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# REPORT OF THE GCOS ATMOSPHERIC OBSERVATION PANEL

## First Session

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## SUMMARY OF THE SESSION

The First Session of the GCOS Atmospheric Observation Panel met to consider actions necessary to begin implementation of the Initial Operational System (IOS). The Panel reviewed earlier work by GCOS Task Groups and by the Joint Scientific and Technical Committee. The Panel sought to refine requirements and make specific recommendations where possible.

The Panel addressed principally the close correspondence between observations taken to support Numerical Weather Prediction (NWP) and those to support climate requirements. The members agreed that the requirements for NWP meet many of those required for climate, but important additional requirements remain. For example, additional observations are required to provide boundary conditions, both at the top and bottom of the atmosphere, additional attention must be paid to the accuracy, homogeneity, continuity and intercomparability of the measurements.

The Panel developed an outline of the IOS for atmospheric observations and provided a specific recommendation for a baseline upper-air network for climate. It also proposed specific actions to identify a surface reference climate network and to co-ordinate atmospheric composition measurement programmes. The Panel gave strong support to the development of Climate Data Assimilation Systems (CDAS), and to the establishment of centres for the dissemination of climate information including data and products.

Some specific recommendations include:

1) Baseline upper-air network -- Having developed a baseline upper-air network, the Panel recommended:
   - The network design be presented to the WMO Commission for Basic Systems, and its Working Group on Observations, to WMO Regional Associations, and to particular countries or agencies;
   - That a comprehensive approach to the data management issues associated with the baseline network be developed in partnership with the Data Management Panel. It suggested: (1) that a proposal be prepared for CBS to designate a lead centre; (2) that users be identified to assist in providing a quality control activity; and (3) that a special archive for the data be established.

2) Surface reference climate network -- The Panel was unable to develop the detailed network for surface observations, but proposed that:
   - A joint meeting of selected members of the CC1 Working Groups on Data Management and Climate Change Detection, staff of the World Climate Programme Data and Monitoring Programme (WCDMP), and representatives of the AOP be scheduled to address the network issues.

3) Atmospheric Composition -- Representatives of the various networks for composition measurements should be brought together to consider mutual plans for observations, including quality assurance. The Panel noted that there is a continuing need for the development of models, and that specific observations will be required for their development.

4) Climate Data Assimilation System -- The Panel noted the value of the reanalyses now underway or being planned for the near future. Building on the experience with reanalysis, the Panel urged that Climate Data Assimilation Systems (CDAS) be developed in the appropriate centres and should convey this view to the centres, inviting them to provide information on their plans.

5) The "fingerprint" approach -- Noting that some parameters may be particularly sensitive to the changes in climate, the Panel strongly supported a meeting to identify those parameters which might be particularly valuable as indicators.

6) Ice and snow observations -- Noting that many observations of ice and snow are made, but not distributed effectively, the Panel suggested that an individual be identified to prepare a report which could serve as a proposal.

7) Membership and terms of reference -- The Panel considered that additional experts, particularly in atmospheric composition and climate diagnostics, should be invited to future meetings.

# REPORT OF THE GCOS

# ATMOSPHERIC OBSERVATION PANEL

## 1. OPENING OF THE SESSION

1.1 Dr. Lennart Bengtsson, Chairman of the Atmospheric Observation Panel (AOP), opened the meeting at the Max Planck Institute for Meteorology, Hamburg, Germany, on 25 April 1994 and welcomed the participants (See Annex I). Noting that this was the first meeting of the Panel, he invited each of the participants to provide a brief personal introduction.

1.2 The Chairman briefly reviewed the overall concept of GCOS, stressing the importance of the discipline-oriented panels such as the AOP in developing the requirements for observations, and in establishing mechanisms for implementation. He noted that the work of the AOP would be critical to the Joint Scientific and Technical Committee (JSTC) for GCOS. As a member of the JSTC, he will plan to report the results of the Panel meeting.

1.3 The Chairman reviewed the provisional agenda, which was briefly discussed and accepted (See Annex II), and proposed working hours for the session. He informed the participants about the material arrangements and in particular, noted a special seminar on the use of the refraction of radiowaves from Global Positioning System (GPS) satellites for the determination of temperature and moisture profiles in the atmosphere to be given by Dr. Gorbunov and Dr. Sokolovsky later in the session.

## 2. INTRODUCTION AND GCOS BACKGROUND

2.1 Dr. Spence, Director of the Joint Planning Office (JPO) for GCOS provided an overview of the GCOS planning activities to date. He reviewed the highlights from the inception of the programme at the Second World Climate Conference to the present meeting, and noted the responsibilities of the JSTC in planning, implementing, and overseeing the development of the GCOS programme. He specifically noted that the Third Session of JSTC established several discipline-oriented panels and cross-cutting task groups.

2.2 The Director described the other panels and task groups, pointing out their responsibilities. He noted the recent meetings of the Data System Task Group and the Ocean Observation System Development Panel (OOSDP), and the upcoming schedule of other meetings.

2.3 He pointed out that the AOP was established to develop specific scientific and technical input concerning atmospheric observations. Fundamentally, the Panel will be expected to formulate and design the long-term systematic observing system as an integrated part of GCOS. They will co-ordinate their activities with the other task groups and panels to ensure consistency among the programme components. They will make specific recommendations regarding implementation.

## 3. OPENING STATEMENT OF THE CHAIRMAN

3.1 The Chairman, referring to the terms of reference of the Task Group (See Annex III), reviewed the objectives, work plan, and actions to be taken. He provided an overview of the importance of the AOP in defining requirements and proposing mechanisms to implement the needed observing system components.

3.2 The Chairman reviewed the objectives of GCOS, and in particular, noted the priorities established by the JSTC:

- o Seasonal to interannual prediction,
- o Climate change detection at the earliest date,
- o Reduction of the uncertainties in climate change.

3.3 Regarding the first item, he illustrated the recent progress in predicting El Nino phenomena, and commented on the various models which are effective in providing forecasts of the events. He indicated the widespread influence of El Nino on the climate, but noted that many of the regional impacts are not well documented as yet. In particular, he noted the increase of cyclonic activity in the Pacific and the changes in precipitation in mid-latitude regions. He challenged the Panel to determine what observations should be obtained to improve our capability to predict such phenomena.

3.4 Similarly, with respect to the other priorities, he underlined the dependence on observations of parameters such as global temperature, aerosol loading in the atmosphere, atmospheric constituents, particularly radiatively active gases, and others useful in assessing change, and leading to reductions in uncertainty.

3.5 The Chairman outlined his expectations for the meeting. He recommended that attention focus on: (1) the strategy to design the atmospheric components; (2) the development of the GCOS Initial Operational System (IOS); (3) the definition of baseline networks; and (4) future systems. For all these, actions leading to implementation should be specifically developed.

3.6 The remarks of the Chairman stimulated a discussion session among the participants. They expressed concerns about the links to operational programmes such as the World Weather Watch (WWW), the difficulty of gaining access to some of the categories of data which are being collected (e.g., snow depth), and the use being made of existing data. Further, members were concerned about the adequacy, quality, and representativeness of observations being taken for other purposes insofar as they satisfy climate needs.

## 4. INVITED REPORTS

The Chairman invited a few reports to provide a context for the future deliberation of the Panel.

### 4.1 Task Group on Atmospheric Processes

4.1.1 Dr. Trenberth was invited to review the earlier work of the Task Group on Atmospheric Processes, and to take a critical and constructive look at its conclusions. He was further asked to outline a set of key issues for the Panel to consider.

4.1.2 Dr. Trenberth stated that the success of GCOS will be contingent upon developing compelling needs for the climate observations. While noting the significant scientific uses of the data, he argued that the real benefits would be for the societally-important questions that influence the well being and economic security of the people. For the latter, he discussed two time scales seasonal-to-interannual, and decadal-to-century.

(a) At the seasonal-to-interannual time scale, improved monitoring and prediction will provide information that is potentially exceedingly valuable provided it is appropriately disseminated. Proposals are underway to develop an infrastructure that would provide such dissemination and increase the utility of such information.

(b) For the decadal to century time scale, principal focus is on anthropogenically induced climate change. Key questions arise concerning the timing, the magnitude, and regional impact of the climate change. The observational data base and subsequent analyses should provide guidance to policy makers engaged in response and mitigation strategies. In this regard, the observations from GCOS will contribute to the Intergovernmental Panel on Climate Change (IPCC), and other political and economic fora in this arena.

4.1.3 Dr. Trenberth elaborated on four specific sciences issues:

(a) Climate change detection -- The issue is how to detect anthropogenic climate change in an unambiguous way in the presence of a very noisy background natural variability. Needed is a stable quality assured network of observations with homogeneous, long-term records;

(b) Seasonal' to interannual prediction -- The TOGA research programme has established the feasibility for skilful predictions up to several seasons in advance for certain regions. To support this activity, an ocean and surface climate observing network has been established and needs to continue. Some needs are common to those of Numerical Weather Prediction (NWP), namely timely observations over the Global Telecommunication System (GTS), 4-D Data Assimilation (4DDA) to produce global analyses and to initialize ocean models. Such data come in part from the Tropical Ocean-Global Atmosphere (TOGA) TAO Array. Detailed recommendations may be found in the GCOS document "Operational Ocean Observing System for Seasonal to Interannual Climate Prediction";

(c) Climate monitoring and regional climate anomalies -- This activity monitors climate in near real-time and produces regional climate anomalies and diagnostics throughout the world. The analyses and statistics have many uses (e.g., research on empirical studies, model development and validation; climatology; hydrology; agriculture; impact assessment). In addition to observing conventional physical climate variables, this includes monitoring the chemical composition of the atmosphere (developing understanding of biogeochemical cycles, tracking emissions versus controls; international agreement requirements, etc.);

(d) Climate forcings -- To determine the causes of climate change and further diagnose the feedback processes, several other forcing fields are needed. These include top-of-the-atmosphere radiation (solar, infrared, net), cloud cover, global precipitation, aerosol (loading and characteristics), and principal chemical species in the atmosphere. In addition, boundary forcing parameters including sea surface temperature, land surface characteristics (albedo, soil moisture, roughness, vegetation, etc.).

4.1.4 Using these illustrations, Dr. Trenberth provided justification for the collection of data based on their subsequent use. He noted that the observations must be linked to specific needs, and must: (1) be science driven; (2) be prioritized and optimized as far as possible; (3) entrain interested users both for original observations and for products derived from them; and (4) involve "proactive" data centres.

4.1.5 Dr. Trenberth noted that observations to meet climate requirements mandate certain additional things: (1) additional requirements for climate versus weather; (2) specific additional observations of certain kinds for climate purposes; (3) additional processing and product generation, especially global analyses; and (4) additional issues of data availability and access (See Annex IV).

