WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH
(A system for environmental pollution monitoring and research)

No. 92

REPORT OF THE SECOND WMO MEETING OF EXPERTS ON THE QUALITY ASSURANCE/SCIENCE ACTIVITY CENTRES OF THE GLOBAL ATMOSPHERE WATCH
(Garmisch-Partenkirchen, Germany, 7 - 11 December 1992)
NOTE

The designations employed and the presentation of material in this document/publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Meteorological Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

This report has been compiled from information furnished to the WMO Secretariat. It is not an official WMO publication and its distribution in this form does not imply endorsement by the Organization of the ideas expressed.
REPORT OF THE SECOND WMO MEETING OF EXPERTS ON THE QUALITY ASSURANCE/SCIENCE ACTIVITY CENTRES OF THE GLOBAL ATMOSPHERE WATCH

(Garmisch-Partenkirchen, Germany, 7 - 11 December 1992)

Preparation coordinated by Prof. Volker A. Mohnen and Prof. Wolfgang Seiler

CO-SPONSORED BY
Der Bundesminister für Forschung und Technologie and WMO

A contribution to the Global Environment Monitoring System (GEMS)
WMO/TD-No. 580
# TABLE OF CONTENTS

1. OPENING OF THE MEETING, ELECTION OF CHAIRMAN, AND INTRODUCTION .................................................. 1

2. ADOPTION OF THE AGENDA ......................................................................................................................... 3

3. EXECUTIVE SUMMARY ................................................................................................................................. 3
   3.1 Introduction .................................................................................................................................................. 3
   3.2 Scientific Guidance for QA/SACs .................................................................................................................. 4
   3.3 Relationship to GAW .................................................................................................................................. 6
   3.4 Relationship to Existing Programmes ......................................................................................................... 8
   3.5 Education .................................................................................................................................................... 9
   3.6 Final Statement ......................................................................................................................................... 9

4. WORKING GROUP REPORTS ......................................................................................................................... 11
   4.1 Global Atmosphere Watch: Science - Policy Rationale .................................................................................. 11
   4.2 Data Quality and Information Flow ............................................................................................................. 16
   4.2.1 Introduction, Background, and Scope .................................................................................................... 16
   4.2.2 QA/SAC Function: Communications ................................................................................................... 17
   4.2.3 QA/SAC Function: Data Quality and Flow ............................................................................................ 19
   4.3 Education/Training ................................................................................................................................... 22
   4.3.1 IUPAC - Activity .................................................................................................................................... 22

**APPENDIX A** List of Participants

**APPENDIX B** Agenda
1. OPENING OF THE MEETING, ELECTION OF CHAIRMAN, AND INTRODUCTION

The representative of the World Meteorological Organization (WMO), Dr. John M. Miller, opened the meeting and welcomed all participants on behalf of the Secretary-General of the WMO, Professor G.O.P. Obasi (see Appendix A for list of participants).

Dr. Miller briefly outlined the Global Atmosphere Watch (GAW) programme, which represents an effort of unprecedented complexity in the field of environmental measurement and assessment. Given both the magnitude of the GAW programme objectives and the level of coordination that must occur across numerous national organizations, planning for uniform data quality will be a cornerstone of the GAW quality assurance (QA) programme designed and implemented by the Quality Assurance/Science Activity Centres (QA/SACs).

When fully implemented, the GAW will include approximately 30 global stations and 200 - 300 regional stations. Global stations, as described in WMO Fact Sheet No. 3 and WMO Report No. 64, are located in unpolluted remote areas and measure as many species as possible, including:

(a) Greenhouse gases - water vapour, carbon dioxide, chlorofluorocarbons and substitutes, methane, nitrous oxide, tropospheric ozone;

(b) Ozone - surface, total column, vertical profile and precursor gases, using ground-based instruments such as spectrophotometers, sondes, lasers, microwaves, as well as satellites;

(c) Radiation and the optical depth or transparency of the atmosphere, including turbidity, solar radiation, UV-B, visibility, total aerosol (dust particles);

(d) Chemical composition of rainfall, snow, and cloud water;

(e) Reactive gas species such as sulphur dioxide and the reduced sulphur species, nitrogen oxides and the reduced nitrogen species, carbon monoxide, volatile organic carbon species;

(f) Particle mass, particle concentration, size distribution, and composition characteristics, including mineral aerosols;

(g) Radionuclides, including krypton-85, radon, tritium, beryllium-7, and the isotopic composition of selected substances.

Dr. Miller noted that the measurement programme at global stations is not routine, requiring considerable scientific skills which include operational and, sometimes, development of highly sophisticated instruments; data acquisition and interpretation; as well as modelling activities. Such programme implementation demands dedicated scientific interest and close, competent supervision.

Regional stations are located such that the observations are representative of a significant portion of the region. They will have a reduced programme of measurements, focusing on those species that are of particular interest for the region. Core measurements for GAW regional stations, as proposed in WMO-GAW Report No. 71, Report of Experts to Consider Desirable Observational Practices and Distribution of GAW Regional Stations (Halkidiki, Greece, 9 - 13 April 1991), include:

- Surface ozone (free tropospheric ozone);
- Precipitation chemistry;
- Radiation (visible, UV-B);
- Methane;
- Carbon monoxide;
o Aerosol composites;
o Black carbon;
o Total ozone;
o Meteorological parameters.

It is recognized, however, that reliable, standardized instruments are not yet available for all of these measurements.

Dr. Miller emphasized the strong commitment by the WMO to strengthen existing QA programmes and to implement expeditiously new ones for measurement systems not yet covered by a QA protocol. He also emphasized the need for a unified QA approach for the entire GAW programme and summarized the major recommendations of the previous WMO Meeting of Experts on Quality Assurance, which are published in WMO Report No. 80. He reported that the WMO Forty Fourth Executive Council endorsed the concept of establishing QA/SACs and requested that the WMO Secretariat proceed with their development:

"The Council, recalling previous concerns of data reliability and recognizing the importance of quality assured data, fully supported the actions taken by the Secretary-General and the EC Panel/CAS Working Group to improve the quality assurance (QA) and quality control (QC) of GAW data. It endorsed the structure proposed in which GAW stations would submit their data for quality control to a designated independent GAW QA/QC Science Activity Centre(s) that would be responsible for interacting with individual stations, for critical review and acceptance and/or for adding QA flags to data and for identifying and resolving quality performance differences among stations in their regions. They would also be responsible for the provision of reference material, the design of QA experiments and expert consultations to resolve problems, for training, instrument intercomparisons, and workshops. It was hoped that Members with suitable facilities would volunteer their services in establishing these GAW QA/QC Science Activity Centres and that all Members would strive to assist in whatever way they could. The Council requested that the Secretary-General proceed with this development." (July 1992)

Dr. Miller stated that the QA/SACs will serve as the crucial QA link (i.e., the "quality filter") between the individual sampling sites--where the above parameters are measured--and the ultimate data depositories (Data Centres)--where the quality-assured data are archived and distributed.

To further strengthen WMO’s QA programme for GAW and help WMO in its implementation, it became necessary to call the present consultation of experts.

It was the aim of this meeting to develop concrete plans and recommendations for the establishment and functions of QA/SACs as called for in WMO Report No. 80. Dr. Miller concluded his remarks by underlining again the need for GAW to produce quality-assured data, which are essential for scientific and technical assessments. Such assessments require the integration of contributions from several nations and numerous GAW research/monitoring institutions and must be based on data sets that are scientifically sound and of known quality.

Dr. Gisela Helbig, on behalf of the Bundesministerium für Forschung und Technologie (BMFT), and Professor Dr. Wolfgang Seller, Director of the Fraunhofer Institut für Umweltforschung (IFU) in Garmisch-Partenkirchen and local organizer of the workshop, welcomed the participants. Dr. Helbig stated that this century has witnessed dramatic changes in two key factors that define the physical reality of man’s relationship to the global environment: a startling surge in human population, with the addition of one billion people every 10 years, and an increased acceleration of the scientific and technological progress, which has allowed an almost unimaginable magnification of our power to affect the world around us. Human activity has an increasingly powerful influence on all of nature and has become, in effect, a force comparable to natural forces that influence all processes on earth. This "global change" caused by human activity has become the prime focus of intense international discussions, and detection
and documentation of global change have been elevated to the highest level in international research and monitoring priorities. In response to the WMO-Executive Council Resolution of June 1992, the BMFT is now establishing a QA/SAC for Europe/Africa at IFU. The forthcoming advice given by the panel of experts is therefore both welcomed and timely.

Professor Seiler emphasized the significant progress achieved since the plan for comprehensive QA and QC for the GAW programme was first conceptualized in March 1992. He expressed his gratitude for the confidence that both the WMO and the German BMFT have invested in the IFU.

