

GAW Report No. 172

WMO Global Atmosphere Watch (GAW)
Strategic Plan: 2008 – 2015

WORLD METEOROLOGICAL ORGANIZATION GLOBAL ATMOSPHERE WATCH

No. 172

WMO Global Atmosphere Watch (GAW) Strategic Plan: 2008 – 2015

A Contribution to the Implementation of the WMO Strategic Plan: 2008-2011

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FOREWORD

World Meteorological Organization (WMO) Members have long recognized the importance of atmospheric chemistry in their weather, climate and air quality programmes and activities. In 1989, this resulted in the establishment of the Global Atmosphere Watch (GAW) Programme by the forty-first session of the WMO Executive Council. In so doing, two long-term monitoring programmes dating back to the 1970s or earlier were merged: the Global Ozone Observing System (GO₃OS) and the Background Air Pollution Monitoring Network (BAPMoN).

In the report of its tenth session (Offenbach, 1990), the Commission for Atmospheric Sciences welcomed this decision and emphasized that “a fundamental concept of GAW was that atmospheric composition observations must be given the same importance as that given to the classical meteorological parameters such as temperature, wind and precipitation”. In 1991, Eleventh World Meteorological Congress endorsed the GAW and, in 1992, the forty-fourth session of the Executive Council approved the GAW Technical Regulations.

Since that time, the GAW has evolved into a major programme in the context of WMO's leading efforts to implement an Integrated Global Atmospheric Chemistry Observations (IGACO) strategy and the monitoring needs for essential climate variables like ozone, aerosols and greenhouse gases.

It is a pleasure to introduce the third GAW Strategic Plan for the period 2008 to 2015, which is consistent with the WMO Strategic Plan: 2008 – 2011. I wish to thank all contributing experts of the Commission for Atmospheric Sciences' Open Programme Area Group for Environmental Pollution and Atmospheric Chemistry (CAS OPAG-EPAC), for their role in its development. The task involved a series of consultations within the international GAW community, including the Scientific Advisory Groups, as well as leaders of the Quality Assurance/Science Activity Centres, Central Calibration Laboratories, World or Regional Calibration Centres and World Data Centres. The Plan was reviewed and endorsed by the Joint Scientific Steering Committee of CAS OPAG-EPAC in April 2007.

The GAW Strategic Implementation Plan: 2008 - 2015 incorporates the successful aspects of previous plans and makes some positive changes in order to address future needs. By implementing the IGACO strategy, GAW rises to meet the atmospheric chemistry-related challenges of the next decade. The GAW 2008 - 2015 programme is a key component of the WMO observing system that, in turn, is a major contribution to the Global Earth Observation System of Systems (GEOSS). This strategic plan addresses a number of recent developments in numerical weather prediction that, no doubt, will require information on aerosols, ozone and greenhouse gases. This expands the community of practice of GAW, necessitates even stronger links to the WMO Information System (WIS) and brings GAW closer to the forecasting research activities of the World Weather Research Programme (WWRP), including THORPEX. The strategic plan sets GAW on a course that underscores its role as a unique international mechanism for applying systematic atmospheric chemistry observations and analysis in addressing societal needs under a constantly changing climate.

(M. Jarraud)

Secretary-General

EXECUTIVE SUMMARY

Based on an assessment of the programme status, this Global Atmosphere Watch (GAW) Strategic Plan is the foundation for developing the components of GAW over the next eight years (2008-2015). It is in line with a framework strategy, namely, the Theme Report of the International Global Observing Strategy (IGOS) on Integrated Global Atmospheric Chemistry Observations [IGACO, 2004]. Goals are formulated for the entire period while specific implementation tasks are defined for 2008 – 2011 only. For the remainder of the planning period, they will be developed in 2011 after assessing progress made.

This GAW Strategic Plan is the product of a joint effort of numerous key-players of the GAW community, reviewed and endorsed in its entirety by the Joint Scientific Steering Committee of the WMO Open Programme Area Group on Environmental Pollution and Atmospheric Chemistry (JSSC OPAG-EPAC) and acknowledged by the Fifteenth WMO Congress in 2007.

The GAW Strategic Plan addresses the GAW community, its partner programmes and interested scientists at large.

Rationale and Mission of GAW

The **rationale** for the Global Atmosphere Watch is the need to understand and control the increasing influence of human activity on the global atmosphere. Among the grand challenges are

- Stratospheric ozone depletion and the increase of ultraviolet (UV) radiation.
- Changes in the weather and climate related to human influence on atmospheric composition, particularly, greenhouse gases, ozone and aerosols
- Risk reduction of air pollution on human health and issues involving long-range transport and deposition of air pollution.

Many of these have socio-economic consequences affecting weather, climate, human and ecosystem health, water supply and quality, and agricultural production.

The **mission** of GAW, taking into account the Integrated Global Atmospheric Chemistry Observations (IGACO) strategy, is to

- Reduce environmental risks to society and meet the requirements of environmental conventions.
- Strengthen capabilities to predict climate, weather and air quality.
- Contribute to scientific assessments in support of environmental policy.

through

- Maintaining and applying global, long-term observations of the chemical composition and selected physical characteristics of the atmosphere.
- Emphasising quality assurance and quality control.
- Delivering integrated products and services of relevance to users.

GAW also fulfils a **mandate from WMO Members** by responding to the needs and clearly linking to the plans of national, regional, and international observing projects, programmes, systems and strategies, *e.g.*

- As a component of the WMO integrated global observing system, contributing to Global Monitoring for Environment and Security (GMES) in support of Global Earth Observation System of Systems (GEOSS).
- In supporting the United Nations Framework Convention on Climate Change (UNFCCC), especially by contributing to the implementation plan for the Global Climate Observing System (GCOS) [WMO, 2003a].

- In observing the Vienna Convention on the Protection of the Stratospheric Ozone Layer and follow-up protocols.
- In supporting the Convention on Long-Range Transboundary Air Pollution (CLRTAP).
- In providing a comprehensive set of observations of atmospheric composition in support of the Intergovernmental Panel on Climate Change (IPCC) process.

Programme Status

Since its inception in 1992, GAW has matured and developed into a programme with support from a large number of WMO Members. More than 100 countries have registered approximately 700 stations with the GAW Station Information System (GAWSIS). As of March 2007, each of the GAW World Data Centres (WDCs) have registered anywhere between 80 and 400 stations.

The **surface-based observational network** remains the back-bone of GAW. Twenty-four (24) stations (comprising one or several individual sites) constitute the network of Global GAW stations, with Jungfrauoch (Switzerland) and Danum Valley (Malaysia) being among the most recent additions. The remaining stations represent the GAW network of Regional and Contributing stations which add significantly to the global observing systems.

In the last decade, **airborne and space-based observations** have begun to contribute significantly to the characterization of the upper troposphere and lower stratosphere, in particular with regards to ozone, solar radiation, aerosols, and certain trace gases. Some aircraft measurements remain in continuous danger of being terminated because of insufficient funding. A new generation of satellite sensors have begun operation, in some cases adding to relatively long measurement series, in other cases beginning new measurement series (see IGACO report). During the last years, expertise has been built up to use satellite information to explore the composition of the lower and middle troposphere. Data access has been improving, but is still not optimal.

Various **GAW expert groups and central facilities** exist under the oversight of the WMO Commission for Atmospheric Sciences (CAS) and its Joint Scientific Steering Committee of the WMO Open Programme Area Group on Environmental Pollution and Atmospheric Chemistry (JSSC OPAG-EPAC). These comprise as of May 2007:

- 6 Scientific Advisory Groups (SAGs) to organise and co-ordinate GAW activities by parameter, and the Expert Teams on World Data Centres (ET-WDC) and Near-Real-Time Chemical Data Transfer (ET-NRT CDT).
- 4 Quality Assurance/Science Activity Centres (QA/SACs) perform network-wide data quality and science-related functions.
- 15 Central Calibration Laboratories (CCLs) and World and Regional Calibration Centres (WCCs, RCCs) maintain calibration standards and provide instrument calibrations and training to the stations.
- 5 World Data Centres archive the observational data and metadata, which are integrated by the GAW Station Information System (GAWSIS).

Main Long-Term Objectives

The **main long-term objectives** of GAW are in line with the WMO Strategic Plan 2008-2011 and identical with those expressed in the IGACO report [IGACO, 2004]. With respect to the last GAW Strategic Plan (2001-2007) [WMO, 2001b], the present version strives for the following main programme developments:

- Develop GAW into a three-dimensional global atmospheric chemistry measurement network through the **integration of observations** of surface-based, balloon-borne, aircraft, satellite and other remote sensing observations.

- Make certain sectors of GAW, such as total ozone, ozone sounding and aerosol observations, compatible with **near-real-time (NRT)¹ delivery of data**. Increase the usage of the WMO Global Telecommunication System/WMO Information System (GTS/WIS) for exchange of GAW data.
- Fuse observational systems, data assimilation and modelling, databases and product delivery, and quality assurance and validation into coherent data processing chains, related to a defined GAW **quality management system** within the WMO Quality Management Framework (QMF).
- Support research and development leading to **assimilation of the essential climate variables** – aerosols, ozone and greenhouse gases – in atmospheric transport and numerical weather prediction models and the production of related products and services.

Implementation Principles

The **implementation principles** for this GAW Strategic Plan are:

- Regularly **assess the status** of the GAW networks and projects on a biennial basis through the JSSC OPAG-EPAC.
- Establish and operate dedicated **IGACO offices** for the thematic foci on ozone/UV, aerosols, greenhouse gases and air quality/long-range transport of air pollution, to strengthen research and application activities in the focus area.
- Support continued operations and development of **existing GAW observatories** that have a solid record of achievement.
- Improve the collaboration between the NMHSs, environmental agencies and research organizations **in filling gaps** in the GAW three-dimensional observing network.
- Deliver in **near-real-time** total ozone, ozone sonde and aerosol optical depth data, making increasing use of the WMO GTS/WIS system.
- **Standardize** quality-related processes and procedures for the primary GAW variables: ozone, UV, greenhouse gases, aerosols, selected reactive gases and precipitation chemistry.
- Ensure that data collected and archived by WMO/GAW WDCs are of **known quality** and promote open access under a '**fair-use**' data policy.
- Continue to build up resident **expertise in developing countries** so that they are linked to strong science programmes.
- Increase **the visibility** of GAW through the quadrennial GAW Symposium and co-sponsoring specialized sessions at large conferences such as those of the American Geophysical Union (AGU) and the European Geosciences Union (EGU).

Development of the Focal Areas

The status and future development of the various GAW focal areas have been elaborated by the various SAGs and are detailed in Chapter 7 of this report. In summary:

Ozone (O₃) plays a central role in physical, chemical, and radiative processes in the atmosphere. The success of the Vienna Convention on Protection of the Ozone Layer and its Montreal Protocol is undisputed. However, the need to continue observations of stratospheric ozone has been re-enforced in the early 21st century with the occurrence of ozone holes of unprecedented dimensions. Trends, both in the stratosphere and in the troposphere remain a topic of scientific debate. A comprehensive network of Dobson and Brewer instruments for total ozone measurements needs to be continued with an emphasis on making QA/QC information including calibration histories publicly available. Satellite retrievals have become mature, and the focus

¹ Defined through-out this document as being within 1-2 hours from time of observation

should be on establishing good calibration histories for validation purposes and to enable the transition from one sensor to another. Further integration of the ozone sonde networks and other sources of vertical profile information (Umkehr, Lidar and microwave) into one global network is needed. Implementation of near-real-time data delivery capabilities will further increase the value of these observations for numerical weather prediction and model validation. The recognition of the GAW ozone networks as comprehensive GCOS networks is a priority.

Of the **greenhouse gases** that are directly affected by anthropogenic activities, carbon dioxide (CO₂) has the largest total radiative effect, followed by chlorofluorocarbons (CFCs), methane (CH₄), tropospheric ozone (O₃), and nitrous oxide (N₂O). Reliable long-term estimates of sources and sinks appropriate to particular emission management scenarios require very high accuracy and precision observations of the abundance and the vertical distribution of CO₂ and CH₄ as well as their isotopes. The global networks are still incomplete and should be augmented with continuous measurements on the continents, the Arctic, the tropics, and the oceans. A challenge and opportunity is the validation and use of satellite observations that are becoming available. Apart from the major greenhouse gases CO₂ and CH₄, the emergence of substitutes for chemicals banned under the Montreal Protocol and regulated under the Kyoto Protocol needs to be closely monitored. Calibration standards for some of these compounds still need to be harmonized and an accuracy of observations achieved that is sufficient to verify emission inventories. The GAW CO₂ and CH₄ networks have already been identified as comprehensive networks in GCOS and the incorporation of the GAW N₂O, CFCs and SF₆ networks is a priority.

The **reactive gases** as a group are very diverse and include surface ozone (O₃), carbon monoxide (CO), volatile organic compounds (VOCs), oxidised nitrogen compounds (NO_x, NO_y), hydrogen (H₂), and sulphur dioxide (SO₂). These compounds determine the oxidizing capacity of the atmosphere and influence the formation of tropospheric ozone and aerosols, and are therefore relevant to air quality and climate. The surface-based observational network for most of these compounds is totally inadequate and a continuous challenge for the development of the programme. A wealth of information has been obtained through aircraft programmes that are of high priority for GAW, and limited information has been derived from satellites. The global trends of most of these compounds are not sufficiently well understood, and are probably influenced by increasing emissions in Asia. The objectives are to expand the current networks and establish global networks, to further improve and institutionalise the quality assurance and control processes, and to better integrate various data sources. For surface ozone, near-real-time data delivery of the majority of Global and selected Regional GAW stations for inclusion in data assimilation efforts is foreseen.

Atmospheric deposition remains a major environmental issue in several parts of the world due to concerns over acid deposition, eutrophication, trace metal deposition, ecosystem health, biogeochemical cycling, and global climate change. In many areas reductions in emissions of sulphur dioxide have been reflected in precipitation chemistry, but it is increasingly evident that the deposition of nutrients (nitrogen and perhaps phosphorous) in precipitation is contributing to the eutrophication of ecosystems. In other parts of the world, increasing industrialisation has led to increasing emissions of reactive gases. The monitoring of precipitation chemistry worldwide remains, therefore, an important GAW contribution. Despite this, the GAW precipitation chemistry programme has only developed in areas where acid rain has been a major environmental concern. In other areas, the programme has been facing severe funding problems. The objectives, therefore, are primarily to maintain the existing networks, while expanding the observational base wherever possible. In addition, a major challenge is to maintain and improve the central facilities needed for quality control and data management.

The radiation component of GAW is concentrated on **UV radiation**. GAW shares stewardship for aspects of solar radiation with other WMO programmes. UV radiation is linked to several harmful effects on many forms of life, and there is a clear necessity for monitoring surface UV radiation and quantifying future changes. The global observational network is distributed irregularly. The main goals of the UV component of GAW are to expand the observational base in the Tropics and the Southern Hemisphere, to further improve the quality of UV data, to better integrate the ground-based networks with regards to data archiving and distribution of UV data, and to promote the use of UV data for satellite validation.

Aerosol activities are a core component of GAW because of the importance of aerosols to a wide range of issues including global climate change, weather prediction, and air quality/health. Aerosol-related concerns may frequently be equally or more important on the regional scale than on the global scale. For the future, it will be important to enhance the coverage, effectiveness, and application of long-term aerosol measurements within GAW and with cooperating networks worldwide. One important task will be the delivery of aerosol observations at selected stations in near-real-time for use in data assimilation to improve numerical weather prediction.

In addition to the parameters discussed above, a number of **ancillary variables** are important to exploit the chemical observations to the fullest. From the point of view of GAW, these ancillary variables mostly serve to characterise the origin of air masses or to directly characterise the radiative balance of the Earth. These ancillary variables include solar radiation, meteorological variables and radionuclides. Long-term observations of direct, diffuse and global **solar radiation** components at surface stations are important to answer questions on climate variability and climate change. The distribution and quality of the ground-based observations is very heterogeneous, and the main objective is to integrate surface-based and satellite measurements for the purpose of trend analysis. Local **meteorological information** is usually not satisfactory for advanced integration of meteorological and atmospheric chemistry, but it is essential to understand local transport processes and interactions between atmospheric thermodynamics and atmospheric chemistry. Meteorological measurements are usually made at GAW stations, however, they are not always easily available in sufficient temporal resolution. The primary objectives are therefore to enhance the availability, accessibility and use of meteorological information for better specification and understanding of atmospheric chemistry processes. The global distributions of the source-sink terms of the naturally occurring **radionuclides** (^{210}Pb and ^{222}Rn) and the anthropogenic radionuclide (^{85}Kr) are reasonably well known. They serve as ideal tools to assess large- and global-scale transport of gases and aerosols. Thus in future, the ability to monitor and measure atmospheric radionuclides at GAW stations should be improved.

The important cross-cutting area of urban air quality is the focus of the **GURME** project. National Meteorological and Hydrological Services (NMHSs) around the world are broadening their traditional roles to include air quality and related weather-sensitive public health threats. GURME addresses the end-to-end aspects of air quality, linking the observational capabilities of GAW with the needs of chemical weather prediction, with the goal of providing enhanced air quality services of high quality. Priority activities include: the improvement of observing systems and their integration with urban-scale models; the application of satellites in air quality; and capacity building/training initiatives focused on air quality.

Commitment

The coordination of joint activities of GAW with other relevant international and national organizations and programmes will continue to be very important. As all other WMO programmes, GAW is based on voluntary contributions by WMO Member countries, partners and the scientific community. WMO will take the lead but can only encourage rather than require regular contributions to the programme. Its objectives have to be realised bottom-up through a process of identification of individuals and organizations with the programme.

A new set of partnerships will be needed with the environmental agencies of Member countries. It is therefore important that NMHSs build bridges of cooperation with environmental monitoring agencies. GAW will help do this.

1 INTRODUCTION

1.1 The Rationale for GAW

The Members of the WMO have long recognized the importance of atmospheric chemistry in weather, climate and air quality. The atmosphere, like the other components of the Earth system, is affected by the continuous increase in human population and activity, which have resulted in a variety of remarkable changes since the industrial revolution of the 19th century. Among these are [IGACO, 2004]:

- The increase in greenhouse gases and aerosols in the atmosphere and associated climate change.
- The global decrease in stratospheric ozone and the attendant increase in surface ultraviolet radiation, affecting human health and ecosystems.
- The occurrence of summer smog over most cities in the world, including developing countries, and the increased ozone background in the northern troposphere.
- Acid rain and the eutrophication of surface waters and other natural ecosystems by atmospheric deposition.
- Enhanced aerosol and photo-oxidant levels due to biomass burning and other agricultural activity.
- The increase in fine particles in regions of industrial development and population growth with an attendant reduction in visibility and an increase in human health effects; and
- The long range transport of air pollution to regions far from the industrial activity.

Many of these changes in atmospheric composition have socio-economic consequences affecting weather, climate, human and ecosystem health, water supply and quality, and agricultural production. A variety of abatement measures have been introduced or considered to reduce the effects. However, continued growth in human activities, to expand economies and to alleviate poverty, will ensure that these effects continue to be important for the foreseeable future and will require information for sound policy making.

Through its GAW programme, WMO provides essential support to all of the nine societal benefit areas of the GEOSS [GEO, 2005], which aim at reducing loss of life and property from natural and human induced disasters; understanding environmental factors affecting human health and well-being; improving management of energy resources; understanding, assessing, predicting, mitigating and adapting to climate variability and change; improving water resource management through better understanding of the water cycle; improving weather information, forecasting and warning; improving water resource management and prediction of terrestrial, coastal and marine ecosystems; supporting sustainable agriculture and combating desertification; and understanding, monitoring and conserving biodiversity.

Further, WMO has been actively involved in supporting the UNFCCC, the Vienna Convention on the Protection of the Stratospheric Ozone Layer, and the Convention on Long-Range Transboundary Air Pollution (CLRTAP). The GAW component of the WMO integrated global observing system is recognized as a contribution to GMES in support of GEOSS. The GAW scientific and technical community have contributed to the Strategic Implementation Plan of the Second Report on the Adequacy of the Global Observing Systems for Climate by the Global Climate Observing Strategy (GCOS) [WMO, 2003a]. GAW is designated as the lead international programme in implementing the actions related to three important types of Essential Climate Variables (ECVs), namely, greenhouse gases, ozone and aerosols.

In addition to addressing climate applications, the GAW community is responding to the increasing demand by numerical weather prediction research and operations for support in adding aerosols, ozone and their gaseous precursors to research and operational forecasting. It is recognized that the inclusion of chemical variables not only adds air quality forecasts and climate-forcing analyses to the products and services of meteorological services but also influences the

accuracy and usefulness of a traditional weather forecast through feedback on direct and indirect radiative forcing and precipitation formation.

The chemical composition of the atmosphere is determined by the balance between four groups of controlling factors: Emissions, transformation, transport and sinks. GAW has up to now mainly focused on the observation of atmospheric composition. With the current Strategic Plan, GAW will strive to fulfil its complete mission, which is to integrate the controlling factors of atmospheric composition through observations and modelling into products that serve the application needs highlighted in Figure 1 and in the nine GEOSS societal themes.

To meet its mission and long-term objectives, the next generation GAW programme (2008-2015) builds on a framework strategy, namely, the Theme Report of the International Global Observing Strategy (IGOS) on Integrated Global Atmospheric Chemistry Observations [IGACO, 2004] (Figure 1). Through the GAW programme, WMO will take the lead in implementing the recommendations of IGACO, aiming at better integration of global atmospheric chemistry observations. As shown in Figure 1, the integrated system deals with measurements throughout the atmosphere including observations, quality assurance and calibration/validation (cal/val), and data delivery—partly in near-real-time, but mostly more slowly - to World Integrated Data Archive Centres (WIDACs). WIDACs are centres, or networks of centres, that archive all observations for a particular variable and make them accessible to users. Researchers involved in inversion modelling to better quantify emissions and air/surface exchange of chemicals are a good example of an important user community. A prime example of a WIDAC for classical meteorological variables is the input data set used for reanalysis by meteorological centres (e.g. ECMWF, NCEP, and JMA, see Annex for Acronyms). Currently, there are data centres dedicated to archiving observations from particular networks or instruments, but no well coordinated WIDAC exists for atmospheric chemistry variables. Such a system is needed to meet socio-economic challenges related to climate change, ozone depletion/UV increase, air quality and long range transport/removal of pollution and will deliver products and services needed by WMO members and various science communities.

In leading the implementation of IGACO, GAW will follow the mandate from WMO Members. It will also respond to the needs and clearly link to the plans of national, regional, and international observing projects, programmes, systems and strategies (e.g. GCOS, IGOS, GEO, IGAC, see Annex for Acronyms).

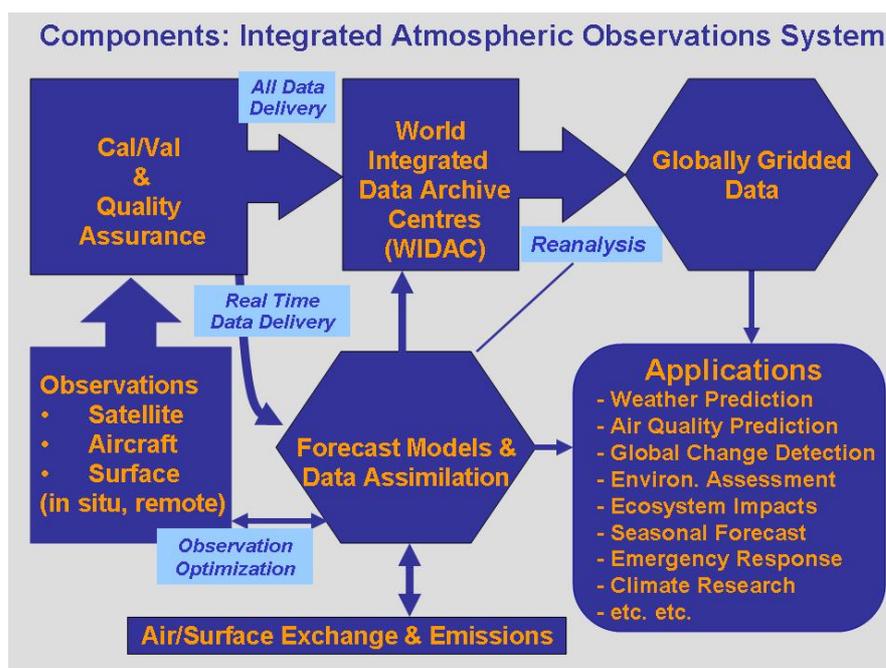


Figure 1. Framework of a global integrated atmospheric observations system [IGACO, 2004].

1.2 Mission

The *mission* of the Global Atmosphere Watch, taking into account the Integrated Global Atmospheric Chemistry Observations (IGACO) strategy, is to

- Reduce environmental risks to society and meet the requirements of environmental conventions.
- Strengthen capabilities to predict climate, weather and air quality.
- Contribute to scientific assessments in support of environmental policy.

Through

- Maintaining and applying global, long-term observations of the chemical composition and selected physical characteristics of the atmosphere.
- Emphasising quality assurance and quality control.
- Delivering integrated products and services of relevance to users.

1.3 Main Long-Term Objectives

The main long-term objectives of GAW address the WMO Strategic Plan 2008-2011 and are adapted from the IGACO Strategy [IGACO, 2004]:

1. Detection of long-term man-made trends in the concentration of greenhouse gases and aerosols related to climate change above natural variability and the corollary impacts of climate change on atmospheric composition.
2. Better environmental assessments related to climate, air quality, ozone depletion and the long-range transport of pollution between regions.
3. Better quantification of pollution sources and their atmospheric pathways to sensitive downwind receptors.
4. Reliable global concentration fields of the selected chemical variables and aerosols at various altitudes for the study of outstanding problems in atmospheric chemistry.
5. Better predictions of UV intensities at the Earth's surface both in populated and remote regions.
6. Direct observation of plumes from major events such as forest fires, dust storms and volcanic eruptions; and
7. Improved regional forecasts of both weather and air quality, and forecasts in regions where these are unobtainable at the moment.

1.4 Implementation Principles 2008-2015

Integrated End-to-End Approach

- Implement the GAW programme in response to recommendations of the IGACO strategy [IGACO, 2004].
- Combine in GAW modelling activities with atmospheric composition observations, quality assurance, data management, and outreach to enable data assimilation in forecasting systems and reanalysis of past atmospheric composition.

General Management and Operations

- Involve top level research groups in the GAW programme, the application of GAW data and the development of GAW products and services.

- Assess the status of the GAW networks and projects, on a biennial basis, through the JSSC OPAG-EPAC.

Observing Systems

- Support continued operations and development of existing GAW observatories that have a solid record of achievement and that fill critical gaps in the global network.
- Identify and fill the gaps in the global network by working with the GAW observational community and Contributing Partners that have substantive networks to complete the global network, and improve the collaboration between the NMHSs, environmental agencies and research organizations in filling gaps in GAW networks and projects.
- Develop GAW into a three-dimensional global atmospheric chemistry measurement network through the integration of surface-based, balloon-borne, aircraft, satellite and other remote sensing observations by implementing the recommendations of the IGACO strategy [IGACO, 2004].

Quality Management

- Define a quality management system (QMS) for GAW to meet the requirements of the WMO QMF, and appoint a quality manager as part of CAS.
- Standardize as much as possible data quality objectives and measurement methods and procedures for the primary GAW variables: ozone, UV, greenhouse gases, aerosols, selected reactive gases and precipitation chemistry.

Data Management

- Improve open access to data and comprehensive metadata including calibration histories of ground-based, aircraft and satellite observations for the primary GAW variables.
- Strive to harmonize GAW data management activities with the WMO Information System (WIS) whenever possible.
- Develop and promote support of data archiving and analysis centres that address the needs of an integrated global atmospheric chemistry observational system.
- Ensure that data collected and archived by WMO/GAW WDCs are of known quality, adequate for their intended use and documented comprehensively.
- Deliver those variables pertinent to air quality and forecasting in near-real-time, using WMO GTS/WIS as it evolves into an open, decentralized and node-oriented structure. Ozone and selected aerosol variables will be the initial priority.

Outreach

- Continue to build up resident expertise in developing countries so that they are linked to strong science programmes wherever possible.
- Make efficient use of the internet to distribute GAW publications, information and data, and to manage GAW activities.
- Improve and accelerate the development and implementation of the GAW programme through the Quadrennial GAW Symposium and specialised meetings and workshops.
- Increase the visibility of the GAW network and the results that stem from it through co-sponsoring specialized sessions at large international conferences, such as the assemblies of AGU and EGU.

2 ORGANIZATIONAL COMPONENTS

2.1 Overview of the Structure of GAW Including IGACO

As the air chemistry part of the WMO Integrated Global Observing System (**WIGOS**), GAW maintains global networks that deliver observations which are then used to address gaps in understanding of climate, weather and air pollution issues and to deliver services and products required by WMO Members in fulfilling their national mandate. As shown in Figure 2, the GAW monitoring system focuses on six classes of variables (i.e. ozone, **UV** radiation, greenhouse gases, aerosols, selected reactive gases and precipitation chemistry). For these variables, GAW acts as a “steward of global coordination” supporting all components needed for a rational observing system. Each of the six variable groups has a **SAG** and GAW Central Facilities responsible for scientific guidance and technical details of the global network. The mandate and operating principles of these GAW components are described in detail below. An additional SAG exists for the GAW Urban Research and Meteorology Experiment (GURME) described in Section 9.

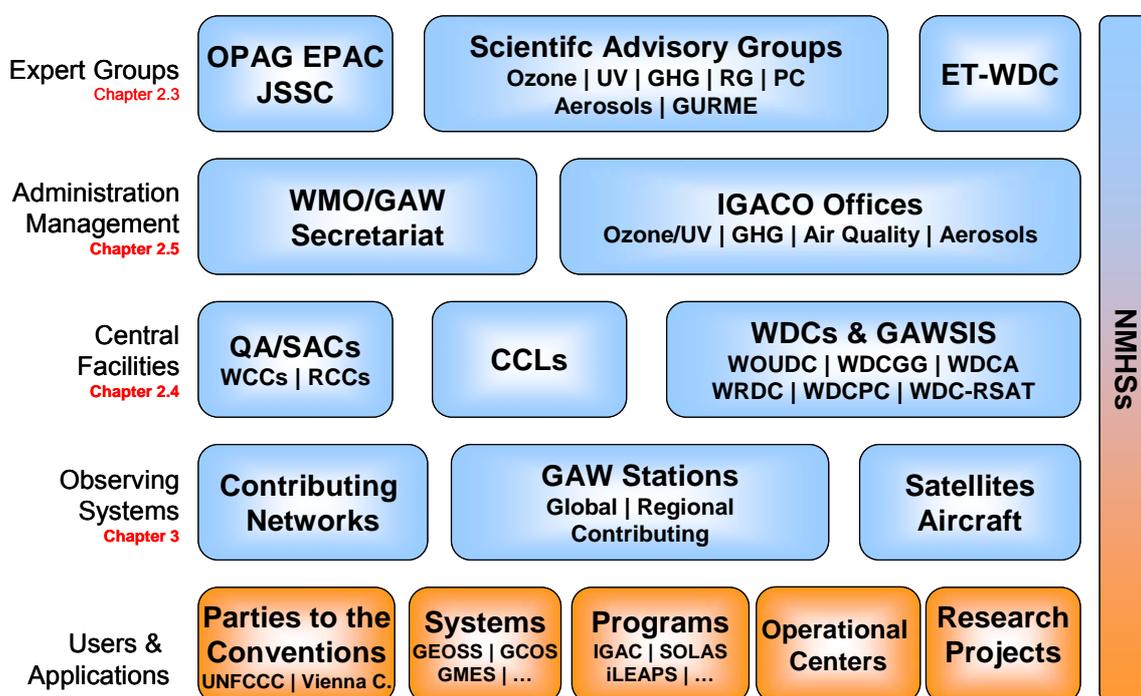


Figure 2. Components of the WMO-GAW programme.

The IGACO strategy [IGACO, 2004] contains guidance/recommendations on how to deliver services and products through integration of global air chemistry observations. It assesses the past, present and future state of global air composition observations, and the requirements and priorities in the future for an IGACO system (see Figure 1). IGACO provides a rationale, a conceptual framework and recommendations for the next generation GAW programme, addressing gaps in the integration of ground-based, aircraft and satellite observations of fourteen target variable groups of chemical species in the atmosphere (see Section 7, Table 2).

Implementation of IGACO involves thematic foci and cross cutting issues. Each thematic focus will have an implementation plan developed by an IGACO office hosted by a WMO Member or partner institution with a strong record of research and application in the focus area. Each will be co-sponsored by WMO through GAW and major partners that bridge GAW to the research community and community of users of products and services. The appropriate GAW SAG(s) will advise the relevant IGACO office and use a community consultative workshop to finalize its

contribution to the IGACO implementation plan. IGACO foci on ozone/UV, aerosols, greenhouse gases and air quality/long-range transport of air pollution will be emphasized. Cross cutting issues to be addressed include the observational system, data assimilation and modelling, databases and product delivery, and quality assurance and validation.