4.1.6 Finally, Dr. Trenberth reviewed the "Report of the GCOS Task Group on Atmospheric Processes" noting that the Task Group had developed a good framework for further work. Based on his and other comments, the Panel recommended that the draft report should be updated and published. Members agreed to provide some specific inputs to the report to make it more useful as an element of the overall GCOS documentation.

4.1.7 Dr. Trenberth's presentation prompted a broader discussion concerning support for the needed enhancements to present systems for climate. Since the implementation of GCOS is anticipated to be based on national contributions, the need for national groups to be established and to respond to the needs of GCOS was acknowledged. Members who represent operational systems agreed that, given specific requirements and guidelines, they may be able to make major contributions. However, the Panel agreed that resource considerations must be kept in mind when proposals are being developed.

4.1.8 Regarding the availability and accessibility of data, Dr. Sato commented that much information on snow and ice, while collected, is not being made available. The Panel agreed that data availability issues should be seriously addressed.

## 4.2 Task Group on Atmospheric Constituents

4.2.1 Dr. Seiler was invited to review the earlier work and the "Report of the GCOS Task Group on Atmospheric Composition" and to highlight priorities for the Panel to consider. He felt the document was a good statement of the needs for measurements of atmospheric constituents, including aerosols. He noted that the proposed "comprehensive network" of stations was being implemented -- albeit rather slowly. He noted some specific areas in which the Task Group report could be improved for publication as a contribution to the GCOS documentation.

4.2.2 Dr. Seiler provided an overview of some current observational programmes for atmospheric constituents. With regard to some atmospheric composition measurement programmes, Dr. Seiler was concerned that quality assurance was not given adequate priority. He urged that future GCOS networks include quality assurance *ab initio.*

4.2.3 Members of the Panel stressed the difficulties about the incorporation and integration of atmospheric chemistry data into dynamical models. Since some of the processes are indirect, they have not been adequately modeled. Some members were concerned about the large variation in time and space scales for constituent measurements -- some constituents have very short lifetimes; some have regionally dependent concentrations. It was agreed that a composite sampling system including surface stations, profiling techniques, and space-based observations is required.

4.2.4 The Panel felt that credible arguments exist for developing the requirements for atmospheric constituents and recommending a network. It was recognized that the GAW programme is proceeding to develop a network of global stations. A close collaboration between GCOS and such programmes was urged. However, it was noted that close contacts with the science community is also critical, since constituent observations often require sophisticated sampling strategies and techniques. GCOS was urged to take a leadership role in developing a forum for discussion of the atmospheric constituent requirements for climate, and to insure that the appropriate bodies are actively involved in the discussion.

## 4.3 The GCOS Plan

4.3.1 The steps leading to the development of the GCOS *Draft Plan* were reviewed by the Chairman. The relevant atmospheric components of the plan were based on the work of the two task groups noted above, and the discussions at JSTC-II in Washington. Future versions of the plan will be closely related to the progress of the various panels and task groups established by the JSTC. It was emphasized that the process of developing and maintaining a consistent plan is an evolutionary one.

## 5. STRATEGY FOR DESIGN OF THE ATMOSPHERIC OBSERVATIONAL PROGRAMME

Several brief presentations on the development of GCOS planning to date were provided to the Panel as background for its deliberation.

### *5.1* The Historical Perspective

5.1.1 Since the establishment of GCOS, one key priority has been to develop the concept and define the components of the Initial Operational System (IOS). The IOS should consist of: (1) those essential observational components which are currently operational; (2) those essential enhancements and augmentations to current operational components which may be identified for implementation now; and (3) a comprehensive data management system.

5.1.2 With regard to the atmospheric elements of the IOS, Task Groups on Atmospheric Processes and on Atmospheric Composition met in September and in October 1992 respectively. Each group prepared a report which included discussions of the observational requirements, and each developed both short-term and longer-term recommendations. The reports were discussed at JSTC-II in January 1993, and incorporated in the initial ***Draft Plan*** of April 1993. Both Task Group reports are available from the Joint Planning Office.

### 5.2 Relations between GCOS and WWW

5.2.1 Many of the requirements for atmospheric measurements to meet GCOS objectives are currently being met by elements of the World Weather Watch (WWW) of WMO. Consequently, the Panel considered the evolving relationship between WWW and GCOS, which it felt to be critically important. Mr. Mildner, Vice President of the Commission for Basic Systems (CBS) briefed the Panel on recent changes in the CBS terms of reference. The new terms of reference encourage CBS to address specifically the needs of GCOS and other related users of the basic systems.

5.2.2 Mr. Mildner reported on the meeting of the Advisory Working Group (AWG) for CBS at which GCOS requirements were discussed. The AWG agreed that the primary contribution would relate to the observational systems and networks for both surface-based and space-based data management, telecommunications, and data processing. Specific contributions should include:

arrangements for making CBS experts available to GCOS and for active cooperation with the relevant GCOS bodies;
use of existing observational networks and new observing systems;
design and use of baseline networks;
data management planning, procedures and systems;
guidance on data structures, availability and quality for long-term operational systems;
advice on archiving of data;

- exploitation of Numerical Weather Prediction (NWP) techniques for climate modelling;
- use of NWP models to produce long-term uniform data sets for climate research;
- procedures for data quality control and quality assurance;
- advice on data assimilation techniques;
- use of a modernized telecommunication system.

The AWG report and other documents concerning CBS contributions to GCOS will be submitted to the CBS Extraordinary Session in July for consideration. He reminded the Panel that many of these activities will involve incremental costs for which resources will need to be secured.

5.2.3 Mr. Mildner further urged the Panel to work out the detailed requirements for measurements and for data management in cooperation with the Working Groups of CBS (Observations, Global Telecommunications, Data Management, Data Processing, Satellites) so they may be presented to the nations for implementation. In this context, he specifically recommended that the developing countries be kept fully informed, since their participation will be essential to an effective system.

## 5.3. Data Requirements for the GCOS Atmospheric Component

5.3.1 The Panel considered that observations for climate research can conveniently be arranged into six specific categories, namely:

1) The 3-D state of the atmosphere including second order moments, vertical fluxes of heat, moisture and momentum, as well as other similar physical and dynamical quantities.

These data are presently produced by 4DDA systems using advanced high resolution general circulation models. The overall observational requirements for global NWP as formulated by the CBS Joint Working Group on Data Processing and Working Group on Observation Task Team on Data Requirements (See Annex V). The Panel noted that the observations being used by such data assimilation systems will also satisfy the requirements the climate applications with the proviso that for such applications, the mean error must be a very small fraction of the root mean square error. In addition climate studies also need data throughout the whole middle atmosphere up to some 80 km; the observational requirements are here the same as in the lower stratosphere. The Panel stressed the great importance of accurate vertical profiles for wind and temperature which determine the quality of many other parameters. The Panel also recommended that 4DDA systems be run in a delayed mode with a frozen system in a way similar to that done in the reanalysis projects (See section 6.4).

2) Data for the determination of the state of the surface of the earth, SST, soil moisture, vegetation, albedo, roughness, snow, ice, etc.

These requirements are more stringent than in NWP since small errors in these data may influence the large scale circulation in a detrimental way, especially in long integrations. In addition, data must be available for the whole surface of the earth. This is presently not the case since data for snow and soil moisture, for example, are not exchanged globally (See Annex V).

3) Data for the determination of clouds, and of radiation fluxes at the surface and at the top of the atmosphere.

Accurate knowledge of the large scale radiation balance is important for reducing the overall systematic biases in climate models and to use such data for example to better determine representative cloud properties for large scale processes (See Annex V).

4) Data on the composition of the atmosphere.

The chemical composition of the atmosphere, in addition to the clouds, exerts a dominant influence on the radiation balance of the atmosphere. The atmosphere contains many gases, most in only trace quantities, which are critical in controlling climate. Observations of these gases are important elements of GCOS. Additional detail on atmospheric composition requirements is contained in the "Report of the GCOS Task Force on Atmospheric Composition".

5) Data for process studies.

Process studies in the form of specific field programmes play a central role in model development. GCOS presently has no specific requirements in addition to the programmes presently underway within WCRP, IGBP or other research programmes.

6) Data for long-term monitoring.

The GCOS requirements include five **datasets** in this group:

(a) an upper-air baseline network consisting of selected upper-air stations;
(b) a surface baseline network of selected SYNOP stations;
(c) a surface baseline network for atmospheric composition;
(d) satellite systems for monitoring the temperature of the atmosphere;
(e) global observations of the hydrological cycle, precipitation, river runoff, lake water levels.

## 6. THE INITIAL OPERATIONAL SYSTEM -- ATMOSPHERIC COMPONENT

The Chairman suggested that the Panel give priority to a consideration of the IOS, particularly with regard to the atmospheric component. He asked a small group, considering the requirements for the IOS, to develop a comprehensive outline of the IOS for the Panel to review later in the meeting (See Annex V). He then invited several members to provide insight in current observational programmes and issues.

## 6.1 The Current WWW -- Status and Prospects

6.1.1 Dr. Julian presented a background document on the IOS. He recommended that the Panel should consider a detailed *in situ* atmospheric observing system which would include: (1) the present WWW; (2) enhancements to the WWW Global Observing System (GOS); (3) new operational components (e.g., the TOGA observing system); and (4) data assimilation aspects. He noted that these recommendations echo the short-term actions recommended in the "Report of the GCOS Task Group on Atmospheric Processes".

6.1.2 Noting that Climate Data Assimilation Systems (CDAS), are similar to global NWP models, he observed they should have similar data requirements. For example he noted:

- they require similar primary dependent variables (temperature, humidity, winds, pressure);
- they use similar accuracies and quality control procedures;
- they produce similar derived quantities;
- their assimilation techniques are identical.

However, he cited notable differences such as:

- CDAS focus on analyses, not forecasts. Thus, re-tuning is warranted;
- time-averaged quantities are important in climate so controlling bias is important;
- CDAS may use sources not available in real-time.

As a result of these 'factors, atmospheric components of the IOS should be based heavily (but not exclusively) on the WWW/GOS.

6.1.3 On the basis of the foregoing discussion, Dr. Julian presented a document relating to the operation of the WWW. With regard to upper-air stations, for example, he noted that several important stations fail to report regularly, are in danger of closing, or are already closed. He acknowledged the difficulty of maintaining stations in remote locations, but noted that they are often the most significant in building a representative data base for climate purposes. He urged the Panel to consider, define, and recommend a network of selected stations to provide a baseline upper-air network for climate.