Prof. Dr. Volker A. Mohnen was unanimously elected chairman of the meeting. In his opening remarks he reviewed the major recommendations of the previous panel of experts as published in WMO Report No. 80. He made particular reference to the QA/SACs, the first one being now established by the German BMFT. Professor Mohnen outlined the workshop structure and suggested three sub-working groups dealing with the various aspects of implementing the proposed QA/SACs for GAW: (1) science policy rationale, (2) data quality and information flow; and (3) education/training. Professor Mohnen agreed to serve as workshop rapporteur, to produce an Executive Summary for review by the four external reviewers designated by the WMO after completion of the workshop, circulate the reviewed document to all participants, and prepare a final report for publication by the WMO.

2. ADOPTION OF THE AGENDA

The proposed agenda, which had been distributed in advance by the WMO Secretariat, was accepted by the meeting (see Appendix B).

3. EXECUTIVE SUMMARY

3.1 Introduction

In response to the World Meteorological Organization (WMO) Executive Council decision of July 1992 relating to the operation of the WMO "Global Atmosphere Watch - GAW" programme it is proposed to establish Quality Assurance/Science Activity Centres (QA/SACs) for the geographic regions Europe/Africa, the Americas, Australia, and Asia in accordance with general guidelines developed for the WMO in March 1992 by a panel of experts (WMO GAW Report No. 80). Subsequently, the current meeting of experts—invited by WMO and hosted by the Institut für Atmosphärische Umweltforschung (IFU) (Garmisch-Partenkirchen, December 7 - 11, 1992)—developed a set of specific guidelines and recommendations for the functions and implementation of these QA/SACs.

The purpose and long-term goal of the Global Atmosphere Watch (GAW) is to provide data, scientific assessments, and other information on the atmospheric chemical composition and related physical characteristics of the background atmosphere from all parts of the globe, which is required to improve understanding of the behaviour of the atmosphere and its interactions with the oceans and the biosphere, and to enable prediction of the future states of the earth-atmosphere system. GAW is a coordinated system of networks of observing stations, related facilities, and infrastructure encompassing the measurement and related scientific assessment activities devoted to the investigation of the changing chemical composition and related physical characteristics of the global atmosphere.

National and international policy decisions affecting the environment in the 21st century will rely heavily on scientific data gathered through GAW. The need for better data on the global atmosphere is driven by both scientific and policy considerations. In practice, there is no strong societal incentive to resolve scientific uncertainties unless a policy issue is at stake, and it is mostly when scientific uncertainties and policy requirements coincide that the need for new data is strongest. A sequence of steps then follows, leading to the selection of appropriate methods, through the design of appropriate QA steps, and eventually to the provision of the desired data.
3.2 Scientific Guidance for QA/SAC

The success of GAW in general, and of the QA/SACs in particular, will depend to a great degree on close interactions with the atmospheric science community. Several large multicomponent international scientific programmes in atmospheric chemistry and aerosols are presently getting underway and should have strong interactions with GAW and its sites. While the focus of GAW is on long-term observations to measure changes in the chemical composition and physical characteristics of the atmosphere through a network of global and regional sites as one of the basic systems encompassed by the Global Climate Observing System (GCOS), other international programmes are more process-oriented and hence involve intensive campaign-type measurements in specific geographic regions of the globe. Together, the measurement programmes complement each other and contribute to the GCOS.

In view of this, the QA/SACs should receive direction and advice from the scientific community and interact with it through three formal mechanisms:

- The WMO Executive Council Panel of Experts/Commission on Atmospheric Sciences Working Group on Environmental Pollution and Atmospheric Chemistry. The specification and prioritization of science and science-policy-driven objectives will be developed under the guidance of the WMO EC Panel and with the support of the QA/SACs. These specifications will define the complement of measurement parameters, performance criteria, and analysis requirements necessary to meet the stated objectives. The QA/SACs, based on these specifications, will develop the data quality objectives (DQOs) and provide the QA plans and implementation procedures for the participating GAW sites (Figure 1).

- International Scientific Programmes in Atmospheric Chemistry and Aerosols. At present, primary examples of these programmes include the International Global Atmospheric Chemistry (IGAC) Project and the International Global Aerosol Programme (IGAP).

- In addition, to enhance interactions between the QA/SACs and the scientific community, each QA/SAC should have a Science and Technology Advisory Panel (STAP). This panel would provide advice on matters concerned with site selection, instrumentation selection, instrument calibration, auditing procedures, etc. Its membership should include GAW site managers, representation from the process-oriented science programmes utilizing sites in that region, as well as other scientists utilizing data being generated at the GAW sites in the network. This panel should also have the responsibility to provide overall scientific and technical guidance of the QA for the measurement programmes carried out at the QA/SACs and to make certain that the scientific community is aware of, and participates as much as possible in, the programmes and facilities available within the geographical region of responsibility of each QA/SAC.

To enhance communications among these three committees, the EC Panel should include representatives from IGAC and IGAP. It would also be desirable for selected GAW scientists to be at least ex officio members of IGAC and IGAP. Similarly, the STAP should include liaison members from IGAC, IGAP, and the EC Panel.
Figure 1. Flow Diagram of Quality Assurance Implementation Plan for GAW
3.3 Relationship to GAW

The QA/SACs are an integral part of a tripartite structure--GAW sites, QA/SACs, and Data Centres--designed as a means of ensuring that the GAW network produces a high-quality, reliable, and harmonized global data set (Figure 1). The activities of the QA/SACs are loosely divided into "network-wide" and "centre-specific" tasks. The "centre-specific" communication tasks can again be subdivided into those associated primarily with data flow (e.g., measurements of environmental variables, flags, and metadata), those associated primarily with quality assurance support, and those designed to ensure effective communication and dissemination of information among the various partners. This procedure is to be reviewed after three to five years.

(a) Network-wide activities

The QA/SACs have the responsibility for developing and administering the GAW-QA programme, which includes the preparation of appropriate QA plans for all measurement components of GAW (including intercomparisons, instrument testing, auditing, DQOs, QA project plans, sources and usage of standards). It is the general philosophy of GAW that all countries and all organizations will abide by the procedures and methodologies set forth in the GAW QA Plan so that the GAW data base will be of a consistent and known quality and thus permit reliable conclusions to be drawn. The fundamental concept in this approach is that WMO, through its Members, carries the overall responsibility for all GAW data. For an individual site operator from a particular country to be supplier to the GAW programme, certain standardized QA procedures must be followed uniformly. A country supporting a GAW site is the primary owner of data from that site and may release them as it desires. However, the data can only be accepted as GAW data after GAW QA procedures have been completed.

Network-wide activities are related to the group of QA/SACs which are conceived as forming a closely linked structure with minimum duplication and close coordination of activities. Many of the activities described are the same in all centres. Any activities concerned with the development of specific protocols which are applied across the network (QA routines, archiving software at the site, operation of communications facilities) should be coordinated by one of the QA/SACs in close cooperation with the others. A system should be developed for close coordination and networking between centres. Thus responsibility should be allocated for the following activities:

- General networking and information exchange. All the information described under the centre-specific functions must be passed on to the other QA/SACs to ensure maximum benefit to all network participants. In many cases, joint activities (workshops, newsletter, etc.) will be more appropriate than single-centre activities.

- Procedures should be developed to ensure mutual coordination of all development activities and to minimize duplication across the network.

An essential task of the QA/SACs is the management review of GAW data, flags, and metadata. The following information should be supplied to the designated QA/SAC by the individual sites: (1) measurement parameters, (2) identification of the standard and the history of the standards used, (3) results of calibration, (4) measurement of variance or other indicators of instrument performance (as specified by the standard operating procedures) (e.g., control charts), (5) equipment used, (6) changes in site conditions, (7) results of QA experiments performed at the site.

The QA/SACs then perform the QA functions using criteria as outlined in the QA Project Plan (QAP)P), which defines the DQOs for each GAW measurement component. In the light of the information provided to the QA/SACs, the data can be:

\[(a)\] transmitted to the appropriate data centre as designated by the WMO;
\[(b)\] returned to the site with questions regarding the data quality. In collaboration with the site the data are then reviewed. The final status (flags) is assigned by
the site, and the data are returned to the QA/SAC for transmittal to the appropriate data centre.

To ensure that there is no undue delay in transmittal of data to the data centre(s), the QA/SACs are required to forward the data within an agreed time— if necessary with an appropriate flag indicating that they have not been reviewed. The flagging process should cover problems relating to:

- Accuracy estimate;
- Precision estimate;
- Data completeness;
- Representativeness (e.g., in free troposphere);
- Plausibility;
- Deviations from standard operating procedures;
- Audit/QC performed;
- Calibration reliability;
- Selectivity of measurements (possible interference);
- Measurement type (time resolution, continuous, etc.);
- Co-data missing.

As a result of identified problems, additional QC tests may be necessary, which should be sorted out by the QA/SAC and site.

(b) Centre-specific

From the communications point of view, the most important aspect of data flow is the development of methodologies which facilitate the uninterrupted and reliable recording and transfer of data from the site, through the QA/SAC, to the data centre. This includes:

- Identification or, where necessary, development of a standardized data format;
- Archiving software for recording of data, which can be made available to sites;
- Software for acceptance of data sets and "repackaging" into component parts for transfer to the data centres;
- A schedule for transfer of data.

