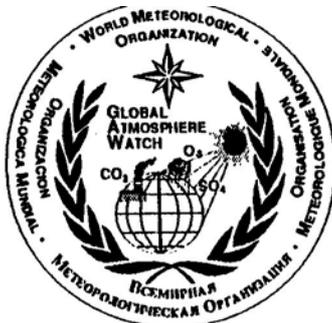


# WORLD METEOROLOGICAL ORGANIZATION GLOBAL ATMOSPHERE WATCH

(A system for environmental pollution monitoring and research)



No. 111

## WMO-BMBF Workshop on VOC

### Establishment of a "World Calibration/Instrument Intercomparison Facility for VOC" to Serve the WMO Global Atmosphere Watch (GAW) Programme

Organized by the QAISACs for Europe/ Africa and the Americas  
and hosted by the Fraunhofer Institute of Atmospheric  
Environmental Research (IFU)

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A Contribution to the Global Environment Monitoring System  
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## TABLE OF CONTENTS

1.	OPENING OF THE MEETING, ELECTION OF CHAIRMEN AND INTRODUCTION	1
2.	ADOPTION OF THE AGENDA	3
3.	OVERVIEW	3
4.	WORKSHOP REPORT	4
4.1	Subworking Group I -- Recommendations for VOC Measurements and Associated QAIQC Activities on the WMO Global Atmosphere Watch Network	6
4.1.1	Introduction	6
4.1.2	GA W Objectives for VOC Measurement	6
4.1.3	Rationale for VOC Measurements and the GA W Network Configuration	7
4.1.3.1	Basic rationale	7
4.1.4	Measurement System Description	8
4.1.4.1	GA W VOC Demonstration Network	8
4.1.4.2	Implementation of the GA W VOC Demonstration Network	9
4.1.4.3	Establishment of a World Calibration Facility for VOC	9
4.1.5	Evaluation of Existing Global/Regional VOC Data Sets	10
4.1.6	Training, Technology Transfer and Educational Infrastructure	10
4.2	Subworking Group II -- Sample Collection and Analytic Procedures	11
4.2.1	Techniques	11
4.2.2	Collection	11
4.2.3	Analytical Procedure	12
4.2.3.1	Method	12
4.2.3.2	Laboratory practice	12
4.2.3.3	Data archival	13
4.2.3.4	Pilot stations	13
4.2.3.5	WMO World Calibration Facility for VOC	13
4.3	Subworking Group III -- QAIQC, Calibration and Intercomparisons	13
4.3.1	Organization of QA/QC and of Calibration	13
4.3.2	Organization of VOC Analysis	14
4.3.3	QA/QC Centre Functions	14
4.3.4	Calibration Standards	15
4.3.4.1	Reasons for calibration	15
4.3.4.2	Calibration standards required	15
4.3.4.3	Sources of calibration standards	17
4.3.5	Use of Calibration Standards	18
4.3.5.1	Frequency of use	18
4.3.5.2	Conditions of use	18
4.3.5.3	Linearity	18
4.3.5.4	Storage	18
4.3.6	Audit Standards	18
4.3.7	Intercomparisons	19
4.3.7.1	Intercomparison of main GA W standard	19
4.3.7.2	Intercomparison of GA W analytical laboratories	19
4.3.7.3	Intercomparison of sampling techniques	19
4.3.7.4	Intercomparison of GA W with external laboratories	19
5.	CLOSING OF THE MEETING	19
6.	REFERENCES	20
	ANNEX A -- List of Acronyms	23
	ANNEX B -- List of Participants	25
	ANNEX C -- Agenda	29

## 1. OPENING OF THE MEETING. ELECTION OF CHAIRMEN AND INTRODUCTION

The joint World Meteorological Organization. (WMO)-Bundesministerium für Bildung Wissenschaft, Forschung und Technologie (BMBF) Meeting of Experts on the Establishment of a "World Calibration/Instrument Intercomparison Facility for Volatile Organic Compounds (VOCs)" was opened by Professor Dr. Volker Mohnen, Quality Assurance/Science Activity Center of WMO.

On behalf of Dr. John Miller, Chief, Environment Division of WMO, Professor Mohnen welcomed the participants (see Annex B for list of participants). In his opening address, Professor Mohnen reviewed the current status of the WMO-Global Atmosphere Watch programme (GAW).

The Global Atmosphere Watch (GAW) programme of WMO is an integral part of the Global Climate Observing System (GCOS) established by WMO, UNESCO/IOC, UNEP and ICSU. GAW is devoted to the investigation of changing chemical composition and related physical characteristics of the global atmosphere. GAW is a coordinated network of observing stations, associated facilities and infrastructure encompassing measurement and related scientific assessment activities. The overall role of GAW is to supply basic information of known quality indicative of the atmospheric environment that transcends specific issues.

The GAW measurement responsibilities include:

- greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, CFCs)
- ozone (surface, total and profile)
- radiation (including UV-B) and optical depth
- precipitation chemistry
- chemical and physical properties of aerosols
- reactive gases (eO, VOCs, NO<sub>x</sub>, SO<sub>2</sub>)
- radionuclides (<sup>222</sup>Rn, <sup>7</sup>Be)
- related meteorological parameters.

The data obtained by GAW initially provide:

- integrated monitoring
- scientific assessment
- early warnings.

The GAW-structure calls for (1) up to 30 global stations located at remote pristine locations; (2) over 300 regional stations for characterizing the regional environmental quality away from direct pollution sources; and (3) a mechanism/system of activities for producing measurements of known quality and of value for making environmental policy decisions (quality assurance/quality control).

WMO's strategy for implementing total quality assurance is built around Quality Assurance/Science Activity Centres (QA/SACs); following the recommendations of a meeting of experts assembled by WMO (March 26-30, 1992, Garmisch-Partenkirchen, Germany) and charged with the development of a quality assurance plan for GAW (WMO/GAW Report No. 80, 1992: "Report of the WMO Meeting of Experts on the Quality Assurance Plan for the Global Atmosphere Watch"). In June of 1992, the Executive Council of WMO, recalling previous concerns of data reliability and recognizing the importance of quality assured data, fully supported the actions taken by the Secretary-General and the EC Panel of Experts/CAS Working Group and endorsed the structure and establishment of QA/SACs within GAW. The Executive Council requested that the Secretary-General proceed with this development. Accordingly, the WMO arranged a second meeting of experts (December 7-11, 1992, Garmisch-Partenkirchen, Germany) to develop guidelines for the implementation of these QA/SACs (WMO/GAW Report No. 92, 1993: "Report of the WMO Meeting of Experts on the Implementation of Quality Assurance/Science Activity Centres for GAW").