6.1.4 Dr. Sarukhanian, Chief of the Observing System Division of the WWW, provided additional information concerning the Regional Basic Synoptic Network. He noted that the requirements for observational data have been promulgated, and call for:

- surface observations from surface synoptic land stations reporting at least 4 times per day with a desirable horizontal resolution of better than 250 km;

upper-air observations from a land-based synoptic network of stations complemented by pilot balloon and radiowind observations stations in the tropics, reporting at least daily and a horizontal resolution better than 250 km.

He noted that inadequate data return is often due to a lack of equipment, supplies, or communication failures. He described the situations in Africa and South America, and shared a set of proposals and recommendations that are being presented to the appropriate Regional Associations for consideration.

6.1.5 The Panel, after considerable discussion, accepted the premise that many requirements for GCOS are being satisfied by the WWW/GOS, but went on to note that there are critical parameters that are not being satisfied by current observational programmes of GOS, and must be addressed either as enhancements to the current programmes, or as new elements. Examples of such requirements include boundary condition and validation parameters which are discussed later (See Annex V). In addition, the Panel also noted the need for improved continuity of measurements in the WWW.

## 6.2 Enhancements Needed -- GCOS Perspective

6.2.1 Dr. Julian presented a document which outlined a network of upper-air stations, suitably selected to meet climate requirements. While he observed that it is essential that the entire network of stations continue to provide data for NWP (See section 6.1.4), and for assimilation into 4DDA models, he proposed that a subset of stations be identified for long-term and continuous support. He recommended that the criteria for selection include: (1) station location (as homogeneously distributed as possible); (2) station reliability; and (3) length of record at the station.

6.2.2 The Panel discussed the upper-air network as an atmospheric element of the IOS and agreed to accept the criteria for its definition. A small working group was assigned to develop further details and identify specific stations to be included in the network (See section 7.1).

6.2.3 The Panel discussed the need for a surface climatological network analogous to that for upper-air measurements. It recommended that the Panel designate representatives to work with members of the Commission for Climatology (CCl) Working Group on Climate Change Detection (CCD) to develop a specific proposal for an appropriate station network (See section 7.2).

6.2.4 The Panel also considered the requirement for atmospheric composition measurements. It acknowledged that the chemical composition, in particular the climatically relevant trace constituents, have an important influence on the earth's radiation budget. Any change of the distribution and abundance of these constituents will have an impact on the temperature and thus on climate. Boundary layer and free air measurements are required both for monitoring and for model input and validation. The Chairman requested Dr. Seiler to detail these requirements (See section 7.3).

6.3 New Operational Systems

6.3.1 At its first session, the JSTC recognized that some observing systems established for research purposes could become an essential component of GCOS. An example of such a system is the TOGA observing network in the Pacific. Since the TOGA programme terminates at the end of 1994, and since the information deriving from the programme is being used in some operational centres, it is expected that components of the observing network essential for climate prediction should be continued under the auspices of programmes such as GCOS (or as an element of the Global Ocean Observing System (GOOS) whose climate module is the same as the GCOS ocean component).

6.3.2 The Panel discussed a document, "Operational Ocean Observing System for Short-term Climate Prediction" prepared by the JPO on the requirements for a continuing observing system in the Pacific. Although the focus of the document was principally on the oceanic elements, it provided justification for continuing a subset of the upper-air network. Upon review of the document, the Panel suggested a few modifications to update the text, and recommended that it be prepared for publication as a GCOS contribution.

6.4 Data Assimilation and Data Management Aspects

6.4.1 The Panel considered the data assimilation and management issues to be an essential element of its remit. As a result, the Panel was updated on current work and plans for data assimilation, reanalysis, and progress toward the establishment of a Climate Data Assimilation System (CDAS) by Dr. Ropelewski.

6.4.2 He noted that data assimilation is an important part of all modem NWP schemes. It provides, via a self-consistent, physically and dynamically-based system, gridded analyses using data from a wide range of sources. Specifically, assimilation systems provide an optimal way to merge surface, upper air, satellite, aircraft and other data into global analyses. In an operational framework, however, frequent improvements and modifications to the models and data assimilation systems limit their usefulness for climate studies. Thus, several meteorological centres have initiated projects to reanalyse data with an unchanging assimilation system.

6.4.3 Dr. Ropelewski described the "frozen" assimilation system (T62, 28 levels) which will be used by the U.S. National Climate Center (NMC) to reanalyse data back to 1958, and forward from 1994. This CDAS/reanalysis will generate four analyses per day with data to be saved in model coordinates. In addition, a flux data set consists of most of the components of the surface heat, moisture and radiation budgets and six diabatic heating terms will also be saved, all to be made available in various formats including subsets on CD-ROM.

6.4.4 He also updated the Panel on the European Centre for Medium-Range Weather Forecasts (ECMWF) ReAnalysis (ERA) that is being carried out for the period 1979 through 1993 (T106, 31 levels). All analysis parameters and the six-hour first guess forecast will be archived in model coordinates. In addition, post-processed files will be saved for 17 pressure levels and 10 potential temperature levels at the original model resolution (T106) as well as on a 2.5 ° latitude/longitude grid. Monthly statistics, temporal, zonal and global means, variances and covariances fluxes, etc. will also be computed. Twice a day precipitation will be calculated in a 24 hour forecast mode. Data will be available in GRIB format.

6.4.5 The Panel appreciated the update, and concluded that assimilation, reanalysis, and in particular, the CDAS will be extremely important in meeting GCOS objectives,

6.4.6 As additional information, the Panel was provided with a Draft Plan for Data Management which was reviewed and revised at the GCOS Data System Task Group. Also, the Panel received an update concerning the GCOS Space-based Observation Task Group which planned to meet the following week, and documents on Global Ocean Observing System. Finally, an interim report of a study of user requirements was provided to the Panel.

## 7. DESIGNATION OF GCOS BASELINE NETWORKS

### 7.1 Upper-air Network

7.1.1 The Chairman noted that the purpose of specifying global baseline networks was to insure a permanent network of high quality, well-distributed observing sites dedicated to making measurements of the basic meteorological variables. He invited the working group that was considering the upper-air network as an element of the IOS to report its progress in selecting a subset of stations for inclusion.

**7.1.2** In selecting stations from the presently operating GOS, the working group used the following criteria in order of importance: (1) the remoteness of the station, since that determines its relative contribution to the desired homogeneous distribution; (2) the performance of a site in producing high quality observations;' and (3) the existence of a reasonable length of historical record. The performance evaluation was based on the Lead Centre quality monitoring programme of the WMO CBS.

7.1.3 The Panel noted that the present **WWW/GOS** has experienced and continues to experience problems in the number, availability and quality of its upper-air network in some areas of the world. A number of GOS geographically isolated, and therefore important, sites have been closed for logistic and economic reasons. Thus, while the density and performance of stations is generally adequate for the IOS over the major land areas of the Northern Hemisphere, the situation is not so for much of the tropics and Southern Hemisphere. It was also pointed out that in 1985 approximately 1500 soundings per day were produced, but that in 1994 only about 1050 were available. Moreover, it now appears likely that some key island sites will be lost in the near future unless action is taken to reverse this decline.

7.1.4 After discussing many of the specific stations and related issues, the Panel accepted a baseline network consisting of about 150 stations (See Annex V). The Panel urged that the recommendations concerning the make up of the network be provided to the

WWW/GOS for action as appropriate. The Panel noted that Dr. Baede serves as Rapporteur on GCOS Matters to the CBS Working Group on Observations. Dr. Baede agreed to stage a review of the proposed upper-air baseline network by members of this Working Group.

7.1.5 The Panel recognized the difficulty in maintaining some of the stations in the network, and that some of them may be more suitable to profiling instrumentation. Members of the panel agreed to work with appropriate agencies to develop a strategy for implementation in these difficult situations.

7.2 Surface Network

7.2.1 The Panel noted the earlier efforts made by the CC1 Working Groups on Climate Data and Climate Change Detection toward the development of a network of Reference Climatological Stations (RCSs) suitable for monitoring and research on climate change. Data from such a network can describe inter-annual variability and inter-decadal and longer trends which must be documented in order to describe climate change and corroborate climate models.

7.2.2 The Panel recognized that many WMO Member countries have long-established surface stations whose records have sufficient continuity and homogeneity, but that cooperation is needed to enable the retrieval of copies of these records and their metadata to a central repository. The Panel therefore supported the recommendation of the CC1 Working Groups to invite World Data Centres to identify, with the assistance of a small group of experts, suitable stations to form the (RCS) network. Criteria would include: (1) record quality; (2) representativeness of the location; (3) areal coverage; and (4) prospect for continuity in the future. The WMO Members having potential RCSs within their national boundaries are invited to contribute copies of their records and metadata to the World Data Centres.

7.2.3 Taking note of the work done by the CC1 Working Groups, the Panel proposed that a joint task group of members designated by AOP and by CC1 address the selection of stations to comprise the network. Existing RCSs would be selected to form a GCOS Baseline Surface Network. The Panel recommended that the WMO Secretariat prepare a list of approximately 200 stations as candidate stations. It was suggested that the list should include, where possible, stations co-located with the upper-air stations proposed above for a GCOS Baseline Upper-Air Network, and RCSs which have long-term records.

7.3 **Atmospheric Composition**

7.3.1 The Panel considered the needs for measurements of the atmospheric composition, and determined that GCOS should assist in the implementation of the GAW global station network. The global network for detecting climate change and the chemical composition of the atmosphere should consist of:

(a) Global or baseline stations -- These stations should be representative for air masses or a regional scale and therefore should make observations outside the planetary boundary layer. The measuring programme should include almost all atmospheric parameters listed in Annex V. In addition, these stations should be operated or closely associated with research institutes to ensure that the data obtained are systematically evaluated scientifically. Global stations must be operated on a long-term basis and fulfil Quality Assurance/Quality Control requirements.

(b) Regional stations -- These stations may be operated either on a limited time basis, may include measurements of only a sub-set of the global station measurement programme, or may be located within the planetary boundary layer with local effect influence.

(c) Intensive stations -- Some of the global stations should provide resources to allow the performance of scientific field campaigns to study atmospheric processes relevant to climate change, etc. and to test new equipment and investment for future installations of the GCOS network (e.g., side by side operation). The ground-based observing network should be completed by mobile platforms e.g., aircraft, balloon and satellite measurements. These platforms are urgently needed to measure the global coverage of short-lived atmospheric components and perform process studies.

7.3.2 The Panel noted that an essential and crucial component of the GCOS network are the Quality Assurance-Science Activity Centres (QA-SAC) which:

define and execute the quality assurance plans for the individual chemical, physical and meteorological component of the measurement programme;
perform programmes for training and educating personal of the regional stations;
provide standards for the individual parameters;
encourage improvement of techniques/instrumentation for operational purposes.