QA support activities include:

- Developing the schedule for QC activities (site visits, performance and systems audits, calibration schedules, intercomparison schedules, etc.);
- Designing and conducting of QC experiments, either to resolve discrepancies observed during review of data from individual sites, or in response to a request from a data centre (to resolve discrepancies between data and different regions);
- Arranging and promoting twinning between sites with more experience in the type of measurements required, and those where increased training is desirable. (Such twinning arrangements are likely to be the most effective means of ensuring rapid upgrading of all measurements in the network to the same high standard.);
- Periodically reviewing site locations to ensure that (a) the locations are sufficient to meet the requirements for any new scientific objectives included in the programme and (b) possible gaps resulting from fundamental changes in site locations are identified during routine QA checks. (Such a review might result in the suggestion of additions to a site complex, the inclusion of new sites, or the reclassification of existing sites.)
- Allocating station performance categories according to well-defined criteria and recommending removal of a station from the network if data are continually
found to be substandard and therefore to affect the credibility of the global data set;

- Developing procedures for raising awareness of technological changes and ensuring efficient technology transfer within the network (collecting and disseminating remarks/reports by network scientists and others on new methods available or under development, arranging workshops and hands-on training, testing of instruments in pilot projects, etc.);

- Conducting instrument-comparison workshops, instrument improvements and developments.

- Establishing research ties with those members of the scientific community who are potential users of the GAW data. This direct and immediate involvement in data interpretation, model application, etc., of the scientific community—mediated by the QA/SACs—will unequivocally demonstrate the overall "usefulness" of the GAW data and hence provide a powerful quality indicator. This process also provides an efficient feedback loop for implementing necessary corrective actions.

Specific communication functions which can be identified include the following:

- Establishing an efficient communications network (e.g., e-mail/bulletin boards, regular distribution of updated address and contact lists, newsletter, etc.);

- Identifying and responding to information or QA support needs of network participants;

- Recognizing, and responding to, challenging scientific issues by relaying information from within and outside the network;

- Recognizing, and responding to, technological changes;

- Developing ongoing network-specific educational programmes (training courses, seminars etc.) to ensure familiarity at all sites with current methods.

3.4 Relationship to Existing Programmes

Networking between a QA/SAC and specific existing QA expertise developed under existing national and international research programmes for the measurement of trace substances of interest to GAW should be encouraged. The QA/SACs should establish contact with the Principal Investigators of existing global or regional research networks to do the following:

- Review the methods and procedures being used for QA/QC at existing research networks.

- Determine the adequacy of such QA/QC programmes with regard to GAW for individual trace substances and relevant other measurements.

- Decide if the QA/SACs of GAW will "network" with existing QA programmes for certain trace substances. For example, an external QA project for an individual trace gas could be performed and executed on behalf of the QA/SAC. Although the QA/SACs would be responsible and accountable for the establishment, implementation, and supervision of QA at all GAW stations, it may be advisable for the QA/SACs in specific instances to contract out QC experiments to these existing programmes.

To promote and coordinate the provision of data and other information concerning the atmospheric composition and related physical characteristics on a global basis, periodic review meetings organized by the QA/SACs should be an integral part of the GAW programme. Such meetings would satisfy several goals, including presenting the scientific results from GAW and other related programmes, providing a means of exchanging technical information on GAW measurements, and allowing coordination of QA procedures by the QA/SAC.
In the long term, the QA/SACs will be the central QA support and communications centres for all GAW stations—global and regional—with which they are associated. As with all ambitious programmes, this goal can only be successfully achieved by using a phased approach. Priorities for implementation should be established in every area of function in close collaboration with the EC Panel and STAP.

3.5 Education

Throughout the deliberations of the workshop participants, one concern kept rising to the surface of the discussions: the lack of indigenous technical and scientific expertise in developing countries. The ability of a country to follow a sustainable research path is determined by the capacity of its people and its academic institutions. The participants call for capacity-building programmes designed to help countries build their academic infrastructures with regard to atmospheric sciences/atmospheric chemistry. In the meantime, however, there is an urgent need for technicians to operate the new GAW sites who can be trained by the QA/SAC in cooperation with their associated global station.

The key to obtaining high-quality data is to have available a well-trained cadre of atmospheric scientists/chemists capable of executing the complex and ambitious GAW measurement programme. Since atmospheric chemistry is a rather young discipline, but technically very demanding, the WMO workshop members strongly support the establishment of educational programmes in lesser developed countries participating in GAW. The objective would be to enhance the academic infrastructure in these countries with regard to the discipline of atmospheric chemistry so that the scientific manpower required to carry out all GAW measurements could be trained within the country. Because education is an integral part of total QA (the "human factor"), the QA/SACs should organize these educational programmes. An outline for the execution of such an ambitious programme is presented in Figure 2. In addition to improving the academic infrastructure in a country participating in GAW there is an immediate and continuous need for "hands-on" training of GAW station operators. This specialized training can be best accomplished through extended workshops at one of the QA/SACs in cooperation with the collocated global station or by short-term secondments of technical staff to a global station.

3.6 Final Statement

The participants of this WMO meeting reiterated their strong belief that total quality assurance is an essential part of all measurement systems, nearly as important as the measurements themselves, and they appealed to the WMO for the swift implementation of uniform QA/QC procedures for GAW. The information derived from this international network of long-term measurement stations will only be accepted by (i.e., useful to) the national and international decision-making bodies if all underlying data are obtained through strict adherence to a comprehensive QA/QC programme. The participants recognize that the implementation of this programme through the QA/SACs depends on the availability of funds which must be raised from international funding agencies.
GAW - EDUCATION

BUILDING AN INFRASTRUCTURE IN
ATMOSPHERIC CHEMISTRY / METEOROLOGY

Figure 2. Proposed Education Plan for GAW
4. WORKING GROUP REPORTS

4.1 Global Atmosphere Watch: Science - Policy Rationale

The specification and full complement of measurement parameters under Global Atmosphere Watch (GAW) are currently under development. The selection of measurements will reflect GAW's long-term goals and purposes, which include its responsibility for measuring changes in the chemical composition of the atmosphere through a network of global and regional monitoring sites. The final selection of measurements and related performance parameters is closely related to the defined scientific objectives of the GAW. The specification and prioritization of science and science-policy-driven objectives will be developed under the guidance of the World Meteorological Organization Executive Council Panel of Experts/Commission on Atmospheric Sciences Working Group on Environmental Pollution and Atmospheric Chemistry. These specifications will define the complement of measurement parameters, performance criteria, and analysis requirements necessary to meet the stated objectives. The Quality Assurance/Science Activity Centres (QA/SAC), based on these specifications, will then develop the data quality objectives and provide the QA and quality control (QC) plans and implementation procedures for the participating GAW sites. Though it is not the role of the QA/SACs to define or prioritize the scientific objectives for GAW, the opportunity to draw on the extensive expertise at these centres should not be overlooked.

The need for better data on the global atmosphere is driven by both scientific and policy considerations. In practice, there is no strong societal incentive to resolve scientific uncertainties unless there is a policy issue at stake, and it is mostly when scientific uncertainties and policy requirements coincide that the need for new data is strongest. A sequences of steps then follows, leading to the selection of appropriate methods, through the design of appropriate QA steps, and eventually to the provision of the desired data. This is shown in the schematic diagram presented in Figure 1.

The GAW programme identifies data needs which require the operation of two distinct types of measurement stations:

- A network of global stations to monitor change in the global atmosphere (early warning) in a way that is inherently immune from doubts concerning the credibility of the data.

- A broader network of regional stations utilizing uniform sampling protocols and standardized data quality controls so as to provide a method for coupling data sets from otherwise unconnected national networks. Regional stations consider a reduced programme of measurements which are relevant to GAW objectives as well as specific to the interests of the region.

The need for improved data quality within these networks is recognized, as is the need for the establishment of QA/SACs to accomplish this task. The design of appropriate QA programmes for global and regional networks will mostly differ based on the demands of the proposed scientific objectives. In light of the sheer magnitude of the numbers of stations to be considered within the regional context, it may be necessary to review and further develop the selection process and criteria for regional stations.

The following discussion focuses mainly on the global network stations, where a substantial complement of QA/QC activities are currently in place. It should however, be noted that the fundamental nature of these principles will mean that a substantial portion of these activities will be directly transferable for application to the regional stations. These activities relate mainly to the exchange of samples and standards, the analysis of blind samples, and open scientific discussion of results and new developments. In many other cases, such as for the chemical and physical properties of aerosols, the current state of knowledge is still evolving. In such cases, it is recommended that GAW consider small trial programmes to test alternative methodologies and refine appropriate QA/QC procedures.
**Interface with the Scientific Community:** The success of GAW in general, and of the QA/SACs in particular, will depend to a great degree on close interactions with the atmospheric and ecosystem science community. These interactions will include contacts with scientists involved directly with the regular measurement programmes carried out at the sites, those utilizing the data generated at GAW sites, and those undertaking their own individual or cooperative scientific studies at the sites or with the data. Several large multicomponent international scientific programmes in atmospheric chemistry and aerosols are presently getting underway and should have strong interactions with GAW and its sites. In view of this, we recommend that the GAW QA/SACs receive direction and advice from the scientific community and interact with it through three formal mechanisms:

- The WMO EC Panel/CAS Working Group on Environmental Pollution and Atmospheric Chemistry. This panel will define the parameters to be measured (with the advice of the scientific community) and the spatial distribution and frequency of the measurements for the goals of GAW.