The essential functions of these QA/SACs include the preparation and execution of (1) the comprehensive GAW Quality Assurance programme for all measurement components, and (2) a plan for education and capacity building within the countries that have committed to maintain and operate GAW sites. Building the indigenous technical and scientific capabilities and infrastructure (particularly in developing countries) is an integral part of an effective QA programme.

The ECPanel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (The Panel) has reviewed the WMO Reports No. 92 and 93 and, in its role as an advisory body, endorsed its recommendations.

Professor Mohnen reiterated the basic philosophy of the QA/SACs, namely to build a global alliance with internationally recognized scientists and research institutes/organizations to establish World Calibration Facilities (WCFs) for each of the GAW measurement parameters. Such WCFs are now operational for CO<sub>2</sub>, O<sub>3</sub> (surface, Dobson and ozone sondes), precipitation chemistry, aerosol optical depth (sun photometry), aerosol chemistry, CO, and radioactivity (222Rn, 7Be). Professor Mohnen expressed his sincere hope that the experts from throughout the World participating in this meeting will succeed in guiding WMO towards an effective implementation strategy for producing VOC measurements of high and known quality within the global and regional GAW network.

In welcoming the workshop participants to the Fraunhofer Institute for Atmospheric Environmental Research (IFU) and to the resort town of Garmisch-Partenkirchen, Professor Dr. W. Seiler assured the participants of his personal interest in the topic of this workshop. A significant and increasing portion of the Institute's research activities is indeed devoted to problems related to VOCs, in determining their source strength, their atmospheric distribution and their chemical reactivities. The measurement of VOCs of natural and manmade origin is still a complex research task, and the exchange of ideas and concepts among leading scientists--as it will occur during this workshop--is an effective and most welcome avenue for promoting progress in this specialized field of atmospheric chemistry. Professor Seiler also offered the help of the Institute in establishing a World Calibration Facility for VOCs.

Professor Mohnen, in following up on the overall description of the GAW activities, emphasized the growing interest within the scientific and monitoring community in tropospheric ozone as a climate gas and an atmospheric oxidant which has heightened the need in GAW to document the global distribution of VOCs as one of the precursor substances responsible for ozone formation. The measurement of VOCs in relatively unpolluted or background air is far from routine and will pose a formidable challenge to the monitoring community in the near future. The formation of a "WMO World Calibration Facility for VOC (WCF-VOC)" is considered by WMO as an essential step towards building a viable global network.

The proposed "WMO World Calibration Facility for VOC" will benefit from the experience gained in international projects, most notably in IGAC-NOMHICE (Non-Methane-Hydrocarbon Intercomparison Experiment). The main functions of the facility will be to provide calibration standards (performance audit), to organize intercomparison experiments, to develop standard operating procedures, and to advise the WMO-Quality Assurance/Science Activity Centers (QA/SACs) on all matters influencing the quality of VOC measurements in air.

Professor Mohnen defined the topics to be discussed at the meeting as follows:

- Measurement strategies for VOCs and required co-data.
- Calibration standards and quality assurance procedures.
- Instrument/method intercomparisons and standard operating procedures.
- Network harmonization (WMO-GAW, EMEP, NARSTO, IGAC projects, etc.).
- Duties and responsibilities of the proposed WMO World Calibration Facility for VOC.

On the basis of recent discussions, developments and progress within the respective IGAC, EUROTRAC, EMEP, SOS (Southern Oxidant Study, EPA/USA)-, NARSTO (North America) communities and on advice from the WMO Executive Council of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (The Panel), Professor Mohnen defined the overall objectives of this WMa/BMBF workshop as follows:

- To assess ongoing national/international activities related to VOC calibration, measurement methodologies and network implementation strategies;
- To provide guidance for the establishment of a WMO-GAW Calibration Facility for Volatile Organic Compounds (VOCs); and
- To explore opportunities for international cooperation in areas related to quality assurance of VOC measurements.

Professor Mohnen proposed to elect Dr. F. Slemr and Dr. N. Schmidbauer as chairmen of the workshop and to charge them with the preparation of a draft report to be circulated to all workshop participants for review. Professor Mohnen agreed to serve as editor and to prepare a final report for publication by WMa-BMBF.

## **2. ADOPTION OF THE AGENDA**

The chairmen, Dr. F. Slemr and N. Schmidbauer, introduced the agenda, which was adopted unanimously and is reproduced in Annex C.

## **3. OVERVIEW**

3.1 The production of photooxidants and other secondary pollutants by reactions of nonmethane hydrocarbons (NMHCs) with nitrogen oxides in the presence of sunlight has been recognized as an increasingly serious problem in both developed and developing countries all over the world. The most significant of these secondary pollutants is ozone which can be harmful to human health, to crops, trees and certain materials. In addition, ozone is one of the most important greenhouse gases. Many other secondary photochemical pollutants are known, such as the strong oxidant hydrogen peroxide, and the irritant peroxyacetyl nitrate (PAN).

3.2 Current VOC monitoring is being met by the establishment of a variety of monitoring networks on a national and global basis, coupled with local monitoring by urban authorities, environmental health bodies and universities. Two main approaches to VOC monitoring have emerged in the last decade:

- grab air sampling into suitable canisters, with subsequent analysis in a laboratory using gas chromatography (GC); and
- real-time sampling and on-line analysis of the ambient air at the monitoring site, using GC.

Both of these approaches are valuable and have their specific advantages and disadvantages. Real-time monitoring provides a good time resolution but is expensive, since a GC and a skilled operator are needed at each site. Grab sampling has low time resolution but it is much cheaper since the analyses can be performed with a few central GC laboratories with a few skilled operators. This approach is thus well suited for extensive monitoring networks covering large areas including those in lesser developed countries. Much of the VOC monitoring in Europe has been by grab sampling (e.g. the EMEP network). Grab sampling may also be favored for the newly established WMa Global Atmosphere Watch (GAW) network now under discussion.

3.3 Many different methods are currently being used for the analysis of air samples from the canisters. The low concentrations of VOCs require a preconcentration step prior to GC separation. The VOCs are preconcentrated in a cryogenic trap or in a trap filled with an absorbent, or sometimes a combination of both is used. Since atmospheric water can plug the preconcentration

trap, the air sample is usually dried before preconcentration. Nafion dryers or columns packed with drying agents such as Mg(C104h are in use, each with its specific advantages and disadvantages. To enhance the reproducibility of the retention times during the GC separation of VOCs, CO<sub>2</sub> is also trapped in some instruments using sodium hydroxide on some support material. Different columns may be used to separate different groups of hydrocarbons. Incomplete separation of the target VOCs from other VOCs leads to erroneous quantisation. Consequently, the deviations observed in the intercomparisons may, to a large degree, be caused by the different procedures in use. In addition to these analytical problems, many of the quantisation errors are due to the use of inadequate calibration standards and to the variation in the relative response factors of the various VOCs with changes in the operating conditions of the flame ionization detector (FID) in each GC. The most pronounced example of variable 'relative response factors is ethyne.

