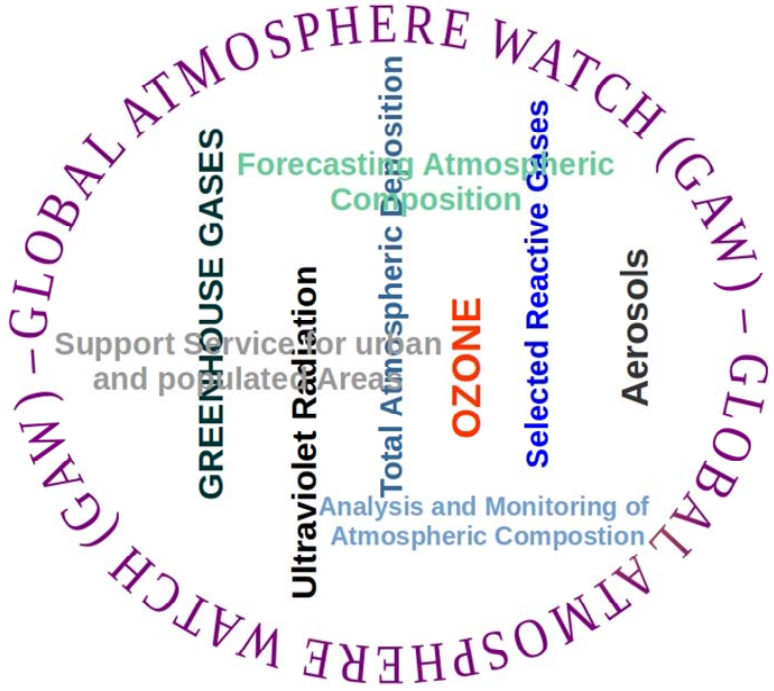
Research Enabling Services

The next Decade for the Global Atmosphere Watch Programme (GAW)



Implementation Plan 2016-2023

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1. FOREWORD

Atmospheric composition matters to climate, weather forecasting, human health, terrestrial and aquatic ecosystems, agricultural productivity, aeronautical operations, renewable energy production, and more. The Global Atmosphere Watch (GAW) Programme was established twenty-five years ago in recognition of the need for improved scientific understanding of the increasing influence of human activities on atmospheric composition and subsequent environmental impacts. GAW provides international leadership in research and capacity development in atmospheric composition observations and analysis through maintaining and applying long-term systematic observations of the chemical composition and related physical characteristics of the atmosphere, emphasizing quality assurance and quality control, and delivering integrated products and services related to atmospheric composition of relevance to users.

This Implementation Plan (IP) builds upon the growing importance of atmospheric composition observations and predictions, and focuses on research that enables a wide variety of ***Products*** and ***Services*** related to atmospheric composition. New GAW-lead thematic application areas will help reduce societal risks from climate change, high-impact weather and events, and urban air pollution; and support conventions and treaties focused on sustainable development.

This IP is designed to help WMO Members meet their needs and to support plans of national, regional, and international observing projects, programs, systems and strategies. The plan supports the WMO priority areas identified in the WMO strategic plan for the period 2016-2019 through observations, analysis and modelling activities that allow for the development of services to WMO Members. Particular contributions of GAW include improvement of forecasting capability for air quality in support of disaster risk reduction, sustained long-term global observations of the major climate change drivers, and development of the Integrated Global Greenhouse Gas Information system that will be useful for greenhouse gas emission negotiations in support of Global Framework for Climate Services. GAW coordinated observations also contribute to implementation of the WMO Integrated Global Observing System. GAW supports enhancement of aviation meteorological services through research of atmospheric aerosol dispersion. It also supports research related to Polar and high mountain regions trough analysis of the impact of atmospheric composition on air quality and snow albedo in related areas. Capacity development remains one of the key GAW activities and it is implemented through GAW dedicated training events, support of summer schools, exchange of expertise and other means.

This Implementation Plan also directly addresses and supports the priority areas identified by the Commission for Atmospheric Sciences (CAS) at its 16th session: High Impact Weather and its socio-economic effects in the context of global change; Modelling and predicting the water cycle for improved disaster risk reduction (DRR) and resource management; Integrated Global Greenhouse Gas Information System: Serving society and supporting policy; Aerosol Impacts on air quality, weather and climate; Research and services for megacities and large urban complexes; and Impacts of Evolving Technologies on science and its use.

April 2016

Greg Carmichael
Chair, EPAC Scientific Steering Committee

2. 25 YEARS OF THE GLOBAL ATMOSPHERE WATCH PROGRAMME

2.1 Background

Scientific curiosity drove the early observations of atmospheric constituents. In the 1950s, the World Meteorological Organization (WMO) launched a programme on atmospheric chemistry and the meteorological aspects of air pollution that transformed these early sporadic measurements into regular observations (Fig. 1). This programme soon determined that characterizing atmospheric composition and its changes requires that all measurements be expressed in the same units and on the same scale, thus enabling measurements performed by different countries to be compared and combined.