2.2 National Meteorological and Hydrological Services (NMHSs)

Current Status

The rationale for GAW and the commitment of NMHSs to its further development are described in section 1.1. The co-ordination of national activities on behalf of GAW, including those of research institutes and other organizations, is the responsibility of the NMHSs. About 80 Member countries are participating in the GAW measurement programme and the number is growing. Twenty of them are operating Global stations, partly with support from other Members or international organizations/networks. The responsibility for operation of the stations lies with the participating countries. A number of WMO Members already provide vital central facilities for GAW (for details see section 2.4). National responsibilities for environmental activities are frequently not entirely within the jurisdiction of the NMHSs. They may even be the responsibility of several national authorities (e.g., environment and research ministries). In such cases, national discussions should take place and the NMHSs may need strong support from WMO and other international organizations to negotiate a successful outcome. Furthermore, Members must decide if they can support GAW Global and Regional stations on a long-term basis. This requires considerable resources and technical skill.

Goals

- Support and encourage the operation of the existing GAW central facilities (cf. section 2.4) and stations on the basis of commitments to WMO Congress.
- Increase the number of countries participating in GAW, particularly those that may contribute to central facilities and expert groups, by inviting Member countries with extensive know-how and development capabilities to expand their training and outreach support.
- Encourage all NMHSs and other interested national organizations to establish internal co-operation between appropriate laboratories and institutes.
- Ensure compliance with GAW observational guidelines and procedures.
- Promote the exchange of observations of aerosols, ozone and related variables in near-real-time through the WMO GTS/WIS.
- Support research and development leading to assimilation of the essential climate variables – aerosols, ozone and greenhouse gases – in atmospheric transport and numerical weather prediction models and the production of related products and services.
- Implement the development of services and products for GAW.

Implementation Strategy

Task 2.1 Promote support of GAW by Member countries that is key to the success of GAW, and the need to add more partners, while recognizing the long standing commitments from Canada, China, the Czech Republic, Egypt, Germany, Finland, Japan, South Africa, Spain, Switzerland, and the USA.

(Secretariat – annually)

Task 2.2 Identify and approach Member countries for their support of GAW tasks of high priority. Commitments are needed at least from additional countries of the European Union.

(Secretariat – annually)

- Task 2.3 Strengthen co-operation between various agencies within countries.
(Secretariat – EC LIX-LXIII and Congress XVI, 2011)
- Task 2.4 Cooperate in cross-programme and inter-commission activities that promote the near-real-time delivery of observations and their utilization in providing better warning systems to reduce risk.
(Secretariat – annually)
- Task 2.5 Ensure the traceability of observations to recognized WMO-GAW standards through implementation of GAW observational guidelines and procedures.
(Observational programmes of NHMSs and SAGs – ongoing)
- Task 2.6 Support Members in their research and development activities leading to the incorporation of aerosols, ozone and their precursors in regional air quality and climate models and in numerical weather prediction models.
(Secretariat – annually)
- Task 2.7 Support implementation of IGACO recommendations [IGACO, 2004] leading to integration of air chemistry observations with meteorological observations using numerical modelling and assimilation techniques and to the production of new effective environmental prediction products.
(Secretariat – ongoing)

2.3 Expert Groups

Current Status

The Commission of Atmospheric Sciences is the lead WMO technical commission for research activities in atmospheric chemistry, including (GAW) and weather forecast research, including the World Weather Research Programme (WWRP). CAS-XIV [WMO, 2006] formally established the JSSC OPAG-EPAC as the steering body for GAW and formulated terms of reference [WMO, 2006]. CAS-XIV further acknowledged the GAW Strategic Plan: 2001-2007 [WMO, 2001b; 2004b] and the expert bodies defined therein. The Executive Council LVIII accepted the Commissions report [WMO, 2007b].

Under the JSSC OPAG-EPAC, seven SAGs deal with the following topics: greenhouse gases, aerosols, ozone, UV radiation, reactive gases, precipitation chemistry, and the GAW Urban Research and Meteorology Environment (GURME) project. Some SAGs have established sub-groups of experts to address particular aspects or variables within their scope. The SAGs have the following general **terms of reference** [WMO, 2006]:

Box 1. Terms of Reference for GAW Scientific Advisory Groups [WMO, 2006]

- (a) To provide guidance and advice on assessments relevant to OPAG-EPAC;
- (b) To develop scientific priorities based on user requirements;
- (c) To contribute to the GAW Strategic Plan, taking into account the IGACO strategy and regional needs;
- (d) To implement recommendations, tasks and projects as defined in the GAW Strategic Plan;
- (e) To monitor operations at sites and recommend the development of networks, observation methodologies and techniques;
- (f) To develop measurement procedures and guidelines, data quality objectives and, when applicable, standard operating procedures;
- (g) To report to the JSSC OPAG-EPAC on progress and critical problems;
- (h) To interact with the OPAG for the World Weather Research Programme.

In addition, an **Expert Team on GAW World Data Centres (ET-GAW WDCs)** was established with the following **terms of reference** [WMO, 2006]:

Box 2. Terms of Reference for the Expert Team on GAW World Data Centres [WMO, 2006]

- (a) To coordinate the activities of GAW WDCs and the GAW Station Information System (GAWSIS);
- (b) To formulate GAW requirements for the WMO Information System (WIS) and contribute to defining and coordinating services for operational, time-critical applications so that GAW and other environmental observational data are available to users online and, when possible, in near-real-time.

At the first in-term meeting of the JSSC, recognizing the importance of near-real-time data delivery mechanisms and the need for a responsible World Data Centre, an **Expert Team on Near-real-time Chemical Data Transfer (ET-NRT CDT)** was established with the following **terms of reference**:

Box 3. Terms of Reference for the Expert Team on Near-real-time Chemical Data Transfer (ET-NRT CDT)

- (a) To contribute to the design of activities that enhance the transfer of GAW data in near-real-time through the WMO GTS/WIS to meet the needs of NWP and air quality monitoring and forecasts centres.
- (b) To actively participate in the implementation of pilot projects that develop and demonstrate ways to solve problems in near-real-time delivery of GAW data.
- (c) To contribute to the development of the WMO GTS/WIS as representatives of the atmospheric chemistry observations community.

The members of the JSSC OPAG-EPAC are the chairmen of the SAGs and other experts selected to fill gaps in geographical and thematic representation. Upon the recommendation of the OPAG-EPAC chairman, the members are appointed by the CAS Management Group chaired by the President [WMO, 2006].

Under the GAW Strategic Plan: 2001-2007 [WMO, 2001b; 2004b], the SAGs have made important contributions to the programme and their activities are now well established. Every two years, a review of the activities of the SAGs, the ET-GAW WDC and the ET-NRT CDT will be made by the JSSC. The chairman prepares, in consultation with the Secretariat, a list of proposed chairs. The list is circulated to the JSSC for their advice. It is recommended that SAG chairmen serve a maximum of four terms (8 years total). The chairman of the JSSC, the approved SAG chairmen, and the Secretariat will select/confirm the members of the individual SAGs based upon their expertise and the current needs and availability of financial resources within the GAW programme.

In addition to groups that act within the GAW programme to implement activities, there are inter-commission activities in which GAW experts represent CAS. Three of these that are currently ongoing are the Inter-Commission Coordinating Group on WIS (ICCG-WIS), the Inter-Programme Expert Team on Metadata Implementation (IPET-MI) and the Inter-Commission Task Team on Quality Management Framework (ICTT-QMF).

Leading the implementation of IGACO through the GAW programme entails additional activities as summarized in Section 2.1. The four IGACO Theme Foci are to be implemented through IGACO offices (or a network of offices) supported by a WMO Member or partner institution. The Theme Focus leader should have appropriate scientific expertise and experience and will be a member of the SAG(s) most appropriate to the Theme area. The general **terms of reference** of each of the **IGACO Theme Foci Offices** are defined as follows:

Box 4. General Terms of Reference for an IGACO Theme Focus Office

- (a) Cooperate with WMO and partners through the appropriate GAW SAG(s) to develop an implementation plan for the IGACO Theme Focus and then, to support implementation. This will follow recommendations in Chapter 5 of the IGACO report [IGACO, 2004].
- (b) Assign a scientific officer with appropriate facilities, secretarial support and travel funds to head the Office and to be a member of the appropriate GAW SAG.
- (c) Maintain effective communications of IGACO Theme Foci activities (current state of observational systems, brochures, web portal etc)
- (d) Assist WMO in developing appropriate services and products (e.g. bulletins etc)

Goals

- Specify clear scientific leadership responsibility for all activities within the GAW organization, especially for the activities of experts and central facilities and the support activities of WMO.
- Standardise and establish an effective management structure for all programme components of GAW and, in particular, to co-ordinate and connect the functions of the QA/SACs, Calibration Centres (CCs) and WDCs.
- Enlarge the circle of active experts who will share responsibility for the guidance of GAW over the longer term.
- Lead the implementation of IGACO through this GAW Strategic Plan, consistent with recommendation 1 of CAS-XIV [WMO, 2006].

Implementation Strategy

- Task 2.8 Review progress in implementation of the GAW programme by fulfilling the Terms of Reference and activities listed in section 2.3 (Current Status) above.
(JSSC, Secretariat – every two years).
- Task 2.9 Lead the implementation of the GAW programme and IGACO strategy according to the general terms of reference and activities listed in section 2.3 (Current Status) above.
(SAG Chairs, Secretariat – ongoing)
- Task 2.10 Define, in cooperation with the appropriate WMO Technical Commissions (e.g. CBS and CIMO, see Annex for Acronyms), the community of practice for radiation measurements of the global surface radiation network of WMO and, if necessary, seek financial support for a SAG to merge and coordinate the requirements and technical expertise for radiation measurements and archiving within relevant WMO programmes in response to EC LVIII (parag.3.3.1.4) [WMO, 2007b].
(JSSC, Secretariat – 2008)
- Task 2.11 To increase the number of available experts by increasing the involvement of Members not only in routine operations but also in other activities, such as providing additional stations, including chemical measurements and standard meteorological measurements, and hosting central facilities.
(Secretariat – ongoing)

2.4 Central Facilities

Current Status and Terms of Reference

Five types of central facilities dedicated to six groups of measurement variables (Figure 2) are operated by WMO Members and form the basis of quality assurance and data archiving for the GAW global monitoring networks. They include Central Calibration Laboratories (CCLs) that host

primary standards (PS), QA/SACs, World Calibration Centres (WCCs), Regional Calibration Centres (RCCs), and WDCs with responsibility for archiving and access to GAW data.

Table 1 below lists the facilities and organisations responsible for each measurement variable as of May 2007. The terms of reference of the various central facilities are defined as follows:

Box 5. Terms of Reference for GAW Central Calibration Laboratories (CCLs)

- (a) Host in the long term (many decades) the GAW primary standard and scale for a particular variable.
- (b) Serve the needs of the other quality assurance facilities and activities of GAW.
- (c) Prepare or commission laboratory standards required by the GAW network members for calibration purposes.
- (d) Supply well-calibrated air to GAW analytical laboratories as needed for conducting inter-comparisons (in collaboration with the World or Regional Calibration Centres).

Box 6. Terms of Reference for GAW Quality Assurance/Science Activity Centres (QA/SACs)

- (a) Provide an operating framework for GAW quality assurance activities and calibration facilities for a specific variable and geographical area of responsibility (world, regional, national).
- (b) Coordinate the activities of WCCs and RCCs.
- (c) Provide advice and support for the local QA system at individual GAW sites.
- (d) Co-ordinate instrument calibrations and inter-comparisons and other measurement activities.
- (d) Perform or oversee regular system audits at GAW sites.
- (e) Provide training, long-term technical help, and workshops for station scientists and technicians.
- (f) Promote the scientific use of GAW data, and encourage and participate in scientific collaboration.

Box 7. Terms of Reference for World and/or Regional Calibration Centres (WCCs, RCCs)

- (a) Assist Members operating GAW stations to link their observations to the GAW primary standard.
- (b) Develop quality control procedures following the recommendations by the SAGs, support the QA of specific measurements and ensure the traceability of these measurements to the corresponding primary standard.
- (c) Maintain laboratory and transfer standards that are traceable to the primary standard.
- (d) Perform regular calibrations and performance audits at GAW sites using transfer standards in co-operation with the established RCCs.
- (e) Provide, in co-operation with the QA/SACs, training and long-term technical help for stations.

Box 8. Terms of Reference for World Data Centres (WDCs)

- (a) Assist users of atmospheric chemistry observations for which GAW has global coordination responsibilities to easily access observations of known quality through an appropriate archiving or archive networking mechanism.
- (b) Establish harmonized guidelines and data formats for data submission and retrieval for each parameter.
- (c) Check submitted data for necessary format elements and the availability of comprehensive metadata and reject the submission of data that do not meet these formal criteria.
- (d) Perform plausibility and consistency checks on submitted data, flag data problems, and provide feedback to the stations, when necessary.
- (e) Participate in – and contribute to meeting the goals of – the Expert Team on GAW World Data Centres (ET-GAW WDCs)
- (f) Keep abreast of and evolve WDC operations in line with the development of WIS with particular attention to harmonizing data formats and the needs of NRT data delivery.

Goals

- Complete and extend the establishment of GAW central facilities to increase the robustness of the GAW programme.

Implementation Strategy

- Task 2.12 Promote the establishment of GAW central facilities to fill gaps in the programme.
(JSSC OPAG-EPAC, Secretariat – ongoing)
- Task 2.13 Define clearly the strategy for an appropriate archiving or archive networking mechanism for each of the GAW variables.
(SAGs, QA/SACs, WDCs – ongoing)
- Task 2.14 Make available observations through WIDACs (cf. Figure 1) for future applications and re-analysis for the pilot-variables ozone and aerosols.
(JSSC OPAG-EPAC, Secretariat, SAGs – ongoing)

Table 1: Overview of the GAW World Central Facilities (as of May 2007). The World Central Facilities have assumed global responsibilities, unless indicated (Am: Americas; E/A: Europe and Africa; A/O: Asia and the South-West Pacific).

| Variable | QA/SAC | Central Calibration Laboratory (CCL) Host of Primary Standard | World Calibration Centre (WCC) | Regional Calibration Centre (RCC) | World Data Centre (WDC) |
|-------------------------|-----------------------------|---|---|--|--|
| CO ₂ | JMA (A/O) | ESRL | ESRL | | JMA |
| CH ₄ | Empa (Am, E/A) JMA (A/O) | ESRL | Empa (Am, E/A) JMA (A/O) | | JMA |
| N ₂ O | UBA | ESRL | IMK-IFU | | JMA |
| CFCs, HCFCs, HFCs | | | | | JMA |
| Total Ozone | JMA (A/O) | ESRL ¹ , Environment Canada ² | ESRL ¹ , Environment Canada ² | BoM ¹ , ESRL ¹ , IZO ² JMA ¹ , MOHp ¹ , MGO ³ , OCBA ¹ , SAWS ¹ , SOO-HK ¹ | Environment Canada ⁵ , DLR ⁶ |
| Ozone Sondes | FZ-Jülich | FZ-Jülich | FZ-Jülich | | Environment Canada |
| Surface Ozone | Empa | NIST | Empa | OCBA, SOO-HK | JMA |
| Precipitation Chemistry | ASRC-SUNY | ISWS | ASRC-SUNY | | ASRC-SUNY |
| CO | Empa | ESRL | Empa | | JMA |
| VOC | UBA | | IMK-IFU | | JMA |
| SO ₂ | | | | | JMA |
| NO _x | | | | | JMA |
| Aerosol | | | IFT (Physical Properties) | | JRC ⁵ , DLR ⁶ |
| Optical Depth | | PMOD/WRC ⁴ | PMOD/WRC | | JRC |
| UV Radiation | | | | ESRL (Am) | Environment Canada |
| Solar Radiation | | PMOD/WRC | PMOD/WRC | | MGO |

ASRC-SUNY Atmospheric Sciences Research Centre, State University of New York (SUNY), Albany NY, USA (World Data Centre for Precipitation Chemistry, WDCPC)

BoM Bureau of Meteorology, Melbourne, Australia (Regional Dobson Calibration Centre, RDCC for Australia)

BSRN Baseline Surface Radiation Network, Federal Institute of Technology (ETH), Zürich, Switzerland

DLR German Aerospace Centre, Oberpfaffenhofen, Weßling, Germany (World Data Centre for Remote Sensing of the Atmosphere, WDC-RSAT)

ESRL Global Monitoring Division, Earth System Research Laboratory (ESRL), National Oceanic and Atmospheric Administration (NOAA), Boulder CO, USA

EML Environmental Measurements Laboratory, Department of Energy (DoE), New York City NY, USA

Empa Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland (QA/SAC Switzerland and WCC-Empa)

FZ-Jülich Forschungszentrum Jülich, Jülich, Germany

IFT Institute for Tropospheric Research, Leipzig, Germany

IMK-IFU Institut für Meteorologie und Klimatologie Atmosphärische Umweltforschung, Forschungszentrum Karlsruhe, Garmisch-Partenkirchen, Germany

ISWS Illinois State Water Survey, Champaign IL, USA

IZO Izaña Observatory, Tenerife, Spain (Regional Brewer Calibration Centre, RBCC)

JMA Japan Meteorological Agency, Tokyo, Japan (World Data Centre for Greenhouse Gases, WDCGG; QA/SAC Japan, Regional Dobson Calibration Centre, RDCC for Asia)

JRC Institute for Environment and Sustainability, Joint Research Centre, Ispra, Italy, World Data Centre for Aerosols, WDCA)

MGO A.I. Voeikov Main Geophysical Observatory, Russian Federal Service for Hydrometeorology and Environmental, St. Petersburg, Russia (World Radiation Data Centre, WRDC; RCC for Filter Instruments)

MOHp Meteorologisches Observatorium Hohenpeissenberg (Regional Dobson Calibration Centre, RDCC for Europe)

Environment Canada Environment Canada, Toronto, Canada (World Ozone and UV Data Centre, WOUDC)

NIST National Institute for Standards and Technology, Gaithersburg MD, USA

OCBA Observatorio Central Buenos Aires, Argentina (Regional Dobson Calibration Centre, RDCC for South America)

PMOD/WRC Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre, Davos, Switzerland

SAWS South African Weather Service, Pretoria, South Africa (Regional Dobson Calibration Centre, RDCC for Africa)

SOO-HK Solar and Ozone Observatory, Hradec Kralove, Czech Republic (RCC)

UBA German Environmental Protection Agency, Berlin, Germany

¹ Dobson, ² Brewer, ³ Filter instruments

⁴ Precision Filter Radiometers (PFR)

⁵ ground-based, ⁶ satellite-based

2.5 Secretariat

Current Status

Within the WMO Secretariat, the Environment Division (referred to as the Secretariat in this document) of the Atmospheric Research and Environment Programme (AREP) Department provides the operational support for GAW. It co-ordinates with other WMO programmes such as the World Weather Watch Programme (WWW), the World Climate Programme (WCP), the World Climate Research Programme (WCRP), the Global Climate and Observing System (GCOS), the Space Programme and the Education and Training Programme (ETR). The Secretariat, under the institutional guidance of the appropriate WMO bodies, is in continual contact with the NMHSs in the participating countries, the institutions of WMO's Regional Associations, the various GAW Central Facilities, and the relevant international organizations and programmes.

The management and leadership of the operation of GAW, the co-ordination of Expert Groups, Central Facilities and quality assurance activities is a major task of the Secretariat. Arrangement of inter-comparisons and calibrations is a part of this. Continuing efforts are being made to acquire funds for the different GAW activities and facilities and to arrange twinning partners and other contacts. The Secretariat prepares special WMO bulletins, (e.g. for Antarctic and Arctic Ozone and for Greenhouse Gases) and also assists countries in co-ordinating related activities and in capacity building. The interaction and synchronisation of activities with other UN organizations (especially WHO, UNEP, UNECE), regional programmes (e.g. CAPMoN, EANET, EMEP, IMPROVE, NADP,), International Commissions of ICSU (CACGP) and IGBP projects (IGAC, SOLAS, iLEAPS) is ongoing (see Annex for Acronyms).

The Secretariat issues an unofficial "newsletter" periodically on the activities that have taken place in GAW and the Secretariat, including an annual list of meetings. This is distributed to the whole GAW community for information and planning. For training and scientific purposes, about 30-50 conferences, workshops, and sessions of GAW bodies are organised or co-sponsored by the Secretariat annually. The outcomes of these are documented in reports of the GAW Report Series (<http://www.wmo.int/pages/prog/arep/gaw/gaw-reports.html>). This report series, which is GAW's backbone documentation, is of great value to active GAW participants and to external users and is distributed free of charge. GAW's organisational and co-ordinating tasks are complex, the workload is considerable and resources available to the Secretariat from WMO sources are limited. These conditions combine to make it difficult to provide optimum operational leadership for the programme.

Goals

- Optimise co-ordination of the individual programme components of GAW.
- Implement the priorities set up within this strategic plan through co-ordination and oversight.

Implementation Strategy

- Task 2.15 Recommend specific tasks to GAW participants and manage their activities.
(Secretariat – ongoing)
- Task 2.16 Maintain the GAW web site as an interactive tool for the GAW system so that all GAW components have appropriate web pages.
(Secretariat, SAGs, WDCs, WCCs, RCCs, QA/SACs – ongoing)
- Task 2.17 Initiate meetings and sessions dedicated to critical issues of the GAW system.
(Secretariat – ongoing)
- Task 2.18 Formally survey the GAW activities of Members and make this information available to the GAW community.
(Secretariat – ongoing)

- Task 2.19 Keep abreast of the activities and reports from the central facilities and the expert groups on a routine basis.
(Secretariat – ongoing)
- Task 2.20 Establish priorities for funding arrangements and prepare plans for the use of available funds (budgets).
(Secretariat – every three months)
- Task 2.21 Employ GAW Advisors to assist with operational matters.
(Secretariat – as appropriate)
- Task 2.22 Improve the information flow to the GAW community by regular distribution of the GAW Newsletter at least once per year.
(Secretariat – ongoing)
- Task 2.23 Review annually the station information pages of GAWSIS for all countries represented and give feedback to GAW country contacts by email and fax.
(Secretariat – ongoing)

2.6 GAW Partners

Current Status

GAW is linked to a larger international scientific community. All GAW activities depend on collaboration, resource sharing, and interaction with many other partner organizations and networks including:

- Acid Deposition Monitoring Network in East Asia (EANET).
- Arctic Monitoring and Assessment Programme (AMAP).
- Baseline Solar Radiation Network (BSRN).
- Bureau of International Weights and Measures (BIPM).
- Canadian Air and Precipitation Monitoring Network (CAPMoN).
- Commission on Atmospheric Chemistry and Global Pollution (CACGP).
- Committee on Earth Observation Satellites (CEOS).
- Committee for International Weights and Measures (CIPM).
- Deposition of Biogeochemically Important Trace Species (DEBITS).
- DG Environment of the European Commission.
- European Monitoring and Evaluation Programme (EMEP).
- European Environment Agency (EEA).
- Group on Earth Observations (GEO) and Global Earth Observation System of Systems (GEOSS).
- Integration of routine Aircraft Observations into a Global Observing System (IAGOS/MOZAIC).
- Integrated Global Observing Strategy (IGOS).
- Intergovernmental Panel on Climate Change (IPCC).
- International Atomic Energy Agency (IAEA).
- International Council for Science (ICSU).
- International Global Atmospheric Chemistry Project (IGAC).
- International Geosphere/Biosphere Programme (IGBP).

- Interagency Monitoring of Protected Visual Environments (IMPROVE).
- International Ozone Commission (IOC).
- International Radiation Commission (IRC).
- International Union of Pure and Applied Chemistry (IUPAC).
- Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP).
- National Atmospheric Deposition Programme (NADP).
- Network for the Detection of Atmospheric Composition Change (NDACC).
- North American Research Strategy for Tropospheric Ozone (NARSTO).
- Ozone Convention Secretariat.
- Stratospheric Processes and Their Role in Climate (SPARC).
- United Nations Development Programme (UNDP).
- United Nations Environment Programme (UNEP).
- United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollution (UNECE-LRTAP).
- World Health Organization (WHO).

GAW is recognized as the leading international programme in integrated global atmospheric chemistry observations by many measurement strategies, systems and organizations. It is responsible for the atmospheric chemistry component of GCOS, coordinating global atmospheric observations of the ECVs aerosols, ozone and greenhouse gases. The weather forecast research community is now beginning to recognize aerosols and ozone as “essential weather variables” that will eventually be assimilated into forecast models upon delivery in near-real-time. GAW is recognized by the satellite community through IGOS and CEOS as the lead in implementing IGACO which will merge satellite, aircraft and surface-based observations more effectively. For international research programmes, the systematic global observations of GAW naturally complement campaign-type observation programmes aimed at elucidating processes or validating predictive models. The role of GAW and its collaboration with other international programmes that have complementary or compatible objectives should be encouraged. For example in co-operation with regional networks, efforts should be made to co-locate observatories with GAW Global or Regional stations and to involve Members and stations in integrated monitoring activities. It is important, however, to avoid duplication with other programmes and to use GAW's limited resources primarily for the identified GAW core activities. Programmes that operate long term measurement networks that wish to take advantage of the GAW international framework may consider becoming a Contributing partner network, linking to GAW primary standards and registering stations in GAWSIS.

Within Europe, regional environmental monitoring is organised under EMEP, to which almost all nations contribute monitoring information in support of the overall modelling effort guiding the European emission control and regulation activities. Presently, WMO is co-chairing the EMEP Task Force on Measurements and Modelling. WMO also contributes to GMES, the joint initiative of the Commission and European Space Agency (ESA) to co-ordinate the European *in situ* and remote monitoring, that involves co-ordination and further development of existing capacities to provide user-driven services in climate change, air quality and stratospheric ozone/UV themes. Further collaboration is occurring among the regional air chemistry and deposition programmes being conducted in North America (CAPMoN, NADP, IMPROVE) and Asia (EANET). As real-time data for aerosols and ozone become important for input to next generation numerical weather and air quality prediction models operated by WMO Members, a whole new set of partnerships will be needed with the environmental agencies of Member countries. It is therefore important that NMHSs build bridges of cooperation with environmental monitoring agencies. GAW can help do this.

Goals

- Nurture strong relationships with research and process oriented programmes.
- Seek the active participation of our partners, national and international organizations in fulfilling the responsibilities of GAW.
- Seek closer cooperation between meteorological and environmental monitoring agencies through NMHSs or directly through contributing partnerships.

Implementation Strategy

- Task 2.24 Liaise with other international research and measurement programmes – with priorities to IGBP, WCRP (SPARC, BSRN), NDAC and regional networks – by regular participation in appropriate meetings.
(JSSC OPAG-EPAC, Secretariat – ongoing)
- Task 2.25 Distribute relevant GAW information and publications originating from the Secretariat, the GAW central facilities, and GAW bodies to the officials of other international programmes interested in GAW.
(Secretariat – ongoing)
- Task 2.26 Support efforts that assist NMHSs and Environmental Agencies in combining observations to yield better services and products for their countries.
(Secretariat – ongoing)

3 OBSERVING SYSTEMS

Satellite, aircraft and surface-based observations play complimentary roles, and all are essential in addressing the challenges defined in Chapter 1 that require integrated global atmospheric chemistry observations. The GAW programme will address the challenge of implementing the WMO Integrated Global Observing System by initially developing pilot projects focussing on ozone/UV and aerosols.

3.1 Surface-based Observations

Current Status

Clearly, a globally integrated system of observations must include highly accurate measurements at and near the ground in all regions of the globe. This cannot be provided by space-based measurements alone. In 1992, the EC (XLIV) adopted Resolution 3-Technical Regulations of the WMO (Chapter B.2, Global Atmosphere Watch, GAW) under which all stations in the existing WMO Global Ozone Observing System (GO₃OS) and the Background Air Pollution Monitoring Network (BAPMoN) were declared GAW stations [WMO, 1992]. Surface-based *in situ* and remote sensing observations are the backbone of the GAW network, which consists of Global, Regional and Contributing stations as defined in Box 9 and Box 10. Members wishing to contribute new stations to the network are requested to contact the GAW Secretariat.

Global or Regional GAW stations are operated by WMO members. A Contributing station is one that is operated by a WMO partner network or organization that contributes data of known quality to one of the GAW World Data Centres and that is linked to the GAW Primary Standard for a particular variable. Contributing station networks include the Network for Detection of Atmospheric and Climate Change (NDACC), BSRN and EMEP. Some of the stations within these networks are also classified as Global or Regional GAW stations.

Box 9. Essential Characteristics of a GAW Regional or Contributing Station

1. The station location is chosen such that, for the variables measured, it is regionally representative and is normally free of the influence of significant local pollution sources.
2. There are adequate power, air conditioning, communication and building facilities to sustain long term observations with greater than 90% data capture (i.e. <10% missing data).
3. The technical support provided is trained in the operation of the equipment.
4. There is a commitment by the responsible agency to long term observations of at least one of the GAW variables in the GAW focal areas (cf. Section 7).
5. The GAW observation made is of known quality and linked to the GAW Primary Standard.
6. The data and associated metadata are submitted to one of the GAW World Data Centres no later than one year after the observation is made. Changes of metadata including instrumentation, traceability, observation procedures, are reported to the responsible WDC in a timely manner.
7. If required, data are submitted to a designated data distribution system in near-real-time.
8. Standard meteorological *in situ* observations, necessary for the accurate determination and interpretation of the GAW variables, are made with known accuracy and precision.
9. The station characteristics and observational programme are updated in the GAW Station Information System (GAWSIS) on a regular basis.
10. A station logbook (i.e. record of observations made and activities that may affect observations) is maintained and is used in the data validation process.

Box 10. Essential Characteristics of a GAW Global Station

In addition to the characteristics of Regional or Contributing stations, a GAW Global station should fulfil the following additional requirements², namely

11. Measure variables in at least three of the six GAW focal areas (see item 4 above).
12. Have a strong scientific supporting programme with appropriate data analysis and interpretation within the country and, if possible, the support of more than one agency.
13. Make measurements of other atmospheric variables important to weather and climate including upper air radio sondes at the site or in the region.
14. Provide a facility at which intensive campaign research can augment the long term routine GAW observations and where testing and development of new GAW methods can be undertaken.

The present network of GAW Global stations as of April 2007 consists of 24 stations as shown in Figure 3. These key observatories provide comprehensive atmospheric observations of all sorts and many serve as centres for process oriented research that benefit from a core set of observations at the station and long time series of composition measurements. These long time series can be used to assess how representative a campaign was of the climatological atmospheric chemical situation. It should be emphasized that not only Global stations but also Regional and Contributing stations are needed for an adequate global network of any of the GAW variables. In some cases, such as greenhouse gases and total column ozone, global observations are mostly made by the research departments of NMHSs. However, in most cases the global network consists of a large number of stations in networks operated independently by other research or environmental institutions. WMO Members must cooperate with these networks if they are to have access to – and realize the power of – the full set of global observations. In this respect,

² Global Stations in developing countries that fill major gaps in the global network are allowed exceptions as they strive toward these criteria.

the role of the GAW programme in expediting cooperation and sometimes taking the lead internationally is central.

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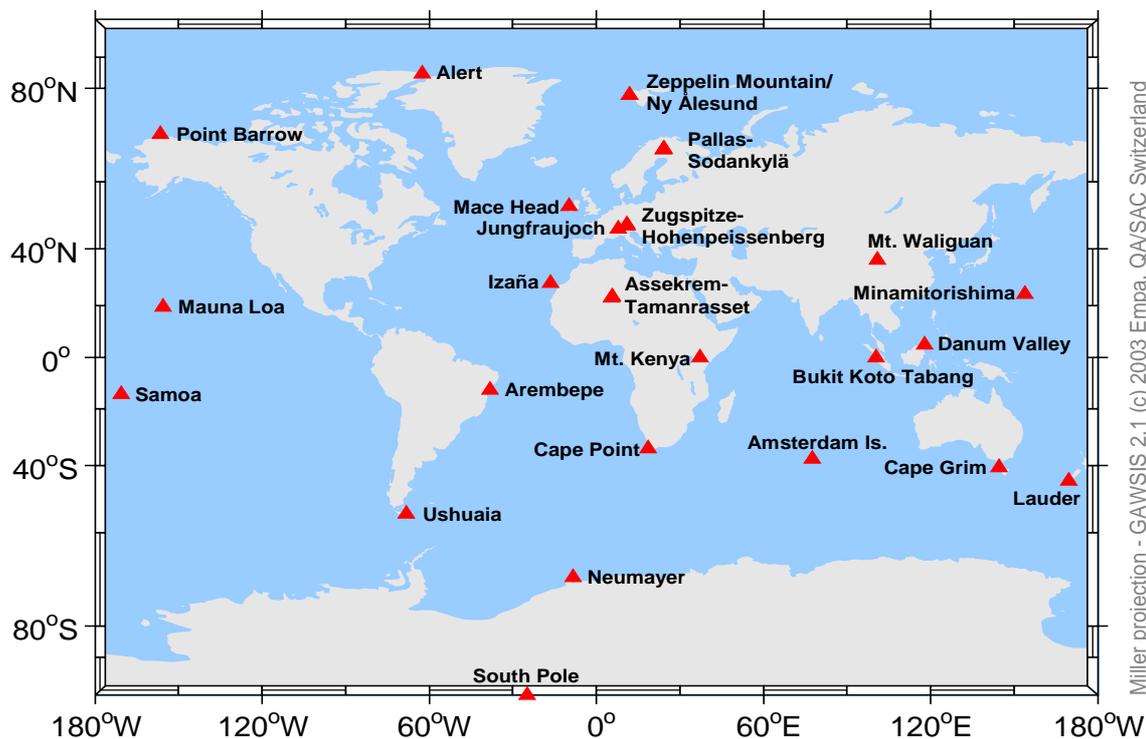


Figure 3. GAW Global surface-based *in situ* and remote sensing stations as of 2006.