3.4 Measurement of the wide range of ambient VOC gases is almost always performed by a gas chromatograph with FID. Mass spectrometry is rarely used, due to its expense, and then usually only for identification purposes. Though convenient, the almost exclusive use of GC/FID carries the very real risk that some of the VOCs will be mis-identified due to confusion with other similar VOCs or other trace gases. Also, quantitative determination may be biased by an overlap with another, sometimes unidentified compound. Calibration of the GC using accurately prepared standard gas mixtures is thus essential, both to enable efficient identification of individual VOCs and as a necessary prerequisite for accurate measurement of their concentrations. Quantisation errors due to peak overlap may require additional verification by MS.

3.5 It is most important that the concentrations of the VOCs in both the grab samples and the calibration standard mixtures shall be stable with time. The possibility of short-term instabilities in fresh grab samples due to gas phase reactions must be investigated. Studies of longer-term instabilities due to wall reactions in the sample and calibration mixture containers must also be considered.

3.6 Intercomparisons between different laboratories are essential in demonstrating the extent to which harmonization has produced uniform analytical results across a wide range of different laboratories. Such intercomparisons can be initiated with the use of made-up VOC mixtures, such as the standard calibration mixtures distributed under the IGAC-NOMHICE project. However, the use of artificial mixtures may not reveal all the problems connected with the analysis of real air samples, since the former generally employ (for technical reasons) dry nitrogen as the diluent rather than humid air. In addition there are many more gases in real air samples than in artificial ones, and the VOCs are usually at appreciably lower concentrations (typically less than 1 ppbv, rather than more than 10 ppbv for artificial samples). A combination of all these factors has been responsible for much poorer intercomparison results for "whole air" samples than for artificial gas mixtures (JRC 1995).

3.7 The necessity for improvements in VOC measurement technique have been demonstrated by various recent intercomparisons, such as those organized by Joint Research Centre (JRC) for the EC in 1991 and again in 1994 (JRC 1995), by TOR (part of EUROTRAC) in 1994 (Hahn 1994), by EMEP in 1995 (Romero, 1995) and by the Southern Oxidant Study in the USA in 1992 to 1995 (Shreffler, 1993; Apel et al., 1995). These intercomparisons produced some widely differing results in some cases, indicating serious analytical problems in some participating laboratories.

#### **4. WORKSHOP REPORT**

After adopting the agenda, plenary sessions were conducted on December 18 and 19. The discussion focused predominantly on hydrocarbons because the hydrocarbon monitoring with respect to the GAW needs is currently more developed than monitoring of other organic compounds.

In the first plenary session chaired by R. Partridge, the results of several national and international NMHC intercalibration experiments in the period from 1987 to 1995 were discussed.

In particular, the results of the 1987 intercomparison in marine air organized by NOAA, the 1988 intercomparison in UK organized by NPL, the 1992 intercomparison of European TOR (Tropospheric Ozone Research) groups organized by IFU, the 1991 and 1994 European intercomparisons organized by Joint Research Centre (JRC), and 1991 intercomparison organized by the National Center for Atmospheric Research (NCAR) as part of NOMHICE exercise. The results showed substantial inconsistencies between measurements by different laboratories even for simple NMHC mixtures at about 10 ppbv levels. Only a few intercomparisons were performed with background whole air samples with mixing ratios on the order of 1 ppbv and below, with substantially larger inconsistencies than observed in intercomparisons of the artificial samples. Thus extensive QA/QC activities are necessary to ensure sufficient quality of VOC data produced by any monitoring network.

In the second plenary session, chaired by F. Slemr, the possible objectives of VOC measurements at global GAW stations were discussed. In addition to the general goal of the GAW network aiming at documentation of the changes in atmospheric composition, several specific scientific goals were discussed. Seasonal and spatially distributed NMHC measurements may provide important information about the oxidation capacity of the troposphere. NMHC monitoring at regional GAW stations is essential for understanding the role of biogenic and anthropogenic emission processes in the biogeochemical cycles of individual NMHC compounds. The NMHC monitoring may also serve for the validation of global and regional transport/chemistry models.

The discussions in these plenary sessions resulted in an impression that NMHC monitoring at global GAW stations places high requirements on the data quality. The results of the discussed intercomparisons showed that the data quality requirements are higher than the capabilities of many participating laboratories. Taking these difficulties into account K. Demerjian, as the chairman of the third plenary session, proposed to establish a pilot project which should demonstrate the feasibility of NMHC monitoring within the GAW network. This proposal was discussed in the third plenary session.

After achieving a general agreement about the pilot project proposed by K. Demerjian and its possible implementation, the related necessary QA/QC activities were discussed during the fourth session chaired by V. Mohnen.

After the initial plenary sessions, three subworking groups were established to review different aspects of the VOC monitoring within the GAW network:

- Subworking Group I  
VOC measurements and associated QA/QC activities on the WMO Global Atmosphere Watch network. Chairman K. Demerjian; participants: Hales, Bottenheim, Hoffmann, Tavares.
- Subworking Group II  
VOC sample collection and analytic procedures. Chairman D. Blake; participants: Burgess, Schaug, Plass-Duelmer, Gehrig.
- Subworking Group III  
QA/QC, calibration and intercomparisons. Chairman R. Partridge; participants: Apel, Schmid bauer, Jaeschke, Slemr J., Slemr F.

The discussions were continued during separate sessions and R. Hales (replacing K. Demerjian who had to leave the workshop), D. Blake, and R. Partridge as rapporteurs summarized the results and presented them during the final plenary session on December 21, the last day of the workshop. The written reports including the results of the final discussion are presented in the following chapters of this report.

## **4.1 Subworking Group I -- Recommendations for VOC Measurements and Associated GA/GC Activities on the WMO Global Atmosphere Watch Network**

### **4.1.1 Introduction**

This report summarizes activities of the WMO/GAW panel on volatile organic compound (VOC) measurement, which was held in Garmisch-Partenkirchen during December 18-21, 1995. Products of the meeting include development of the rationale and objectives for the Global Atmosphere Watch's (GAW) future activity in this area, recommendations for the configuration and approach of the proposed VOC measurement system, and recommendations for the associated configuration and activities of the GAW/Quality Assurance/Science Activity Center (QA/SAC).

There are several reasons why it is important to possess an improved understanding of the state, the behaviour, and the potential for changes in tropospheric VOCs. It is well established, for example, that atmospheric VOCs are pollutants whose concentrations depend on rather complex biogeochemical balances between their sources, their transport, and their sinks. A number of phenomena, including fossil-fuel emissions, biomass burning, deforestation, agricultural practices, and climate change are (or at least

3. Establishing the chemical basis for the ozone content and general oxidative capacity of the remote troposphere, including its variation in space and in time.