These activities evolved in 1989 into the Global Atmosphere Watch (GAW) Programme. GAW was established in response to the growing concerns related to human impacts on atmospheric composition and the connection of atmospheric composition to weather and climate. GAW's mission is focused on the systematic global observations of the chemical composition and related physical characteristics of the atmosphere, integrated analysis of these observations and development of predictive capacity to forecast future atmospheric composition changes (Laj et al., 2009). These observations and analyses are needed to advance the scientific understanding of the effects of the increasing influence of human activity on the global atmosphere as illustrated by such pressing societal problems as: changes in the weather and climate related to human influence on atmospheric composition, particularly, on greenhouse gases, ozone and aerosols; impacts of air pollution on human and ecosystem health and issues involving long-range transport and deposition of air pollution; and changes in UV radiation as consequences of changes in ozone atmospheric content and climate, and subsequent impact of these changes on human health and ecosystems.

Figure 1 - Continuous Total Ozone Measurements (from manual operations to automatic instrumentation– from the 1950s to today)

2.2 GAW Mission Statement

The **mission** of GAW is to

- Reduce environmental risks to society and meet the requirements of environmental conventions,
- Strengthen capabilities to predict climate, weather and air quality, and
- 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, and
- Delivering integrated products and services of relevance to users.

The GAW Programme is implemented and undertaken by WMO Members and supported by international scientific communities. Together, these communities perform long-term observations of chemical composition and related physical characteristics of the atmosphere on a global scale, emphasizing quality assurance and quality control of the data, developing appropriate analysis and modelling tools and providing integrated products and services to users.

Since its beginning, GAW has fulfilled a mandate from WMO Members by responding to their needs and clearly linking to the plans of national, regional, and international observing projects, programs, systems and strategies, e.g.:

- In providing a comprehensive set of high quality and long-term observations of atmospheric composition to support 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), the Intergovernmental Panel on Climate Change (IPCC) and to the development of Global Framework for Climate Services (GFCS).
- In supporting the Montreal Protocol for the Protection of the Ozone Layer and follow-up amendments.
- In supporting the Convention on Long-Range Transboundary Air Pollution (CLRTAP).
- In providing reliable observations and forecasting tools to support assessment of the temporal and spatial variability of aerosols (including sand and dust) and reactive gases required to understand the impact of air quality on human health, ecosystems and infrastructure security.
- In providing guidance for optimizing regional observation networks (potential contributing networks) that address atmospheric composition and related physical parameter observations.

- In promoting high-quality observations and enhancing the use of GAW's quality controlled data and inferred products in routine/operational services and research activities.
- In supporting studies on environmental protection, including protecting the health of marine and other ecosystems.
- In providing GAW products supporting agriculture and food security aspects.

The importance of atmospheric composition in the above matters was emphasized in resolutions from the Seventeenth World Meteorological Congress, which stressed the need to enhance the capacity of NMHSs to deliver on their mission by developing and improving competent human resources, technical and institutional capacities and infrastructure; particularly in countries where the capability to maintain high standards of observations, data and metadata is problematic. It also included Resolution 60 of the 17th Congress, which urges members to strengthen their support to the framework of the GCOS Essential Climate Variables (ECVs) in the collection and supply of data and products to support the GFCS on a free and unrestricted basis. Among others, GCOS ECVs include data on the composition of the atmosphere including aerosols and their precursors, greenhouse gas and atmospheric ozone data together with climate relevant cryosphere data, including glacial monitoring.