Goals

- Secure precise and traceable measurements to meet the GAW long-term objective.
- Increase the number and quality of GAW stations to provide better global coverage focusing particularly on areas where there are significant regional issues.
- Maintain and improve the network of observing stations for near-real-time monitoring of the atmosphere, producing comprehensive, reliable, and timely measurements that cover all regions of the world.
- Improve collaboration and communication between all station types and networks.
- Improve and extend observations on the total column and vertical profiles of appropriate atmospheric variables.
- Support the development of formats for near-real-time (NRT) data transmission of chemical variables to GTS/WIS for appropriate variables.

Implementation Strategy

Task 3.1 Pursue funding opportunities to maintain and improve the GAW network of stations. (NMHSs, Secretariat, CAS OPAG-EPAC – ongoing)

Task 3.2 Study the geographical distribution of GAW Global, Regional and Contributing stations for each variable measured and make recommendations regarding placement of stations.

(Secretariat, SAGs – ongoing)

- Task 3.3 Take action aimed at increasing the availability of key instrument spare parts for developing countries to minimise data gaps.
(Secretariat, NMHSs – ongoing)
- Task 3.4 Promote NRT transmission of ozone and aerosols data through pilot projects.
(Secretariat, SAGs – ongoing)
- Task 3.5 Promote the augmentation of surface-based observations (total column, LIDAR profiling, balloon sondes) by remote sensing observations.
(Secretariat, SAGs, QA/SACs – ongoing)
- Task 3.6 Encourage and organise meetings (including the quadrennial GAW meeting at WMO, Geneva) of the Global station managers to increase communication and co-ordination between Global stations.
(Secretariat, SAGs, QA/SACs – ongoing, next event 2009)
- Task 3.7 Integrate more stations from existing networks into the GAW observing system.
(Secretariat – ongoing)

3.2 Aircraft Observations

Current Status

Aircraft have been used for many years to probe the free troposphere and lower stratosphere on a research basis. In the European programme MOZAIC/IAGOS, automatic instruments for O₃ and H₂O (plus CO and NO/NO_y in 2001) were installed on several commercial aircraft in 1994 and have, since then, provided regular data for the upper troposphere/lower stratosphere (UT/LS) with more than 2000 flights and 4000 tropospheric profiles per year. Other projects with commercial aircraft include grab sampling packages, flown biweekly, since 1993 between Australia and Japan on Japan Airlines (JAL) to provide CO₂, CH₄ and CO data at cruise altitude. This is now being upgraded to include continuous measurements of CO₂ on numerous JAL aircraft. The Swiss NOXAR project provided the first regular NO_x data with 500 flights between 1995 and 1996. In CARIBIC (www.caribic-atmospheric.com), an air freight container with *in situ* instruments for O₃, CO, and aerosol measurements and grab samples for VOCs, halocarbons, CFCs, N₂O, CO₂ and isotopic analysis was deployed during 83 flights between 1997 and 2002. CARIBIC resumed operation as a complete flying observatory in 2005 with an extended package of instrumentation (including total H₂O, gaseous H₂O, mercury, camera for clouds, and a DOAS remote sensing instrument) regularly until at least 2014.

Routine aircraft measurements are currently the most efficient tool for obtaining representative information on the upper troposphere and lower stratosphere and vertical profiles in the troposphere at high resolution and with uniform quality. However, as most ongoing projects are funded under short term research contracts, they are in continuous danger of being terminated. An extension of the MOZAIC-type measurements with many flights per day and expansion of global coverage, as foreseen in the new European Research Infrastructure IAGOS-ERI, is urgently needed.

There are also a few initiatives for using small aircraft on a regular basis. Examples are the NOAA ESRL programme for collecting vertical profiles of CO₂, CH₄, O₃, and other long-lived trace gases several times per week at a number of North American sites up to 8 km altitude.

Goals

- Stabilise support and operation of routine air chemistry observations from aircraft.
- Encourage quality assurance in aircraft programmes that ensures traceability to the (WMO) primary standard.
- Promote the integration of aircraft observations with surface-based and satellite observations.

Implementation Strategy

- Task 3.8 Promote the establishment and support the continuation of routine aircraft air chemistry monitoring programmes.
(Secretariat, SAGs – ongoing)
- Task 3.9 As a step toward integration of aircraft observations with other observations, assist aircraft programmes in delivering data in near-real-time through the Aircraft Meteorological Data Relay (AMDAR) system.
(CAS OPAG-EPAC, Secretariat – ongoing)
- Task 3.10 Encourage archiving greenhouse gases data from aircraft monitoring programmes in WDCGG.
(WDCGG – ongoing)
- Task 3.11 Ensure that links are well established between operators of routine aircraft observations of GAW variables and the WMO/GAW primary standards or—in the absence of primary standards—that observations conform to recommended WMO/GAW calibration practices.
(SAGs, Secretariat – ongoing)

3.3 Satellite-based Observations

Current Status

Space based observations are an important component of an integrated global atmospheric chemistry observing system. They are especially beneficial in providing information in remote areas, particularly over oceans and developing continental regions of Africa, Asia and South America where there are gaps in GAW's surface-based monitoring network. Integration of satellite observations into the GAW programme is highly desirable. In turn, satellite systems can only meet their established requirements if they are checked against highly accurate surface-based measurements of known quality. As stated in a WMO/CEOS Report [*WMO and CEOS, 2001*], and confirmed in the IGACO Report [*IGACO, 2004*] "...there must be formal recognition and support for the international community who are providing critical data from ground-based systems for the calibration and validation of the space-borne systems." The GAW network of surface-based stations has provided both total column ozone and vertical profile ozone data from balloon sondes for satellite validation for the past few decades.

A new generation of satellite sensors has begun operation, in some cases adding to a relatively long measurement series, in other cases beginning new measurement series. The latter include measurements of carbon monoxide (free troposphere or total column), column methane, column nitrogen dioxide, columns and vertical profiles of ozone, aerosol optical depth over land and ocean, aerosol optical property profiling and in 2008 and beyond, column carbon dioxide. The IGACO report summarizes the past, present and future projections for satellite observations. It also points out the limitations of satellites in resolving the spatial distribution of many of the GAW variables in the lower to middle troposphere where air quality and carbon exchange processes cause the greatest variability in atmospheric composition. Nevertheless, there have been promising developments in better interpreting satellite observations in terms of describing the composition of the lower and middle troposphere.

Goals

- Establish easy access to satellite data and analysis products relating to the GAW variables.
- Provide ground-truth information for satellite validation of ozone, CO, aerosol parameters and other components.

- Promote regular reviews of the status and measurement requirements for satellite observations of atmospheric chemistry variables.

Implementation Strategy

- Task 3.12 Strengthen the representation of the space community in the GAW organisational structure.
(JSSC OPAG-EPAC, Secretariat – ongoing)
- Task 3.13 Encourage space agencies to realize satellite missions covering the needs of the GAW Strategic Plan.
(Secretariat – ongoing)
- Task 3.14 Seek support from space agencies for ground truth observations at certain selected GAW station sites and encourage the expansion of the GAW measurement programme accordingly.
(JSSC OPAG-EPAC, Secretariat, SAGs – ongoing)
- Task 3.15 Develop an operating agreement and implementation plan for a WMO World Data Centre for Remote Sensing of the Atmosphere WDC-RSAT at DLR.
(JSSC OPAG-EPAC, Secretariat – 2008)
- Task 3.16 Specify the requirements for new generation air chemistry satellite observations and surface-based measurements associated with calibration and validation of existing satellites.
(WMO Space lead, GAW partners, CEOS, IGACO Offices – ongoing).
- Task 3.17 Keep an up to date time-line chart of the past, present and projected state of the global observing system (surface-based, aircraft and satellites) for a particular GAW variable as initiated in the IGACO report.
(WMO Space lead, GAW partners, CEOS, IGACO Offices – ongoing)

3.4 Integration of Observations

Current Status

Four thematic foci have been identified for the implementation of the IGACO strategy, namely ozone and UV, greenhouse gases, aerosols, and long-range trans-boundary air pollution / air quality.

During late 2005 and early 2006, the IGACO-Ozone International Science Advisory Panel (ISAP) was established as an ad-hoc advisory group to assist the Finnish Meteorological Institute (FMI) and WMO in developing the IGACO-Ozone/UV initiative. The role of the ISAP is now the responsibility of the SAGs for Ozone and UV.

In February 2006, the IGACO-Ozone ISAP held its first meeting at FMI in Helsinki, Finland. The scope of IGACO-Ozone/UV was discussed, especially with respect to the recommendations of the IGACO Report. The scope and goals of IGACO-Ozone/UV were further developed in a consultation workshop in Anavyssos, Greece on 14-15 May 2006. The participants of the meeting represented all communities working on ozone measurements and modelling, and included members of the International Ozone Commission (IOC) and GAW Ozone and UV SAGs. A number of activities were discussed. Twelve projects were defined as pilot projects to get started with the IGACO-Ozone/UV implementation. For the ozone and UV theme an office has been set up at the Finnish Meteorological Institute. This office will help with the development of the IGACO-Ozone/UV implementation plan, with the arrangement of workshops and it also hosts a web site for the IGACO-Ozone/UV activities (<http://www.igaco-o3.fi/en/index.html>).

Goals

- Establish an office for each of the three remaining IGACO thematic foci: greenhouse gases, aerosols and air quality.
- Define activities that will help the implementation of the GAW-IGACO strategy.
- Make certain sectors of GAW, such as the networks for total ozone, ozone sondes and aerosol properties, compatible with near-real-time delivery of data data.
- Increase the usage of the WMO GTS/WIS system for exchange of GAW data, so that it becomes easier for data providers to submit data and for end users to find and access data.
- Grant easier access to meteorological data for researchers who are not affiliated with an NHMS.

Implementation Strategy

- Task 3.18 Establish an office for IGACO-GHG, IGACO-Aerosols, and IGACO-LRTAP/Air Quality. (JSSC OPAG-EPAC, Secretariat, Appropriate SAGs – 2010)
- Task 3.19 Implement the tasks that have been developed by the SAG Ozone in agreement with SAG UV and the IGACO-Ozone/UV office. These tasks are described in http://www.igaco-o3.fi/linked/en/IGACO-O3_Greece-06_Task_Summaries.pdf (SAGs, IGACO-Ozone/UV office – 2011)
- Task 3.20 Arrange workshops to discuss and define activities that support the implementation of the GAW-IGACO goals. (Secretariat, IGACO-Ozone/UV office – ongoing)
- Task 3.21 Conduct two pilot projects involving near-real-time exchange of data that implement IGACO recommendation-SRA1 [IGACO, 2004] to establish an integrated observation system for ozone and aerosols. (Secretariat, SAGs, 2008-2010).

4 QUALITY ASSURANCE (QA)

Current Status

The GAW quality assurance (QA) system impacts all aspects of atmospheric chemistry observations, including training of station personnel; assessment of infrastructures, operations and the quality of observations at the sites; documentation of data submitted to the WDCs; and improvement of the quality and documentation of legacy data at the WDCs.

The *primary objectives* of the GAW QA system are to ensure that the data in the WDCs are consistent, of known and adequate quality, supported by comprehensive metadata³, and sufficiently complete to describe global atmospheric states with respect to spatial and temporal distribution.

The *principles* of the GAW QA system apply to each measured variable and encompass

- Full support of the GCOS Climate Monitoring Principles [WMO, 2003a].
- Network-wide use of only one reference standard or scale (primary standard). In consequence, there is only one institution that is responsible for this standard.

³ Metadata is information on methods and instruments, calibrations, calculation methods, etc. Metadata is essential for data quality assurance and assessment, and proper data use.

- Full traceability to the primary standard of all measurements made by Global, Regional and Contributing GAW stations.
- The definition of data quality objectives (DQOs)⁴.
- Establishment of guidelines on how to meet these quality targets, i.e., harmonized measurement techniques based on Measurement Guidelines (MGs) and Standard Operating Procedures (SOPs)⁵.
- Establishment of MGs or SOPs for these measurements.
- Use of detailed log books for each parameter containing comprehensive meta information related to the measurements, maintenance, and 'internal' calibrations.
- Regular independent assessments (system⁶ and performance⁷ audits).
- Timely submission of data and associated metadata to the responsible World Data Centre (cf. Box 9) as a means of permitting independent review of data by a wider community.

The GAW QA system further recommends the adoption and use of internationally accepted methods and vocabulary to describe uncertainty in measurements [ISO, 1995; 2003; 2004]. To promote the use of common terminology, a web-based glossary is being developed (<http://www.empa.ch/gaw/glossary.html>).

The GAW central facilities established so far (cf. Table 1) have – in most cases – taken on global responsibility for the implementation of these principles. For some parameters (but not nearly all), DQOs have been established by the responsible SAG, and Measurement Guidelines or standard operating procedures (SOPs) have been established by the responsible SAG, (QA/SAC) and/or WCC. The stations themselves have primary responsibility for the quality of the data they generate. As is apparent from Table 1, the GAW QA system continues to be incomplete, although progress has been made on all fronts.

⁴ DQOs define qualitatively and quantitatively the type, quality, and quantity required of primary data and derived parameters to yield information that can be used to support decisions. In particular, DQOs specify tolerable levels of uncertainty in the data, required completeness, comparability and representativeness based on the decisions to be made.

⁵ An SOP is a written document that is officially approved by the relevant SAG and that details the method for performing a certain operation, analysis, or action by thoroughly prescribing techniques and steps involved. Recognizing the diversity – even for similar methods – of measurement equipment and set-ups, the SAGs have preferred to establish Measurement Guidelines rather than SOPs in the past. Measurement Guidelines recommend techniques and even instrumentation, but are less detailed in comparison to SOPs.

⁶ A system audit is generally defined as a check of the overall conformity of a station with the principles of the GAW QA system. It involves an assessment of station siting, infrastructure, organization, operation, etc. The reference for conformity of a station will evolve as the GAW QA system evolves.

⁷ A performance audit is a voluntary check for conformity of a measurement where the audit criteria are the DQOs for that parameter. In the absence of formal DQOs, an audit will at least involve ensuring the traceability of measurements to the Reference Standard.

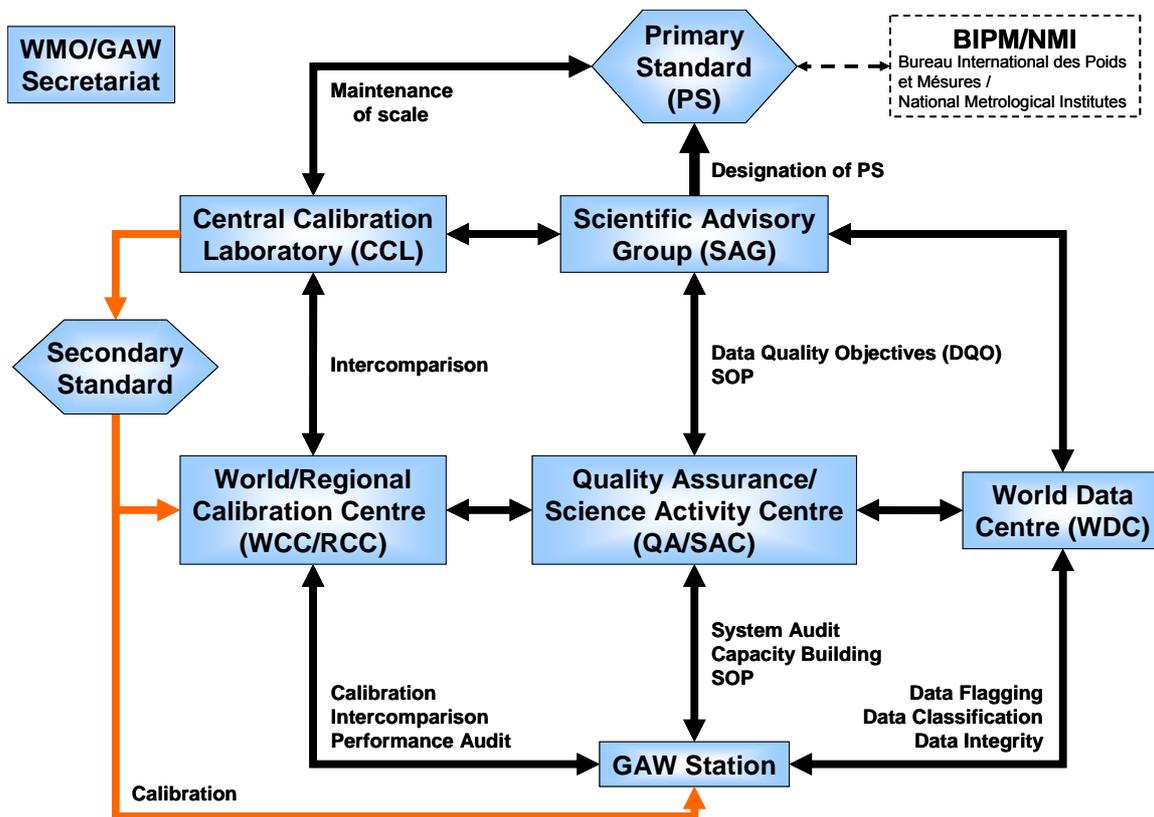


Figure 4: Conceptual framework of the GAW quality system and major interactions involved.

The responsibility of the various partners in GAW for the implementation of the GAW QA system (Figure 2 and Figure 4), are mainly specified in their respective terms of reference (Chapter 2). The following responsibilities emphasize the aspects specifically related to quality assurance:

Joint Scientific Steering Committee (JSSC) of OPAG-EPAC

- Develop guidelines to improve the consistency, effectiveness and efficiency of the GAW programme.
- Identify, understand and manage the processes and organizations involved in IGACO as a holistic system.
- Structure the GAW QA system to achieve its objectives in the most effective and efficient way.
- Establish clear responsibility and accountability for participation of Partners in the GAW programme.
- Seek political and community support for recommendations.

GAW Secretariat

- Implement the recommendations of the JSSC OPAG-EPAC.
- Establish clear responsibility and accountability for managing key activities.
- Oversee and document the work of the SAGs and other GAW Central Facilities.
- Ensure that the information flow within GAW is timely, sufficiently accurate and reliable.

Scientific Advisory Groups

- Establish DQOs for each assigned parameter.
- Develop and approve Measurement Guidelines and SOPs.
- Provide guidelines and recommendations for achieving the DQOs and implementing the SOPs.
- Develop and approve methods to trace observations to the WMO primary standard.
- Promote training and twinning in developing countries.
- Critically review GAW services and products.

Quality Assurance/Science Activity Centres

- Follow the SAGs' guidelines and recommendations and assist the SAGs' in establishing Measurement Guidelines and SOPs.

GAW Stations

- Adopt and follow the GAW Measurement Guidelines and SOPs and identify the need for such documents where these are missing.
- Establish quality control procedures by following the guidelines of the responsible QA/SAC and WCC.
- Practice quality control of all parameters and identify questionable data residing at WDCs.
- Submit data in a timely manner and no later than one year after data collection to the responsible WDC so as to allow further analysis and comparison with other stations.

Goals

- Define a quality management system for GAW to meet the requirements of the WMO Quality Management Framework and to consider the development of joint ISO/WMO technical standards.
- Complete the GAW organizational structure (i.e., SAGs, Central Facilities) and harmonise the GAW QA procedures across parameters and station types.
- Increase the frequency of instrument calibrations and inter-comparisons at Global stations and explore other means of ensuring the traceability to the WMO primary standard of measurements made at Regional and Contributing stations.
- Build alliances between and among Global and Regional stations (scientific and technical co-operation, twinning), and twinning between individuals (scientists, station personnel).
- Develop and implement methods for ensuring the traceability of remote sensing equipment, both ground- and satellite-based, to the WMO primary standard.
- Continue to improve the quality and interoperability of data sets residing at the GAW World Data Centres.
- Define and harmonize the core and extended metadata set for GAW observations.

Implementation Strategy

- Task 4.1 Appoint a quality manager as part of CAS to (a) document the process structure of GAW (GAW core and support responsibilities and management processes); (b) define and describe the core processes (data stream/flow, support and management processes); (c) prepare a quality management manual.

(Secretariat – 2009)

- Task 4.2 Follow-up on the ICTT QMF recommendations on the review of GAW technical documents.
(GAW representative in ICTT-QMF – ongoing)
- Task 4.3 Establish DQOs for GAW chemical and UV radiation variables where they are still missing.
(SAGs, QA/SACs, Secretariat - 2010)
- Task 4.4 Identify and, where feasible, establish SAG sub-groups, WCCs/RCCs and CCLs/primary standards for the variables not currently covered.
(SAGs, QA/SACs, Secretariat - ongoing)
- Task 4.5 Develop measurement guidelines and, when appropriate, SOPs for a prioritized list of variables.
(SAGs, QA/SACs, WCCs - ongoing)
- Task 4.6 Identify the need for, seek funding support for and establish regional calibration and training centres for selected GAW variables.
(Secretariat, QA/SACs, SAGs - ongoing)
- Task 4.7 Provide training and workshops for GAW measurement personnel with emphasis on building capacity and partnerships for developing countries while simultaneously improving the quality of data provided by all GAW stations.
(Secretariat, QA/SACs, WCCs - ongoing)
- Task 4.8 Approach Members to report traceability chains and internal quality control measures relevant to the measurement programmes of all stations in their country and document this in GAWSIS and the respective WDCs.
(Secretariat, QA/SACs – 2010)
- Task 4.9 Assess the quality of data residing at the WDCs, and identify and reject questionable data.
(QA/SACs, WDCs, SAGs – 2009, then ongoing)
- Task 4.10 Continue to improve methods for data quality checks of newly submitted data at the WDCs using statistical tools and expert judgement.
(WDCs, QA/SACs, SAGs – ongoing)
- Task 4.11 Establish guidance documents detailing the methods for ensuring traceability of remote-sensing equipment to the GAW primary standards.
(SAGs – 2010)
- Task 4.12 Generalize the guidelines for GAW system audits to include all GAW variables.
(QA/SACs, WCCs - 2009)
- Task 4.13 Intensify the involvement of GAW in WMO Expert Teams dealing with the definition and implementation of data formats and metadata profiles.
(Secretariat, QA/SACs, WDCs – ongoing)
- Task 4.14 Upon consultation with the SAGs, update the Technical Regulations Volume 1 B.2 Global Atmosphere Watch (GAW) [WMO, 1992] and contribute to the planned Volume 4 on Quality Management Framework.
(Secretariat – 2009)
- Task 4.15 Develop, maintain and promote the use of the web-based glossary on GAW QA/QC-related terminology.
(SAGs, QA/SACs, Secretariat – ongoing)

5 DATA MANAGEMENT

Current Status

GAW observations are archived and made available by GAW World Data Centres (WDCs, cf. Table 1). The purpose of the WDCs is to collect and archive processed GAW data, to make them publicly available (cf. Box 11), and to provide support in the quality assurance, analysis and interpretation of these data for scientific advances and policy decisions. The WDCs are committed to align their operations to the needs of data submitters and data users alike. Since 2001, information has been collected in GAWSIS (Empa, Switzerland) on the terrestrial observation network. Metadata provided by WOUDC and WDCGG are incorporated regularly, and contributors can provide information on their stations, measurement programmes and contacts online.

Box 11. Data-use policy of Global Atmosphere Watch

Use of data obtained from one of the WMO/GAW World Data Centres is subject to the following statement endorsed by the WMO Executive Council/Committee on Atmospheric Sciences (EC/CAS) Panel of Experts Working Group on Environmental Pollution and Atmospheric Chemistry [WMO, 2001a]:

“For scientific purposes, access to these [GAW] data is unlimited and provided without charge. By their use you accept that an offer of co-authorship will be made through personal contact with the data providers or owners whenever substantial use is made of their data. In all cases, an acknowledgment must be made to the data providers or owners and to the data centre when these data are used within a publication.”

The World Ozone and UV Data Centre (WOUDC, Environment Canada, Canada) archives and manages data on total column ozone, vertical ozone distribution, and UV data from ground-based networks. In recent years, WOUDC has made a great effort to extend data quality-related information of the variables concerned. The WOUDC also contributes to the Antarctic ozone Bulletins and produces daily composite ozone maps.

The World Data Centre for Greenhouse Gases (WDCGG, JMA Tokyo, Japan) is responsible for archiving greenhouse and other gas data, and has acted as the WDC for surface ozone since October, 2002. WDCGG also accepts ancillary meteorological information together with the chemical observations. Under the agreement between GCOS and WMO/GAW that considers the WMO/GAW global atmospheric CO₂ and CH₄ monitoring network as a comprehensive network of GCOS, WDCGG is charged with the data management and dissemination of value-added products to facilitate more reliable monitoring and data analysis.

The World Data Centre for Aerosols (WDCA, JRC Ispra, Italy) collects ground-based aerosol data. Arrangements between EMEP and GAW define the data flow of aerosol data from WMO RA VI. In particular, EMEP is now responsible for submitting their aerosol data to WDCA in the appropriate format. For other stations or networks, aerosol data should be submitted directly to WDCA. In the case of aerosol remote sensing observations, in which large networks are operated outside WMO, there is a need to explore additional approaches in providing user access to data.

The World Radiation Data Centre (WRDC, MGO St. Petersburg, Russia) has archived broadband irradiance and sunshine duration data for more than 40 years. Since the mid-1990s, data submissions have declined somewhat, mainly due to the reorganization of the radiation networks in many NMHSs. Some of these data still exist and can be recovered. Radiation data are outside the core observations mandated by GAW but are considered critical ancillary observations. Due to infrastructural constraints, public access to the data has been relatively difficult in the past.

The World Data Centre for Precipitation Chemistry (WDCPC, SUNY Albany, United States of America) ceased operations in 2006. Global precipitation data is currently hosted in five mature regional archives that hold datasets in a variety of formats. Some stations have data records of 30

years or more. There is a clear need for coordination and to explore feasible approaches for delivering value-added products.

The World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT, German Aerospace Centre (DLR)) is the most recent data centre in the WMO-WDC family. It has already been accepted as an ICSU World Data Centre for remote sensing data of the atmosphere. This data centre will give the research community simplified access to data on the chemical composition of the atmosphere, either by giving access to data stored at the centre or by acting as a portal that contains links to other satellite data centres. As a GAW WDC, it will be initially focussing on a limited number of parameters, such as ozone and aerosols.

To date, the WDCs have focused on their main tasks, namely data archiving and data exchange. Data submission via the Internet is supported by all, and submission of CDs or diskettes is discouraged. Data submission in hardcopy is no longer supported. Requested data and metadata formats for submitted data files still vary between WDCs, but they try to accommodate different formats. The WDCs are continuing their collaboration on issues such as standardisation, harmonisation, linkage of Web sites, co-ordination, and quality assurance. Through GAWSIS, common sites have been identified and a common site identification system is being implemented. WDC managers are also working very closely with their respective SAGs to ensure that data archiving, data quality assurance and data exchange activities are guided by, and in tune with, the needs of the scientific community.

All WDCs archive data in individual files, mostly on ftp servers. Almost all WDCs have established web-interfaces for data access at varying levels of sophistication. WDCGG and WOUDC produce regular data reports either on CD or DVD. WDCGG and WOUDC are also actively involved in producing data analysis projects.

In the past, the WDCs have concentrated on collecting, archiving and publishing processed GAW data. While considerable effort has been made to ensure adequate data quality of submitted data, the set of requested metadata has not always been sufficient or has not even been completely submitted for some of the legacy data in the WDCs. Therefore, data series exist in the WDCs that are poorly documented, thereby compromising the value of the entire archive. Web-based data submission and access has been greatly improved, but for some of the data centres, substantial efforts are needed to make data access more flexible and user-friendly. Considering an increasing number of stations reporting data, and an increasing number of parameters on which data are reported, the burden on both data submitters and the WDCs needs to be reduced. This must be reconciled with the need to extend the amount of metadata describing data at the data centres to facilitate data discovery and data quality assessment by users. GAW has taken note of the development of the WMO Information System (WIS) and work of the associated Inter-Programme Expert Team on Metadata Implementation (IPET-MI), however, these links should be strengthened to take full advantage of these efforts for GAW.

Extended quality assurance of submitted data is impossible for GAW WDCs and is the responsibility of the data submitter. However, in light of data distribution to and data use by the scientific community, there is an obvious need for some data validation by the WDCs before acceptance of data. Most WDCs have developed basic quality assurance procedures to validate incoming data, but few go beyond testing the formal integrity and completeness of data. More advanced plausibility checks and statistical tests are certainly desirable.

There is a need for all WDCs and GAWSIS to co-ordinate their Web-based data access/distribution activities to ensure that data users can obtain data in a consistent manner across different WDCs. Close collaboration between SAGs and WDCs has been extremely fruitful in the past and is expected to result in higher quality data and more participation of the WDCs in the analysis of scientific data. In the long term, it is envisaged that the WDCs will become information centres that will work with the scientific community (including the satellite community) to produce value-added scientific reports and global science assessments for scientists and laymen.

Goals

- Ensure the long-term viability of all WDCs, and adhere to WMO policies and plans for data exchange, data management and data use.
- Enhance data submission to the WDCs, and foster and build upon relationships between data originators and the WDCs.
- Improve and harmonise the quality of data and the extent of metadata archived at each WDC.
- Provide easy access to GAW measurement data, metadata, quality assurance information, related meteorological data, and value-added analysis products at each WDC and GAWSIS.
- Actively promote and participate in the analysis, assessment and scientific use of GAW data, and assist data users.
- Promote mechanisms for real-time delivery of data via the GTS/WIS (addressing IGACO recommendation GR8).

Implementation Strategy

- Task 5.1 Secure proper resources, develop comprehensive back-up strategies, maintain up-to-date storage devices, and implement appropriate network, data access and security policies.
(WDCs - ongoing)
- Task 5.2 Extend metadata information within each WDC, and centrally, at GAWSIS – in line with the recommendations of the IPET-MI.
(WDCs, in co-operation with Secretariat and QA/SACs – ongoing)
- Task 5.3 Continue cooperative relationships with NDACC and other contributing networks to increase submission of data to the WDCs.
(WDCs, Secretariat – ongoing)
- Task 5.4 Operate within the WDCs a comprehensive set of data quality assurance and validation checks, incorporating timely feedback on data problems to data submitters before acceptance of data.
(SAGs, QA/SACs, WDCs – ongoing)
- Task 5.5 Identify gaps in the metadata record for legacy data, and approach data submitters with requests for clarification.
(WDCs – 2009)
- Task 5.6 Implement the WMO core metadata profile in GAWSIS, identify deficiencies and propose necessary extensions.
(QA/SACs, WDCs – 2008)
- Task 5.7 Implement WMO policy on data usage regarding the international exchange of meteorological and related data and products as it applies to the measurements made in GAW (Resolution 40, Cg-XII [WMO, 1995]).
(WDCs, Secretariat - continuous)
- Task 5.8 Further develop and maintain central Internet sites for GAWSIS and World Data Centres that provide user friendly access to measurement data, metadata, quality assurance information, relevant meteorological information, and value-added products such as reports on measurement guidelines, quality assurance and technical issues.
(WDCs, Secretariat, QA/SAC - ongoing)
- Task 5.9 Support scientific assessments and produce a set of value-added data analysis products such as maps of GAW stations by variable, statistical summaries, quality assurance information and data visualisation.
(WDCs, QA/SACs - ongoing)

- Task 5.10 Assist the SAGs and QA/SACs in improving data quality control and data analysis activities.
(WDCs, Secretariat - ongoing)
- Task 5.11 Implement data management under the agreement between GCOS and WMO/GAW.
(WDCGG – ongoing)
- Task 5.12 Effect efficient, timely and flexible data and metadata submission protocols through the Internet – with as much harmonisation between WDCs as possible.
(WDCs, QA/SACs – ongoing)
- Task 5.13 Provide advice and guidance to SAGs, QA/SACs and individual sites/scientists regarding possible improvements in their measurement programmes based on problems discovered during the data management and analysis process.
(WDCs, QA/SACs – ongoing)
- Task 5.14 Work through pilot projects (section 3.4) in developing the near-real-time data management and transmission capability needed for integrated observation systems for aerosols and ozone.
(ET-NRT-CDT, CAS OPAG-EPAC, WDCs, Secretariat, WMO/WIS, WMO Space Programme partner programmes – ongoing)
- Task 5.15 For appropriate variables, develop cooperative systems for global data access and synthesis by linking to major regional networks.
(Secretariat, SAGs, WDCs – ongoing)

6 INTEGRATION AND APPLICATION OF OBSERVATIONS

The emphasis of the current GAW Strategy is mainly on surface monitoring of the atmospheric composition. However, the mandate of the GAW programme includes the integration of satellite and aircraft observations with surface measurements, as well as the integration of chemical data and numerical models [IGACO, 2004]. Chemical data and model integration was further recommended by the ACCENT/WMO “Expert Workshop in support of IGACO on Chemical Data Assimilation for the Observation of the Earth's Atmosphere”, April 2006. Finally, through a joint initiative of EPAC and WWRP, integration of data on mineral aerosol with corresponding models is supported to enhance the capabilities of NHMSs to operationally monitor and predict sand and dust storms. The implementation of IGACO will reinforce the GAW alliance of observational groups, modellers, researchers and users of GAW products.

