

As mentioned above, ozone measurements in Northern Norway were performed in Tromsø until 1999 and at ALOMAR/Andøya from 2000. Correlation studies have shown that the ozone
climatology is very similar at the two locations and that the two datasets are considered as equivalent representing one site.

During the years with absent Dobson total ozone measurements in Tromsø/Andøya in 1979 and the 1980s, total ozone values from the satellite instrument TOMS (Total ozone Mapping Spectrometer) over Andøya were used in the trend studies. The results of the analyses are summarized in Table 3.

Similar to Oslo, the ozone layer above Andøya declined significantly from 1979 to 1997. This decline was evident for all seasons. The negative trend for the spring season was as large as -8.4%/decade, whereas the negative trend for the summer months was -2.8%/decade. The yearly trend in total ozone was -5.8%/decade. In contrast, no significant trends were observed for the second period from 1998 to 2012. For this period an ozone decrease of -0.7%/decade was observed for the spring, whereas a trend of -0.8%/decade was found for the summer months. The annual trend for the period 1998-2012 was -0.2% /decade. None of the 1998-2012 trend results were significant at either 1σ or 2σ significance level.

### Table 3: Percentage changes in total ozone over Andøya/Tromsø for the period 1979 to 2012. The numbers in parenthesis represent uncertainty (1σ).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring (Mar – May)</td>
<td>-8.4 (1.5)</td>
<td>-0.7 (2.4)</td>
</tr>
<tr>
<td>Summer (Jun – Aug)</td>
<td>-2.8 (0.9)</td>
<td>-0.8 (1.4)</td>
</tr>
<tr>
<td>Annual (Mar – Sep)</td>
<td>-5.8 (1.0)</td>
<td>-0.2 (1.5)</td>
</tr>
</tbody>
</table>

### 2.3 Ozone observations in Ny-Ålesund

The first Arctic ozone measurements started in Svalbard almost 65 years ago. In 1950 a recalibrated and upgraded Dobson instrument (D8) was sent to Longyearbyen, and Søren H.H. Larsen was the first person who performed systematic ozone measurements in polar region (Henriksen and Svenby, 1997).

Regular Dobson ozone measurements were performed in Svalbard until 1962. The data have been reanalyzed and published by Vogler et al. (2006). After 1962 only sporadic measurements were performed in Longyearbyen, but after the instrument was moved to Ny-Ålesund in 1994 more systematic measurements took place. However, the Dobson instruments require manual operation and it soon became more convenient to replace the Dobson instrument with the more automatic SAOZ and GUV instruments.

The ozone trend studies presented in Table 4 are based on a combination of Dobson, SOAZ, GUV and satellite measurements. For the years 1979 to 1994 the monthly mean ozone values have been based on TOMS Nimbus 7 and Meteor-3 overpass data. For the latest 20 years only ground based measurements have been used in the trend studies: Dobson data have been included when available, SAOZ data have been the next priority, whereas GUV data have been used when no other ground based measurements have been available.

As seen from Table 4 the ozone trend pattern in Ny-Ålesund has many similarities to the Oslo and Andøya trend series. A massive ozone decline was observed from 1979 to 1997, especially during winter and spring. The trend for the spring season was as large as -11.4%/decade, whereas the negative trend for the summer months was only -1.0%/decade. The annual trend in total ozone was -6.4%/decade during these years. In contrast, no significant trends were observed for the second period from 1998 to 2012. During this period an ozone decrease of -1.9%/decade was observed for the spring months, whereas a trend of +1.2%/decade was found for the summer months. The annual trend for the period 1998-2012 was -0.7% /decade. None of these results are significant at either 1σ or 2σ significance level.

### Table 4: Percentage changes in total ozone over Ny-Ålesund for the period 1979 to 2012. The numbers in parenthesis represent uncertainty (1σ).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring (Mar – May)</td>
<td>-11.4 (1.8)</td>
<td>-1.9 (3.3)</td>
</tr>
<tr>
<td>Summer (Jun – Aug)</td>
<td>-1.0 (1.3)</td>
<td>1.2 (1.6)</td>
</tr>
<tr>
<td>Annual (Mar – Sep)</td>
<td>-6.4 (1.1)</td>
<td>-0.7 (2.0)</td>
</tr>
</tbody>
</table>
2.4 UV observations

The Norwegian UV network, established in 1994/95, consists of nine 5-channel GUV instruments located from 58°N to 79°N (see Figure 1). NILU is responsible for the daily operation of three of the instruments, located at Oslo (60°N), Andøya (69°N) and Ny-Ålesund (79°N). The Norwegian Radiation Protection Authority (NRPA) is responsible for the operation of the measurements performed at Trondheim, Bergen, Kise, Landvik, Finse and Østerås.

Table 5: Annual integrated UV doses (kJ/m²) at three stations during the period 1995 - 2012.

<table>
<thead>
<tr>
<th>Year</th>
<th>Oslo</th>
<th>Andøya</th>
<th>Tromsø*</th>
<th>Ny-Ålesund</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>387.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996</td>
<td>387.4</td>
<td>253.6</td>
<td>218.5</td>
<td></td>
</tr>
<tr>
<td>1997</td>
<td>415.0</td>
<td>267.0</td>
<td>206.5</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>321.5</td>
<td>248.4</td>
<td>217.7</td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>370.5</td>
<td>228.0</td>
<td>186.1</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>363.0</td>
<td>239.7</td>
<td>231.0</td>
<td></td>
</tr>
<tr>
<td>2001</td>
<td>371.0</td>
<td>237.0</td>
<td>208.6</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>382.5</td>
<td>260.0</td>
<td>201.8</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>373.2</td>
<td>243.4</td>
<td>190.5</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>373.2</td>
<td>243.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td>No annual UV doses due to calibration campaign</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>372.4</td>
<td>219.4</td>
<td>No measurements</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>351.8</td>
<td>253.3</td>
<td>No measurements</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>375.3</td>
<td>266.5</td>
<td>No measurements</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>278.6</td>
<td>254.1</td>
<td>No measurements</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>360.5</td>
<td>225.6</td>
<td>201.6</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>365.2</td>
<td>254.8</td>
<td>200.8</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>352.6</td>
<td>227.5</td>
<td>211.6</td>
<td></td>
</tr>
</tbody>
</table>

*The GUV instrument at Andøya was operating in Tromsø for the period 1996 – 1999

Annual UV doses for the period 1995 - 2012 are shown in Table 5 for the three GUV instruments located in Oslo, at Andøya and in Ny-Ålesund. For days with missing data daily UV doses are calculated from a radiative transfer model, FastRt, http://nadir.nilu.no/~olaeng/fastrfastrt.html. UV measurements in Ny-Ålesund were excluded from the national monitoring programme from 2006 to 2009 due to lack of financial support, but the GUV instrument is now back in daily operation.

No significant UV trends have been detected at any of the three sites listed in Table 5

3 THEORY, MODELLING, AND OTHER RESEARCH

3.1 University of Oslo

Department of Geosciences runs two models to study stratospheric ozone, namely Oslo CTM3 (updated version of the CTM2) and WACCM. The Oslo CTM3 model is a global three-dimensional chemical transport model covering the troposphere and stratosphere.

The model can be run in different horizontal and vertical resolution and can be forced by either IFS or ERA-40 data. Two comprehensive and well-tested chemistry schemes are included in the model, one for the troposphere and one for the stratosphere. An extensive heterogeneous chemistry has been included. Photo dissociation coefficients are calculated on-line. Emissions of source gases are also included. The Oslo CTM3 model is used in various experiments to look at the chemical changes in ozone. Past time slice runs have used emissions from the Edgar Hyde database to look at the chemical changes up to present. IPCC SRES scenarios have been used for calculating chemical changes in future ozone. Because of large uncertainties in future emissions in the source gases, several time slice runs with different scenarios have been performed.

The WACCM model is a general circulation model (Whole Atmosphere Community Climate Model) developed at the National Center of Atmospheric Research (NCAR). It is now running at the University of Oslo. WACCM is a coupled climate chemistry model providing a platform for various predictions of the interaction between chemistry and climate. It has 66 vertical levels from the surface through the troposphere, stratosphere and the mesosphere.
In general, the Department of Geosciences are working substantially on stratospheric modelling in order to better understand how the ozone-layer dynamics work. Comprehensive research on atmospheric ozone modelling has been performed by comparing observations with model results. The results show that it is possible to reconstruct the distribution of the ozone layer (Eleftheratos et al., 2011; Isaksen and Dalsøren, 2011).

Department of Physics is operating the Brewer instrument and a GUV instrument at the roof of the Chemistry building at the University of Oslo. The institute has also been involved in ground-based measurements of solar UV radiation in developed countries with extreme UV levels, e.g. at the Tibetan Plateau (Norsang et al., 2014). The University of Bergen and NTNU have also participated in these studies.

At the Physics department there has been a focus on developing tools for deriving total ozone and cloud parameters from filter instruments and global irradiance UV measurements (Dahlback et al., 2005). Radiative transfer models are used for many purposes, including UV effect studies related to various cancer types and Vitamin D production (e.g. Moan at al., 2012).

3.2 NILU - Norwegian Institute for Air Research

At NILU there has been a main research focus on understanding the dynamical influence on the variability in total ozone, especially at the northern hemisphere at mid and high latitudes. Several studies and research activities are done in collaboration with Birkeland Center for Space Research (University of Bergen), the University of Oslo, CICERO and the Norwegian Radiation Protection Authority. Some of the more recent activities and results are listed below:

- Studies of the record low Arctic ozone of spring 2011, driven by cold temperatures, weak transport from lower latitudes, and halogen-driven chemical loss (Balas et al., 2011; Isaksen et al., 2012). The respective roles of transport and chemical loss during 2010 and 2011 were compared in simulations with the CTM2. While halogen-induced ozone depletion was record high for the Arctic, it appears that dynamics was important in setting the scene for the low ozone amount. While the chemical loss in 2011 was much higher than in 2010, the relative weakness of transport into the very stable and narrow vortex was the dominating factor.

- Contribution to the NOAA Report Card, organized by the Arctic Monitoring and Assessment Programme of the Arctic Council (Bernhard et al., 2013a). The work includes analysis of ozone and UV radiation at 12 sites located throughout the Arctic, ranging from latitudes 60° to 83° north. Work on the Report Card foster collaboration between scientists observing ozone and UV radiation at high northern latitudes, and has been leading to a joint publication on high levels of UV radiation observed by ground-based instruments below the 2011 Arctic ozone hole (Bernhard et al., 2013b).

- Mesospheric ozone following stratospheric sudden warmings, associated with elevated stratopause events has been studied (Kvissel et al., 2012a; Tweedy et al., 2013). The work is based on simulations with the Whole Atmosphere Community Climate Model (WACCM), and also the Soundings of the Atmosphere using Broadband Emission Radiometry (SABER) observations aboard the NASA TIMED satellite.

- Studies of the solar impact on the chemistry of the middle atmosphere through energetic particle precipitation (Kvissel et al., 2012b). It is introduced a chemical pathway that produces HNO₃ by conversion of N₂O₅ upon hydrated water clusters H⁺(H₂O)n, that ultimately triggers statistically significant changes in the climatological polar distributions of constituents such as O₃. Through O₃ changes, both temperature and dynamics are affected.

- NILU has developed reliable and robust filter instruments for measuring irradiances at UV and visible wavelengths. The NILU-UV instrument has been thoroughly tested through comparisons with well calibrated spectral radiometers over extended time periods with significant variations in ozone and cloud cover (e.g. Norsang et al., 2014). NILU is currently upgraded the NILU-cube 4π radiometer (Kylling et al., 2003). The next-generation multichannel moderate bandwidth filter.
instrument, designed for deployment on balloons, will include near-infrared channels in addition to the traditional UV and VIS channels.

### 3.3 CICERO Centre for International Climate and Research – Oslo

CICERO is involved in numerous modelling studies. They have the main responsibility of developing the Oslo CTM3, and is also the main user of both Oslo CTM2 and Oslo CTM3. The Oslo CTM3 description was published in 2012 by Søvde et al. (2012) and is now a part of several new studies, along with the former version CTM2.

In Hodnebrog et al. (2011, 2012) the impact of future aircraft emissions on atmospheric chemistry was investigated. CICERO has also been part of the setup of a model chain trying to reduce the radiative impact of aircraft emissions by using climate cost functions in a flight planning tool (Grewe et al., 2014). However, the impact on stratospheric ozone is relatively small, as the main contributor to changing the radiative impact is contrail cirrus and methane.

Using e.g. stratospheric ozone from Oslo CTM3, Holmes et al. (2013) constructed a parametric model that reproduced most of the interannual variability of the methane lifetime, and it was also used to predict future methane lifetime.

CICERO was also involved in the Arctic ozone depletion study reported by Balis et al. (2011) and Isaksen et al. (2012), where the special conditions during the spring 2011 were investigated.

### 4. DISSEMINATION OF RESULTS

#### 4.1 Data reporting

The complete set of revised Dobson total ozone values from Oslo is available at The World Ozone and Ultraviolet radiation Data Centre (WOUDC), http://www.woudc.org/. Also, Brewer DS measurements are regularly submitted to WOUDC. There are established daily routines submitting ozone data from the University of Oslo and from Andøya to WOUDC. Updated maps can be seen at http://exp-studies.tor.ec.gc.ca/e/ozone/Curr_allmap_g.htm

The complete set of total ozone and NO$_2$ measured from the SAOZ instrument at Ny-Ålesund has recently been submitted to the Network for the Detection of Atmospheric Composition Change (NDACC).

#### 4.2 Information to the public

Real time values of total ozone, UV indices and cloud thickness (CMF) for Oslo are available at http://tid.uio.no/ozone/. Also, near real time data and historical ozone time series from the SAOZ instrument in Ny-Ålesund can be found at http://saoz.obs.uvsq.fr.

NILU has developed a web portal for dissemination of UV-observations and UV forecasts for Norway and common global tourist destinations, available at http://uv.nilu.no. The content of the UV web pages are:

- UV forecast for three days for user-selected locations in Norway. The UV forecast is given for clear-sky, partly cloudy and cloudy conditions. Snow cover is also taken into account.
- Global UV forecast for common tourist destinations
- Measured UV doses and total ozone values measured at the Norwegian stations
- Facts on UV radiation and the ozone layer
- Information about sun protection for different locations and situations
- Preliminary total ozone values derived from the GUV instruments.

The public may receive ozone and UV forecasts at user-selected locations by e-mail. Also, a smartphone app is under construction. The web application has been developed by NILU in cooperation with the Norwegian Radiation Protection Authority, Storm Weather Center, and the
Norwegian Environment Agency. The Norwegian Meteorological Institute has developed an additional UV forecast service, where the weather forecast is an integrated part of the forecasted UV index.

Observations performed by the Norwegian Radiation Protection Authority and NILU are also available at [http://www.nrpa.no/uvnett/](http://www.nrpa.no/uvnett/) together with annual doses and information on sun protection.

In 2013 the Norwegian Environment Agency co-funded the production of a UNEP movie "The Arctic & the Ozone Layer: Stabilizing our Environment and Climate". Several Norwegian key researchers participated in the movie, together with the personnel operating the monitoring stations.

4.3 Relevant scientific papers
The ozone and UV monitoring and model studies in Norway give rise to research collaboration with national and international partners. In chapters 3 and 8 some the most relevant publications are referred and listed. They give an impression of international collaboration and ongoing research in the Norwegian ozone and UV scientific community the last few years.

5. PROJECTS AND COLLABORATION
Norwegian institutions and scientists are participating in several international and national projects related to ozone and UV. However, the number of projects have decreased significantly the last years due to reduced funding and focus on stratospheric ozone. Below is an overview of some of the most important projects related to ozone and UV research in Norway:

**International projects**

**NDACC:** The Network for the Detection of Atmospheric Composition Change (1991-> present) is a set of high-quality remote-sounding research stations for observing and understanding the physical and chemical state of the stratosphere. Ozone and key ozone-related chemical compounds and parameters are targeted for measurement. The NDAAC is a major component of the international middle atmosphere research effort and has been endorsed by national and international scientific agencies, including the International Ozone Commission, the United Nations Environment Programme, and the World Meteorological Organization. Web-site: [http://www.ndsc.ncep.noaa.gov/](http://www.ndsc.ncep.noaa.gov/)

**SHIVA:** Stratospheric ozone: Halogen Impacts in a Varying Atmosphere (2009-2012) aimed to reduce uncertainties in present and future stratospheric halogen loading and ozone depletion, resulting from climate feedbacks between emissions and transport of ozone depleting substances (ODS). Of particular relevance has been the studies of short and very short-lived substances (VSLS) with climate-sensitive natural emissions. It has been performed field studies of ODS production, emission and transport, using ship, aircraft and ground-based instrumentation. Web-site: [http://shiva.iup.uni-heidelberg.de](http://shiva.iup.uni-heidelberg.de)

**National projects**

**SATLUFT I and II:** Use of Satellite observations in the national and regional assessment of air quality, the atmospheric ozone layer, ultraviolet radiation, and greenhouse gases (2007-2013). The main objectives of the projects are to use Earth Observation data to improve the national and regional monitoring and assessment of the stratospheric ozone layer and surface UV exposure, the air quality in Europe and greenhouse gases. NILU coordinates this project which is funded by the Norwegian Space Centre and the European Space Agency.

**Atmo-TROLL:** Atmospheric research and monitoring at Troll – a long-term observational program (2007->). This program intends to establish new knowledge on annual and short-term variability as well as long-term changes of climate and pollution parameters. The list of parameters comprises
physical, optical and chemical properties of aerosols, ozone and UV, organic and inorganic pollution including Hg, CO and NMHC and surface ozone. The project is coordinated by NILU and funded by The Research Council of Norway.

Arctic EO: Arctic Earth Observation and Surveillance Technology (2009-2014). In the project an unmanned aircraft systems (UAS) platform is used, which can carry science payloads for research within meteorology, climate, environment and Earth observation disciplines. The project includes measurements and analyses of UV radiation and surface characteristics such as albedo and BRDF (bidirectional reflectance distribution function).

6. FUTURE PLANS

A short presentation of future plans are summarised below:

- It will be a continued focus on the existing ozone and UV monitoring activity in order to ensure high quality data series which is important for UV/ozone research
- The cooperation with CNRS, France, regarding long-term series of O₃ and NO₂ measurements with the SAOZ instrument in Ny-Ålesund will continue.
- The University of Oslo and NILU are already involved in community medicine activities related to ozone/UV and health and will continue to establish cooperation with the community medicine institutions.
- NILU has deployed a NILU-UV instrument that is installed at the Norwegian Antarctic Troll Station (71° S). Analysis, further development, and applications of the instrument are planned for the upcoming years. Also, an upgraded NILU-cube 4π radiometer, designed for deployment on balloons, will be further developed.

Apart from the activities listed above, there are no immediate plans for changes in the ozone monitoring programs in Norway.

7. NEEDS AND RECOMMENDATIONS

For the past years ozone and UV monitoring in Norway has been suffering from lack of funding. This means that ozone sonde measurements at Ørlandet and LIDAR measurements for ozone profile observations at Andøya have been excluded from the national monitoring programme. The UV-monitoring programme in Norway is a split cooperation between the Norwegian Radiation Protection Authority (NRPA) and NILU, but is funded from different sources. This situation is untenable, as the funding to NRPA is on a long-term basis, and the funding to NILU relies more on short term decisions.

In general there is a need for predictable multi-annual funding schedules in order to free operations from additional funding sources. In order to manage surveillance programmes and run instruments properly and continuously, stable long-term economic support is warranted. The trend over the last decade has been that long-term monitoring programmes have been supported through other channels, like satellite validation or other short-term research projects. This is a concern regarding the stability and quality of long-term data sets needed for trend analyses, in particular.

8. PUBLICATIONS


Dahlback, Arne; Eide, H.; Høiskar, B.a.k; Olsen, R. O.; Schmidlin, F.j.; Tsay, S-c. & Stamnes, K. Comparison of data for ozone amount and ultraviolet doses obtained from simultaneous measurements with various standard ultraviolet instruments. Optical Engineering: The Journal of SPIE. ISSN 0091-3286. 44(4), s 041010-1-041010-9, 2005


POLAND

In Poland, ozone and UV monitoring and related research activities are conducted by the Institute of Meteorology and Water Management- National Research Institute (IMWM), and Institute of Geophysics of the Polish Academy of Sciences (IGF PAS). The ozone and UV-B monitoring and research, carried on in both Institutes, are supported by: Chief Inspectorate for Environmental Protection; National Fund for Environmental Protection and Water Management; Ministry of the Environment, and National Science Centre.

OBSERVATIONAL ACTIVITIES
Column measurements of ozone and other gases/variables relevant to ozone loss

Institute of Geophysics of the Polish Academy of Sciences
IGF PAS has been involved in the long-term monitoring of the ozone layer for over 50 years. Measurements of the total ozone content and ozone vertical profile by the Umkehr method at Belsk (51°50'N, 20°47'E) by means of the Dobson spectrophotometer No.84 started in 1963, long before the depletion of the ozone layer became a great challenge for research community and the policy makers. In 1991 the Brewer spectrophotometer No.64 (single monochromator) with a UV-B monitor was installed. The Brewer spectrophotometer No. 207 (double monochromator) has been put into operation in 2010. The column ozone and ozone content in the Umkehr layers are measured simultaneously by 3 instruments that helps to determine precision of the ozone observations by each spectrophotometer. The surface ozone measurements with Monitor Labs, ML8810 meter started in 1991 (replaced by ML9811 in 2004) and since 1992 NOx measurements have been performed with Monitor Labs ML8841 meter (replaced by API200AV in 2004). The extended duration of the measurements and the high quality of the ozone data were essential for trend detection. Because the high quality of the ozone data is crucial subject in the analysis of the ozone variability the quality control and quality assurance of the ozone measurements is the major concern of the ozone research group. The Belsk ozone data were revaluated in 1983 and 1987 on a reading-by-reading basis, taking into account the calibration history of the instrument. The performance of the Belsk’s ozone instruments has been compared several times with the ground-based reference instruments (during international intercomparisons campaigns) and the satellite spectrophotometers (TOMS, OMI).

Institute of Meteorology and Water Management
Surface ozone measurements with Monitor Labs, ML9810 are performed at 3 stations: Leba (54.75N, 17.53E) on the Baltic Coast, Jarzcew (51.81N, 21.98E) located in the central Poland, Sniezka (50.73N, 15.73E) in Sudety Mountains.

Profile measurements of ozone

Institute of Geophysics of the Polish Academy of Sciences
The ozone content in selected layers in the stratosphere over Belsk have been calculated using the Umkehr measurements by the Dobson spectrophotometer (since 1963) and the Brewer spectrophotometers (the Brewer No.64 since 1992 and Brewer No.207 since 2010). UMK04 algorithm is used both for to the Dobson and Brewer Umkehr data. The Belsk ozone profiles have been used in the validation of ozone profiles derived by Microwave Limb Sounder on board of the Aura satellite.
Institute of Meteorology and Water Management
The ozone soundings have been performed at Legionowo (52.40N, 20.97E) upper-air station since 1979. Up to May 1993 the OSE ozone sensor with the METEORIT/MARZ radio sounding system was used. Later on the ECC ozone sensor and DigiCora/RS80/92 radio sounding system of Vaisala is in use. The ozone soundings are launched regularly on each Wednesday. Additional ozone soundings were performed for the purpose of the MATCH campaign (statistical evaluation of ozone chemical destruction in Polar Vortex). The Legionowo ozone profiles were also used in the validation procedures of ozone profiles derived from satellite projects: MIPAS, SCIAMACHY and OMI. Legionowo is a complimentary station of the global NDACC/NDSC ozone sounding network. Ozone sounding data from Legionowo are submitted to the NDACC database. Since 1993, on the base of the NOAA/TOVS/ATOVS satellite data, total ozone maps over Poland and surroundings have operationally been performed at the Satellite Remote Sensing Center of IMWM in Krakow.

UV measurements
Broadband measurements

Institute of Meteorology and Water Management
Broadband UV Biometers model SL 501 vers. 3 have been used for UV measurements at three IMWM stations: Leba (54.75N, 17.53E), on the Baltic Coast, Legionowo (52.40N, 20.97E), in central Poland, Zakopane 857m, in Tatra Mountains (49.30N, 19.97E). Since 2006, broadband OPTIX UVEM-6C have been used for nowcasting purposes at six IMWM stations in Poland: Leba (54.75N, 17.53E), Mikolajki (53.78N, 21.58E), in the northeastern Poland, Legionowo (52.40N, 20.97E), Katowice (50.23N, 19.03E) in the southern Poland, Zakopane 857m, in Tatra Mountains (49.30N, 19.97E), Mount Kasprowy Wierch 1988m (49.23N, 19.98E), in Tatra Mountains.

Institute of Geophysics of the Polish Academy of Sciences
Systematic measurements of ground level ultraviolet solar radiation (UV-B) with the Robertson-Berger meter were carried out at Belsk station in the period May 1975 – December 1993. In 1992 UV Biometer SL501A (replaced by the same type of the instrument in 1996), and in 2005 Kipp and Zonen UVS-AE-T broadband radiometer were installed. The instruments have been operated continuously up to now. The UV monitoring has been conducted at the Polish Polar Station at Hornsund, Svalbard (77°00'N, 15°33') in the period 1996-1997 by UV Biometer SL501A and since spring 2006 up to now by Kipp and Zonen UVS-AE-T.

Narrowband filter instruments
Two NILU-UV spectral filter instruments installed at IMMW station Legionowo measure the UV-B, UV-A, total ozone and cloud transmission.

Spectroradiometers
Spectral distribution of UV radiation has also been monitored with the Brewer spectrophotometers at Belsk since 1992 (Brewer No.64) and in addition since 2010 (Brewer No.207). The spectra with 0.5 nm resolution for the range 290-325 nm and 286-363 nm have been calculated by the Brewer (No.64) and Brewer (No.207), respectively. Several spectra per hour are usually obtained for the solar zenith angles less than 85°.
Calibration activities

Institute of Meteorology and Water Management
The UV Biometers model SL 501 have been regularly calibrated at PMOD/WRC in Davos. The next calibration of the instrument is planned in 2014. A method of calibration of the Biometers OPTIX UVEM-6C which does not disturb the continuity of measurements on the IMMW network has recently been elaborated.

Institute of Geophysics of the Polish Academy of Sciences
The Dobson and Brewer spectrophotometers have been regularly calibrated. The recent calibrations of the Dobson instrument took place at the Hohenpeissenberg Observatory of DWD in 2010, and the next calibration is planned in June 2014. The intercomparisons were carried out against the European substandard Dobson No.64. The Brewer spectrophotometer No.64 was calibrated against the reference instrument Brewer No.17 maintained by the International Ozone Corporation (Canada) at the Belsk observatory in 2012, the Hradec Kralove Observatory (Czech Hydrometeorological Institute) in 2013, and the next calibration is planned at Belsk in 2014. During the Brewer intercomparison campaigns both the total ozone and UV spectra were calibrated. Since 2010 the output of the Belsk’s broad band UV meters is compared against the Belsk’s Brewer No.207 (double monochromator).

RESULTS FROM OBSERVATIONS AND ANALYSIS

![Figure 1. Annual means (1963-2013) of total ozone at Belsk, Poland, from the Dobson spectrophotometer measurements.](image-url)
Figure 2. Fractional deviations of the annual mean ozone content in the upper stratosphere (32.5km - 37.5km) from the long-term (1963-2013) annual mean in percent of the long-term mean, from the Umkehr observations carried out at Belsk

Figure 3. Annual means (1992-2013) of surface ozone concentration at Belsk, Poland.
Institute of Meteorology and Water Management

Long term changes in ozone profile at Legionowo, Poland, have been studied. Significant downward trends of ozone concentration in winter and spring months in the lower stratosphere have been found during the period of acceleration of ozone depletion processes on global scale (1979-1993). In recent years (1998-2012) signs of ozone recovery in the middle stratosphere have been detected. The observed differences in stratospheric ozone destruction from year to year are the result of changing meteorological conditions in the NH stratosphere. Legionowo is often located at the edge of the polar vortex and since 1995 participates in MATCH campaigns (statistical evaluation of ozone chemical destruction in Polar Vortex). Episodes of serious ozone deficiencies, observed during the displacements of the cold polar vortex in the winter/spring seasons have been observed.