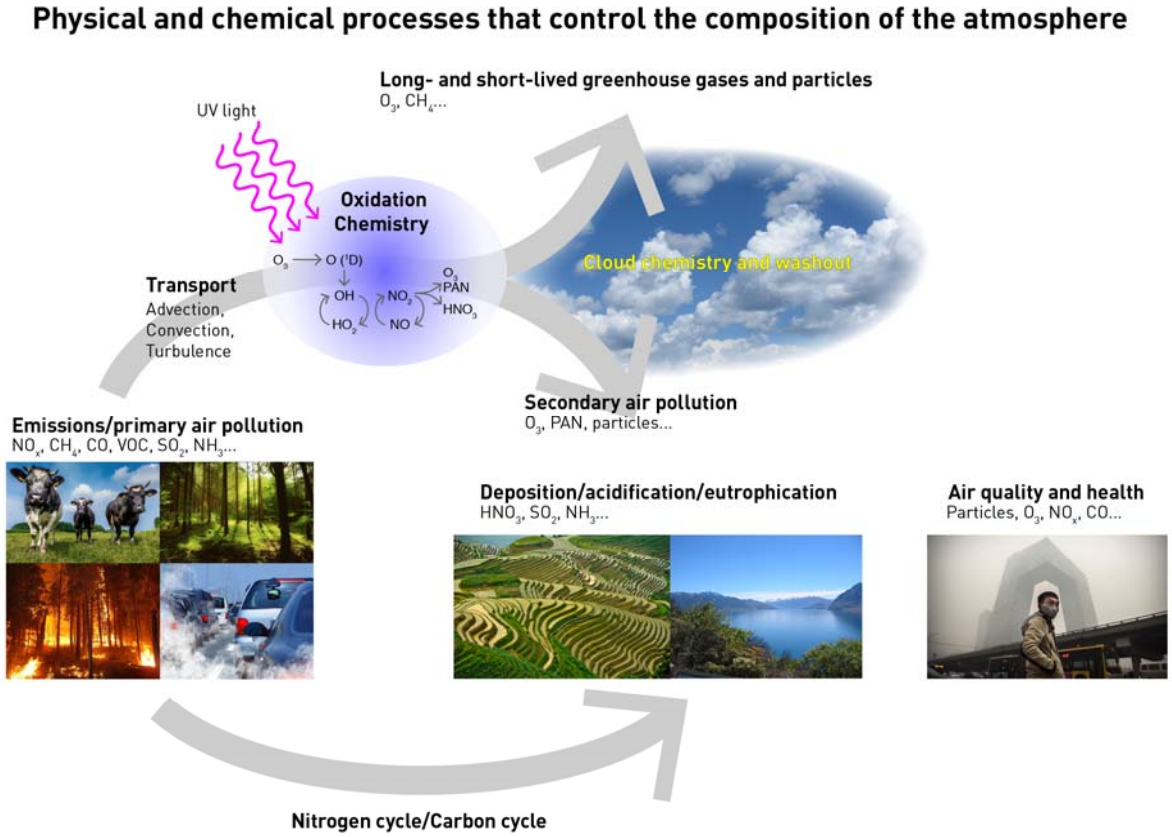

Figure 2 - Physical and chemical processes that control the composition of the atmosphere on different scales.

The main GAW achievements of the last 25 years are **long-time records of globally harmonized data sets for various trace gases, aerosols, deposition and UV radiation with the highest-possible accuracy**, quantified with common procedures within the GAW Programme, and their use in the establishment of the long-term trends on the global scale.

2.3 The Components of GAW

The complexity of the physical and chemical processes that control the composition of the atmosphere on different scales is depicted on Fig. 2. To address such a complex system, GAW research activities are directed towards conducting observations to document changes in atmospheric composition, continuous improvement of the observational and data management infrastructure, analyses of the data to improve knowledge on the processes controlling atmospheric composition change, and the development of GAW products and services. These research activities are supported through the infrastructure reflected in Fig. 3, which includes

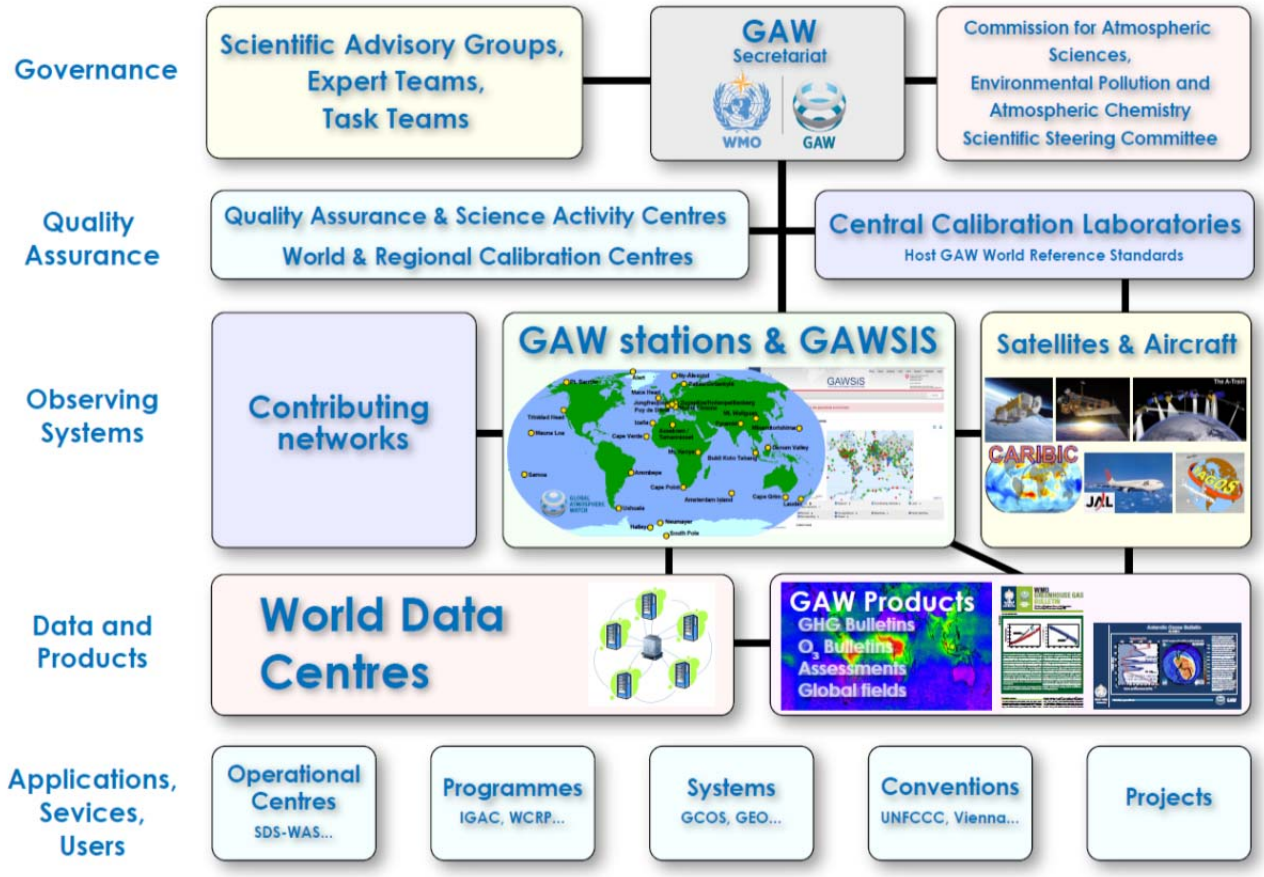

Figure 3 - Components of the WMO/GAW Programme.

observing systems supplemented by a set of Central Facilities supporting the quality assurance system, a data management system, advisory groups, expert teams and a steering committee. General governance of the programme is organized through focal areas. Various GAW expert groups exist under the oversight of the WMO Commission for Atmospheric Sciences (CAS) and

its Environmental Pollution and Atmospheric Chemistry Scientific Steering Committee (EPAC SSC). EPAC SSC takes the responsibility for the programme strategic leadership and coordinates cross-cutting thematic activities and overarching activities in GAW. Terms of reference of the GAW Scientific Advisory Groups and Expert Team and Central Facilities are summarized in Chapter 6.