6.1 Reanalysis and Forecasts including Assimilation

Lead Responsibility: Expert Team on Near-real-time Chemical Data Transfer (ET-NRT-CDT)

Current Status

Data assimilation (DA) was originally introduced in numerical weather prediction systems to incorporate observations into prediction models and provide a unified and consistent description of the initial states of the atmospheric system. Assimilation of atmospheric chemistry data in numerical models should follow similar principles. However, DA techniques, although well established in meteorology, cannot be directly applied to atmospheric chemistry due to the differing natures of weather/climate and atmospheric chemistry processes that should be reproduced. Thus, DA methods specific and tailored to chemical data need to be developed. A research effort will be required to adapt existing techniques and develop new ones, in order to incorporate chemical data into chemical weather/climate models and to produce results of the required quality and reliability.

Chemical reanalysis is another methodology that integrates observations and models. While chemical weather prediction is constrained by real-time delivery and may lead to some chemical simplifications for real-time production, the chemical reanalysis focuses on providing the most

complete analysis of the past atmospheric composition states. For this, it is likely to use the most complete and quality assured observational data, a comprehensive atmospheric chemistry model with an advanced chemical assimilation system, and the most accurate surface boundary conditions.

There is growing scientific evidence that there are different and significant impacts of the atmospheric chemical composition to the weather/climate thermodynamics [Dunion and Velden, 2004; Haywood *et al.*, 2005; Kaufman *et al.*, 2005; Koren *et al.*, 2005; Pérez *et al.*, 2006]. Current weather forecasting systems often treat the interaction between the atmosphere and ozone, aerosol, greenhouse and reactive gases in a rather simplistic way, e.g., using uniformly mixed CO₂, latitudinally- and seasonally-varying climatological ozone, and accounting for aerosol simply with a reduced solar constant. During the period of this Strategic Plan, it is expected that weather/climate models will be extended with new prognostic variables related to atmospheric chemistry. Within these future *chemical* weather/climate models, new variables will simultaneously interact with conventional meteorological parameters. In response to requests to integrate chemistry and meteorology data and models, several projects have recently been initiated. For example, the European GEMS project (Global and regional Earth-system (atmosphere) Monitoring using Satellite and *in situ* data, http://www.ecmwf.int/research/EU_projects/GEMS/), involves NWP research that will eventually integrate chemical data as essential weather and climate variables on one side, and forecast models on the other side, thus improving the NWP dynamics. In the field of sand and dust storm prediction, several models already exist that provide semi-operational sand/dust forecasts, serving the interest of numerous WMO member countries in such products.

Inverse modelling (IM) is used to better constrain surface emissions of chemical species and can be applied at different time/space scales ranging from local/regional to global/climate. It is also a useful tool for verification of national bottom-up inventory data, to estimate global or hemispheric mean mixing ratios, and a promising alternative to explicit source parameterization of forward modelling systems. IM is still in a development phase, considering ensemble modelling, Kalman filtering, adjoint modelling and 4DVAR as possible background methods.

Validation of chemical climate/weather modelling systems includes objective assessments of chemical weather simulation/forecast skills, comparing the model results against available observations. Validation also includes controlled model inter-comparison exercises with agreed forecast protocols, and verification metrics. Further improvements of any of the above mentioned techniques after identification of specific weaknesses is considered to be a permanent task.

An important aspect of IGACO, reflecting also requirements of the future chemical weather forecasting system is enhancement of *global real-time transmission* of a) chemical observations to support the assimilation component of the forecasting systems, and b) dissemination of chemical weather products to users, up to 10 days in advance. Real-time delivery of ozone and aerosol observations and *in situ* data of aerosol particulate matter (PM) through the GTS/WIS are considered to be a priority, because NWP centres could readily use such data in their data assimilation schemes.

Goals

- Integration of *in situ* and satellite atmospheric composition data.
- Assimilation of atmospheric composition data in chemical weather/climate models.
- Further development of
 - operational chemical weather/climate modelling systems,
 - inverse modelling,
 - chemical reanalysis.
- (Near) real-time GAW chemical data exchange to provide operational data input to chemical weather forecasting models.
- Promote the development of mechanisms including WIS for NRT GAW chemical data exchange.

- Promote through pilot-projects, WIDACs for ozone and aerosols.
- Intercomparisons and validations of chemical weather/climate models.

Implementation Strategy

- Task 6.1 Establish a pilot project for near-real-time exchange of GAW data of ozone and aerosol parameters within WIS.
(JSSC OPAG-EPAC, ET-NRT-CDT, Secretariat – 2008-2010)
- Task 6.2 Cooperate with centres that lead developments in chemical weather/climate modelling.
(CAS OPAG-EPAC, Secretariat – ongoing)
- Task 6.3 Stimulate developments in chemical data assimilation, chemical weather modelling and chemical model reanalysis.
(CAS OPAG-EPAC, Secretariat – ongoing)
- Task 6.4 Support the use of observations for validating chemical weather/climate models.
(CAS OPAG-EPAC, Secretariat – ongoing)
- Task 6.5 Coordinate activities of centres currently executing experimental sand and dust storm models to provide user-tailored products.
(CAS OPAG-EPAC, Secretariat – ongoing)
- Task 6.6 Support cooperation between data producers, modellers and end-users, in the process of chemical weather/climate modelling.
(ET-NRT-CDT, Secretariat – 2008-2009)
- Task 6.7 Support the education of the public in applying chemical weather forecast products.
(CAS OPAG-EPAC, Secretariat – 2008-2010)
- Task 6.8 Enhance capabilities of NHMSs in delivering/transmitting observations through the WMO GTS/WIS and retrieving/using chemical weather forecasts.
(CAS OPAG-EPAC, Secretariat – 2008 onwards)

6.1.1 Product and Services

Current Products and Services

Research and operational centres are developing next-generation atmospheric/climate models, including atmospheric chemistry modules that interact with atmospheric transport models. Several research projects are already established to integrate chemical and meteorological data with models: WRF-CHEM (USA), GEMS (EU), CHRONOS (Canada), Earth Integrator (Japan); among others. Most of these modelling systems are currently run in an experimental mode and rely on the use of source-data from GEIA, EDGAR, EMEP, IPCC etc., and on transport data from ECMWF, NCEP, JMA, and others.

Future Products and Services

It is expected that integrated weather/climate-chemistry modelling systems will provide new classes of products (4D atmospheric chemistry parameters), but will also improve the quality of conventional weather forecasting itself. Improvements in parameterization of direct and indirect effects of atmospheric composition on the atmospheric thermodynamics are of key importance for appropriate incorporation of chemistry into meteorological models. Future products and services will thus include:

- Weather forecasts improved by consideration of atmospheric composition.
- Chemical composition forecasts.
- Climate models with built-in interaction between atmospheric composition and thermodynamics.

- Near-real-time delivery of chemical data observations, in particular, surface-based ozone and aerosol variables, through WIS.
- Near-real-time delivery of short- to medium-range chemical weather forecasts through WIS.

6.2 Assessments

Current Status

One major aspect of the GAW mission is to organize, participate in and coordinate assessments of the chemical composition of the atmosphere at a global scale. Assessments include, among others, data collected by GAW and collaborating observation networks. In this way, GAW provides reliable scientific information for national and international policy makers, supporting international conventions on stratospheric ozone destruction, climate change, and long-range trans-boundary air pollution.

In 2006, a new scientific assessment of ozone depletion has been finalized by WMO and UNEP, based on a report prepared by over 250 international scientists. Among its findings, the assessment concludes that the stratospheric ozone layer that protects life on earth from excessive solar radiation will recover five to 15 years later than previously expected. The assessment serves the Parties of the Montreal Protocol in making informed decisions related to the protection of the stratospheric ozone layer. GAW ozone data are also used for preparation of the WMO Ozone Bulletin regularly issued by AREP-ENV.

In support of the 1999 Gothenburg Protocol, GAW contributes to the ongoing work on the assessment of the hemispheric transport of air pollution (HTAP) that will also address linkages between long-range transport and climate change. The assessment will be based largely on integrating observation data and modelling tools.

In 2003, the WMO/IUGG International Aerosol precipitation Science Assessment Group (IAPSAG) was established to assess the potential danger from effects of air pollution on cloud formation and precipitation. Among the factors that could contribute to cloud and rain modification are the effects of air pollution from various sources such as urban air pollution and biomass burning. The ongoing work on this assessment will be finalized in 2007.

WMO published in 2006 the first Greenhouse Gas Bulletin, in which the latest trends and the atmospheric burden of the most influential long-lived greenhouse gases (carbon dioxide, methane and nitrous oxide) were reported. The Bulletin will continue to be issued regularly on an annual basis.

Goals

- Organize and/or participate in scientific assessments of various atmospheric chemical composition components.
- Promote the use of GAW data and GAW project output for performing scientific assessments.
- Coordinate scientific assessments of emerging issues.

Implementation Strategy

Task 6.9 Organize scientific assessments of the following GAW components: stratospheric ozone, greenhouse gases, and aerosols.

(Secretariat – 2010)

Task 6.10 Regularly issue Antarctic and Arctic Ozone Bulletins.

(SAG Ozone, Secretariat – ongoing)

- Task 6.11 Regularly issue Greenhouse Gas Bulletins.
(CAS OPAG-EPAC, Secretariat – ongoing)
- Task 6.12 Regularly issue Aerosol and Precipitation Bulletins.
(CAS OPAG-EPAC, Secretariat – 2008, then ongoing)

7 GAW FOCAL AREAS

GAW provides the technical basis for parameters that characterize the state and the development of environmental issues related to atmospheric chemical composition. GAW contributes to a core service of combining observations and model calculations to provide high quality parameter fields in space and time. Out of this core service specialized products can be derived for science and for policy applications. GAW provides essential data for the integration of all factors controlling atmospheric trace species (sources, sinks, transformation, transport) and methodologies (observations, quality assurance, models, data assimilation, data flow, storage and retrieval; and outreach).

Atmospheric monitoring is a focus during the first phase of the strategic plan period, at the same time as the other elements mentioned above are being addressed to support the whole framework of a global integrated atmospheric observations system (See Figure 1).

The IGACO strategy [IGACO, 2004] identified a list of target atmospheric chemistry and related radiation variables that are ripe for an integrated approach to monitoring (Table 2).

Table 2: List of atmospheric key constituents to be targeted in IGACO in the context of four atmospheric challenges. Also included are aerosol optical properties – a broad categorisation which encompasses the scattering and absorption of solar radiation by particles of all sizes. Bold: GAW component of the WMO integrated global observing system (adapted from [IGACO, 2004]).

| <i>Property or Chemical Variable</i> \ <i>Context</i> | Air Quality | Oxidation Efficiency | Climate | Stratospheric Ozone Depletion |
|---|-------------|----------------------|---------|-------------------------------|
| O ₃ | ✓ | ✓ | ✓ | ✓ |
| CO | ✓ | ✓ | | |
| <i>j</i> (NO ₂) | ✓ | ✓ | | |
| <i>j</i> (O ¹ D) | ✓ | ✓ | | |
| H ₂ O (water vapour) | ✓ | ✓ | ✓ | ✓ |
| HCHO | ✓ | ✓ | | |
| VOCs | ✓ | ✓ | | |
| <i>active nitrogen:</i> NO_x = NO+NO₂ <i>reservoir species:</i> HNO ₃ | ✓ ✓ | ✓ ✓ | ✓ | ✓ ✓ |
| N₂O | | | ✓ | ✓ |
| SO₂ | ✓ | | ✓ | |
| <i>active halogens:</i> BrO, ClO, OCIO <i>reservoir species:</i> HCl, ClONO ₂ <i>sources:</i> CH ₃ Br, CFC-12 , HCFC-22 , halons | | | ✓ | ✓ ✓ ✓ |

| <i>Property or Chemical Variable</i> \ <i>Context</i> | <i>Air Quality</i> | <i>Oxidation Efficiency</i> | <i>Climate</i> | <i>Stratospheric Ozone Depletion</i> |
|---|--------------------|-----------------------------|----------------|--------------------------------------|
| Aerosol optical properties¹ | ✓ | ✓ | ✓ | ✓ |
| CO₂ | | | ✓ | |
| CH₄ | | ✓ | ✓ | ✓ |

¹IGACO recommended a focus on aerosol optical properties mainly because of the limitations of satellite instruments, while the GAW SAG Aerosols emphasizes the need for a focus on mass, size distribution and chemical composition as well.

Variables printed in bold are the focus of the GAW component of the WMO integrated global observing system. It should be emphasized that implicit in the GAW programme is the recognition that systematic measurements of all IGACO variables need to be undertaken in collaboration with partner programmes. For example, the WCRP's Coordinated Enhanced Observing Period (CEOP) is focussing on the development of an integrated observing system for atmospheric water which is the major weather variable, the most important natural greenhouse gas and—as the major source of the hydroxyl radical—heavily involved in controlling the oxidative capacity of the atmosphere. In addition, the GAW focal areas also include variables that are not explicitly mentioned in Table 2, mostly due to a lack of satellite capability, but that directly address one or several of the atmospheric challenges mentioned in Table 2. These include most notably, aerosol properties other than optical. The GAW SAG Aerosols has recommended aerosol mass, chemical composition and many other properties. Certain species such as mercury (Hg) and persistent organic pollutants (POPs) that are not mentioned in Table 2, albeit important for the understanding of global biogeochemical cycles, are the focus of other specialized programmes.

7.1 Ozone

7.1.1 Column (Total) Ozone

| | |
|---------------------|--|
| Lead Responsibility | SAG Ozone |
| QA/SAC | JMA (for Asia and the south-west Pacific) |
| CCL | NOAA ESRL, USA (Dobson Nr. 83) Environment Canada (Brewer triad), Canada |
| WCC | NOAA ESRL, USA (Dobson) Environment Canada (Brewer) |
| RCC Dobson | BoM, JMA (for Asia and the south-west Pacific), MoHp/SOO-HK, OCBA, SAWS |
| RCC Brewer | IZO |
| RCC Filter Inst. | MGO |
| DQO | Available for total ozone from Dobson and Brewer instruments; contact: johannes.staehelin@env.ethz.ch |
| SOP | SOPs for the Brewer spectrophotometer are in preparation SOPs for the Dobson spectrophotometers are available. An updated version is in press. |
| Data Centre | World Ozone and UV Data Centre (WOUDC), Canada |

Current Status

Most precise information on total ozone and its changes at individual sites can be obtained by measurements from the ground, e.g. by solar spectroscopy in the wavelength region of 300-340 nm. Within the GAW system, Dobson spectrophotometers (designed for manual operation) and

Brewer spectrophotometers (designed for automatic operation) are used as the station instruments for total ozone observations, thus providing two independent networks. The world (primary) standard instruments of both networks are calibrated by the Langley plot method performed at the Mauna Loa Observatory at Hawaii (every 2-4 years); regional standards are calibrated against the primary standard every 2-3 years; and the station instruments are calibrated by side-by-side calibration with the standard instruments every 4 years.

Complementary measurements of total ozone are provided by the DOAS/SAOZ type UV/visible spectrometers that also allow detection of various minor trace gases (e.g. NO₂ and BrO). They are part of the measurement suites within the NDACC network. Compared to the more established Brewer/Dobson network, the measurement and analysis procedures for DOAS type instruments are less standardized, but regular comparison campaigns have been carried out.

Satellite total ozone measurements in the UV spectral range have achieved a high maturity (TOMS, GOME) and accuracy when compared to the Brewer/Dobson instruments. The new generation of satellite instruments (SCIAMACHY, OMI, GOME2, OMPS), however, require standardization of retrieval and life time quality control (by continuous in-flight calibration procedures) to continue the long-term satellite data record started in the 1970s. Careful adjustments are needed that account for the differences in the spectrometer types with respect to calibration, spectral and spatial resolution, and retrieval procedures.

For both Brewer and Dobson networks, the calibration history and the long-term stability of the world standard instruments are well documented. For the Dobson network, SOPs are available and the calibration history of most individual Dobson instruments is well documented. For Brewer instruments, the calibration of the operational instruments of the Brewer network is performed predominantly by private companies. A standard procedure for the calibration of the station instruments is not available and the calibration history of the individual instruments operated in the network is presently not available to the scientific community. Other instruments providing total ozone measurements from the ground (Russian filter instruments or those of the DOAS/SAOZ type) are not operated under the same data QA/QC programme as Dobson and Brewer instruments. The Russian and other filter instruments are not independently calibrated, but are tied to either Dobson or Brewer instruments. Data quality of all individual total ozone series deposited at WOUDC needs to be documented for the users.

With the advancement in the satellite retrieval algorithms (TOMS/SBUV V8, GOME V4) the agreement with ground standard instruments is now within a few percent. Establishing a good calibration history that allows adjustments to correct for optical degradation in space is one of the most demanding tasks during the lifetime of the satellites. In addition, combining data sets from different platforms is important, particularly during periods of change between satellite instrument type and platforms, and is a prerequisite if these composite data sets from multiple satellite platforms are to become complementary to the long-term ground data.

Goals

The primary goal is the measurement of changes in stratospheric total ozone with sufficient precision to determine the effects of human activity, which involves

- Maintaining two independent networks of high quality total ozone measurements based on Dobson and Brewer spectrophotometers with transparent calibration histories.
- Making best use of this information for validation of satellite ozone observations.
- Providing quality control of ground stations by comparison with long-term satellite data records (data gaps, correction of jumps, etc.).
- Documenting the data quality of satellite and ground-based data records for the users.
- Improving the characterization of the small but distinct differences between Dobson and Brewer total ozone measurements and between different UV measuring satellite instruments.
- Submitting Level 0 data and associated calibration information to the WOUDC.

- Conduct a pilot project for ozone involving NRT exchange of data (cf. Chapter 3.4).

Implementation Strategy

- Task 7.1 Continue high quality measurements and calibrations of the Dobson network and update SOPs for Dobson instruments.
(SAG – ongoing)
- Task 7.2 Finalize the station calibration procedure and SOPs of Brewer instruments.
(SAG – end of 2008)
- Task 7.3 Ensure that the calibrations of the station instruments of Brewer instruments are performed in a proper way.
(SAG – ongoing)
- Task 7.4 Document the calibration histories of the individual station instruments so that the Brewer network obtains a long-term perspective.
(SAG, WOUDC – end of 2008)
- Task 7.5 Create a virtual database for available satellite data.
(WDC-RSAT – First database end of 2008, then continuous)
- Task 7.6 Submit Level 0 data and associated calibration information to the WOUDC to accurately trace the performance of the individual instruments;
(SAG, WOUDC – mid 2008)
- Task 7.7 Implement data quality indicators of individual total ozone series deposited at WOUDC in a simple way for the users.
(SAG, WOUDC – end of 2010)

7.1.2 Ozone Profile Measurements

| | |
|---------------------|---|
| Lead Responsibility | SAG Ozone |
| QA/SAC | FZ Jülich |
| CCL | World Calibration Centre for Ozone Sondes (WCCOS), FZ Jülich (UV photometer in environmental chamber at WCCOS ([Smit <i>et al.</i> , 1996]) |
| WCC | World Calibration Centre for Ozone Sondes (WCCOS), FZ Jülich |
| DQO | Not available |
| SOP | In preparation (for ECC sonde) |
| Data Centre | World Ozone and UV Data Centre (WOUDC), Canada |

Current Status

Ozone measurements from light balloons provide the longest archives of ozone in the troposphere and the lower stratosphere, going back at few selected sites to the late 1960s. Different types of sensors are applied to measure ozone concentration from the balloons which burst at altitudes of approximately 30 km above sea level; ECC (Electro chemical sonde) sensors are currently most widely used. SOPs for ECC sondes are in preparation.

Ozone profile information with low vertical resolution extending up to 45 km can be obtained by the Umkehr technique by both Dobson and Brewer spectrophotometers. The profile information has to be extracted from zenith sky measurements by a retrieval algorithm. Ozone measurements of the Umkehr technique are most valuable for long-term changes in the upper stratosphere, since the vertical resolution and precision of single profile measurements by the Umkehr technique is more limited than those of ozone sonde measurements.

Ozone profile measurements are also obtained by other instruments operated under the umbrella of NDACC. Lidar and microwave measurements are part of the NDACC suite of measurements and are valuable for assessing ozone trends in the upper stratosphere and for validating satellite measurements in the upper atmosphere. The disadvantage of microwave ozone

measurements is the rather poor vertical resolution, but they have a potential to measure up to the mesopause region. The combination of sonde, Umkehr, lidar, and microwave data from the ground is important for assessing the quality of the ozone profile measurements from space. A closer co-operation between WMO-GAW and other important networks, such as GCOS, NDACC, EARLINET and SHADOZ, with complementary instruments and stations is an important goal in the GAW strategic planning and required for a successful implementation of the IGACO strategy.

Over the last several years it became clear that the pumps of the two manufacturers (EnSci and Science Pump) and the solute concentrations of the sondes influence the ozone profile measurements of ECC sondes significantly, which particularly affects ozone concentrations in the troposphere. However at present, not all relevant information concerning type of pump and solute concentration is included in the data archived at WOUDC. Furthermore, ozone sonde data are stored in different archives (WOUDC, NDACC, SHADOZ, NILU).

For the retrieval of Umkehr measurements, a new retrieval algorithm has recently been developed that is applicable to the retrieval of Dobson and Brewer measurements. While a few stations of Dobson instruments report their measurements to WOUDC regularly, Umkehr observations by Brewer instruments are not commonly reported to WOUDC at present.

Goals

- Operate a world wide network of ozone sonde stations to provide data of known quality according to GAW QA/QC guidelines.
- Document adequately important properties and data quality of ozone sonde data deposited at WOUDC, including the characterization of individual series in a simple way for the users by data quality indicators.
- Operate a well maintained network of stations providing Umkehr measurements from Dobson and Brewer instruments.
- Process routinely Umkehr measurements of Dobson and Brewer instruments deposited at WOUDC by a well tested retrieval algorithm.
- Continue cooperative relationships with NDACC, SHADOZ and NILU to integrate lidar and microwave measurements into a global (possibly virtual) database of ground-based vertical ozone profile data sets.

Implementation Strategy

- Task 7.8 Finalize SOPs for ECC sondes.
(SAG, QA/SAC – end of 2008)
- Task 7.9 Continue the operation of a long-term data quality control programme for ozone sondes including regular tests of delivered ozone sondes by chamber measurements possibly supported by inter-comparison flights.
(QA/SAC, WCC – continuous)
- Task 7.10 Enhance the reporting of ozone sonde data to – and the documentation of data at – the WOUDC in order to document all important quantities and to characterize the data quality of the individual series.
(WOUDC, SAG – end of 2008)
- Task 7.11 Install the most suitable retrieval Umkehr algorithm at WOUDC for routine data processing of the Umkehr data from Dobson and Brewer instruments.
(WOUDC – end of 2010)
- Task 7.12 Foster close cooperation of the networks of GAW and SHADOZ, NILU, NDACC to make best use of synergies.
(SAG – continuous)

Task 7.13 Regularly compare ozone sonde measurements with other tropospheric ozone measurements from suitable other platforms such as aircraft (MOZAIC, CARIBIC) and high mountain sites.

(SAG – continuous)

Task 7.14 Assess the quality of satellite data and create a virtual database for satellite data (present and past missions) as part of implementing the IGACO strategy. This task should be seen in conjunction with Task 7.5.

(IGACO-Ozone/UV office, SAG – continuous)

7.1.3 Products and Services

Existing products and services

There are a number of data centres and web services that collect, store and give access to data, graphical presentations and other information pertinent to stratospheric ozone and man-made ozone depletion.

Under the auspices of WMO GAW, and in addition to GAWSIS and WMO's own ozone pages, there are four centres that handle data and information on stratospheric ozone:

- The World Ozone and UV Data Centre (WOUDC), hosted by Environment Canada, Toronto (<http://www.woudc.org>).
- The WMO Northern Hemisphere Ozone Mapping Centre, hosted by the [Laboratory of Atmospheric Physics](http://lap.physics.auth.gr/ozonemaps2/) at the [Aristotle University of Thessaloniki](http://lap.physics.auth.gr/ozonemaps2/), Greece (<http://lap.physics.auth.gr/ozonemaps2/>).
- The IGACO-Ozone/UV Office hosted by the Finnish Meteorological Institute, Helsinki (<http://www.igaco-o3.fi>).
- The World Data Centre for Remote Sensing of the Atmosphere, hosted by the German Aerospace Centre (<http://wdc.dlr.de/>).

The data deposited at WOUDC include atmospheric ozone measurements from the ground (total ozone and ozone profile information) of known (high) data quality that are suitable for long-term trend analysis and have been produced for many years. These data are also valuable for short term ozone forecasts i.e. for public warnings. Total ozone and ozone profile measurements are also crucial for validation of ozone measurements from space. These data sets and the knowledge about data quality are crucial for the implementation of IGACO-Ozone/UV, providing important information for validation of satellite ozone measurements and its composites obtained from measurements of different satellite instruments.

These data products are central for the evaluation of the success of the Montreal Protocol and its amendments, which limit the release of ozone depleting substances, and for the evaluation of the radiative forcing (and therefore anthropogenic changes of climate) of tropospheric ozone caused by anthropogenic ozone precursor emissions and its changes.

Tropospheric ozone measurements from ozone sondes are commonly used for the evaluation of global numerical simulations of the tropospheric ozone cycle. Since ozone is an important greenhouse gas, these data are important in the context of the work of IPCC.

Ozone sonde measurements are also valuable to test the predictions of weather forecast models. They are presently used for the evaluation of the results of European Centre of Medium Range Weather Forecast (ECMWF).

The WOUDC has a sophisticated system for retrieval of data from individual stations and from the entire network. It is also possible to get plots of ozone time series from individual stations, based on total ozone observations and ozone sonde profiles.

The WOUDC produces global and hemispheric maps of total ozone based on a combination of ground-based and satellite data. These maps, which are updated daily, are very useful for the WMO Antarctic and Arctic Ozone Bulletins.

The Ozone Mapping Centre at the University of Thessaloniki produces maps of total ozone over the Northern Hemisphere where one blends satellite and ground-based data.

The IGACO-Ozone/UV web site at FMI, Helsinki (<http://www.igaco-o3.fi/en/index.html>), contains information on the progress of the implementation of IGACO-Ozone/UV and will also contain a portal with links to ozone relevant sites.

The WDC-RSAT web site gives access to satellite data on atmospheric trace gases, aerosols, clouds, solar radiation, surface parameters and dynamics. Some data are stored at the centre itself and other data will be accessible through links to the relevant satellite data centres.

Future products and services

- A one-stop portal that contains links to and information about all available data and services.
- A service that can acquire ozone data from various data sources in NRT, carry out analysis on these data and visualise the data and analysis results (time series, 2-D maps and animations). In addition to ozone data, this is also useful for data on other atmospheric constituents pertinent to ozone depletion.
- Easier access to meteorological data and analyzes including trajectories for individual stations, for researchers who are not directly affiliated with NMHSs.
- Global and various regional total ozone products (Arctic, Antarctic, NH Mid-latitude, SH mid-latitude etc.) for use in the WMO/UNEP Scientific Assessment of Ozone Depletion. For greenhouse gases one has developed an Annual Greenhouse Gas Index (AGGI). Similarly, one should develop an Annual Total Ozone Index, which would reflect the annual state of the ozone layer in various regions of the world. This index will be interesting for comparison with the Ozone Depleting Gas Index that has been developed by NOAA.

7.2 Greenhouse Gases

7.2.1 Carbon Dioxide (CO₂) (including $\Delta^{14}\text{C}$, $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in CO₂, and O₂/N₂ Ratios)

| | |
|---------------------|--|
| Lead Responsibility | SAG for Greenhouse Gases and community of CO ₂ measurement experts. |
| QA/SAC | JMA, Japan (for Asia and the south-west Pacific) |
| CCL | NOAA ESRL, USA/IAEA (for isotopic standards) |
| WCC | NOAA ESRL |
| DQO | Documented in GAW Report No. 161 |
| SOP | GAW Report No. 134, constantly evolving through semi-annual meetings of CO ₂ measurement experts. |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

The atmospheric abundance of carbon dioxide (CO₂) increased from about 280 ppm in the pre-industrial era to a global average of 379 ppm in 2005; this increase is responsible for about 60% (1.5 W m⁻²) of the total radiative forcing by long-lived greenhouse gases. In the past 10 years, increases in CO₂ have been responsible for 84% of the increase in global radiative forcing. Most of this increase in CO₂ abundance is due to emissions of CO₂ from fossil fuel combustion (currently more than 7 Pg C yr⁻¹, where 1 Pg = 10¹⁵ g). Future radiative forcing will be dominated by CO₂ if conventional fossil fuels are continued to be exhausted.

About one half of the carbon emitted by combustion remains in the atmosphere, while the other half is taken up by the oceans and terrestrial biosphere. Based on measurements of CO₂ abundance, its stable isotopes of carbon and oxygen, and O₂/N₂ ratios, IPCC 2001 estimated that

average uptake was $1.7 \pm 0.5 \text{ Pg yr}^{-1}$ by the oceans and $1.4 \pm 0.7 \text{ Pg yr}^{-1}$ by the land biosphere for the 1990s [Houghton *et al.*, 2001]. These are net fluxes; gross fluxes between atmosphere and oceans, and atmosphere and terrestrial biosphere (photosynthesis and respiration), are on the order of 100 Pg yr^{-1} . Since this partitioning of fossil CO_2 between the oceans and biosphere has policy implications, it is important to reduce uncertainties to make better estimates on regional scales (e.g., using inverse modelling to estimate regional fluxes).

Atmospheric CO_2 monitoring began in 1958 to document the rate of increase. While monitoring temporal trends is still necessary, measurements are now much more useful when observed spatial gradients are combined with atmospheric transport models (and measurements of other tracers, e.g., isotopic composition of CO_2 and O_2/N_2) to assign fossil CO_2 emissions to the three major reservoirs (atmosphere, oceans, and terrestrial biosphere). This approach requires observations that are accurate and internally consistent within and among different national monitoring programmes. A Central Calibration Laboratory that maintains the GAW CO_2 mole fraction scale and GAW-supported inter-comparison experiments aid labs in meeting current objectives for inter-laboratory comparability of CO_2 measurements ($\pm 0.1 \text{ ppm}$ for the northern hemisphere and $\pm 0.05 \text{ ppm}$ in the southern hemisphere). Recent inter-comparison results are promising; however consistency among all GAW network members has not yet been achieved.

Despite more than 80 GAW sites monitoring atmospheric CO_2 in 2005, continued expansion of measurement networks to include more high-frequency measurements at continental locations and vertical profiles is necessary. Beyond that, space-based retrievals of column densities such as those planned by the Orbiting Carbon Observatory (OCO, scheduled for launch in 2008), and Greenhouse gases Observing SATellite (GOSAT), will be used by the Global and regional Earth-system Monitoring using Satellite and *in situ* data (GEMS) project, and they will greatly enhance spatial coverage of measurements and are expected to improve regional carbon exchange estimates. After OCO is launched, precise surface measurements will have the additional role of validating measurements of CO_2 from space.

Measurements of O_2/N_2 ratios and stable isotopes of CO_2 ($\delta^{13}\text{C}$ and $\delta^{18}\text{O}$) help to partition carbon sources and sinks between the ocean and biosphere. Isotopic measurements are often made from the same discrete samples used for CO_2 mole fraction measurements. Isotopic standards are maintained by the International Atomic Energy Agency (IAEA), but measurement sites are part of the GAW CO_2 network. Objectives for network comparability are $\pm 0.01\text{‰}$ for $\delta^{13}\text{C}$ and 0.05‰ for $\delta^{18}\text{O}$. There are currently about 10 laboratories measuring O_2/N_2 ratios. These measurements are difficult, but useful in partitioning fossil fuel CO_2 emissions between the ocean and the biosphere. The community has set a goal of ± 1 per meg (parts in 10^6 variation in the O_2 to N_2 ratio) for network comparability. As yet, there is no world standard for these measurements, and relatively few systematic inter-comparisons of scales have been made.

Measurements of CO_2 mole fractions and its stable carbon isotopes alone can not effectively distinguish between emissions from biological processes and fossil fuel combustion. Fossil fuel CO_2 emission inventories along with CO and SF_6 measurements can help constrain emissions from fossil fuel combustion, but the most effective tracer for this task is radiocarbon (^{14}C) measurements in atmospheric CO_2 . In atmospheric CO_2 , the relative abundance of ^{14}C is about 1 part in 10^{12} , but there is no ^{14}C in fossil fuels. NIST standard reference material SRM4990C (oxalic acid) is used as the standard for these measurements, and the recommended inter-laboratory comparability is $\pm 1\text{‰}$.

The GAW CO_2 network has been identified as a comprehensive network in GCOS as of October, 2005.

Goals

- Produce internally consistent CO_2 , $\delta^{13}\text{C}$, $\delta^{18}\text{O}$, $\Delta^{14}\text{C}$ and O_2/N_2 data sets through regular calibration and inter-comparisons of measurements, and scrutiny of archived data.
- Expand the global CO_2 measurement network. Emphasis should be on high-frequency measurements on the continents and increased sampling (high or low frequency) in the

tropics, from vertical profiles, and from ships (though the Ship of Opportunity Programme, SOOP).

- Cooperate with process-oriented research programmes including the ocean carbon cycle community (e.g., IGBP projects SOLAS, IMBER, and GLOBEC, and the WCRP project CLIVAR) and terrestrial C flux measurements (e.g., FLUXNET). Emphasis should be on the importance of the flux measurement communities rigorously calibrating their measurements to the WMO CO₂ mole fraction scale.
- Develop comprehensive mechanistic carbon cycle models that include soil, terrestrial ecosystem, and ocean processes. These models will be linked to GAW measurements through assimilated CO₂ mole fractions, flux measurements, and other auxiliary information (land cover maps, soil moisture, chlorophyll, sea surface temperatures, etc.).
- Integrate satellite and *in situ* measurements of CO₂. Emphasis should be on ensuring that remotely-sensed retrievals of CO₂ columns are validated with vertical profiles of *in situ* measurements and surface-based column abundances determined using FTIR spectrometry.
- Expand the possibilities of archiving meteorological information needed for assimilation models.