It should be noted the GAW VOC measurements are expected to be applied in conjunction with a variety of interpretive techniques, including comprehensive three-dimensional modeling, to accomplish these objectives.

#### **4.1.3 Rationale for VOC Measurements and the GAW Network Configuration**

##### **4.1.3.1 Basic rationale**

At the outset it is important to note that any data set to emerge from this sampling program will be incomplete in a number of ways, and thus can be expected to advance our understanding of the above elements in an incremental--as opposed to a complete--fashion. Several of the practical reasons for this are itemized below:

1. Within the context of tropospheric ozone and other oxidants, it is recognized that VOCs are oxidant *precursors*, and are *consumed* by the oxidant-generation process. Because of this, VOC concentrations at any given time and location are only indirect indicators of oxidant production, thereby complicating the interpretive process appreciably. Also because of this, it is important to possess VOC measurements at a number of locations, including points in source regions as well as those in the free troposphere.
2. Other important oxidant precursors (especially nitrogen oxides) exist, and a complete examination of oxidant production must consider these compounds as well.
3. A huge variety of VOCs exists, and some are much more difficult to measure than others. Therefore any practical sampling program will produce only a limited subset of the total VOC-concentration spectrum. Because the value of any such data base increases with the number of species measured, an optimum measurement configuration will represent a balance between information content and practical measurement considerations.
4. In reflection of the above considerations and the current state of measurement technology, GAW intends to proceed with its VOC measurements on a staged basis, proceeding from the easiest measurements to those that are more difficult, as follows:  
  
*Stage 1 Measurements:* C2-C9 hydrocarbons, including alkanes, alkenes, alkynes, dienes and monocyclics.  
  
*Stage 2 Measurements:* C10-C14 hydrocarbons, including higher homologs of the Stage-1 set as well as biogenic hydrocarbon compounds.  
  
*Stage 3 Measurements:* Oxygenated VOCs, including alcohols, carbonyls, carboxylic acids
5. Despite the difficulties noted in items 1-4 above, there are several elements that will empower the data set envisioned here to make significant inroads towards accomplishing the stated objectives. The simultaneous measurement of a large number of VOC species, for example, will allow ratioing and tracing techniques which can be applied to high benefit for these purposes.

#### 4. 1.4 Measurement System Description

##### 4. 1.4. 1 GA W VOC Demonstration Network

It is recommended that the introduction of VOC measurements as part of the GA W monitoring network should proceed via a staged approach. Stage one will consider the implementation of a VOC Demonstration Network consisting of a subset of GA W global and regional stations. The distribution of stations in the initial Demonstration Network be represented by approximately six global and 12 regional sites:

The selection of the global stations will be based on:

1. spatial and latitudinal representativeness (i.e. NH/SH 0-30, 30-60, 60-90 deg)
2. data representativeness in characterizing marine, continental and free tropospheric regimes
3. data representativeness, in conjunction with other codata, in characterizing the oxidizing capacity of global/latitudinal regimes
4. capabilities, interests and resource commitments of global network contributors.

The selection of regional stations will be based on:

1. data representativeness in characterizing source attribution (i.e. anthropogenic < fossil, solvent use>, biomass burning, biogenic)
2. identification of strategic locations expected to undergo significant change in source attribution (e.g. anticipated regions to undergo intensive development, land use change over the next decade)
3. data representativeness, in conjunction with other codata, in characterizing the oxidizing capacity of the regional atmosphere
4. capabilities, interests and resource commitments of regional network contributors.

The VOC measurement programme will be carried out at the designated stations throughout the year via the collection of air samples within suitably prepared canisters. The desirable minimum frequency of sampling at the regional stations would be two samples per week at the regional stations, in order to capture seasonal features of sources and associated tropospheric photochemistry of specific hydrocarbon species. Higher frequency VOC measurements (e.g. continuous/hourly integrated samples) are very desirable and should be encouraged where feasible at regional stations. Such measurements enhance source attribution capabilities in particular for those sources which vary diurnally and will enhance analyses with codata of the oxidizing capacity of the region.

In the case of global stations, one sample per week is likely adequate, and we suggest that sampling at these sites be consistent with other ongoing flask sampling activities which are operational for climate gases.

The primary rationale for the measurement system described above is based on estimated variability of VOCs--both in the regional boundary layer and in the free troposphere as a function of space and time, along with the practical and economic constraints of network deployment. The array of free-tropospheric sampling stations is expected to be sufficient to capture basic elements of global variability of these compounds, with inter-hemispheric differences being a particularly

important feature. The twice-weekly sampling frequency is deemed adequate for capturing temporal variability of free-tropospheric VOC concentrations on seasonal and long-term bases.

#### 4. 1.4.2

- canister sampling methodologies
  - calibration procedures
4. Provides guidance on VOC GC analysis methodologies (canister analysis)
    - sample pretreatment
    - water management
    - cryotrapping, cryofocusing
    - GC columns
    - generic SOPs for GC operation
  5. Proponent for development activities'
    - standards for > 1= C'o species and oxygenated species
    - analysis and assessment of new sampling techniques
      - \* new material surface canisters
      - \* absorption substrates and techniques
      - \* in situ sampling techniques (e.g. automated systems)
      - \* assessment of automated GC analysis systems

#### **4.1.5 Evaluation of Existing Global/Regional VOC Data Sets**

The success and effectiveness of the GAW VOC measurement programme is strongly dependent on the development of diagnostic data analysis and evaluation procedures for addressing the scientific objectives identified for the program. Several global/regional/intercomparison VOC data sets (Partridge et al., 1990; Apel et al., 1994; Hahn, 1994; Partridge, et al., 1994; De Saeger, 1994; Apel, 1995; Romero, 1995; Blake et al., 1996; Bonsang et al., 1995; Bottenheim and Shepherd, 1995; Donahue and Prinn, 1993; Greenberg et al., 1992; Greenberg and Zimmermann, 1984; Koppmann et al., 1992; Rudolph et al., 1989; 1992; Rudolph, 1995; Singh et al., 1988; Singh and Zimmerman, 1992) with attributes similar to those proposed for the GAW VOC Demonstration Network should be analyzed as part of and prior to the implementation of the proposed Demonstration Network.

These analyses should explore and demonstrate the utility of such data in:

1. source attribution studies to reconcile specific anthropogenic sources, anthropogenic vs. biogenic sources, ...,
2. correlational analyses with other surrogate codata if available (e.g. CO, NO<sub>x</sub>, NO<sub>y</sub>,...) to corroborate source emission contributions
3. correlational analyses with ozone and other available oxidized species to characterize atmospheric oxidation capacities.