2.3.1 GAW Focal Areas

To address the needs of the Members related to the environmental issues mentioned above, GAW currently focuses on six[1] groups of variables (also called focal areas):

- *Greenhouse Gases*
- *Ozone*
- *Aerosol*
- *Selected Reactive Gases*
- *Total Atmospheric Deposition*
- *Ultraviolet (UV) Radiation*

Each of these groups includes a set of gases or aerosol parameters that are the most critical to the environmental problems that the programme addresses. For example, the set of measured greenhouse gases includes the key long-lived greenhouse gases that provide 96% of the radiative forcing on climate by long-lived greenhouse gases, and tracers used for source attribution of these gases. The detailed list of variables addressed in GAW is provided in Box 8.1 (Annex B). New variables are added over time to address the evolving needs of the user community.

The **surface-based observational network** includes distributed worldwide GAW Global (31 stations) and Regional (about 400 stations) stations where observations of various GAW parameters occur. These stations are complemented by regular ship cruises and various contributing networks. All observations are linked to common reference standards and the observational data are made available at seven designated World Data Centres. Depending on data submission the status of the network ("health of the network") can be assessed (Fig. 4). GAW data archives have accumulated a substantial volume of data related to atmospheric composition (Fig. 5). Information about GAW stations and contributing networks is summarized in the GAW Station Information System (GAWSIS, http://gawsis.meteoswiss.ch).

[1] Atmospheric Water Vapour was tentatively included in GAW in 2015 by the decision of the EPAC SSC (GAW Report No. 220) but the infrastructure has not been defined yet.

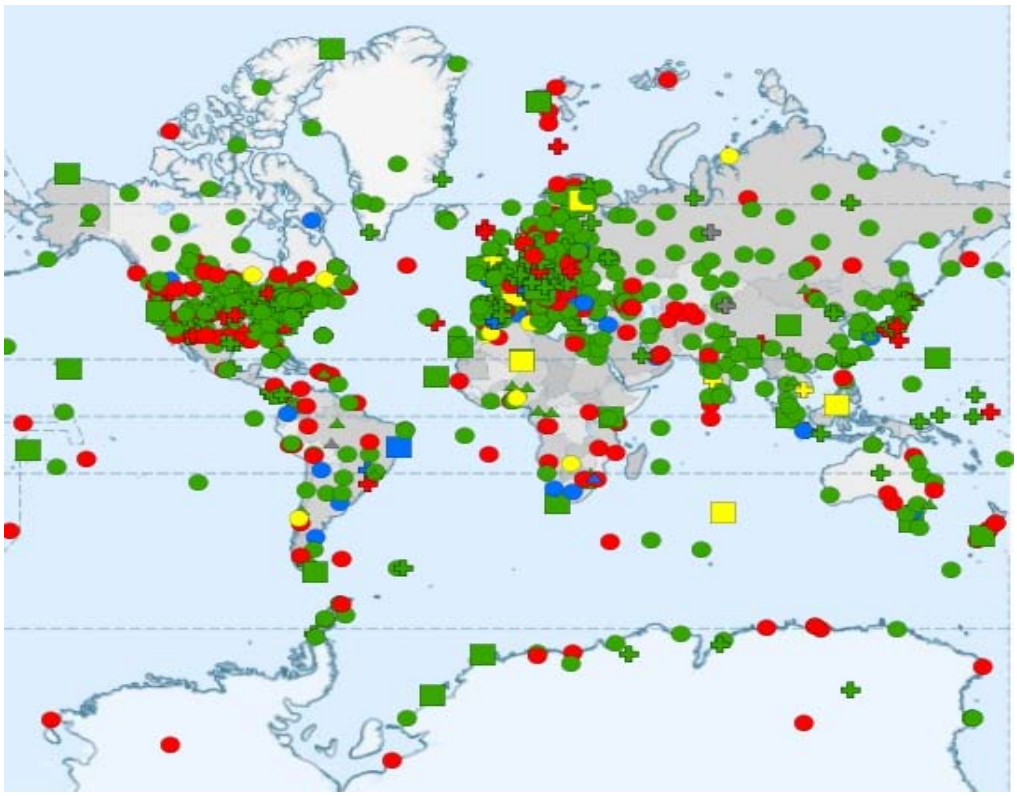

Figure 4 - Health of the GAW observational network (the map is based on the information in GAWSIS, different shapes correspond to different station categories, while the colour reflects the reporting status: green are reporting stations, yellow are partly reporting stations and blue are non-reporting stations, red are closed stations).