Implementation Strategy

Task 7.15 Continually review DQOs for CO₂ (and its isotopes) and O₂ measurements to ensure that they meet the scientific needs to reduce uncertainties in our knowledge of the carbon cycle.

(CO₂ Experts – ongoing).

Task 7.16 Develop procedures and inter-comparison strategies to ensure that GAW stations measure CO₂ relative to the WMO CO₂ mole fraction scale.

(CCL and QA/SAC in cooperation with SAG GHG and CO₂ Experts – ongoing)

Task 7.17 Develop partnerships to increase CO₂ measurements from ships (e.g., through the VOS programme), aircraft, and tall towers (greater than 400 meters).

(SAG GHG – ongoing)

Task 7.18 Make recommendations for expansion of the CO₂ measurement network that will improve attribution of fluxes in inverse model studies.

(CO₂ Experts and SAG GHG – 2009)

Task 7.19 Promote the validation of remotely-sensed CO₂ measurements with *in situ* measurements.

(SAG GHG – ongoing)

Task 7.20 Encourage CO₂ flux measurement networks to rigorously calibrate to the WMO CO₂ mole fraction scale and submit data to the WDCGG.

(SAG GHG – ongoing)

Task 7.21 Review the internal consistency of CO₂ observations archived at the WDCGG. Data should be available in “versions” (similar to NOAA’s GLOBALVIEW-CO₂ product) with consistent quality control flags. Develop methods to archive quality-assured retrievals of CO₂ column abundance.

(QA/SAC and WDCGG with guidance from SAG GHG – 2010)

Task 7.22 Develop methods to archive new quality-assured data streams needed for assimilation models. For example, these include analyzed meteorological fields that conserve mass and are available at high temporal and spatial resolution. These fields should be available within one month of data collection for long-term carbon cycle studies, but shorter time scales will be needed for applications such as the impacts of drought on carbon sinks.

(SAG GHG – ongoing)

- Task 7.23 Appoint a scientific advisory panel charged with developing an implementation strategy for IGACO-GHG. A major component of this task will be to produce guidelines for a comprehensive, internally-consistent data set that includes *in situ* measurements and remotely-sensed retrievals of CO₂.
(SAG GHG, Secretariat – 2009)
- Task 7.24 Develop the capability to accept and archive CO₂ column data from satellite observations.
(WDCGG – 2009)
- Task 7.25 Archive and develop integrated data sets using satellite, aircraft and surface-based measurements of CO₂.
(WDCGG in consultation with SAG GG – ongoing)

7.2.2 Methane (CH₄)

| | |
|---------------------|--|
| Lead responsibility | Scientific Advisory Group for Greenhouse Gases (SAG GHG) |
| QA/SAC | Empa, Switzerland (for Europe, Africa, and the Americas) JMA, Japan (for Asia and the south-west Pacific) |
| CCL | NOAA ESRL, USA |
| WCC | Empa, Switzerland (for Europe, Africa, and the Americas) JMA, Japan (for Asia and the south-west Pacific) |
| DQO | In preparation |
| SOP | In preparation |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

Methane's contribution to anthropogenic radiative forcing, including direct and indirect effects, is about 0.7 W m⁻², half that of CO₂. Also, changes in the burden of methane feed back into atmospheric chemistry, affecting the concentrations of OH and O₃. The increase in methane since the pre-industrial era is responsible for about half of the estimated increase in background tropospheric O₃ during that time. Changes in OH concentration affect the lifetimes of other greenhouse gases such as the replacement refrigerants (HFCs, HCFCs).

Methane is emitted to the atmosphere by natural and anthropogenic sources. Natural sources include wetlands, vegetation, termites, oceans, and geologic sources (e.g., hydrocarbon seeps, hydrates, mud volcanoes). Anthropogenic sources include fossil fuel exploitation, rice agriculture, landfills, domestic ruminant animals, landfills, municipal waste treatment, and biomass burning. Emission rates from many sources are difficult to quantify from the top-down perspective using atmospheric measurements, because fluxes are small, diffuse, and vary by orders of magnitude, both spatially and temporally. Estimating emissions is especially difficult in the tropics where sampling coverage is sparse and high CH₄ abundances are rapidly diluted by strong vertical mixing. As a result, the current network is not sensitive to the suggested new large source of CH₄ from vegetation in the tropics. Significant progress has been made using current measurement networks in reducing uncertainties on emissions from mid- to high-northern latitudes. But predictions of large increases in annually-averaged temperature, the huge amount of carbon stored in permafrost (estimates range from 500 to 900 x10¹⁵ g C, [Zimov *et al.*, 2006]), and the potential for significantly increased CH₄ emissions from the Arctic, suggest that expansion of sampling there would be prudent.

As stated above, more data are needed from the tropics and the Arctic, particularly from high-frequency measurements. Space-based measurements are also proving useful (e.g., SCIAMACHY and AIRS), but it is important that these measurements are validated by *in situ* measurements or ground-based remotely sensed column densities using FTIR spectrometers (e.g., from sites in the Total Column Carbon Observing Network, TCCON).

The GAW CH₄ network has been identified as a comprehensive network of GCOS as of October, 2005.

Goals

- Produce an internally consistent CH₄ data set through the use of standards regularly calibrated by the CCL, audits by the WCCs, and inter-comparisons of measurements.
- Improve coverage of the GAW network by adding sites in the tropics, in the Arctic, and on continents. Emphasis should be on high-frequency measurements and vertical profiles.
- Integrate satellite and *in situ* measurements of CH₄. Emphasis should be on the validation of remotely-sensed CH₄ columns with vertical profiles of *in situ* measurements.

Implementation Strategy

Task 7.26 Develop procedures to ensure that CH₄ data archived with the WDCGG are reported on the current WMO CH₄ mole fraction scale. These procedures will include audits and inter-comparisons of standard scales and atmospheric measurements.
(SAG GHG, CCL, and QA/SACs – 2011)

Task 7.27 Enhance cooperation among GAW laboratories on CH₄ measurement techniques and quality assurance.
(SAG GHG, QA/SACs– ongoing)

Task 7.28 Appoint a scientific advisory panel to develop an implementation strategy for IGACO-GHG. A major component of this task will be compilation of a comprehensive, internally-consistent data set that includes *in situ* and remotely-sensed measurements of CH₄.
(SAG GHG– 2010)

Task 7.29 Increase number of sampling sites, particularly those making high-frequency measurements, in the tropics, in the Arctic, and on continents.
(GAW members – ongoing)

7.2.3 Nitrous Oxide (N₂O)

| | |
|----------------------|---|
| Lead responsibility: | Scientific Advisory Group for Greenhouse Gases (SAG GHG) |
| QA/SAC | UBA, Germany |
| CCL | NOAA ESRL, USA |
| WCC | FZ Karlsruhe IMK-IFU, Germany, with partial support by WCC-Empa |
| DQO | In preparation |
| SOP | In preparation |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

Nitrous oxide increased from about 270 ppb in the pre-industrial era to about 320 ppb in 2005. Its average rate of increase in the past few decades, 0.8 ppb yr⁻¹, indicates that emissions are greater than sinks by 30%. The major natural sources of N₂O to the atmosphere are the ocean and soil processes; anthropogenic sources are agriculture, through use of nitrogen fertilizers, biomass burning, industrial processes (nylon and nitric acid production), and cattle feedlots. While the major sources have been identified, uncertainties in emissions from each are still large. Two major sink processes are responsible for N₂O removal from the atmosphere, both of them in the stratosphere: photolysis and reaction with electronically excited oxygen atoms (O(¹D)). The lifetime of N₂O is estimated at about 120 years.

The contribution of nitrous oxide to radiative forcing is about 0.15 W m⁻². Its reaction with electronically excited oxygen atoms is the major source of NO_x in the stratosphere, which impacts

O₃ there. Actions to mitigate N₂O impacts on the environment require better understanding of the global N₂O budget and the effects of changing land use and climate. Measurements of N₂O from GAW stations provide the basis for this improved understanding.

The most commonly used technique for measurements of N₂O at GAW stations is gas chromatography (GC) with electron capture detection (ECD). This technique offers good repeatability, but it can be difficult to implement. Because the N₂O lifetime is long and fluxes small, spatial gradients are small; therefore, their quantification requires very precise measurements. Measurements of N₂O are only recommended for programmes with strong analytical expertise and commitment to high-quality measurements. The current GAW network is adequate for determining N₂O trends, but a wider distribution of sampling sites, more high-frequency measurements, particularly in the tropics, and vertical profiles are necessary to reduce uncertainties on emissions from particular sources and improve understanding of the processes responsible for its emission. Estimation of emissions using 3D transport models and atmospheric measurements is further complicated by inter-annual variability in stratosphere/troposphere exchange (STE), whose effects may be interpreted by models as variability in emissions. Vertical profiles may be helpful in partially resolving this problem, especially when combined with measurements of other tracers of STE such as CFCs and beryllium isotopes (¹⁰Be/⁷Be).

Goals

- Produce an internally consistent N₂O data set through regular calibration by the CCL, audits by the WCC, and inter-comparisons of measurements.
- Improve coverage of the GAW network by adding sites in the tropics and on continents. Emphasis should be on high-frequency measurements and vertical profiles.
- Develop robust, inexpensive, precise techniques for measurement of atmospheric N₂O.
- Incorporate the GAW N₂O measurement network into the GCOS comprehensive network.

Implementation Strategy

- Task 7.30 Develop procedures to ensure that N₂O data archived with the WDCGG are reported on the WMO N₂O mole fraction scale. These procedures will include audits and inter-comparisons of standard scales and atmospheric measurements.
(SAG GHG, CCL, WCC, and QA/SAC – ongoing)
- Task 7.31 Enhance cooperation between GAW laboratories on N₂O measurement techniques and quality assurance.
(SAG GHG, WCC, QA/SAC – ongoing)
- Task 7.32 Identify laboratories with the appropriate expertise to participate in expansion of the GAW N₂O measurement network.
(SAG GHG – ongoing)
- Task 7.33 Increase the number of sampling sites.
(SAG GHG – ongoing)

7.2.4 Halocarbons and SF₆

| | |
|----------------------|--|
| Lead responsibility: | Scientific Advisory Group for Greenhouse Gases (SAG GHG) |
| QA/SAC | Not yet established |
| CCL | Not yet established |
| WCC | Not yet established |
| DQO | Not yet established |
| SOP | Not yet established |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

Various halogenated compounds that are important with regard to radiative forcing only (perfluorocompounds (PFCs), hydrofluorocompounds (HFCs), and SF₆), radiative forcing and stratospheric ozone depletion (chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and Halons), and ozone-depletion only (methyl halides) are measured at GAW sites. These compounds are used mostly as refrigerants and solvents, but many also have very specialized uses (e.g., the predominant use of SF₆ is as an insulator in electrical switching gear). The methyl halides (CH₃Br and CH₃Cl) are different from the other compounds in this section because they have significant natural and anthropogenic sources. The contribution of these gases to radiative forcing is about 0.3 W m⁻² (most of it contributed by CFC-11, CFC-12, and a few other compounds), or about 12% of the total due to long-lived greenhouse gases. Monitoring these compounds in the atmosphere is important because their emissions are controlled by the Montreal Protocol (e.g., CFCs, HCFCs, and Halons) or the Kyoto Protocol (e.g., HFCs, PFCs, and SF₆), and they should be tracked for verification of compliance.

These compounds are measured by GC with either ECD or mass spectrometric detectors. Since their atmospheric abundances range from less than 1 ppt to a few hundred ppt (parts per trillion, by moles), they require a great deal of technical expertise to measure properly. Participating GAW laboratories either make their own standards or work closely with a programme that does and participate in comparisons of standards (e.g., IHALACE) and measurements.

Measurements of some of these compounds have important other uses in atmospheric chemistry and climate change. Methyl chloroform (MC) has been used to calculate large scale averages of the concentration of hydroxyl radical (OH), the troposphere's main oxidant. The concentration of OH determines the lifetimes of other long-lived greenhouse gases such as CH₄, HCFCs, and HFCs. As the atmospheric abundance of MC declined because of controls on its emissions imposed by the Montreal Protocol, it has become less useful for determining OH. Other compounds, e.g., HCFC-22, may be useful in the future. Sulphur hexafluoride (SF₆) has been used to check atmospheric transport in 3D chemistry-transport models and as a tracer to distinguish between natural and fossil fuel-derived CO₂ at a particular measurement site. CFCs are used as tracers of stratosphere/troposphere exchange. These uses require higher precision measurements than simple emissions verification.

Goals

- Provide measurements representative of large spatial scales that are of sufficient accuracy to verify emission inventories of these compounds.
- Quantify differences between standards from different measurement programmes.
- Establish a quality assurance system for halocompound measurements.
- Determine which species are useful in studies of the troposphere's oxidizing capacity or as transport tracers, and develop robust measurement techniques with improved precision.
- Develop the GAW network for CFCs and SF₆ into a GCOS comprehensive network.

Implementation Strategy

Task 7.34 Conduct an inter-comparison of calibration standards that allows measurements from all GAW programmes to be combined into a single large data set archived with the WDCGG.

(NOAA ESRL – in progress)

Task 7.35 Support establishment of a quality assurance system for measurements of halogenated compounds.

(Secretariat, SAG GHG – ongoing)

Task 7.36 Develop a technique that offers repeatability of SF₆ of 0.02 ppt (1 standard deviation) or better.

(Measurement community, SAG GHG – ongoing)

7.2.5 Products and Services

Current products and services

- Calibrated standards for selected greenhouse and reactive gases for use at observatories throughout the world.
- Greenhouse gas data and plots thereof from contributing GAW laboratories available through WDCGG. Based on these data, the SAG GHG and WDCGG prepare a Greenhouse Gas Bulletin, once per year, which gives background information on CO₂, CH₄, and N₂O, the 3 gases with the largest contribution to radiative forcing, and their current globally averaged abundances in the atmosphere.
- NOAA produces an Annual Greenhouse Gas Index that describes the relative changes in radiative forcing due to CO₂, CH₄, N₂O, and a suite of 10 minor gases since 1990, the target year of the Kyoto Protocol.
- NOAA provides the Interactive Data Visualization (IADV) tool. Using IADV, one can view up-to-date plots of greenhouse and other gases, including plots of CO₂ from Mauna Loa Observatory (and globally averaged CO₂), to see current trends in atmospheric CO₂.
- Finally, the GAW community works together with NOAA to produce data products for CH₄ and CO₂ called GLOBALVIEW that are favoured by carbon cycle modellers. These products come in versions that provide a convenient starting point for comparisons of different models.

Future products and services

- Validated retrievals of column averaged mole fractions for many of the greenhouse gases, particularly CO₂ and CH₄, which are particularly important in advancing the understanding of the trace gas cycling on regional scales.

7.3 Reactive Gases

The reactive gases as a group are very diverse and include surface ozone (O₃), carbon monoxide (CO), volatile organic compounds (VOCs), oxidised nitrogen compounds (NO_x, NO_y), and sulphur dioxide (SO₂). All of these compounds play a major role in the chemistry of the atmosphere and as such are heavily involved in inter-relations between atmospheric chemistry and climate, either through control of ozone and the oxidising capacity of the atmosphere, or through the formation of aerosols. The global measurement base for most of them is entirely unsatisfactory, the only exceptions being surface ozone and carbon monoxide.

7.3.1 Surface Ozone

| | |
|---------------------|---|
| Lead responsibility | Scientific Advisory Group for Reactive Gases (SAG RG) |
| QA/SAC | Empa, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland |
| CCL | National Institute of Standards and Technology (NIST), Gaithersburg MD, USA [a member of the Bureau International des Poids et Mesures (BIPM), Paris, France] |
| WCC | Empa, Switzerland |
| RCC | Czech Hydrometeorological Institute, Prague, Czech Republic Servicio Meteorologico Nacional (SMN), Buenos Aires, Argentina |

| | |
|-------------|---|
| DQO | GAW Report No. 97 (1995) (to be updated), WCC-Empa [<i>Klausen et al.</i> , 2003] |
| SOP | GAW Report No. 97 (1995) (to be updated) |
| Data Center | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

Not considering water vapour, tropospheric ozone is currently the third most important greenhouse gas after CO₂ and CH₄ [*Houghton et al.*, 2001] and is central to the physics, chemistry, and radiative processes in the troposphere. Tropospheric ozone profile information is available from ozone sonde measurements. Surface (ground-level) ozone significantly influences the formation of photochemical smog, and it is an irritant with effects both on the biota and human health. Because of these roles, it is imperative that the GAW measurement programme for surface ozone be continued and extended to provide sufficient high quality data to characterise the global background distribution and trends.

Our knowledge of trends in the global distribution of surface ozone is still incomplete and observed trends have varied both temporally and spatially [*Oltmans et al.*, 2006]. The Global GAW stations are distributed relatively evenly, but overall, most surface ozone monitoring stations are still located in northern mid-latitudes. There is a need for more remote stations measuring ozone in the middle of continents (e.g., continental Asia), in the tropics and in the southern hemisphere.

Regular performance audits at many of the Global GAW stations show that these stations are providing measurements of the required quality. The existing DQOs are met by almost all stations.

The WDCGG continues to archive surface ozone and the body of available data is steadily increasing.

Goals

- Extend the archive of surface ozone at the WDCGG by encouraging submission of data and improve the documentation of traceability of surface ozone data.
- Achieve near-real-time data delivery to the GTS for the majority of Global and Selected Regional GAW stations.
- Improve the traceability and harmonization of surface ozone measurements at Regional GAW stations.
- Identify or establish between five and eight additional observation sites in continental Asia, in the tropics, and in the southern hemisphere, respectively.
- Improve our understanding of the global tropospheric distribution and transport pattern of ozone.

Implementation Strategy

Task 7.37 Issue a SAG Guidance Document on surface ozone measurements containing updated DQOs and SOPs for continuous measurements including calibration and quality assurance.

(SAG RG – 2009)

Task 7.38 Continue biennial calibrations by the RCC for the South American stations.

(RCC-SMN – ongoing)

Task 7.39 Identify possible partners and seek agreements for the establishment of RCCs in China and South-East Asia.

(Secretariat, SAG RG – 2009)

- Task 7.40 Compile existing audit information on surface ozone measurements at GAW Global and Regional stations and provide summaries of what is available.
(WCC, QA/SAC, WDCGG – 2009)
- Task 7.41 Encourage data exchange agreements between regional networks and the WDCs.
(Secretariat, WDCGG, SAG RG – ongoing)
- Task 7.42 Encourage archiving of greenhouse gases data from aircraft monitoring programmes in WDCGG (see Section 3.2).
(Secretariat, WDCGG – ongoing)

7.3.2 Carbon Monoxide (CO)

| | |
|----------------------|---|
| Lead responsibility: | Scientific Advisory Group for Reactive Gases (SAG RG) Sub-Group on CO |
| QA/SAC | Empa, Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland |
| CCL | NOAA ESRL, USA |
| WCC | Empa, Switzerland |
| DQO | Being established |
| SOP | Being established |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Tokyo, Japan |

Current Status

The tropospheric burden of carbon monoxide, like that of many other trace gases, has been increasing due to man's activities, although its upward trend ceased around 1995. Average CO abundances for the NH and SH are approximately 110 and 60 nmole/mole (ppb). The lifetime of CO is on the order of a few months only, and its significance in atmospheric chemistry lies mainly in its competition with many other gaseous pollutants—importantly the greenhouse gas CH₄—for the hydroxyl radical (OH, CO + OH → CO₂ + H). Increased CO emissions cause higher CO burdens and more reaction with OH, leaving less OH for cleansing the troposphere of other reduced gases. In the background troposphere, about one third of all OH is removed by CO that reacts rapidly with OH (contributing to the latter's very short lifetime of 1 second only).

The major sources of CO are the combustion of fossil fuels and biomass, and the oxidation (through reaction with OH) of methane and non-methane hydrocarbons. Emissions from industry and transport, despite their global growth, may not have caused much increase in CO over the past decades due to the increased use of catalysts and generally higher efficiency combustion technology. The slight shift of fuel usage from coal towards more natural gas may also have also decreased emissions. CO is produced copiously by biomass burning (forest, savannah, and agricultural waste). Inter-annual variations in wildfires are thought to largely drive year to year variations in tropospheric CO. An equally important contribution to the troposphere burden arises from photo-chemically driven oxidative processes. The oxidation of CH₄ by OH to CO is often considered the largest term in the CO budget, however, as for the other sources, large uncertainties remain in its source strength. Observations of CO are of great importance to document and understand its budget. CO is a general indicator of pollution, and its enhancement in relation to that of ozone in polluted air masses is an important metric of air quality. The prediction of future CO levels clearly is fraught with uncertainties, and therefore its measurement in GAW is very important.

Until recently, we were mostly informed about tropospheric CO concentrations via surface measurements. Now, results from remote sensing and an increasing number of aircraft flights give improved global coverage and some vertical resolution. Since the launch of the MOPITT satellite instrument, followed by SCIAMACHY, AIRS and others, we have a much better picture of large scale continental pollution plumes. The vertical resolution of satellite based remote sensing is limited to several km at best, and vertical profiles coordinated with satellite overpasses are needed to better define vertical variability. Before the satellite, surface and aircraft measurements are combined, their relative calibration must be accurately determined.

In summary, CO is a pivotal, chemically active, relatively short-lived, non-greenhouse trace gas with large spatial variability. Its sink is well understood and constrained, but in particular its non-photochemical sources are variable in time and space and will remain difficult to quantify. Surface measurements (the backbone of CO monitoring over decades) alone do not suffice to construct its tropospheric distribution in sufficient detail. The accompanying uncertainties threaten to limit the usefulness of models in predicting important chemical changes in the atmosphere.

Goals

- Improve our knowledge of the 3D distribution of CO in the troposphere including its seasonal and inter-annual changes, mainly by increasing observations.
- Produce an internally consistent CO data set through the use of standards regularly calibrated by the CCL, audits by the WCCs, and inter-comparisons of measurements.

Implementation Strategy

- Task 7.43 Finish the harmonization of CO scales using the improved instrumental techniques and inter-comparisons.
(SAG, QA/SAC, WCC – 2009)
- Task 7.44 Develop an SOP detailing the necessary steps for the harmonization of CO time series currently archived at WDCGG, correct data accordingly, and request approval by the data submitters.
(SAG, QA/SAC, WCC, WDCGG – 2009)
- Task 7.45 Motivate Members to add observational surface sites in the tropics, the SH and Asia as far as feasible. Shipping lines may be added as platforms.
(Secretariat, SAG – ongoing)
- Task 7.46 Support civil aircraft based regular observations for the free troposphere.
(Secretariat, SAG – ongoing)
- Task 7.47 Support surface sites interested in vertical profiling, with some flights coincident in time/space with satellite overpasses.
(Secretariat, SAG – ongoing)
- Task 7.48 Define requirements for combining satellite, aircraft and surface measurements and integrate these data sources.
(SAG – 2009, 2012)

7.3.3 Volatile Organic Compounds (VOCs)

| | |
|----------------------|---|
| Lead responsibility: | Scientific Advisory Group for Reactive Gases (SAG RG) Sub-Group on VOCs |
| QA/SAC | Umweltbundesamt Berlin (UBA), for Europe and Africa |
| CCL | NIST, USA |
| WCC | FZ Karlsruhe IMK-IFU, Germany |
| DQO | available [WMO, 2007c] |
| SOP | available for canister sampling [Rappenglück, 2005] |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

Measurement of VOCs is complex due to the many different molecules present in the atmosphere. The measurement of many of these species is important for air quality purposes, however, only a few molecules can be measured routinely in the background atmosphere. A workshop was held in Geneva in January/February 2006 to discuss the needs of a manageable VOC measurement programme for GAW [WMO, 2007c]. A core set of molecules was identified,

taking into account their ease of measurement in a flask network, and their usefulness in providing information on many processes such as emissions from defined sources, long-range transport, and chemical loss processes (cf. Table 3). In addition, a basic flask network was identified making use of existing networks used to provide greenhouse gas measurements for GAW via NOAA, and for regional VOC measurements in Europe via EMEP. The core species measured in this network, with a frequency of the order of one per week would be supplemented by more frequent measurements of a wider range of species at a small number of well-maintained sites in Europe and North America, and on mid Atlantic islands. With the advent of IGACO, the GAW data base on VOCs will include measurements made from aircraft, both research aircraft and in-service aircraft operating in the CARIBIC project. Also measurements of formaldehyde (CH₂O) and glyoxal (1,2-ethanedione, HCOOCH) will be made at specific sites for the ground truthing of data produced by satellites. The GAW Workshop proposed the following molecules, as shown in the Table below:

Table 3. List of VOCs recommended for measurement by GAW sites.

| Compound | Lifetime | Purpose |
|----------------|------------------|--|
| Ethane | 2-4 months | Mixed, mainly anthropogenic, sources; tracer for methane sources; trends in global OH; impact of Cl atom chemistry |
| Propane | 3 weeks | Mixed, mainly anthropogenic, sources; tracer for methane; trends in global OH |
| Acetylene | 3 weeks | Tracer for vehicular emissions and biomass burning; air mass age |
| Isoprene | 1-2 hours | Biogenic emissions; source of formaldehyde; ozone precursor; emissions sensitive to environmental conditions/climate |
| Terpenes | 1 hour | Aerosol precursor |
| DMS | 1 day | Aerosol precursor; tracer for marine emissions/productivity |
| Formaldehyde | 2 hours – 2 days | Indicator of isoprene oxidation; satellite validation |
| Acetonitrile | 0.4 – 1 year | Biomass burning tracer |
| Methanol | 2 weeks | Oxidation product; biogenic emissions |
| Ethanol | 1 week | Oxidation product; biofuel tracer |
| Acetone | 1 month | Oxidation product; source of free radicals |
| Benzene | 1 week | Tracer for combustion processes |
| Toluene | 2 days | Aerosol precursor |
| Iso-/n-Butane | 2-3 days | Air mass age/OH concentration |
| Iso-/n-Pentane | 2-3 days | Impact of NO ₃ chemistry |

Goals

- Collect a data base of core VOC measurements in a global network for use in global models of atmospheric chemistry and transport.
- Combining ground-based measurements with measurements collected by aircraft and by satellite.
- Make use of VOC data as tracers of atmospheric emission, transport, mixing, chemistry, particle formation, scavenging and deposition.
- Identify emissions from various sources (industrial, biomass burning, etc).

- Quantify atmospheric chemical processing by different types of radicals (hydroxyl, nitrate radical, halogens).
- Enhance our knowledge about atmospheric VOC distribution, its variation in time and the correlation of VOCs with other species, to better understand the workings of the atmosphere.
- Reduce the uncertainty in climate models by providing information on the atmospheric distribution of sulphate and carbonaceous aerosol precursors.

Implementation Strategy

Task 7.49 Set up a global flask network for weekly measurements of core VOCs. The network will make use of air samples already collected for other purposes by NOAA and by EMEP.

(Secretariat, SAG – 2010)

Task 7.50 Encourage a programme of more frequent measurements of a wider range of VOCs at a small number of well-maintained sites.

(Secretariat, SAG – ongoing)

Task 7.51 Set up a CCL.

(Secretariat, SAG – 2009)

Task 7.52 Enhance the VOCs data archived at the WDCGG to include ground-based data, aircraft data, and to consider how to link to satellite data suitable for IGACO purposes.

(Secretariat, WDCGG – 2010)

7.3.4 Nitrogen Oxides (NO_x)

Lead responsibility: Scientific Advisory Group for Reactive Gases (SAG RG)

QA/SAC Not yet established

CCL Not yet established

WCC Not yet established

DQO Not yet established

SOP Not yet established

Data Centre World Data Centre for Greenhouse Gases (WDCGG), Japan

Current Status

The sum of nitric oxide (NO) and nitrogen dioxide (NO₂) has traditionally been called NO_x. Likewise the sum of many oxidised nitrogen species, both organic and inorganic but excluding nitrous oxide (N₂O) and ammonia (NH₃), acetonitrile (CH₃CN) and hydrocyanic acid (HCN) have traditionally been referred to as NO_y. Their measurement in the global atmosphere is very important since NO has a large influence on both ozone and on the hydroxyl radical (OH). NO₂ is now being measured globally from satellites and these measurements suggest that substantial concentrations of this gas are present over most of the continents. A large reservoir of fixed nitrogen is present in the atmosphere as NO_y. The influence of the deposition of this reservoir on the biosphere is not known at present but could be substantial. There are efficient *in situ* measurement techniques for NO and NO_y, and to a lesser extent NO₂. A large amount of data on these species has been collected in the past in association with the control of regional pollution. The global data base is more limited and consists mostly of aircraft measurements collected over the world oceans.

Goals

- Identify a global network suitable for GAW purposes utilising existing activities.

- Take note of and utilise ongoing activities to create a common database of aircraft measurements of NO_x and NO_y worldwide.
- Establish DQOs and SOPs, as well as the missing GAW central facilities and develop a GAW-compliant QA/QC programme for NO_x and NO_y measurements.

Implementation Strategy

Task 7.53 Set up a workshop to discuss the establishment of a GAW network for global NO_x and NO_y measurements including surface stations, aircraft measurements and satellite measurements. The workshop should include members of the existing NO_x/NO_y measurement community worldwide, including the satellite community who require extensive NO₂ measurements for validation purposes.

(SAG RG, Secretariat – 2008)

7.3.5 Sulphur Dioxide (SO₂)

| | |
|----------------------|---|
| Lead responsibility: | Scientific Advisory Group for Reactive Gases (SAG RG) |
| QA/SAC | Not yet established |
| CCL | Not yet established |
| WCC | Not yet established |
| DQO | Not yet established |
| SOP | Not yet established |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

Sulphur dioxide (SO₂) is the main precursor to the sulphate aerosol which exerts a large influence on world climate. It is a regulatory pollutant controlled in many countries for human health effects by monitoring networks that may or may not be operated by NHMSs. Many measurements have been made in association with its role as a regional pollutant, particularly its role as a precursor to acid rain. Many measurements are available from integrating techniques such as filter observations used by regional networks such as EMEP, CAPMoN and NADP. However, there are very few measurements in the background atmosphere. This is a very unsatisfactory situation that has a number of causes, in particular the lack of a suitable instrument for regular measurement at the low concentrations found there. It is important to remedy this in order to create a database suitable for the proper validation of models used to predict global sulphate aerosol distribution, and its present and future influence on climate.

Sulphur dioxide concentrations in many areas in the developed world have been declining due to restrictions on emissions. It is possible that they may increase in some areas with currently expanding economies such as South and South-East Asia. The impact of these emissions and indeed emissions from all regions on the global sulphate aerosol distribution needs to be quantified urgently through an organised measurement programme. There is a major role here for GAW/IGACO.

Goals

- Fill gaps in the observation network, focussing in particular on remote areas with low concentrations.
- Quantify and assess the impact of emissions of rapidly developing economic regions, in particular South and South-East Asia.
- Validate models used to predict the global sulphate aerosol distribution.

Implementation Strategy

- Task 7.54 Encourage agencies with the capability to make measurements of SO₂ in the remote atmosphere, including ground-based and aircraft measurements.
(Secretariat, SAG RG – ongoing)
- Task 7.55 Set up a workshop to discuss all aspects of SO₂ measurements in global and regional atmospheres pertinent to GAW.
(Secretariat, SAG RG – 2009)

7.3.6 Molecular Hydrogen (H₂)

| | |
|---------------------|--|
| Lead Responsibility | Scientific Advisory Group for Reactive Gases (SAG RG) |
| QA/SAC | Not yet established |
| CCL | Not yet established, but various standards and calibration scales exist (e.g. NOAA, AGAGE) |
| WCC | Not yet established |
| DQO | Not yet established |
| SOP | Not yet established |
| Data Centre | World Data Centre for Greenhouse Gases (WDCGG), Japan |

Current Status

Molecular hydrogen (H₂) is considered by many to be one of the most important fuels of the future, notably for mobile use. The benefits of a hydrogen fuel economy are reduced urban pollution (the emissions from H₂ combustion consist simply of water vapour) and, if H₂ can be produced from non-fossil fuel dependent sources, reduced CO₂ emissions from the transport sector [Schultz *et al.*, 2003; Tromp *et al.*, 2003].

Large scale use of H₂ fuel would inevitably lead to increased atmospheric concentrations of this gas due to leakage during production and handling. The atmospheric residence time of H₂ in the troposphere has been estimated to be 1.4±0.2 years [Xiao *et al.*, 2007]. The soil sink of H₂ may also be subject to climatic or land use changes, with consequential positive or negative effects on atmospheric concentrations. While H₂ has no direct effect on the atmospheric radiation budget, it does have an indirect effect through its reactivity with hydroxyl radical (OH). If this were to lead to a reduced OH abundance then the lifetime of many gases of environmental interest, for example methane, would become longer [Schultz *et al.*, 2003; Tromp *et al.*, 2003]. In one modelled scenario a 120% increase in global H₂ burden resulted in a 10% increase in methane lifetime [Schultz *et al.*, 2003]. Increased H₂ would also increase water vapour in the stratosphere, potentially leading to stratospheric cooling, and possibly increased ozone loss through enhanced heterogeneous activation of chlorine.