#### **4.1.6 Training, Technology Transfer and Educational Infrastructure**

Specific training and educational requirements with regard to the GAW VOC Demonstration Network will initially require, in terms of operational needs, training in canister sampling and handling. In addition, basic educational activities should be considered including: 1) VOC measurement techniques, 2) VOC emissions and chemistry, and 3) diagnostic analysis techniques in the use of VOC and other codata for studying source attribution and the oxidation capacity of the atmosphere.

The mechanism for implementing the above respective training and educational activities within GAW QA/SAC and in cooperation with IGAC-ACEED has been documented in WMO/GAW Report No.104. Interested parties are referred to this document for further details.

## 4.2 Subworking Group II -- Sample Collection and Analytic Procedures

### 4.2.1 Techniques

Whole air grab sampling and in situ measurements are the two approaches currently used for nonmethane hydrocarbon analysis. Both methods have advantages and disadvantages and have been briefly mentioned. Many of the problems associated with in situ and grab sampling methods are discussed in the following references: Blake et al., 1992, 1994 and 1996; Bonsang et al., 1995; Bottenheim and Shepherd 1995; Donahue and Prinn, 1993; Greenberg et al., 1992; Greenberg and Zimmerman, 1984; Hoffmann, 1995 Hoffmann and Klockow, 1993; Koppmann et al., 1995; Oliver et al., 1986; Rudolph, 1995; Rudolph et al., 1989 and 1992; Singh and Zimmerman, 1992; Singh et al., 1988. Although there can be significant problems associated with canister sampling the suggested approach for nonmethane hydrocarbon analysis is via grab samples.

### 4.2.2 Collection

At the selected sites it is suggested that duplicate samples be collected twice a week. Random diurnal samples should also be collected. The specific days for canister filling may vary from station to station but occasionally samples should be collected on weekends to ascertain whether significant differences exist between weekday and weekend air masses.

The length of the stainless steel tubing used to bring the sample into the station should be minimized. The height of the inlet should generally be 2-10 meters unless otherwise specified by the individual site locations. For example, if a site is located in a heavily forested area the inlet should be located above the canopy to avoid biased data resulting from emissions from the nearest tree. The group was divided as to whether significant amounts of ozone make it through a metal bellows pump and into canisters. Thus, there was no agreement as to whether ozone should be scrubbed prior to canister filling.

The evacuated canisters should be filled to a pressure of 45 psig using a stainless steel metal bellows pump. The 45 psig ultimate pressure of the cans will allow them to be safely transported and stored yet provide stability for the sample, which for unknown reasons occurs when filling canisters to these pressures. Prior to filling the inlet line and pump should flush for at least 5 minutes. The filling time of the samples should be in the 1-5 minute range. Although many groups, particularly in urban studies, collect integrated samples for periods of as much as 24 hours, it was noted that integrated samples can often times be difficult to interpret because they are a combination of many sources. If the sample station is remotely located then the air reaching it should be homogeneous and an integrated sample would not be necessary. For the benefit of the station operator it was suggested that all samples, excluding the diurnal samples, be filled at local noon or at the time samples are routinely collected at that site.

The logging of co-data corresponding to canister sample collection are important. The minimum parameters listed for each sample are GMT and local time, ozone, carbon monoxide, black carbon, and humidity. If other data at a station exist, such as concentrations of halocarbons, methane or nitrous oxide, they should also be recorded.

There are many types of canisters currently being used with different degrees of success. Double valve canisters are more expensive but allow for flushing the canister prior to pressurization. Members of this panel had experience using both one and two valve canisters and it was the consensus of the group that accurate results were possible with or without flushing the canisters prior to pressurization. The current canisters available on the market and those made by the individual research groups vary significantly in size and shape but all are in the same price range of 400-550 US dollars per canister. There are about as many conditioning processes as there are varieties of canisters. Each type of canister is unique and so is its conditioning process. Because many research groups have reported canister problems when samples were allowed to

sit for extended lengths of time it is suggested that filled samples sit for no more than one month before being shipped from the field. Thus, sample boxes capable of holding 8 to 12 samples should be used. Both grab sampling and in situ measurements are advantageous and we feel that the station at Hohenpeissenberg would be ideal to perform a parallel study using both techniques. Using standards provided by the IIWMO World Calibration Facility for VOC" and directed by Dr. Christian Plass-Duelmer, a rigorous comparison using in situ and canister samples should be conducted. Many uncertainties associated with both techniques would be addressed in this study. Also, it has been suggested that a new aluminum canister will soon be available at a reduced price and it is supposed to have fewer nonmethane hydrocarbon storage problems. This in situ/canister study would be ideal for testing new types of canisters, such as those made of aluminum.

### **4.2.3 Analytical Procedure**

#### *4.2.3.1 Method*

There are many analytical configurations currently being used in nonmethane hydrocarbon analysis. Different columns, pre concentrating materials, temperature programs and carrier gases are just a few of the parameters that vary from group to group. Although there is some merit in having a standardized method of analysis it has been shown that using different combinations of these parameters can yield accurate and precise results. Therefore, proposals for nonmethane hydrocarbon analysis will be judged on results from various intercomparisons (NOMHICE being a must) and their publications in the field of nonmethane hydrocarbon analysis and interpretation. Also, because of the different analytical techniques employed the specific amount of sample used for analysis likely will be different among laboratories, thus, it is up to the responsible laboratory to determine the optimum sample amount for their system. This initial study focuses on C2-C9 nonmethane hydrocarbons. At least 4 reviewers, all with considerable experience in nonmethane hydrocarbon analysis, will be used for each proposal. In addition to privately prepared whole air working standards, calibration standards will be provide by the IIWMO World Calibration Facility for VOC".

#### *4.2.3.2 Laboratory practice*

Recording information in a laboratory notebook is considered important for successful quality assurance. Listing time and date of analysis for each sample and standard and the time and date when the sample was collected is essential. The sample volume, pressure and laboratory temperature should be recorded. Also necessary are operator comments which may be useful for understanding analytical anomalies discovered after analysis. Copies of the laboratory notebook and the raw computer data should be made each day. It is advisable to store the raw chromatograms on at least two types of storage disks.

During the early stages of this program the nonmethane hydrocarbon analysis laboratory will be required to undergo frequent audits. Once the laboratory has demonstrated a high level of accuracy and precision the audits will continue but their frequency will decrease. The laboratory is required to run at least one blank each day. The frequency of whole air standard analysis will be decided by the laboratory but no more than 10 samples will be run between standards.

It was mentioned in the sample collection section that canister storage of whole air samples for lengthy periods of time can lead to erroneous results. Therefore, it was decided that filled samples should remain in the field for no more than one month before their return to the laboratory for analysis. Thus, it is important that filled canisters not sit in the analytical laboratory for extended lengths of time prior to analysis. It is suggested that samples be assayed within one month of their return to the laboratory.