7.3.3 The Panel recommended that GCOS establish a forum to encourage close collaboration and interactions between the operational and scientific programmes. This forum should consist of representatives of the individual networks and scientists responsible for the major scientific programmes in atmospheric sciences. The scientific members of this forum should provide advice on the type of network, measurement programme, type of instrumentation and assist in establishing new stations or abandon existing stations.

## 8. THE PANEL REPORT

8.1 The Panel was divided into small working groups to develop particular elements of the report. One group was asked to consider the overall design of the atmospheric components of the IOS. The group produced the design outline for the atmospheric component (Annex VI). A second group was invited to consider the designation of baseline networks, and developed the proposal for the baseline upper-air network (Annex VII). A third group considered the future needs for the IOS (Annex VI). In addition, statements were developed on the overall strategy for design of the atmospheric component, and a summary of atmospheric composition observations needed. These elements were used in the assembly of the report of the panel.

## 9. ACTIONS/RECOMMENDATIONS

### 9.1 Future Work Programme

9.1.1 The Panel considered a number of specific implementation actions:

***The Initial Operational System:***

The Panel reviewed the Design Outline (Annex VI), and recommended that it be provided to the JSTC for further refinement, and to develop particular projects in light of JSTC priorities.

***Baseline upper-air network:***

Having developed a baseline upper-air network, the Panel recommended that:

The network be documented and presented to appropriate groups in WMO including the Commission for Basic Systems, and in particular, its Working Group on Observations, WMO Regional Associations, and particular countries or agencies as appropriate;

Logistical issues associated with some of the stations and sites be addressed by the WMO organizations in cooperation with the Panel;

The concept of "lead centre" of the WWW Global Data Processing System be used to monitor the observations from the network with regard to quality and regularity of reporting;

A comprehensive approach to data management associated with the baseline network be developed in partnership with the Data Management Panel;

Further that: (1) a proposal be prepared for CBS to designate a lead centre; (2) users be identified to assist in providing a quality control activity; and (3) a special archive for the data be established.

***Surface reference climate network:***

The Panel was unable to develop the detailed network for surface observations, but proposed that:

A joint meeting of selected members of the CC1 Working Groups on Data Management and Climate Change Detection, staff of the World Climate

Programme Data and Monitoring Programme (WCDMP), and representatives of the AOP be scheduled to address the network issues. A joint invitation letter should be prepared which outlines the objectives of the meeting. ***[The meeting has been scheduled for January, 19%. ]***

***Atmospheric Composition issues:***

In consideration of the need for atmospheric composition observations, the Panel recommended that the representatives of the various networks for composition measurements be brought together to consider mutual plans for observations, including quality assurance. The Panel noted that there is a continuing need for the development of models, and that specific observations will be required for their development. However, the Panel agreed that the climate requirements should provide a mechanism for specifying a priority for certain measurements.

***The Climate Data Assimilation System:***

The Panel noted the value of the reanalyses now underway or being planned for the near future. Building on the experience with reanalysis, the Panel urged that Climate Data Assimilation Systems (CDAS) be developed in the appropriate centres. The Panel recommended that this recommendation be conveyed to the centres inviting them to provide information on their plans.

***The "fingerprint" approach:***

Noting that some parameters may be particularly sensitive to the changes in climate, the Panel briefly considered the potential for detecting climate change using the “fingerprint” approach. The Panel felt that the scientific community had so far failed to identify (multivariate) parameters that could serve as fingerprints of climate change. Members proposed a workshop be held to focus specifically on those parameters which might be particularly valuable as indicators. ***[Note: A meeting to address these issues on behalf of GCOS has been scheduled in Asheville, N. C. in January*** 1995. ***]***

***Ice and snow observations:***

Members noted, that many observations of ice and snow are made, but that they are not distributed effectively. The Panel suggested that an individual be identified to prepare a study of the situation, and if warranted, a proposal should be developed.

***Membership and terms of reference:***

The Panel considered that additional experts, particularly in atmospheric composition and climate diagnostics should be invited to future meetings.

## 10. CLOSURE

The meeting was concluded on 28 April at 1 p.m.

Annex I

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## Annex II

## Agenda

1. Opening of the Session

2. Introduction and GCOS Background

3. Opening Statement of the Panel Group Chairman

4. Invited Reports
   - 4.1 Task Group on Atmospheric Processes
   - 4.2 Task Group on Atmospheric Composition
   - 4.3 GCOS Plan

5. Strategy for Design of the Atmospheric Observational Programme
   - 5.1 The historical perspective
   - 5.2 Relations between GCOS and WWW/GOS
   - 5.3 Requirements for GCOS

6. The Initial Operational System -- Atmospheric Component
   - 6.1 The current WWW -- status and prospects
   - 6.2 Enhancements needed -- GCOS perspective
   - 6.3 New operational systems (eg., TOGA)
   - 6.4 Data assimilation and data management aspects

7. Designation of GCOS Baseline Networks
   - 7.1 Upper-air network
   - 7.2 Surface network
   - 7.3 Atmospheric composition

8. The Panel Report

9. Actions/Recommendations
   - 9.1 Future work programme

10. Closure of the Meeting

## Annex III

### Terms of Reference for the Atmospheric Observation Panel

Recognizing the need for specific scientific and technical input concerning atmospheric observations, the Joint Scientific and Technical Committee (JSTC) for GCOS hereby establishes an Atmospheric Observational Panel for climate with the following terms of reference.

***Terms of Reference:***

- In accordance with the GCOS Plan, to formulate and design a long-term systematic observing system for the atmosphere as an integrated part of GCOS, with the objective to monitor, understand and provide information for the possible prediction of the dynamical, physical and chemical processes that determine the state of the atmosphere from seasonal to multi-decadal time-scales;

- To seek review and implementation support from the operators of other relevant research or operational programs (e.g., WWW, GAW, WCRP, IGBP) and to collate, review, publish, and prioritize data requirements and observing system specifications, to ensure the best possible support for GCOS;

- To coordinate the activities with other GCOS panels and task groups to ensure consistency of requirements with the overall program;

- To report regularly to the JSTC.

***Chairman:*** Dr. Lennart Bengtsson, Germany

## Annex IV

## Data Acquisition and Management Issues

Dr. Trenberth presented the following outline during his discussion.

***Data Acquisition Issues:***

- o Dependent upon the World Weather Watch
  - Decline of the WWW should be reversed,
  - data must serve both weather and climate,
  - Global Telecommunication System and ARGOS issues,
  - Global Data Processing System issues.

***Climate versus weather observations:***

- o Cannot expect to set up full climate network;
- o GCOS depends on WWW, but small incremental cost will serve climate also;
- o Stable observing system with quality assurance is needed to account for:
  - changes in instrumentation, calibration, measurement technique,
  - changes in time of observation,
  - changes in exposure, station environment, urbanization,
  - changes in spatial distribution, areal coverage,
  - changes in methods of processing, analysis methods,
  - use of anomalies versus absolute values,
  - overlap if instruments are changed;
- o Adequate metadata required;
- o Standards required
  - compatibility of rawinsondes
  - processing (e.g., algorithims, definition of constants)

***Data Management Issues:***

- o Should be tied to the uses of the data;
- o Distributed system;
- o Quality assurance and integrity;
- o Metadata;
- o Archival;
- o Access;
- o Cost effectiveness, cost recovery;
- o Accountability;
- o Catalogues, directories;
- o Communications, networking;
- o Hardware systems;
- o Data archaeology, data rescue;
- o Issues of what to save (especially from satellite data sources)

## Annex V

## Data Requirements for the Atmospheric Component of GCOS

The following three tables were extracted from the Final Report of a Joint Task Team on Data Requirements from the Commission for Basis Systems Working Groups on Data Processing and Observations which met in March 1994.

### *Content of the Tables:*

The following notes provide some explanation of how the lists were prepared and some provisos on their use:

### Variables

Following past convention, the observational requirements for data assimilation are stated in terms of geophysical variables. This is thought to be useful since, from a user's perspective, these are the variables on which information is required. However it is important to note that these variables are not always observed directly (satellite systems observe none of them directly, with the exception of top-of-the-atmosphere radiation). Also it is no longer true that the users need their data exclusively in the form of geophysical parameters; recent developments in data assimilation have demonstrated the potential and the benefits of using data at the engineering level (e.g. radiances, brightness temperatures).

### Horizontal resolution

In general (and with some over-simplification), data are useful for assimilation and validation on spatial scales which the models are attempting to represent. 100 km is given as the requirement for the variables listed in the tables. However, it is possible to benefit from higher resolution data, considering the current developments towards global models with a grid length of less than 50 km. Regional models attempted to represent spatial scales above the meso-scale. Observational data are required at a resolution of 10 km.

### Vertical resolution

The same rationale is applied here: global NWP models are expected to have a resolution of less than 1 km throughout the troposphere and lower stratosphere, with considerably higher resolution in the planetary boundary layer. In the mid and upper stratosphere, a resolution of 2 km is likely to be sufficient. The requirements for observations should be comparable. For regional models, observations are required at a resolution of 100 m (50 m in the planetary boundary layer).

### Temporal resolution

Just as with spatial resolution, data will be useful for assimilation and validation on temporal scales which the models are attempting to represent. In the past this has not been the case; so-called "four-dimensional" assimilation systems would more appropriately be described as "intermittent three-dimensional" systems, and they have not been able to make proper use of observations more frequent than the period of the data assimilation cycle (typically 6 hours). However, continued progress towards truly four-dimensional data assimilation is making it possible to extract useful information from observations at higher temporal frequency. With such systems, higher temporal resolution can compensate to some extent for poor horizontal resolution when the atmosphere is moving. A requirement of 3 hours for upper-air data and 1 hour for surface data has been specified. However, like in the case of spatial resolution, upper-air data of higher specification (up to 1 hour) should also be made available (e.g. cloud motion wind data from geostationary satellites, wind profiles from wind profilers). For regional models, both upper-air and surface data are required at a resolution of 1 hour.

**Accuracy**

The values given are intended to represent the RMS of the observation errors. The assessment of accuracy should include not only the true instrumental error but also the representativeness error (i.e. the characteristics of some observing systems, particularly in situ systems, which sample spatial and temporal scales which are not represented by the models). For NWP applications, such effects appear as though they were observation errors.

**Timeliness**

In NWP, the value of data degrades with time, and it does so particularly rapidly for variables which change quickly. Operational assimilation systems are usually run with a cut-off time of about 3 hours for global models, 1.5 hour for regional models. For observations which are expected to be used for validation, and not for analysis/assimilation in near real-time, the timeliness is less critical.