Present day global average concentrations of H₂ are between about 500 and 550 ppb (slightly lower in the Northern Hemisphere due to the larger soil sink there). These levels are believed to be supported principally by emissions from fossil fuel and biomass burning, and from the atmospheric oxidation of methane and other hydrocarbons, balanced primarily by uptake by soils and secondarily reaction with atmospheric OH.

In the past rather little attention has been paid to measurements of atmospheric H₂. Long term measurements have been made by NOAA ESRL, and by CSIRO Marine and Atmospheric Research (CMAR) in cooperation with AGAGE, yet there is disagreement even on the sign of the long term trend [Langenfelds *et al.*, 2002; Novelli *et al.*, 1999]. There has been no concerted effort to date to coordinate global measurement activities. A recent development has been the funding by the EU of a coordinated network "EUROHYDROS". This network has yet to become operational, but will comprise 12 continuous measurement and 7 flask sampling sites in Europe, and 6 global flask sampling sites. It will make efforts to ensure consistency of calibration and data quality across the network. Clearly there is a need to bring the various measurement groups together to stimulate further measurement activities, and encourage consistency in measurement standards.

Goals

- Develop a strategy for GAW oversight of existing and planned H₂ measurement activities.
- Consolidate the NOAA, CSIRO/AGAGE and emerging EUROHYDROS measurement activities into a collaborative global network for hydrogen measurements.
- Cooperate with the above measurement groups to establish a common calibration scale, and encourage inter-calibration exercises and consistent protocols for data acquisition and reporting.
- Identify changes in source and sink strengths by determining the spatial, seasonal, and long term variations in atmospheric H₂. A large, worldwide, data set will enable global scale modelling of the H₂ budget and its consequent impacts on oxidation capacity, lifetime of OH-sensitive gases, stratospheric water vapour, and indirect radiative forcing. In this respect an important aspect will be the integration of other key GAW measurements such as CH₄, CO, VOCs, and NO_x into global models.

Implementation Strategy

- Task 7.56 Develop and seek approval for a hydrogen measurement programme under the auspices of GAW with oversight by the SAG RG.
(Secretariat, SAG – 2010)
- Task 7.57 Initiate establishment of a WCC for H₂.
(Secretariat, SAG – 2012)
- Task 7.58 Begin developing DQOs and SOPs in cooperation with current measurement groups (NOAA, CSIRO, AGAGE, EUROHYDROS).
(SAG – 2009)
- Task 7.59 Initiate establishment of a QA/SAC for H₂.
(Secretariat – 2009)
- Task 7.60 Coordinate intercalibration exercises.
(QA/SAC – beginning in 2009)
- Task 7.61 Promote scientific collaboration between the various measurement and modelling groups to develop predictive modelling capabilities for present and future H₂ scenarios.
(SAG, QA/SAC – beginning in 2009)

7.3.7 Products and Services

Current Products and Services

- Archives of WDCGG.
- A strategy for long-term measurements of VOCs.

Future Products and Services

- Near-real-time data delivery to the GTS/WIS (surface ozone).
- Inter-calibration reports.
- Integration of reactive gases observations and models.
- Bulletins, measurement guidelines (surface O₃, CO, others) and assessments for reactive gases.
- Easily accessible validated data sets on H₂; SO₂ (including emission data); NO_x and NO_y; VOCs (including emission data).

7.4 Atmospheric Wet Deposition

| | |
|---------------------|---|
| Lead Responsibility | Scientific Advisory Group for Precipitation Chemistry and Deposition (SAG PC) |
| QA/SAC | Atmospheric Sciences Research Centre (ASRC), State University of New York (SUNY), Albany, USA; for all regions of the world |
| CCL | Illinois State Water Survey (ISWS), Champaign, IL, USA |
| WCC | ARSC-SUNY; Artificial precipitation samples are prepared by ISWS and distributed to all laboratories by QA/SAC Americas, |
| DQO | Established for precipitation measurements [WMO, 2004c] |
| SOP | Established for precipitation measurements [WMO, 2004c] |
| Data Centre | World Data Centre for Precipitation Chemistry (WDCPC), ARSC-SUNY, USA |

Current Status

Precipitation chemistry remains a major environmental issue in several parts of the world (e.g., eastern North America, southeast Asia, and Europe) due to concerns over acid deposition, eutrophication, trace metal deposition, ecosystem health, biogeochemical cycling, and global climate change. In more recent years, concerns have expanded from wet deposition alone to include such considerations as air concentrations, dry deposition, and surface-air exchange, particularly as they relate to the atmospheric lifetimes of acidifying species, greenhouse gases, and oxidizing species. In spite of these concerns, little has been done to bring these additional factors to the framework of GAW, primarily due to budgetary limitations.

Measurements of precipitation chemistry and wet deposition have been made for many years in various regions of the world with varying degrees of success. In general, those areas in which acid deposition has been a major environmental concern have developed and implemented sophisticated, high quality measurement systems. In other areas, however, the number of sites has been insufficient and the measurement methods and programmes remain inadequate and poorly integrated into the GAW programme. On a brighter note, while the inconsistency in sampling instrumentation and sampling methods around the world remains a daunting problem, representatives from major networks from Asia, Europe, and North America are in strong agreement about the major tenets of an acceptable GAW programme and have recently issued a comprehensive set of guidelines for the GAW programme. The challenge of the present strategic planning period will be to reduce inconsistencies among established programmes and to ensure high quality programmes in present data sparse regions of the globe.

The number of official GAW precipitation chemistry measurement sites remains insufficient in South America, Africa, Asia, and Oceania. New, high quality sites have recently been established under the DEBITS (Deposition of Biogeochemically Important Trace Species) programme in each of these areas, however, the DEBITS sites remain in tenuous financial circumstance. Both the DEBITS programme and legacy data collected under the US Global Precipitation Chemistry Programme (GPCP) still require formal incorporation under GAW. Although both of these programmes are working closely with GAW, financial difficulties in maintaining the World Data Centre for Precipitation Chemistry (WDCPC) are a primary reason for this.

Many of the chemical laboratories from DEBITS laboratories and from stations associated with other remote regions of the globe do continue to participate in the GAW annual laboratory inter-comparison studies. Unfortunately, the performance of many of the laboratories has been substandard, and some laboratories simply do not participate. The laboratory inter-comparisons will continue in the future under the auspices of QA/SAC Americas. Powerful tools have been established to clearly identify poorly performing laboratories and protocols have been established to work with such laboratories to improve performance. Twinning activities and expert site visits will be required to ensure measurable progress.

Some precipitation chemistry data are presently archived at the WDCPC in Albany, New York, USA. However, funding for this facility has been eliminated and this effort has been

suspended pending resolution to budget shortfalls. It is the goal of the new strategic planning period to re-establish the WDCPC, and to incorporate all reporting requirements as established in the GAW Precipitation Manual (GAW 160). Furthermore, in the spirit of supporting IGACO, greater effort will be made to improve reporting capabilities to ensure that data are both user friendly and readily available to the broader scientific community. Given the nature of GAW precipitation chemistry data, no immediate availability of data in near-real-time is currently envisioned.

To date, the GAW Precipitation Chemistry Programme has focused largely on major ions. Established measurement and analysis methodologies may be found in the Manual for the GAW Precipitation Chemistry Programme [WMO, 2004c]. Information regarding major national and regional networks is accessible online, e.g., the Canadian Air and Precipitation Monitoring Network (CAPMoN; http://www.msc-smc.ec.gc.ca/capmon/index_e.cfm), the Co-Operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP; <http://www.emep.int/>), the Acid Deposition Monitoring Network in East Asia (EANET; <http://www.eanet.cc/>) and the US National Atmospheric Deposition Programme (NADP; <http://nadp.sws.uiuc.edu/>).

Although trace metals are included in the GAW suite of desirable measurements, they have not been measured at many sites, and the present quality assurance activities for trace metals have been managed through the EMEP programme. An assessment of the need for trace metal measurements will be revisited when financial and scientific considerations warrant additional attention. Similar assessments are envisioned for organics, including pesticides, PCBs, PAHs and for dry deposition and droplet (i.e., cloud or fog water) deposition measurements.

Goals

- Archive global precipitation data and make products freely available via the World Wide Web.
- Enhance the timely submission and distribution of GAW precipitation chemistry data through use of the World Wide Web and to promote the use of these data both for scientific and pollution control purposes.
- Upgrade the GAW Precipitation Chemistry Programme in terms of implementing new standard operating procedures, more complete data collection, improved quality control, better instrumentation, and more consistent laboratory performance.
- Incorporate new stations from data sparse regions of the globe into the GAW precipitation chemistry programme and improve the operation of existing stations for major ions as necessary to meet the objectives of characterizing global precipitation chemistry and detecting spatial and temporal changes.

Implementation Strategy

- Task 7.62 Re-establish and stabilize funding for the World Precipitation Chemistry Data Centre so that it is able to accept, quality-assure, and make available historical and current data in a timely manner.
(SAG PC – June 2008)
- Task 7.63 Publish and post on the QA/SAC web page results of WMO inter-laboratory quality assurance assessments using the Environment Canada ring diagram scheme.
(SAG PC – June 2008)
- Task 7.64 Enforce strict data acceptance criteria, clear procedures, and effective feedback for nations and stations wishing to make precipitation chemistry measurements as described in GAW report 160 [WMO, 2004c]
(SAG PC, Regional Data Centres)
- Task 7.65 Continue the annual GAW Laboratory Intercomparison Studies.
(QA/SAC – ongoing)

- Task 7.66 Make data easily accessible to a wide range of users.
(SAG PC – June 2009).
- Task 7.67 Assist in developing regional programmes, and identify and attempt to increase the number of precipitation chemistry monitoring sites, most notably in South America, Asia, and Africa in large and relatively homogeneous ecosystems such as rain forests, savannahs, and Arctic regions, and in rapidly industrializing areas to provide information required for political decisions to reduce emissions of pollutants.
(Secretariat, SAG – ongoing)
- Task 7.68 Assess the quality of GAW precipitation chemistry data and the success of the new SOPs.
(QA/SAC – ongoing)
- Task 7.69 Organize a scientific assessment of precipitation chemistry, combining GAW data, data from cooperating regional networks and from simulation models. In line with IGACO objectives, GAW data should be optimally integrated with model exercises and data assimilation techniques
(QA/SAC – 2010)
- Task 7.70 Cooperate with other international organizations expressing interest to use information on precipitation chemistry.
(QA/SAC – ongoing)

7.4.1 Products and Services

Current Products and Services

- Biannual laboratory inter-comparisons (through the support of ISWS working jointly with QA/SAC Americas).

Future Products and Services

- Coordinated work on a scientific assessment of precipitation chemistry, combining GAW data, data from cooperative regional networks and input from simulation models.
- Comprehensive collection of global precipitation chemistry observations, easily accessible, with comprehensive documentation.
- Basic global data analysis of major ions presented in graphical analysis and made easily accessible.
- Assistance with site establishment and laboratory operations as necessary for developing programmes.

7.5 UV Radiation

| | |
|---------------------|--|
| Lead Responsibility | Scientific Advisory Group for UV Radiation (SAG UV) |
| QA/SAC | Not yet established |
| CCL | Not yet established |
| WCC | Not yet established |
| RCC | Regional Calibration Centre Central UV Calibration Facility, ESRL, Boulder, USA (Am) |
| DQO | In preparation |
| SOP | Guidelines available [<i>Webb et al., 2007</i>] |
| Data Centre | World Ozone and UV Data Centre (WOUDC), Canada |

Current Status

Solar UV radiation is currently measured at a total of about 135 GAW stations (Global, Regional and Contributing), while a recent review by the SAG UV indicates that there are approximately 300 stations measuring UV globally. These figures include spectral, broadband and multifilter measurements with a variety of different instruments covering different wavebands and wavelength ranges. The sites are irregularly distributed, both within GAW and more generally. The greatest concentration of sites is in North America and Western Europe, with very sparse data collection in some other regions, e.g., the Tropics and the Southern Hemisphere.

There are neither standard instruments for UV measurement nor a single parameter that all instruments measure. However, the erythemally effective UV, and hence the UV Index, is measured approximately, or can be derived by the great majority of UV instruments. The UV Index is therefore taken as the single common factor that should be obtained from the data at every site. However, time and wavelength resolved data from a site is of much greater value for most applications and should be submitted to the data centre.

Because of the large variety of instruments available for monitoring solar UV, the SAG UV has produced a number of documents detailing the characteristics and operational requirements for the different categories: spectral, broadband and multifilter instruments. The documents discuss the instrument specifications required to allow a number of data applications as defined in the UV Data Quality Objectives (currently in draft format), the supporting infrastructure and operational protocols required to operate the instruments to GAW standards. Standard Operating Procedures are available for broadband instruments and further SOPs are under consideration for spectral and multifilter instruments.

The UV community lacks an acknowledged world reference centre for calibration. Underlying all calibrations are standards of spectral irradiance available from national standards laboratories. The standards of different laboratories vary in the UV region and there is no accepted true value. Even assuming that national laboratories will converge to a universal standard, the standard still has to be maintained and transferred to the measurement instruments. It is not viable to have the facilities required for this task at every site. Thus central facilities are required to calibrate and characterise site instruments and provide quality assurance for the GAW network. At present there is only one GAW calibration facility, the Central UV Calibration Facility in Boulder, USA. A calibration facility for Europe was developed within the European Union project QASUME (Quality Assurance of Spectral UV Measurements in Europe) and work is on-going to establish a permanent home for this facility.

UV data is submitted to the WOUDC in Toronto, Canada. As of 2006, the WOUDC archive contains spectral UV observations from 45 sites mostly located in North America and Asia; multi-band UV data from 35 sites, mostly from the US; and broadband UV data from 4 sites. Archives of the European UV Data Base (EUVDB) and NSF Polar UV network contain UV measurements from European and polar sites respectively. Most of these data are not available from the WOUDC.

While UV at the Earth's surface is not directly measured from satellites, it is derived using a number of other satellite products (ozone amount, aerosol optical depth and absorption, Rayleigh scattering, and cloud reflectivity) and radiative transfer theory. The great advantage of satellite information is global coverage over land and oceans and uniformity of calibration. Satellite data is excellent for estimating the irradiance over wide areas, but will usually overestimate specific sites. This is because both aerosols and cloud amounts vary strongly over small spatial scales. Satellite estimates of UV irradiance exist continuously for the entire globe since 1979 at a spatial resolution of 1° by 1°. These data have been extensively compared with ground measurements of UV irradiance. In general, satellites tend to overestimate the amount of radiation reaching the ground by 10% to 20% compared to the best-calibrated ground instruments. The major source of this disagreement is from atmospheric aerosols that are not properly accounted for in satellite estimates. For cloud-free and aerosol-free situations, the agreement is within instrumental experimental error. Similar agreement is obtained when aerosol absorption is known from external data. A significant change in the comparison of a ground-based UV instrument with satellite estimates of UV irradiance is a strong indicator that there may be something wrong with its

calibration. The SAG UV is engaging with the satellite community to improve the accuracy of the available data and to improve its accessibility to the user community.

Goals

- Enhance the global coverage of UV measurements.
- Increase availability and accessibility of UV data.
- Improve QA/QC of UV data.

Implementation Strategy

- Task 7.71 Increase the number of GAW associated monitoring sites. Invite selected UV stations, known from the SAG inventory, to become contributing GAW stations.
(Secretariat, SAG – 2008)
- Task 7.72 Work with the satellite community to improve validation of satellite data. Improve accessibility of satellite data for any specified site. The satellite community is represented on the SAG to help move this goal forward.
(SAG – ongoing)
- Task 7.73 Monitor improvements in use of inexpensive modern small fibre optic CCD spectrometers for making both irradiance and radiance measurements of UV at a spectral resolution of approximately 1 nm.
(SAG – ongoing)
- Task 7.74 Increase the amount of UV data held at WOUDC by simplifying the submission procedure, in particular for broadband data. Encourage sites from the SAG inventory to submit their data.
(WOUDC, SAG – 2009, ongoing)
- Task 7.75 Improve integration of contributing networks and databases (e.g., EUVDB, NSF Polar Network, NDACC) by adopting similar data exchange formats and by setting direct links between existing databases.
(SAG, WOUDC – ongoing)
- Task 7.76 Work with the satellite community to incorporate satellite derived UV data into the GAW system. Satellite-derived UV data products that mimic ground-based observation should be used for validation purposes. Satellite data products with high spatial resolution are able to provide detailed information about UV distribution that cannot be achieved by ground-based networks alone. This is also a part of implementing the IGACO Ozone/UV strategy and is related to Task 7.72.
(SAG, IGACO Ozone/UV office, Secretariat – ongoing)
- Task 7.77 Complete SOPs for all instrument types. Much of the information for the SOPs is contained in other documents. The SAG will use these and the experience from the broadband document to complete the remaining SOPs.
(SAG – 2010)
- Task 7.78 Encourage the establishment of additional RCCS. First explore possibility for one in Europe.
(SAG, Secretariat – 2009)
- Task 7.79 Determine requirements and candidates for a world calibration centre. Existing RCCs will be approached about their capability and willingness to expand their remit into that of a WCC.
(SAG, Secretariat – 2010)

7.5.1 Products and Services

Current Products and Services

- Guideline documents for different types of UV instruments and for QA/QC of measurements.
- Data sets provided through WOUDC.
- Provision of erythemally effective UV, *i.e.*, the UV Index.
- Provision of UV Index forecasts for the public by NMHSs.
- Calibration services for North America.
- Instrument inter-comparisons for the quality and harmonization of measurements.

Future Products and Services

In addition to above

- Improved data availability to users especially due to more available broadband data sets.
- Improved accessibility of satellite data for any specified site.
- Globally linked calibration services in different regions.
- SOPs for all instrument types.

7.6 Aerosols

| | |
|---------------------|---|
| Lead Responsibility | Scientific Advisory Group for Aerosols (SAG Aerosol) |
| QA/SAC | Not yet established |
| CCL | Not yet established |
| WCC | World Calibration Centre for Aerosol Physics (WCCAP), Germany World Optical Depth Research and Calibration Centre (WORCC), Switzerland GAW Regional Calibration Centre for Aerosol Optical Depth in China, CAWAS, Chinese Meteorological Administration |
| DQO | See recommendations in GAW Report No. 153 [WMO, 2003b] |
| SOP | Currently being established for selected parameters |
| Data Centre | World Data Centre for Aerosols (WDCA), Italy |

Current Status

Atmospheric aerosols are important for a diverse range of issues including global climate change, acidification, regional and local scale air quality, and human health. The climate impact of aerosols is a result of both direct radiative effects and indirect effects on cloud properties. Regional problems include potential impacts on human health and mortality and environmental impact such as visibility impairment. Major sources of aerosols include urban/industrial emissions, smoke from biomass burning, secondary formation from gaseous aerosol precursors, sea salt and dust. Outstanding problems include determining the natural sources of aerosols, and the organic fraction.

The GAW aerosol programme objective is “to determine the spatio-temporal distribution of aerosol properties related to climate forcing and air quality up to multidecadal time scales” (SAG Aerosol, Wengen, Switzerland, 1998) [WMO, 2003b]. Multidecadal is considered a key word, because of GAW’s mission to provide long-term measurements globally.

The GAW aerosol programme has been set up with the philosophy that it should address not only climate-related, but also air-quality issues. For developing countries in particular, regional aerosol issues may be equally or more important than global concerns. The SAG Aerosol also recognises that climate related and regional environmental measurements can frequently employ common methods.

Table 4 provides a list of recommended aerosol parameters, with a subset of core variables, as identified by the Aerosol SAG [WMO, 2003b].

Table 4. List of comprehensive aerosol measurements with a subset of core variables (in bold) that are recommended for long-term measurements in the global network [WMO, 2003b].

| Type | Parameter |
|--------------|--|
| Continuous | Multiwavelength aerosol optical depth |
| | Mass concentration in two size fractions (fine, coarse) |
| | Mass concentration of major chemical components in two size fractions |
| | Light absorption coefficient |
| | Light scattering coefficient at various wavelengths |
| | Hemispheric backscattering coefficient at various wavelengths |
| | Aerosol number concentration |
| | Cloud condensation nuclei at 0.5% supersaturation |
| | Vertical distribution of light extinction coefficient |
| Intermittent | Aerosol size distribution |
| | Detailed size fractionated chemical composition |
| | Dependence of aerosol variables on relative humidity |
| | Cloud condensation nuclei spectra (various supersaturations) |
| | Vertical distribution of aerosol properties |

In March 2004, a workshop on Aerosol Optical Depth (AOD) with participation of all major networks worldwide took place in Davos, Switzerland [WMO, 2005]. The major conclusions include the following:

- The international coordination of AOD networks is inadequate and could be improved by a federation of networks under the WMO/GAW umbrella with potential endorsement by ICSU.
- A standing sub-committee of the WMO SAG for Aerosols, including expert representatives from interested networks, should foster the coordination by development of common data policy agreements, technical standards, and strategies to fill spatial gaps in observation sites.
- Contributing networks should become traceable to WORCC through inter-comparisons of representative instruments or co-location at specific GAW sites.

A recent initiative is the GALION (GAW Aerosol Lidar Observation Network), with the objective to set up a long-term monitoring programme for the aerosol vertical distribution on a global scale using advanced laser remote sensing. The activities of existing networks will be coordinated and expanded to achieve global coverage. A GALION Lidar Experts Workshop Report is expected to be released by GAW in 2008.

GAW strongly supports the harmonization of procedures for aerosol chemistry in the various regional networks and will contribute to its facilitation where possible, e.g. in a working group for harmonization of aerosol chemistry procedures. The establishment of a WCC for aerosol chemistry by GAW is however not considered a high priority as the regional networks are best placed to deal with global harmonization. To assess the degree of harmonization long-term collocation of instruments from different networks is required.

Further information on the SAG activities is found at the SAG Aerosol Web site: <http://gaw.tropos.de/>

Goals

Enhance the coverage, effectiveness, and application of long-term aerosol measurements within GAW and with cooperating networks worldwide, by

- Further harmonizing aerosol measurements where no agreed procedures are yet available.
- Promoting coordination of networks for *in situ* observations of aerosol chemical and physical properties.
- Establishing coordination of the AOD measurements as outlined in GAW Report 162 [WMO, 2005].
- Establishing a GAW aerosol lidar network in cooperation with existing networks and interested research groups.
- Contributing to the integration of satellite, aircraft, and surface-based aerosol observations.
- Fostering activities and contacts that result in greater data submission and utilisation of GAW aerosol data.
- Conduct a pilot project for aerosols involving NRT exchange of data (cf. Chapter 3.4).

Implementation Strategy

- Task 7.80 Finalize the development and publication of standard operating procedures (SOPs) for selected aerosol variables (mass concentration, light absorption coefficient, light scattering coefficient).
(WCCAP – 2009)
- Task 7.81 Conduct on-site audits, calibrations, comparisons and training activities related to aerosol variables.
(SAG, WCCAP – ongoing)
- Task 7.82 Develop procedures for quality assurance, integration, delivery, and application of data from AOD networks.
(SAG, SAG subgroup on AOD – ongoing)
- Task 7.83 Assist the development of the GAW RCC for Aerosol Optical Depth in China.
(SAG, WCCAP – ongoing)
- Task 7.84 Through GALION, participate in the establishment and coordination of long-term, high-quality lidar networks worldwide for obtaining aerosol profiles.
(Secretariat, SAG – ongoing)
- Task 7.85 Identify and address gaps in global coordination of aerosol chemistry observations.
(SAG – 2009, then ongoing)
- Task 7.86 Enhance aerosol measurements and continue capacity building in developing countries, e.g. by twinning activities.
(Secretariat, SAG, WCCAP – ongoing)

- Task 7.87 Improve the timeliness of submission of data to the WDCA.
(Secretariat, SAG – ongoing)
- Task 7.88 Produce a brochure and promote the WDCA to user communities.
(Secretariat, SAG – 2008)
- Task 7.89 Contribute to validation of satellite-derived aerosol products with long-term measurements.
(SAG – ongoing)
- Task 7.90 Establish and maintain an international sand and dust storm warning system in cooperation with WWRP.
(Secretariat, SAG – ongoing)

7.6.1 Products and Services

Current Products and Services

- Easily accessible data, traceable to international standards.
- Climatologies of GAW aerosol variables.
- Outreach products (e.g., brochures, technical reports, bulletins)
- Calibration and comparison of aerosol instruments (*in situ* and AOD) for the GAW community and beyond.
- Standard operating procedures for aerosol instruments used in GAW.
- Global coordination of aerosol optical depth and aerosol profiling networks.

Future Products and Services

In addition to above

- Near-real-time data for selected variables for assimilation and verification of numerical weather and air quality forecast models.

8 ANCILLARY VARIABLES

Ancillary variables are useful in the interpretation of GAW observations related to the major challenges of weather, climate, oxidants, air quality and ecosystem impacts but in general, the GAW programme does not support all components of the global network for these variables. Instead the role of GAW is to ensure through partnerships with other WMO programmes (e.g. WWW, GCOS) that all the components of an end-to-end approach to observation are addressed. Here, the particular role that GAW will play in supporting observations of ancillary variables is described.

8.1 Solar Radiation

| | |
|---------------------|---|
| Lead Responsibility | To be established |
| CCL | World Radiation Centre (WRC), Physikalisch-Meteorologisches Institut Davos, Switzerland |
| WCC | WRC-PMOD, for the WWW |
| DQO | Established by WMO-WWW |
| SOP | Established by WMO-WWW |
| Data Centre | World Radiation Data Centre (WRDC), St. Petersburg, Russia |

Current Status

The radiation component of GAW has concentrated its efforts on UV radiation. UV radiation, however, is only a part of the solar spectrum observed at the surface. The GAW programme under CAS has traditionally supported the WRDC in St. Petersburg while other functions of the global network are supported by the World Weather Watch (WWW) under CIMO and CBS. Global observations of surface radiation made at all stations operated by WMO Members comprise the Global Surface Radiation Network (GSRN). There are over 180 stations with a record of more than 30 years observations. The BSRN comprised of ~38 stations is a baseline network of GCOS and a subset of the GSRN. BSRN is well coordinated by a community involved in radiation research under a project of the World Climate Research Programme (WCRP). Currently, the much larger GSRN lacks coordination in WMO owing to a diverse user community, few of whom place radiation observations at the top of their measurement list but, most of whom regard them as critical ancillary data. When these users are taken collectively, they constitute a large “community of practice” whose requirements need to be addressed. These include, but are not be limited to applications related to:

- Solar energy resource assessment.
- Architectural (daylighting, HVAC sizing, construction).
- Radiation model development/validation (satellite and ground-based).
- Climatology (characterization of the earth’s radiation budget).
- Agriculture (evapotranspiration).
- Biology / Medical applications.
- Materials science.

In response to a request by the WMO EC-LVII (parag. 3.3.2.6), AREP acting on behalf of CAS, CBS and CIMO organized a WMO Ad-Hoc Group Meeting on “Programmatic Gaps Related to the Global Radiation Network Served by the WRDC, MGO, Russia”, 7-8 June 2006 St. Petersburg Russia.

The ad-hoc Group made various recommendations that are reflected in tasks listed below. However it should be emphasized that implementation of these tasks is conditional upon appropriate resource allocation and the implementation of the first task below.

Goals

- Coordinate systematic global and regional monitoring of radiation balance components at GSRN stations.
- Improve submission of and access to data archived at the WRDC.
- Integrate surface-based and satellite measurements for the purpose of monitoring of trends.

Implementation Strategy

Task 8.1 Establish under appropriate leadership an inter-commission Scientific Advisory Group for Radiation with specific terms of reference and membership to address the programmatic gap in GSRN oversight identified by the ad-hoc inter-commission expert team.

(WMO, CAS, CIMO, CBS – 2008)

Task 8.2 Convene an expert workshop to identify the “community of practice” for WRDC data, products and services.

(SAG, Secretariat – 2009)

- Task 8.3 Work with the other GAW WDCs, GAWSIS, BSRN and the satellite community to define and implement user-friendly interfaces for the presentation of radiation data and results of analysis from WRDC.
(ET-WDC, Secretariat – ongoing)
- Task 8.4 Maintain close cooperation with and support of the WRC on the World Radiometric Reference (WRR) for monitoring of calibration procedures carried out on the global network.
(Secretariat – ongoing)
- Task 8.5 Ensure that all data submitted to the WRDC from the GSRN is accompanied by meta-data on traceability to the primary standard and that WRDC clearly flags data in WRDC as to whether or not this meta-data has been provided.
(WRDC, SAG – 2009, ongoing)
- Task 8.6 Analyze the WRDC data submitted from the Global Surface Radiation Network (GSRN) including BSRN to address the needs of users.
(WRDC – 2010, ongoing)
- Task 8.7 Update QA/QC procedures at the WRDC, based on historical data archive and using satellite information for particular site areas and especially during clear sky conditions.
(WRDC – 2010)
- Task 8.8 Ensure that the system of RCCs maintained by WMO Members is improved through support of the regional inter-comparisons that are missing in some developing countries.
(SAG, WWW/GOS – ongoing)
- Task 8.9 Review periodically and publish as a WMO technical document WRDC data management procedures/practices.
(WRDC, Secretariat – ongoing)

8.2 Meteorological Observations

| | |
|---------------------|---|
| Lead Responsibility | WMO-WWW |
| QA/SAC | Not established for GAW |
| CCL | Not established for GAW |
| WCC | Not established for GAW |
| DQO | Established by WMO-WWW |
| SOP | Established by WMO-WWW |
| Data Centre | The World Data Centre for Greenhouse Gases (WDCGG) accepts meteorological data from GAW stations. |

Current Status

Meteorological information, when combined with atmospheric composition data, is essential to understand processes such as

- Upwind, downwind and vertical transport of chemical compounds.
- Influence of convection, turbulence and clouds on atmospheric chemistry.
- Inter-actions and feedbacks between atmospheric thermodynamics and atmospheric chemistry.

Therefore, meteorological measurements are usually available from GAW stations and are routinely embedded as auxiliary parameters in the data files archived at WDCGG. However, such data sets are of a limited spatial and temporal nature and thus they are not satisfactory for advanced integration of meteorological and atmospheric chemistry information. Use of actual or

archived WMO Global Telecommunications System (GTS) meteorological observations provides more complete information on meteorological conditions that affect atmospheric chemistry. In addition, long-term archived objective analyses, re-analyses and forecasts from global atmospheric models, and GTS data available at several centres (e.g. NCAR, NCEP, ECMWF) are of particular importance for studying air chemistry processes. Evaluated from such meteorological data, some centres (e.g. DWD, NOAA) provide online web services for calculating forward and backward trajectories, today extensively used by many GAW research groups. The meteorological information within the GAW system becomes even more important in the forthcoming period in which integration of chemical data and numerical models represents one of the strategic goals of GAW.

Goals

- Enhance use of meteorological information for better specification and understanding of atmospheric chemistry processes.
- Support integration of atmospheric chemistry and meteorological data.
- Increase availability and accessibility of meteorological information.

Implementation Strategy

- Task 8.10 Promote data exchange and scientific cooperation between the atmospheric chemistry and meteorological community.
(Secretariat, WDCs – ongoing)
- Task 8.11 Support implementation of WMO policy regarding the international exchange of meteorological and related data and products, including relationships to commercial meteorological activities (Resolution 40, Cg-XII [*WMO*, 1995]).
(Secretariat, WDCs – ongoing)
- Task 8.12 Encourage developments of user-oriented tools for effective access to meteorological data bases (advanced graphics, web-based access, etc.).
(Secretariat – ongoing)
- Task 8.13 Improve discovery of and access to meteorological information from WDCGG and WRDC.
(WDCGG, WRDC – 2009)

8.3 Natural Radioactivity

| | |
|---------------------|---|
| Lead Responsibility | Not yet established |
| QA/SAC | Not yet established |
| CCL | Not yet established |
| WCC | Not yet established |
| DQO | Not yet established |
| SOP | Not yet established |
| Data Centre | For ⁸⁵ Kr and ²²² Rn: World Data Centre for Greenhouse Gases (WDCGG), JMA, Tokyo, Japan |

Current Status

The global distributions of the source/sink terms of the naturally occurring radionuclides (⁷Be, ¹⁰Be, ²¹⁰Pb, and ²²²Rn) and the anthropogenic radionuclides (⁸⁵Kr) are reasonably well known. ⁷Be and ¹⁰Be are produced by cosmic-ray interactions in the upper troposphere and the lower stratosphere. ²²²Rn is exhaled from the Earth's land surface as a result of uranium decay in soil. ²¹⁰Pb is produced in the lower troposphere from the decay of ²²²Rn. Most of the ⁸⁵Kr in the atmosphere is released during nuclear fuel reprocessing. Atoms of ⁷Be, ¹⁰Be and ²¹⁰Pb attach

themselves to submicron-size aerosol particles, and therefore, act as aerosol-borne tracers in the atmosphere. ^{222}Rn and ^{85}Kr , chemically and physically inert, act as noble gases in the atmosphere.

Because these source/sink distributions are reasonably well constrained, these radionuclides can be used to assess the characteristics of the large- and global-scale transport of gases and aerosols as depicted in General Circulation Models (GCMs). For example, high ^7Be concentrations with coincident low ^{210}Pb concentrations could indicate subsidence of air from upper altitudes, which might explain a simultaneous increase in ozone concentrations.