#### 4.2.3.3 *Data archival*

Data should be submitted to a designated archival center every 6 months for results from samples collected 6-12 months before the archival date. That allows for a minimum of at least 4 months for sample analysis, data quality control, and assimilation of data into spreadsheet format. Data should be submitted in comma-delimited ASCII format, Lotus 1-2-3 format, and Excel 3.0 (or above) format. This variety of data formats will allow maximum usage by the atmospheric sciences community.

#### 4.2.3.4 *Pilot stations*

At this time it is felt that although some research groups may be quantifying terpenes successfully, analytical problems associated with terpene storage and analysis are significant, thus the initial phase of this program will deal only with C2-CQ hydrocarbons. It is recognized that terpenes can play a significant role in photochemical ozone production and eventually these gases need to be included in the GAW site hydrocarbon analysis. Therefore, we suggest that a pilot station for developing methods for terpene analysis and storage be initiated. At that site canister storage issues, tenax traps, pressurizing pump studies, and various analytical problems can be addressed. Hohenpeissenberg is the logical site for this project because findings from this study could be compared to their in situ results. This program would be overseen by Dr. Christian Plass-Duelmer.

#### 4.2.3.5 *WMO World Calibration Facility for VOC*

There are many research groups around the world involved in nonmethane hydrocarbon analysis. Many of these groups are successfully quantifying numerous nonmethane hydrocarbons. However, some groups are currently experiencing difficulties and it is the feeling of this group that a major problem is the lack of accurate calibration standards. If a "WMO World Calibration Facility for VOC" were established and all research groups had access to standards, major hydrocarbon discrepancies currently seen in the literature would be significantly reduced. Also, once standards are available, groups still unable to quantify test standards will know that their problem is not with calibration gases but are analytically based. Once these groups improve their abilities to quantify nonmethane hydrocarbons, intercomparison of sample data among groups will be possible. We strongly support the establishment of a WMO World Calibration Facility for VOC and feel that it will contribute significantly to improving agreement between laboratories involved in nonmethane hydrocarbon analysis.

### **4.3 Subworking Group III -- GA/GC, Calibration and Intercomparisons**

#### **4.3.1 Organization of QA/QC and of Calibration**

In order both to assure and to demonstrate the accuracy of the VOC data produced by the planned GAW network the GAW management should set up a WMO World Calibration Facility for VOC (WCF-VOC).

The WCF-VOC Centre will be responsible for ensuring and demonstrating that all GAW measurements of VOCs are of high quality, and are thus fit to be used by governments and scientific organizations. This will be achieved through the application of well-established QA/QC techniques, such as the production and use of Standard Operating Procedures (SOPs), the critical evaluation of the GAW data (Section 4.3.3), the organization of intercomparisons (Section 4.3.7) and the auditing of the GAW sites and analytical laboratories (Section 4.3.3).

The Calibration Centre will be responsible for obtaining the VOC standards required by the GAW network for calibration purposes (Section 4.3.4), for supplying these standards to the GAW analytical laboratories as needed and for conducting intercomparisons (in collaboration with the QA/QC Centre).

The QA/QC Centre and the Calibration Centre could be the *same* organization or two separate organizations, although in the latter case the two would need to work closely together. They would operate also in collaboration with the existing QA/SAC units set up by GA W for calibration and supervision of the measurement of various atmospheric species (CO, CO<sub>2</sub>, O<sub>3</sub>, etc.).

#### **4.3.2 Organization of VOC Analysis**

GA W is currently planning to make its VOC measurements by canister grab sampling of ambient air, with *subsequent* analysis of the samples. It could thus, in principle, operate with a *single* VOC analysis laboratory, and send all grab samples to that laboratory from all the global sites. This has the great advantage of a common analysis system for samples.

A disadvantage, however, of a single analytical laboratory is that some grab samples may be in transit for long periods before measurement and might be subjected to extremes of temperature. This could lead to alteration of the VOC content before they were measured. Furthermore, when the network is being set up it may prove necessary for GAW to agree that some countries which have undertaken to operate GAW VOC sites shall be allowed to analyze their own ambient air samples. Thus the GAW network may well be required to use several different analytical laboratories, rather than a single central one.

The calibration and QA/QC procedures required will be similar whether one or more laboratories make the VOC analytical measurements for GAW, although for multiple laboratories the QA/QC requirements, and hence the costs, will clearly be greater. It is *most* important, however, that the QA/QC Centre should be *separate*, and be seen to be separate, from all of the GAW VOC analysis laboratories. Use of a common laboratory for both functions would not give any confidence that the analytical results were being impartially assessed and validated.

#### **4.3.3 QA/QC Centre Functions**

This centre would have responsibility for both quality assurance (QA) and quality control (QC) in the GAW VOC network.

Quality assurance is the arrangement of activities such as to provide confidence that an agreed performance will be delivered. Quality control is the regular monitoring of those activities to ensure that the agreed performance is actually being obtained.

QA as applied to the GA W network would cover items such as the ambient air sampling methods, the transport of the air samples, the organizational structure of the analytical laboratories-, the working environments of the analytical laboratories, the suitability of the analytical instrumentation, the suitability of the data processing and storage systems, and the maintenance of all parts of the analytical system.

QC for the GAW network would in the first instance be applied by the GAW sampling sites and analytical laboratories themselves. However, to provide confidence that QC was indeed being applied, and applied correctly, the QA/QC Centre should supply *auditors* to make regular checks. The auditors would examine both the QA arrangements, noted above, and the QC arrangements. The latter would cover items such as the manner in which the ambient air sampling and transport was actually being conducted and the records associated with it, the records of the analytical laboratories in respect of the samples analyzed and of the maintenance of the complete analytical system, and the validity of the analytical data.

Checks on the validity of the analytical data are important, especially in the early stages of a network, in order to provide confidence in the reliability of the data. They should include examination of items such as the consistency of the VOC retention times in the GC analyses over periods of months, the existence of any VOCs internally-generated by the analytical system, the adequacy of the calibrations performed (Section 4.3.4), difficulties with variable chromatogram

backgrounds and overlapping peaks and incorrect peak identifications. Some of these items can be examined with the use of audit standards (Section 4.3.6).

#### **4.3.4 Calibration Standards**

##### *4.3.4.1 Reasons for calibration*

The accurate measurement of VOCs in ambient air samples by gas chromatography requires the use of VOC calibration mixtures for the following main reasons:

1. to record the retention times of all the VOCs that it is required to measure, in order to enable *identification* of each VOC.
2. to note *changes* in the retention times due to changes in the GC system, and thus avoid *mis-identification*.
3. to establish the *response* of the GC system to all the required VOCs, and thus enable the measurement of *concentrations*.
4. to check the GC system for measurement *problems* (such as breakthrough of low molecular weight compounds or adsorption of high ones), through observation of *anomalous* VOC responses.
5. to provide a short-term check (typically daily) that the GC system is working correctly.