## Table 1 - Three-dimensional fields

| | Horizontal resolution (km) | Vertical resolution (km) | Temporal resolution (hours) | Accuracy (RMS error) | Notes |
|---|---|---|---|---|---|
| **Wind (horizontal)** | 100 | .1 up to 2km<br>.5 up to 16km<br>2.0 up to 3okm | 3 | 2 m/s in the troposphere<br>3 m/s in the stratosphere | (1)<br>(2) |
| Temperature | 100 | .1 up to 2km<br>.5 up to 16km<br>2.0 up to 3okm | 3 | SK in the troposphere<br>1.0K in the stratosphere | (3) |
| Relative humidity (RH) | 100 | .1 up to 2km<br>.5 up to the tropopause | 3 | 5% (RH) | |

Notes:

(1) Accuracy specified as RMS vector error

(2) Hourly wind data from geostationary satellites and from wind profilers are also required.

(3) Geopotential height can be retrieved from specified T and RH with sufficient accuracy

**Table 2 - Surface fields**

| | Horizontal resolution (km) | Temporal resolution (hours) | Accuracy (RMS error) | Notes |
|---|---|---|---|---|
| Pressure | 100 | lh | 0.5 hPa | |
| Wind | 100 | lh | 2 m/s | (1) |
| Temperature | 100 | lh | 1 K | |
| Relative humidity | 100 | lh | 5% | |
| Accumulated precipitation | 100 | 3h | 0.1 mm | (2) |
| Sea surface temperature | 100 | 1 day | 0.5 K | |
| Soil temperature | 100 | 3h | 0.5 K | |
| Sea-ice cover | 100 | 1 day | 10% | |
| Snow cover | 100 | 1 day | 10% | |
| Snow equivalent-water depth | 100 | 1 day | 5 mm | |
| Soil moisture, O-10 cm | 100 | 1 day | 0.02 $m^3/m^3$ | |
| Soil moisture, 10-100 cm | 100 | 1 week | 0.02 $m^3/m^3$ | |
| Percentage of vegetation | 100 | 1 week | 10% (relative) | |
| Soil temperature, 20 cm | 100 | 6h | 0.5 K | |
| Deep soil temperature, 100 cm | 100 | 1 day | 0.5 K | |
| Albedo, visible | 100 | 1 day | 1% | |
| Albedo, near infra-red | 100 | 1 day | 1% | |
| Longwave emissivity | 100 | 1 day | 1% | |
| Ocean wave height | 100 | 1h | 0.5 m | |

Notes:

(1) Wind at 10 metre over land;
Over sea, height in the range 1 to 40 metres (to be transmitted with the observation)

(2) Required principally for model validation, not time critical.

**Table 3 - Other two-dimensional fields**

| | Horizontal resolution (km) | Temporal resolution (hours) | Accuracy (RIMS error) | Notes |
|---|---|---|---|---|
| Cloud fractional cover | 100 | 3 h | 10% | |
| Cloud top height | 100 | 3 h | 0.5 km | (1) |
| Cloud base height | 100 | 3 h | 0.5 km | (1) |
| Total liquid water content | 100 | 3 h | 20% | |
| TOA net shortwave radiation | 100 | 3 h | 5 W/m² | (2) |
| TOA net longwave radiation | 100 | 3 h | 5 W/m² | (2) |
| Multi-purpose IR/VIS imagery | 5 | 3omin. | - | (3) |

Notes:

(1) Accuracy higher in planetary boundary layer.

(2) Required principally for model validation; not time critical.

(3) Required to assist real-time observation monitoring and analysis/forecast validation.

## Annex VI

### Design Outline for the Atmospheric Component of the IOS

The following outline was formulated to illustrate the process of developing the atmospheric component of the Initial Operational System for GCOS. While incomplete in detail, it should illustrate an overall structure to: (1) outline the requirements; (2) assess the efficacy of current systems in contributing data to meet the requirements; (3) propose enhancements or augmentations to the existing systems; and (4) guide the development of the data management system for this component and its integration into the larger data system of GCOS.

### I. Introduction

***Why is an IOS required?***

- The IOS is the first step towards a fully developed GCOS;
- GCOS to be based on existing systems, operational or experimental.

***Purpose of IOS***

- The IOS aims at the provision of data principally for:
  - prediction of climate change on a seasonal or inter-annual time scale,
  - detection of climate change,
  - climate system monitoring.

***Range of data***

- IOS should provide the following two broad categories of data:
  - physical meteorological data, describing the physical state of the climate system,
  - data describing the chemical composition of the atmosphere.

***Scope of IOS***

- The IOS should be based on an "end-to-end" approach;
- Only data sources for which there is a long-term commitment to apply such approach are considered for inclusion in the IOS;
- It therefore should comprise:
  - data reception and collection,
  - quality assurance,
  - data assimilation,
  - metadata,
  - product (generation),
  - data and product archiving and dissemination.

## II. Data Requirements

### A. *Climate Change Detection*

#### 1. Physical/meteorological data

o Climate data requirements are similar to global NWP requirements to the extent that:
- primary dependent variables pressure (p), temperature (t), specific humidity (q), vector wind (V) are required,
- comparable accuracies and data control procedure are used,
- similar assimilation techniques are used;

o Climate data requirements differ from NWP requirements in that:
- cut-off time is much less stringent,
- observing, and assimilation systems could be frozen for extended time periods,
- many quantities that may be computed as derived quantities from NWP (such as radiation field, clouds, precipitation) should also be observed in a climate observation system because they are essential elements,
- climate assimilation systems may have to be tuned or adapted to their special application;

o Currently it is well accepted that combinations of model output and observed data may produce the most reliable products;

The following is a list of quantities to be observed and made available as quality controlled data sets:

o Primary dependent variables p, t, q, V as functions of height;

o Surface boundary data:
- sea surface temperature (SST),
- snow/ice cover/depth,
- albedo,
- soil moisture,
- vegetation index.

o Radiation data:
- top of the atmosphere (TOA), long-wave (LW) and short-wave (SW) radiation,
- surface, LW and SW.

o Cloud parameters:
- cloud cover and optical properties,
- cloud liquid water content,
- vertical distribution of clouds;

o Aerosols;

0 Precipitation.

Some of these quantities, in particular the terrestrial/ecosystem variables are to be considered in the development of the terrestrial component of IOS:

2. Chemical Atmospheric Composition

0 Purpose of the data:
- description of the role of the atmosphere in radiative balance of the earth,
- description of the processes leading to ozone depletion,
- description of atmospheric chemistry relevant to previous two points.

o Data should therefore cover:
- concentrations of all GHGs,
- concentrations of all precursors,
- aerosols and stratospheric clouds.

### *B. Climate Change Prediction on Seasonal or Inter-annual Time Scale*

o Data requirements include conventional meteorological variables for Numerical Weather Prediction (NWP) and additional oceanic variables described in the draft GCOS document, "Operational Ocean Observing System for Short-term Climate Prediction";

o Atmospheric data related principally to computation of wind stress (and heat fluxes from atmospheric models) for spin-up;

o The IOS atmospheric data required are therefore:
- sea surface winds,
- boundary layer variables (moisture, temperature) and their structure in tropical regions,
- precipitation.

## III. Existing Systems

### *A. Introductory remarks*

o IOS atmospheric component may be composed of operational and experimental systems;

o Availability and long-term stability of data should be guaranteed;

o Data frequency and data cut-off may be (considerably) relaxed with respect to NWP requirements.

### *B. Operational Systems*

o All WWW systems contribute, and are required;

o Operational meteorological and environmental satellites:
- geostationary,
- polar orbiting;

o All GAW stations contribute, and are required;
- global,
- regional,
- intensive.

### *C. Enhancement Systems*

o WWW-type systems, such as:
- data buoys,
- profilers,
- (Doppler) radars;

o Experimental satellites:
- ERS-1,
- others as noted in the GCOS Space Plan;

0 Specialized networks:
- TOGA network including the TAO array,
- other networks for precipitation, radiation, etc.

## IV. Ability of Existing Systems to Meet Requirements

### *A. Introductory remarks*

o In order to judge the ability of existing systems to meet the requirements, systems and individual stations should be judged on the basis of several criteria:
- proven continuity, reliability and accuracy,
- spatial and temporal resolution,
- availability,
- general design principles.

These criteria lead to a so-called "baseline" approach i.e., a selection of a subset of stations fulfilling all or most of the above criteria.

### *B. Surface (synoptic) network*

o This network is very unevenly distributed and mainly concentrated in N. Hemisphere;

o Over large areas, in particular the oceans, this network does not fulfil spatial resolution requirements;

o Baseline approach may be desirable, but to date only preliminary attempts to select a baseline network have been made;

o Maintenance and quality assurance poses problems in particular in developing countries and remote oceanic sites.

**Conclusion:**
This is an essential component of IOS; baseline network desirable; network does not meet requirements over large areas; enhancements are essential.

### *C. Upper-air network*

o This network is unevenly distributed and concentrated over continental areas;

- o In particular over oceans, the network does not fulfil spatial resolution;
- o Network is in decline; many stations threatened;
- o In some countries, network does not meet quality requirements;
- o Maintenance and quality assurance poses problems in particular in developing countries and remote oceanic station sites;
- o A baseline network has been proposed based on station location to optimize horizontal homogeneity; length of data record; proven quality; and availability and continuity of future data.

**Conclusion:**
This an essential part of **IOS**. A baseline network has been proposed; network does not meet spatial resolution and quality requirements over large areas; enhancements are essential but pose problems in particular in developing countries and over oceanic regions.

### *D. GCOS Atmospheric Composition Component*

- o Several networks exist (See Report of GCOS Task Group on Atmospheric Composition);
- o GAW plans to continue most of these activities;
- o Some limitations of GAW:
  - some elements of the system still under development,
  - array of global stations only partly implemented (five out 15 stations),
  - one of three Quality Assurance Science Centres exists,
  - differences in performance of GAW stations,
  - disparity of instrumentation and techniques;
- o Need exists for process studies and additional information to optimize the GAW component for GCOS.

**Conclusion:**
Present observations in GAW contribute surface observations from selected regions, but additional stations are needed and measurements from the free atmosphere are required. An integrated view of the climate requirements for atmospheric composition observations is essential This view should be developed with inputs from GCOS.

### *E. Satellites*

- o A combination of geostationary and polar satellites complements surface-based network in their global coverage;
- o Several **IOS** requirements, particularly those related to radiative properties of the climate system, can only be observed **from** satellites;
- o Present satellite network however has severe limitation in accuracy and in the range of variables which may be adequately measured;
- o Satellite data lack continuity, especially from one satellite mission to the next, but also due to orbit drift on any particular mission;

o GCOS Space-based Observation Task Group has proposed suite of "GCOS Missions" to address the comprehensive requirements for all GCOS components, including the atmospheric component. (See GCOS Draft Space Plan).