Similarly, enhanced ^{222}Rn concentrations at a coastal station could announce the arrival of air that had recently passed over land. Other interpretations of these tracers are possible, depending upon specific station characteristics. The $^{10}\text{Be}/^7\text{Be}$ ratio is an ideal indicator for studying the atmospheric exchange between the stratosphere and the troposphere. ^{222}Rn and its long lived decay product, ^{210}Pb , can also provide a means to assess the parameterisations in GCMs of the vertical transport and mixing processes in the troposphere of the GCMs. In addition, the large concentration difference of measured ^{222}Rn between continental and maritime air provides a further means to validate synoptic scale horizontal transport.

^{212}Pb , a decay product of ^{220}Rn (thoron) complements the air mass tracing capabilities of ^{222}Rn . Due to its shorter half-life (10.6 hours) it is useful at smaller temporal and spatial scales and can be effectively used to establish whether an air sample has had recent contact with land. Consequently, simultaneous measurements of radon (^{222}Rn) and ^{212}Pb provide an experimental discrimination between samples affected by distant and local interaction with land and may make it possible to estimate the distance of the pollution source from the monitoring station.

Concentrations of these natural and anthropogenic radionuclides should be monitored at GAW Global stations if they can aid the interpretation of meteorological processes occurring at the stations, especially as these processes affect concentrations of other atmospheric pollutants measured at the stations.

There are a number of GAW and non-GAW stations measuring some of the radioactive isotopes mentioned above. In 2003, WMO/GAW co-sponsored with the International Atomic Energy Association (IAEA) the first International Expert Meeting on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies at CNRS France [WMO, 2004a] to review the knowledge regarding sources and the state of routine global measurements. Two working groups made recommendations on how to advance knowledge of the sources of natural radionuclides and on the best approach to monitoring. This diverse community pledged to meet again at a meeting hosted by IAEA to review progress.

In parallel with these efforts, WMO has approached the office of the Comprehensive Test Ban Treaty Organization (CTBTO) and reached mutual agreement to develop mechanisms to exchange data on natural radionuclides observed at GAW and CTBTO network stations.

Goals

- Improve our ability to monitor and measure atmospheric radionuclides at GAW stations to better understand atmospheric chemistry observations and to improve the simulation of transport, vertical mixing and deposition processes in climate, weather and air quality models.
- With international partners, contribute to a global monitoring network for natural radionuclides that implements an end-to-end approach to observation and application.

Implementation Strategy

Task 8.14 Maintain and develop measurements of natural radionuclides in the GAW network using recommendations made at the 1st International Expert Workshop on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies, 3-5 June 2003, Gif sur Yvette, France [WMO, 2004a].

(Secretariat – ongoing)

- Task 8.15 Co-sponsor with IAEA the 2nd International Expert Workshop on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies to: (i) review progress on recommendations made in the first workshop, (ii) recommend a plan for developing measurement guidelines, data quality objectives and standard operating procedures for ²²²Rn measurements.
(Secretariat – 2008)
- Task 8.16 Encourage installation of surface air sampling systems for natural radionuclides recommended at the two Expert meetings (Task 1 and Task 2) at selected GAW sites.
(Secretariat – ongoing)
- Task 8.17 Review the status of radioactivity data collected at WDCGG, JMA, Japan (for gaseous ⁸⁵Kr and ²²²Rn); and at Environment Measurement Laboratory, USA (for aerosol-bound ⁷Be and ²¹⁰Pb) and recommend further action.
(Secretariat, WDCGG – 2009)

9 GAW URBAN RESEARCH METEOROLOGY AND ENVIRONMENT (GURME) PROJECT

Lead Responsibility Scientific Advisory Group for GURME (SAG GURME)

Current Status

The WMO GURME project is the GAW activity most closely focused on air quality.

WMO established GURME as a means to help enhance the capabilities of NMHSs to handle meteorological and related aspects of urban pollution and provides an international platform for cross-cutting urban air pollution activities. GURME is designed to do this through co-ordination and focussing of present activities, and initiation of selected new endeavours. GURME also collaborates with environmental agencies responsible for air quality measurements and management. GURME addresses the end-to-end aspects of air quality that link observational issues, data assimilation techniques, numerical models, dissemination methods, and capacity building required for developing countries to reap the full benefits of GURME.

GURME achievements for the period covered by the previous strategic plan included improved programme delivery through web-based techniques; establishment of links to EU projects, the Atmospheric Brown Cloud (ABC) project, and to IGAC megacity projects; development of guidelines for observations and forecasting; surveys to assess the nature of urban air quality activities within NMHSs and to determine the spectrum and need of air quality modelling/forecasting; establishment of GURME training material for a basic air quality forecasting course; and training courses in air quality modelling.

Goals

- Continue to address the end-to-end aspects of air quality that link observational issues, data assimilation techniques, numerical models, dissemination methods, and capacity building.
- Enhance the capabilities of NMHSs in providing urban-environmental forecasting and air quality services of high quality.
- Provide the technical basis for the calculation of cost efficient emission reductions to reach sustainable atmospheric composition.
- Provide with other WMO programmes, international organizations and environmental agencies an international platform for cross-cutting urban air pollution activities.
- Define necessary meteorological and air quality measurements, to better match the observational capabilities of GAW with the needs of chemical weather forecasting, and to stimulate the integration of observations and models.

- Provide NMHSs with easy access to information on measurement and modelling techniques.
- Promote a series of pilot projects in urban environment issues, showcase new technologies, and develop illustrative examples.
- Assist providers of air quality forecasting services in outreach and public information aspects of air quality, including developing more effective ways to serve user needs and to communicate to policy makers.

Implementation Strategy

The tasks identified for the planning period 2008 – 2015 are presented in Figure 5 and enumerated.

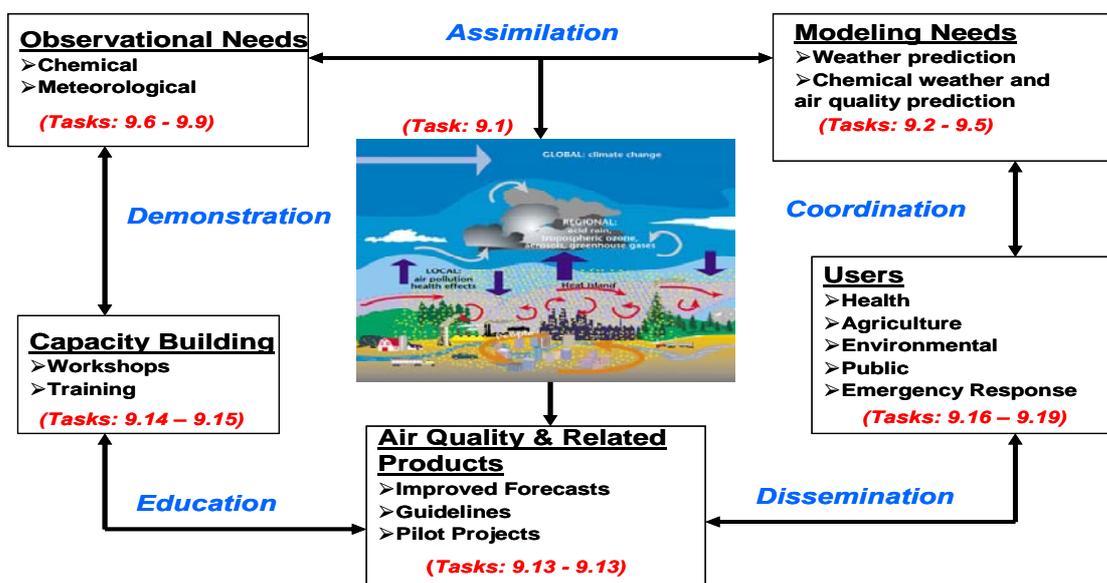


Figure 5: GURME tasks for the current planning period (2008 – 2015) and relation to the main elements and goals for GURME.

Task 9.1 Develop criteria for acceptance of GURME pilot projects.
(SAG GURME, Secretariat – 2009)

Modelling Needs

Task 9.2 Link, wherever appropriate, GURME activities to related/complementary activities within the international scientific community (e.g., megacity initiatives within IGAC, urbanization of meteorological models in the European Commission and COST studies).

(SAG GURME, Secretariat – 2008-2015)

Task 9.3 Actively participate and contribute to the new Task Force on Hemispheric Transport of Air Pollution (HTAP) under UNECE CLRTAP, which will provide additional avenues for interactions related to modelling and measurements on different scales.
(SAG GURME, Secretariat – 2009)

Task 9.4 Help improve air quality forecasts by documenting various performance metrics in use for evaluating air quality forecasts, and conduct workshops to share best practices and to explore new methods and metrics.

(SAG GURME, Secretariat – 2008-2015)

- Task 9.5 Initiate a model inter-comparison study to identify the primary sources of uncertainty in high resolution urban air quality models and identify those models most suitable, especially regarding on-line versus off-line model set-up.
(SAG GURME, Secretariat – 2010)

Observational Needs

- Task 9.6 Continue to document and provide guidance on the use of passive samplers by expanding the passive sampler content of GURME, giving examples of their use, conducting a workshop on regular and precision passive samplers, stimulating performance assessment and quality assurance activities and by linking users in developing countries to the experts.
(SAG GURME, Secretariat – 2008-2010)
- Task 9.7 Document and articulate ways in which satellite data can be applied to meet GURME objectives and organize workshops on this issue.
(SAG GURME, Secretariat – 2008-2014)
- Task 9.8 Provide advice and guidance to NMHSs on measurements in support of GURME activities, by developing a web-based resource that provides basic requirements and points to accessible relevant materials from various national Environmental Agencies' guidelines.
(SAG GURME, Secretariat – 2009)
- Task 9.9 Stimulate the advancement of chemical data assimilation as a means of increasing capabilities of air quality predictions. This will include activities focused both on research and operational elements, and will be accomplished through expert meetings, pilot projects, and sessions at conferences. These activities will be coordinated with other GAW SAGs, and will include both *in situ* and satellite observations.
(SAG GURME, Secretariat – 2008-15)

Air Quality & Related Products

- Task 9.10 Extend the existing GURME web site with information from the pilot projects, results from recent workshops, and training materials, and to better serve its role as a resource centre for countries involved in GURME.
(SAG GURME – 2008-2015)
- Task 9.11 Develop new and promote established GURME pilot projects to illustrate the spectrum of NMHSs urban-related activities and opportunities for co-operation with environmental agencies. Examples of new projects include an urban meteorology test-bed; improving air quality forecasting in Shanghai/Beijing; inter-comparison of chemical transport and air quality models; and application of inverse modelling for emissions inventory verification and improvement.
(SAG GURME, Secretariat – 2008-2013)
- Task 9.12 Link wherever appropriate into related/complementary activities within WMO by collaborating on a common topic and/or by collocating a project. Examples are issues related to aerosols, heat islands, fine scale meteorological forecasting (including that in support of emerging needs such as wind power forecasting), and urban climate monitoring within IPCC, CIMO, WWRP programmes.
(SAG GURME, Secretariat – 2009-2015)
- Task 9.13 Continue to promote GURME activities and accomplishments by organising GURME sessions and presentations in international conferences.
(SAG GURME, Secretariat – 2008 through 2015)

Capacity Building

- Task 9.14 Expand the activities of the GURME Training Team (GTT). This includes the further development and refinement of the training materials for the basic course in air quality

forecasting, the incorporation of additional case-studies from various regions, and the inclusion of these materials on the GURME website to facilitate their broad use in air quality forecasting training.

(SAG GURME, Secretariat – 2009-2015)

- Task 9.15 Conduct additional regional workshops focused on “Advanced air quality modelling” and “Capacity building on basic aspects of air quality forecasting”.
(SAG GURME, Secretariat – ongoing)

User Community

- Task 9.16 Foster and continue close co-operation with the urban health impacts community on topics such as climate change, and changes in air quality resulting from climate change. This will include efforts to coordinate sessions at relevant conferences.
(SAG GURME, Secretariat – ongoing)

- Task 9.17 Assist providers of air quality forecasting services in outreach and public information aspects of air quality by compiling best-practices and experiences and disseminating them through the GURME web, and by working more closely with forecast users, through the establishment of a users group and focused workshops.
(SAG GURME, Secretariat – 2013)

- Task 9.18 Expand the scope of activities and help NMHSs improve their urban air quality products and promote these activities to user groups in all related socioeconomic sectors including human-health (asthma and pollen) and agriculture. Activities should include continued development of guides of best practices focusing on, (i) experimental design of meteorological and air quality observations, (ii) effective ways to serve user needs and to communicate to policy makers, (iii) partnerships with key sectors including health through establishment of routine procedures of information-evaluation-feedback and re-orientation, (iv) capacity building.
(SAG GURME, Secretariat – 2012)

- Task 9.19 Contribute air quality forecasting techniques as an important element of multi-hazard early warning systems for integrated disaster risk management.
(SAG GURME, Secretariat – 2010-15)

9.1 Products and Services

Current Products and Services

- Survey of NMHSs’ needs and capabilities in urban air quality activities.
- GURME website as a resource for NMHSs and others involved in urban air quality issues.
- Provision of information on use of air quality forecasting models.
- Facilitation or initiation and expansion of urban meteorological and air quality activities through pilot projects.
- An international cross-cutting platform for connecting scientists, experts, and operational personnel between and within NMHSs, environmental agencies, municipal governments, international organizations and others involved in air quality issues.
- Support for developing country participants to relevant international conferences.
- Provision of expertise for improved air quality modelling.
- GURME air quality forecasting training course.
- Training courses in air quality modelling and use of satellite data in air quality.

Future Products and Services

- Definition of meteorological and air quality measurements needed for chemical weather forecasting.
- Expert guidelines on the use of precision passive samplers.
- Stimulation of the advancement of chemical data assimilation through expert meetings, pilot projects and sessions in conferences.
- Refined GURME air quality forecasting materials.
- Provision of information for outreach and public information aspects of air quality.
- Continued development of guides of best practices.
- Contribution of air quality forecasting techniques as an important element of multi-hazard early warning systems for disaster risk management.

10 OUTREACH

10.1 Communications

Current Status

To secure funding for the continued operation, maintenance and expansion of the GAW network and funding for the development of end products based on data from GAW, it is necessary to maintain and increase the visibility of the network and its products, and to strengthen the identification of individuals and organizations with their role in GAW. The WMO/GAW Secretariat facilitates and coordinates the dissemination of information on the network, its data and end products using print and electronic media as well as meetings, workshops and conferences, including the following:

- The GAW web site at WMO.
- The GAWSIS web site at Empa.
- The GAW Newsletter, distributed in print.
- The WMO Antarctic Ozone Bulletin, distributed electronically.
- The WMO Arctic Ozone Bulletin, distributed electronically.
- The WMO Greenhouse Gas Bulletin, distributed electronically and in print.
- The Quadrennial GAW Symposium, proceedings distributed in print and electronically.
- Technical publications in the GAW Research and Monitoring Report, and WMO Global Ozone Research and Monitoring Project Report series.
- The Ozone Research Managers' Meeting, organised every three years in cooperation with UNEP.

Some GAW partners share data and scientific results through station-specific or institution-specific web sites. Such web sites are very useful for the production of ozone bulletins and newsletters.

Goals

- Increase the visibility and credibility of GAW in the NHMSs, the scientific community and political decision makers.
- Improve the GAW web site at WMO so that it will be easier to navigate and find information and GAW related reports.

- Encourage more GAW partners to establish their own web sites with access to data and scientific results. Such web sites should also provide metadata and information.
- Further improve the GAW web site to include information on stations in collaborating networks, such as BSRN, SHADOZ, NDACC etc. and provide direct links to all of the WMO-GAW data centres.
- Expand the publication of WMO Bulletins, covering more topics than the current ozone and greenhouse gas bulletins.

Implementation Strategy

- Task 10.1 Continue to maintain and improve the existing products and services listed above
(Secretariat – ongoing)
- Task 10.2 Cooperate with Members, station personnel and during audits to update GAW web site.
(Secretariat, SAGs, WCCs – ongoing)
- Task 10.3 Improve the navigation, and include and maintain more links to web sites hosted by various GAW partners and individual GAW stations on the WMO-GAW website.
(Secretariat – ongoing)
- Task 10.4 Revive the GAW Newsletter and have it published in print and electronically with two issues per year.
(Secretariat – end of 2008 and then ongoing)
- Task 10.5 Continue the publication of bi-weekly WMO Antarctic Ozone Bulletins during the ozone hole season.
(Secretariat – ongoing)
- Task 10.6 Increase the frequency of the WMO Arctic Ozone Bulletin so that 2-3 issues are made each season rather than just one.
(Secretariat – spring 2009 and then ongoing)
- Task 10.7 Continue the annual publication of the WMO Greenhouse Gas Bulletin.
(Secretariat – ongoing)
- Task 10.8 Establish an annual WMO Bulletin on reactive gases, such as surface ozone, Nox, CO and VOCs.
(Secretariat – autumn of 2009 and then ongoing)
- Task 10.9 Establish an annual WMO Bulletin on aerosols, including sand and dust storms.
(Secretariat – late 2010 and then ongoing)
- Task 10.10 Establish a library/gallery of photographs, graphs and cartoons pertaining to the GAW network. This library/gallery should reside on the WMO GAW web site.
(Secretariat – late 2009 and then continuous expansion)
- Task 10.11 Establish a GAW-oriented session at the General Assembly of the European Geophysical and the American Geophysical Union.
(Secretariat – 2009, ongoing)

10.2 Capacity Building

Current Status

Atmospheric scientists are in limited supply, and this shortage is particularly acute in developing countries. **Training and education** are critical to the long-term success of the GAW programme, particularly within the developing countries that have committed to maintain and operate Global or Regional stations. In addition to the immediate need for training in the operational aspects of the GAW programme, there is a need to enhance the overall scientific capacity and further expand the scientific infrastructure in the host developing countries. Scientific capacity building requires a commitment of the host country to provide university trained scientists

who will remain in the GAW programme for many years to translate into action the GAW specific training they have received. One of the most challenging problems is to acquire sufficient funding to provide adequate education and training for GAW station personnel in developing countries.

The GAW Training and Education Centre (GAWTEC) at the Environmental Research Station 'Umweltforschungsstation Schneefernerhaus' (UFS), which also accommodates the high-alpine platform of the GAW Global Station Zugspitze/Hohenpeissenberg, has become an essential part of the capacity building efforts of the GAW programme. Funded by Germany, with in-kind contributions by Empa, NOAA and others, GAWTEC assists the QA/SAC Germany in training and education of station personnel from global and regional GAW stations by teaching measurement techniques and data analysis twice a year for about 10 trainees per session (two weeks). The courses are offered to technicians and junior scientists who work at GAW stations with instruments and data. With the efforts of GAWTEC, over 130 persons have been trained from 46 countries from all over the world. This has greatly enhanced the quality and availability of data.

The ozone sonde station in Nairobi (Kenya), the high-altitude station Mt. Kenya (Kenya), and the station Bukit Koto Tabang (Indonesia) are examples where **twinning** (in this case with MeteoSwiss and Empa) continues to help maintain the important equatorial measurement activity. Considerable training has taken place for three stations in Indonesia for aerosol measurements with the instruments acquired within the WMO/ESCAP project "Support to the Implementation of the Regional Haze Action Plan of ASEAN Member Countries".

Members of the SAG Aerosol have contributed in various ways to training and capacity building. Examples are the set-up of aerosol sampling units in Cape Point and Mt Waliguan by NOAA, the twinning of IfT Leipzig with Danum Valley and BEO Moussala, or the provision of sampling inlets for Beo Moussala and Monte Cimone based on the experience at the Jungfraujoch (all of which are sites frequently within clouds). Important training activities are also the numerous training courses (involving IfT and other SAG members) and inter-comparison workshops and audits performed by IfT.

Capacity building for ozone monitoring and research in developing countries and in countries with economies in transition comes from the general commitments anchored in the Vienna Convention. The Parties under the Vienna Convention established the Trust Fund for Research and Systematic Observations for funding activities consistent with the objectives of the Vienna Convention and the recommendations of the Ozone Research Managers' Meetings. Enhancement of the GAW ozone monitoring network in all continents and creation of local scientific communities contributing to the world ozone science are the main goals of the capacity building.

Personnel in countries hosting GAW ozone monitoring stations that use Dobson and Brewer spectrophotometers have participated in **workshops, international and local scientific meetings**, and instrument calibration. The Dobson inter-comparisons that are organised by WMO have been strongly supported by the National Oceanic and Atmospheric Administration (NOAA) Earth System Research Laboratory (ESRL) and have also provided many opportunities to teach the operators of Dobson spectrophotometers about ozone measurements and their importance. The Solar and Ozone Observatory of CHMI at Hradec Kralove (SOO-HK) organizes training for Dobson operators either at SOO-HK or at the stations. The Swiss Laboratories for Materials Testing and Research (Empa), the Institute for Atmospheric Environmental Research (IfU), NOAA (ESRL and Aeronomy Laboratory), MeteoSwiss, and Solar and Ozone Observatory (SOO-HK) of the Czech Hydrometeorological Institute, have all worked directly with capacity building of station personnel.

Many GAW stations are located in developing countries and countries with economies in transition. The instruments at these sites require **calibration and maintenance**, much of which is unavailable without international capability. The number of regional centres for research, calibration, and validation is insufficient, especially in developing countries. It is vitally important that sufficient resources are made available to maintain the current GAW network, and to expand it to uncovered areas, such as the tropics. Satellite measurements are very valuable but need to be checked against ground based observations to be qualified as data of sufficient quality for trend analyses and other applications, such as detection of ozone recovery. Hence, ground based measurements are needed in all regions of the world to validate the satellite observations. There is

a need for more modern technology in the tropics, throughout much of Africa, South America, parts of Asia, and in the territories of the former Soviet Union.

The Spanish Meteorological Institute hosts the Regional Brewer Calibration Centre for Europe (RBCC-E), officially nominated by WMO in November 2003. It consists of a triad of Brewer spectrophotometers. Together with the Brewer triad maintained at Environment Canada, Toronto this constitutes an international Brewer calibration system with quality assurance procedures similar to those of the Dobson network. In addition to serving the 50 Brewer spectrophotometers in Europe, the RBCC-E also takes care of stations in North Africa (Casablanca and Cairo). The first GAW regional Brewer inter-comparison for Europe was arranged by RBCC-E in Spain in September 2005 and a new inter-comparison is planned in 2007.

Many UV instrument inter-comparisons have also been organized enhancing the understanding and capabilities of the participating scientists.

Many stations that used to observe the thickness of the ozone layer with Dobson spectrophotometers have switched over to the more automatic Brewer spectrophotometer. After some years of overlapping measurements, the Dobson instruments are no longer needed at these sites and can be relocated to sites in developing countries. Such **instrument relocation** is a very cost effective way of transferring knowledge and observing capacity to developing countries since the instrument is obtained at no cost. However, there is a need for calibration, transport and training of the personnel at the site that receives such instruments. Recently, unused Dobson instruments have found new homes in Armenia, Botswana and Kenya. Currently, about ten Dobson/Brewer spectrophotometers are available for relocation. More might be available in the future. Candidates for receiving such instruments are: China, Mongolia, Russia and Vietnam. The cost for relocation is approx. USD 15,000 per instrument. This includes training of personnel to operate the instruments. Funds for relocation, maintenance, calibration and purchase of new instruments are lacking. To modernise and fill the gaps in the global network, there is a need to deploy 2-4 new instruments per year over the next several years. Over the next ten years this will cost approx. USD 4 million.

The **WMO/UNEP Scientific Assessments of Ozone Depletion** constitutes the most authoritative overview of the stratospheric ozone problem that is available. The authors who write these assessments and the reviewers are almost exclusively scientists from the developed countries. To increase the awareness of the importance of compliance with the Montreal Protocol, it is of vital importance that each Party to the Protocol has resident expertise in ozone matters. This can be obtained through transfer of knowledge from the industrialised world to the developing countries. One way to accomplish this is through the establishment of monitoring programmes that will produce observational data of value to the assessment process. Researchers from developing countries should be encouraged to take part in analysis of data and scientific publications where their data is used. Assistance to evaluation of historical data series of ozone observations and presentation of results can be a part of this knowledge transfer. Many developing countries are located in the tropics, and this is also an area of the globe where there is a lack of observations.

Goals

- Conduct GAW training and education activities in developing countries for “start-up” training and beyond including workshops, station audits/visits, intensive training at the GAW training and calibration centres, and participation in international scientific meetings appropriate for the individual country’s GAW scientific programme.
- Promote twinning relationships between station personnel in developing countries and established atmospheric scientists, who may wish to collaborate in the measurement programme at the station and use of GAW station data for research.
- Building up regional Dobson and Brewer calibration centres.

Implementation Strategy

- Task 10.12 Organise and support training and education workshops related to the GAW core measurement parameters.
(Secretariat, QA/SAC, SAGs – ongoing)
- Task 10.13 Identify and provide training through international scientific meetings, and workshops to appropriate station personnel.
(All GAW bodies – ongoing)
- Task 10.14 Promote performance of GAW measurement networks by encouraging GAW global station managers to participate in appropriate GAW training courses, meetings and workshops.
(Secretariat, QA/SACs – ongoing)
- Task 10.15 Encourage twinning partnerships of developing GAW measurement programmes with established GAW facilities, laboratories and stations, to develop the capacity for sustained quality-assured measurements and effective use and publication of data.
(Secretariat, SAGs, QA/SACs – ongoing)
- Task 10.16 Build capacity for urban air quality forecasting and management by organizing expert and training workshops and through pilot projects in selected urban regions.
(SAG GURME, Secretariat – ongoing)
- Task 10.17 Publish guidelines for the different GAW measurement parameters.
(JSSC OPAG-EPAC, Secretariat, SAGs – ongoing)
- Task 10.18 Seize all opportunities to conduct on-site audits, calibrations, comparisons and training activities.
(All GAW bodies – ongoing)

10.3 Products and Services

Current Products and Services

- A number of web sites providing and cross-linking GAW-related information.
- Printed and electronic newsletter and GAW-related bulletins (Ozone, GHG).
- Organisation of meetings providing platforms for scientific/technical and personal exchange.
- Publication of proceedings of symposia, conferences, workshops.
- Lobbying at the management level of organizations, promoting GAW-relevant issues.
- Hands-on training and sharing of technical expertise.
- Definition and maintenance of reference standards for global atmospheric monitoring.
- Calibration of instrumentation.

Future Products and Services

- Improved web sites, increasing the visibility of the GAW programme and GAW partners.
- More frequent publication of newsletters and bulletins.
- More direct representation/participation of WMO/GAW in international science projects.
- A more comprehensive set of guidelines and training material.
- Regular presence at international science/technical meetings, providing a platform for the presentation of GAW-related research.

11 RESOURCES

Current Status

Resources for GAW are currently available from the following sources:

- Regular budget of WMO for GAW, covering costs for the Secretariat staff, external consultants/experts working for GAW, selected calibrations, meetings, travelling costs, general services (reports, computer and transmission facilities, etc.).
- Special WMO Trust Funds maintained by Members, other external agencies or Parties to Conventions that are dedicated to specific GAW activities, e.g., maintenance of ozone soundings at Nairobi Kenya; calibration and maintenance of Brewer total ozone spectrophotometers in developing countries.
- External financial funding of specific GAW facilities by Member countries or other organizations. This constitutes in-kind support for GAW. Examples include national support for Central Calibration Laboratories, Calibration Centres, national networks and World Data Centres.
- Regular budget of WMO for Voluntary Co-operation Programme (VCP), specially used for training and education funding.

An overview of resources available for 2008-2012 is presented in the budget proposal for the WMO fifteenth financial period [WMO, 2007a]. GAW is implemented in accordance with the principle that all activities in the territories of individual countries are within the responsibility of the countries themselves and should be borne by national resources. When a Member agrees to participate in GAW, full responsibility of any activity stays with the Member. WMO cannot, for example, cover the costs of long-term maintenance of GAW stations and facilities. Nevertheless, many countries, mostly in data sparse areas, require outside support to start, sustain or improve participation in GAW. It is important to provide the support for such sites if the network is to be truly global. In recognition of this, WMO has over the years tried to provide funds to developing countries if available through the funding sources listed above for calibration and training, maintenance, spare parts and consultant services. WMO has encouraged Members to include GAW projects in their UNDP national programmes, and to enter "twinning" arrangements wherein, on a bilateral basis, a laboratory, institute or individual scientist in an industrialised country undertakes to sponsor a station or measurement parameter in a participating developing country. The Secretary-General is authorised to seek extra-budgetary funding for implementation of such projects.

Funding needs, especially for capacity building, continue to exceed the resources available. Substantial additional funds required to provide instruments, spare parts, and expert services, central calibration and fellowship for training are essential to the future development of GAW.

Goals

- To provide regular overviews of costs and available resources and to introduce financial feasibility in the priority setting and planning procedures of GAW.
- To make additional funds available as soon as possible. To assist NMHSs in obtaining financial support from national funds by providing, when requested, the relevant national governments with information on the importance of the GAW programmes both for the national and international communities.

Implementation Strategy

Task 11.1 To review annually GAW costs, for:

- expert advisory, training and education purposes;
- operational services and maintenance of GAW .

(Secretariat – beginning of each calendar year)

- Task 11.2 To continually review the funding needs of the programme and identify:
- how much is needed to achieve specific GAW goals;
 - how WMO Member countries can help meet these needs.
- (Secretariat – ongoing)
- Task 11.3 To publicize a list of programme needs for which resources are required and to use all avenues to recruit sponsors, as NMHSs, or commercial institutions, etc.
- (Secretariat, JSSC OPAG-EPAC – annually)

12 OUTLOOK

The goals specified in this strategic plan provide guidelines for developing GAW and its components over the next eight years (2008-2015). They are the basis for establishing specific working plans and programmes for each component. Implementation steps are given only for 2008 – 2011, i.e. for the first half of the period. For the remainder of the planning period, they will be developed in 2011 after assessing progress made.

The long-term plan of WMO requires CAS to review developments in AREP and to coordinate the operation and further development of GAW. Since CAS XIV [WMO, 2006] the OPAG-EPAC JSSC has been responsible for the development and approval of GAW's strategic planning. To control and keep on track the GAW programme, it is foreseen that during the second half of 2010 a review process of the programme status will be started, involving the IGOS partners concerned (i.e., the IGACO implementation group, consisting of representatives of major partners together with several scientists prominent in the field.)

The coordination of joint activities of GAW with other relevant international and national organizations and programmes will continue to be very important. As all other WMO programmes, GAW is based on voluntary contributions by the Member countries. WMO can encourage rather than require its Members to make regular contributions to the programme. Therefore, all institutions and individuals engaged in GAW operations – station managers, WDCs, SAGs, QA/SACs, CCs – are called upon to actively participate and contribute to increasing the visibility of WMO as the leading organization in the field of the atmospheric environment.