Institute of Geophysics of the Polish Academy of Sciences

The ozone time series (from the observations taken at Belsk and from the global ozone data bases) are examined by statistical models developed in IGFPAS to determine factors responsible for the ozone changes. The ozone variability and quantification of the impact of human activities on the ozone layer is essential because of the coupling of the ozone layer and the global climate system. The changes in the ozone layer are examined in connection with changes in the dynamic factors characterizing the atmospheric circulation in the stratosphere. Various studies have been carried out in the Institute focusing on the role played by the dynamical factors of the ozone variability. Natural dynamical processes in the Earth’s atmosphere could perturb the recovery of the ozone layer.

Variability of solar UV radiation over Belsk since 1976 up to now, based on the world longest

The research achievements since the previous Report (2011) could be summarized as follow:

- Developing a novel trend model to disclose the temporal variability of the long-term component of the ozone variability and to discuss effectiveness of the Montreal Protocol (MP) 1987 and its subsequent Amendments regulations to save the ozone layer. The model has been used for the trend detection in the global satellite and Belsk’s ozone data. (Krzyścin, 2012a, Krzyścin et al., 2013)
- Calculation of the vertical profile of ozone from the Umkehr observations using neural network approach. The ozone pattern in the troposphere and lower stratosphere could be calculated with higher accuracy than that by the standard inverse Umkehr retrieval (Jaroslawski, 2013)
- Finding evidences of slowing down the recovery rate of the Belsk’s total ozone (see Figure 1) since ~ 2005 especially in the summer total ozone data due to unknown yet dynamical process (Krzyścin et al., 2013)
- The pattern of the upper stratospheric ozone changes over Belsk with the trend overturning about 1996 corroborates the success of the Montreal Protocol and its further Amendments regulations to save the ozone layer (see Figure 2)
- Modelling biomedical aspects of solar and artificial (due to fluorescent tubes) UV radiation. The UV level at Belsk has stabilized since the beginning XXI century at level ~10% higher than that in the mid 1970s (see Figure 4). Scenarios for getting the appropriate vitamin D level due to solar radiations and basis for anti-psoriatic heliotherapy in Poland have been prepared (Lesiak et al., 2011; Krzyścin et al., 2011; Krzyścin et al., 2012b; Krzyścin et al., 2012d)
- Finding the impact of Eyjafjallajokull volcano ash on surface UV at Belsk. Eruption of Eyjafjallajokull volcano on 13-14 April 2010 created an ash cloud moving towards densely populated areas in Europe. Since 16 April thin aerosol clouds, linked to the volcanic eruption, were found below 5 km at Belsk. The optical thickness of the cloud (at 500 nm) varied only slightly in the range of a few hundredths that had no impact on surface UV there. (Pietruczuk et al., 2011).
- Developing a multiple regression model to attribute the Arctic total ozone variability to various chemical and dynamical ozone forcing factors. The total area with extremely depleted total ozone over the Arctic reached the maximum at the end of March 2011, equal to ~11×10^6 km^2. The model reproduces the ozone loss in early 2011 and the overall picture of the ozone long-term changes since 1979. The extreme ozone decline in 2011 could be attributed to the long-lasting period with low stratospheric temperature (<195 K), weaker than the normal Brewer-Dobson circulation, and the Arctic Oscillation in a strong positive phase. (Krzyścin, 2012c)
DISSEMINATION OF RESULTS

Data reporting

The ozone data taken at Belsk are regularly submitted to the World Ozone and Ultraviolet Radiation Data Centre in Toronto. The mean daily values of total ozone are also submitted operationally to the Laboratory of Atmospheric Physics, Aristotle University of Thessaloniki, Greece. The ozone sounding data from Legionowo are submitted to the World Ozone and Ultraviolet Radiation Data Centre in Toronto regularly on monthly schedule, and operationally to the Data Base at NILU (Norway).

Information to the public

- Since 2006, an operational monitoring of UV Index from the IMWM network has been published on IMWM web pages.
- Since 2000, the UV Index forecast for Poland has been available from May to September on IMWM web pages.
- An information system of solar UV radiation for outdoor workers was developed in the frame of project ‘Determination of UV radiation on Polish territory for the purposes of risk assessment’. (IM WM)
- Since 2001, the daily means of total ozone from the Dobson measurements at Belsk and UV Index from the SL501A measurements are displayed in almost real time on web pages http://ozon.igf.edu.pl and http://uvb.igf.edu.pl, respectively. (IGF PAS)

Relevant scientific papers

Institute of Meteorology and Water Management


Institute of Geophysics of the Polish Academy of Sciences


Krzyścin, J.W., (2012c) Extreme ozone loss over the Northern Hemisphere high latitudes in the early 2011, Tellus Series B- Chemical and Physical Meteorology, 64, 17347, doi.10.3402/tellusb.v64i0.17347


Krzyścin, J.W., Rajewska-Wiech, B., Jarosławski, J., (2013) The long-term variability of atmospheric ozone from the 50-yr observations carried out at Belsk (51.84 degrees N, 20.78 degrees E), Poland, Tellus Series B- Chemical and Physical Meteorology, 65, 21779, doi.10.3402/tellusb.v65i0.21779


PROJECTS AND COLLABORATION

Institute of Geophysics of the Polish Academy of Sciences

- 2013-2015 National Science Centre (Poland) grant No. 2012/05/B/ST10/00495 “ Modelling of ground level solar UV radiation for assessment of antipsoriatic heliotherapy in Poland”

FUTURE PLANS

Continuation of the current monitoring and research:
● continuation of the ozone (column, profile and surface) and UV observations at Belsk Observatory
● trend analyses of updated time series of the ground-based and satellite ozone and biologically weighted solar UV
● searching for pro-healthy scenarios of out-door activities taking into account erythema risk
● elaboration of the atlas containing spatial and temporal distribution of UV radiation over Poland using the reconstructed data. (IMWM)

NEEDS AND RECOMMENDATIONS

IMWM and IGF PAS recommend closer international collaboration on interactions between the ozone and climate changes to determine the ozone recovery date and evolution of policy instruments to reduce greenhouse gases.
1. OBSERVATIONAL ACTIVITIES

1.1. Column measurements of ozone and other gases / constituents responsible for ozone loss

Routine observations of atmospheric ozone comprise observations of total ozone (TO) and ozone vertical distribution.

Routine observations of nitrogen dioxide comprise observations of its content in the vertical atmospheric column.

In the Russian Federation, responsibility for regular total ozone measurements and interaction with the corresponding WMO bodies lies with the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). Daily TO measurements are being performed on the network of ozone measuring stations, which numbered 33 on April 1, 2014, equipped with filter ozonometers М-124 and located on the territory of the Russian Federation and Kazakhstan. Technical and methodological support of the network is provided by A.I. Voeykov Main Geophysical Observatory (MGO). Observational data are transmitted on-line to the Central Aerological Observatory (CAO), MGO, and RF Hydrometeorological Center. Observational data are transmitted on-line to the Central Aerological Observatory (CAO) and MGO. CAO transmits the data online to the World Ozone and UV Data Centre (WOUDC) under the Environment Service of Canada.

Apart from that, total ozone measurements are performed by institutions of Roshydromet and the Russian Academy of Sciences using ozonometers M-124, Brewer spectrophotometers as well as SAOZ instruments. Brewer spectrophotometers measure TO in Kislovodsk (Obukhov Institute of Atmospheric Physics, RAS), Tomsk (Zuev Institute of Atmospheric Optics, RAS Siberian Branch), and Obninsk (SI RPA “Typhoon”), with the measurement data also transmitted to WOUDC. Total ozone and NO$_2$ measurements on the territory of Russia using SAOZ are made by CAO specialists, at 6 high-latitude stations: Anadyr (64°N, 177°E), Zhigansk (67°N, 123°E), Irkutsk (52°N, 104°E), Salekhard (67°N, 67°E), Dolgoprudny (56°N, 37°E), Murmansk (68N°.,33°E.). Data from Salekhard and Zhigansk are available at (http://saoz.obs.uvsq.fr/).

The first TO measurements from the Russian geostationary weather satellite Elektro-L have been obtained (Kramchaninova and Uspensky, 2013).

Regular measurements of NO$_2$ content in the vertical atmospheric column have been conducted at Zvenigorod research station (ZRS) of A.M. Obukhov Institute of Atmospheric Physics (IAP), RAS, since 1990. The measurements are made with a spectrophotometer based on a domestically produced monochromator MDR-23, by an original technique based on the reconstruction of NO$_2$ vertical distribution. The station is included in the International Network for the Detection of Atmospheric Composition Change (NDACC), its NO$_2$ measurement data readily available at the NDACC server (http://www.ndacc.org/).

At the Chair of Physics of the Physics Faculty of St.Petersburg State University, regular ground spectroscopic measurements of ozone and ozone-depleting gases are being continued. IR solar spectra are measured on sunny days using a special ground-based system based on high-resolution Fourier spectrometer.
1.2. Profile measurements of ozone and other gases / constituents responsible for ozone loss

During 2011 and 2012 spring seasons, several measurements of ozone vertical profiles were made using ozone sondes at Salekhard station; the data is available at NDACC server (http://www.ndacc.org/).

Measurements of ozone profiles in the stratosphere and mesosphere with a microwave radiometer (142.2 GHz) are conducted on a regular basis at P.N. Lebedev Physical Institute of RAS in Moscow (Solomonov et al., 2012).

Occasionally, ozone profiles are measured with microwave radiometer in Nizhniy Novgorod and Tomsk (Marichev et al., 2012; Ryskin et al., 2012). Besides, lidar measurements of ozone and aerosol profiles up to 70 km are made (particularly, in relation with observations of polar stratospheric clouds) at Tomsk (Zuev Institute of Atmospheric Optics, RAS Siberian Branch (Marichev et al., 2012; Cheremisin et al., 2013).

Also, NO2 vertical profiles are retrieved at the ZRS of the Institute of Atmospheric Physics, RAS, from spectroscopic zenith measurements of scattered solar radiation. Similar measurements are made in Tomsk.

1.3 UV measurements

1.3.1 Broadband measurements

Pilot measurements of UVB-radiation have been carried out at 14 ozone measuring station of Roshydromet since 2006. The UV radiation (UVR) measurements follow the technique developed by MGO and use M-124 ozonometers with correction attachments (Larche sphere). Observational results will be available after calibration of the ozonometers with attachments against an UVR reference sample.

Long-term regular measurements of UV-irradiation in an UV-B spectral range, using an UVB-1YES pyranometer, have been conducted at Lomonosov Moscow State University (MSU) since 1999, and in a 300-380 nm range since 1968 (Chabarova, Ozone Assessment, chapter 7, 2007; ACP, 2008).

1.3.2 Spectroradiometers

UV-B radiation monitoring using Brewer instruments have been carried out in Kislovodsk since 1989, in Obninsk since 1994, and in Tomsk since 2006. Besides, at 4 stations of Roshydromet, pilot measurements of the spectral composition of total (global) UV radiation within a 290-400 nm range have been conducted since 2008.

1.4 Calibration activities

1.4.1 Calibration of ozonometers M-124

The MGO fulfils calibration of ozonometers M-124. TO reference is provided by Dobson spectrophotometer No.108, which, in turn, once in 4 years undergoes intercalibration procedure at the WMO European Calibration Center. Since 1988, the departure of Dobson No.108 TO measurements from the WMO reference values has not exceeded 1%.
1.4.2 Regular TO measurement quality control

TO measurement scale stability is maintained through regular calibration of ozonometers M-124 at MGO and monthly ozonometer intercomparisons at the stations. Each station has got 3 instruments – operational, back-up, and reserve. After repair (upgrading) and calibration at the MGO, the reserve ozonometer is set up at the station and becomes operational. The cycle covers 2 years.

The MGO provides continuous control of measurement quality and performance rate of ozonometers to reveal measurement scale changes and, if required, correct measurement results. Ozonometers showing considerable changes in measurement scale are replaced ahead of the schedule time, and undergo calibration.

1.4.3 UV calibration

In 2010, an operational, Category 1 reference sample of irradiation spectral density in a 250-800 nm range, based on a quartz-halogen bulb, certified by the Russian Federation State Agency for Standardization, Gosstandard, was introduced to practice. Absolute-scale calibration of UV radiation measurements has been fulfilled at the MGO since 2011.

1.4.4 Brewer spectrophotometer calibration

All the Brewer spectrophotometers in Russia, operated in Obninsk, Kislovodsk, and Tomsk, were last calibrated in 2012.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Observation analysis has been primarily aimed at understanding the reasons for occasional ozone anomalies and long-term ozone layer changes.

Analysis of the evolution of profiles of the vertical ozone mixing ratio distribution over South Pole station, based on the US NOAA data (ftp://ftp.cmdl.noaa.gov/), has demonstrated that the deepening of the ozone hole during the first decade since its opening was accompanied by temperature decrease in the lower stratosphere (Fig.1). During the following decade, both the temperature in the lower stratosphere and the ozone hole over the Antarctic stabilized (Zvyagintsev et al., 2012).

Some papers are devoted to the investigation of an unprecedentedly deep and long-term 2011 anomaly in the high-latitude Northern Hemisphere (Bazhenov and Burlakov., 2011; Ananiev et al., 2012; Zvyagintsev et al., 2013). It is shown, in particular (Ananiev et al., 2012; Zvyagintsev et al., 2013), that the anomaly was caused by very low temperatures that persisted for a record-long time in that region (Fig. 2), with the lower stratospheric temperatures exceeding those characteristic of the Antarctic ozone hole by nearly 10°C. Also, no Northern Hemisphere stations flying ozone sondes observed the local minimum in the vertical distribution of ozone mixing ratio at 15-20 km characteristic of the Antarctic ozone hole (Fig.1).
Fig. 1. Mean annual variation of temperature (°C; left) and common logarithm of ozone mixing ratio (billion^{-1}; right) at different heights H (km) over NOAA South Pole station, based on ozone sounding data: during 1986-1990 (top), 1996-2000 (middle), 2006-2010 (bottom) (Zvyagintsev et al., 2012).

Fig. 2. Interannual variation of mean monthly temperatures during the period December-March at 30 hPa (about 23 km) over the Northern Pole, based on Freie Universität, Berlin, data. Dashed line marks -78 °C level, below which polar stratospheric clouds can originate (Zvyagintsev et al., 2013).
The influence of different factors (sun elevation, total ozone content, surface albedo, optical properties of aerosols and clouds) on two types of biologically active UV radiation – the one causing erythema (erythema-weighted) and the other producing vitamin D – was studied (Zhdanova and Chubarova, 2011). A new classification of UV-resources was proposed which helped to estimate the natural areas with UV-deficiency, UV-excess, and UV-optimum for human health in Eurasia (Chubarova and Zhdanova, 2012, 2013; Zhdanova and Chubarova, 2013). This classification takes into account aerosol distribution, surface albedo, and total ozone content for different seasons. In particular, it is shown that UV-irradiance in Europe is more comfortable than in Asia, while the largest part of Russia suffers from UV deficiency during cold seasons (Fig.3).

![Spatial distribution of UV resources for the 2nd skin type](https://example.com/example.png)

**Fig. 3.** Examples of the spatial distribution of UV resources for the 2nd skin type under typical cloud conditions in January, April, July, and October. Based on the data from (Chubarova and Zhdanova, 2013).

A number of studies is devoted to the analysis of NO₂ time variability in the atmosphere. The regimes of NO₂ amount variability in the stratosphere and in the boundary layer, based on the data of Zvenigirod station of the Institute of Atmospheric
Physics, RAS, differ considerably (Gruzdev and Elokhov, 2011). Stratospheric NO\textsubscript{2} content is rather variable both annually and daily, with less regular annual oscillations, intra-annual and inter-annual variations. The amount of NO\textsubscript{2} in the atmospheric boundary layer, which is largely affected by pollution events, is highly variable. Against this background there occur irregular daily, intra-annual (within 15-100-day periods), and annual variations. The interannual variability of NO\textsubscript{2} content in the stratosphere includes quasi-biennial variations with 2-3% amplitude in middle and high latitudes and 4-5% in the tropics and near the poles (Gruzdev, 2011a).

Part of the studies are devoted to weekly atmospheric cyclicality. Weekly variations have been revealed in the lower tropospheric and stratospheric NO\textsubscript{2} values at the ZRS IAP RAS, as well as in weather parameters (temperature, geopotential, and wind speed) both in the surface layer and stratosphere in Moscow environs and in Western Siberia (Gruzdev, 2011b). For a weekly cycle to exist, weekly variations have to occur synchronously with calendar weekly rate. Weekly cyclicity has been revealed in NO\textsubscript{2} content throughout the stratosphere over the ZRS, total ozone, temperature, geopotential, and meridional wind speed in the upper troposphere and lower stratosphere over Moscow environs during warm half-year periods (Gruzdev, 2013). However, weekly cyclicity has been found neither in surface NO\textsubscript{2} content, nor aerosol mass concentration at the ZRS, although weekly variations in surface NO\textsubscript{2} and aerosol have been found to occur (Gruzdev et al., 2012).

According to the ZRS NO\textsubscript{2} observations, a strong negative anomaly in total NO\textsubscript{2} was detected in late March 2011 (Gruzdev and Elokhov, 2013a). Then, NO\textsubscript{2} content was about 40% less than the mean NO\textsubscript{2} value for the season. The anomaly was caused by stratospheric air transport from the zone of the ozone hole then observed over the Arctic.

NO\textsubscript{2} measurement validation has been continued using OMI instrument, based on the ZRS measurement data (Gruzdev and Elokhov, 2013b).

3. THEORY, MODELLING AND OTHER RESEARCH

The MGO is continuing studies devoted to the prediction of changes in ozone, surface UV fluxes, and atmospheric dynamics during the XXI century, using chemical climatic models. In order to assess the changes produced by anthropogenic influences, a three-dimensional chemical climatic model, SOCOL 2.0, is applied (Zubov et al., 2011, 2013a, 2013b). Such factors as atmospheric concentrations of green-house gases, ozone depleting substances, sea surface temperatures, and sea ice are considered.

At the Chair of Atmospheric Physics of St. Petersburg University Physics Department, investigations are being continued to find the ways of measuring atmospheric gaseous composition through ground-based and satellite-borne spectroscopic observations (Makarova et al., 2011; Polyakov et al., 2011, 2013; Virolainen et al., 2011, 2013; Yagovkina et al., 2011; Kostsov et al., 2012; Ionov et al., 2012, 2013; Pastel et al., 2013; Gavrilov et al., 2013; Semakin et al., 2013). For ozone and main ozone-depleting gases (H\textsubscript{2}O, CH\textsubscript{4}, N\textsubscript{2}O, etc.), optimal IR spectral intervals in which measurement should be made, “interfering” gases, and random errors in single measurements of gas content have been determined. The acquired results are exemplified in Fig. 4 by showing some measurements of chlorine nitrate (ClONO\textsubscript{2}) at different observational sites.
4 DISSEMINATION OF RESULTS

4.1 Data Reporting

The data from routine TO observations on the network using M-124 are transmitted to the Hydrometeorological Center of Russia, CAO, and MGO daily. CAO archives the data received on-line, performs their primary quality control, and transmits them to the WOUDC. This data, together with that from other countries, is employed by the WOUDC for operational imaging of TO fields (http://woudc.org/). Also, CAO performs operational mapping of TO distribution over Russia and the neighboring countries, reveals anomalies and analyzes the reasons for their origination. At the MGO, the data undergo more thorough quality control, which enables assessing the performance of separate instruments, data correction, and transmission of final results to the WOUDC. M-124 ozonometers having been employed on the network for over 25 years, a considerable number of cases with the measurement scale deviations at observational sites occurs despite instrument upgrading fulfilled. Therefore, the measurement data have to be
thoroughly verified, leading, sometimes, to extra ozonometer calibration, which detains presentation of the verified data to the WOUDC.

The WOUDC also regularly receives TO and UV data measured with Brewer spectrophotometers at Kislovodsk, Obninsk, and Tomsk stations.

SAOZ measurements from the Russian stations of Zhigansk and Salekhard can be readily available on-line at the site of the Data Acquisition Center in France [http://gosic.org/geos/SAOZ-data-access.htm](http://gosic.org/geos/SAOZ-data-access.htm).

Measurements of NO₂ content in the stratospheric column and atmospheric boundary layer are regularly transmitted from Zvenigorod Research Station of the Institute of Atmospheric Optics, RAS, to the NDACC, and are readily available at [http://www.ndacc.org/](http://www.ndacc.org/).

### 4.2 Information to the public

Analyses of the current ozone layer state are presented by CAO in the quarterly reviews of the journal “Meteorologia i Gidrologia” (with the English version disseminated by Springer Publishing House). Annually, the reviews include data on long-term changes of the ozone layer over Russia, which are compared with those observed in other regions of the globe. Information about the ozone layer state over Russia is also published annually in “Reports on the features of climate on the territory of the Russian Federation” and “Reviews of the environment state and pollution in the Russian Federation” presented by Roshydromet.

The technology of TO and UV-index forecasting for the Russian territory has been developed by CAO in cooperation with the Hydro-meteorological Center of Russia. TO forecasting uses current TO observations and weather parameter predictions. To determine the current state and forecast UV-B irradiance fields, observational data and forecasts of TO, cloudiness, and underlying surface albedo are employed. In warm seasons, maximum probable UV-index forecast, with indication of cloud amount, for the current and next 24 hours on the territory of Russia is presented at the website of the Hydrometcenter of Russia ([http://meteoinfo.ru/](http://meteoinfo.ru/)). This site also contains information about possibly high UV-B irradiance in the case of high UV-index values predicted, the vulnerable territory is indicated, and recommendation for protective measures to be taken by different groups of the population are given. The methodology for predicting TO and UV-index is available in Russian at [http://method.meteorf.ru/methods/pollut/uv/uv.html](http://method.meteorf.ru/methods/pollut/uv/uv.html).

### 5. RELEVANT SCIENTIFIC PAPERS

**Reviews:**


**Original papers:**


6. FUTURE PLANS

At present, Roshydromet ozone monitoring network is being retooled with up-to-date instrumentation. Specialist from the MGO and St. Petersburg’s optical institutes have developed an automated UV ozone spectrometer (UVOS) enabling measurements of total ozone and spectral composition of incident UV radiation in 290-400 nm range. The instrument is meant for operation under any working conditions on the Russian territory. The manufacture of the instrument has begun, and 14 stations are planned to be equipped with the new tool in 2014.

The quality of UVOS performance is expected to be tested during Dobson spectrophotometer calibration in Hohenpeissenberg (Germany) on 3-14 June 2014. In July 2014, the new instrument will be presented at the WMO Technical Conference in St. Petersburg.
1. Monitoring Activities

Saint Lucia does not currently have an institute or body that undertakes monitoring in ozone or ozone depleting gases. Saint Lucia depends on monitoring conducted by other countries and as a result, these results may not necessarily be applicable for Saint Lucia, as the focus may be national/regional rather than a broader international, and more specifically, conditions in the Eastern Caribbean.

2. Research on stratospheric ozone

Saint Lucia does not have the capacity to undertake research on stratospheric ozone levels. Owing to this, Saint Lucia depends on research conducted by other countries such as Canada through its Canadian Brewer Ozone Spectrophotometer Network and the United States SA through its National Oceanic and Atmospheric Administration/Environment Protection Agency (NOAA/EPA) Brewer spectrophotometer network. It should be noted that this research may not cover the Eastern Caribbean area.

3. Research on stratospheric ozone depletion processes

Saint Lucia does not have the capacity to conduct research on the stratospheric ozone depletion process.

4. Services of relevance to the ozone depletion problem

The Government of Saint Lucia, through the National Ozone Unit (NOU), hosts a web site which provides information on Saint Lucia’s ODS phase out programme. This includes background on the Montreal Protocol, the national compliance strategy and plan, policies and legislation, projects and activities, and public awareness and education activities. The website, http://www.estis.net/sites/nou-lc/, also contains information on the ozone layer, ozone layer depletion, brief information on ozone measurements and the ozone hole.

Owing to the constraints noted in 1, 2 and 3 above, the website links to other research and monitoring institutes such as the National Aeronautics and Space Administration’s (NASA) Ozone Resource Page, to allow visitors to the page to easily access current data on ozone layer depletion, status of the ozone hole and other research activities.
As part of the HCFC Phase out Management Plan (HPMP) and the Institutional Strengthening Project (ISP) for Saint Lucia, the NOU constantly provides information on ozone layer depletion to the general public through various mediums such as new paper articles, press releases, workshops, seminars and televised programmes produced by agencies such as UNEP.

5. Future Plans and Recommendations

Saint Lucia is part of the English-Speaking Caribbean Region and Haiti, which is comprises of 14 Small Island Developing States (SIDS). The unique challenges facing SIDS within the context of sustainable development were first recognized by the international community at the UN Conference on Environment and Development (UNCED), also known as the Earth Summit, held in Rio de Janeiro, Brazil in 1992. The special case of small islands and coastal areas was highlighted in Agenda 21 – the programme of action for sustainable development adopted as an essential outcome of the conference. The peculiar challenges that SIDS face include, among others: difficulties in benefitting from trade liberalization and globalization; heavy dependence on coastal and marine resources for their livelihood including food security; heavy dependence on tourism which can be easily impacted by climate change and natural disasters; energy dependence and access issue; the limited freshwater resources; limited land resulting in land degradation, which affects waste management, and vulnerable biodiversity resources.

Central and Satellite Monitoring and Research Stations for the Caribbean

The ability of SIDS of the English Caribbean and Haiti, to develop and access country-specific data on the status of the ozone layer, ODSs in the atmosphere and levels of UV is of critical importance to its tourism and fisheries sectors, as well and the health of its citizens and visitors. Considering the small size and dispersed nature of the countries, an approach would be to build capacity within a central institute in one of the Caribbean Islands, to allow for ozone and ODS monitoring and research. Satellite monitoring and research stations could then be established by building capacity within existing national meteorological or other suitable stations, to allow for the sharing of and access to this data. National satellite monitoring and research stations would also have the ability to upload country-specific data that perhaps the regional central institute may not have covered or may not have been able to detect.

This network for the Caribbean will not only strengthen regional and global ozone monitoring and research, but will also create and foster a culture of research and monitoring specific to ozone layer protection and environmental management.

Enhancing National Cooperation

The NOU will engage national meteorological office, with the view of discussing the possibility of including UV readings in its monitoring and reporting system. This should be done in consultation with other interested parties.
SOUTH AFRICA

1. **Introduction**

The depletion of the stratospheric ozone layer, increases in troposphere ozone, higher levels of acidity in rain, rising carbon dioxide and methane concentrations, and changes in the radiative balance of the earth-atmosphere energy system all reflects the increasing influence of human activity on the global atmosphere, the life-support system of planet Earth. Environmental issues and policy matters have to play a pivotal role in meeting the developing needs and challenges of the people in a new democratic South African society.

South Africa as Party to the Montreal Protocol, sets out to protect the ozone layer by phasing out the ozone depleting substances in accordance with the requirements of the Protocol.

The main focus of this report is on the ozone research and monitoring efforts, as well as the relevant atmospheric compounds related to the ozone questions. Just a brief reference is made to the Ozone Depletions Substance – Actions, as this is reported at other important forums of the UNEP process.