Note that it is not sufficient to obtain the full set of hydrocarbon response values by calibrating with one or two hydrocarbons only, and then scaling these results to all the other hydrocarbons on the basis of their number of carbon atoms. This would require the assumption that there are no problems of the type noted in (4) above, which is often unjustified.

##### *4.3.4.2 Calibration standards required*

The following gas standards (Woods et al., 1993) should be used in the GAW VOC analysis system

1. A multi-component VOC mixture containing, in nitrogen, *all* of the VOCs that GA W is expecting to measure (this number may be increased in stages after the initial set-up of the GAW network). This "full VOC" mixture should be carefully prepared (by gravimetric techniques) so that the concentration of the VOCs in it are accurately known; preferably to better than  $\pm 3\%$  (at 95% confidence). This mixture would be used to establish and check all retention times, to provide the response factors of all VOCs measured and to check for measurement anomalies.

2. A "restricted VOC" mixture, containing a few C<sub>2</sub>, C<sub>3</sub> and ~ hydrocarbons plus benzene. This would allow a frequent check of the GC system, typically daily. As it does not contain high molecular weight species it is not likely to cause any VOC adsorption in the GC system (such as could contaminate the next ambient air sample run).

3. A "whole air" sample, containing a typical range of VOCs in humidified air. This should give slightly more accurate retention times for the VOCs, as it is closer to the actual ambient samples. However, it would probably have to be instituted as a "second stage" of the GAW calibration scheme, since no fully satisfactory calibration mixtures are available at present.

**TABLE 1****Recommended Contents of Full VOC Calibration Mixture****(First stage of VOC selection for GA W)**

Ethane	Trans 2 Pentene
Ethene	Cis 2 Pentene
Ethyne	N-Hexane
Propane	Cyclohexane
Propene	2 Methyl Pentane
Propyne	3 Methyl Pentane
N-Butane	Isoprene
2 Methyl Propane	N-Heptane
2 Methyl Propene	Benzene
Trans 2 Butene	Toluene
Cis 2 Butene	Ethyl Benzene
1 Butene	1,2 Xylene
1,3 Butadiene	1.3 Xylene
N-Pentane	1,3,5 Trimethyl Benzene
2 Methyl Butane	1,2,4 Trimethyl Benzene

4. A "blank" gas, of very pure nitrogen or helium (preferably with no VOC in it having a concentration of greater than about 20 ppt) for "background" VOC measurements. This gas is needed to check for "memory effects" in the GC system due to contamination by previous samples, and for similar memory effects in *canisters* that have not been well cleaned.

The composition of the "full VOC" calibration mixture in (1) above depends upon the range of VOCs that GAW wishes to measure. It is recommended that GAW should *initially* measure just hydrocarbons from, C<sub>2</sub> to C<sub>9</sub>. In this case we further recommend that GAW should aim to measure 30 specific hydrocarbons, as listed in Table 1. Of these hydrocarbons, 26 were recommended by an EC Working Group as being the main ozone-producing species in European air. Four other hydrocarbons have been added to these on the basis of their observed prevalence in typical ambient air samples. These 30 hydrocarbons should therefore all be present in the "full VOC" standard.

If GAW wishes later to increase the range of VOCs measured to hydrocarbons up to C<sub>15</sub>, or to a range of oxygenated or halogenated species, then these would also need to be present in the "full VOC" calibration mixture.

The concentration of the VOCs in the first "full VOC" calibration mixture should be around 10 ppbv or, if shown technically possible, around 1 ppbv. The latter approximates the VOC concentrations found in many ambient air samples, except those in "background" sites (which are appreciably lower). The "whole air" calibration samples should have similar concentrations. Concentrations much higher than these would risk contaminating the GC system, requiring extra flushing with "blank" gas.

#### 4.3.4.3 Sources of calibration standards

For the "full VOC" calibration mixture, which will be used to obtain the actual concentrations of VOCs in ambient air, it is advisable that the supplier should be a national standards laboratory (such as NPL in the UK or NIST in the USA) who uses proven gravimetric preparation techniques. This is in accordance with the QA/QC concept of "traceability", by which all calibrations shall be performed using standards that have been verified, directly or indirectly, against the highest international primary standards.

Any set of "full VOC" standards obtained from one organization should be compared with any available similar standards from other reputable organizations, in order to further check their validity.

The "restricted VOC" mixture would not need to be made up to a high accuracy, as it would not be used for calculating the grab sample VOC concentrations. It should, however, be prepared in large size batches, since the daily performance of a GC system should be recorded and examined over a long period of time, to check for any steady deterioration. The same VOC mixture should be used for this, as long as possible. The mixture could be obtained from national laboratories or gas companies.

"Whole air" samples are being developed in Europe by, for example, IFU in GarmischPartenkirchen and by laboratories associated with VOC networks such as TOR and EMEP. The progress of such work will need to be monitored by GAW.

"Blank" gas samples may be obtained at relatively high purity from gas companies, and can be purified further by the use of special filters or cryogenic adsorption in liquid nitrogen. This could be done by the VOC Calibration Centre or by laboratories such as NPL. The permissible level of VOC impurities will depend on the lower limit of VOC concentration that is required to be detected at a particular site (in the case of canister testing) or by a particular GC system.

### **4.3.5 Use of Calibration Standards**

#### **4.3.5.1 Frequency of use**

We recommend that the "full VOC" calibration mixture should be run on the analysis GC approximately once every week, in order to demonstrate the correct operation of the complete GC system. The results should be recorded and plotted, to provide a long term "control chart" showing the stability of the system over many months or years. The "full VOC" mixture should also be run after every column change or significant system maintenance, as should the "whole air" sample.

The "restricted VOC" mixture should be run every day, and the results recorded as for the "full VOC" sample.

A "blank" sample should be run after *each* calibration sample, to demonstrate that the GC system is clear and ready for ambient air sample measurement.

#### **4.3.5.2 Conditions of use**

The VOC standards should always be run under the *same* conditions of sample flow rate, sample pressure and sample temperature, to ensure good reproducibility of the results.

#### **4.3.5.3 Linearity**

The linearity of the GC system with respect to VOC concentration should be checked over a concentration range of at least 100, and preferably 1000, about once a year or when the FID is changed or its gas input flows are significantly altered.

It is desirable that the same sample *volume* should be used for each linearity sample as is used for each ambient air analysis. To enable this the VOC Calibration Centre could arrange with the suppliers of the "whole VOC" or "restricted VOC" standards to supply a few of these mixture at several different concentrations.