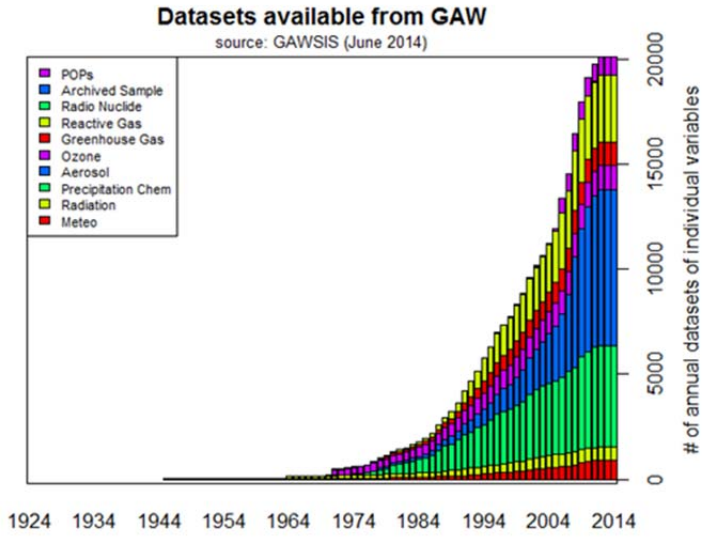

Figure 5 - Statistics of the data sets available from GAW, contributing networks and predecessor programmes in the World Data Centres

Surface-based observations are complemented by **airborne** and **space-based observations** that help to characterize the upper troposphere and lower stratosphere, in particular with regards to ozone, solar radiation, aerosols, and certain trace gases. Examples of observations and analyses are presented below.

Observations of **long-lived greenhouse gases (LLGHG)** within GAW include both discrete air sampling in flasks and continuous measurements. This network of fixed stations is supported by aircraft measurements and retrievals of column averaged mole fractions of a number of LLGHG. Annual levels of the global averaged mole fractions of LLGHG and the rate of their change are reported in WMO Greenhouse Gas Bulletins (http://www.wmo.int/pages/prog/arep/gaw/ghg/GHGbulletin.html). This information is used to support negotiations at the conferences of the parties to UNFCCC. Only thanks to the globally harmonized use of reference scales and measurement techniques, the calculation of the globally averaged levels of GHG is possible with a very small uncertainty, allowing reliable determination of interannual variability, long-term trends and detections of the small spatial gradients. For example, surface observations from background sites are used to estimate LLGHG contribution to radiative forcing; from 1990 to 2014 radiative forcing by LLGHG increased by 36%, with CO_2 accounting for about 80% of this increase (Fig. 6).

The observed spatial patterns in LLGHGs are used with chemical transport models (CTM) to estimate emissions at continental to country scales as shown by Thompson et al. (2014) for N_2O.

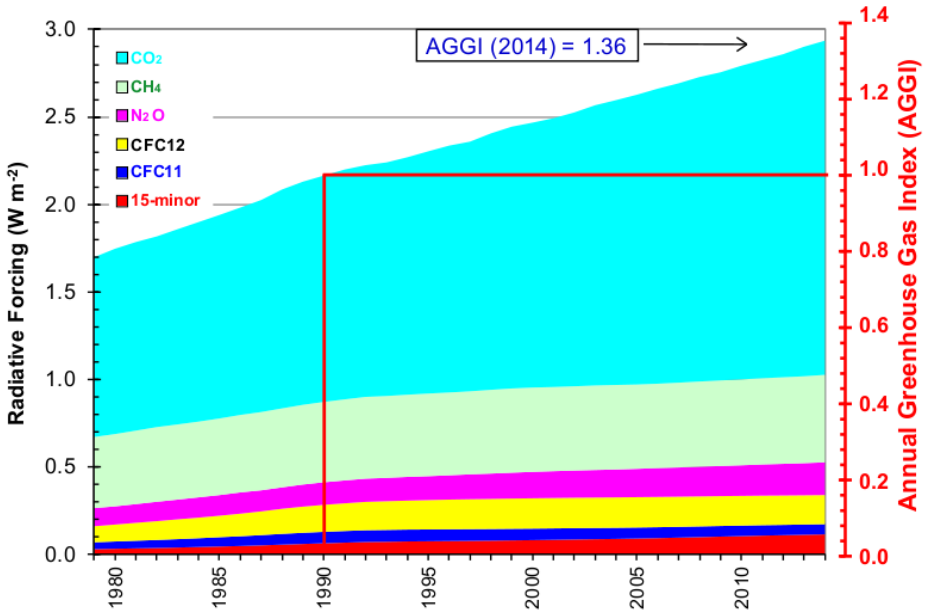

Figure 6 - Increase in radiative forcing by long-lived greenhouse gases (LLGHG) since 1979. CO_2 is the largest contributor to total radiative forcing by LLGHGs. Based on the NOAA Annual Greenhouse Gas Index (AGGI) (http://www.esrl.noaa.gov/gmd/aggi/).