1.1 **Ozone depletions substances and actions**

The country restricts and controls the use of Ozone Depleting Substances (ODS) by also working with other departments that control our borders and also promotes the use of ozone-friendly substances. Furthermore, the Department of Environmental Affairs has ongoing processes of developing Regulations to control Ozone Depleting Substances.

Clauses in protecting and respecting the environment in a sustainable context, is embedded in the South African Constitution. Recently the national Department of Environment Affairs (DEA) and its National Ozone Unit (Chemicals Management) has collaborated with the South African Revenue Services (SARS), International Trade Administration Commission and the Department of Agriculture Forestry and Fisheries to set up an import permit system to control trade in ozone depleting substances in order to meet the obligations the Montreal Protocol. A HCFC Phase-out Management Plan (SA HPMP) has been developed which has been approved by the United Nations Environmental Programme (UNEP) Ozone Secretariat and this is currently being implemented.

Ozone-Depleting Substances (ODS): Insofar as reducing the consumption of and phasing out the use of ODS South Africa has done well. South Africa managed to reduce consumption of ODS by reducing the imports of OD-associated substances. Progress has been made in achieving the target of freezing consumption of hydrochlorofluorocarbons (HCFC) and Bromochloromethane (BCM) by 2013 and the phasing out thereof by 2040. South Africa achieved the target of phasing out the consumption of Methyl bromide (MeBr) by 2010 [ref. - Millennium Development Goals, Country Report 2013 / Statistics South Africa. Pretoria: 2013].

The DEA Ozone Unit trains the South African Revenue Services (SARS) customs inspectors at the ports of entry into the country for regulating efficiencies. The government does not only seek to ban imports of these ozone depleting substances where cost-effective alternatives are available, but also intends to prevent the loss of jobs and collapse of businesses. Hence there
are regular engagements with relevant Stakeholders by the Department to ensure that compliance with the Montreal Protocol is done in a sustainable manner. The following action plan (tabled below) was drafted at a meeting in January 2014.

Table 1: DEA actions for the HCFC Phase-out Management Plan

<table>
<thead>
<tr>
<th>Action</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quota system for the assignment of import licences for all HCFC</td>
<td>1 January 2013</td>
</tr>
<tr>
<td>Ban on import of HCFC-141b either in pure form or as a component of blended chemicals; for the purpose of placing on the market, or use in the production of polyurethane foams, or as solvents, or any other application.</td>
<td>1 January 2016</td>
</tr>
<tr>
<td>Ban on import of any new or used air conditioning systems or equipment fitted with a compressor and pre-charged partially charged with HCFC-22 or any refrigerant or refrigerant blend containing any HCFC</td>
<td>1 July 2014</td>
</tr>
<tr>
<td>Ban on the use of HCFC-22 (or any other refrigerant containing HCFCs) either in pure form or as a component of blended refrigerants; in the construction, assembly, or installation of any new refrigeration or air-conditioning system, or equipment which requires a compressor to be fitted in South Africa</td>
<td>1 January 2015</td>
</tr>
<tr>
<td>Mandatory recovery and recycling of HCFCs and other ODS refrigerant</td>
<td>1 September 2014</td>
</tr>
<tr>
<td>License/certification required for anyone purchasing refrigerant</td>
<td>1 January 2015</td>
</tr>
</tbody>
</table>

In light of the above stated commitment and planned activities, the following describes the ongoing ozone research and monitoring and direct related efforts in South Africa.

2. Ozone -Atmospheric Research and Monitoring Activities

Most of the sustained systematic atmospheric monitoring is conducted by the South African Weather Service. In particularly this is done by the research and monitoring program work of the WMO global Global Atmosphere Watch Station (GAW) at Cape point and its regional network of stations. Figure below shows WMO global stations and the Cape Point laboratory.
2.1 Cape Point (GAW) Global Station - status of Chlorofluorocarbons measurements.

The Cape Point (CPT) Global Atmosphere Watch (GAW) station is mandated to measure several climatically significant trace gases on a long-term basis as part of a global network of about 33 stations. Reported here is the monthly mean Chlorofluorocarbons (CFCs) since inception of the measuring programme, essentially representing the global atmospheric background levels for the Southern-Hemispheric mid-latitudes.

September 16, 1987, saw 27 nations (including South Africa) sign a global environmental treaty, called the Montreal Protocol. The primary aim was to reduce substances that deplete the Ozone Layer with a specific proviso to reduce the 1986 production levels of these compounds by 50% before the year 2000. This international agreement included restrictions on production of CFC-11, -12, -113, -114, -115, and the Halons (chemicals used as a fire extinguishing agents). In 1990, an amendment approved in London was more forceful, and called for the elimination of production of these listed compounds by the year 2000. Certain chlorinated solvents, like methyl chloroform (CH3CCl3), and carbon tetrachloride (CCl4) were added to the London Amendment in 1992. Subsequent amendments added methyl bromide (with exemptions for specific uses), hydrobromofluorocarbons, and bromochloromethane.

The halocarbon measurements at Cape Point GAW station date back to 1979 when the hype surrounding the stratospheric ozone hole and CFC-catalyzed O3 destruction in the stratosphere (coupled to increased biologically harmful surface UV levels), was most prominent in the public eye. Since then, the data record from CPT shows the effectiveness and successes of a concerted effort from many inter-governmental agencies (including South Africa) to adopt legislation to curb the emissions of certain CFC’s (e.g. Montreal Protocol, 1987). Despite the longevity of most halocarbons in the atmosphere (CH3CCl3 being an exception), it is evident from Figure 2. that the negative growth rates observed is sound cause for a successful recovery of the stratospheric O3 layer in the next 20 – 30 years, provided that other ozone depleting compounds (ODCs) (not discussed here) are curtailed effectively globally as well. Monitoring these halocarbons are still important for recording the recovery of the stratospheric ozone layer back to pre-”Ozone Hole” levels that are expected to occur between 2040 and 2050.

![Figure 2: Long term measurement of selected CFC’s at Cape Point. Source: Casper Labuschagne, Cape Point GAW station.](image-url)
2.2 Ozone observational activities

The South African Weather Service (SAWS), an agency of the Government Department of Environmental Affairs and Tourism (DEAT), is a focal point of ozone monitoring and research activities in South Africa. These activities are enhanced by collaboration with a few national research centers and universities within the country and many international collaboration.

The ozone monitoring and research activities are conducted also within the context of the World Meteorological Organizations (WMO) Global Atmosphere Watch (GAW) program.

2.3.1 Atmospheric Ozone Monitoring

The first South African column ozone measurements were made during 1964 until 1972 with Dobson #089 operating from Pretoria. Reinstating South Africa’s commitment to the Vienna Convention, the Weather Service now operates two Dobson ozone spectrophotometers, #089 at Irene near Pretoria (25.9 S, 28.2 E) since 1989, and #132 at Springbok (29.7 S, 17.9 E) since 1995. Both these instruments have been regularly calibrated with reference to the world standard. Our 2011 participation at the recent UNEP/WMO Dobson Data Workshop held in Hradec Kralove, Czech Republic re-affirmed good quality data sets.

The Dobson Ozone Spectrophotometers at Springbok D132 has been operating well during this period conducting daily Total Ozone (TO3) column observations. Dobson 089 from Irene experienced optical wedge belt problems in 2012 and again December 2013, but was repaired and placed back in operation in mid-January 2014. All the 2013 Dobson data (level 0) was submitted to WOUDC as part of our WMO Data Obligations following the 8ORM recommendations. Dobson 035, on “permanent’ loan from the UK Met. Office, has most unfortunately not been operating continuously at Cape Point since we still need to do some building construction changes to the GAW laboratory. However, D035 proved its value and has been operating in place of D089 at Irene for 2013, when D089 became inoperable. The value of the WMO/UNEP Inter-calibrations here also proved that the data sets can be made totally compatible and sustain a consistent long-term station record.

Our Dobson data sets are maturing towards long-term climatic data sets. Figure 3a below depicts the Irene total ozone data record, since 1989, with overall negative trend (-0.03). The negative trend is even more profound in the 80’s and 90’s. There is significant evidence that the total ozone has entered a positive trend in the early 2000’s. This can be seen in figure 3b below, with a sustained positive trend since 2002 (+0.048).

Whether this is an indication of Stratospheric Ozone Recovery (90 percent of the atmosphere’s ozone concentration resides in the Stratosphere) we still are not sure. Together with the data from the Irene balloon ozonesoundings, we are also investigating the questions whether pollution is also a contributing to enhanced “bad” ozone levels in the troposphere and near surface.
Concerning the Springbok Dobson data set, not shown here in this report, the trend analyses are not that clear. This being the fact that Springbok is in a different climate zone with different atmospheric dynamic influences.

During 2009, the 3rd African UNEP/WMO International Comparison of Dobson Spectrophotometers was organized by the World Meteorological Organization and the South African Weather Service in close cooperation with the World Calibrations center at NOAA and the European calibrations center hosted by Deutsche Wetterdienst (DWD), Germany. This event was conducted during October 2009 at the Irene Weather Service Technical Centre, just south of Pretoria.

After a three year break the Weather Service has been fortunate to reinstate its Vaisala ECC RS92 Ozonesonde sounding program form Irene a GAW regionals station in September 2012. The soundings are conducted with the Vaisala MW31 Digicora and RS92 GPS sondes and 1200g totex balloons. Thus we can state that we have been using the same system since 1990 when
we started, which implies the data sets is much more compatible. Irene operated weekly ozone sounding since 1990 until early 2007 with a few data gaps. We joined the Southern Hemisphere Additional Ozonesondes (SHADOZ) program under leadership of the principle investigator Dr. Anne Thompson in 1997 (http://croc.gsfc.nasa.gov/shadoz/). This is a program from NASA, USA, which also is submits all data to WOUDC and NDACC regularly.

Figure 4 above. Irene ozone climatology : (a) 1990-1993 SAWS ozonesondes, (b) 1995-1998 MOZAIC (4-11 km profiles are taken by commercial aircraft in landing/takeoffs from nearby Johannesburg International Airport) and 1999-2001 SHADOZ, (c) 2002-2007 SHADOZ, and (d) 2012-2013 SHADOZ. [Figure and data with courtesy of Nikolai V. Balashov1 and Dr. Anne M. Thompson, Penn State University, Department Meteorology and NASA, USA.]

Surface Ozone measurements started in 1982 at the Cape Point site, and continuous time series are available since then. Currently three ozone analyzers are used at the station for continuous surface ozone measurements at three different sampling altitudes (4m, 14m, and 30m above ground). An additional ozone analyzer was purchased following a recommendation made after the last audit by WCC-EMPA. This data was also used for and MSc Study, currently (2013 T Mkololo) to be finalized and published.

3.3.2 Other relevant Trace Gases and profile measurements

The pristine location of the Cape Point Global Atmosphere Watch GAW station (34.3S, 18.5E) enables measurements to be made in air that has passed over the vast clean Southern Ocean. Such long-term observations are representative of background conditions, making it possible to detect changes in the atmosphere's composition. The Cape Point GAW Laboratory is also scientifically twinned with a research partner, namely the Fraunhofer Institute for Atmospheric
Environmental Research (IFU) in Garmisch, Germany, now IMK-IFU (Forschungszentrum Karlsruhe).

Measurements include a wide range of parameters namely: - surface O$_3$, gases which lead to stratospheric ozone depletion such as: CFCl$_3$, CCl$_2$F$_2$, CCl$_2$F-CCIF$_2$, CH$_3$CCl$_3$, CCl$_4$ and N$_2$O greenhouse gases in the troposphere such as CO$_2$ and CH$_4$ and reactive gases such as CO.

Furthermore, UV-A, UV-B and global radiation (total and diffuse) are also measured as well as the normal surface meteorological parameters. Radon measurements to assist with the classification of air masses arriving at Cape Point have been successfully established over the last five years. Regular scientific audits from EMPA, Switzerland for surface O$_3$, CO and CH$_4$ have been successfully conducted over the past seven years. In 2003 the WCC-N$_2$O (Forschungszentrum Karlsruhe IMK-IFU and Umweltbundesamt) conducted an audit for N$_2$O at Cape Point. During 2006 with German collaborations (GKSS Research Centre Geestacht) the Cape Point gashouse mercury measurement program was also revived.

Since 2005 a project was undertaken for the continuous measurements of aerosols. This is now a well-established program at the Cape Point GAW station and includes physical, chemistry and optical properties being measured. This milestone was reached with start-up funding support from WMO, scientific partnering with NOAA ESRL scientists (who designed and constructed the aerosol system) and local SAWS station scientist running and maintaining the system. The latest addition was the establishment of Aerosol Optical Depth (AOD) measurement relevant to global climate change in accordance to detailed guidelines set out in GAW Precision Filter Radiometer Network (GAWNET) [http://www.pmodwrc.ch/worcc](http://www.pmodwrc.ch/worcc) and Global Atmosphere Watch Program of the World Meteorological Organization (GAW) [http://gaw.tropos.de](http://gaw.tropos.de)

2.3.3 Ultraviolet-B measurements

Since January 1994 the South African Weather Service has maintained a routine program for monitoring erythemally weighted UV-B radiation at Cape Town (34.0S, 18.6E), Durban (30.0S, 31.0E) and Pretoria (25.7S, 28.2E), De Aar (30.7S, 24.0E) and Port Elizabeth (33.9S, 25.5E). The equipment used in this network is the Solar Light Model 501 Robertson-Berger UV-Biometer. The program was motivated by and in collaboration with the School of Pharmacy at the Medical University of Southern Africa (MEDUNSA), near Pretoria. The main purpose of the UV-Biometer network is to make the public aware of the hazards of excessive exposure to biologically active UV-B radiation, and it contributes to the schools' awareness programs for education. Regular enquiries from scholars are dealt with to satisfy their need to acquire more ozone and ultraviolet radiation knowledge. Celebrations around 16 September, each year, usually focus on public awareness. At these events the ministerial appearance encourages and informs scholars on the issues and actions of government.

Since 2012 the SAWS is revamping its Solar Radiation network with SOLYS2 tracking stations. High quality DNI, GHI and DIFF are measured. In addition UVB and UVA (for the first time) is also measured. Instruments used for this is the CMP11 and UVS-AB-T UVB an UVA radiometers from Kipp&Zonen. This new network is a tremendous advantage for addressing our Ozone and UV issues in the country and displays cross cutting uses of technology for covering multi-purpose project aims.

An intense project to re-evaluate the UVB Biometer data set is underway. Traceable calibrations, scale factors and changes are being put together and some inter-referencing of
sensors has been undertaken. We are looking to establish a routine “round-robin” type of network referencing on a routine bi-annual time scale.

The main purpose of the UV-Biometer network is to make the public aware of the hazards of excessive exposure to biologically active UV-B radiation, and it contributes to the schools' awareness programs for education. Regular enquiries from scholars are dealt with to satisfy their need to acquire more ozone and ultraviolet radiation knowledge. Celebrations around 16 September, each year, usually focuses to create public awareness. Once a year on this day it is also dedicated to the hard working ozone observers and technicians gathering the measurements.

Renewed UV research is being undertaken by the Council for Scientific and Industry Research (CSIR) under the leadership of Dr. C Wright at the School of Health. Their research unit is conducting research and monitoring of UVB exposure amongst scholars and many other outdoor activities by means of tagged badge dosimeters. The SunSmart Schools Research Project, which was co-funded by the Cancer Association of South Africa (Cansa), the South African Medical Research Council and the CSIR. In one outcome of the research, CSIR environmental health researchers have drafted a sun protection policy for schools and a roadmap for future actions. [http://www.ehrn.co.za/sunsmart/](http://www.ehrn.co.za/sunsmart/)

### 2.3.4 The South African Air-Quality Information System (SAAQIS - SAWS)

The South African Air Quality Information System (SAAQIS), provides a common platform for managing air quality information in South Africa. It makes data available to stakeholders including the public and provides a mechanism to ensure uniformity in the way air quality data is managed i.e. captured, stored, validated, analyzed and reported on in South Africa.

The SAAQIS aims to:

- Ensure that air quality information management and reporting requirements directed or implied by the National Environmental Management: Air Quality Act, Act 37 of 2004 (NEM-AQA) are efficiently and effectively met.
- Ensure that air quality management decisions, interventions, activities and actions are informed by accurate, current and complete information.
- Ensure that accurate, current, complete and relevant air quality information is available to all stakeholders and the public.
- Provide all South African’s with information on the state of their air quality and the status of efforts to progressively ensure their right to air that is not harmful to health and well-being.
- Improving the availability of air quality information facilitates transparency in processes, informs decision making, and helps build capacity.

The South African Weather Service is now well settled in its role of the custodian of the South African Air Quality Information System (SAAQIS) which has been developed and launched during 2010. The SAAQIS is a web-based interactive air quality information system which seeks to provide state of the air quality information to citizens and it is a research portal for strengthening policy development related to air quality issues. This has a profound advantage in that the country we can begin to assess whether air quality is improving and also identify areas where potential air pollution problems exists.
Various national air-quality monitor stations is linked in real time gathering vital atmospheric data for decision making for improving ambient air quality in especially our industrial areas. Technical staff off the SAWS is tasked to calibrate and maintain these monitoring stations as part of the normal weather observational system across the country. [http://www.saaqis.org.za/](http://www.saaqis.org.za/)

### 2.3.5 Other Observation/Monitoring Networks - Research Aircraft

The South African Weather Service’s two research aircraft Aerocommanders are used as Airborne monitoring platforms. Site sampling is conducted at a speed of 100 ms$^{-1}$, at low atmospheric levels (500 – 3000m above ground level) and the range of the aircraft is around 3.5 hours, over predetermined pollution hotspot areas over the country.

In addition to standard meteorological parameters, instruments mounted in and on the aircraft measure the following trace gases and aerosols:

- Carbon dioxide, Carbon monoxide, Sulphur dioxide, Hydrogen sulphide, Oxides of nitrogen, Ozone, Volatile organic compounds, and the concentration of aerosols between.

There has been a shift in air quality management in South Africa from source control to pollution prevention by focussing on ambient air quality is intended to ensure improved air quality for future generations. The aircraft monitoring capabilities complements other ground-based research and monitoring processes to ensure that information and data associated with air pollution are of the highest quality and are accessible to all South Africans.

The primary airborne monitoring project objectives are:

- To determine the spatial and temporal characteristics of air quality over South Africa through the use of ground-based, airborne and satellite measurements;
- To validate the various measurements and integrate them into a holistic picture of the South African air quality situation with the context of the region;
- To build capacity in the fields of air quality and atmospheric chemistry through hands-on training.

The Aircraft research and monitoring facilities are jointly managed by the South African Weather Service and the Climatology Research Group of the Witwatersrand University (Wits) in Johannesburg. These aircrafts and logistical staff have taken part in field experiments conducted in UAE and India within the last few years.

### 2.3.6 LIDAR

The Council for Scientific and Industrial Research - CSIR has developed a new mobile LIDAR. The Light Detection and Ranging (LIDAR) has become an excellent tool for monitoring the atmosphere in a relatively short period of time (within a few seconds to minutes). Currently, LIDAR systems are used for studying the atmospheric structure and dynamics, trace constituents, aerosols, clouds, boundary and mixed layers and other meteorological applications although ground based LIDAR systems are deployed for atmosphere studies in many developed countries, it is still a very novel technique for South Africa and African countries. There are currently two different LIDARs available in South Africa, located in Pretoria and Durban respectively. Field experiments were also conducted during this period at the NW University’s Elandsfontein long-term atmospheric monitoring station. A station that we also hope in future...
to register as a GAW regional station which has its very own unique location and very high quality data sets. Norwegian scientific involvement is also very prominent at this station as part of the NW Groups international collaborations.

The Durban LIDAR is operated at University of KwaZulu-Natal as part of cooperation between the Reunion University and the Service d’Aéronomie (CNRS, IPSL, and Paris) for climate research studies. It allows for studying the stratosphere-mesosphere (30-80 km) thermal structure and troposphere-stratosphere aerosol (8-40 km). Future plans include field campaign measurements in and around South Africa, for qualitative industrial pollutant measurements and higher atmosphere characteristic changes in ozone, aerosol and other parameters.

3. Calibration activities and data submissions

The main progress in data quality and research activities can also be ascribed to the fact that SAWS became an ISO 9001 certified national Meteorological institute. Improvements on instrument calibration and standard operating procedures has been upgraded. This is kept in check with regular internal and external audits to maintain the ISO accreditation.

All primary GAW data sets (ozone and trace gas data) are submitted regularly to WMO recognized World Data centers. Dobson column ozone is submitted to WOUDC, Toronto, Canada. Since the 8ORM and recommendations Level 0 Dobson Total ozone data forms part of the annual submission.

The last Dobson Intercomparison was conducted in 2009 at Irene Weather Office. On the recommendations of the WMO SAG for ozone the IC intervals has been moved along and the next African (WMO Region 1) intercomparison could take place in 2015 at Irene.

Since the inception of the Dobson programs these instruments have been internationally calibrated through inter-comparison campaigns as supported by UNEP and WMO. Various regular external international (EMPA) scientific audits remain in place for the Cape Point GAW station. Round-robin exercises amongst the Global GAW network with travelling standard gasses also remain in place.

Two of our broad band UVB Biometers, also were re-calibrated (and capacity building undertaken) with German collaboration. Dr. Uwe Feister from the Deutscher Wetterdienst Meteorologisches Observatorium Lindenberg, facilitated this processes.

In-house stronger ties are forged with the SA National Metrology Institute of South Africa (NMISA) in a similar way as WMO GAW’s collaboration with the Swiss GAW auditing group, EMPA. This will also enhance our ozone and trace gas measuring program as NMISA is in the process of developing locally developed reference standards for others also to use.

4. Capacity Building and Collaboration (national and international)

4.1 Capacity building:

Capacity building remains a focal point of our activities. Regular school and student visits take place at GAW Cape point station and regional GAW sites such as the Irene Weather office. Below Figure 5:- From top left clockwise. a) La Reunion, Franch visiting students receiving
information on the purpose and operations of the Dobson 089 Irene instrument, b) Mr. Ernst Brunke lecturing Western Cape university students, in the CPT Laboratory, c) Springbok Dobson operators receiving certificates of appreciations on World Ozone Day, and d) training on the ozone calibrators preparing ECC Cells for sonde flights form Irene.

**Figure 5:- Capacity building in progress**

### 4.2 Collaboration

We also wish to take this opportunity to thank our many collaborators (listed below) for the many decades of support and obtaining results driven valuable atmospheric information from our region.

Nationally, the ozone research related activities are included with outside institutions and universities, mostly linked to post-degree studies. These are institutions and universities are a) Council for Industrial Research (CSIR), b) University of KwaZulu Natal, Durban c) the universities of Cape Town, Stellenbosch and Western Cape d) University of North West, Potchefstroom and e) University of Pretoria.

South Africa must also acknowledge its many international collaborators with specific references to international programs and institutions such as:

- The World Meteorological Organization (WMO) and many other NHMS in our region. Participation of Experts at a) SAG-OZONE Dobson Ad Hoc Group, SAG greenhouse Gasses, Representatives at CAS management level and WMO OPAG EPAG meetings.
• Project SASRIO (RSA and French) ARSAIO, A South African and French Collaboration project. In this context, CNRS and NRF have established a GDRI project called ARSAIO (Atmospheric Research in Southern Africa and Indian Ocean) along with French and South African laboratories and scientists involved in atmospheric research and observations in Southern Africa and the neighboring regions of the Indian Ocean. The GDRI ARSAIO project focuses on following scientific themes aimed at obtaining a better understanding of southern tropics/sub-tropical:–
  • Atmospheric pollution and climate change in Southern Africa
  • Troposphere ozone and aerosol studies over Indian Ocean Region
  • Greenhouse gas measurements
  • Middle atmosphere dynamics and thermal structure
  • Observations and comparative studies from ground-based and satellite observations
  • Water vapor cycle study in the Upper Troposphere-Lower Stratosphere
  • Stratospheric ozone variability and UV radiations in the southern tropics


• SHADOZ: - Penn State University, NASA. A largest partner in ozone research and part of the ozonesonde sounding network.

• NOAA-ESRL, Boulder, USA Dobson spectrophotometer calibrations, and Flask sampling and aerosol monitoring, HATS etc.

• WOUDC and ARQP, Toronto, Canada Ozone data submissions, Research data GAPS Program sampling at De Aar Station

• UEA, Norwich Univ. , UK Flask Sampling O2/N2

• CSIRO, ANSTO & Wollongong Univ., Aus. Monitoring/ research 222Rn at Cape Point

• PMOD, Davos, Switzerland PFR-AOD measurements 2AP tracker CPT

• GAWTEC, Germany. A special word of appreciation is extended to GAWTEC. From its inception six young South African GAW scientist has participated in this special training [http://www.schneefernerhaus.de/e-gawtec.htm](http://www.schneefernerhaus.de/e-gawtec.htm),

• DWD, Hohenpeissenberg, Germany, Dobson calibration assistance, Submission of CO 8 O3 data for Modelling purposes, GEMS

• GMOS- Global mercury observation system of which the Cape Point station takes Coordination in done by CNR - Institute of Atmospheric Pollution Research, Rome, Italy.

• MPI-BGC in Jena, Germany. The Tall tower atmospheric gas measurements group (TAG) of the Max Planck Institute for Biogeochemistry (MPI-BGC) in Jena, Germany, has established an atmospheric observatory for trace gases at Gobabeb, Namibia in 2012,

• IMK-IFU Garmisch, Germany for ongoing collaboration and GAWSIS [http://www.empa.ch/gaw/gawsis/] and IMK-IFU Garmisch, Germany. The long-term measurements (meta data, trace gas species, instrument type) which are being conducted at Cape Point and its regional GAW sites are listed on the site

• GAWNET [http://www.pmodwrc.ch/worcc/pmod.php]

• The DEBITS Program - Passive sampling and rain water analyses from the Group of the Northwest University is here involved.

• LSCE, CNRS and DEBITS, Paris and Toulouse, and La Reunion Island - France. (Flask sampling, the SASRIO project and GDRI offices)

• The CZECH SOO-HK, in Hradec Kralove – collaboration in the region.

5. FUTURE PLANS AND RECOMMENDATIONS

For the future our first quest will remain to sustain our Cape Point GAW facilities and monitoring program, and this includes the regional aspects as described earlier in the report. Upgrading instruments either by obtaining new ones or by collaboration exchanges shall be pursued. Honoring our WMO commitments, especially with regards to data depository in World Data Centers will continue and we shall nourish our current and future collaborations to enhance our standing and role to be fulfilled in the international arena.

We would like to re-evaluate our Dobson data records since 1989 and create proper level 0 and level 1 data sets. Data capturing for the 1966 - 1972 Dobson 89 period is much more difficult, but we still hope to bring this to a conclusion. Our research efforts will continue with data analyses to address not only stratosphere ozone recovery but also to note results to ozone concentrations changes in the troposphere and near surface as the country industrialise further. The Irene site, once a very rural site, has become an important site in the middle of the developing Mega-City of Johannesburg and Pretoria where air quality aspects are a growing concern.

Research work at the South African Weather Service continues to include a service rendering UVB Forecast, especially during summer months. The UV forecast modelling issues needs more attention as South Africa has some of the world’s highest UVB levels during the summer months. The need to establish long term continued high-resolution spectro-radiometer UV observations at some suitable sites in southern Africa is only partially being addressed alongside the role out of a new Solar Tracking (Solys2) station network. The replacement/extensions of the Dobson’s with Brewer spectrophotometers are still some of our future expectations to be fulfilled.

To continue building our scientific capacity – ozone, atmospheric research and monitoring in general, and related Climate Change Activities). The South African “ozone” community is very small and published peer reviewed articles of research findings remain admittedly very scarce.
5.1 Recommendations addressed to the 9ORM

- In light of a diminishing based ground observational network it is essential that we first of all sustain what we have, and encourage new stations. Satellite verification with a diminishing ground based network also runs into verification difficulties. However it is encouraging to see a few new ground based monitoring efforts.