**Conclusion:**
Present satellite system is a necessary but by no means sufficient complement to the surface-based system. In particular there are serious deficiencies in accuracy and observational capability. Considerable improvement will occur if plans currently being developed by agencies that providing space-based observations are brought to fruition.

### *F. Use of Satellite Capabilities*

o Increased availability of primary and derived data from satellites;
0 Improved use of satellite data in models.

## V. Comprehensive Data Systems

o Tailored system for data generation, data collection, distribution;
o Establishment of systematic QC, QA at various levels (including lead centres);
o Establishment of a system of DDBs for common use;
o Regular information on system functions, network components and data sets (including metadata);
o Securing data availability and access rights/procedures;
0 Provision of products.

Additional data considerations are more fully detailed in the GCOS Data Management Plan. .

## VI. Funding Issues and Options

### *A. Shortcomings*

o Dependency on national priorities and constraints;
o Observational components from oceanic regions not well covered;
o Research activities lacking funding continuity;
o Inefficient use and uncoordinated distribution of existing funds;
o Essentially no provisions for central funding of IOS.

### *B. Potential Funding Sources and Options*

o The GCOS plan must include mechanisms for assisting some countries to develop capacity to participate;
o Some funds may be available from international sources, e.g., climate funds, GEF, bilateral or multilateral under Agenda 21, etc.;
o Regular funds for operational systems (including inter-government);

- o Consortia-type funding arrangements.

### *C. Need for organizational Support*

- o Central Management of the IOS requires staff resources not presently available.

## VII. Short-term Developments (until 2005)

### *A. Enhancements for the WWW Components*

- o Securing the full functionality of the baseline stations for GCOS;
- o Adding to the observing programme new elements;
- o Exchange of data now available only for national/regional use (snow, radiation).

### *B. Enhancements for the GAW Components*

- o Increase the number of stations in the global networks, and add capability for aerosols;
- o Expand capability for observations in the free troposphere and lower stratosphere:
  - installed additional instruments at existing stations to extend the measuring programme,
  - introduce ground-based remote sensing techniques to probe the free troposphere and lower stratosphere,
  - establish new stations, in particular in the continental areas (e.g., Africa, South America, Russia);
- o Encourage training activities, particularly in developing countries;
- o Increase and centralize support activities for:
  - quality assurance,
  - technical workshops.

### *C. Emerging Technology*

- o Increased automation of observations (surface and upper-air);
- o Introduction of profilers and radar systems supplementing conventional system;
- o Development of improved data assimilation schemes (4DDA);
- o Development of climate models (coupled) and increased computer power;
- o Increased availability of aircraft data;
- o Reorganization of the GTS using satellite communications (e.g., VSAT) ;
- o Development of temperature and moisture retrieval techniques using GTS radiowave refractometry;
- o Introduction of global data management standards, client/server concepts and distributed data bases (DDB).

*D. Comments on present systems as elements **of** the Initial Operational System*

Measurements taken as part of the WWW, both surface and upper air, should be enhanced for climate purposes by taking more account of the need for long-term stability and quality assurance. Of particular concern are instances when there are changes in instrumentation, calibration, or measurement technique; changes in station location, exposure, environment or degree of urbanization; and changes in forms of observation. Firstly, comprehensive metadata are needed about each station record for all stations, and variables. Secondly, these factors should be considered whenever changes are contemplated. The need should be recognized for periods of overlap to document the effects of any changes on the climate record.

This aspect also carries over to products such as global analyses. Here, changes in spatial distribution of observations and **areal** coverage as well as changes in methods of processing and analysis can also interfere with the climate record. Again a form of metadata that documents any such changes and their impacts on the analyses are needed. Secondly strategies are needed for reanalysis of the data to reconstruct the climate record and overcome these problems (See section 6.4).

## *VIII.* Future Requirements and Longer-term Prospects (post 2005)

Future observing systems to provide enhancements to GCOS are dependent upon properly functioning individual observing networks taken in a composite sense, improved communication methodologies, data processing capabilities, and a data management function capable of providing the overall integration of monitoring, quality control, and definition of codes where necessary to expedite data exchange. These resemble the structure already in place for decades as part of the WWW, but they need to be expanded to support GCOS and other relevant programmes.

In constructing this section it is assumed that:

- The **IOS** will continue to operate post-2005 or be modified and extended as described below;
- The number and range of users requiring access to data and products for climate purposes will increase;
- Resolution of numerical models used for deterministic NWP, data assimilation and climate prediction will increase at least two-fold (x8 in 3D);
- Focus on regional and sub-regional issues will increase and be driving the investment in GCOS;
- Demand for an ability to include chemical and aerosol effects in models will increase;

- Coupled atmospheric-ocean models will be running operationally;
- Observing systems will remain the component of GCOS requiring the most substantial investment;
- Techniques and observing systems will increasingly have a heritage which does not derive from operational meteorology;
- Process studies will continue to be defined, driven, and enabled by research programme (WCRP, IGBP, etc.) activities, not GCOS;
- Automation will continue to increase;
- Integration of ground and space-based observing systems will continue to increase;
- Advanced 4-DDA will have been developed to the point where the technique is capable of making significantly better and more reliable use of observations;
- Economic benefits, achievable from well-informed investment on a regional scale, will justify the further investment in GCOS.

The following sections are included to provide an indication of areas where improvements may make substantial contributions to the GCOS. (The discussion is selective; not exhaustive).

### A. ***Requirements*** *for new systems*

When compared with the long-term requirements for GCOS as described in planning documents, an assessment of the IOS indicates some deficiencies as noted:

- wind field -- for model validation, and inter-annual/seasonal prediction, the IOS is deficient in providing data of the required accuracy, vertical and horizontal resolution, particularly over the tropics where such data are very important;
- temperature and humidity fields -- for the characterisation of climate on a regional scale, model validation and development, and for inter-annual/seasonal prediction, the IOS is deficient in the coverage of ground-based systems and in the accuracy/vertical resolution of temperature and humidity profiles, inferred from satellite instruments;
- precipitation -- for analyses and validation of the hydrological cycle, monitoring of climate, and for inter-annual/seasonal prediction, the IOS is deficient in coverage, particularly over the oceans, and in representativeness and accuracy of measurement;
- cloud properties -- the vertical and horizontal distribution, composition, radiative properties, and extent of cloud coverage may provide an important determinant of the sources of climate change; the capabilities of the IOS are inadequate for the purpose and for the development of accurate simulations of clouds in atmospheric models. In general, higher accuracy data are required both directly and to infer the radiative properties;
- aerosol-troposphere -- measurement of the loading, distribution and understanding of the role of aerosol in contributing to climate change are quite inadequate. Significant expansion, particularly of the ground-based network in and above the planetary boundary layer is required to improve the IOS;

- chemical composition -- measurement of the concentration and understanding of the effects of short-lived species, and those exhibiting strong vertical and horizontal gradients, particularly in the troposphere, is quite inadequate.

### *B. New Ground-based Observations*

- New commercial aircraft systems, incorporating space-based communications and wind temperature measurements (ADS - Automatic Dependent Surveillance), will provide high quality measurements globally while in flight, and soundings in ascent and descent made at airport hubs by the thousands in the 2000 time frame. Humidity sensor 'add-ons' will be operational;
- Operational Wind Profilers, and future elements for sensing temperature, will provide nearly continuous, unattended soundings from near the surface (approx. 200 m) through 18 km. Wind measurements will provide accuracy of 1 m/sec and a vertical resolution of *200* m;
- Modifications to radiosondes will include GPS location techniques, and reduced bandwidth requirements for communications in response to externally imposed conditions to meteorological systems due to competition for spectrum allocations. Efforts will be made to limit, and when possible, reduce costs. It is expected that some early trade-offs will be made with wind profilers at operationally difficult and costly sites;
- 'Add ons' to radiosondes will include GAW sensors to enable measurement of chemical composition of the troposphere and lower stratosphere;
- Doppler radars will be expanded for operational use in hydrology and meteorology, as well as to provide comprehensive, accurate estimates of regional precipitation for climate use. Velocity Azimuth Display (VAD) techniques will also provide "winds of opportunity" in the lower 4000 ft of the atmosphere;
- Drifting buoys (now primarily a research tool with some operational deployments in the North Atlantic, Western Atlantic, and Central Pacific) will be deployed and maintained as an operational buoy network, through GCOS and the Global Ocean Observing System (GOOS). Joint funding deployment and maintenance mechanisms will expand. New sensor improvement will continue, particularly for pressure sensors;
- Automated Shipboard Aerological Programme (ASAP) ship reports, providing high quality radiosonde measurements on commercial and national vessels, having been redesigned for increased efficiency and reduced cost, will be deployed more widely than in the North Atlantic. Joint funding mechanisms will continue to evolve;
- Automated Surface Observing Systems (ASOS) will continue to proliferate as nations seek to reduce surface observing costs and increase the frequency of observations in support of operational meteorological programmes. Changes to the suite of surface parameters to be measured will require comparison of manually provided and automated parameters for an agreed overlap period, if stability of the climate record is to be maintained. The suite of measured parameters will change as the data from satellite, radar, and surface sensors are blended.

## *C. Selected New Satellite-based Measurement Techniques*

- The Advanced Infra-Red Sounder (AIRS) and Infra-Red Atmospheric Sounding Interferometer (IASI), to be flown on the EOS and METOP series of satellites respectively, are expected to provide temperature and humidity soundings of the required accuracy, resolution and coverage sought by GCOS (and operational NWP);
- The cloud/water vapour track technique of wind finding is not capable of meeting the GCOS requirement for wind field data. Active satellite laser instruments, such as Differential Absorption Laser (DIAL) and Laser Wind System (LAWS) may be able to make a significant additional contribution, but at present they have no identified flight opportunity, and are expected to be very complex, expensive instruments;
- WCRP programmes such as GEWEX and research instruments such as TRMM will identify the detailed measurements which are required, and the techniques which are candidates for operational implementation, to meet GCOS requirements for precipitation data;
- Instruments such as the Medium Resolution Imaging Spectrometer (MERIS) to be flown on ENVISAT, the Multi-frequency Imaging Microwave Radiometer (MIMR) to be flown on METOP and the EOS series, the Moderate Resolution Imaging Spectrometer (MODIS) to be flown on the EOS series and the Spinning Enhanced Variable and Infra-Red Imager (SEVIRI) will enter service around the turn of the century. They will provide additional insight into the optimal technique(s) to be used to meet GCOS requirements for data on cloud properties;
- Tomographic techniques based on the occultation of radio/microwave transmissions from GPS satellites, received by suitably equipped Low Earth Orbit (LEO) satellites, offer some exciting possibilities to infer profiles of atmospheric temperature and humidity profiles at very low cost. This could become a very significant source of data for GCOS (and NWP), particularly through model assimilation.