The GAW **reactive gases** network (Schultz et al., 2015) is supported by more than 150 stations worldwide and comprises observations of tropospheric ozone, carbon monoxide,

nitrogen oxides (NO and NO_2), sulfur dioxide (SO_2) and a number of volatile organic compounds (VOCs) selected based on their relevance for air pollution and tropospheric chemistry. All observations are tied to global reference standards/scales (Klausen et al, 2003; Novelli et al., 2003; Zellweger, 2009). GAW reactive gases data have been used in a large number of scientific studies including review articles (Cooper et al., 2014), trend analyses (Gilge et al., 2010; Parrish et al., 2012; Logan et al., 2012), process studies (Mannschreck et al., 2004) and the evaluation of chemistry climate models (Parrish et al., 2014). One illustrative result is the use of GAW observations for detections of a slight negative CO trend in the northern hemisphere related to the reduction of anthropogenic emissions (Fig. 7), which helped to understand the complex patterns of tropospheric ozone changes during the past decades (Cooper et al., 2014).

Data from several GAW stations are used in delayed mode for verifications of the European Monitoring Atmospheric Composition and Climate (MACC) project forecasting system (http://www.gmes-atmosphere.eu/d/services/gac/verif/grg/gaw/). There is increasing demand for near real-time delivery of reactive gases data so that they can be used in the data assimilation or validation of global and regional air quality forecast systems.

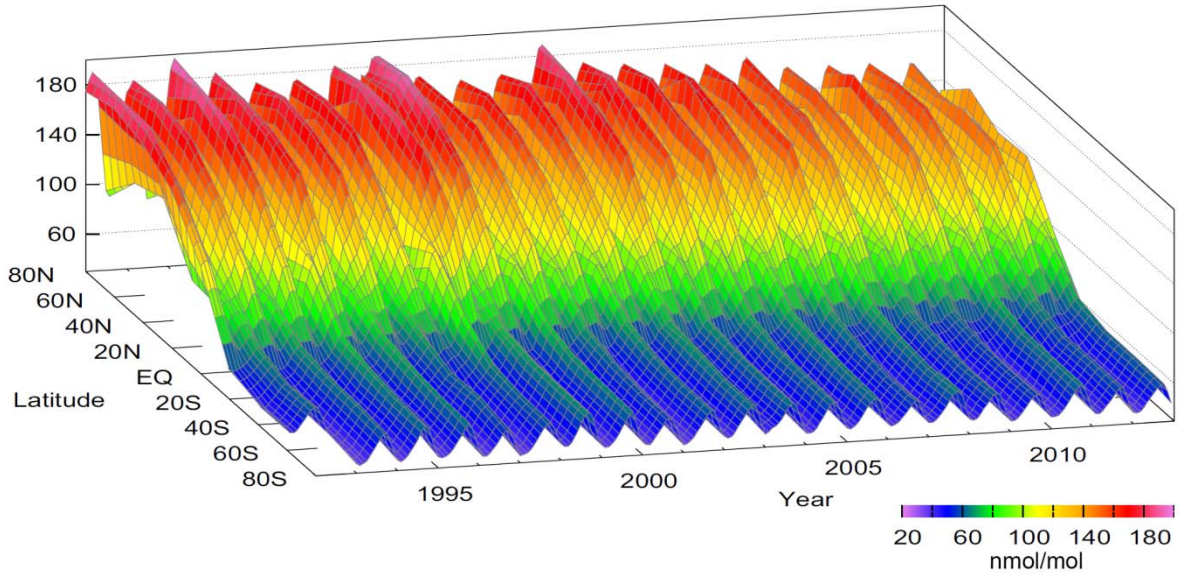

Figure 7 - Global distribution and changes in surface carbon monoxide mixing ratios since 1993. (Figure from Schultz et al., 2015)

GAW coordinated observations of **total ozone** support the Scientific Assessments of Ozone Depletion, prepared jointly by WMO and the United Nations Environment Programme (UNEP) for many decades. Total ozone measurements are primarily performed by Dobson and Brewer spectrophotometers, while the vertical distribution of ozone is measured either in situ with ozonesondes (carried by small balloons) and aircrafts, or remotely from the ground by lidars, microwave radiometers and Umkehr inversions of zenith UV radiances measured by ozone spectrophotometers (Dobsons and Brewers). Ground based total ozone observations are also important for the validation of satellite-derived ozone data and for ensuring the continuity among different satellite missions. Near real-time observations from Antarctic stations are used for the preparation of the Antarctic Ozone Bulletins (http://www.wmo.int/pages/prog/arep/gaw/ozone/index.html), which regularly document the current state of the ozone layer over Antarctica during Antarctic spring (Fig. 8).