- Renewed efforts for renewing monitoring stations. The relocation of unused instruments remains a viable option. For monitoring of total ozone (Dobson) and possibly also UV (Brewer) it is also an important part of the capacity building. Though each campaign usually has specific features, general rules on ownership, financial support for transport of instruments, training of operators and installation at the site should be defined and fixed under the umbrella of WMO and UNEP. This will make preparation and realization of such actions faster, simple and more efficient.

- Mitigating and adapt to Climate Change also indicates to us that more (not less) monitoring is needed. This is also crucial to enhance early warning systems and real time data. Changes are imminent just as the recent detection of 4 banned CFC’s in the atmosphere and their fast rising levels.

- Gaps in ozone research prevents a full understanding of the potential climate change impacts (and vise-versa) and this complicates the impact on the health and food security sectors especially. Models and/or methodologies exist to begin projecting the impacts of ozone change on human health such as heat stress, crop production, and growth inhibitors (ozone and UVB burn), etc. but they are still very robust. Thus there is a need for application development to forecast impact on health and such other risks.

- Economics (finding) plays a huge part in ozone research and monitoring. There is an ever increasing demand on providing commercial revenue and thus is detrimental to our traditional way of research and monitoring. We shall have to find alternative projects such as the Alternative Sector activities to assist in finding mutual grounds for enhancing and even sustaining monitoring capabilities. For example the Solar Energy sector provides a very good vehicle for additional solar, AOD and UV related measurements and we should exploit these options.

- There are three-way links to bring resources together and to consolidate ground-based measurements for Stratospheric, Troposphere and near surface ozone. Thus combined research projects with earmark on Ozone - Air Quality and Climate Change could pull resources together and provide more efficient impact on efforts which started out more than 25 years ago just to monitor the Ozone Layer only.

- Balloon ozonesonde networks provide critical observations which give high resolution vertical profiles (sampling every 2 sec.) of ozone and water vapour that are needed for multiple scientific activities in ozone research and therefore sounding need to be maintained and increased.
The need for International Data Archives (such as WOUDC) needs to be preserved with great care, and services from these centers could be enhanced.

By the same token, MOU’s, bilateral agreements between countries, institutions and NMHS’s should be exploited more and must reach the scientist on the ground-level. This is perhaps to be propagate at important managerial meetings such as this meeting so that tangible actions can filter through to enhance research and monitoring at ground-level. Many of these agreements do not go further than the signed document.

6. Region relevant research literature

Besides many presentations and talks at Conferences such as QO3, IGAC, IUPPA, SPARC, SASSAS etc. many relevant published material has been established: - The list below is not exhaustive at this stage:


C Y Wright, PhD (Public Health). Ambient solar UV radiation and seasonal trends in potential sunburn risk among schoolchildren in South Africa. SAJCH JULY 2011 VOL. 5 NO. 2 33. C Y Wright, PhD (Public Health), MSocSc, BSocSc (Hons), Council for Scientific and Industrial Research, Pretoria, G Coetzee, BSc, K Ncongwane, BSc, BPhil, MPhil, South African Weather Service, Pretoria, Corresponding author: C Y Wright (cwright@csir.co.za)


V. SIVAKUMAR - Tropopause Characteristics and Variability from 11 yr of SHADOZ Observations in the Southern Tropics and Subtropics, Pennsylvania DOI: 10.1175/2011JAMC2453.1, 2011 American Meteorological Society


Wright, C., the Solar UVR Exposure Research Environment in South Africa: Past, Present and Future. CSIR Biennial Conference, August-September, Pretoria, 2010


Bencherif H., T. Portafaix, N. Mzé, G. Kirgis, LiDAR measurements and Stratospheric Ozone, 29th Annual conference of South African society for atmosphere science, Durban (South Africa), 26-27 September 2013, (invited talk)
Sri Lanka National Report relevant to Ozone Research

Introduction

Sri Lanka is a developing country and annual calculated level of consumption of the controlled substances in Annex A is less than 0.3 kilograms per capita on the date of the entry into force of the Protocol. Sri Lanka ratified both the Vienna Convention and Montreal Protocol on 15th of December 1989. Sri Lanka has phase out CFCs, and Halons in advance of the phase-out schedule prescribed by the Montreal Protocol. Sri Lanka has been able to achieve Montreal Protocol targets on time without any complications due to successful awareness creation and legislative processes.

Recognition of Sri Lanka contribution

In honor of the 20th Anniversary of the Montreal Protocol in 2007, the United Nations Ozone Secretariat awarded the Implementer’s Award to Sri Lanka, recognizing extraordinary contributions of the National Ozone Units and people whose hard work on the country level over the years has helped to make the Protocol’s phase-out goals a reality. Sri Lanka’s effort in preserving Ozone layer has been recognized and appreciated once again at the 25th Anniversary of Montreal Protocol in 2012.

Future aspects of Research

The government of Sri Lanka has now embarked on an ambitious mission to make this island the education hub in Asia. Whilst improving the existing facilities in the public universities, the government’s aim is to encourage universities to conduct more researches. Sri Lanka has 15 National Universities, 17 Higher Educational Institutes and 12 Advance Technological Institutes, to develop and implement as local and international research and training centers for knowledge. Research plays a critical role in the innovation process. It is essentially an investment in technology and future capabilities which is transformed into new discoveries.

For an example, the National Ozone Unit (NOU) has conducted a study survey on health impacts of Ozone Layer Depletion in the North – Central Province in Sri Lanka last year in collaboration with one of the State Universities. Perfect and accurate data on UV radiation was not available in Sri Lanka or within countries close to Sri Lanka in this region and therefore the study had been done based on temperature data recorded by the Meteorological Department of Sri Lanka.
Importance of establishing ozone related research facilities was realized for conducting such sensitive scientific surveys.

**Sri Lanka interest for Monitoring Station**

Sri Lanka has no ozone monitoring stations and Sri Lanka continue with its interest to establish a monitoring station in order to gather crucial data on pollution linked with damage to the Earth's ozone layer. It is difficult to carry out proper researches concerned to ozone depletion and monitoring activities in Sri Lanka until monitoring station is established.

Establishing a Monitoring station in Sri Lanka has many global advantages as follows.

- Sri Lanka is located at the southern most part of the continent of South Asia close to the equator
- Sri Lanka is a small island monitors or researchers can reach any part of the island conveniently within short period of time.
- Facilitating Scientists to conduct research over tropics to ascertain the prediction that the ozone layer might have fully recovered by somewhere around the 2060s as a result of past, current and future actions of Montreal Protocol.
- The climate of Sri Lanka can be described as tropical and warm. Its position between 5 and 10 north latitude endows the country with a warm climate moderated by ocean winds and considerable moisture. The mean temperature ranges from about 16 °C in the Central Highlands (2500 m above sea level), where frost may occur for several days in the December-January) to a maximum of approximately 37 °C.
- Ability to connect with regional and global atmosphere monitoring networks, since Sri Lanka has very advanced communication facilities
- Assistance from Department of Meteorology and state Universities is readily available for setting up an Ozone Monitoring Centre in Sri Lanka and maintain equipment.

**Conclusion**

Since there is no ozone monitoring stations in this country, Sri Lanka wishes to propose to establish a monitoring station, in Sri Lanka to gather crucial data on adverse effects linked with damage to the Earth's ozone layer and also to observe the recovery of damaged ozone layer is genuinely taking place.

In this endeavour, Sri Lanka would strongly have to depend on UNEP assistance for setting up a monitoring station or any recognized facility for research work. Further Sri Lanka expects to enhance its cooperation with UNEP in order to encourage Ozone research officers to engage with more research works in future.

*Signature*

B.M.B.D. Basnayake
Secretary
Ministry of Environment & Renewable Energy of Sri Lanka
1. OBSERVATIONAL ACTIVITIES

1.1 Column measurements of ozone

Total ozone is monitored at two sites in Sweden by SMHI (Swedish Meteorological and Hydrological Institute) on behalf of the Swedish Environmental Protection Agency. Daily measurements started in Norrköping in 1988 using the Brewer #6, which was replaced by Brewer #128 in 1996. In Vindeln manual measurements started in 1991 using the refurbished old Dobson #30 and since 1996 the automatic Brewer #6 is also used.

The instruments are calibrated and served regularly. The Dobson #30 was completely refurbished and calibrated by DWD at Hohenpeissenberg in 2010. Efforts have been spent on improving the algorithms for cloud covered skies and the methods to retrieve good observations at low solar elevations since the 1990-ties. Therefore Dobson #30 and the Brewer #6 participated in the CEOS campaign in Sodankylä in 2011, Karppinen et al. (2014).

1.2 Profile measurements of ozone and other gases

Chalmers University of technology (Earth and Space Sciences department) is operating a monitoring station in Norway (60ºN 10.75ºE) within the NDACC network (Network for the detection of stratospheric change, www.ndsc.ncep.noaa.gov). Ground based measurements of the sun have been conducted here since 1994 with a high resolution Solar FTIR with a spectral resolution of 2.5–10-3 cm⁻¹. From the recorded spectra the atmospheric columns, and partial columns of up to 25 atmospheric species can be retrieved with good accuracy. This includes stratospheric ozone, reservoir species (HCl, ClONO2, HF, HNO3) and climate gases (CH4, N2O) and species of relevance to atmospheric chemistry (CO and ethane). The data are stored at the NDACC data base.

Today there are 10-15 instruments in operation for atmospheric solar absorption measurements worldwide and within the NDACC Infrared working group Chalmers is doing data comparisons of the measurements and the retrieval algorithms.
At the Swedish Institute of Space Physics in Kiruna there are a number of sophisticated instruments in operation. The ESRAD radar observes the horizontal and vertical winds in the troposphere, the lower stratosphere, and the mesosphere. LIDAR observations give a profile aerosol in the stratosphere, when there are no interfering clouds. There is also an instrument KIMRA (Kiruna Millimeter wave radiometer) that is used to monitor strato-mesospheric O3 and CO. The vertical resolution may not be the best, but it is independent of the weather so it can operate continuously and it has now a time series of ozone measurements since 2002. Since 1996 the Karlsruhe Institute of Technology (KIT) operates a FTIR (Fourier-Transform Infrared) Spectrometer at the same site to record long-term trends, see Figure 2.2 and 2.3.

The KIT owned millimeter wave radiometer MIRA2 is operated at RF since November 2012, aiming for long-term observation of ozone and possibly other trace gases, Kohlhepp et al. (2012). There is also a DOAS-instrument from University of Heidelberg recording primarily the total column density of NO2, but funding provided total column density of ozone and a number of other species would be possible.

1.3 Satellite measurements

The Swedish-led Odin satellite continuous to make global ozone observations and entered its 13th year of operation. Odin was launched on 20 February 2001 and is a project funded by Sweden (SNSB), Canada (CSA), France (CNES), Finland (Tekes), and the 3rd party mission program of the European Space Agency (ESA). This satellite provides valuable long-term time series of ozone and related species from its two instruments, the "Sub-Millimetre Radiometer" (SMR) and the "Optical Spectrograph and InfraRed Imaging System" (OSIRIS).

1.4 UV measurements

1.4.1 Broadband measurements

Monitoring of broadband UV (CIE-erythema weighted) started relatively early in Sweden. Supported by SSM (the Swedish Radiation Safety Authority) SMHI has been measuring since 1983. There has also been a small network of five stations for a limited period. Presently, SMHI operates one station in Norrköping using a Solar Light Model 501. In the northernmost part of Sweden the Abisko Scientific Research Station is also using a similar instrument.

1.4.2 Spectroradiometers

In the past UV-spectra were recorded in between the monitoring of total ozone using Brewer instruments. These data have been included in EC-funded projects SUVDAMA, EUDUCE and SCOUT-O3, e.g. Bais et al. (2007). Measurements have stopped as funding ceased.

1.5 Calibration activities

The Brewer instruments for total ozone are calibrated and serviced regularly by three year interval by IOS (International Ozone Services Inc.). Thus the output will be traceable to the Brewer Triad, which forms the WMO/GAW calibration centre. The Dobson instrument is recalibrated roughly every fifth year by visits to the WMO regional calibration centre at Hohenpeissenberg, Germany. The last calibrations were in 2007 and in 2010, when the instrument was served, calibrated and the electronics was replaced.

1.6 Modelling and process studies

The Meteorological Institute Stockholm University (MISU) has been involved in modelling and process studies mainly regarding PSC (Polar Stratospheric Clouds) and ozone.
2. RESULTS FROM OBSERVATIONS AND ANALYSIS

Controlled and processed total ozone and broadband UV-data are available from web-sites of SMHI and/or WOUDC. Below is shown a summary of various observations made at Norrköping, Sweden. Interestingly, the Brewer spectrophotometer data can also be used to compute the aerosol optical depth (AOD), see e.g. Cheymol et al. (2006).

Figure 2.1. Long-term, 1983-2013, CIE-weighted UV, total ozone, global radiation and sunshine duration from Norrköping, Sweden. A linear trend is tested on the level of 95% significance for each variable.
Since 1996 the Karlsruhe Institute of Technology (KIT) operates a FTIR (Fourier-Transform Infrared) Spectrometer at Kiruna to record long-term trends, see Figure 2.2 and 2.3.

Figure 2.2 HCl total column from FTIR-measurements over Kiruna. Linear trend -0.5±0.2 % per year, update from Kohlrepp et al. (2011).

Figure 2.3 The ozone change in several atmospheric layers over Kiruna has been studied using the FTIR, from Barthlott et al. (2011).
Ground based measurements from Harestua of the column ozone using a high resolution Solar FTIR, Figure 2.4.

Figure 2.4. The ozone columns (daily and annual average) measured above Harestua between 1995 and 2012.

3. THEORY, MODELLING, AND OTHER RESEARCH

3.1 Modelling

At MISU some work has been done on the O3/N2O relationship as well as studies of the formation of Polar Stratospheric Clouds (PSC), Achtert et al. (2011), Koshrawi et al. (2011) and Koshrawi et al. (2012)

In early 2000 the STRÅNG-model system Landelius, Josefsson and Persson (2001) was launched, see http://strang.smhi.se/ as a co-operation between SMHI, the Swedish Environmental Protection Agency and the Swedish Radiation Safety Authority. Now, there is over 10 years of hourly data available for anyone to download, period 1999- up to yesterday. The modelled variables are CIE-weighted UV, global radiation, direct solar radiation, sunshine duration and photosynthetic photon density (PAR). The geographical area covers a large part of northern Europe with a present spatial resolution of 11 km.

3.2 Satellite

The Swedish led Odin satellite continues to provide relevant data for monitoring and understanding the development of the ozone layer. Data assimilation techniques are used to access ozone loss see e.g. Rösevall et al. (2008), the time series is now over 11 years long and is being incorporated into several international initiatives such as ESAs Essential climate variable initiative Sofieva et al. (2013) and SPARC's data initiative. The data assimilation work is continuing to obtain a series of ozone loss measurements for both Antarctic and Arctic pole and for other instruments, ACPD, Sagi et al. (2014).

The Odin ozone data are for example used in international activities in preparation of the 2014 WMO ozone assessment, such as the so-called "SI2N" activity on changes in the vertical distribution of ozone, an activity supported by WCRP/SPARC (World Climate Research program / Stratosphere-troposphere processes and their role in climate), IOC (International Ozone Commission), IGACO-O3/UV (GAW) and NDACC (Network for Detection of Atmospheric Composition Change), e.g. http://www.sparc-climate.org/activities/ozone-profile-ii/

Odin ozone data are also used together with ozone observation from other satellites in the O3-CCI (ozone climate change initiative) project funded by the European Space Agency ESA. The
objective is to create long-term quality-assessed time-series of essential climate variables to be used in climate research, and ozone is one of the essential climate variables under study. http://www.esa-ozone-cci.org/

Odin data with relevance for ozone are also exploited within the SPARC data initiative on Trace Gas Climatology which aims to inter-compare vertically-resolved chemical trace gas climatologies derived from a large number of satellites in order to improve our knowledge and ability to test chemistry-climate models, e.g. Tegtmeier, S. et al. (2013) http://www.sparc-climate.org/activities/trace-gas-climatologies/

Measurements by the Odin satellite are also used on a regular basis in order to quantify ozone loss and explore responsible chemical mechanisms in the spring-time polar lower stratosphere in the Antarctic ("ozone hole") and in the Arctic, e.g. http://www.rss.chalmers.se/~jo/SMRquicklook/Arctic-winter-2011-report/ Odin-NH2011-report.pdf

Odin data are also used in ozone and climate related activities such as the SPARC WaVAS stratospheric water vapour assessment and activities like SPARC/HEPPA (High Energy Particle Precipitation in the Atmosphere) focusing on exploring the effect of solar activity on the atmosphere, e.g. http://www.sparc-climate.org/activities/water-vapour-ii/ and http://www.sparc-climate.org/activities/solar-influence/

Finally, it should be noted that presently work is going on in Sweden in preparation of the STEAM (Stratosphere-Troposphere Exchange and Climate Monitor) satellite instrument which will besides its main (climate related) objectives also has the capability to make global observations of ozone.

4. DISSEMINATION OF RESULTS

4.1 Data reporting

Daily total ozone data are submitted once a month to the WOUDC. These data are also available at the www.smhi.se where also daily UV can be downloaded.

4.2 Information to the public

General information on the stratospheric ozone and UV-radiation can be found at www.smhi.se and at www.naturvardsverket.se/

In an annual follow-up of the environmental quality objectives, an assessment is made of whether the policy instruments decided on and the measures to be introduced before 2020 will be sufficient to achieve the healthy environment which the objectives describe. A protective ozone layer is one of the objectives. Every few years, a more in-depth evaluation is carried out. The results are coordinated and collated by the SEPA (Swedish Environmental Protection Agency). General information and the results can be found at www.miljomal.se.

The SSM (the Swedish Radiation Safety Authority) has more public information on their web-site www.ssm.se. This governmental authority also produce brochures and some of them are possible to download from their web site. They also have had activities with the goal to change the tanning behavior of people mainly directed towards children.

One activity was to publish and distribute “A book about the sun” to all kindergartens in Sweden, another one was to educate the teachers of preschools and primary schools on the basics of and risks of UV, see http://www.stralsakerhetsmyndigheten.se/start/Sol-och-solarier/

Another one is films see e.g. http://www.stralsakerhetsmyndigheten.se/start/Sol-och-solarier/njut-av-solen/450-nyanser-av-rott/ There is also an app for smart phones that calculates possible time in the sun without sunburn.
The distribution of daily UV-index forecasts started in 1993 from SMHI. In 1996 the UV-index forecast was introduced on the web (http://www.smhi.se) as a Table for 15 regions in Sweden and three resorts. Next year, 1997, the graphical layout was improved and since then the daily course of the UV-index is presented for a number of climatological similar regions in Sweden. During the first winters there was no forecasting of UV-index done. The season started in late March and stopped at the end of August. Since the year 2000, it is in operation all the year around. There is also some additional text presenting some specific features of interest regarding UV-radiation in general.

5. RECOMMENDATIONS

Concerning future research and activities regarding the ozone layer monitoring is still needed using both ground and space based instruments. Models needs to be improved, especially the CCMs. Predictions about when and to what extent the ozone layer will recover have still uncertainties and the model results deviate from each other by one or two decades.

Another valuable contribution from long-term measurements of ozone and related species from ground or from satellites are their connection to the climate change issue.

Relevant scientific papers


Angelbratt, J., Mellqvist, J. et al. (2011), A new method to detect long term trends of methane (CH4) and nitrous oxide (N2O) total columns measured within the NDACC ground-based high resolution solar FTIR network. Atmos. Chem. Phys. Discuss., 11, 8207–8247.


von Hobe et al., Reconciliation of essential process parameters for an enhanced predictability of Arctic stratospheric ozone loss and its climate interactions (RECONCILE): activities and results, ACP, 2013. http://www.atmos-chem-phys.net/13/9233/2013/acp-13-9233-2013.pdf


Journal Of Geophysical Research-Atmospheres, 2008, 113, D13301

Geophysical Research Letters, 2007, 34, L21809


TOGO

INTRODUCTION

Le Togo, à l’instar de la plupart des pays, est préoccupé par les problèmes afférents aux enjeux de l’environnement notamment dans le cas des émissions de substances chimiques dans l’environnement. Le cadre institutionnel est assez bien balisé pour chaque problème spécifique.

A cet effet, et conformément à ses engagements au titre du Protocole Montréal et de ses amendements et aux autres textes y afférents, le Togo a pris un certain nombre de dispositions réglementaires et mène des actions pertinentes pour l’élimination des Substances Appauvrissant la couche d’Ozone (SAO).

En revanche, dans le domaine de la recherche sur l'ozone, des initiatives des laboratoires nationaux restent timides par faute de moyens nécessaires pour réaliser leurs objectifs.

Le présent rapport rend compte de l’état des recherches en cours et futures sur les rejets des substances chimiques.

1. ETAT DES ACTIVITÉS DE RECHERCHE

Les différents laboratoires de recherche des Universités publiques du Togo, Université de Lomé et Université de Kara mènent des activités de recherche qui portent sur l’émission des substances chimiques dans l’écosystème et l’étude de leurs impacts sur la santé, l’eau, les aliments etc. Ce sont pour l’Université de Lomé, le Laboratoire de chimie atmosphérique, le laboratoire GTVD (Gestion Traitement et Valorisation des Déchets), le laboratoire de Chimie des Eaux, l’Unité de Recherches des Agros-Ressources (URASE) et pour l'Université de Kara, le Laboratoire d’Assainissement Sciences de l'Eau et Environnement (LASEE).

Les activités de recherche des laboratoires visent d’une manière générale à réduire et éliminer ces substances chimiques y compris les SAO. Elles portent sur l'évaluation des rejets de substances chimiques dans l’environnement en l’occurrence dans l’eau, sols, atmosphère voire dans des aliments et des impacts y afférents.

plus utilisé ces dernières années (figure ci-dessous). Les données en ordonnées sont exprimées en tonnes.

En marge des activités de recherche spécifiquement liées à l’ozone qui sont plutôt très timides, d’intenses actions sont menées sur le plan nationale pour réduire, éliminer ou mieux cerner la problématique des SAO. A titre d’exemple, une stratégie de gestion de l’élimination des HCFCs a été élaborée. Il en est de même d’un plan de mise en œuvre de cette stratégie d’élimination des SAO.

En outre, des séances de formation, sensibilisation portant sur les dangers de ces substances sur l'environnement sont couramment organisées par le Bureau National Ozone à l'endroit des techniciens frigoristes, principaux manipulateurs des CFC et des douaniers. Ils sont également sensibilisés sur les bonnes pratiques en vigueur dans le secteur du froid.

II. PERSPECTIVES ET PROJETS

- le suivi de l’évolution de la couche d’ozone stratosphérique ;
- la recherche de nouvelles substances inoffensives ;
la réhabilitation de la station de Kouma-Konda qui est une nécessité pour initier de véritables actions de recherche sur l’ozone;
le suivi du processus de réduction et d’élimination des SAO;
la recherche des alternatives à faible coût;
l'évaluation qualitative et quantitative de rejets de polluants notamment les SAO dans l'atmosphère.

III. BESOINS ET RECOMMANDATIONS

BESOINS
• des dispositifs scientifiques simples et complets pour l’observation et le suivi de l’évolution de l’ozone stratosphérique pour des recherches;
• des équipements scientifiques légers pour la récupération et la gestion des résidus des SAO impliquant les structures de recherche;
• un soutien pour la mise en œuvre de la stratégie et du plan d’élimination des HCFCs;
• des soutiens financiers à l’endroit des laboratoires sur la base des projets soumis pour mener des activités de recherches;
• la réhabilitation de la station de Kouma-Konda du Togo pour le suivi de l’évolution de l’ozone stratosphérique dans la sous-région.

IV. RECOMMANDATIONS A L’ENDROIT DU PNUE

• l’initiation des appels à projets compétitifs de recherche sur des questions relatives aux substances appauvrissant la couche d’ozone;
• la création en Afrique d’un centre régional de recherche sur les interactions ozone-changements climatiques;
• l’initiation des projets de recherches sous-régionaux impliquant des chercheurs de plusieurs pays;
• la mise en place de réseaux régionaux et internationaux d’échanges de données, d’informations et d’expériences sur les questions relatives aux SAO;
• l’implication des industriels dans la recherche des solutions relatives aux SAO;
• la sensibilisation plus accrue des décideurs afin qu’ils s’impliquent davantage dans la recherche des solutions aux problèmes d’environnement.
CONCLUSION
La problématique des substances appauvrissant la couche d’ozone est d’autant plus préoccupante que la plupart de ces substances peuvent avoir des interactions avec les changements climatiques. Il importe donc d’inciter les chercheurs à s’impliquer davantage dans le domaine de la recherche sur l’ozone. Mais le principal frein dans les pays en développement étant le manque d’équipement appropriés, une solution globale ne saurait être trouvée sans l’encouragement des recherches dans ces pays. Malgré les efforts fournis par les états dans le respect des conventions internationales, si de véritables activités de recherche ne sont pas encouragées et soutenues dans les pays en développement, les initiatives internationales basées sur des données scientifiques obtenues parfois par simulations et attribuées à ces pays par extrapolation, peuvent s’avérer inefficaces.

Les chercheurs du Togo sont assez disponibles et intéressés par ces recherches mais, il leur faut un soutien conséquent.

Fait à Kara, le 31 mars 2014

Professeur Gnon BABA
TURKEY

Turkish State Meteorological Service is responsible for observing and promoting research activities on measurements of ozone and UV radiation.

OBSERVATIONAL ACTIVITIES

Ozone measurements are made by Brewer Spectrophotometer in Ankara.

Ultraviolet radiation measurements are made in totally 15 stations with different specification instruments which of one is broad band and others are narrow band.

Column Measurements Of Ozone And Other Gases/Variables Relevant To Ozone Loss

<table>
<thead>
<tr>
<th>Station</th>
<th>Instrument</th>
<th>Institution</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Start date of observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankara</td>
<td>Brewer MKIII-188</td>
<td>TSMS</td>
<td>39° 57’ (N)</td>
<td>32° 53’ (E)</td>
<td>Sep., 2006 to present</td>
</tr>
</tbody>
</table>

Brewer spectrophotometer is deployed on a solar azimuth tracker which allows daily automatic measurements of total ozone, zenith sky and direct sun in Ankara station which is the component of WMO-Global Atmosphere Watch Programme.

Data, measured by Brewer MK III Spectrophotometer, measurement data are stored in the database of The Data Processing Department of TSMS and are also sent to the World Ozone and UV radiation Data Center (WOUDC) in Toronto, Canada and are archived in there.

Profile Measurement Of Ozone And Other Gases/Variables Relevant To Ozone Loss

<table>
<thead>
<tr>
<th>Station</th>
<th>Instrument</th>
<th>Institution</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Start date of observation</th>
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</thead>
<tbody>
<tr>
<td>Ankara</td>
<td>Ozonesonde(ECC)</td>
<td>TSMS</td>
<td>39° 57’ (N)</td>
<td>32° 53’ (E)</td>
<td>Sep., 2006 to Marc 2013</td>
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</table>

Ozone profile measurements by TSMS Research Department in the method of ozonesonde between January 1994 and March 2013 was held in Ankara.