## *D. Communication Improvements*

- The GTS will be redesigned to take advantage of advances in satellite communications technology as well as the establishment and expansion of the "communications superhighway". Early implementation will see an increased use of intemet-like linkages to provide additional special datasets not currently provided by GTS. The additional capacity will be needed to carry new datasets in support of GCOS and provide a dissemination means to users of advanced products. Overall, communication capabilities will increase, and costs are expected to drop significantly;

## *E. Data Processing Improvements*

- Computer processing power will continue to increase substantially at limited numbers of major centers where a critical mass of modellers and scientists will undertake advanced model development and scientific research in support of GCOS and production of an expanded set of products for users;

- Local computer processing power will also increase, making possible advanced limited area model use at an increasing number of local research centers, meteorological and hydrological offices. Local **datasets** will flourish for special research projects and operational use.

## IX. Priorities for Action in Enhancing the IOS

### *A. First Priority*

- To encourage long-term operational use by meteorological services of new ground-based techniques for the measurement of wind, temperature and humidity in the free atmosphere, and to generate data sets for GCOS form them through stable data assimilation by global models;
- To support the long-term operational use of the following satellite instruments which have been proven capable of meeting GCOS requirements:
  - AIRS and IASI, and tomographic occultation of GPS signals by LEO satellites for temperature and humidity profiles,
  - AATSR for sea surface temperature,
  - wide-swatch derivations of **ASCATT** and NSCAT for ocean surface wind,
  - an imaging multi-spectral radiometer for cloud and precipitation properties and sea-ice and snow cover.

### *B. Second priority*

- To support the long term, operational use of those of the following satellite instruments which have been proven capable of meeting GCOS requirements:
  - an advanced atmospheric chemistry spectrometer for tropospheric and stratospheric chemistry measurements,
  - a solar flux radiometer, such as **ACRIM,** to monitor the stability of the solar 'constant',
  - an earth budget radiometer, such as Scarab or CERES for the **TOA** radiation budget.

## Annex VII

### The GCOS Baseline Upper-air Network

The criteria for selecting presently-operating GOS stations to be included in the Network were, in order of importance: (1) the remoteness of the station, which determines its relative contribution to as homogeneous distribution as is possible given the global land/ ocean distribution; (2) the performance of a site in producing high quality observations; and (3) the existence of a reasonable length of historical record. The material used in the selection process consisted of performance records of existing GOS stations and station quality information from the Lead Centre quality monitoring programme of the WMO Commission on Basic Systems (CBS).

The present WWW/Global Observing System (GOS) has experienced and continues to experience problems in the number, availability and quality of its upper-air network in some areas of the world. Although a number of GOS geographically isolated, and therefore important, sites have been closed for logistic and economic reasons, the density and performance of stations is generally adequate for IOS objectives over the major land areas of the Northern Hemisphere. The situation is not acceptable over much of the tropics and the Southern Hemisphere. The current performance of the GOS upper-air network, compared with the performance ten years ago, can be judged by the fact that in 1985 approximately 1500 soundings per day were produced by the GOS while in early 1994 that number was reduced to about 1050 per day. Moreover, it now appears likely that key stations, in particular island sites, will not continue in the future unless action is taken to reverse the decline of the GOS.

The IOS Upper-air Baseline Network will be discussed at the CBS Extraordinary Session in August. A resolution has been prepared and included as an Appendix to this Annex. The resolution contains the identified stations in the network. It is divided into a Northern Hemisphere set (90N-20N) of 50 stations; a Southern Hemisphere set (90S-20S) of 40 stations; and a Tropical set (20N-20S) of 50 stations.

Some recommended sites to be implemented are included but are not presently in the GOS (**). Some existing sites which have performance or quality problems, or appear to be at risk are also included (*). In addition, the Panel recommends that in the tropical regions, a number of sites presently using rawinsonde equipment be seriously considered for replacement with alternative or developing wind measuring systems. Such a change may prove to be cost effective in logistically difficult sites, while enabling the meteorological variable of principal dynamic importance there to continue to be observed.

Note: The letter grades attached to the station list (column "status") are based upon the performance of each, as determined by the average number of reports received by ECMWF in a 30-day month:

A - from 24 to 30 reports per month;
B - from 18 to 23 reports per month;
C - from 11 to 17 reports per month.

## Appendix

**Draft recommendation:**

**CBS Contribution to the Global Climate Observing System**

THE COMMISSION FOR BASIC SYSTEMS,

NOTING:

(1) Resolution 9 (Cg-XI) - Global Climate Observing System,

(2) Resolution 8 (CBS-X) - Rapporteur on the follow-up to UNCED,

(3) Report of the eighteenth session CBS Advisory Working Group (Offenbach, Germany, 21-23 April 1994),

(4) Final report of the first session GCOS/JSTC Atmospheric Observation panel (Hamburg, Germany, 25-28 April 1994),

CONSIDERING:

(1) That there is international recognition of the importance of systematic observations and full and open exchange of data for detection and prediction of potential climate change,

(2) That WWW basic systems provide both the common infrastructure and the database to support all WMO programmes and relevant efforts of international organizations,

(3) That the GCOS will build, as far as possible, on existing operational and scientific observing, data management and information distribution systems, and further enhancement of those systems,

(4) That Regional Basic Synoptic Networks (RBSN), which form the major part of the surface-based component of the GOS, would provide an ideal basis from which to select a network of baseline stations representative of air masses on a regional scale and operated on a long-term basis with required regularity and observational accuracy,

ENDORSES the concept that the GCOS Initial Operational System be established on the basis of the World Weather Watch and other existing structures, including in particular:

the establishment of GCOS baseline upper-air and surface networks;

arrangements for additional data exchange (e.g. snow depth, radiation and soil moisture);

- arrangements for end-to-end monitoring and near-real-time feed back;
- systematic quality control of data through the WWW lead centres on monitoring of observational data quality;
- co-ordination of satellite data requirements and service.

CONFIRMS that CBS will play an active role in the design, development and implementation of the GCOS Initial Operational System.

RECOMMENDS:

(1) that Regional Associations be urged to consider the proposed list of stations comprising the GCOS Baseline Upper-air Network as given in Annex to this Recommendation and give them high priority for implementation within RBSNs;

(2) that Members be urged to make a long-term commitment to maintain and operate the upper-air stations proposed within the GCOS Baseline Upper-air Network.

(3) that Members be invited to initiate joint schemes for funding and managing observing systems, where possible, to cover large data-void areas and meet the needs of GCOS.

REQUESTS the president and vice-president of CBS to maintain close contacts with GCOS/JSTC and its Atmospheric Observation Panel and to include GCOS related issues in the work programme of the CBS Working Group on Observations, Satellites and Data Management.

## GCOS Global Baseline Upper-air Network

### Northern Hemisphere

| Station Index | Name | Latitude | Longitude | Status |
|---|---|---|---|---|
| 01001 | Jan Mayen | 70 56N | 008 40W | A |
| 02836 | Sondankyla | 67 22N | 026 39E | A |
| 03006 | Lerwick | 60 08N | 001 11W | A |
| 03953 | Valentia observatory | 51 56N | 010 15w | A |
| 04270 | Narssarssuaq | 61 09N | 045 26W | A |
| 08495 | Gibraltar | 36 09N | 005 2ow | A |
| 08508 | Lajes/Santa Rita (Azores) | 38 44N | 027 04W | A |
| 10868 | Munchen-Oberschleissheim | 48 15N | 011 33E | A |
| 16245 | Pratica di Mare | 41 39N | 012 26E | A |
| 17130 | Ankara/Central | 39 57N | 032 53E | A |
| 20674 | Ostrov Dikson | 73 30N | 080 24E | A |
| 21965 | Ostrov Chetyrehstolbovoy | 70 38N | 162 24E | A |
| 23472 | Turuhansk | 65 47N | 087 57E | A |
| 24266 | Verhojansk | 67 33N | 112 26E | A |
| 28698 | Omsk | 54 56N | 074 23E | A |
| 30230 | Kirensk | 57 46N | 108 07E | A |
| 32540 | Petropavlovsk-Kamchatskij | 52 58N | 158 45E | A |
| 33345 | Kiev | 50 24N | 030 27E | A |
| 35121 | Orenburg | 51 45N | 055 06E | A |
| 38880 | Ashabat | 37 58N | 058 20E | A |
| 41217 | Abu Dhabi | 24 26N | 054 39E | A |
| 45004 | King's Park | 22 19N | 114 10E | A |
| 47401 | Wakkanai | 45 25N | 141 41E | A |
| 47827 | Kagoshima/Yoshino | 31 38N | 130 36E | A |
| 47971 | Chichijima | 27 05N | 142 11E | A |
| 4799 1 | Minamitorishima | 24 18N | 153 58E | A |
| 50527 | Hailar | 49 13N | 119 45E | A |
| 51709 | Kashi | 39 28N | 075 59E | A |
| 5268 1 | Minqin | 38 38N | 103 05E | A |
| 53068 | Erenhot | 43 39N | 112 OOE | A |
| 55299 | Naggu | 31 29N | 092 04E | A |
| 56778 | Kunming | 25 01N | 102 41E | A |
| 57494 | Wuhan | 30 37N | 114 08E | A |
| 60020 | Santa Cruz de Tenerife | 28 27N | 016 15W | A |
| 60680 | Tamanrasset | 22 47N | 005 31E | A |
| 70026 | Barrow/W. Post W. Rogers | 71 18N | 156 47W | A |
| 70308 | St. Paul | 57 09N | 170 13w | A |
| 70398 | Annette Island | 55 02N | 131 34w | A |
| 71072 | Mould Bay, N.W.T. | 76 15N | 119 21w | A |
| 71815 | Stephenville UA, NFLD | 48 34N | 058 34W | A |

## Northern Hemisphere (continued)

| Station Index | Name | Latitude | Longitude | Status |
|---|---|---|---|---|
| 71836 | Moosone, ONT. | 51 16N | 080 39W | A |
| 71934 | Fort Smith UA, N.W.T. | 60 02N | 111 56W | A |
| 72201 | Key West/ Int., FL | 24 33N | 081 45W | A |
| 72250 | Brownsville/Int., TX | 25 54N | 097 26W | A |
| 72293 | San Diego/Miramar, NAC CA | 32 51N | 117 07W | A |
| 72532 | Peoria/Greater Peoria, IL | 40 40N | 089 41W | A |
| 72694 | Salem/Mcnary, OR | 44 55N | 123 OOW | A |
| 72775 | Great Falls/Int., MT | 47 29N | 111 22w | A |
| 78016 | Bermuda Naval Air Station | 32 22N | 064 41w | A |
| 91165 | Lihue, Kauai, Hawaii | 21 59N | 159 21w | A |