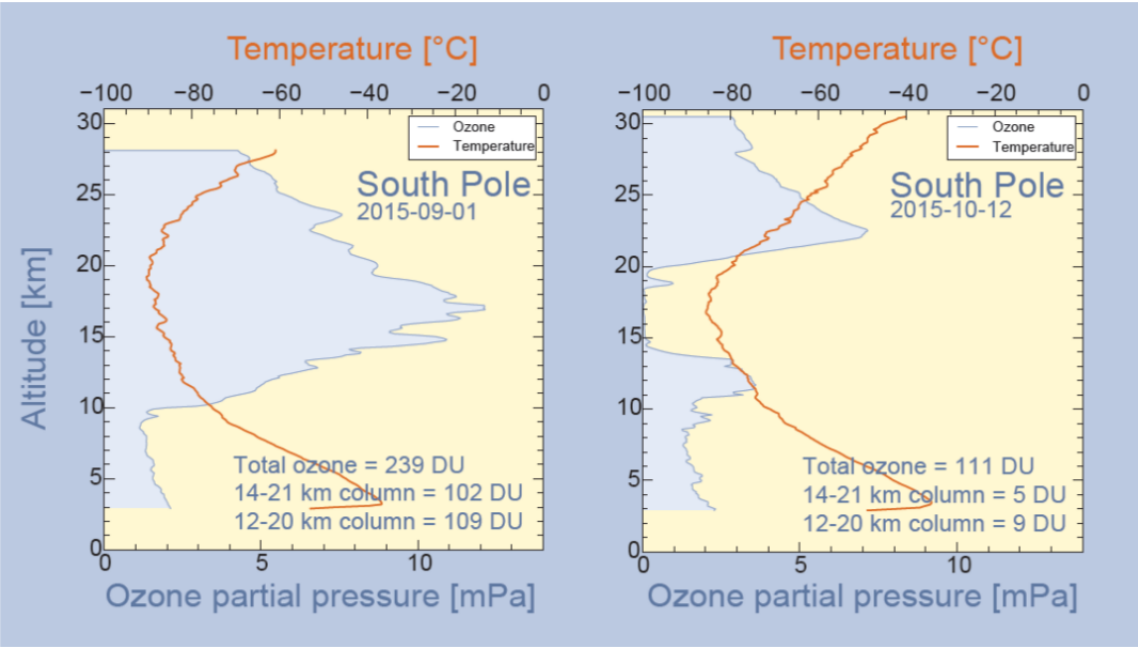

Figure 8 - Examples of the vertical ozone distribution (shaded area) measured by ozonesondes at the GAW Global station South Pole. Red line represents the temperature profile (top axis) in ^{o}C.

Aerosol plays an important role in a spectrum of meteorological, climate and environmental services (e.g., sand and dust storms and volcanic ash can impact transportation systems and pose public health concerns). Aerosol impacts atmospheric radiation transfer and interacts with cloud processes in complex ways, and its impacts on numerical weather prediction and climate change are active areas of research. The GAW aerosol observations enable exceptional analysis of the spatio-temporal distribution of aerosol particle properties related to climate forcing and air quality on multi-decadal time scales and on regional, hemispheric and global spatial scales (Collaud Coen et al., 2013; Asmi et al, 2013). Through scientific and technological recommendations to station operators (GAW report 153, Petzold et al., 2013), the techniques and instrumentation used at GAW sites continue to improve, and new parameters have been added in response to requests from the user community (Laj et al., 2010). A direct result of these efforts is the capability to derive long-term trends for non-CO_2 climate forcers on the global scale, as for example depicted on Fig. 9 (Asmi et al., 2013; Collaud Coen et al., 2013).

The GAW Aerosol Lidar Observation Network (GALION) provides the vertical component of aerosol distributions through advanced laser remote-sensing in a network of globally distributed ground-based stations, used for example to detect volcanic ash layers (Pappalardo et al., 2013).