UV Measurements

<table>
<thead>
<tr>
<th>Station</th>
<th>Instrument</th>
<th>Institution</th>
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<th>Longitude</th>
<th>Start date of observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ankara</td>
<td>Solar Light 501</td>
<td>TSMS</td>
<td>39° 57’ (N)</td>
<td>32° 53’ (E)</td>
<td>1997 to present</td>
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<tr>
<td>Antalya</td>
<td>Solar Light 501</td>
<td>TSMS</td>
<td>36° 42’ (N)</td>
<td>30° 44’ (E)</td>
<td>1997–2003</td>
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</table>

UV-Biometer Model 501 is used for broad band UV radiation measurements.
Narrow band filter instrument

<table>
<thead>
<tr>
<th>Station</th>
<th>Instrument</th>
<th>Institution</th>
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<td>39° 35’ (E)</td>
<td>2009 to present</td>
</tr>
<tr>
<td>Aksaray</td>
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<td>38° 23’ (N)</td>
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<td>Elazıg</td>
<td>Middleton Solar UVR1-B Radiometer</td>
<td>TSMS</td>
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<td>39° 28’ (E)</td>
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</tr>
<tr>
<td>Göksun</td>
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<td>TSMS</td>
<td>38° 01’ (N)</td>
<td>36° 30’ (E)</td>
<td>2009 to present</td>
</tr>
<tr>
<td>Mardin</td>
<td>Middleton Solar UVR1-B Radiometer</td>
<td>TSMS</td>
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<td>40° 73’ (E)</td>
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<td>Oltu</td>
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<td>37° 02’ (E)</td>
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<tr>
<td>Tarsus</td>
<td>Middleton Solar UVR1-B Radiometer</td>
<td>TSMS</td>
<td>36° 55’ (N)</td>
<td>34° 54’ (E)</td>
<td>2009 to present</td>
</tr>
<tr>
<td>Tokat</td>
<td>Middleton Solar UVR1-B Radiometer</td>
<td>TSMS</td>
<td>40° 30’ (N)</td>
<td>36° 57’ (E)</td>
<td>2009 to present</td>
</tr>
<tr>
<td>Van</td>
<td>Middleton Solar UVR1-B Radiometer</td>
<td>TSMS</td>
<td>38° 45’ (N)</td>
<td>43° 32’ (E)</td>
<td>2009 to present</td>
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<tr>
<td>İstanbul, Florya</td>
<td>PMA1102</td>
<td>MGM</td>
<td>40° 59 (N)</td>
<td>28° 45 (E)</td>
<td>2012 to present</td>
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<tr>
<td>İzmir, Güzelyalı</td>
<td>PMA1102</td>
<td>MGM</td>
<td>38° 43 (N)</td>
<td>27° 17 (E)</td>
<td>2012 to present</td>
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<tr>
<td>Antalya, Kale</td>
<td>PMA1102</td>
<td>MGM</td>
<td>36° 15 (N)</td>
<td>29° 57 (E)</td>
<td>2012 to present</td>
</tr>
<tr>
<td>Afyon, Çay</td>
<td>PMA1102</td>
<td>MGM</td>
<td>38° 35 (N)</td>
<td>31° 02 (E)</td>
<td>2012 to present</td>
</tr>
</tbody>
</table>

UVR1-B Global Spectral Radiometers and PMA1102 UV detector are used for narrow band UV radiation measurements.

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**Figure 1.** Turkey, UV-B Meteorological Stations.
Spectroradiometers

Spectral UVB measurements (290-325 nm) by Brewer spectrophotometer #188 MK III have started from 09 September, 2006 in Ankara station.

<table>
<thead>
<tr>
<th>Station</th>
<th>Instrument</th>
<th>Institution</th>
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<td>Ankara</td>
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<td>39° 57’ (N)</td>
<td>32° 53’(E)</td>
<td>Sep.2006 to present</td>
</tr>
</tbody>
</table>

Calibration Activities

Calibration of Brewer Spectrophotometer #188 has performed since it was installed in 2006. First Brewer S. calibration was carried out by International Ozone Services Inc. (IOS) which provides worldwide ozone and UV calibration services to customers with Brewer Ozone Spectrophotometer instruments. IOS used Brewer Ozone Spectrophotometer #017 as a reference instrument on 07–12 October 2008 in Ankara station.

**Figure 2.** First calibration of Brewer MKIII #188 with the reference Brewer MKIV #017 in Ankara station.

**Figure 3.** Second calibration of Brewer MKIII #188 with the reference Brewer MKIII #158 in Ankara station.

**Figure 4.** Third calibration of Brewer MKIII #188 with the reference Brewer MKIII #158 in Ankara station.

Second calibration of Brewer S. #188 was carried out from 22 to 29 September in 2010 and Third calibration of Brewer S. #188 was carried out from 23 to 27 September in 2013 by Kipp& Zonen. Kipp& Zonen used Brewer Ozone Spectrophotometer #158 as a reference instrument during calibration in Ankara station.
RESULTS FROM OBSERVATIONS AND ANALYSIS

Brewer Ozone Variability Over Ankara, Comparison Between OMI and Brewer Ozone Measurements For Ankara (2007-2013)

Figure 5. Comparison of OMI_TOMS from satellite with the total ozone measurements of Brewer S. #188 between 11 June 2006 and 31 December 2013.

In figure 5, relationship between total ozone measurements of Brewer #188 and OMI_TOMS observed total ozone data from satellite indicates high correlation. Correlation coefficient is $R=0.97$ and $R^2=0.9493$.

Turkey's Total Ozone Sattalite (TOMS-OMI) Data Assesment For Long Period (1979-2012)

TOMS-OMI satellite ozone data used in this study is selected from the global data set which is in http://ozoneaq.gsfc.nasa.gov/ NASA’s web address. Data is range Turkey's 25 ° - 45 ° East Longitude and 34 ° - 42 ° North Latitude, data resolution is 1°x1.25° and data grid consists of 82 points.

Data time range covers between 1979 to 2012 (34 years) years. The data set which is consist of total 2788 data and is belong to Turkey domain. 984 of data are used for monthly comparison and 328 of data are used for seasonal comparison.
Figure 6. Total Column Ozone Distribution (TOMS and OMI Satellite Data, 1979-2012)

Average total ozone value has been found in 318 DU from data set which is used in mapping. The lowest average value is 291 DU in point 37 °N and 44 °E in 1993. The highest average value is 351 DU in point 42°N and 28°E in 1991.

The average total ozone is approximately 306 DU at Turkey's southern latitudes and in northern latitudes is approximately 331 DU. The average total ozone difference is also 25 DU between the northern and southern latitudes in Turkey.

DISSEMINATION OF RESULTS

Data Reporting

Products of ozone and UVB radiation measurements are stored at the Research and Data Processing Section of TSMS and can be accessible through intranet to users.

All data measured by Brewer MK III Spectrophotometer #188 and ozonosonde are sent regularly to the World Ozone and UV radiation Data Center (WOUDC). They are archived and published with the station number 348 in Toronto, Canada. At the same time, Ankara station is a part of the Global Atmosphere Watch Programme (GAW).

Information to The Public

Since 2008, daily total ozone and ultraviolet index forecast information, which is derived by using a statistical model in Turkey’s 125 points and Northern Cyprus Turkish Republic (TRNC)’s 5 points, are published through internet web site. [http://www.mgm.gov.tr/kurumici/tahmin-ozon-mgm.aspx](http://www.mgm.gov.tr/kurumici/tahmin-ozon-mgm.aspx)
In addition, MGM and the German Meteorological Service (DWD) have been cooperation for ozone and ultraviolet index forecast. Daily total ozone and ultraviolet index forecast information, which is produced by DWD for Turkey’s 125 points and Northern Cyprus Turkish Republic (TRNC)’s 5 points, are published through internet web site. http://www.mgm.gov.tr/kurumici/tahmin-ozon-mgm.aspx
Figure 8. DWD model products showing information on daily forecasted total ozone and maximum UV index to the public at the TSMS web page for Turkey.

Relevant Scientific Papers


FUTURE PLANS

- to establish a Brewer Spectrophotometer Network to cover and to represent whole Turkey for measuring total ozone and UV index by purchasing more Brewer Spectrophotometer.
- to study on interactions between stratospheric ozone and climate change.
- to examine variation in ozone and UV index in time.
- to evaluate interaction between ozone change and climate change.
- to contribute to ozone assessments by sharing information.
- to seek for research at the European level implemented through the Framework Programmes for research and technological development (FPs) of European Commission.
- to participate seminars, conferences and meetings related with global ozone research and international monitoring programme.

NEEDS AND RECOMMENDATIONS

Providing a continued maintenance and calibration of instruments such as Brewer S. and UV sensor with the support of WMO is important.
Turkmenistan

Monitoring of atmospheric ozone

In Turkmenistan monitoring of atmospheric ozone is accomplished by a National Committee on Hydrometeorology at the Cabinet of Ministers of Turkmenistan (Turkmengidromet). At present continue systematic daily observations of the total amount of the atmospheric ozone at one station:

Repetek (38.34° N, 63.11° E, 185 m, since 1983)

The measurements of total ozone amount are done by means of the ozonometer M-124, manufactured in Russia. The ozonometers physically became obsolete, already many years they were not calibrated. Spare and reserve ozonometers for replacement and control are absent. Nevertheless the carried out comparative analysis between the temporary changes in the total ozone amount, obtained using the ozonometers M-124 and by data of Central Aerological Observatory scientific report, gives satisfactory agreement.

Information

The daily averaged data of total ozone amount, obtained at three stations are sent by telegram to Moscow 736 OZONE. Monthly schedules O-3 not later than 3 days of the following month are sent to the Main Geophysical Observatory named Voeikov. Further all data are transferred to the coordinated international network by data exchange of the World Meteorological Organization (WMO).

All primary data are stored in the archive of Turkmengidromet on the paper carrier. As it is known, the paper becomes yellow at long storage, records grow dull and there is a danger of important information loss received for a long time. Therefore in the near future it is necessary to transfer all information on ozone in the electronic format.

Studies

It is known that the ozone actively absorbs UV - radiation of the Sun and hereby influences on temperature distribution in the stratosphere, consequently on climate. By-turn climate changes, leading changes of temperature and composition of the atmosphere can influence on condition of ozonosphere. Depletion of the ozone layer will increase hard spectrum of UV - radiation which promote initiation of sun burnings, eye diseases, allergic reactions and skin diseases including cancer. Therefore studying of change of the total content of atmospheric ozone appears as actual task of the present.
Studying of the total amount of atmospheric ozone is conducted by the Scientific and Technical Center "Climate" of Turkmengidromet. The conducted investigation is directed toward the study of regional special features of the total ozone amount change and their time variations, and also determination of possible sources responsible for the ozone layer destruction. Though obtained results of scientific analysis regarding influence of hard spectrum of UV - rays on condition of the ozonosphere in a phase of high solar activity, presently an opinion about role of anthropogenic factor becomes prevalent.

In the last years an increase of the quantity of industrial objects in Turkmenistan can lead to the growth of the role of anthropogenic factor.

Turkmenistan having ratified the Vienna Convention and the Montreal Protocol, and also London Amendment to the Montreal Protocol undertook the corresponding obligations on the problem solution of the Ozone depleting substances (ODS). Plan of actions is developed on decrease of pollutants emission in the atmosphere and on ODS phase-out. 22nd of January 2008 the Medjlis (Parliament) of Turkmenistan has accepted a Decree about acceding to the Beijing, Montreal and Copenhagen Amendments of the Montreal Protocol on Substances that Deplete the Ozone Layer.

Problems and needs

The contemporary level of investigations requires the presence of new technical equipment, which will permit to carry out the regular control of the content of ozone both in the atmospheric surface layer and at the stratosphere heights.

This is dictated by the fact that decrease of the total ozone amount in the stratosphere leads to an increase of the intensity of UV - rays dangerous for the life, and its increase in the atmospheric surface layer adversely affects on human health and it leads to a drop in the productivity of agricultural crops (wheat, rice, potato and etc.).

For obtaining more reliable information about the total ozone amount it is necessary to enlarge a network of regular daily observations. Also necessary to more widely use the data, obtained from the satellites. This can be carried out with the aid of the acting stations equipping by the contemporary instruments and opening of new stations with the technical support of international organizations.

Turkmenistan near future is planning to purchase a new ozonometer Mikrotops-2.

In Turkmengidromet also there is necessity in training of young specialists with purpose of effective usage of contemporary instruments for measuring the total amount of atmospheric ozone and ultraviolet radiation.
Taking into consideration recommendations of the seventh meeting of the Ozone Research Managers of the Parties to the Vienna Convention, which was held in Geneva from 2 to 4 May 2011, Turkmenistan is in need of support, namely:

1. In gradually taking out from the operation existing M124 ozonometr.
2. To get more technical information on exiting modern devices or ozonometers.
3. There is a need to transfer all information on ozone to the electronic format.
4. To allocate resources for the visits of personnel from monitoring stations in order to ensure technology and knowledge transfer and sustained measurement programmes.
5. Resources should be provided to support to scientists from developing countries to attend conferences and workshops.

This report follows with additional report as attached.
The data of ozone content in observable atmosphere for period from May, 2011 to January, 2014 at the Repetek meteorological station (10^3 cm).

<table>
<thead>
<tr>
<th>Year</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
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<th>VII</th>
<th>VIII</th>
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Executor: Muhammedova M.
Phone: 93-54-64

/signature/
1. OBSERVATIONAL ACTIVITIES

1.1. Column measurements of ozone and other gases/variables relevant to ozone loss

The UK Government Department for Environment, Food and Rural Affairs (Defra) funds an ongoing monitoring programme that records total values of stratospheric ozone at two UK locations. Measurements with a Dobson instrument are taken at the Lerwick Observatory in the Shetland Islands (N of Scotland) and a Brewer spectrophotometer is used at the Reading site in Berkshire (S England). The latter site replaced the Camborne Observatory site in Cornwall at the end of 2003, where a Dobson instrument had been used for ozone measurements. The spectrophotometers sample the ozone column at frequent intervals throughout the day to produce daily mean values, except for when weather conditions prevent values from being recorded and during the winter at Lerwick when the sun is too low in the sky.

Column ozone measurements are also made at the University of Manchester (N England) using a Brewer instrument. These are also made available to the above monitoring programme (but are separately funded) and similarly submitted to the World Ozone and Ultraviolet Radiation Data Centre (WOUDC).

Measurements using a Systeme D'Analyse par Observations Zenithale (SAOZ) instrument are made in Aberystwyth. These measurements have not been processed for over two years. The University of Manchester are looking to bring them into the ozone and UV monitoring project over a period of time depending on their resource availability.

The British Antarctic Survey (BAS) continues total column ozone measurements at Halley with a Dobson spectrophotometer, and supports those made at Vernadsky (Ukraine). BAS also continues total ozone and nitrogen dioxide (NO2) column measurements at Rothera with a SAOZ spectrometer and commenced such measurements at Halley on 30th January 2013. A radiosonde programme continues at both Halley and Rothera. The Met Office funds the Halley radiosonde program, while BAS covers the cost of the gas. BAS covers the main cost of the Rothera radiosonde program.

The UK Met Office lent Dobson #35 to the South African Weather Service in June 2006, and it has remained on loan to the South African Weather Service. Dobson 35 is currently fully operational at the Irene Operational unit standing in for Dobson 89 which required maintenance. The data are being prepared to be submitted to WOUDC in place of 89 for 2013. It is still the intention to install Dobson 35 at the Cape Point Facility when renovations are complete.

It is hoped that South African Weather Service will be hosting the African Dobson Inter comparison during 2014 in which Dobson 35 will also participate.

1.2. Profile measurements of ozone and other gases/variables relevant to ozone loss

High frequency, real time in situ measurements of the principal halocarbons and radiatively active trace gases have been made at Mace Head on the West coast of Ireland since 1987. These measurements form a key part of the international Advanced Global Atmospheric Gases Experiment (AGAGE) measurement programme. For about 70% of the time Mace Head monitors clean westerly air that has travelled across the North Atlantic Ocean. For the remaining time, Mace Head receives substantial regional scale pollution in air that has travelled from the industrial regions of Europe. The site is therefore ideally situated to record trace gas concentrations associated with both the Northern Hemisphere background levels and with the more polluted air arising from Europe.

Using the Mace Head data, coupled with a Lagrangian dispersion model that determines the history of the air arriving at Mace Head at the time of each observation, estimates of the mid-latitude Northern Hemisphere baseline concentrations are made for each trace gas, see Figure 1 below for the surface ozone trend at Mace Head. By removing the underlying baseline trends from
the observations and by modelling where the air passed over on a regional scale on route to Mace Head, an iterative best-fit technique can then search for a regional emission map that generates a time-series that most accurately mimics the Mace Head observations (www.metoffice.gov.uk/atmospheric-trends).

![Figure 1 Surface ozone as measured at Mace Head; Top plot: monthly and annual mixing ratios; Middle plot: annual growth rate using 2 methods; Lower plot: mean seasonal cycle.](image)

The grey area on each plot contains data that are unratified and therefore provisional.

The UK Department for Energy and Climate Change has expanded the atmospheric observation network (UK DECC network) to include three additional sites in the UK, Angus north of Dundee; Tacolneston near Norwich, and Ridge Hill near Hereford. These sites significantly increase the spatial and temporal resolution for the interpretation work, enabling UK emission estimates to be made from atmospheric observations as well as decreasing the uncertainties associated with the UK estimates.
Analysis of the atmospheric observation data also identifies sources of and trends in ozone formation from different areas, including comparison of observed data with expected trends, to identify any new substances with ozone depleting or radiative forcing properties. DECC are engaged in EU and global networks where the possible use and analysis of any data coming from other sites remains under review.1

1.3. UV measurements

1.3.1. Broadband measurements
The solar UV index is measured at nine sites (from 50 to 60° N) across the UK by the Centre for Radiation, Chemical and Environmental Hazards of Public Health England (PHE). A tenth site is located at Thule in Greenland, which is operated in conjunction with the Danish Meteorological Institute. The Department of Health provides support for this UV monitoring work, which provides information for the Global Solar UV Index in association with World Health Organisation (WHO), World Meteorological Organization (WMO), United Nations Environment Programme (UNEP) and the International Commission on Non-Ionizing Radiation Protection.

1.3.2. Narrowband filter instruments
Since the 8th Ozone Research Managers meeting we have become aware that there is a Ground-based Ultraviolet (GUV) instrument routinely in use at Manchester.

1.3.3. Spectroradiometers
A spectroradiometer is co-located with the Brewer spectrophotometer in Reading, funded as part of the Defra monitoring programme. The Bentham DM150 UV spectroradiometer has been in place since 1993, and is regularly calibrated in situ. The instrument takes measurements from 290nm to 500nm at 0.5nm resolution at half-hour periods during daylight hours, every day of the year.

A multi-filter radiometer is also co-located with the Brewer spectrophotometer at the University of Manchester, which provides one minute averages in each of the five narrow wavebands (305, 313, 320, 340, 380nm). Apart from calibration periods, the Manchester instrument has been in continuous operation since 1997. Data are submitted to WOUDC alongside the ozone data series.

The BAS made spectral measurements of UV using a Bentham spectroradiometer at Rothera from 09/02/1997 until 2012, the data record stops at 12/3/2012.

Spectral UV measurements are carried out at the PHE site at Chilton. Two portable spectral measurement systems have been developed for temporary deployment during extreme weather, atmospheric events or at locations where large numbers of people gather outside during the UK summer.

1.4. Calibration activities
Regular calibrations have been carried out on both Met Office Dobson instruments and the Reading Brewer spectrophotometer. The current recommendation is to re-calibrate Brewer Spectrophotometers every two years. Dobson Spectrophotometers are now recommended to be re-calibrated every 4 or 5 years depending on their condition. Dobson #41 is being re-calibrated after 5 years for that reason.

An intercomparison took place with Dobson #32 in 2011. The change of calibration detected at the initial intercomparison was too small to require any revision of data since the previous intercomparison. The final intercomparison showed that the instrument was in good condition with no significant ozone airmass Mu dependence. Dobson #41 was taken to Hohenpeissenberg for international inter-comparison in June 2009 and was found to be performing well. The next intercomparison of Dobson #41 is planned for 2014 at Hohenpeissenberg.

http://www.metoffice.gov.uk/atmospheric-trends/
Brewer #075 was re-calibrated in 2011 at El Arenosillo with a new filter after further technical problems. Subsequent calibration at El Arenosillo in 2013 showed instrument extremely stable in good working order.

2. RESULTS FROM OBSERVATIONS AND ANALYSIS

The long-term annual mean trend in ozone for the Lerwick site, and a combined southern England trend from the Camborne (up to 2003) and Reading (2003 onwards) are given in Figure 2.

Smedley et al., (2011), analysed the trend data from these sites and demonstrated that the year at which total ozone stopped decreasing over the UK was 1993, by which time statistically significant reductions of 4.8% per decade for southern England and 5.8% per decade for Lerwick were observed. These rates of decrease are at the upper end of the range in comparison with other European ozone trends before the mid-1990s.

From 1993 to the present the data did not show any significant trend to 2008, although small average increases were noted. A more recent analysis following the methodology in Smedley et al., (2010) but including data up to 2013 now shows an upward trend of 2.0% (only significant at the 10% level). In part that there is now a observable trend since 1993 is due to higher ozone column values in 2010, which was on average some 7.6% larger than the 1993-2013 mean.

The data from the monitoring programme have also been analysed seasonally. Table 1 shows that a significant decline at Lerwick since 1978 is seen in the annual mean, Spring and Autumn for both single and multiple regression analysis. There are no significant changes at Reading since 2003. Multiple regression has a large impact on seasonal trends at Reading because of the shorter record. The autumn decline is somewhat surprising as this is before the seasonal chemical ozone depletion (Winter/Spring). We are investigating different statistical techniques to test the autumn trend.

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Table 1: Column ozone trend in Dobson Unit (DU) per year with standard errors. Numbers in bold are significant at the 95% confidence level (P<0.05) SR: single regression; MR: multiple regression. Lerwick since 1978 and Reading since 2003 and both to November 2013.

<table>
<thead>
<tr>
<th>Site</th>
<th>Annual to 2012</th>
<th>Winter (DJF) to 2013</th>
<th>Spring (MAM) to 2013</th>
<th>Summer (JJA) to 2013</th>
<th>Autumn (SON) to 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lerwick -SR</td>
<td>-0.59 +/- 0.18</td>
<td>-0.21 +/- 0.50</td>
<td>-0.75 +/- 0.27</td>
<td>-0.16 +/- 0.14</td>
<td>-0.47 +/- 0.18</td>
</tr>
<tr>
<td>Lerwick -MR</td>
<td>-0.50 +/- 0.19</td>
<td>-0.18 +/- 0.51</td>
<td>-0.57 +/- 0.22</td>
<td>-0.16 +/- 0.12</td>
<td>-0.35 +/- 0.16</td>
</tr>
<tr>
<td>Reading -SR</td>
<td>+0.59 +/- 1.16</td>
<td>+0.90 +/- 2.12</td>
<td>+0.57 +/- 1.28</td>
<td>+0.49 +/- 0.61</td>
<td>+0.85 +/- 1.03</td>
</tr>
<tr>
<td>Reading -MR</td>
<td>-0.53 +/- 1.16</td>
<td>-1.03 +/- 1.48</td>
<td>+0.42 +/- 1.11</td>
<td>+0.30 +/- 0.64</td>
<td>0.00 +/- 0.65</td>
</tr>
</tbody>
</table>

Low ozone events observed by the Defra monitoring programme are reported in near real-time. There appear to be long-term decadal cycles of the ratio of high and low ozone events. We have not identified a cause for this but it is consistent with shifting patterns of tropospheric indicators, such as the North Atlantic Oscillation (NAO), which also remain unexplained. The cycles are out of phase. In this decade we are experiencing relatively more high/low event ratios in Reading and Lerwick. However, 2012 was a year of typical number high and low events compared to the 20 year moving average. The low events defined as a departure of more than two standard deviations below the long-term monthly mean value since 2011 are shown in the Table 2.

Table 2 shows days that meet the Low Ozone Event criteria since 2011

<table>
<thead>
<tr>
<th>Lerwick date of departure</th>
<th>Reading date of departure</th>
</tr>
</thead>
<tbody>
<tr>
<td>16-Oct-13</td>
<td>16-Mar-14</td>
</tr>
<tr>
<td>15-Oct-13</td>
<td>06-Mar-14</td>
</tr>
<tr>
<td>23-Apr-13</td>
<td>21-Sep-13</td>
</tr>
<tr>
<td>27-Mar-12</td>
<td>25-Apr-13</td>
</tr>
<tr>
<td>26-Mar-12</td>
<td>24-Apr-13</td>
</tr>
<tr>
<td>15-Feb-12</td>
<td>23-Apr-13</td>
</tr>
<tr>
<td>31-Jan-12</td>
<td>27-Jun-12</td>
</tr>
<tr>
<td>09-Apr-11</td>
<td>28-Mar-12</td>
</tr>
<tr>
<td>30-Mar-11</td>
<td>24-Feb-12</td>
</tr>
<tr>
<td>29-Mar-11</td>
<td>23-Feb-12</td>
</tr>
<tr>
<td>28-Mar-11</td>
<td>16-Feb-12</td>
</tr>
<tr>
<td>27-Mar-11</td>
<td>18-Jan-12</td>
</tr>
<tr>
<td>14-Jan-12</td>
<td></td>
</tr>
<tr>
<td>27-Dec-11</td>
<td></td>
</tr>
<tr>
<td>26-Dec-11</td>
<td></td>
</tr>
<tr>
<td>25-Dec-11</td>
<td></td>
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<tr>
<td>23-Dec-11</td>
<td></td>
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<tr>
<td>08-Oct-11</td>
<td></td>
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<tr>
<td>27-Jun-11</td>
<td></td>
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<tr>
<td>09-Apr-11</td>
<td></td>
</tr>
<tr>
<td>06-Apr-11</td>
<td></td>
</tr>
</tbody>
</table>

3 Annual is to 2012 only
4 Winter (DJF) season includes December of preceding year e.g. winter 2013 is December 2012 to February 2013.

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The UV monitoring results from the Defra programme were also assessed in the Smedley et al. paper, which found no significant trend between 1993 and 2008 in the daily totals of UV, but an increase of 6% per decade was seen in the mid-day values of the UV index. This, combined with a lack of correlation between ozone and UV anomalies suggested that changes in cloud cover were the cause. Re-assessing the UV data series to include data up to 2013, shows there is no longer a significant trend in the mid-day values of UV index, due to a general decrease in daily peak values since 2008.

It should be noted that despite the long-term data produced by the UK total ozone and spectral UV records, in order to clearly observe significant trends since the mid-1990s several more years of high quality data are necessary.

3. THEORY, MODELLING AND OTHER RESEARCH

Polar stratospheric clouds (PSCs) play a crucial role in controlling polar stratospheric ozone depletion. Temperature fluctuations induced by mountain waves are an important source of PSCs. However, this formation mechanism is usually missing in chemistry-climate models because the temperature fluctuations are neither resolved nor parameterised, suggesting that models underestimate the related polar ozone loss. To remedy this, scientists at the BAS have inserted a mountain wave parameterisation scheme (which computes the temperature fluctuations due to unresolved (sub-grid scale) mountain waves) into the chemistry-climate model configuration of the UK Met Office Unified Model. Having firstly validated the parameterised temperature fluctuations, the scientists showed that passing the parameterised mountain wave cooling to the PSC scheme of the chemistry-climate model caused around 20% more PSCs over the Antarctic Peninsula at 21 km compared to a control simulation.

4. DISSEMINATION OF RESULTS

4.1. Data reporting

The ozone monitoring data from Lerwick and Reading are processed daily by local operators prior to being quality checked and disseminated. A number of checks are performed to ensure the integrity of these data, including comparison of daily results with the Ozone Monitoring Instrument (OMI) satellite measurements and the nearest ground-based measurements.

Results are disseminated by uploading to a dedicated website (http://uk-air.defra.gov.uk/research/ozone-uv) and issuing results to the WOUDC Real-time Mapping Centre. Monthly data are submitted to the WOUDC for inclusion on their archive.