- International Scientific Programmes in Atmospheric Chemistry and Aerosols. At present primary examples of these programmes include:

  (a) The International Global Atmospheric Chemistry (IGAC) Project. IGAC is a core project of the ICSU International Geosphere/Biosphere Programme and is managed jointly with the International Association of Meteorology and Atmospheric Sciences (IAMAS) International Commission on Atmospheric Chemistry and Global Pollution (ICACGP). IGAC is an international process-oriented research effort designed to address major scientific questions in atmospheric chemistry. Its goals are:

  o To develop a fundamental understanding of the chemical processes that determine the chemical composition of the atmosphere;

  o To understand the interactions between atmospheric chemical composition and biological and climatic processes;

  o To predict the impact of natural and anthropogenic forcings on the chemical composition of the atmosphere;

  o To provide the necessary knowledge for the proper maintenance of the biosphere and climate.

  Much of IGAC is related to campaign-oriented research programmes in specific geographic regions, although some network operations (e.g., a global ozone network) are also proposed. State-of-the-art instrumentation will be utilized in a research mode in IGAC.

  (b) The International Global Aerosol Programme (IGAP). IGAP is a programme of IAMAS through its International Commissions on Radiation (IRC), on Clouds and Precipitation (ICCP), and on Atmospheric Chemistry and Global Pollution (ICACGP). Planning for IGAP has been sponsored by the WMO (through GAW and the World Climate Research Programme (WCRP). The overall objective of IGAP is "to improve understanding of the role of atmospheric aerosols in the forcing mechanisms and prediction of changes in global climate and in geospheric-biospheric processes."

  It is proposed that IGAP will consist of three main components:

  o Long-term monitoring to provide the data base for aerosol climatology studies and for the input and testing of global aerosol models;

  o Process-oriented studies that will be carried out through laboratory measurements, special field campaigns, and theoretical studies;
Aerosol model development.

Several types of interaction and networking should develop between GAW and scientific process-oriented research programmes, such as IGAC and IGAP. Obviously, GAW sites can provide excellent facilities and locations for process-oriented research programmes and can also provide vital background information on meteorological and some atmospheric chemical and aerosol parameters. At the sites utilized, the scientific programmes can provide scientific expertise and advice to GAW, as well as state-of-the-art instrumentation. For example, the North Atlantic Regional Experiment (NARE) within IGAC will include studies of the oxidizing characteristics of the atmosphere over the North Atlantic and how they are modified as air masses are transported across this region. This programme will utilize facilities and measurements at two GAW stations (Macehead, Ireland; Izaña, Tenerife) as an integral part of the overall scientific plan for the NARE experiments. Strong benefits can accrue to both programmes through extensive interactions by participants.

- **A GAW QA/SAC - STAP.** To enhance interactions between the QA/SACs and the scientific community, each QA/SAC should have a Science and Technical Advisory Panel (STAP). This panel will provide advice on matters concerned with site selection, instrumentation selection, instrument calibration, auditing procedures, etc. Its membership would include GAW site managers, representation from the process-oriented science programmes utilizing sites in that region, as well as other scientists utilizing data being generated at the GAW sites in the network. This panel would also have the responsibility to provide overall scientific and technical guidance of the QA for the measurement programmes carried out at the QA/SAC and to make certain that the scientific community is aware of, and participates as much as possible in, the programmes and facilities available within the geographical region of responsibility of each QA/SAC.

To enhance communications between these three committees, we recommend that the EC Panel include representatives from IGAC and IGAP. It would also be desirable for GAW representatives to be at least *ex officio* members of IGAC and IGAP. Similarly, the STAP should include liaison members from IGAC, IGAP, and the EC Panel.

**QA - Current State and Potential Networking:** For some compounds, particularly several long-lived radiatively active gases, adequate QA procedures are in effect in the general scientific community involved for such measurements. Foremost among these is CO$_2$. Over a period of several decades, precise measurement procedures for CO$_2$ concentration have been developed at the Scripps Institute of Oceanography (SIO), at the Climate Monitoring and Diagnostics Laboratory (CMDL), and at the Australian CSIRO Division of Atmospheric Research. This includes the measurement technology itself (nondispersive IR) as well as extensive development of flask sample technology (storage stability most particularly) and detailed establishment of calibration standards. Calibration standards are available at cost from Scripps or CMDL. It is therefore not necessary for the expensive standards development to be repeated; it is nevertheless desirable that the global community all relate to a central standard. The establishment of carbon isotope standards for CO$_2$, however, is not yet completed, and financial support for this task is required.

The situation for CH$_4$ is approximately the same as that for CO$_2$. Extensive work on standards has been carried out at CMDL, and standards can be provided at cost. The situation for CO is somewhat less satisfactory because of a far more difficult storage stability problem. CO concentration standards have been changed by as much as 30% in recent years. There are cutting edge scientific programmes also on these carbon cycle compounds in France, Germany, New Zealand, Australia, and elsewhere where advice and assistance, and possibly standards also, may be available.

In the case of CFCs and N$_2$O, precise measurement technology is widely in place, involving gas chromatographic (GC) measurement, flask storage technology, and calibration standards. Standards would be available from CMDL and perhaps from other places.

For the hydrohalocarbons (HCFCs) (being introduced as chlorofluorocarbons (CFC) replacements) the situation is less advanced. The standard GC - electron capture detection (ECD)
measurement techniques are less sensitive and the concentrations are lower, so that various concentration technologies are being developed and different analytical techniques are being utilized. This information and support are available from CMDL (Elkins) as development continues.

For nonmethane hydrocarbons (NMHCs), IGAC's NOMHICE (nonmethane hydrocarbon intercomparison experiment) programme with a broadly representative international planning committee is developing information and protocols for hydrocarbon standard preparation, for elusion time standards, and for the preparation of "known" HC mixtures for use as "challenge" samples in the QA. The NOMHICE scientists and their advisory committee (International Hydrocarbon Intercomparison Planning Committee) can provide guidance and counsel for the QA/SACs design of sampling procedures and analysis protocol.

For column ozone measurements, a world standard Dobson instrument has been maintained by CMDL for many years, and periodic comparisons of instruments used worldwide have been carried out. The level of support for this effort has been eroding, so that the longrange future of Dobson calibrations is uncertain. The German Weather Service (DWD) is now building a similar facility at Hohenpeißenberg and will make it available to the community. The Canadian Atmospheric Environment Service maintains a calibration facility at Toronto for Brewer ozone spectrophotometers. This includes a travelling standard which is used worldwide for instrument comparisons.

Networking between a QA/SAC and specific existing QA expertise developed under national and international research programmes for the measurement of trace species of interest to GAW should be encouraged. The QA/SACs will maintain contact with the QA centres of existing research networks to do the following:

- Review the methods and procedures that are being used for QA at existing research networks.
- Determine the adequacy of such QA programmes with regard to GAW for individual trace substances and precipitation composition.
- Decide if the QA/SACs of GAW will "network" with existing QA programmes for certain trace substances and precipitation composition such as to commission an external QA project for an individual trace gas in lieu of having the work performed by a QA/SAC.

Although they will be responsible and accountable for the establishment, implementation, and supervision of QA at the GAW stations, it may be advisable for the QA/SACs in specific instances to contract out QC experiments to existing programmes and, within those, to QA centres of said programmes.

This procedure is advisable if high-accuracy, high-precision QA programmes for individual trace species in air and precipitation already exist which would make their duplication at the QA/SAC unnecessary.