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OVERVIEW OF RESPONSIBLE BODIES AND ASSIGNED TASKS

| Responsible Body | | Tasks Assigned (bold: lead responsibility) |
|------------------|------------------------------|---|
| WMO | | 8.1 ; 8.8 |
| CAS OPAG-EPAC | | Task 3.1; 3.9 ; 5.14; 6.2 ; 6.3 ; 6.4 ; 6.5 ; 6.7 ; 6.8 ; 6.11 ; 6.12 ; 10.17 ; 11.3 |
| JSSC OPAG-EPAC | | Task 2.8 ; Task 2.10 ; Task 2.12 ; Task 2.14 ; Task 2.24 ; 3.12 ; 3.14 ; 3.15 ; 3.17 ; 6.1 |
| NMHSs | | 3.1 ; 3.3; 3.4 |
| SAGs | All | 2.9 ; 2.13 ; 2.14; 2.16; 3.2; 3.4; 3.5; 3.6; 3.8; 3.11 ; 3.14; 3.19 ; 3.21; 4.3 ; 4.4 ; 4.5 ; 4.6; 4.9; 4.10; 4.11 ; 4.15 ; 5.4 ; 5.15; 10.2; 10.12; 10.15; 10.17 |
| | Aerosol | 3.18; 7.81 ; 7.82 ; 7.83 ; 7.84; 7.85; 7.86; 7.87; 7.88; 7.89 ; 7.90 |
| | GHG | 3.18; 7.16; 7.17 ; 7.18; 7.19 ; 7.20 ; 7.21; 7.22 ; 7.23 ; 7.25; 7.26 ; 7.27 ; 7.28 ; 7.30 ; 7.31 ; 7.32 ; 7.33 ; 7.35; 7.36 |
| | Ozone | 3.19; 3.20; 7.1 ; 7.2 ; 7.3 ; 7.4 ; 7.6 ; 7.7 ; 7.8 ; 7.9 ; 7.10; 7.12 ; 7.13 ; 7.14 |
| | PC | 7.62 ; 7.63 ; 7.64 ; 7.66 ; 7.67 |
| | RG | 3.18; 7.37 ; 7.39; 7.41; 7.43 ; 7.44 ; 7.45; 7.46; 7.47; 7.48 ; 7.49; 7.50; 7.51; 7.54; 7.55; 7.56; 7.57; 7.58 ; 7.61 |
| | UV | 3.19; 3.20; 7.71; 7.72 ; 7.73 ; 7.74; 7.75 ; 7.76 ; 7.77 ; 7.78 ; 7.79 |
| | GURME | 9.1 ; 9.2 ; 9.3 ; 9.4 ; 9.5 ; 9.6 ; 9.7 ; 9.8 ; 9.9 ; 9.10 ; 9.11 ; 9.12 ; 9.13 ; 9.14 ; 9.15 ; 9.16 ; 9.17 ; 9.18 ; 9.19 ; 10.16 |
| SolRad | 8.2 ; 8.5; 8.8 | |
| QA/SACs | | Task 2.13; Task 2.16; 3.5; 3.6; 4.3; 4.4; 4.5; 4.6; 4.7; 4.8; 4.9 ; 4.10; 4.12 ; 4.13; 4.14; 5.2; 5.4; 5.6 ; 5.8; 5.9; 5.12; 5.13; 7.8; 7.16; 7.21 ; 7.26; 7.27; 7.30; 7.31; 7.40; 7.43; 7.44; 7.60 ; 7.61; 7.65 ; 7.68 ; 7.69 ; 7.70 ; 10.12; 10.14; 10.15 |
| CCL | | 7.16 ; 7.26; 7.30 |
| WCCs | | Task 2.16; 4.5; 4.7; 4.12; 7.9; 7.30; 7.31; 7.40 ; 7.43; 7.44; 7.80 ; 7.81; 7.83; 7.86; 10.2 |
| RCCs | | Task 2.16; 7.38 |
| WDCs | ET-GAW or All | Task 2.13; Task 2.16; 4.9; 4.10 ; 4.13; 5.1 ; 5.2 ; 5.4; 5.5 ; 5.6; 5.7 ; 5.8 ; 5.9 ; 5.10 ; 5.12 ; 5.13 ; 5.14; 5.15; 8.3 ; 8.11; 8.12 |
| | WDCGG | 3.10 ; 5.3; 5.11 ; 7.21; 7.24 ; 7.25 ; 7.40; 7.41; 7.42; 7.44; 7.52; 8.13 ; 8.17 |
| | WOUDC | 5.3 ; 7.4; 7.6; 7.7; 7.10 ; 7.11 ; 7.74 ; 7.75 |
| | WRDC | 8.5 ; 8.6 ; 8.7 ; 8.9 ; 8.13 |
| | WDC-RSAT | 7.5 |
| ET-NRT CDT | | 5.14 ; 6.1; 6.6 |
| Secretariat | | Task 2.1 ; Task 2.2 ; Task 2.3 ; Task 2.4 ; Task 2.5 ; Task 2.6 ; Task 2.7 ; Task 2.8; Task 2.9; Task 2.10; Task 2.11 ; Task 2.12; Task 2.14; Task 2.15 ; Task 2.16 ; Task 2.17 ; Task 2.18 ; Task 2.19 ; Task 2.20 ; Task 2.21 ; Task 2.22 ; Task 2.23 ; Task 2.24; Task 2.25 ; Task 2.26 ; Task 3.1; 3.2 ; 3.3 ; 3.4 ; 3.5 ; 3.6 ; 3.7 ; 3.8 ; 3.9; 3.11; 3.12; 3.13 ; 3.14; 3.15; 3.20 ; 3.21 ; 4.1 ; 4.3; 4.4; 4.6 ; 4.7 ; 4.8 ; 4.13 ; 4.14 ; 4.15; 5.2; 5.3; 5.7; 5.8; 5.10; 5.15 ; 6.1; 6.5; 6.6; 6.7; 6.8; 6.9 ; 6.10; 6.11; 6.12; 7.23; 7.35 ; 7.39 ; 7.41 ; 7.42 ; 7.45 ; 7.46 ; 7.47 ; 7.49 ; 7.50 ; 7.51 ; 7.52 ; 7.54 ; 7.55 ; 7.56 ; 7.57 ; 7.59 ; 7.67 ; 7.71 ; 7.76; 7.77; 7.78; 7.79; 7.84 ; 7.86 ; 7.87 ; 7.88 ; 7.89; 7.90 ; 8.2; 8.3; 8.4 ; 8.9; 8.10 ; 8.11 ; 8.12 ; 8.14 ; 8.15 ; 8.16 ; 8.17 ; 9.1; 9.2; 9.3; 9.4; 9.5; 9.6; 9.7; 9.8; 9.9; 9.11; 9.12; 9.13; 9.14; 9.15; 9.16; 9.17; 9.18; 9.19; 10.1 ; 10.2 ; 10.3 ; 10.4 ; 10.5 ; 10.6 ; 10.7 ; 10.8 ; 10.9 ; 10.10 ; 10.11 ; 10.12 ; 10.14 ; 10.15 ; 10.16; 10.17; 11.1 ; 11.2 ; 11.3 |

| Responsible Body | Tasks Assigned (bold: lead responsibility) |
|--|---|
| GAW partners | 3.16; 3.17; 7.29; 7.36; 10.13; 10.18 |
| WMO Space Programme | 3.16; 3.17 ; 5.14 |
| CEOS | 3.16; 3.17 |
| IGACO Offices | 3.16; 3.17; 7.14 ; 7.76 |
| CO ₂ Experts | 7.15 ; 7.16; 7.18 |
| GAW rep in ICTT-QMF | 4.2 |
| WMO/WIS | 5.14 |
| NOAA/ESRL | 7.34 |
| Regional (Precipitation) Data Centres | 7.64 |

ANNEX: ACRONYMS AND ABBREVIATIONS

| | |
|-----------|--|
| ABC | Atmospheric Brown Cloud |
| ACCENT | Atmospheric Composition Change European Network of Excellence |
| AGAGE | Advanced Global Atmospheric Gases Experiment |
| AGGI | Annual Greenhouse Gas Index |
| AGU | American Geophysical Union |
| AIRS | Advanced InfraRed Sounder (instrument on NASA's Aqua satellite) |
| AMAP | Arctic Monitoring and Assessment Programme |
| AMDAR | Aircraft Meteorological Data Relay Programme |
| AOD | Aerosol Optical Depth |
| AREP | Atmospheric Research and Environment Programme |
| ASEAN | Association of South-East Asian Nations |
| ASRC-SUNY | Atmospheric Sciences Research Centre, State University of New York (SUNY), Albany NY, USA |
| BAPMoN | Background Air Pollution Monitoring Network |
| BIPM | Bureau of International Weights and Measures |
| BoM | Bureau of Meteorology, Melbourne, Australia |
| BSRN | Baseline Surface Radiation Network |
| CACGP | Commission on Atmospheric Chemistry and Global Pollution |
| CAPMoN | Canadian Air and Precipitation Monitoring Network |
| CARIBIC | Civil Aircraft for the Regular Investigation of the atmosphere Based on an Instrument Container |
| CAS | Commission for Atmospheric Sciences |
| CAS WG | CAS Working Group on Environmental Pollution and Atmospheric Chemistry (replaced by the JSSC OPAG-EPAC) |
| CBS | Commission for Basic Systems |
| CCL | Central Calibration Laboratory, in most cases host of the designated WMO standard for a particular variable |
| CEOPs | Coordinated Enhanced Observing Periods |
| CEOS | Committee on Earth Observation Satellites |
| CFC | Chlorofluorocarbon |
| CG | Congress |
| CIMO | Commission for Instruments and Methods of Observation |
| CIPM | Committee for International Weights and Measures |
| CLIVAR | Climate Variability and Predictability |
| CLRTAP | Convention on Long-Range Transboundary Air Pollution |
| CMAR | CSIRO Marine and Atmospheric Research |
| CMDL | Climate Monitoring and Diagnostic Laboratory, NOAA (now Global Monitoring Division of the Earth System Research Laboratory, NOAA ESRL) |
| COST | European Cooperation in the field of Scientific and Technical Research |
| CSIRO | Commonwealth Scientific and Industrial Research Organisation |
| DA | Data Assimilation |
| DEBITS | Deposition of Biogeochemically Important Trace Species |
| DLR | German Aerospace Centre, Oberpfaffenhofen, Wessling, Germany |
| DOAS | Differential Optical Absorption Spectroscopy |

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| DOAS/SAOZ | Differential Optical Absorption Spectroscopy/Système d'Analyse par Observations Zénithales |
| DQO | Data Quality Objective |
| EANET | Acid Deposition Monitoring Network in East Asia |
| EARLINET | European Aerosol Research Lidar Network to Establish an Aerosol Climatology |
| EC | Executive Council |
| EC | European Commission |
| ECC | Electro Chemical Sonde |
| ECD | Electron Capture Detection |
| ECMWF | European Centre of Medium Range Weather Forecast |
| ECVs | Essential Climate Variables |
| EEA | European Environment Agency |
| EGU | European Geosciences Union |
| EMEP | Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe |
| EML | Environmental Measurements Laboratory, New York, USA |
| Empa | Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland |
| EPAC | Environmental Pollution and Atmospheric Chemistry |
| ERI | European Research Infrastructure |
| ESA | European Space Agency |
| ESRL | Earth System Research Laboratory, NOAA |
| ET-NRT CDT | Expert Team on Near-real-time Chemical Data Transfer |
| ET-WDC | Expert Team World Data Centre |
| EU | European Union |
| EUROHYDROS | European Network for Atmospheric Hydrogen observations and studies |
| EUSAAR | European Supersites for Atmospheric Aerosol Research |
| EUVDB | European UV Data Base |
| FLUXNET | International network measuring terrestrial carbon, water and energy fluxes |
| FMI | Finnish Meteorological Institute |
| FTIR | Fourier Transform Infrared (Spectroscopy) |
| FUMAPEX | Integrated Systems for Forecasting Urban Meteorology, Air Pollution and Population Exposure |
| FZ-Jülich | Forschungszentrum Jülich, Germany |
| GALION | Gaw Aerosol Lidar Observation Network |
| GAW | Global Atmosphere Watch |
| GAW-CCL | GAW Central Calibration Laboratory |
| GAWSIS | GAW Station Information System |
| GAWTEC | GAW Training and Education Centre |
| GC | Gas Chromatography |
| GCOS | Global Climate Observing System |
| GEMS | Global and regional Earth-system Monitoring using Satellite and <i>in situ</i> data |
| GEO | Group on Earth Observations |
| GEOMON | Global Earth Observation and monitoring |
| GEOSS | Global Earth Observation System of Systems |
| GESAMP | Joint Group of Experts on the Scientific Aspects of Marine Environmental |

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| | Protection |
| GHG | Greenhouse Gas |
| GLOBEC | Global Ocean Ecosystem Dynamics |
| GMES | Global Monitoring for Environment and Security |
| GOME | Global Ozone Monitoring Experiment |
| GOME2 | Global Ozone Monitoring Experiment 2 |
| GPCP | Global Precipitation Chemistry Programme |
| GSP | GAW Strategic Plan |
| GSRN | Global Surface Radiation Network |
| GTS | Global Telecommunication System |
| GTT | GURME Training Team |
| GURME | GAW Urban Research Meteorology and Environment project |
| HCFC | Hydrochlorofluorocarbons |
| HFCs | Hydrofluorocompounds |
| HTAP | Hemispheric Transport of Air Pollution |
| IADV | Interactive Data Visualization |
| IAEA | International Atomic Energy Agency |
| IAGOS-MOZAIC | Integration of routine Aircraft Observations into a Global Observing System |
| IAPSAG | International Aerosol Precipitation Science Assessment Group |
| ICTT QMF | Inter-Commission Task Team on Quality Management Framework |
| IFT | Institute for Tropospheric Research, Leipzig, Germany |
| ICSU | International Council for Science |
| IGAC | International Global Atmospheric Chemistry Project |
| IGACO | Integrated Global Atmospheric Chemistry Observations |
| IGOS | Integrated Global Observing Strategy |
| IGBP | International Geosphere-Biosphere Programme |
| IHALACE | International Halocarbon Intercomparison Experiment |
| iLEAPS | Integrated Land Ecosystem – Atmosphere Processes Study |
| IM | Inverse Modelling |
| IMBER | Integrated Marine Biogeochemistry and Ecosystem Research |
| IMK-IFU | Institut für Meteorologie und Klimaforschung-Fraunhofer Institut für Atmosphärische Umweltforschung, Garmisch-Partenkirchen, Germany |
| IMPROVE | Interagency Monitoring of Protected Visual Environments |
| IOC | Intergovernmental Oceanographic Commission |
| IPCC | Intergovernmental Panel on Climate Change |
| IPET-MI | Inter-Programme Expert Team on Metadata Implementation |
| IRC | International Radiation Commission |
| ISAP | International Science Advisory Panel |
| ISO | International Organization for Standardization |
| ISWS | Illinois State Water Survey |
| IUGG | International Union of Geodesy and Geophysics |
| IUPAC | International Union of Pure and Applied Chemistry |
| IZO | Izaña Observatory, Tenerife, Spain |
| JMA | Japan Meteorological Agency |
| JRC | Joint Research Centre of the European Commission, Ispra, Italy |
| JSSC | Joint Scientific Steering Committee |

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| JSSC OPAG-EPAC | Joint Scientific Steering Committee of the Open Area Programme Group on Environmental Pollution and Atmospheric Chemistry |
| LIDAR | Light Detection And Ranging |
| MC | Methyl Chloroform |
| MGO | Main Geophysical Observatory, St Petersburg, Russian Federation |
| MOHp | Meteorologisches Observatorium Hohenpeissenberg, Germany |
| MOPITT | Measurements Of Pollution In The Troposphere |
| MOZAIC | Measurement of Ozone by Airbus In-service airCRAFT |
| NADP | National Atmospheric Deposition Programme (in the United States of America) |
| NARSTO | North American Research Strategy for Tropospheric Ozone |
| NCEP | National Centres for Environmental Prediction |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| NH | Northern Hemisphere |
| NILU | Norwegian Institute for Air Research |
| NIST | National Institute of Standards and Technology, Gaithersburg MD, USA |
| NMHS | National Meteorological and Hydrological Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NSF | National Science Foundation |
| NRT | Near-real-time, specifying observations 'not older than 1-2 hours that can be incorporated into the data assimilation schemes of weather or air quality forecast models' |
| NWP | Numerical Weather Prediction |
| OCBA | Observatorio Central Buenos Aires, Argentina |
| OCO | Orbiting Carbon Observatory |
| OH | Hydroxyl Radical |
| OMI | Ozone Monitoring Instruments |
| OMPS | Ozone Mapping and Profiler Suite |
| OPAG | Open Programme Area Group |
| PAHs | Polycyclic Aromatic Hydrocarbons |
| PC | Precipitation Chemistry |
| PCBs | Polychlorinated biphenyls |
| PFCs | Perfluorocompounds |
| PFR | Precision filter radiometer |
| PM | Particulate matter |
| PMOD/WRC | Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre |
| POPs | Persistent organic pollutants |
| QA | Quality Assurance |
| QA/QC | Quality Assurance/Quality Control |
| QA/SAC | Quality Assurance/Science Activity Centre |
| QASUME | Quality Assurance of Spectral Measurements in Europe |
| QMF | Quality Management Framework |
| QMS | Quality Management System |
| RA | Regional Association |
| RCC | Regional Calibration Centre |
| RG | Reactive Gas |

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| SAG | Scientific Advisory Group |
| SAWS | South African Weather Service, Pretoria, South Africa |
| SBUV | Solar Backscatter Ultraviolet Instrument |
| SCIAMACHY | Scanning Imaging Absorption SpectroMeter for Atmospheric ChartographY |
| SCOUT-O3 | Stratospheric-ClimatE links with emphasis On the Upper Troposphere and lower stratosphere |
| SH | Southern Hemisphere |
| SHADOZ | Southern Hemisphere Additional Ozonesondes programme |
| SMN | Servicio Meteorologico Nacional, Argentina |
| SOLAS | Surface Ocean – Lower Atmosphere Study |
| SOO-HK | Solar and Ozone Observatory, Czech Hydrometeorological Institute, Hradec Kralove |
| SOOP | Ship-of-Opportunity Programme, a joint IOC-WMO programme |
| SOPs | Standard Operating Procedures |
| SPARC | Stratospheric Processes and Their Role in Climate |
| SRRB | Surface Radiation Research Branch of NOAA's Air Resources Laboratory (now part of NOAA ESRL) |
| STE | Stratosphere/Troposphere Exchange |
| SUNY | State University of New York |
| TCCON | Total Column Carbon Observing Network |
| TF HTAP | Task Force on Hemispheric Transport of Air Pollution |
| TOMS | Total Ozone Mapping Spectrometer |
| UBA | Umweltbundesamt/The Federal Environmental Agency, Germany |
| UFS | Umweltforschungsstation Schneefernerhaus |
| UNDP | United Nations Development Programme |
| UNECE | United Nations Economic Commission for Europe |
| UNECE-LRTAP | United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollution |
| UNEP | United Nations Environment Programme |
| UNESCAP | United Nations Economic and Social Commission for Asia and the Pacific |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UV | Ultraviolet Radiation |
| VOCs | Volatile Organic Compounds |
| VOS | Voluntary Observing Ship |
| WCC | World Calibration Centre |
| WCCAC | World Calibration Centre for Aerosol Chemistry |
| WCCAP | World Calibration Centre for Aerosol Physics |
| WCP | World Climate Programme |
| WCRP | World Climate Research Programme |
| WDC | World Data Centre |
| WDCA | World Data Centre for Aerosols |
| WDCGG | World Data Centre for Greenhouse Gases |
| WDCPC | World Data Centre for Precipitation Chemistry |
| WDC-RSAT | World Data Centre for Remote Sensing of the Atmosphere |
| WHO | World Health Organization |
| WIDAC | World Integrated Data Archive Centre |
| WIGOS | WMO Integrated Global Observing System |

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| WIS | WMO Information System |
| WMO | World Meteorological Organization |
| WORCC | World Optical Depth Research and Calibration Centre |
| WOUDC | World Ozone and UV Data Centre |
| WRC | World Radiation Centre |
| WRDC | World Radiation Data Centre, St Petersburg, Russia |
| WWRP | World Weather Research Programme |
| WWW | World Weather Watch Programme |

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51. Report of the NBS/WMO Expert Meeting on Atmospheric CO₂ Measurement Techniques, Gaithersburg, USA, 15-17 June 1987. December 1987.
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56. Report of the First Session of the Executive Council Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, Hilo, Hawaii, 27-31 March 1988. June 1988.
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81. Report of the Second Meeting of Experts to Assess the Response to and Atmospheric Effects of the Kuwait Oil Fires, Geneva, Switzerland, 25-29 May 1992 (WMO TD No. 512).
82. Global Atmospheric Background Monitoring for Selected Environmental Parameters BAPMoN Data for 1991, Volume I: Atmospheric Aerosol Optical Depth (WMO TD No. 518).
83. Report on the Global Precipitation Chemistry Programme of BAPMoN (WMO TD No. 526).
84. Provisional Daily Atmospheric Carbon Dioxide Concentrations as measured at GAW-BAPMoN sites for the year 1991 (WMO TD No. 543).
85. Chemical Analysis of Precipitation for GAW: Laboratory Analytical Methods and Sample Collection Standards by Dr Jaroslav Santroch (WMO TD No. 550).
86. The Global Atmosphere Watch Guide, 1993 (WMO TD No. 553).
87. Report of the Third Session of EC Panel/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, Geneva, 8-11 March 1993 (WMO TD No. 555).
88. Report of the Seventh WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques, Rome, Italy, 7-10 September 1993, (edited by Graeme I. Pearman and James T. Peterson) (WMO TD No. 669).
89. 4th International Conference on CO₂ (Carqueiranne, France, 13-17 September 1993) (WMO TD No. 561).
90. Global Atmospheric Background Monitoring for Selected Environmental Parameters GAW Data for 1992, Volume I: Atmospheric Aerosol Optical Depth (WMO TD No. 562).
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 to 8 October 1993 (WMO TD No. 563).
92. Report of the Second WMO Meeting of Experts on the Quality Assurance/Science Activity Centres of the Global Atmosphere Watch, Garmisch-Partenkirchen, 7-11 December 1992 (WMO TD No. 580).
93. Report of the Third WMO Meeting of Experts on the Quality Assurance/Science Activity Centres of the Global Atmosphere Watch, Garmisch-Partenkirchen, 5-9 July 1993 (WMO TD No. 581).
94. Report on the Measurements of Atmospheric Turbidity in BAPMoN (WMO TD No. 603).
95. Report of the WMO Meeting of Experts on UV-B Measurements, Data Quality and Standardization of UV Indices, Les Diablerets, Switzerland, 25-28 July 1994 (WMO TD No. 625).
96. Global Atmospheric Background Monitoring for Selected Environmental Parameters WMO GAW Data for 1993, Volume I: Atmospheric Aerosol Optical Depth.
97. Quality Assurance Project Plan (QAPjP) for Continuous Ground Based Ozone Measurements (WMO TD No. 634).

98. Report of the WMO Meeting of Experts on Global Carbon Monoxide Measurements, Boulder, USA, 7-11 February 1994 (WMO TD No. 645).
99. Status of the WMO Global Atmosphere Watch Programme as at 31 December 1993 (WMO TD No. 636).
100. Report of the Workshop on UV-B for the Americas, Buenos Aires, Argentina, 22-26 August 1994.
101. Report of the WMO Workshop on the Measurement of Atmospheric Optical Depth and Turbidity, Silver Spring, USA, 6-10 December 1993, (edited by Bruce Hicks) (WMO TD No. 659).
102. Report of the Workshop on Precipitation Chemistry Laboratory Techniques, Hradec Kralove, Czech Republic, 17-21 October 1994 (WMO TD No. 658).
103. Report of the Meeting of Experts on the WMO World Data Centres, Toronto, Canada, 17 - 18 February 1995, (prepared by Edward Hare) (WMO TD No. 679).
104. Report of the Fourth WMO Meeting of Experts on the Quality Assurance/Science Activity Centres (QA/SACs) of the Global Atmosphere Watch, jointly held with the First Meeting of the Coordinating Committees of IGAC-GLONET and IGAC-ACE, Garmisch-Partenkirchen, Germany, 13 to 17 March 1995 (WMO TD No. 689).
105. Report of the Fourth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Garmisch, Germany, 6-11 March 1995) (WMO TD No. 718).
106. Report of the Global Acid Deposition Assessment (edited by D.M. Whelpdale and M-S. Kaiser) (WMO TD No. 777).
107. Extended Abstracts of Papers Presented at the WMO-IGAC Conference on the Measurement and Assessment of Atmospheric Composition Change (Beijing, China, 9-14 October 1995) (WMO TD No. 710).
108. Report of the Tenth WMO International Comparison of Dobson Spectrophotometers (Arosa, Switzerland, 24 July - 4 August 1995).
109. Report of an Expert Consultation on 85Kr and 222Rn: Measurements, Effects and Applications (Freiburg, Germany, 28-31 March 1995) (WMO TD No. 733).
110. Report of the WMO-NOAA Expert Meeting on GAW Data Acquisition and Archiving (Asheville, NC, USA, 4-8 November 1995) (WMO TD No. 755).
111. Report of the WMO-BMBF Workshop on VOC Establishment of a "World Calibration/Instrument Intercomparison Facility for VOC" to Serve the WMO Global Atmosphere Watch (GAW) Programme (Garmisch-Partenkirchen, Germany, 17-21 December 1995) (WMO TD No. 756).
112. Report of the WMO/STUK Intercomparison of Erythemally-Weighted Solar UV Radiometers, Spring/Summer 1995, Helsinki, Finland (WMO TD No. 781).
113. The Strategic Plan of the Global Atmosphere Watch (GAW) (WMO TD No. 802).
114. Report of the Fifth WMO Meeting of Experts on the Quality Assurance/Science Activity Centres (QA/SACs) of the Global Atmosphere Watch, jointly held with the Second Meeting of the Coordinating Committees of IGAC-GLONET and IGAC-ACE^{Ed}, Garmisch-Partenkirchen, Germany, 15-19 July 1996 (WMO TD No. 787).
115. Report of the Meeting of Experts on Atmospheric Urban Pollution and the Role of NMSs (Geneva, 7-11 October 1996) (WMO TD No. 801).
116. Expert Meeting on Chemistry of Aerosols, Clouds and Atmospheric Precipitation in the Former USSR (Saint Petersburg, Russian Federation, 13-15 November 1995).
117. Report and Proceedings of the Workshop on the Assessment of EMEP Activities Concerning Heavy Metals and Persistent Organic Pollutants and their Further Development (Moscow, Russian Federation, 24-26 September 1996) (Volumes I and II) (WMO TD No. 806).
118. Report of the International Workshops on Ozone Observation in Asia and the Pacific Region (IWOAP, IWOAP-II), (IWOAP, 27 February-26 March 1996 and IWOAP-II, 20 August-18 September 1996) (WMO TD No. 827).
119. Report on BoM/NOAA/WMO International Comparison of the Dobson Spectrophotometers (Perth Airport, Perth, Australia, 3-14 February 1997), (prepared by Robert Evans and James Easson) (WMO TD No. 828).

120. WMO-UMAP Workshop on Broad-Band UV Radiometers (Garmisch-Partenkirchen, Germany, 22 to 23 April 1996) (WMO TD No. 894).
121. Report of the Eighth WMO Meeting of Experts on Carbon Dioxide Concentration and Isotopic Measurement Techniques (prepared by Thomas Conway) (Boulder, CO, 6-11 July 1995) (WMO TD No. 821).
122. Report of Passive Samplers for Atmospheric Chemistry Measurements and their Role in GAW (prepared by Greg Carmichael) (WMO TD No. 829).
123. Report of WMO Meeting of Experts on GAW Regional Network in RA VI, Budapest, Hungary, 5 to 9 May 1997.
124. Fifth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry, (Geneva, Switzerland, 7-10 April 1997) (WMO TD No. 898)
125. Instruments to Measure Solar Ultraviolet Radiation, Part 1: Spectral Instruments (lead author G. Seckmeyer) (WMO TD No. 1066)
126. Guidelines for Site Quality Control of UV Monitoring (lead author A.R. Webb) (WMO TD No. 884).
127. Report of the WMO-WHO Meeting of Experts on Standardization of UV Indices and their Dissemination to the Public (Les Diablerets, Switzerland, 21-25 July 1997) (WMO TD No. 921).
128. The Fourth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting, (Rome, Italy, 22-25 September 1996) (WMO TD No. 918).
129. Guidelines for Atmospheric Trace Gas Data Management (Ken Masarie and Pieter Tans), 1998 (WMO TD No. 907).
130. Jülich Ozone Sonde Intercomparison Experiment (JOSIE, 5 February to 8 March 1996), (H.G.J. Smit and D. Kley) (WMO TD No. 926).
131. WMO Workshop on Regional Transboundary Smoke and Haze in Southeast Asia (Singapore, 2 to 5 June 1998) (Gregory R. Carmichael). Two volumes.
132. Report of the Ninth WMO Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques (Edited by Roger Francey), (Aspendale, Vic., Australia).
133. Workshop on Advanced Statistical Methods and their Application to Air Quality Data Sets (Helsinki, 14-18 September 1998) (WMO TD No. 956).
134. Guide on Sampling and Analysis Techniques for Chemical Constituents and Physical Properties in Air and Precipitation as Applied at Stations of the Global Atmosphere Watch. Carbon Dioxide (WMO TD No. 980).
135. Sixth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Zurich, Switzerland, 8-11 March 1999) (WMO TD No.1002).
136. WMO/EMEP/UNEP Workshop on Modelling of Atmospheric Transport and Deposition of Persistent Organic Pollutants and Heavy Metals (Geneva, Switzerland, 16-19 November 1999) (Volumes I and II) (WMO TD No. 1008).
137. Report and Proceedings of the WMO RA II/RA V GAW Workshop on Urban Environment (Beijing, China, 1-4 November 1999) (WMO-TD. 1014) (Prepared by Greg Carmichael).
138. Reports on WMO International Comparisons of Dobson Spectrophotometers, Parts I – Arosa, Switzerland, 19-31 July 1999, Part II – Buenos Aires, Argentina (29 Nov. – 12 Dec. 1999 and Part III – Pretoria, South Africa (18 March – 10 April 2000) (WMO TD No. 1016).
139. The Fifth Biennial WMO Consultation on Brewer Ozone and UV Spectrophotometer Operation, Calibration and Data Reporting (Halkidiki, Greece, September 1998)(WMO TD No. 1019).
140. WMO/CEOS Report on a Strategy for Integrating Satellite and Ground-based Observations of Ozone (WMO TD No. 1046).
141. Report of the LAP/COST/WMO Intercomparison of Erythemal Radiometers Thessaloniki, Greece, 13-23 September 1999) (WMO TD No. 1051).
142. Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), A Contribution to the Implementation of the Long-Term Plan (WMO TD No.1077).

143. Global Atmosphere Watch Measurements Guide (WMO TD No. 1073).
144. Report of the Seventh Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry and the GAW 2001 Workshop (Geneva, Switzerland, 2 to 5 April 2001) (WMO TD No. 1104).
145. WMO GAW International Comparisons of Dobson Spectrophotometers at the Meteorological Observatory Hohenpeissenberg, Germany (21 May – 10 June 2000, MOHp2000-1), 23 July – 5 August 2000, MOHp2000-2), (10 – 23 June 2001, MOHp2001-1) and (8 to 21 July 2001, MOHp2001-2). Prepared by Ulf Köhler (WMO TD No. 1114).
146. Quality Assurance in monitoring solar ultraviolet radiation: the state of the art. (WMO TD No. 1180).
147. Workshop on GAW in RA VI (Europe), Riga, Latvia, 27-30 May 2002. (WMO TD No. 1206).
148. Report of the Eleventh WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracer Measurement Techniques (Tokyo, Japan, 25-28 September 2001) (WMO TD No 1138).
149. Comparison of Total Ozone Measurements of Dobson and Brewer Spectrophotometers and Recommended Transfer Functions (prepared by J. Staehelin, J. Kerr, R. Evans and K. Vanicek) (WMO TD No. 1147).
150. Updated Guidelines for Atmospheric Trace Gas Data Management (Prepared by Ken Maserie and Pieter Tans (WMO TD No. 1149).
151. Report of the First CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Geneva, Switzerland, 18-19 March 2003) (WMO TD No. 1181).
152. Current Activities of the Global Atmosphere Watch Programme (as presented at the 14th World Meteorological Congress, May 2003). (WMO TD No. 1168).
153. WMO/GAW Aerosol Measurement Procedures: Guidelines and Recommendations. (WMO TD No. 1178).
154. WMO/IMEP-15 Trace Elements in Water Laboratory Intercomparison. (WMO TD No. 1195).
155. 1st International Expert Meeting on Sources and Measurements of Natural Radionuclides Applied to Climate and Air Quality Studies (Gif sur Yvette, France, 3-5 June 2003) (WMO TD No. 1201).
156. Addendum for the Period 2005-2007 to the Strategy for the Implementation of the Global Atmosphere Watch Programme (2001-2007), GAW Report No. 142 (WMO TD No. 1209).
157. JOSIE-1998 Performance of EEC Ozone Sondes of SPC-6A and ENSCI-Z Type (Prepared by Herman G.J. Smit and Wolfgang Straeter) (WMO TD No. 1218).
158. JOSIE-2000 Jülich Ozone Sonde Intercomparison Experiment 2000. The 2000 WMO international intercomparison of operating procedures for ECC-ozone sondes at the environmental simulation facility at Jülich (Prepared by Herman G.J. Smit and Wolfgang Straeter) (WMO TD No. 1225).
159. IGOS-IGACO Report - September 2004 (WMO TD No. 1235)
160. Manual for the GAW Precipitation Chemistry Programme (Guidelines, Data Quality Objectives and Standard Operating Procedures) (WMO TD No. 1251).
161. 12th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Toronto, Canada, 15-18 September 2003).
162. WMO/GAW Experts Workshop on a Global Surface-Based Network for Long Term Observations of Column Aerosol Optical Properties, Davos, Switzerland, 8-10 March 2004 (edited by U. Baltensperger, L. Barrie and C. Wehrli) (WMO TD No. 1287).
163. World Meteorological Organization Activities in Support of the Vienna Convention on Protection of the Ozone Layer (WMO No. 974).
164. Instruments to Measure Solar Ultraviolet Radiation: Part 2: Broadband Instruments Measuring Erythemally Weighted Solar Irradiance (WMO TD No. 1289).
165. Report of the CAS Working Group on Environmental Pollution and Atmospheric Chemistry and the GAW 2005 Workshop, 14-18 March 2005, Geneva, Switzerland (WMO TD No. 1302).
166. Joint WMO-GAW/ACCENT Workshop on The Global Tropospheric Carbon Monoxide Observations System, Quality Assurance and Applications (EMPA, Dübendorf, Switzerland, 24 – 26 October 2005) (edited by J. Klausen) (WMO TD No. 1335).

167. The German Contribution to the WMO Global Atmosphere Watch Programme upon the 225th Anniversary of GAW Hohenpeissenberg Observatory (edited by L.A. Barrie, W. Fricke and R. Schleyer) (WMO TD No. 1336).
168. 13th WMO/IAEA Meeting of Experts on Carbon Dioxide Concentration and Related Tracers Measurement Techniques (Boulder, Colorado, USA, 19-22 September 2005) (edited by J.B. Miller) (WMO TD No. 1359).
169. Chemical Data Assimilation for the Observation of the Earth's Atmosphere – ACCENT/WMO Expert Workshop in support of IGACO (edited by L.A. Barrie, J.P. Burrows, P. Monks and P. Borrell) (WMO TD No. 1360).
170. WMO/GAW Expert Workshop on the Quality and Applications of European GAW Measurements (Tutzing, Germany, 2-5 November 2004) (WMO TD No. 1367).
171. A WMO/GAW Expert Workshop on Global Long-Term Measurements of Volatile Organic Compounds (VOCs) (Geneva, Switzerland, 30 January – 1 February 2006) (WMO TD No. 1373).