Both total ozone and multi-filter UV data from the Manchester site are submitted regularly to the WOUDC.

Level 0 and Level 1 ozone data from Halley are submitted to the WOUDC by the BAS. Observations are reported in real-time using CREX (Character form for the Representation and EXchange of data) on the Global Telecommunications System (GTS) from Halley, Rothera and Vernadsky. Quality controlled ozone observations are submitted by BAS to the WMO on a weekly basis.
4.2. Information to the public

Ozone monitoring results from the Lerwick, Reading and Camborne sites are publically available on the Defra UK-AIR website, along with relevant reports (http://uk-air.defra.gov.uk/research/ozone-uv/). Broadband UV Index graphs produced by Public Health England are currently not displayed to the public, however Defra are working with PHE to integrate this data onto the Defra website. Public health messages continue to be issued in collaboration with Defra and the UK Met Office at times of higher than expected levels of UV Index.

5. PROJECTS AND COLLABORATION

The UK Met Office

The UK Met Office has previously applied its ozone data assimilation scheme to infer chemical polar ozone loss and to examine phenomena such as low ozone events in the southern summer stratosphere. Studies on the impact of the representation of stratospheric ozone on extended range tropospheric forecasts were also carried out in collaboration with Imperial College London and European partners. A Met Office representative co-leads the World Climate Research Programme Stratospheric Processes and their Role in Climate WCRP SPARC Data Assimilation Working Group.

The UK Met Office Hadley Centre (MOHC) is working on the modelling of stratospheric and tropospheric ozone and their relationship to long- and near-term climate change, as part of its joint DECC/Defra funded MOHC Programme and the EU FP7 StratoClim project. The MOHC is participating in the WCRP’s SPARC Chemistry-Climate Modelling Initiative (CCMI) activity which coordinates the multi-model evaluation of models and projections of stratospheric ozone recovery and its interaction with climate-change.

The MOHC has further developed its whole-atmosphere chemistry and aerosol model, United Kingdom Chemistry and Aerosols (UKCA), in collaboration with the Universities of Cambridge, Leeds and Oxford. These developments represent a significant step change in modelling capability since the 5th assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). In particular, UKCA models gas-phase chemistry and aerosols in both the troposphere and stratosphere, and photolysis rates are calculated interactively and respond to changes in aerosols and ozone column. These improvements ensure that responses to climate change are well modelled and that the role of ozone and aerosols in climate change can be more accurately assessed. This configuration of UKCA, along with the land surface component Joint UK Land Environment Simulator (JULES), will form an important and underpinning component of the joint NERC/Met Office next-generation Earth System Model, UKESM1.

The Natural Environment research Council

The UK Natural Environment Research Council (NERC) supports national capability and funds a number of research programmes relating to stratospheric ozone:

The CLEARFOGG (Checking Layers of the Earth’s Atmosphere For halogenated Ozone-depleting and Greenhouse Gases) project, completed in 2011, performed a systematic screening of various layers in the Earth’s atmosphere for unknown halocarbons, and determined the influence of these halocarbons on stratospheric ozone depletion.

The Southern hemisphere climate change in an era of ozone recovery project, completed in 2011, used state of the art climate modelling to derive a range of predictions of future climate change which take account of our uncertainty in future ozone change, particularly focussing on the southern hemisphere and the Antarctic ozone hole.

The SOLCLI consortium ran a 4-year coordinated study from 2007 to 2011, on the influences of solar variability on atmospheric composition and climate. The consortium was led by Imperial College, with partners at the Universities of Cambridge, Leeds and Reading and the BAS and with collaborators in Germany, Japan, the USA and the UK Met Office. Study topics included: variability over the past 150 years in solar spectral irradiance; detection of solar signals throughout the lower and middle atmosphere; response of stratospheric composition, specifically ozone, to varying UV;
mechanisms for stratosphere-troposphere dynamical coupling; and better representation of solar effects in climate models.

The NERC-funded Co-ordinated Airborne Studies in the Tropics (CAST) project (2012-2016) will study the Tropical Tropopause Layer (TTL) over the Pacific Ocean and South East Asia. The TTL is a crucial region for chemistry/climate interactions and is the main route by which very short-lived halogen species, which represent a large uncertainty in future stratospheric ozone evolution, enter the stratosphere. CAST aims to improve knowledge of the budgets of these gases and of their chemical transformation and transport through the TTL, including the role of convective transport into the TTL and the subsequent routes for transport from the TTL to the lower stratosphere. Improving representation of these processes in global chemistry/climate models is a key aim.

Further NERC-funded research projects relating to stratospheric ozone include: the impact of the representation of ozone on tropospheric weather forecasts; multi-scale modelling of mesospheric metals, and the impact of the mesosphere on stratospheric ozone and climate; interactions of the lower stratosphere with the tropospheric chemistry/climate system (including recovery scenarios for stratospheric ozone); producing a century-long record of trace gases in the northern hemisphere from the North Greenland EEMian ice core drilling project in Greenland; and determining the impact of energetic electrons on polar stratospheric ozone.

The University of Manchester
The University of Manchester is represented on the WMO Brewer sub-committee, and has been active in discussions and final decisions on the effective changeover of ozone absorption coefficients Absorption Cross Sections of Ozone (ACSO) committee, and the need for a reliable historical dataset on ozone profiles (SPARC/IGACO/IO3C/NDACC), required for trend analysis in the presence of climate and circulation changes. In 2012, John Rimmer made a successful bid for funds from the European COST Office to bring all the European Brewer Ozone Spectrophotometer stations together in a formal network. COST Action ES1207 was launched in April 2013 (http://www.eubrewnet.org/cost1207/).

The University of Cambridge
In accordance with Decision XXIII-13 of the Montreal Protocol on Substances that Deplete the Ozone Layer, an assessment of the state of understanding on the science of the ozone layer will be prepared by the Scientific Assessment Panel (SAP) and will be considered by the Parties in 2015. The University of Cambridge provides one of the four international co-chairs for the SAP.

6. FUTURE PLANS
Defra does not have any plans at present to provide direct government funding for any additional ozone, UV or ozone depleting substances (ODS) monitoring sites in the UK. Defra is keeping future research needs for policy development on stratospheric ozone under review.

NERC continues to support BAS and NCAS national capability to monitor ozone and model chemistry and climate. Funding support for new research projects on ozone will be considered through usual processes.

7. NEEDS AND RECOMMENDATIONS
International agreement needs to be reached on the form of zenith polynomial for use in Dobson zenith sky measurements.

COST Action ES1207 aims to provide harmonisation and consistency across Brewer monitoring stations throughout Europe and near neighbours. Other international agencies (NOAA, IOS, WMO, ESA) are also collaborating. This will bring uniformity to calibration and characterisation protocols, data reduction algorithms and a unified quality assurance scheme including near real time data.
Data end users and stakeholders (ozone, UV and aerosol optical depth (AOD) are encouraged to contact the Chair (John Rimmer, University of Manchester) to discuss interaction.

Maintenance of long time-series remains essential, especially for trend analysis and ground truthing of satellite data.

Further work to model emissions of trace gases and ODS will be beneficial for assessing emissions inventories.
United States of America

Observational Activities

Column Measurements

Ozone

US Satellites
Long-term dataset of total column ozone continues to be produced from the SBUV/2 instruments on the NOAA polar orbiting environmental satellites (NOAA-16, 17, 18 & 19). The SBUV record extends back to April, 1970 with a data gap between 1974 and 1978. The TOMS total ozone series started in October 1978 and ended in December 2006. All TOMS data have been reprocessed by applying an empirical correction based on the SBUV/2 record. Hence the SBUV total ozone record is considered the primary record for trend analysis. (NASA, NOAA)

Total ozone data from the Ozone Monitoring Instrument (OMI) on the EOS Aura satellite is available beginning October, 2004. Two independent algorithms are used to produce OMI total ozone data, one developed by NASA the other by KNMI, NL. NASA now has reprocessed SBUV, TOMS and OMI data using a common (version 9) algorithm. Total Ozone is now also available from the two nadir instruments within the Ozone Mapping and Profiler Suite (OMPS) on the Suomi NPP satellite. These data are available since April 2013. The two OMPS nadir instruments are very similar to those on SBUV and TOMS. (NASA)

Ozone Estimates from Infrared Sensors
NOAA produces estimates of total ozone by using information in the 9.7 micron channel of HIRS. The retrieval products are combined with SBUV/2 information to generate global maps of column ozone. See http://www.osdpd.noaa.gov/PSB/OZONE/TOAST/. (NOAA)

Total ozone products from thermal emission spectrometers also exist from both the TES instrument on the EOS Aura satellite and the AIRS instrument on the EOS Aqua satellite. These data are available on the NASA GSFC DAAC at http://disc.gsfc.nasa.gov/. (NASA)

Dobson Network
Dobson total column ozone measurements in the U.S. are done through the NOAA Cooperative Network at 15 locations, including 6 continental U.S. sites and 5 sites in other US territories or states (Hawaii, Alaska(2), Samoa, and South Pole. Four other sites are collaborative international programmes (Perth, Lauder, OHP (France), and Peru). Data are used for satellite validation and determining ozone trends for the WMO/UNEP Ozone Assessments. NASA also supports Dobson measurements within the U.S. under the auspices of the Network for the Detection of Atmospheric Composition Change (NDACC). (NOAA, NASA)

UVB Monitoring and Research Programme (UVMRP)
Direct-sun column ozone is retrieved by UV Multi-Filter Rotating Shadowband Radiometers (UV-MFRSRs) at 34 U.S. sites, 2 Canadian sites, and 1 New Zealand site within the U. S. Department of Agriculture (USDA) UV-B Monitoring and Research Programme (UVMRP).

NOAA-EPA Ultraviolet-ozone Brewer (NEUBrew) Network
NOAA and the EPA have established a network of Brewer Mark IV UV spectrometers that were deployed at six U.S. locations. The six stations have been operating continuously since the fall of 2006 with instruments and initial funding from the EPA and operating funding from NOAA since then. The network Brewers http://esrl.noaa.gov/gmd/grad/neubrew/ are currently focused on taking
spectral UV irradiance measurements in the 286-363 nm wavelength range 5 times per daylight hour and total column ozone measurements 2-3 times per hour of daylight. Absolute spectral UV irradiance, instantaneous UV index, and daily erythemal dose time series are available online with a latency of one day. (NOAA)

The total ozone column and Umkehr profile daily data from the NOAA Dobson network, as well as ozone-sounding profiles will be used in the validation activities of the total column and profile ozone data collected by the Suomi NPP OMPS satellite and the following Joint Polar Satellite System JPSS program. (NOAA)

**Ozone-Relevant Gases and Variables**

*Ozone Monitoring Instrument (OMI) on the Aura Satellite*

In addition to its primary focus on column ozone, OMI measures tropospheric columns of aerosols, nitrogen dioxide, and sulphur dioxide. (NASA)

*Network for the Detection of Atmospheric Composition Change (NDACC)*

This international ground-based remote-sensing network was formed to provide a consistent, standardized set of long-term measurements of atmospheric trace gases, particles, and physical parameters via a suite of globally distributed sites. While the NDACC maintains its original commitment to monitoring changes in the stratosphere, with an emphasis on the long-term evolution of the ozone layer its priorities have broadened considerably to encompass the detection of trends in overall atmospheric composition and understanding their impacts on the stratosphere and troposphere, establishing links between climate change and atmospheric composition, calibrating and validating space-based measurements of the atmosphere, supporting process-focused scientific field campaigns, and testing and improving theoretical models of the atmosphere. NDACC instruments that are particularly suited for column measurements include UV/Visible spectrometers for ozone, NO2, BrO, and OCIO; FTIR spectrometers for a wide variety of source and reservoir compounds; and Dobson and Brewer spectrometers for ozone. Additional information on the NDACC is available at http://www.ndacc.org. (NASA, NOAA)

**Profile Measurements**

*Ozone*

*BUV Instrument Series (10 Instruments)*

The SBUV/2 instruments on NOAA satellites continue to measure ozone vertical profiles in the upper stratosphere (1-30 hPa) with vertical resolution varying from 6 to 8 km. (This technique also provides accurate estimates of the partial column ozone between 30-700 hPa.) This data record extends back to April 1970, with a data gap between 1974 and 1978. Profile datasets are also being produced from the OMI instrument. OMI provides full daily coverage compared to SBUV which provides daily coverage in approximately two weeks. OMI profiles have similar information content as SBUV in the upper stratosphere (1-30hPa) but have higher vertical resolution (~10 km) at lower altitudes. The long-term ozone profile record from the SBUV/2 instrument series has been significantly affected by drifting orbits. Analysis of these effects is currently in progress. NASA has reprocessed data from the entire BUV instrument series, including OMI, using a consistent algorithm (version 9). Current and archived Version 8 ozone profile data are being used in the NOAA/NCEP Climate Forecast System Reanalysis and Reforecast, a successor of the NCEP/DOE Reanalysis 2. (NOAA, NASA)
**Stratospheric Aerosol Measurement (SAM) and Stratospheric Aerosol and Gas Experiment (SAGE) Instrument Series (4 Instruments)**

The SAM/SAGE series of instruments has provided the longest data set on the vertical profile of ozone in the stratosphere. Near-global coverage has been provided on a near-monthly basis for the periods 1979 to 1981 and 1984 to 2005. This series will be resumed in 2015 from the existing SAGE-III instrument when it is deployed on the International Space Station. (NASA)

**OMPS Limb Measurements**

The OMPS Limb instrument within the OMPS suite has been producing vertically resolved ozone and aerosol concentrations since April 2013. These observations will also be a part of the JPSS-2 satellite to be launched in 5-6 years. (NASA, NOAA)

**Aura Satellite Instruments**

Ozone profiles from 0.5- 200 hPa with about 3 km vertical resolution have been produced by the Microwave Limb Sounder (MLS). The high resolution dynamic limb sounder (HIRDLS), which suffers from a partial obscuration of the field of view that occurred during launch, has recently reprocessed the ozone profile data. These data have 1 km or higher vertical resolution in the stratosphere. This data series ended in 2008. Two other instruments on Aura Tropospheric Emission Spectrometer (TES) and OMI produce lower vertical resolution ozone profiles but they measure lower into the troposphere than either HIRDLS or MLS. A new activity to combine the radiances from TES and OMI to obtain better profile information in the troposphere is ongoing. (NASA)

**Balloonborne Measurements**

NOAA routinely conducts ozonesonde measurements at nine locations (5 domestic, 4 international). NASA, in collaboration with NOAA and numerous international partners, supports the operations of the Southern Hemisphere Additional Ozonesonde (SHADOZ) network of ozonesonde launches from several locations in the tropics and southern subtropics. NASA also flies ozonesondes and an ozone photometer as components of moderate-scale balloon campaigns that also utilize a submillimeter/millimeter-wave radiometer, an infrared spectrometer, and a far-infrared spectrometer. (NOAA, NASA)

**Dobson Umkehr**

Profiles are obtained from six automated Dobson instruments using the Umkehr technique (Lauder, Perth, Hawaii, Boulder, OHP, Fairbanks). Through collaboration between NASA and NOAA, a new ozone-profile algorithm was developed to process Dobson Umkehr data. This algorithm is similar to the SBUV V8 algorithm, and has been optimized for deriving trends. The algorithm is made available to the WMO ozone and UV Data (WOUVD) centers for routine Umkehr data processing, which is expected to be applied to data going back to 1992 in the near future. (NOAA, NASA)

**Brewer Umkehr**

Total column ozone and ozone profiles using the Umkehr technique are regularly derived from the Brewer spectrometer around sunrise and sunset. All raw and processed data are posted on the open access NOAA/NEUBrew web-site: [http://esrl.noaa.gov/gmd/grad/neubrew/](http://esrl.noaa.gov/gmd/grad/neubrew/). The Dobson Umkehr ozone profile retrieval algorithm has been modified to process Brewer Umkehr data on a selective basis. It is implemented at all NOAA operated sites. NOAA collaborates with the European BREWer NETwork (EUBREWNET) network through partnership and shares its expertise in data network operations and data processing. The Brewer Umkehr algorithm has been introduced to a large group of Brewer operators at the recent COST Action ES1207 EUBREWNET open Congress, Santa Cruz de Tenerife, Spain- 24th – 28th March 2014. [http://www.eubrewnet.org/cost1207/](http://www.eubrewnet.org/cost1207/) (NOAA)
Network for the Detection of Atmospheric Composition Change (NDACC)

NDACC lidars (whose retrievals are limited primarily to the stratosphere) and microwave radiometers (whose retrievals are limited primarily to the stratosphere) are providing long-term ozone profile measurements. Ozonesondes routinely launched at many NDACC stations also provide ozone-profile data. In addition, several of the high-resolution FTIR spectrometers are beginning to yield ozone-profile information. (NASA, NOAA)

Brewer Umkehr

NOAA-EPA Brewer Spectrophotometer UV and Ozone Network

The NOAA/EPA Brewer Spectrophotometer Network (NEUBrew) consists of six stations located in the western, central and eastern United States. Brewer MKIV instruments provide twice daily ozone vertical profiles based on Umkehr scans. Data is available online with a latency of one day. http://esrl.noaa.gov/gmd/grad/neubrew/ (EPA, NOAA)

Ozone-Relevant Gases and Variables

Stratospheric Aerosol Measurement (SAM) and Stratospheric Aerosol and Gas Experiment (SAGE) Instrument Series (4 Instruments)

The SAM/SAGE series of instruments has provided the longest data set on the vertical profile of aerosols in the stratosphere. Near-global coverage has been provided on a near-monthly basis for the periods 1979 to 1981 and 1984 to 2005. Water vapor profiles are also available. This series will be resumed in 2015 from the existing SAGE-III instrument when it is deployed on the International Space Station. (NASA)

Aura Satellite Instruments

The four Aura instruments provide profile measurements of numerous atmospheric constituents and parameters in the stratosphere and troposphere. MLS is delivering profiles of temperature, H2O, ClO, BrO, HCl, OH, HO2, HNO3, HCN, N2O, and CO. HIRDLS retrieved profiles of temperature, O3, HNO3, aerosols, CFC11, and CFC12 at 1.2 km vertical resolution and will soon deliver profiles of H2O, CH4, N2O, and NO2. TES provides limited profile information for O3, CO, H2O, and HDO from its nadir viewing owing to it’s high spectral resolution. (NASA)

Combined NASA Satellite Data

Past global space-based measurements of atmospheric composition (e.g., from SAGE, SBUV, UARS, and TOMS) are being extended via observations available from the Aura satellite and other A-Train satellites. These new measurements are providing an unprecedented global characterization of atmospheric composition and climate parameters. Merged data sets connecting these recent measurements to past satellite observations of the atmosphere now exist. (NASA)

Balloonborne Water Vapor Measurements

NOAA monitors upper tropospheric and stratospheric water vapor using cryogenic, chilled-mirror hygrometers that are flown with ozonesondes on a biweekly schedule in Boulder, CO, and at Lauder, New Zealand, in collaboration with NIWA, and monthly at Hilo, Hawaii starting in 2010. Water-vapor profiles also are obtained on a campaign basis in Indonesia and the Galapagos Islands. NASA supports the flights of several balloon instruments (primarily on a campaign basis) capable of providing profile information for numerous atmospheric constituents. (NOAA, NASA)

Airborne Measurements

NASA-sponsored airborne campaigns, using both medium- and high-altitude aircraft, have been conducted with NOAA, NSF, and university partnerships, with a focus on satellite validation and scientific study of ozone and climate change. While designed more for process study than for trend determinations, the airborne measurements have provided a unique view of changes in atmospheric composition at various altitudes in response to halogen source gas forcings. The most recent
campaigns are the SEAC4RS mission using the new NASA ER-2 and DC8 and the ATTREX campaign using the NASA Global Hawk. These missions have concentrated on the processes that control the concentrations source gases in the upper troposphere and stratosphere with a goal of understanding the effects on stratospheric ozone. The NSF CONTRAST campaign with components from many US universities was executed in coordination with the ATTREX aircraft and an aircraft funded by the UK NERC in order to understand the source regions that affected the altitudes where the Global Hawk was flying. (NASA, NOAA, NSF)

For the past decade NOAA has supported an additional ongoing program to regularly measure vertical profiles of ozone-depleting substances and substitute gases (especially HFCs) from light aircraft at a suite of approximately 20 sites across North America and above Rarotonga. The program began in 2004 and involves sampling up to 12 flasks at altitudes ranging from ~100 m above ground to ≤ 8 km above sea level. The data from this program is used to provide measurement-based quantification of U.S. emissions for ozone-depleting substances, their substitutes, and long-lived greenhouse gases.

Network for the Detection of Atmospheric Composition Change (NDACC)
Several of the NDACC remote sensing instruments provide profile data for a variety of ozone- and climate-relevant gases and variables. These observations continue the long term trends for ozone, water vapor, CFCs, HCl, HF, CH₄, and N₂O. (NASA, NOAA, DoD/NRL)

Ground-Based In Situ Measurement Networks
Both NASA and NOAA support in situ sampling of ozone- and climate-related trace gases via networks of flask sampling and real time in situ measurements at sites distributed across the globe. These data provide the basis for determining global tropospheric trends and emissions of these gases, and for computing effective equivalent chlorine (EECl) in the lower atmosphere. The NASA Advanced Global Atmospheric Gases Experiment (AGAGE) network has the longest continuous observational record for such species, extending back more than three decades for some CFCs, methyl chloroform, and carbon tetrachloride. New NASA and NOAA instrumentation permits the monitoring of many of the CFC replacements, thereby enabling a tracking of such chemicals from their first appearance in the atmosphere. Measurement and standards intercomparisons between the AGAGE and NOAA networks and with other international collaborators are leading to an improved long-term database for many ozone- and climate-related gases. (NOAA, NASA)

Both the ongoing NASA- and NOAA-based programs have been augmented over time to enable estimates of emission magnitudes on regional scales. The AGAGE effort relies on high-frequency measurements to provide information in surrounding regions, while the NOAA effort (regular aircraft profiling mentioned above, plus, since 2007, daily flask sampling at 10 tower locations) is focused on providing measurement-based emission magnitudes for the United States.

UV Irradiance

Broadband Measurements
SURFRAD Network
Seven Surface Radiation (SURFRAD) sites operate Yankee Environmental Systems, Inc. (YES) UVB-1 broadband radiometers. The ISIS network of solar measurements includes broadband Solar Light 501 UVB biometers at each of seven sites. Other instrumentation (located at the Table Mountain test facility near Boulder, Colorado) includes a triad of calibration-reference YES UVB-1 broadband radiometers, and five calibration reference Solar Light 501 UVB biometers. A Solar Light 501 UVA biometer is also operated at the site. (NOAA)
NOAA Network
Supplemental measurements of UV-B using YES UVB-1 instruments continue at Boulder, Colorado and Mauna Loa, Hawaii, where high-resolution UV spectroradiometers also are operated and can be used to interpret accurately the broadband measurements. (NOAA)

NEUBrew network
Each NEUBrew station has a Yankee UVB-1 broadband radiometer collocated with the Brewer spectroradiometer. The UVB-1 provides measurements of Erythemal daily dose. The NEUBrew Mountain Research Station also includes a broadband Yankee UV-A instrument. (EPA, NOAA)

USDA UV-B Monitoring and Research Programme (UVMRP)
Broadband UVB measurements (erythemally-weighted) are made at each of the 37 USDA/CSU sites. (USDA, CSU)

Narrowband Filter Measurements
Central Ultraviolet Calibration Facility
A Smithsonian 18-channel UV narrow-band radiometer currently operates at the Table Mountain test facility in Colorado. (Smithsonian Institution)

USDA UVB Monitoring and Research Programme (UVMRP)
UV-MFRSRs deployed within this 37 station network measure total and diffuse horizontal and direct normal irradiance at nominal 300, 305, 311, 317, 325, 332, and 368 nm with a 2.0 nm bandpass. In addition, vis-MFRSRs are deployed with nominal 415, 500, 610, 665, 862 and 940 nm wavelengths with 10.0 nm bandpass. These 13 measurements are used to create a continuous synthetic spectra model which can then be convolved with specific weighting functions to meet researcher’s needs. Access to the synthetic spectra is found on the UVMRP web site at: [http://uvb.nrel.colostate.edu/UVB/uvb_dataaccess.jsf](http://uvb.nrel.colostate.edu/UVB/uvb_dataaccess.jsf). Direct-sun column ozone is retrieved using the UV Multi-Filter Rotating Shadowband Radiometers (USDA, CSU)

NEUBrew Network
Five NEUBrew stations have a Yankee UV-MFRSR and all stations have a visible MFRSRs collocated with the Brewer spectrophotometer. (NOAA)

NOAA Antarctic UV Monitoring Network
NOAA/GMD has assumed operations of the Antarctic portion of the former NSF UV Monitoring Network. There are Biospherical Instruments (BSI) GUV-511 10-nm bandwidth multi-channel radiometers deployed at two of the Antarctic stations, McMurdo and Palmer; and a GUV-541 radiometer deployed at the South Pole. (NOAA)

Spectroradiometer Measurements
Central Ultraviolet Calibration Facility
A high-precision UV spectroradiometer and a UV spectrograph are located at the Table Mountain Test Facility in Colorado under the auspices of this programme. The UV spectrograph was removed from operation in August 2009 due to equipment failure. (NOAA)

Network for the Detection of Atmospheric Composition Change (NDACC)
State-of-the-art, high-resolution spectroradiometric UV observations are conducted as a part of the NDACC at several primary and complementary sites. In particular, U.S. collaboration with NIWA (New Zealand) enables such measurements at Mauna Loa, HI and Boulder, CO. The measurements at Mauna Loa were started in 1995, those in Boulder began in 1998, and they continue to the present. (NOAA)
NSF (AON Grant to the University of Chicago) UV Monitoring Network

BSI SUV-100 high-resolution scanning spectroradiometers are deployed at; San Diego, California; (sub-tropical location) and Barrow, Alaska; A BSI SUV-150B spectroradiometer is deployed at the Summit, Greenland. (NSF)

NOAA Antarctic UV Monitoring Network

NOAA has assumed operations of the NSF UV Antarctic Network. BSI SUV-100 scanning spectroradiometers are deployed at the three Antarctic stations, McMurdo, Palmer, and South Pole.