Some examples of species for which QA protocols have been implemented within various programmes are provided in Table 1:
TABLE 1
Examples of QA Protocols Implemented within National and International Programmes

<table>
<thead>
<tr>
<th>Chemical Parameter</th>
<th>Organization/Programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO₂</td>
<td>EUROTRAC TOR</td>
</tr>
<tr>
<td>O₃(surface):</td>
<td>EUROTRAC TOR</td>
</tr>
<tr>
<td></td>
<td>EPA - USA</td>
</tr>
<tr>
<td>O₃ ( sondes):</td>
<td>EUROTRAC TOR</td>
</tr>
<tr>
<td>O₃ (total):</td>
<td>GO₅OS</td>
</tr>
<tr>
<td></td>
<td>AES - Canada</td>
</tr>
<tr>
<td></td>
<td>CMDL - Boulder, CO, USA</td>
</tr>
<tr>
<td>NMHC:</td>
<td>NCAR/NOAA - Boulder, CO, USA</td>
</tr>
<tr>
<td></td>
<td>JRC - ISPRA, Italy</td>
</tr>
<tr>
<td></td>
<td>EUROTRAC TOR</td>
</tr>
<tr>
<td>Radiatively active trace gases (e.g., CO₂, CH₄, N₂O, CFC, HCFC)</td>
<td>CMDL - Boulder, CO, USA</td>
</tr>
<tr>
<td></td>
<td>CSIRO, Australia</td>
</tr>
<tr>
<td>SO₂</td>
<td>EMEP - Europe</td>
</tr>
<tr>
<td></td>
<td>EPA, USA</td>
</tr>
<tr>
<td>H₂O₂</td>
<td>NCAR, Boulder, CO, USA</td>
</tr>
<tr>
<td></td>
<td>IFU, Garmisch-Partenkirchen, Germany</td>
</tr>
<tr>
<td>Precipitation Chemistry</td>
<td>NTN, USA</td>
</tr>
<tr>
<td></td>
<td>EMEP (Europe)</td>
</tr>
<tr>
<td>Radiation</td>
<td>NOAA-ARL, Boulder, CO, USA</td>
</tr>
<tr>
<td></td>
<td>DWD, Hamburg, Germany</td>
</tr>
</tbody>
</table>

**Periodic Review Procedures:** To promote and coordinate the provision of data and other information concerning the atmospheric composition and related physical characteristics on a global basis, the group recommended that periodic review meetings should be an integral part of the GAW programme. Such meetings would satisfy several goals, including presenting the scientific results from GAW and other related programmes, providing a means of exchanging technical information on GAW measurements, and allowing coordination of QA procedures by the QA/SAC. It was suggested that the highly successful U.S. and Australian annual review meetings for their GAW baseline measurement programmes should act as a model.

These meetings have typically included scientists, technicians, and site operators not only from the programme itself but also from outside scientists who can present results related to the GAW activities. Further practical discussions to solve technical problems such as instrument calibration, data archiving, and QA protocols have been a key part of these annual meetings. Before or after the main meeting, workshops are organized to handle special themes such as UVB radiation, precipitation chemistry, or other such specific topics.

These periodic (e.g., annual) GAW meetings would be organized by the WMO Secretariat in collaboration with the QA/SACs and the advisement of its STAP. The STAP would recommend the specific themes and issues to be highlighted at the subject meetings. In addition to these science-specific periodic meetings there will also be GAW Review Meetings held periodically concerning the programme in its entirety. The next of these meetings is planned in conjunction with IGAC for September 1995 in China.
4.2 Data Quality and Information Flow

4.2.1 Introduction, Background, and Scope

The GAW QA/SACs constitute the operational mechanism for harmonization and coordination of data quality activities within the GAW network. The basic purposes of these centres, in conjunction with the GAW network stations and the GAW data centre, have been described in reports from previous workshops (cf. WMO 1992) and can be subdivided into three individual but related functions, as follows:

- To ensure widespread and convenient accessibility to the GAW data set;
- To ensure timely delivery of network data to the GAW data set;
- To ensure and document the quality of data delivered to the GAW data set.

The present section is intended to extend the detail of the previous documentation, with the objective of moving toward an initial design of the QA/SACs.

Relationships of the QA/SACs within the overall GAW system are depicted schematically in Figure 1, which shows the proposed centres, indicating the communication links between the centres and also the links between the centres and the individual GAW measurement stations. GAW measurement stations fall under one of two classifications, depending on whether they are intended to measure regional or global behaviour, with global stations generally being sited at remote and/or high-altitude locations. Both classes of stations are designed to perform long-term measurements for the resolution of identified scientific issues; i.e., the stations are scientifically driven facilities, as opposed to routine monitoring sites. Accordingly, their corresponding QC requirements relate directly to key science objectives.

Although a GAW global station may consolidate its operations at some single site, it is possible also for a global station to consist of two or more sites located in the same geographical region. Because of this, it is appropriate to describe the GAW global stations as GAW "station complexes" which includes both consolidated stations and multi-site stations. Given their long-term nature, the GAW stations (and the associated QA provisions described here) do not directly include campaign-type measurements. It is expected, however, that data obtained from GAW sites will be beneficial to, and supportive of, numerous future scientific campaigns, such as those performed under the auspices of IGAC and IGAP. GAW policy is to encourage and facilitate the use of its data base for all campaigns of this type, as appropriate.

Figure 1 indicates the interaction of a typical QA/SAC within the overall GAW system, wherein data generated at the GAW stations flow directly to the QA/SAC. QA flags are assigned to each data element at the GAW stations, using established flagging criteria. The QA/SAC continually performs secondary quality checks on the data streams and in this process re-flags any questionable data elements and enters into a dialogue with the GAW station for immediate problem identification and resolution. Subsequent to resolution of all quality-related issues, the QA/SAC dispatches the data to the GAW data centre.

Two features are noteworthy in this context. First, it should be emphasized that the country supporting a GAW station is the primary owner of the station’s data prior to its transfer to the GAW data-processing system. As such, the individual stations may release their data directly, at any time, to whomever they choose. Such data, however, are not classified as official GAW data until they have emerged from the QA process and are formally deposited in the data centre. The second important feature concerns possible time delays and bottlenecks within the QA/SACs. Within this operating procedure it is understood that the QA/SACs cannot hold data indefinitely, and after a given time must forward the data to the data centres (with appropriate flags indicating a provisional status).

Figure 1 also indicates a number of functions that are addressed by the QA/SAC, including preparation of QA plans and their constituent elements. These and other functions are described in detail
In the subsections below. In this context it should be emphasized that the primary mission of the QA/SACs is to ensure that these functions are performed, rather than to actually perform all functions internally.

Finally we emphasize that this QA programme is being implemented under GAW as a support system (as opposed to an enforcement entity) for the network stations. The GAW goal of maximizing the quality of its scientific data base will be addressed within this plan through progressive and supportive upgrading of the total GAW measurement complex through education, methods development, and information feedback, based on continual monitoring and evaluation of data quality indicators. The overall structure for this progressive upgrading will center around a three-level site categorization scheme, as indicated below:

- **Category I:** Demonstrated Sustained Quality Performance
- **Category II:** Demonstrated Initial Quality Performance
- **Category III:** Training

All stations entering the GAW system will be placed in Category III until they have satisfied initial performance checks imposed by the QA/SAC, whereupon they will be elevated to Category II. Upon demonstration of sustained performance, Category II stations will be elevated to Category I. Proportionately larger GAW training resources will be allocated to lower-category stations. Implementation of this procedure and the other functions of the QA/SACs are described in the sections immediately following.

### 4.2.2 QA/SAC Function: Communications

As shown in Figure 1, the QA science centres are an integral part of a tripartite structure--GAW sites, QA/SACs, data centres--designed as a means of ensuring that the GAW network produces a high-quality, reliable, and harmonized (comparable and compatible) global data set. This system should be seen as a joint cooperative effort between all partners. The major function of the QA/SAC is to provide the basis for ensuring harmonization between the data sets from different sites in the network by providing the support necessary for achieving consistent data quality and promoting effective communication between all partners in the system. The major scientific efforts will be centred on the sites and data centres; the QA/SAC provides a communications pivot and help-line.

The activities of the QA/SAC can be loosely divided into "centre-specific" and "network-wide" activities, i.e., specific tasks designed to support and link the stations associated with the centre, and tasks focused on the whole network.

(a) **Centre-specific**

"Centre-specific" communications tasks can again be subdivided into those associated primarily with data flow, those associated primarily with QA support, and those designed to ensure effective communication and dissemination of information between the various partners.

**Communication and dissemination of information:** This is one of the key functions of the QA centre. A system must be put in place which ensures efficient communication between participants in the network at all levels. The QA/SAC can be considered a type of clearinghouse for information of all kinds. Some of these activities overlap, or are integrally connected with, activities included in the sections on education and training.

Specific functions which can be identified include the following:

- Establishing an efficient communications network (e.g., e-mail/bulletin boards, regular distribution of updated address and contact lists, newsletter, etc.).
Disseminating information on QA/SAC activities, activities within the network as a whole, and related activities in other groups (meeting publications, fellowship programmes, etc.) and reviewing and changing the type of information disseminated in response to requests from network participants.

Arranging regular meetings and promoting contact between scientists, site operators, data users, etc. Such meetings should be concerned with scientific aspects (regular reporting of results), management aspects, procedural questions, suggested improvements, etc., and respond to needs voiced by network participants.

Identifying and responding to information or QA support needs of network participants.

Recognizing, and responding to, challenging scientific issues by relaying information from within and outside the network, promoting discussion, arranging workshops, etc. A reappraisal of the scientific objectives of the network should be performed at regular intervals based on this information.

Recognizing, and responding to, technological changes.

Developing an ongoing educational programme (training courses, seminars, etc.) to ensure familiarity at all sites with current methods.