## Tropics

| Station Index | Name | Latitude | Longitude | Status |
|---|---|---|---|---|
| 43599 | Gan | 00 41s | 073 09E | ** |
| 48455 | Bangkok | 13 44N | 100 34E | A |
| 48568 | Songkhla | 07 12N | 100 36E | A |
| 48698 | Singapore/Changi Airport | 01 22N | 103 59E | A |
| 61052 | Niamey- Aero | 13 29N | 002 10E | A |
| 61641 | Dakar/Yoff | 14 44N | 017 3ow | A |
| 61901 | St. Helena Is. | 15 56S | 005 4ow | B |
| 61902 | Wide Awake Field (Ascension I.) | 07 58S | 014 24W | * |
| 61976 | Serge Frolow (Ile Tromelin) | 15 53s | 054 31E | A |
| 63450 | Addis Ababa | 08 59N | 038 48E | A |
| 6374 1 | Nairobi/Dagoretti | 01 18S | 036 45E | A |
| 63985 | Seychelles Inter Airport (Rawinsonde station) | 04 41s | 055 32E | * |
| 64700 | Njamena | 12 08N | 015 02E | A |
| 65578 | Abidjan | 05 15N | 003 56W | A |
| 67237 | Nampula | 15 06s | 039 17E | * |
| 78397 | Kingston/Norman Manley | 17 56N | 076 47W | B |
| 78526 | San Juan/Int. Puerto Rico | 18 26N | 066 oow | A |
| 78583 | Belize/Phillip Goldstron Intl. Airport | 17 32N | 088 18W | B |
| 78762 | Juan Santamaría | 10 OON | 084 13w | * |
| 78954 | Grantley Adams | 13 04N | 059 29w | A |
| 80222 | Bogota/Eldorado | 04 42N | 074 08W | * |
| 81405 | Cayenne/Rochambeau | 04 50N | 052 22W | A |
| 82193 | Belem (Aeroporto) | 01 23S | 048 29W | B |
| 82332 | Manaus (Aeroporto) | 03 09s | 059 59w | * |

## Tropics (continued)

| Station | Index | Name | Latitude | Longitude | Status |
|---|---|---|---|---|---|
| 82397 | | Fortaleza | 03 44s | 038 33W | ** |
| 83378 | | Brasilia (Aeroporto) | 15 52S | 047 56W | * |
| 84008 | | San Cristóbal (Galapagos) | 00 54s | 089 36W | * |
| 84628 | | Lima-Callao/Jorge Chavez Aeroporto Intemationale | 12 00S | 077 07W | * |
| 91217 | | Guam, Mariana Is. | 13 33N | 144 50E | A |
| 91285 | | Hilo/Gen Lyman, Hawaii | 19 43N | 155 04W | A |
| 91334 | | Truk, Caroline Is. | 07 28N | 151 51E | A |
| 91376 | | Majuro/Marshall Is. Intnl. | 07 05N | 171 23E | A |
| 91408 | | Koror, Palau Is. | 07 20N | 134 29E | A |
| 91517 | | Honiara | 09 25S | 159 58E | A |
| 91530 | | Nauru Airport | 00 32S | 166 55E | ** |
| 91557 | | Bauerfield (Efate) | 17 42S | 168 18E | A |
| 91610 | | Tarawa | 01 21N | 172 55E | * |
| 91643 | | Funafuti | 08 31s | 179 13E | A |
| 91701 | | Kanton Island | 02 46S | 171 43w | ** |
| 91765 | | Pago Pago/Int. Airport | 14 20s | 170 43w | A |
| 91925 | | Atuona | 09 48S | 139 02W | A |
| 91938 | | Tahiti-Faaa | 17 33s | 149 37W | A |
| 94035 | | Port Moresby M. 0. | 09 26S | 147 13E | * |
| 94120 | | Darwin Airport | 12 24S | 130 52E | A |
| 94203 | | Broome Airport | 17 57s | 122 13E | A |
| 94294 | | Townsville Airport | 19 15s | 146 45E | A |
| 96315 | | Brunei Airport | 04 56N | 114 56E | B |
| 96935 | | Surabaya/Juanda | 07 22s | 112 46E | A |
| 96996 | | Cocos Island Airport | 12 11s | 096 49E | A |
| 98223 | | Laoag | 18 11N | 120 32E | A |

## Southern Hemisphere

| Station Index | Name | Latitude | Longitude | Status |
|---|---|---|---|---|
| 61995 | Vacoas (Mauritius) | 20 18S | 057 30E | B |
| 61996 | Martin de Vivies (N Amst'rdam) | 37 48S | 077 32E | B |
| 61998 | Port-aux-Fraqais (Kerguelen) | 49 21s | 070 15E | B |
| 67197 | Fort-Dauphin | 25 02S | 046 57E | C |
| 68110 | Windhoek | 22 34s | 017 06E | A |
| 68588 | Durban (Louis Botha) | 29 58S | 030 57E | A |
| 68816 | Cape Town (D.F Màlàn) | 33 59s | 018 36E | A |
| 68906 | Gough Island | 40 21s | 009 53w | A |
| 68992 | Bouvet Island | 54 26S | 003 24E | ** |
| 68994 | Marion Island | 46 53S | 037 52E | A |
| 83780 | Sao Paulo (Aeroporto) | 23 37S | 046 39W | * |
| 85442 | Antofagasta | 23 26S | 070 26W | A |
| 85469 | Isla de Pascua | 27 09S | 109 25W | * |
| 85543 | Quintero Santiago | 32 47S | 071 31w | A |
| 85585 | Isla Juan Femandez | 33 40s | 078 59W | ** |
| 85799 | Puerto Montt | 41 25S | 073 05W | B |
| 87155 | Resistencia Aero | 27 27S | 059 03W | A |
| 87860 | Comodoro Rivadavia Aero | 45 47s | 067 30W | A |
| 88889 | Mount Pleasant Airport | 51 49s | 058 27W | A |
| 88903 | Grytviken, South Georgia | 54 16S | 036 30W | ** |
| 89002 | Neumayer | 70 40s | 008 15W | B |
| 89009 | Amundsen-Scott | 90 00S | | C |
| 89022 | Halley | 75 30s | 026 39W | B |
| 89050 | Bellinghausen | 62 12S | 058 56W | A |
| 89532 | Syowa | 69 00S | 039 35E | A |
| 89564 | Mawson | 67 36S | 062 52E | A |
| 89611 | Casey | 66 17s | 110 31E | A |
| 89642 | Dumont 'Urville | 66 40s | 140 01E | A |
| 89664 | McMurdo | 77 51s | 166 40E | * |
| 91592 | Noumea (Nouvelle Caledonie) | 22 16S | 166 27E | A |
| 91958 | Rapa | 27 37S | 144 2ow | A |
| 93012 | Kaitaia | 35 08S | 173 16E | A |
| 93844 | Invercargill Aerodrome | 46 25S | 168 20E | A |
| 93986 | Chatham Is. | 43 57s | 176 34W | A |
| 93997 | Raoul Island, Kermadec Is. | 29 15s | 177 55W | A |
| 94302 | Learmouth Airport | 22 14s | 114 05E | A |
| 94461 | Giles | 25 02S | 128 17E | A |
| 94510 | Charleville Airport | 26 24S | 146 16E | A |
| 94610 | Belmont (Perth Airport) | 31 56S | 115 57E | A |
| 94975 | Hobart Airport | 42 50S | 147 29E | A |
| 94995 | Lord Howe Island | 31 32S | 159 04E | A |
| 94998 | Macquarie Island | 54 29s | 158 56E | A |

## Annex VIII

### Atmospheric Composition Observations

The chemical composition of the atmosphere presently undergoes significant changes, mainly because of several anthropogenic activities such as fossil fuel burning, change in land use, agricultural activities, etc. Because of population growth and increasing standard of living in combination with a higher demand on energy and food the emission of climatically relevant trace constituents will increase with time and will lead to a further climate change. Current climate models predict a temperature increase of 1 .5° - 4.5°C for doubling the atmospheric CO, concentration.

6.2.5 Better forecasting of the potential climate change requires a better understanding of the biogeochemical cycles of the climatically relevant trace constituents and their perturbations by man's activities. Of particular interest are measurements of the global distribution and trends of climatically relevant trace constituents, both gases and aerosols. Particular emphasis should be given to measurements in the free troposphere and the lower stratosphere.

Measurements should focus on:

(a) the directly climate relevant trace constituents such as $H_2O$, $CO_2$, $O_3$, $N_2O$, $CH_4$, CFCs and their substitutes;

(b) the indirectly radiatively centre species such as CO, VOC, NOx (NO, NOz). These species have important influence of the abundance of tropospheric OH, which determine the oxidation capacity of the troposphere and thus the distribution and abundance of several greenhouse gases.

(c) aerosols (and their precursors e.g., sulphate species) which influence the earth's radiation budget, both by direct effects, e.g., absorption and scattering as well as indirectly by contributing to changes of formation, distribution and type of clouds;

(d) radiation parameters including UV-D-radiation, global radiation, and photolysis rates e.g., for NO, and $O_3$.

Measurement programmes must include in situ measurements, ground-based density (e.g., lidar, microwave, FTIR) and balloon soundings in order to provide information sufficient for the calculation of three-dimensional concentration field for the troposphere and lower stratosphere. The frequency of sampling depends on the lifetime of the species and are to a large extent restricted by the instrumental capabilities.

To obtain data which are sufficient to calculate the three-dimensional concentration fields of directly and indirectly radiatively active trace constituents and their changes with time a global network of stations with appropriate geographical coverage is needed. This network should comprise stations which are already in operation within different scientific and operational programme (e.g. NDSC (Network of detection of stratospheric change), the Global Network (GLONET) within IGBP-IGAC (International Global Atmospheric Chemistry Programme), WMO-GAW (Global Atmosphere Watch) and others).

It is recommended that GCOS encourage the co-operation between these programmes in order to establish a network of stations with an appropriate global coverage and measurement programme providing data to be used for:

- evaluating climate and atmospheric transport models;
- better understanding of the biogeochemical cycles and their perturbation by man's activities;
- early detection of climate change and changes of the chemical composition of the atmosphere;
- assessments required by future conventions (e.g., reduction of greenhouse gas emissions).