#### **4.3.5.4 Storage**

The calibration standards should be kept at normal room temperatures, or above. Appreciable cooling, to 0°C or below, could well lead to some of the VOCs condensing on the walls of their cylinder.

### **4.3.6 Audit Standards**

An important part of the OA/QC Centre operations will be to provide and use audit samples, to demonstrate the correct operation of the analytical GC systems used by GAW.

The audit samples will generally need to be identical to the "whole VOC" calibration standards, but will have different concentrations that are known to the auditor but *not* to the laboratory whose GC system is being audited.

The auditor should present the audit sample to the operator of the GC, to be run in the same way as normal ambient air samples. The auditor can then observe the method of analysis and, later, can compare the measured VOC concentrations with the actual concentrations of the prepared mixture. Any measurement problems must then be resolved by discussion and, perhaps, further audit measurements.

A "blank" gas sample should also be available to the auditor, to check the GC system for memory effects.

### **4.3.7 Intercomparisons**

We have identified four different types of intercomparison which the GA W VOC network should undertake.

#### **4.3.7.1 Intercomparison of main GA W standard**

As already noted in Section 4.3.4.3, the "full VOC" GAW calibration standard should be intercompared with any other similar VOC high-quality standards that are available. This will not only give confidence in the GAW standard, with increased acceptance of its concentration, but will also give a linkage to networks that use the other standards employed in the intercomparison. This intercomparison would be carried out by the VOC Calibration Centre. .

#### **4.3.7.2 Intercomparison of GA W analytical laboratories**

If more than one VOC analytical laboratory is used in the GA W network then regular intercomparisons must be arranged between them, to check the internal consistency of the GA W analyses. This will most conveniently be arranged through the use of the Audit Standards discussed in Section 4.3.6. these can be used as transfer standards, with each laboratory measuring the same mixture in turn and the Auditor then comparing the results of all the laboratories. This would be the combined responsibility of the QA/QC Centre and Calibration Centre.

#### **4.3.7.3 Intercomparison of sampling techniques**

Each canister used for sampling will be cleaned before use either at the analytical laboratories or by each GAW site. If the latter is implemented then regular intercomparisons should be organized to test the cleaning efficiencies and, possibly, the sampling efficiency.

The cleaning efficiency should be tested by the QA/QC Centre regularly collecting typical cleaned canisters from all canister-cleaning centres. The canisters will then be filled by the QA/QC Centre with blank gas and with VOC standard gases, and measured over a period of time to check for any signs of VOC loss or VOC contamination.

If the *method* of sampling, rather than the canister used, seems likely to cause problems then the personnel taking the samples at each site could be asked to come to the QA/QC Centre in order to sample gas from a standard VOC mixture supply. This could be made one of the conditions for any organization to become an official GAW VOC sampling site, in order to demonstrate their sampling competence.

#### **4.3.7.4 Intercomparison of GA W with external laboratories**

GAW will need to demonstrate that its analytical results compare well with the best VOC measurement laboratories outside GAW, to increase confidence in the GAW data. This should be done by means of intercomparisons with other laboratories of proven expertise in VOC measurement, and would involve the measurement by all the laboratories of a common "full VOC" test mixture. Organization of this would be the combined responsibility of the QA/QC Centre and the Calibration Centre.

## **5. CLOSING OF THE MEETING**

The outline of the report and the recommendations were presented and accepted.

On behalf of WMO and BMBF, Professor Mohnen thanked the local organizer for making all arrangements and for use of the excellent conference facilities at IFU. Professor Mohnen thanked again Dr. F. Slemr and Dr. N. Schmidbauer for preparing the scientific background material

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<b>ANNEX A</b>	
<b>List of Acronyms</b>	
ACEED	Atmospheric Chemistry and Environmental Education in Global Change
BMBF	Bundesministerium fOr Bildung und Forschung (Germany)
EMEP	European Monitoring and Evaluation Programme
EPA	Environmental Protection Agency
EUROTRAC	European Experiment on Transport and Transformation of Environmentally Relevant Trace Constituents in the Troposphere over Europe
FID	Flame ionization detector
GAW	Global Atmosphere Watch
GC	Gas chromatography
GCOS	Global Climate Observing System
ICSU	International Council of Scientific Unions
IFU	Fraunhofer Institute for Atmospheric Environmental Research
IGAC	International Global Atmospheric Chemistry Programme
IOC	International Ozone Commission
JRC	Joint Research Centre
NARSTO	North American Research Strategy for Tropospheric Ozone
NCAR	National Center for Atmospheric Research
NIST	National Institute for Science and Technology
NMHC	Nonmethane hydrocarbon
NOMHICE	Nonmethane Hydrocarbon Intercomparison Experiment
NPL	National Physical Laboratory
PAN	Peroxyacetyl nitrate
QA/QC	Quality assurance/quality control
QA/SAC	Quality Assurance/Science Activity Centre
SOP	Standard operating procedure
SOS	Southern Oxidant Study
TOR	Tropospheric Ozone Research
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VOCs	Volatile organic compounds
WCFs	World Calibration Facilities

## ANNEX B

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## ANNEX C

### Agenda

Sunday, 17 December

18:00 Hotel Queens/Residence Lobby

"Ice Breaker"

19:00 Conference Dinner

Monday, 18 December

08:30 Transfer from Hotel to IFU

09:00 Opening of Workshop

Prof. Seiler, IFU; Prof. Mohnen, WMO-QA/SACs

Welcome address for

. Charge to the workshop and overview of QA/SAC "Calibration  
Facilities"

. Discussion of Agenda

09:45 General Discussion -- All Participants

Preparation of Final Agenda

10: 1 5 Coffee Break

10:30 Current Status of VOC (NMHC) Intercalibration Experiments

All Participants

12:30 Lunch

13:30 Current Status ... (Continued)

14:45 Coffee Break

15:00 Calibration Strategies for WMO GAW Based on "Available Technology"

All Participants

18:00 End of Session

Transfer to Hotel

Tuesday, 19 December

All day excursion to global GAW station at Zugspitze High Altitude Observatory  
(Weather Permitting)

Wednesday, 20 December

08:30 Transfer from Hotel to IFU

09:00 Development Needs

All Participants

10: 15 Coffee Break

10:30 Development Needs (Continued)  
International Cooperation

12:30 Lunch

13:30 Establishment of a VOC-Calibration Facility for WMO-QA/SAC: Problems and  
implementation strategy  
All Participants

14:45 Coffee Break

15:00 Break-up Sessions and Writing Assignments

18:30 Transfer to Hotel

Thursday / 21 December

08:30 Transfer from Hotel to IFU

09:00 Presentation of Individual Group Discussion Results

10: 1 5 Coffee Break

10:30 Workshop Summary and Final Discussion

12:30 Outlook and End of Workshop