**Quality assurance support:** The nonroutine aspects of QA support can usefully be considered as part of the communications function of the centre. The QA/SAC is designed to be associated with a range of sites in different station performance categories. Thus many of these efforts will be specifically aimed at achieving a consistent high level of capability across the network. Similarly, the QA/SAC is in a unique position to facilitate continuous upgrading of methodology and ensure that network data collection is "state-of-the-art". This is also an integral part of QA support.

**QA support activities include:**

- Developing the schedule for QA activities (site visits, audits, etc.).

- Designing and conducting of QC experiments, either to resolve discrepancies observed during review of data from individual sites, or in response to a request from a data centre (to resolve discrepancies among data from different regions).

- Promoting close links between sites with more experience in the type of measurements required and those where increased training is desirable. (Such twinning arrangements are likely to be the most effective means of ensuring rapid upgrading of all measurements in the network to the same high standard.)

- Allocation of station performance categories according to well-defined definitions, and recommending removal of a station from the network if data are continually found to be substandard and thus to affect the credibility of the global data set.

- Developing procedures for raising awareness of technological changes and ensuring efficient technology transfer within the network (collecting and dissemination of remarks/reports by network scientists and others on new methods available or under development, arranging workshops and hands-on training, testing of instruments in pilot projects, etc.).
**Data flow:** From the communications point of view, the most important aspect of data flow is the development of methodologies which facilitate the uninterrupted and reliable recording and transfer of data from the site, through the QA/SAC, to the data centre. This includes:

- Identification, or where necessary development, of a standardized data format;
- Archiving software for recording of data, which can be made available to sites;
- Software for acceptance of data sets and "repackaging" into component parts for transfer to the data centres;
- A schedule for transfer of data.

**(b) Network-wide activities**

The group of QA/SACs is conceived as forming a closely linked structure with a minimum of duplication and close coordination of activities. Many of the activities described will be the same in all centres. Any activities concerned with the development of specific products which will be applied across the network (QA routines, archiving software, communications facilities) will be coordinated by one of the QA/SAC in close cooperation with the others. A system must be developed for close coordination and networking between centres. Thus responsibility must be allocated for the following activities:

- General networking and information exchange. All the information described under the centre-specific functions must be passed on to the other QA/SACs to ensure maximum benefit to all network participants. In many cases, joint activities (workshops, newsletters, etc.) will be more appropriate than single-centre activities.

- Procedures must be developed to ensure mutual coordination of all development activities and to minimize duplication across the network.

**4.2.3 QA/SAC Function: Data Quality and Flow**

**Definition of Data:** Data include measurements of environmental variables, results of QC experiments, flags, and documentation of the general station condition. These should be archived at the site. GAW data shall/should be stratified into global, regional, or local conditions, based on objective chemical and/or meteorological criteria. The filters used depend on the particular site and form part of the data set.

Systematic data gaps will occur, making it necessary to repair the data record. If this is to be done, the repaired data should be flagged (e.g., shadows affecting solar radiation measurements; to determine total daily sum, it is necessary to interpolate at the time of the shadow).

Data transmitted to the QA centre must include the filter criteria. Data rejected for reasons other than the given filter criteria must be clearly flagged. Under occasions where it is impossible to filter data using the standard criteria because of missing co-data, the data should be submitted, but appropriately flagged.

The entire procedure is to be reviewed every three to five years.

**Supporting information:** The supporting information can be divided into different categories. Some information will be kept at the site, and some of it will be forwarded to the QA centre.

To be forwarded to the QA/SAC:

- Identification of the standard and the history of the standards used;
- Results of calibration;
- Measurement of variance or other indicators of instrument performance (as specified by the standard operating procedures, e.g., control charts);
Equipment used;
Changes in site condition;

To be kept at the site:

- All information forwarded to the QA/SAC;
- Raw data;
- Status information for the instruments (log books, etc.).

The details will be agreed on by the QA/SAC and the site.

Flags: They should cover (not listed in order of priority):

- Data completeness;
- Calibration reliability;
- Representativeness (e.g., in free troposphere);
- Measurement type (time resolution, continuous, etc.);
- Exceeding of minimum requirements;
- Deviations from standard operation;
- Audit/QC performed;
- Data repaired;
- Selectivity of measurements (possible interference);
- Accuracy estimate;
- Precision estimate;
- Plausibility;
- Co-data missing.

QA Processing of Data: Data are provided, as defined above, to the QA centre. A management review of the data flags and metadata is then performed, looking at various components including the plausibility of the data flags. In the light of the information provided, the data can be:

- Transmitted to the data centre;
- Returned to the site with questions regarding the data quality. In collaboration with the site the data are reviewed. The final status (flags) is assigned by the site, and the data are then forwarded to the QA/SAC for transmittance to the data centre(s).

Once data are forwarded to the QA centre, there will be a fixed time in which the centre can review the data. Beyond this time, the data must be forwarded to the data centre, with an appropriate flag indicating they have not been reviewed.

As a result of identified problems, additional QC tests may be necessary, which should be sorted out by the QA/SAC and site.

Creation of a Quality Assurance Plan: The QA plan must be based on the scientific problem to be addressed. The scientific objectives still need to be formulated in sufficient detail for the DQOs to be determined. The QA/SAC has the responsibility to lead the preparation of the QA plan, involving the site scientists and GAW managers and sponsors. From this an assessment of the required quality of data must be made (or DQOs). The quality of the data includes an assessment of the number of sites and the type of the sites that are necessary. As a part of the DQOs it must be clear whether surface data and/or vertical (radar, lidar, etc.) soundings are necessary or whether a chemical complex consisting of several interrelated species should be measured. Such a specification will also require recommendations on the methods necessary to filter the data.
The preparation of the DQOs may also require a development phase. The QA/SAC should organize this, which may include evaluation of existing equipment and procedures, or arrange workshops where methods may not exist.

Following the definition of the DQOs a QAPjP can be established. It will normally be developed by a QA/SAC in conjunction with the single site or others with expertise in a pilot study and will include the sources for suitable standards and the usage of standards (frequency and handling procedures).

This QA plan will also consist of an assessment of the timing and nature of:

- intercomparisons of standards, unknowns (e.g., natural air), and instruments;
- testing, cataloguing of instruments;
- auditing of both the performance and the system.

These should be regularly scheduled by the QA/SAC.

Auditing: Auditing is an important part of the QA process and it is therefore vital that it be carried out in a cooperative manner between the QA/SAC and the site to be audited, at regular and known intervals. Two types of audit are recognized:

Performance audits:
Performance audits are carried out by measurements of samples with a composition unknown to the analysing centre. The audit may be carried out by simply supplying the unknown or by the auditor's bringing the sample to the lab. Alternatively, it may be more practicable that disparate sites measure identical samples for intercomparison across the network (between different QA/SACs). The results of the audit are supplied to the laboratory before they are released elsewhere. Where performance is not satisfactory, the QA/SAC and the site decide on whether another performance audit should be made or whether a system audit is necessary.

System Audit:
A system audit involves an assessment of the total process of sample collection and analysis. An expert in a measurement technique is brought to the site so that problems can be identified and the process of improvement be formulated. The frequency of audits will depend on site performance. Auditors need to be carefully selected so that they have the necessary scientific experience to understand the process at the site. The audit process may consist of a series of visits, each intended to aid in improving the performance level. At the end of the process, an audit report is submitted to the QA centre. Results of audits will also be used for classification of stations and can ultimately be used for the assessment of whether stations should remain within in GAW. However, this is seen as a process of last resort for stations with a consistently unsatisfactory and unimproved performance.

Development Schedule: In the long term, the QA/SAC will be the central QA support and communications centre for all GAW stations—global and regional—with which it is associated. As with all ambitious programmes, this goal can only be successfully achieved by using a phased approach. Priorities for implementation will have to be established in every area of function.

Since the first priority in the GAW network is to produce harmonized data sets for the scientific study of global issues, the first activities of the QA/SAC should be focused on the global stations. Regional stations should be included in the communications network from the beginning, but full QA support (e.g., development of a QA plan) will only be possible as resources become available. Data from regional centres will pass through the QA/SAC without review until the necessary procedures have been developed.
Establishment of the communications network, and development of archiving and transfer software, will be a priority, since they are a prerequisite to the smooth running of the system. However, development of these also implies decisions on a number of factors such as the data variables to be recorded.

Priorities will have to be set in a number of areas. These include establishment of DQOs, development of SOPs, development of audit procedures, standards to be prepared and distributed, training courses to be established, and many other specific points. It will be the task of the QA/SAC to ensure that the information is assembled, and a mechanism put in place, for establishing these priorities. Education should be considered a major priority, and establishing an appropriate educational programme should precede implementation of new sites.

4.3 Education/Training

Atmospheric chemistry is a rather young discipline, but technically very demanding. The international programmes that rely on a well-trained cadre of atmospheric chemists for executing complex and ambitious research and monitoring tasks include, in addition to the GAW programme:

- the IGBP - International Atmospheric Chemistry Programme, IGAC;
- the IGBP - System for Analysis, Research and Training (START) Programme;
- the IGAP - International Global Aerosol Programme.