UV-Net Programme

Brewer Mark IV spectrometers that measure the spectrum between 286 and 363 nm were deployed at all 21 network sites located in 14 U.S. national parks and 7 urban areas around the U.S. This network ceased operation in 2004 and all 21 Brewers were removed from their network sites. (EPA)

NEUBrew Network

The NOAA/EPA Brewer Spectrophotometer Network (NEUBrew) consists of six stations located in the western, central and eastern United States. Brewer MKIV instruments provide UV irradiance over the range 286.5 nm to 363 nm with 0.5 nm resolution up to 20 times per day. Absolute spectral UV irradiance, instantaneous UV index, and daily erythemal dose time series are available online with a latency of one day. http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA, EPA)

Satellite-based Estimation

Surface UV radiation can be estimated using satellite-measured total column ozone and top-of-the-atmosphere radiance at a non-ozone absorbing UV wavelength as input to a radiative transfer code. Such methods have been applied to estimate both the spectral irradiance as well as UVB from the TOMS instrument series. Similar data are being produced by the Finnish Meteorological Institute (FMI) using OMI data. Since the cloud effects vary at very short spatial and temporal scales, the satellite derived UVB data are most useful for making estimates of monthly average UVB and spectral irradiance at ~100 km grid scales. An outstanding problem in the estimation of UVB from satellites is the strong UV absorption of most aerosols, most notably dust and secondary organics. An aerosol absorption correction is applied to the TOMS UVB record (but not to the OMI record) using TOMS-derived aerosol index (AI). Though AI can correct for elevated plumes of dust and smoke, it is not sensitive to aerosols near the surface. As a result the satellites can overestimate UVB by up to 30% in polluted areas. However, this error is largely localized to urban areas and shouldn’t significantly affect regional averages. (NASA)

Calibration Activities

Satellite BUV instruments

The UV instruments have very high susceptibility to degradation in the space environment with unpredictable variability from one instrument to another. In addition, some instruments have had non-linear detector response as well as hysteresis and spectral stray light problems. The EP/TOMS instrument developed a complex cross-track dependent response after several years. NASA has for several decades supported the calibration of NOAA SBUV/2 instruments both before and after launch. The post launch activities include both hard calibration (by monitoring on-board calibration data and the solar irradiance), as well as soft calibration. Soft calibration techniques include analysis of spectral and spatial patterns in measured radiances to separate geophysical effects from instrumental effects. NASA flew the SSBUV instrument 8 times on the Space Shuttle to provide calibration of NOAA SBUV/2 instruments. Other satellite instruments such as SAGE, and currently the MLS instrument on Aura, are also providing useful calibration information. However, ground-based data have not been used for satellite calibration, except for the BUV instrument that operated on the Nimbus-4 satellite from 1970 to 1974. However, NASA uses Dobson/Brewer ozone
network and ozone soundings to verify SBUV/2 and TOMS data after applying soft and hard calibrations. (NOAA)

**Dobson Network**
World Standard Dobson No. 83 is maintained at NOAA/ESRLGMD as part of the World Dobson Calibration Facility, and regularly participates in international intercomparisons of regional and national standards. Since 2006, intercomparisons have been held in Melbourne, Australia; Tsukuba, Japan; Buenos Aires, Argentina (twice) and Irene, South Africa. Investigations into the correct characterization of the Dobson instruments are continuing. (NOAA). NOAA conducts calibration verification of the Dobson 83 instrument by conducting campaigns every two years at the Mauna Loa site.

**Ozone Soundings**
NOAA prepares ozonesonde instruments and follows pre-flight checks according to WMO standard operating procedures. It participates in international intercomparisons of ozone sonde measurements (chamber tests) and develops methods to resolve instrument related differences. It is done to homogenize time series of balloon measurements at each NOAA site. WMO Global Atmospheric Watch sponsors the ozonesonde calibrations where various international groups are invited to the World Calibration Centre for Ozone Sondes, Research Centre Juelich Institute for Chemistry and Dynamics of the Geosphere: Troposphere. These chamber calibration tests were held in 1996 and 2000. The last calibration campaign was a field (balloon) project at Laramie Wyoming called BESOS in 2004: [http://croc.gsfc.nasa.gov/besos/](http://croc.gsfc.nasa.gov/besos/) (NASA, NOAA)

**Network for the Detection of Atmospheric Composition Change (NDACC)**
Several operational protocols have been developed to insure that NDACC data is of the highest long-term quality as possible within the constraints of measurement technology and retrieval theory at the time the data are taken and analyzed. Validation is a continuing process through which instruments and their associated data analysis methods must be validated before they are accepted in the NDACC and must be continuously monitored throughout their use. Several mobile intercomparators within the various NDACC instrument types exist to assist in such validation. (NASA, NOAA)

**Ground-Based In Situ Measurement Networks**
Both the NOAA and NASA/AGAGE networks independently develop and maintain highly accurate and precise calibration scales at ppt and ppb levels for the major and minor long-lived ozone-depleting gases and substitutes gases including hydrofluorocarbons (HFCs). In addition, both networks are developing reliable calibration scales for the shorter-lived halogen-containing gases (hydrochlorofluorocarbons or HCFCs) that have been introduced as CFC replacements. (NOAA, NASA)

**Central Ultraviolet Calibration Facility**
The Central Ultraviolet Calibration Facility (CUCF) is located in NOAA’s David Skaggs Research Center in Boulder, Colorado. The CUCF calibrates UV instruments for several U.S. Government agencies and other UV research concerns, both national and international. The CUCF also measured spectral response and angular response (critical for direct beam retrieval) for broadband and narrowband instruments. In addition to laboratory calibrations, the CUCF has developed a portable UV field calibration system that allows laboratory-grade calibrations to be made at spectroradiometer field sites. The CUCF also produces secondary standards of spectral irradiance that are directly traceable to NIST primary transfer standards. The secondary standards can be calibrated for operation in either the vertical or horizontal orientation. (NOAA)
USDA UVB Monitoring and Research Programme (UVMRP)
NOAA CUCF lamp calibrations performed in horizontal and vertical position using NIST traceable 1000-W halogen lamps are used to calibrate 51 USDA UV-MFRSRs and 52 UVB-1 broadbands. A U-1000 1.0-m double Jobin Yvon with 0.1-nm resolution and $10^{-10}$ out-of-band rejection is used as a reference spectroradiometer to transfer lamp calibration to a broadband triad. The UV-MFRSR radiometer spectral response and its angular response (critical for direct beam retrieval) are measured. The Langley calibration method is employed to provide additional absolute calibration of UV-MFRSRs and to track radiometric stability in situ. (USDA)

NEUBrew network
The NOAA/EPA Brewer spectrophotometer network (NEUBrew) consists of six stations located in the western, central, and eastern United States. Each Brewer Mark IV spectrophotometer is calibrated for absolute spectral UV irradiance at least one per calendar year. (EPA, NOAA) All six of the network Brewers were originally calibrated by International Ozone Services by comparing to the WMO Brewer transfer standard #017. Brewer 017 is directly traceable to the WMO Brewer Ozone Triad located at Environment Canada in Toronto, Ontario, Canada. Two methods of tracking any drift from those original calibrations are employed by NEUBrew. The first is to adjust the extra-terrestrial constant (ETC) calibration constant by using the internally generated R6 value and the second is by performing Langley regressions on the ozone data to derive the ETC. (EPA, NOAA)

RESULTS FROM OBSERVATIONS AND ANALYSIS

Ozone

Merged Satellite Datasets
Since there are often biases between different satellite instruments it is necessary to create consistent long-term data sets by cross-calibration of different records when they overlap and by using ground-based data (including NOAA ground based networks) when they do not. Such data sets have been produced using TOMS and SBUV total column ozone and profile records. Several new efforts to provide long term merged data sets of ozone columns and stratospheric profiles of ozone and other trace gases are ongoing. Many of these activities are part of the SI2N intercomparison efforts. (NASA, NOAA)

Ozone Depletion & Recovery
Statistical analysis of the Umkehr ground based data, FTIR and merged SBUV profile ozone data set from 1979 to June 1997 shows the largest negative trends in the upper stratosphere (35-45 km) at middle latitudes at -10 % per decade at both Southern and Northern Hemispheres. The middle stratosphere (20-25 km) trends are derived from ozonesonde, satellite and FTIR records indicate -7 % per decade decline at both Southern and Northern middle latitudes and less negative trends are found at lower stratosphere (12-15 km) at -9% per decade in the Northern Hemisphere (no information for Southern hemisphere)These trends are in general agreement with previous profile trend estimates from satellite and ground-based records. Since 1997, ozone between 12 and 15 km (lower stratosphere) in the Northern middle latitudes has increased at a larger rate that is expected based on the decline in the ODS abundances. The middle and upper stratospheric ozone has been increasing at some locations at the Northern middle latitudes since 1997, but it is not observed globally. Ground-based and satellite ozone measurements taken at the upper stratosphere since 1997 also indicate positive trends that are consistent with leveling off of the ODS concentrations. However, the derived trends are not always statistically significant, since the natural ozone variability, stratospheric cooling and measurement uncertainties make analyses less certain.
**Antarctic Ozone Hole**

Since approximately 1997, the underlying trend of Antarctic ozone (i.e., the trend after removal of the effect of natural variability in vortex temperatures) has been zero. This cessation of the downward trend in ozone is consistently seen at 60ºS to 70ºS in TOMS total ozone columns, SAGE/HALOE stratospheric columns, ozonesonde ozone columns at Syowa (69ºS), and Dobson total column measurements at 65ºS and 69ºS. The South Pole September 12-20 km ozone loss rate for 2012 and 2013 has remained within the 1992-2011 average linear decline of 3.4 ± 0.03 Dobson Units per day (NOAA).

The cessation of the downward trend is primarily a result of the saturation of the losses, and not due to decreasing levels of stratospheric chlorine. Antarctic ozone depletion is primarily controlled by inorganic chlorine and bromine levels (effective equivalent stratospheric chlorine, EESC), and secondarily controlled by Antarctic stratospheric temperatures and dynamics. Fits of various ozone hole diagnostics to temperature and chlorine and bromine levels suggest that the ozone hole is very slowly improving. However, detection of this slow improvement is masked by the large natural variability of the Antarctic stratosphere. (NASA)

**Ozone Maps**

Daily maps of total ozone and monthly total ozone anomalies are being produced, as well as routine updates of the SBUV-2 total ozone change utilizing a statistical model that includes the 1979 to 1996 trend, the trend-change in 1996, plus ancillary variables of solar variation (f10.7), QBO, and AO/AAO. In addition, twice-yearly (Northern and Southern Hemisphere) winter summaries of selected indicators of stratospheric climate are generated. (NOAA/CPC)

**UV**

**Instrumentation**

NOAA/GRAD and NOAA/NWS/NCEP/CPC in collaboration with Klein Buendel, Inc a health research company developed a prototype for a smart-phone application that utilizes NOAA’s UV forecast. The application is a tool for managing and providing information on sun-burning potential and vitamin D production. The project was funded by the National institute of Health and is ongoing.

**UV Trends**

**SURFRAD Network**

Work by Colorado State University (CSU) UVB researchers continued for analyzing trends in solar UV irradiance at eight stations in the CSU-USDA network stations. Both positive and negative tendencies were detected ranging from −5% to +2% per decade. However, inter-annual variability was between 2 and 5%. (NOAA)

**USDA UVB Monitoring and Research Programme (UVMRP)**

The multidecadal change of ozone is investigated using four UVMRP ground stations, WA01, CO01, MD01, and AZ01. The UV index has increased at the four stations while total ozone has decreased in continental USA. Spatial distribution of ozone shows substantial variation from coastal zones to the Midwest, yet the tendency toward recovery of the ozone layer in the continental USA cannot be fully confirmed.

Scientists analyzing UV-B flux over the continental USA using NASA TOMS data and UVMRP network data found that “ground-based in-situ measurements, like those from the UVMRP network, are indispensible in monitoring atmospheric status and not totally replaceable by space-based
remote sensing retrievals”. The incorporation of these ground-based measurements with current satellite algorithms has improved UV retrievals for the latest satellite package (OMI). (USDA)

**UV Forecasts and Exposure**

**UV Forecasts and Alert System**

NOAA/CPC is producing UV forecasts and has developed a UV Alert system with the EPA. The UV Index forecasts are on a gridded field covering the entire globe. Forecast fields are generated at one hour frequency out to five days. The UV Index forecasts include the effects of Earth-Sun distance, total ozone, solar zenith angle, surface albedo (inclusive of snow/ice), cloud attenuation, and climatological aerosol conditions. The gridded fields are freely available on the NCEP ftp site. The UV Alert system is designed to advise the public when UV levels are unusually high and represent an elevated risk to human health. The UV Alert system consists of a graphical map displaying the daily UV Alert areas, as well as additional information included in the EPA’s UV Index ZIP Code look-up web page and via the EPA’s AIRNow EnviroFlash e-mail notification system. The criteria for a UV Alert are that the noontime UV Index must be at least a 6 and must be 2 standard deviations above the daily climatology. (NOAA/CPC, EPA)

**Effects of UVB Exposure**

A major limitation in predicting the impacts of UVB irradiance on humans, plant leaves and flowers, and aquatic organisms is the difficulty in estimating exposure. An analysis of the spatial variability in the daily exposure to narrowband 300- and 368-nm and broadband 290- to 315-nm (UVB) solar radiation between 12 paired locations in the USDA UV-B Climatological Network over two summer growing seasons has been completed. The spatial correlation of the UVB, 300- and 368- nm daily exposures between locations was approximately 0.7 to 0.8 for spacing distances of 100 km. The 300-nm daily exposure was typically more highly correlated between locations than the 368-nm daily exposure. (USDA)

**THEORY, MODELING, AND OTHER RESEARCH**

**Ozone:**

**Antarctic and Arctic Ozone Loss**

Recent analyses of Arctic and Antarctic ozone loss using observed concentrations of ozone and trace species in the stratosphere, in combination with advanced chemical/transport models show that much of the variability in ozone loss can be well explained by a combination of variations in transport that drive the distribution of ozone and the photochemical loss of ozone. (NASA, NOAA)

**Ozone-Related Gases and Variables**

**Environmental Properties of Atmospheric Gases**

The abundance and atmospheric lifetimes of nitrous oxide (N$_2$O) and carbon tetrachloride (CCl$_4$) are important to understanding stratospheric ozone recovery and climate change as well as the linkage between these issues. Laboratory work has determined updated values for the UV absorption cross sections of these gases and the temperature dependence of these values, for which there are few previous studies. This information has been used in a new international assessment of trace gas lifetimes coordinated by the WCRP’s SPARC program in 2013 with NOAA and NASA contributions (NOAA, NASA). The reduced uncertainties in the N$_2$O and CCl$_4$ absorption cross section data, and in photolysis lifetimes, have improved our understanding of the budgets for these gases and the accuracy of model calculations of ozone recovery. Even with this up-to-date analysis,
however, an imbalance remains in our understanding of CCl₄ sources and sinks that suggests substantial sources of CCl₄ to the atmosphere of unknown origin. (NOAA, NASA)

**Chemistry of Potential ODS Replacements**

Laboratory and theoretical work has provided information about the ozone-layer friendliness and climate friendliness of candidate replacements for ozone-depleting substances used for a variety of societal applications such as refrigeration, air conditioning, electronics manufacture, and fire protections. Early information about the suitability of a proposed substance is needed by industry before costly development investments are made. These results provide important input parameters for model calculations of the future vulnerability of the ozone layer, and are used together with industrial production-and-use information to analyze the growth of such chemicals in the atmosphere. Recent studies have focused reassessing US photolysis of long-lived CFCs, Halons, and greenhouse gases. Model calculations of past and future ozone abundance and its trends rely on accurate measurements of the UV absorption spectra (and temperature dependence) to minimize uncertainty. Laboratory measurements were made to reduce the model input uncertainty for key species to <5%, in some cases. An assessment of the stratospheric ozone and climate impacts of R-316c was conducted. This chemical was found to have a lifetime (75-114 years), ODP (0.46-0.54), and GWPₑ₀₀yr comparable to substances controlled by the Montreal Protocol. Similar studies were conducted for HFC-1234yf (air conditioning fluid), HFC-1233zd(E) and -1233(Z) and it was determined that these chemicals have lifetimes of 11-34 days and relatively low GWPs₁₀₀yr (<5 for HFC-1234yf). Studies of methoxy perfluorinated heptenes have shown substantially different lifetimes for different isomers of these chemicals. (NOAA)

**UV**

**UV Instrumentation**

The temperature dependence of the Brewer UV spectrometer has been studied in order to improve the quality of data for UV trends. (NOAA)

**UV Effects**

The UVMRP supports research studying UVB effects on plants and ecosystems. Numerous publications document the results of these on-going studies, and are listed on the program’s web site at [http://uvb.nrel.colostate.edu/UVB/uvb_pubs.jsf](http://uvb.nrel.colostate.edu/UVB/uvb_pubs.jsf). (USDA)

**UV Model Comparisons**

The UVMRP’s modeling group, “The Center of Remote Sensing and Modeling for Agricultural Sustainability” has published preliminary results of their coupled climate-crop modeling system. Validation and system refinement is underway and has shown promising results. Corn yields for the 16-state USA corn belt over the 27 year span (1979-2005) agree to within +/-10% of the actual yields. This modeling effort is being expanded to evaluate precipitation, temperature and UV effects on the yields, with the ultimate goal of developing a system that will be capable of both achieving credible and quantitative assessments of key stress factors, and evaluating alternative cultural practices for sustainable agriculture production. (USDA)

**DISSEMINATION OF RESULTS**

**Data Reporting**

**Ozone**

Ozone data from 3 Aura instruments (OMI, MLS, and HIRDLS), past TOMS instruments, and the AIRS instrument are routinely distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) at [http://disc.sci.gsfc.nasa.gov/acdisc](http://disc.sci.gsfc.nasa.gov/acdisc). Both level 2 (measured)
data and level 3 (grid averaged) data are distributed in HDF format. OMI level 3 data are distributed in ASCII format via the TOMS web site (http://toms.gsfc.nasa.gov). Ozone data for the TES instrument on Aura can be found on the NASA Langley DAAC at http://cosweb.larc.nasa.gov/. (NASA)

Aura Validation Data Center (AVDC)
Preliminary and near real-time total ozone, ozonesondes, ozone profiles from LIDAR and microwave radiometers are archived from US Government Agencies and investigators worldwide. In addition, the AVDC (http://avdc.gsfc.nasa.gov/) also archives and distributes NASA and NOAA total column, profile and tropospheric satellite data subsets. The collected preliminary ozone data are restricted to participants in Aura validation teams, ESA OMI announcement of opportunity participants, and international validation contributors, while the satellite data is freely available (http://avdc.gsfc.nasa.gov/Data/). (NASA)

Umkehr Dobson Data
Dobson Umkehr data processed using UMK04 algorithm are available from the WOUDC archives. Brewer Umkehr data are available for 6 NEUBrew sites at the web address: http://esrl.noaa.gov/gmd/grad/neubrew/. (NOAA, NASA)

World Ozone and Ultraviolet Radiation Data Center (WOUDC)
Total ozone, Umkehr, and ozonesonde data are reported to the WOUDC from U.S. Government agencies and institutions. Ozone data from sites that are part of the NDACC and the SHADOZ network are available from the programme web sites (http://www.ndacc.org/ and http://croc.gsfc.nasa.gov/shadoz/, respectively), and also are imported to WOUDC. (NOAA, NASA).

NEUBrew Data
UV spectra, total column ozone and Umkehr ozone profile data from the NOAA-EPA network are available at the web site http://esrl.noaa.gov/gmd/grad/neubrew/ (NOAA, EPA)

Maps
All daily SBUV/2 total ozone hemispheric analyses generated from NOAA-16, NOAA-17, and NOAA-18 observations are available on the Climate Prediction Center’s stratospheric web pages at http://www.cpc.ncep.noaa.gov/products/stratosphere/sbuv2to/. The raw data from the SBUV/2 are available from NESDIS. Additionally, the NCEP/GFS total ozone analysis and forecast fields out to five days are available at http://www.cpc.ncep.noaa.gov/products/stratosphere/strat_a_f/. (NOAA/CPC)
Daily maps from the Version 8 total ozone algorithm processing of GOME-2 data are available from NOAA Operations at http://www.osdpd.noaa.gov/PSB/OZONE/gome.html (NOAA/CPC)

Assessments
NASA and NOAA scientists played key roles as reviewers, review editors, and authors for various chapters in the 2014 WMO/UNEP Scientific Assessment of Ozone Depletion, mandated under the provisions of the Montreal Protocol. Other scientists from the U.S. and around the world contributed to the report, which will be given to the Parties to the Montreal Protocol in late 2014 and should be available electronically and in print form (some sections only) and on the UNEP and NOAA websites in early 2015. (NOAA, NASA)

Stratospheric Winter Hemisphere Bulletins
Following each hemisphere’s winter, an assessment of the stratospheric dynamics and chemistry are presented from a NOAA perspective. The southern hemisphere’s winter bulletin focuses upon the ozone hole formation and longevity. Relevant thermal and dynamical attributions are presented.
The northern hemisphere’s winter bulletin will discuss ozone loss conditions and stratospheric warmings. http://www.cpc.ncep.noaa.gov/products/stratosphere/winter_bulletins/ (NOAA/CPC)

**Ozone-Related Gases and Variables**

**Aura Data**
Gas and Aerosol constituent data from Aura instruments (OMI, MLS and HIRDLS) are routinely distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC) at http://disc.sci.gsfc.nasa.gov/acdisc. Both level 2 (measured) data and level 3 (grid averaged) data are distributed in HDF format. OMI level 3 data are distributed in ASCII format via the TOMS web site (http://toms.gsfc.nasa.gov). Data for the TES instrument on Aura can be found on the NASA Langley DAAC at http://eosweb.larc.nasa.gov/ (NASA)

**Ozone-Depleting Substance Data**
Ongoing measurement data for ozone-depleting substances from the NOAA sampling network are updated at least every six months on the website (http://www.esrl.noaa.gov/gmd/) and are submitted annually to the World Data Centre and to the World Data Center for Atmospheric Trace Gases at the Carbon Dioxide Information Analysis Data Center (CDIAC). Data from field missions (e.g., the HIPPO Campaign), are posted shortly after mission completion. (NOAA)

Long-term data from the NASA/AGAGE network are reviewed on a semi-annual basis by the Science Team, and are archived every six months with Carbon Dioxide Information and Analysis Center (CDIAC) <http://cdiac.esd.ornl.gov/>. Data from the UCI flask sampling network are also archived at CDIAC. (NASA)

**UV Data**

**SURFRAD Network Data**
UV data from the SURFRAD Network are available on the NOAA/ESRL/GMD website (http://www.esrl.noaa.gov/gmd/grad/surfrad/index.html). (NOAA)

**NEUBrew Network UV Data**
Spectral UV irradiances are available from the NEUBrew website http://esrl.noaa.gov/gmd/grad/neubrew/ (NOAA)

**NOAA Antarctic UV Data**
Spectral UV irradiances, derivative UV products, and GUV data will be available from NOAA’s Antarctic UV website. http://esrl.noaa.gov/gmd/grad/antuv (NOAA)

**USDA UV-B Monitoring and Research Programme (UVMRP)**
UV, visible and ancillary data from the UVMRP network is available next-day on the UVMRP website (http://uvb.nrel.colostate.edu/UVB/index.jsf).

UVB-1 broadband data and UV-MFRSR data from this network are regularly submitted to the WOUDC. (USDA)

**Information to the Public**

**Ozone**

**TOMS and OMI Data**
Near-real-time ozone data from the OMI instrument on Aura is routinely distributed via the NASA web site (http://toms.gsfc.nasa.gov/). Data are usually available within 48 hours, though faster
access can be arranged. The site provides online access to both TOMS (1978-2006) and OMI (2004-present) data. While used mostly by scientists, educators and students also use the site extensively. An Ozone Hole Watch web site, http://ozonewatch.gsfc.nasa.gov/ provides information for anyone interested in the Antarctic ozone hole. Near real time Ozone profile data from MLS now exist, and are available at http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/MLS/ml2o3_nrt002.shtml. (NASA)

*Merged TOMS/SBUV Total and Profile Ozone Data*
Merged TOMS/SBUV total and profile ozone data sets are available on the Internet (http://hyperion.gsfc.nasa.gov/Data_services/merged/index.html). (NASA)

**UV Forecasts**
Noontime UV forecasts are made available to the public via several formats. One is a text bulletin for 58 cities in the U.S. The other is a map displaying the UV Index forecast at each of the 58 cities’ locations. These can be found at http://www.cpc.ncep.noaa.gov/products/stratosphere/uv_index/. Additionally, gridded fields of the noontime forecast for the U.S. and Alaska are made available via the NOAA/CPC and NOAA/NCEP ftp sites. UV Index forecast gridded fields covering the entire globe at one hour increments out to five days are available on the NCEP ftp site: ftp.ncep.noaa.gov/pub/data/nccf/com/hourly/prod. (NOAA/CPC)

**Advisories**
The primary UVR advisory in the United States is the UV Index, operated jointly by NOAA and EPA. Currently, the UV Index computer model processes total global ozone satellite measurements, a rough cloud correction factor, and elevation to predict daily UV levels on the ground and the resulting danger to human health. This model assumes zero pollution levels. UV Index reports are available in local newspapers and on television weather reports. The EPA also issues a UV Alert when the UV Index is predicted to have a high sun-exposure level and is unusually intense for the time of year. UV Alert notices can be found at EPA's SunWise web site (http://www.epa.gov/sunwise/uvindex.html), in local newspapers, and on television weather reports. (EPA)

**Ozone-Depleting Gas Index**
An ozone-depleting gas index (ODGI), based on Effective Equivalent Stratospheric Chlorine (EESC) derived from global surface measurements of ODSs in the NOAA network, has been implemented. EESC and WMO/UNEP ozone-depleting gas scenarios are used to estimate the progress towards ozone recovery (ODGI = 100 on January 1, 1994 when EESC reached its maximum value and 0 at ‘recovery’ (presumed to be 1980 EESC levels)). The index is updated annually and posted at http://www.esrl.noaa.gov/gmd/odgi. (NOAA)

**Relevant Scientific papers (2011-present):**

*NOAA GMD related publications:*


2012


Nair, P. J, S Godin-Beekmann, A Pazmino, A Hauchecorne, G Anecllet, and L.E FlynnL Froidevaux, (2011), Coherence of long-term stratospheric ozone vertical distribution time series used for the study of ozone recovery at a northern mid-latitude station, Atmospheric Chemistry and Physics, 11, 4957-4975, 10.5194/acp-11-4957-2011


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NASA Aura satellite related publications


Wang, Weihe; Flynn, Lawrence; Zhang, Xingying; et al. (2013) Cross-Calibration of the Total Ozone Unit (TOU) With the Ozone Monitoring Instrument (OMI) and SBUV/2 for Environmental Applications IEEE Trans. Geosci. Rem. Sens. 50 4943-4955 10.1109/TGRS.2012.2210902


Choi S.; Wang Y.; Salawitch R. J.; et al. (2012) Analysis of satellite-derived Arctic tropospheric BrO columns in conjunction with aircraft measurements during ARCTAS and ARCPAC, Atmos. Chem. Phys. 12(3) 1255-1285 10.5194/acp-12-1255-2012


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Ialongo I.; Sofieva V.; Kalakoski N.; et al. (2012) Ozone zonal asymmetry and planetary wave characterization during Antarctic spring, Atmos. Chem. Phys. 12(5) 2603-2614 10.5194/acp-12-2603-2012


Lee, Daegyun; Wang, Jingqian; Jiang, Xun; et al. (2012) Comparison between atmospheric chemistry model and observations utilizing the RAQMS-CMAQ linkage, Atmos. Environ. 61 85-93 10.1016/j.atmosenv.2012.06.083


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Stolarski Richard S.; Douglass Anne R.; Remsberg Ellis E.; et al. (2012) Ozone temperature correlations in the upper stratosphere as a measure of chlorine content, J. Geophys. Res. 117 D10305 10.1029/2012JD017456


Tzortziou, Maria; Herman, Jay R.; Cede, Alexander; et al. (2012) High precision, absolute total column ozone measurements from the Pandora spectrometer system: Comparisons with data from a Brewer double monochromator and Aura OMI, J. Geophys. Res. 117 D16303 10.1029/2012JD017814


de Vries M. Penning; Wagner T. (2011) Modeled and measured effects of clouds on UV Aerosol Indices on a local, regional, and global scale, Atmos. Chem. Phys. 11(24) 12715-12735 10.5194/acp-11-12715-2011


Ern M.; Preusse P.; Gille J. C.; et al. (2011) Implications for atmospheric dynamics derived from global observations of gravity wave momentum flux in stratosphere and mesosphere, J. Geophys. Res. 116 D19107 10.1029/2011JD015821


Li, J. Han, Z. and Zhang, R. (2011) Model study of atmospheric particulates during dust storm period in March 2010 over East Asia, Atmospheric Environment 45(24) 3954-3964 10.1016/j.atmosenv.2011.04.068


Nair, P. J., Godin-Beekmann, S., Pazmino, A., Hauchecorne, A., et al. (2011) Coherence of long-term stratospheric ozone vertical distribution time series used for the study of ozone recovery at a northern mid-latitude station, Atmos. Chem. Phys. 11(10) 4957-4975 10.5194/acp-11-4957-2011


NOAA CSD related references


Baasandorj, M., B.D. Hall, and J.B. Burkholder, 2012, Rate coefficients for the reaction of O(1D) with the atmospherically long-lived greenhouse gases NF3, SF5CF3, CHF3, C2F6, c-C4F8, n-C5F12,


**PROJECTS AND COLLABORATION**

**NOAA**

The Dobson and ozonesonde measurements are included in the WMO Global Atmosphere Watch (GAW) and in the NDACC. Significant collaboration with federal agencies (NASA, DoE) and universities (University of Colorado, Harvard, Princeton, Humboldt State University, etc.) is maintained through both global monitoring and field missions including support for satellite validations. The CUCF is designated by a Memorandum of Understanding to be the national UV calibration facility by agreement among the following organizations: NOAA, USDA, EPA, NASA, National Institute of Standards and Technology (NIST), NSF, National Biological Service, and the Smithsonian Institution. The CUCF compared secondary standards of irradiance with the Joint Research Centre’s European Union UV Calibration Centre’s (ECUV) ultraviolet spectral irradiance scale in Ispra, Italy. The CUCF’s irradiance scale is directly traceable to the NIST spectral irradiance scale, while the ECUV’s irradiance scale is traceable to that of the German national standards laboratory, Physikalisch-Technische Bundesanstalt (PTB).
NOAA/CPC
Activities include participation in several initiatives of Stratospheric Processes and their Relation to Climate (SPARC), i.e., stratospheric temperatures, ozone, UV, climate change; collaboration with the EPA on the UV Index and the UV Alert system; collaboration with NASA in ozone monitoring, calibration of the SBUV/2 instruments, dynamical processes influencing ozone changes, and ozone assimilation; collaboration with the surface radiation monitoring efforts of NOAA/OAR and USDA-CSU for the validation of UV forecasts and NCEP/GFS surface radiation products, and the NDACC Data Host Facility.