There is not doubt that the levels of professional activity in GAW, IGAC, START, IGAP, etc., depend directly on the educational experiences embodied in atmospheric chemistry.

Among the several planned international programmes, two have been discussed in some detail, namely CHEMRAWN (Dr. E. Ferguson) and IUPAC (Dr. J. Calvert).

4.3.1 IUPAC - Activity

The increased interest in the development of international monitoring networks, designed for continuous operation of a variety of air monitoring equipment, has made evident the need for well-planned workshops and training programmes to ensure the uniform quality of the measurements in such programmes. There is a special challenge in the training of scientific personnel from the developing countries where the operations of observation stations in remote regions must be made largely in isolation with a very limited number of scientific staff and few ancillary facilities.

During the past two years, Dr. Calvert and the Commission on Atmospheric Chemistry of the International Union of Pure and Applied Chemistry (IUPAC) have been conducting a project which is of interest in the planning of training programmes and workshops: The project title "Workshops for Training of Scientists from Developing Countries in Atmospheric Chemistry" was designed to accomplish several limited goals: (1) to evaluate the need for workshops and training courses in stimulating the development of the atmospheric sciences in developing countries, (2) to determine the interest of atmospheric scientists in the participation in the instructional programmes, and (3) to design a possible format for the planning and execution of such workshops and training courses.

The IUPAC Commission on Atmospheric Chemistry gained its first experience in the design of atmospheric chemistry training courses during the CHEMRAWN conference on "Chemistry of the Atmosphere; Its Impact on Global Change," which was held in December 1991 in Baltimore, Maryland. A subcommittee of the Commission (chaired by Dr. William Wilson) designed and offered a two-week course on trace gas measurements in ambient air. About 20 young scientists were selected from a group of qualified candidates nominated from a number of universities and agencies in developing countries. The workshop consisted of laboratory, lectures, and field exercises which were based largely on training courses of the U.S. Environmental Protection Agency (U.S. EPA) and designed to introduce the participants (largely B.S. students with varied areas of scientific interest) to the areas of air quality monitoring and atmospheric chemistry. Financial support for the travel and housing of these young
participants was provided by a special grant from the International Development Agency. Support for the workshop itself, including the instructional staff, equipment, and facilities, as provided by the U.S. EPA. Following the workshop, all attendees were invited to attend the CHEMRAWN conference, where they were exposed to lectures and discussions on the major current interests in atmospheric chemistry. Most of the participants responded well to the challenges of this programme, and it was concluded that such a workshop could help in the development of a cadre of young scientists who could be identified and highly motivated to become eventually important partners in future regional and global monitoring programmes.

Discussions of the international members of the IUPAC Atmospheric Chemistry Commission with many of their scientific colleagues in the atmospheric sciences in the developed countries around the world led the Commission to the following conclusions:

(a) There is an increasing need for the training of scientific personnel who will be qualified to make accurate measurements of various global observation sites around the world.

(b) Workshops can be designed carefully to accomplish specific training needs in the atmospheric sciences.

(c) There is a large interest in the existing faculty and research staff of universities, research institutes, and government and industrial laboratories, in volunteering for service on the instructional staff of international workshops for training young scientists from the developing countries in the atmospheric sciences.

The format of the workshops and training courses can be varied from that required for education in specific topics in the atmospheric sciences (e.g., measurement methods to be used for a single atmospheric trace gas experiment) which may last a week or so, to a full academic year course in basic Atmospheric Chemistry, as Atmospheric Sciences, etc. It is the expectation of members of the planning committees that no volunteer faculty member will be asked to spend more than two weeks at the instruction site away from his or her home institution. For the full academic year courses, the coordination of the various course modules will be ensured by a steering committee, and the chosen volunteer faculty of the courses to be offered. Copies of all course notes, reading materials, demonstration materials, etc., used in either the short workshops (one or two weeks duration) or the full academic year courses (two semesters or three quarters), will be turned over to the appropriate faculty member of the local university who will be most directly involved in future local instruction in the atmospheric science area. This procedure should be useful to the local faculty in building their courses for the subsequent years.

In its preliminary report, the IUPAC Commission recommends that Education Committees of the IGAC, American Geophysical Union, IGBP/START, the World Meteorological Organization, and possibly other relevant interested scientific groups, join with it in the formulation of the final format to be used in selecting the sites for such workshops and training courses, and in the solicitation of students and faculty for these workshops. Their current general plan of operation suggested for consideration is the following:

(a) A comprehensive list of potential faculty from the atmospheric sciences (largely atmospheric and analytical chemists, physicists, meteorologists, and engineers) from around the world is being prepared by Dr. Calvert from volunteers solicited from universities, institutes, and industry. Permission will be sought from the IUPAC, AGU, American Chemical Society, and equivalent scientific bodies throughout the developed countries, to canvass their membership for volunteers for the instructional staff. Even without such a formal request for volunteers, a list of over 50 highly qualified international scientists has been made by Dr. Calvert through personal discussion. The names and the final master list will be organized by scientific interests in the various fields of atmospheric sciences, teaching experience of the person, etc.
The scientists on this list will serve as a pool of potential faculty for workshops to be planned.

(b) An executive committee should be formed and should include the appropriate members of the Education Committees of the scientific partners in the venture (IUPAC, IGAC, IGBP/START, AGU, WMO, etc.).

(c) A conceptual plan should be developed by an ad hoc committee of this WMO panel of experts and presented at the next meeting.

A basic outline was presented by the education/training subgroup and is included in the Executive Summary.
APPENDIX A

WMO MEETING OF EXPERTS ON THE QA/SCIENCE ACTIVITY CENTRES OF GAW
Garmisch-Partenkirchen, Germany
7 - 11 December 1992

List of Participants

Chairman
Prof. Dr. Volker A. Mohnen
Fraunhofer - Institut für Umweltforschung (IFU)
and
Department of Atmospheric Science
University at Albany
State University of New York
c/o ASRC
100 Fuller Road
ALBANY NY 12205
USA
Tel: 518 442-3819
Fax: 518 442-3867

Co-Chairman
Prof. Dr. Wolfgang Seiler
Fraunhofer - Institut für Umweltforschung (IFU)
Kreuzeckbahnstrasse 19
D-8100 GARMISCH-PARTENKIRCHEN
Germany
Tel: 49 8821 183100
Fax: 49 8821 73573

Dr. Helmut Bauer
GSF - Forschungszentrum für
Umwelt und Gesundheit, GmbH
Kühbachstrasse 11/3
8000 MÜNCHEN 90
Germany
Tel: 49 89 65 10 88 50
Fax: 49 89 65 10 88 44

Dr. Eugene Bierly
American Geophysical Union
2000 Florida Avenue NW
WASHINGTON DC 20009-1277
USA
Tel: 202 9393202
Fax: 202 3280566

Dr. Kenneth L. Deemerjian
Atmospheric Sciences Research Center
University at Albany
State University of New York
100 Fuller Road
ALBANY, NY 12205
USA
Tel: 518 4423820
Fax: 518 4423867

Dr. Eugene Bierly
American Geophysical Union
2000 Florida Avenue NW
WASHINGTON DC 20009-1277
USA
Tel: 202 9393202
Fax: 202 3280566

Dr. Rumen D. Bojkov
World Meteorological Organization
41, Avenue Giuseppe Motta
Case Postale No. 2300
CH-1211 GENEVA 2
Switzerland
Tel: 41 22 730 8455
Fax: 41 22 740 0984

Prof. Dr. Robert A. Duce
Geosciences & Maritime Studies
Texas A&M University
COLLEGE STATION, TX 77843-3148
USA
Tel: 409 8453651
Fax: 409 8450056

Dr. Jack Durham
US Environmental Protection Agency
RD 682 - Rm 611 WT
401 M Street SW
WASHINGTON DC 20460
USA
Tel: 202 2608932
Fax: 202 2606370

Prof. Dr. Jack G. Calvert
National Center for Atmospheric Research
PO Box 3000
BOULDER, CO 80307
USA
Tel: 303 4971435
Fax: 303 4971400

Dr. Eldon E. Ferguson
Climate Monitoring and
diagnostics Laboratory
US Department of Commerce
NOAA
Environmental Research Laboratories
325 Broadway
BOULDER, CO 80303-3328
USA
Tel: 303 4976966
Fax: 303 4976975
Prof. Dr. Manfred Grasserbauer
Head, Institut für Analytische Chemie
Technische Universität Wien
Getreidemarkt 9/151
A-1060 WIEN
Austria
Tel: 43 222 588 01
Fax: 43 1 56 78 13

Prof. Dr. Peter V. Hobbs
University of Washington
Currently at:
Istituto Fisbat C.N.R.
Via de' Castagnoli 1
40126 BOLOGNA
Italia
Tel: 39 51 287090/287011
Fax: 39 51 229702