NASA:
NASA collaborates extensively with several NOAA laboratories in all areas of ozone and UV research, including space-based, airborne, balloonborne, and groundbased measurements, as well as in various modeling and analysis activities. NASA often supports research activities within these laboratories, including support for NOAA groundbased measurements for satellite validation. The NDACC, which is championed by NASA and NOAA within the U.S., is a major contributor to WMO’s Global Ozone Observing System (GO3OS) within the frame of its Global Atmosphere Watch (GAW) Programme. NASA is closely collaborating with KNMI (Netherlands) and FMI (Finland) on processing data from the Aura OMI instrument. NASA is collaborating with NOAA in the implementation of the OMPS nadir and limb instruments on the Suomi satellite by developing the limb operational algorithms and by performing assessments of the nadir operational products.

USDA:
USDA is actively collaborating with the NASA TOMS and AERONET groups on aerosol absorption using UV-MFRSR and Cimel instruments.

EPA:
The NOAA/EPA Brewer spectrophotometer network (NEUBrew) consists of six stations located in the western, central, and eastern United States. The NEUBrew network has deployed two Brewer Mark IV spectrophotometers to Brisbane, Australia. The data gathered from this location will be used for atmospheric research and human health effects studies.

FUTURE PLANS

Ozone

Column Ozone from Dobson/ Brewer Zenith-Sky Measurements
The operational zenith-sky total ozone algorithm for Dobson and Brewer instruments is based on empirically derived tables. NASA has developed a TOMS-like algorithm to process these data, which has the potential to substantially improve data quality. There are plans to process all historical zenith-sky data using this algorithm. New algorithms to utilize multi-wavelength Brewer zenith sky measurements for improved ozone profile retrieval are underway. The work on improvement of optical characterization of Dobson and Brewer instruments for stray light minimization and new ozone cross-section implementation is underway. (NOAA, NASA)

According to the ACSO (WMO GAW Ad Hoc Expert team on Absorption Cross-sections of Ozone - ACSO) analysis of the impact of a possible change of ozone absorption cross-sections from Bass and Paar to Brion/ Daumont /Malicet (BDM) on Dobson and Brewer total ozone measurements, SAG-Ozone (Activity A9 within the ICAGO-O3/UV implementation plan) recommended to develop procedure to apply ozone cross section changes to processed total ozone data from Dobson and Brewer observations. A NOAA group will proceed to convert retrieved total ozone measurements and submit results to the WOUDC. (NOAA)
Ozone profiles from Dobson/ Brewer Zenith-Sky Measurements
NOAA GMD will convert retrieved ozone profiles from the NOAA operated stations, and will submit results for Dobson stations to the WOUDC, and will make the amendment to the UMK04 algorithm to replace the look-up tables for the BDM cross-section. Results from the NEUBrew instruments will be posted on the network website http://esrl.noaa.gov/gmd/grad/neubrew/, with the follow up submission to the WOUDC Brewer archive. Also, all B-files will be submitted to the WOUDC Brewer archive in accordance with the SAG-Ozone Activity (NOAAESRL/GMD)A new multi-wavelength ozone profile retrieval algorithm for processing Brewer Umkehr measurements (similar to the SBUV retrieval) will be made available for the WOUDC and scientific communities. The algorithm will significantly reduce operational time for the zenith sky measurements as compared to the established “Umkehr” measurements schedule in Brewer operations. It will also allow to process historical data that were not available for standardized processing due to shortness of the solar zenith range coverage. The data processed by the new algorithm will be archived at the WOUDC (NOAA).The Brewer Umkehr data set series from NOAA and other international ground-based stations will be compared to other available co-incident ozone profile data from ozone- sondes, microwave, lidar and Dobson Umkehr profile data. Results will be reported at the next Vertical ozone workshop aimed at understanding of past changes in the vertical distribution of ozone, and will be made available for the next UNEP/WMO Scientific Assessment of Ozone Depletion. (NOAA)

Archiving of the “raw” data at the WOUDC
According to the SAG-Ozone recommendations NOAA will participate in the international effort at the finalization of formats for the storage and reporting of ECC ozonesonde measurements at WOUDC, archiving of R-values of Dobson measurements and related calibration information as well as B-files and relevant information for Brewer measurements. It will provide the updated and modified algorithms used to process these data. NOAA will assist WOUDC with changes of ozone absorption cross sections or other changes that may demand the reprocessing of data records. (NOAA)

Ozone in Climate Forecast Models
NCEP has modified and extended its synoptic forecast model (GFS) to time scales of three weeks to nine months. Ozone forecasts as well as stratospheric temperatures and heights have significant errors in these forecasts. Experiments modifying the model’s physics and structure will need to be conducted in order to improve these forecasts. (NOAA/CPC)

Ozone in the NCEP/Climate Forecast System Reanalysis
NCEP is replacing the NCEP/DOE Reanalysis 2 (R2) with the Climate Forecast System Reanalysis (CFSR). The CFSR improves upon the R2 in many ways. One is by using ozone profile information from the SBUV/2. The CFSR is being rerun from 1979 to present and will continue as the model for NCEP’s Climate Data Assimilation System (CDAS). The CFSR should be the reanalysis of choice to study ozone-dynamics interactions. (NOAA/CPC)

NOAA Antartic UV Network
Future plans are to deploy two NEUBrew Mark IV spectrophotometers to the McMurdo and Palmer stations to provide daily total column ozone and overlapping spectral UV measurements. The two Brewers will be temperature stabilized and modified for Antarctic operation. Before deployment both Brewers will be converted to “red” Brewers to facilitate ozone retrievals in the Chappuis band. After conversion and before deploying they will be operated at the CUCF’s Table Mtn Test Facility (Lat 40 N) over the boreal winter to determine the quality of ozone retrievals from this solar spectral region when compared to direct-sun retrievals from the Hartley-Huggins band.
Ozone-Relevant Gases/Variables:

**OMPS and CrIS on Suomi NPP and JPSS**
The Ozone Mapping and Profiler Suite will become the operational US ozone monitoring instrument in the JPSS period. The suite consists of two nadir detectors; one with coverage in the 310 to 380 nm range to provide daily global total column ozone maps, and the other with coverage from 250 to 310 nm to provide nadir ozone profiles to continue the SBUV(/2) record. The first OMPS is operating on the NASA Suomi NPP launched in 2013. The OMPS Limb instrument will not operate on JPSS-1, but is planned to be on the JPSS-2 platform. The Cross-track Infrared Sounder is a hyperspectral IR instrument with spectral coverage including the ozone lines around 9.7 microns. NOAA has implemented ozone retrieval algorithms with the AIRS instrument on EOS, and plans to use similar algorithms with the IASI on MetOp-A and the CrIS on NPP and JPSS. (NOAA, NASA)

**NASA Earth Venture (EV) Investigations and missions**
NASA selected 5 investigations Earth Venture Suborbital (EVS-1) that are near the end of their 5 years to use suborbital platforms for sustained investigations of Earth System processes. 2 of these selected studies have direct relevance to Ozone related science, the Airborne Tropical Tropopause Experiment (ATTREX) and the Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) investigation. These activities started in 2010 and will continue until 2014. The next round of Earth Venture Suborbital solicitations are currently in review with selections expected in 2014. NASA also initiated the Earth Venture Instrument solicitation series for space-based instruments that take advantage of available accommodations on planned satellites. The first of these solicitations resulted in the TEMPO mission that will observe North America from Geostationary orbit to observe ozone and Air Quality parameters. These solicitations are expected to recur every 18 months. The second Earth Venture Mission solicitation is expected to be released in 2015. (NASA)

**NEUBrew Network**
Future plans for the NEUBrew network are to process historical direct-sun measurement data for total column abundance of NO2 and SO2 data products. (NOAA, EPA)

**UV**

**UV Index Forecast**
Aerosols and clouds are the greatest cause of UV Index forecast errors. NCEP and NESDIS are working together to improve the skill of forecasting aerosols. When model generated forecasts of Aerosol Optical Depth and Single Scattering Albedo become available they will be included in the UV Index forecast system. (NOAA/CPC)

**NEEDS AND RECOMMENDATIONS**

**Ozone**

**Column Ozone**
Column ozone observations from ground stations and satellites provide the foundation for trend studies. Future levels of total ozone will be modulated by climate change effects. The current predictions of total ozone from state-of-the-art models suggest polar ozone recovery in the 2060-2070 period, and midlatitude recovery in the 2040-2050 period. It is a primary requirement to continue this data record and to enable retrieval improvements of the observations.
Column ozone data produced by satellite and ground-based instruments agree well in cloud-free conditions and at solar zenith angles less than 70°. However, the data quality of all measuring systems degrade under cloudy conditions and at large solar zenith angles, with differences of 10% or larger. Given the need for accurate ozone trends in the polar regions, it is important to improve the quality of ground-based data in these regions, and to focus future calibration and data intercomparison efforts accordingly. The work on improvement of optical characterization of Dobson and Brewer instruments for stray light minimization, and therefore improved accuracy at low sun and large total ozone conditions, are under development. In addition, the new ozone cross-section implementation in the Dobson and Umkehr data processing is underway. (NASA, NOAA)

Profile Ozone
Ozone profile information has critical importance for both ozone recovery and climate change. The vertical structure of ozone (~ 1 km resolution) near the tropopause is crucial to calculating the radiative forcing of ozone on climate. Furthermore, polar ozone recovery should first manifest itself in the 20-24 km region of the polar stratosphere. Models of ozone suggest that the cooling of the stratosphere will accelerate ozone recovery in the upper stratosphere leading to a “super-recovery”. Hence, observations of the vertical structure of ozone have a bearing on two key scientific issues: ozone recovery and climate change. Some of these profile observations will be obtained by the OMPs Limb instrument on NPP and the MLS instrument on Aura during the next 3-5 years. These observations will be continued on the following JPSS-2 platforms. OMPs-Limb will be followed by the SAGE-III on the International Space Station, which may provide useful data to about the end of the lifetime of ISS (~2020). (NASA)

There is a vast amount of unprocessed Brewer Umkehr data residing in the archives. A concerted effort should be made to process these data using a common Dobson/Brewer algorithm, which is necessary for trend studies. The new Brewer Umkehr algorithm to derive ozone profiles under low sun condition is also in works (NASA, NOAA)

NASA has two Earth Science Decadal Survey satellite missions recommended in the future. One (GEO-CAPE) is a geosynchronous orbit and designed to study North American air quality, but should also provide column ozone. The second (GACM) is described as a follow up to Aura with analogous instrumentation using more advanced technology. This will provide profiles for ozone and numerous trace gases in the stratosphere and troposphere. Neither project is planned to be launch until some time after 2025, leaving a large gap between Aura and the next mission. (NASA)

The primary method to validate satellite data, and to improve the long-term records using multiple satellite and ground based sensors is through ozone concentration profiles from ozonesondes. Both NASA and NOAA support the SHADOZ network, in collaboration with numerous countries in the tropics and southern hemisphere. The effectiveness of SHADOZ relies critically on these collaborations, which require strong engagement of personnel and resources from these nations to take full advantage of the funding and support from NASA and NOAA. The ozone research community would benefit greatly from continued, and hopefully expanded engagement from countries participating in SHADOZ.

In order for ozone forecasts to improve in the NCEP/GFS, higher quality and greater numbers of ozone profiles need to be available for assimilation than what is available from the current nadir viewing SBUV/2. Ozone profiles from the Aura/MLS and OMI are promising as they provide ozone profiles of greater resolution (MLS) and of greater horizontal coverage (OMI). These products are now available in near-real-time, and are being assimilated into the NCEP/GFS. (NOAA/CPC)
Ozone-Relevant Gases and Variables

Ozone- and Climate-Related Trace-Gas Measurements
There is a need to maintain and expand the existing in situ networks, both geographically and with improved instrumentation. This is particularly true for the accurate estimation of emissions of trace gases on regional scales. Current workforce limitations prevent the development and propagation of gas standards on as rapid a schedule as required by these networks to keep up with the increasing number of new chemicals of scientific interest. In addition, expanded efforts are needed for data analysis as more and more chemicals are being measured. An intercomparison study, IHALACE, for halocarbon standards between measurement groups that has examined differences in the individual gases was completed and a paper summarizing the results was published in early 2014. The work found that most independent calibration groups agreed well for most compounds (<5%). (NASA, NOAA)

Aerosol Absorption Optical Thickness (AAOT)
There are currently no operational ground-based instruments that provide AAOT in UV. AAOT from the AERONET network is limited to wavelengths longer than 440 nm. NASA has improved a long-standing technique to derive AAOT in UV by combining measurements from AERONET and UV Shadowband radiometers. Efforts to utilize this methodology for deriving AAOT in the UV should be implemented. (NASA)

NEUBrew Network
Future plans for the NEUBrew network are for algorithm development for aerosol optical thickness retrievals and direct-sun data processing to provide aerosol optical thickness estimates at the five direct-sun measured UV ozone and five visible NO2 wavelengths.

Ozone- and Climate-Related Trace-Gas Measurements
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Field Campaigns
Aircraft, balloon, and ground-based measurement campaigns for satellite validation and science are expected to continue, but at a much lower level than in the past since Aura is in its Extended Mission phase now. These campaigns will provide important validation data for ozone and ozone- and climate-related trace gases and parameters for Aura and other satellite sensors. They also will address high-priority science questions associated with atmospheric ozone chemistry, transport, and greenhouse gas emissions. (NASA)

UV

USDA UV-B Monitoring and Research Programme (UVMRP)
A new site was installed at the University of Texas at El Paso (UTEP) in November 2008. (UDSA)

Geographical Measurement Coverage
UV monitoring in the tropics is very limited. Relatively inexpensive broadband UV instruments could be set up easily at installations launching ozonesondes (e.g., SHADOZ) in the tropical region. Such efforts should be coordinated with the NDACC. In this way, UV at the surface under
aerosols/pollution can be linked with the ozone profiles measured by the ozonesondes and ground-based profiling instruments. (NOAA/CPC)

Only seven of the EPA Brewers are currently deployed in or near densely populated areas. Satellite-derived UVR is less reliable for urban locations, because satellite instruments do not adequately characterize pollutants at ground level. Because of the deficiency of current urban UVR data, health researchers conducting local studies are sometimes making their own UVR measurements as needed, with instruments that are often not easily compared with those from any of the existing UVR networks. Thus, better ground-level measurements collected in locations close to air-quality monitors are required. Finally, many sites have data gaps and inconsistencies. Only a limited number of ground-based sites provide historically continuous UV records. More analyses of available data and improved calibration could fill gaps in coverage. (EPA)

**Calibration and Validation**

It is now well established that the ratio of UVB and UVA can be predicted accurately under clear conditions and to within a few percent in cloudy conditions wherever quality column ozone data exist. Absolute measurements of ozone amounts from satellites are accurate to 2% resulting in a 2% error in UV irradiance at 310 nm and an 8% error at 305 nm with larger errors at higher latitudes. UVA variability is known to correlate with variations in clouds, NO2, and aerosols, some of which are also measured by satellites. Ground based intercomparisons studies are using long time averages to simulate the spatial footprint of satellites. Further studies are required to determine the effectiveness of this approach. (NASA)

**Effects Research**

Although the effects of UV exposure drive UV monitoring activities, only limited resources historically have been targeted towards UVB effects research. Expansion of UVMRP activities in this critical area is needed at a multi-agency level. (USDA)

**Acronyms and Abbreviations**

AAOT aerosol absorption optical thickness  
ACIA Arctic Climate Impacts Assessment  
AERONET Aerosol Robotic Network  
AGAGE Advanced Global Atmospheric Gases Experiment  
AIRS Atmospheric Infrared Sounder  
AO/AAO Arctic/Antarctic oscillation  
BSI Biospherical Instruments  
BUV Backscatter Ultraviolet  
CAFS CCD Actinic Flux Spectroradiometer  
CCD charge-coupled device  
CDIAC Carbon Dioxide Information Analysis Data Center  
CFC chlorofluorocarbon  
COADS Comprehensive Ocean-Atmosphere Data Set  
CPC Climate Prediction Center (NOAA, U.S.)  
CrIS Cross-track Infrared Sounder  
CSD Chemical Sciences Division (formerly the Aeronomy Lab, NOAA, U.S.)  
CSD Chemical Sciences Division (NOAA,US)  
CSU Colorado State University (United States)  
CTMs chemical transport models  
CUCF Central Ultraviolet Calibration Facility  
DAAC Distributed Active Archive Center (NASA Langley, U.S.)  
DISC Data and Information Services Center (NASA Goddard, U.S.)
DoD Department of Defense (United States)
DoE Department of Energy (United States)
DOAS Differential Optical Absorption Spectroscopy
ECD electron capture detector
ECMWF European Centre for Medium-Range Weather Forecasts (United Kingdom)
ECUV European UV Calibration Center
EECl effective equivalent chlorine
EESC effective equivalent stratospheric chlorine
EOS Earth Observing System
EUroPe Earth Observation Systems
EuMetSat European Organization for the Exploitation of Meteorological Satellites
EPA Environmental Protection Agency (United States)
ESRL Earth System Research Laboratory (NOAA, US)
FMI Finnish Meteorological Institute (Finland)
FTIR Fourier transform infrared
GAW Global Atmosphere Watch
GC Gas Chromatograph
GCM general circulation model
GCMS Gas Chromatography Mass Spectrometry
GES Goddard Earth Sciences
GFS Global Forecast System
GMAO Global Modeling Assimilation Office (NASA Goddard, U.S.)
GMD Global Monitoring Division (formerly CMDL – NOAA, U.S.)
GOES Geostationary Operational Environmental Satellite
GO3OS Global Ozone Observing System (WMO)
GOME Global Ozone Monitoring Experiment
GSFC Goddard Space Flight Center (NASA, U.S.)
HALOE Halogen Occultation Experiment
HIRDLS High-Resolution Dynamics Limb Sounder
HIRS High-resolution Infrared Radiation Sounder
IHALACE International Halocarbons in Air Comparison Experiment
IASI Infrared Advanced Sounding Interferometer
JPL Jet Propulsion Laboratory (United States)
JPSS Joint Polar Satellite System (United States)
KNMI Koninklijk Nederlands Meteorologisch Instituut (The Netherlands)
MetOp Meteorological Operational Satellite
MFRSRs Multi-Filter Rotating Shadowband Radiometers
MIPAS Michelson Interferometer for Passive Atmospheric Sounding
MIRAGE Megacity Impacts on Regional and Global Environments
MLS Microwave Limb Sounder
NASA National Aeronautics and Space Administration (United States)
NCAR National Center for Atmospheric Research (United States)
NCEP National Centers for Environmental Prediction (NOAA, U.S.)
NDACC Network for the Detection of Atmospheric Composition Change
NDIR non-dispersive infrared
NESDIS National Environmental Satellite, Data, and Information Service (NOAA, U.S.)
NIST National Institute of Standards and Technology (United States)
NIWA National Institute of Water and Atmospheric Research (New Zealand)
NOAA National Oceanic and Atmospheric Administration (United States)
NOGAPS Navy Operational Global Atmospheric Prediction System
Suomi NPP National Polar-orbiting Partnership Satellite
NRL Naval Research Laboratory (United States)
NSF National Science Foundation (United States)
NWS National Weather Service (NOAA, U.S.)
ODGI ozone-depleting gas index
ODSs ozone-depleting substances
OHP Observatoire de Haute-Provence (France)
OMI Ozone Monitoring Instrument
OMPS Ozone Mapping and Profiler Suite (NPP)
OMS Observations of the Middle Stratosphere
PSCs polar stratospheric clouds
PTB Physikalisch-Technische Bundesanstalt (Germany)
QBO quasi-biennial oscillation
SAGE Stratospheric Aerosol and Gas Experiment
SAM Stratospheric Aerosol Measurement
SBUV Solar Backscatter Ultraviolet
SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SHADOZ Southern Hemisphere Additional Ozonesonde (Network)
SPARC Stratospheric Processes and Their Role in Climate
VIET NAM

1. Introduction on ozone observation station network

With the kind support from the Russia, 3 ozone and UV-B observation stations were installed in Viet Nam: Ha Noi Station (21°01’N, 105°51’E), Sapa (22°21’N, 103°49’E) and Tan Son Hoa (10°47’N, 106°42’E). These stations were equipped with M-124 filter instrument. All these stations are managed by the Aero-Meteorological Observatory under the National Hydro-Meteorological Service of Viet Nam.

After many years of using, due to the old and backward equipment, the measured data were not exactly. In late 2011, with the concern of the Government and the Ministry of Natural Resources and Environment, the M-124 filter instrument was replaced by Brewer equipment. It is an automatic observation equipment with many elements and high accuracy.

Besides, NHMS of Viet Nam has been participating in the program “Soundings of Ozone and Water in the Equatorial Region/Pacific Mission (SOWER/Pacific) since 2004. In the framework of the program, Viet Nam observes water vapor and ozonesonde in Ha Noi station.

2. Observation activities

2.1 Total amount of atmospheric ozone (TO3) and UV-B Observation

- Before November, 2011: with M-124 filter instrument, TO3 and UV-B were measured as follow:

  + In the summer (01 May to 31 Oct): from 8.00 to 16.00, 9 times per day with sun height.
  + In the winter (01 Nov – 1 April): from 7.30 to 16.30, 11 times per day with sun height.

- From December 2011 to now:

  With new Brewer instrument, TO3 and UV-B are measured 24 times per day.

2.2 Ozonesonde: Observation in the framework of the Program SOWER/Pacific

- From September 2004: measured 1 obs/month
- From February 2006 to now: measures 2 obs/month
- From 2005 to now: in the winter (January), there are more 3 and 4 obs.

3. Observation results and analysis

3.1 Results and analysis on TO3 and UV-B Observation

- From 2003 to November 2011: TO3 and UV-B Observation were implemented as the standard operation procedure with the M-124 filter instrument. However, Due to the old and backward equipment, the measured data were not exactly.
- From December 2011 to now: With new Brewer equipment, the quality of observation is higher. However, due to some reasons such as weather, climate, loss of electric, observation capacity is not high in SaPa Station.
- From 2003 to present, the activities related to the ozone is concentrated mainly on sustaining of observation and data collection. There are no activities of studies and analysis conducted.

3.2 The Results on Ozonesonde Observation and Analysis

With modern equipment, observation is being implemented with good quality.
The Japanese experts used the ozonesonde observation data into the research and analysis. From this, experts gave the initial outlook on ozone fluctuations. The research was reported in some international MAHASRI workshops on Asia Monsoon and Water in 2011, 2013.

4. Future Plan

- Install of TO3 and UV station in Da Nang, Mid central of Viet Nam.
- Continue to implement the observation in the framework of SOWER/Pacific Program.
- Implement research, analysis of ozone
5. **Recommendation**

The Hydro-Meteorology Sector of Viet Nam in the modernization process so systematical equipment investment as well as improvement of staff capacity is necessary and important. In addition, NHMS has a data set with over 20 years. It is useful for researching and giving the initial assessment about change and variation of ozone layer in Viet Nam. Through this, we can give the impact of radiation to the health and agriculture. However, up to now, there is no research implemented.

However, due to the limited budget, NHMS of Viet Nam would like to call for help and support in the field of ozone observation such as instrument, technical assistance, capacity building, research activities.
WMO GLOBAL OZONE RESEARCH AND MONITORING PROJECT REPORTS


4. Report of the Meeting of Experts on Measurements of Rare Species Relevant to the Ozone Budget (Seattle, May 1977).


10. Contribution of Ozone and Other Minor Gases to Atmospheric Radiation Regime and their Possible Effect on Global Climate Change (by E.L. Aleksandrov, I.L. Karol, A. Ch. Khrgian, L.R. Rakipova, Yu. S. Sedunov).


13. Review of the Dobson Spectrophotometer and its Accuracy (by Reid E. Basher).


19. Survey of WMO-Sponsored Dobson Spectrophotometer Intercomparisons (by Reid E. Basher) (TD No. 657).

21. Report of the Preparatory Meeting of the Ozone Research Managers of the Parties to the

22. WMO Consultation on Brewer Ozone Spectrophotometer Operation Calibration and Data
Reporting (Arosa, Switzerland, August 1990).

23. Report of the First Meeting of the Ozone Research Managers of the to the Vienna

24. Report of the International Workshop on Dobson Ozone Data Re-evaluation (Greenbelt,
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26. Report of the Meeting of Experts on Surface Ozone Data, their Analysis and Related

27. Third WMO Intercomparison of the Ozonesondes used in the G030S (Vanscoy, Canada,

28. Visible light Nigrogen Dioxide Spectrophotometer Intercomparison (Mt. Kobau, Canada,


30. Second WMO Consultation on Ozone Measurements by Brewer Spectrophotometer
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31. Atlas of Total Ozone G030S Maps for the European Arctic Stratospheric Ozone
Experiment (November 1991 - March 1992) (Coordinated t R.D. Bojkov and Ch.S.
Zerefos) (TD No. 517).

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33. Report of WMO Consultation on UV-B Monitoring and Functions of WMO Data Centre -

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1993. (Coordinated by R.D. Bojkov and Ch.S. Zerefos) (TD No. 593).

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and Early Warning of Ozone Changes. Saloniki, 27-30 November 1993 (Preparation
coordinated by R.D. Bojkov).

36. Report of WMO/NOAA Meetings on Ozone Data Re-evaluation and use of Dobsons and
Brewers in the G030S (Tenerife, June 1994).


38. Atlas of G030S Total Ozone Maps for the Northern Hemisphere Winter-Spring of 1993-

and 1996-1997 (Co-ordinated by Rumen D. Dimitris Balis and Ch.S. Zerefos).


47. Scientific Assessment of Ozone Depletion: 2002 - Twenty Questions and Answers about the Ozone Layer.


49. An Overview of the 2005 Antarctic Ozone Hole (WMO TD No. 1312).


52. Scientific Assessment of Ozone Depletion: 2010