Dr. Jeremy M. Hales
Atmospheric Sciences Department
Battelle - Pacific Northwest Laboratory
3190 George Washington Way
PO Box 999
RICHLAND, WA 99352
USA
Tel: 509/375-4370
Fax: 509/376-5217

Dr. Dieter Jost
Umweltbundesamt
Bismarckplatz 1
1000 BERLIN 33
Germany
Tel: 030/8903-2294
Telex: 183756

Dr. Gisela Helbig
BMFT
Ref. 521/Ökologische Forschung
Postfach 20 02 40
5300 BONN 2
Germany
Tel:  
Fax:  

Dr. John M. Miller
World Meteorological Organization/Environment Division
41 Giuseppe Motta
Case Postal No. 2300
CH-1211 GENEVA 2
Switzerland
Tel: 4122 730 8240
Fax: 4122 740 0984

Dr. A. Beatrice Murray
United Nations Environment Programme (UNEP)
Harmonization of Environmental Measurement (HEM)
c/o GSF Forschungszentrum für Umwelt und Gesundheit
Ingolstädtler Landstrasse 1
W-8042 NEUHERBERG NEAR MUNICH
Germany
Tel: 49 89 3187 5489
Fax: 49 89 3187 3325

Mr. Bruce B. Hicks
NOAA - Air Resources Laboratory (R/E/AR)
SSMC 3, Rm 3152
1315 East West Highway
SILVER SPRING, MD 20910
USA
Tel: 301 7130684
Fax: 301 7130119

Dr. Michio Hirota
Oceanographical Division
Marine Department
Japan Meteorological Agency
1-3-4 Otemachi, Chiyoda-ku
TOKYO 100
Japan
Tel: 813 2128341
Fax: 813 2112032

Dr. Dieter Kley
Institut für Chemie
Atmospheric Chemistry
Kernforschungsanlage
5170 JULICH, Postfach 1913
Germany
Tel: 49 2461 61 3741
Fax: 49 2461 61 5346

Dr. John M. Miller
World Meteorological Organization/Environment Division
41 Giuseppe Motta
Case Postal No. 2300
CH-1211 GENEVA 2
Switzerland
Tel: 4122 730 8240
Fax: 4122 740 0984

Dr. A. Beatrice Murray
United Nations Environment Programme (UNEP)
Harmonization of Environmental Measurement (HEM)
c/o GSF Forschungszentrum für Umwelt und Gesundheit
Ingolstädtler Landstrasse 1
W-8042 NEUHERBERG NEAR MUNICH
Germany
Tel: 49 89 3187 5489
Fax: 49 89 3187 3325

A-2
Reviewers

Dr. Federick C. Feisenfeld
Aeronomy Laboratory
Mail Code R-446
NOAA/ERL
Boulder CO 80303
USA
Tel: 303 497-5819
Fax: 303 497-5373

Prof. Dr. James N. Galloway
Department of Environmental Sciences
University of Virginia
Clark Hall
Charlottesville VA 22903
USA
Tel: 804 924-7761
Fax: 804 982-2137

Prof. Dr. Dieter Klockow
Institut für Spektrochemie
Gesellschaft zur Förderung der Spektrochemie
und Angewandten Spektroskopie E.V.
4600 Dortmund 1
Bunsen-Kirchhoff-Str.11
Germany
Tel: 0231 1392-0
Fax: 0231 1392-120

Dr. Douglas M. Whelpdale
Atmospheric Environment Service
4905 Dufferin Street
Downsview Ontario
Canada M3H 5T4
Tel: 416 739-4869
Fax: 416 739-4288
APPENDIX B

WMO MEETING OF EXPERTS ON THE QA/SCIENCE ACTIVITY CENTRES OF GAW
(Arranged in collaboration with the Fraunhofer-Institut für Umweltforschung)

Agenda

Sunday, 6 December
Welcome at Hotel "Garmischer Hof"

Monday, 7 December
09.00 - 17.00 Opening of the Meeting at IFU
Presentation of material assigned to each participant
19.00 Reception hosted by German Ministry of Research and Technology
(BMFT) at IFU

Tuesday, 8 December
09.00 - 17.00 Discussion of GAW QA/Science Activity Centres functions and a
general implementation plan; assignment of individual responsibilities
19.00 Bavarian Dinner

Wednesday, 9 December
Excursion to Zugspitze (weather permitting)—visit high altitude
observatory and ski Zugspitz-Platt or shopping excursion to Munich
or Oberammergau
20.00 Individual groups meet separately to work on assignments and
complete draft proposals

Thursday, 10 December
09.00 - 17.00 Individual group meetings and full panel discussions of drafts

Friday, 11 December
09.00 - 14.00 Final preparation and discussion of the proposed GAW-QA/Science
Activity Centres functions and implementation plan
15.00 Close of meeting


7. Fourth Analysis on Reference Precipitation Samples by the Participating World Meteorological Organization Laboratories by Robert L. Lampe and John C. Puzak, December 1981*

8. Review of the Chemical Composition of Precipitation as Measured by the WMO BAPMoN by Prof. Dr. Hans-Walter Georgii, February 1982


11. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at May 1982*

12. Report on the Mount Kenya Baseline Station Feasibility Study edited by Dr. Russell C. Schnell


14. Effects of Sulphur Compounds and Other Pollutants on Visibility by Dr. R.F. Pueschel, April 1983

15. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1981, May 1983*


*Out of Print
17. General Consideration and Examples of Data Evaluation and Quality Assurance Procedures Applicable to BAPMoN Precipitation Chemistry Observations by Dr. Charles Hakkariinen, July 1983


19. Forecasting of Air Pollution with Emphasis on Research in the USSR by M.E. Berlyand, August 1983

20. Extended Abstracts of Papers to be Presented at the WMO Technical Conference on Observation and Measurement of Atmospheric Contaminants (TECOMAC), Vienna, 17-21 October 1983


23. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1982. November 1984


26. Sulphur and Nitrogen in Precipitation: An Attempt to Use BAPMoN and Other Data to Show Regional and Global Distribution by Dr. C.C. Wallén. April 1986


29. Recommendations on Sunphotometer Measurements in BAPMoN Based on the Experience of a Dust Transport Study in Africa by Dr. Guillaume A. d’Almeida. September 1985


33. Man and the Composition of the Atmosphere: BAPMoN - An international programme of national needs, responsibility and benefits by R.F. Fueschel. 1986

35. Provisional Daily Atmospheric CO₂ Concentrations as Measured at BAPMoN Sites for the Year 1983. December 1985


43. Recent progress in sunphotometry (determination of the aerosol optical depth). November 1986


46. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1984. December 1986


50. Provisional Daily Atmospheric Carbon Dioxide Concentrations as Measured at BAPMoN Sites for the Year 1985. December 1987


53. WMO Meeting of Experts on Strategy for the Monitoring of Suspended Particulate Matter in BAPMoN - Reports and papers presented at the meeting (Xiamen, China, 13-17 October 1986). October 1988

55. Summary Report on the Status of the WMO Background Air Pollution Monitoring Network as at 31 December 1987


58. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at BAPMoN sites for the years 1986 and 1987


62. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at BAPMoN sites for the year 1988


64. Report of the consultation to consider desirable locations and observational practices for BAPMoN stations of global importance (Bermuda Research Station, 27-30 November 1989)


68. Global Atmospheric Background Monitoring for Selected Environmental Parameters. BAPMoN Data For 1989, Volume I: Atmospheric Aerosol Optical Depth

69. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at Global Atmosphere Watch (GAW)-BAPMoN sites for the year 1989


72. Integrated Background Monitoring of Environmental Pollution in Mid-Latitude Eurasia by Yu.A. Izrael and F.Ya. Rovinsky, USSR

73. Report of the Experts Meeting on Global Aerosol Data System (GADS) (Hampton, Virginia, 11-12 September 1990)


75. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at Global Atmosphere Watch (GAW)-BAPMoN sites for the year 1990

76. The International Global Aerosol Programme (IGAP) Plan: Overview

77. Report of the WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques (Lake Arrowhead, California, 14-19 October 1990)

78. Global Atmospheric Background Monitoring for Selected Environmental Parameters BAPMoN Data for 1990, Volume I: Atmospheric Aerosol Optical Depth


80. Report of the WMO Meeting of Experts on the Quality Assurance Plan for the GAW (Garmisch-Partenkirchen, Germany, 26-30 March 1992)


83. Report on the Global Precipitation Chemistry Programme of BAPMoN

84. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at GAW-BAPMoN sites for the year 1991

85. Chemical Analysis of Precipitation for GAW: Laboratory Analytical Methods and Sample Collection Standards by Dr. Jaroslav Santroch


88. Guide to the observations by E. Meszaros

89. 4th International Conference on CO₂ (Carqueiranne, France, 13-17 September 1993)


91. Extended Abstracts of Papers Presented at the WMO Region VI Conference on the Measurement and Modelling of Atmospheric Composition Changes Including Pollution Transport (Sofia, 4-8 October 1993)