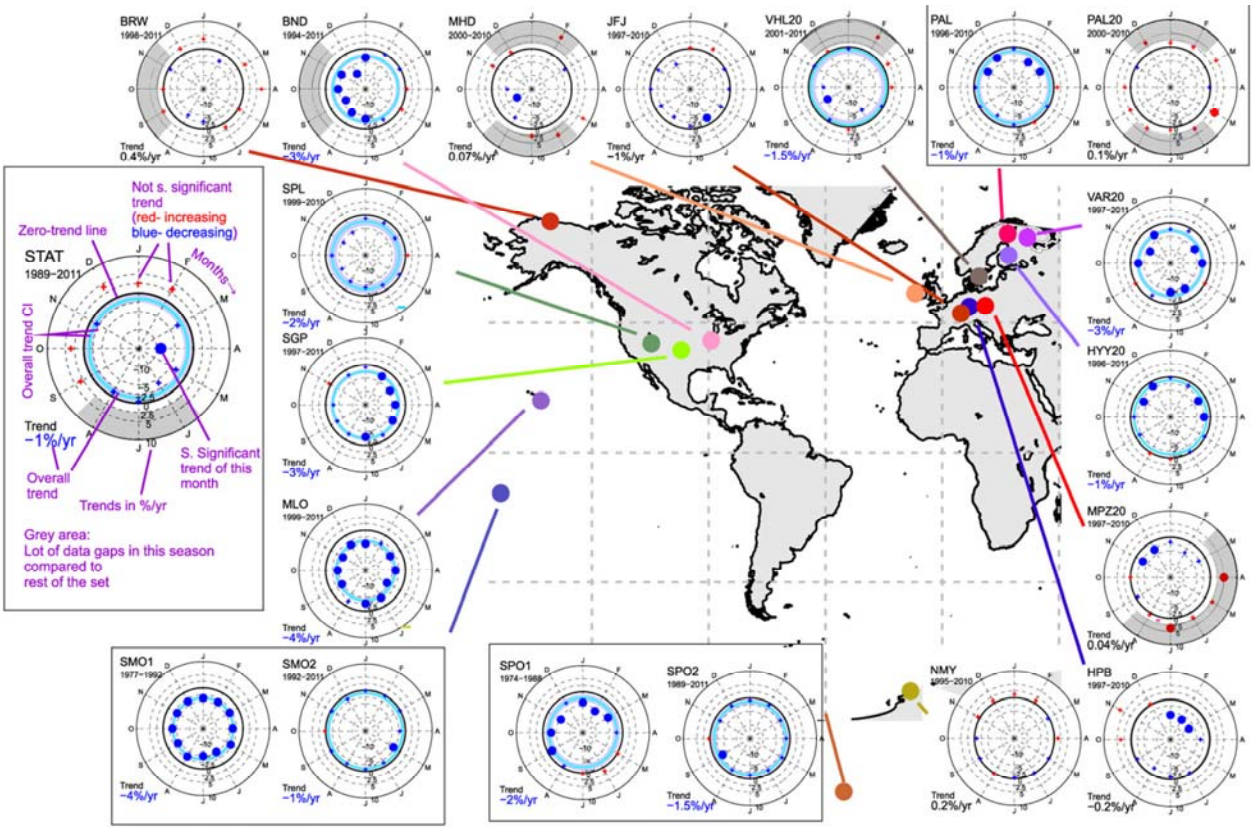

Figure 9 - Observed trends in aerosol number concentration at GAW stations from Asmi et al., 2013

Deposition is an important process by which anthropogenic and naturally occurring gases and particles are removed from the atmosphere. Quantifying the composition of wet and total (wet plus dry) deposition regionally and globally is important to understanding the cause and effect of contemporary environmental issues such as acidification and eutrophication. An important step in building up this focal area was the development of a Manual for the GAW Precipitation Chemistry Programme (GAW Report No. 160). This document led to harmonization of observations by national and regional programmes and to improvement of the quality of global data. A collective effort of the GAW community allowed for the production of *A Global Assessment of Precipitation Chemistry and Deposition of Sulfur, Nitrogen, Sea Salt, Base Cations, Organic Acids, Acidity and pH, and Phosphorus* (Vet et al., 2014). An example of the results published in the assessment is given in Fig.10. A major product of this assessment was a database of quality-assured ion concentration and wet deposition data gathered from regional and national monitoring networks and made available in the World Data Centre for Precipitation Chemistry (http://wdcpc.org/).

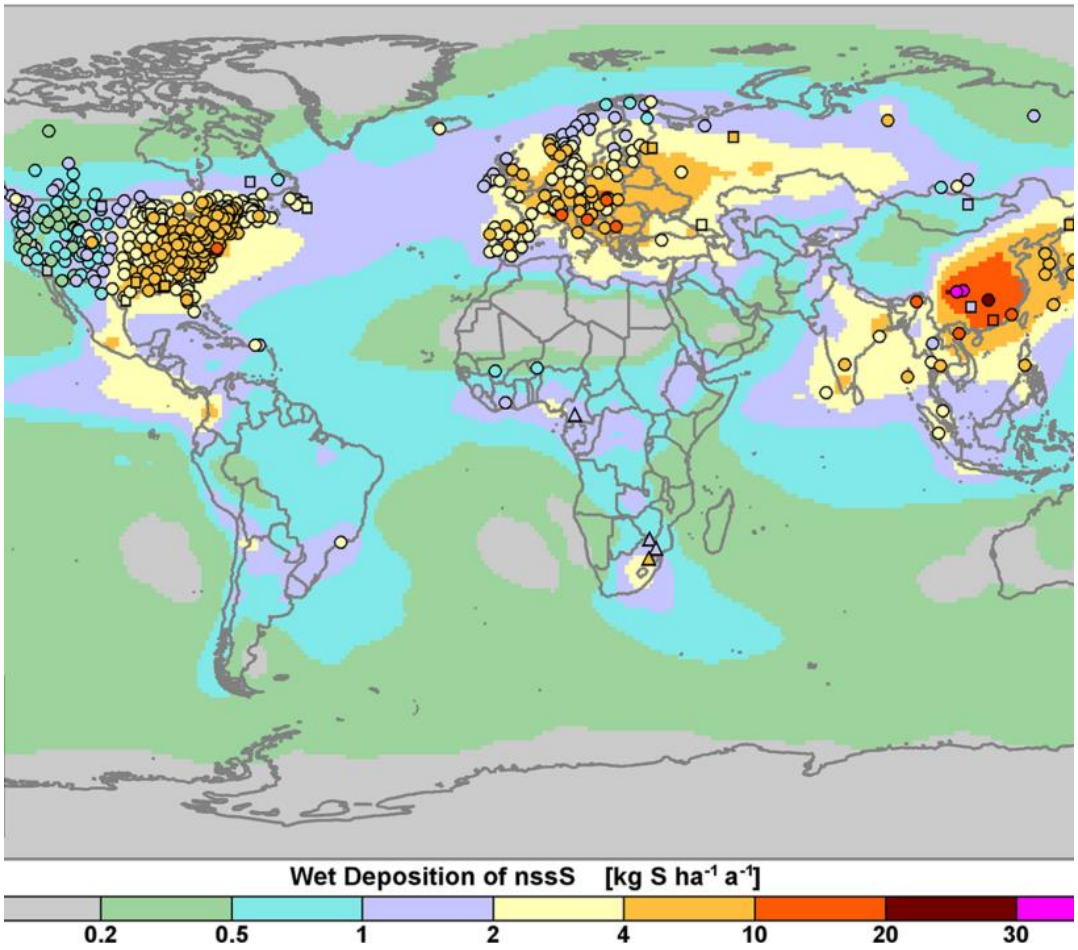

Figure 10- Measurement-model wet deposition of nssS in kg S ha^{-1} a^{-1}. Measurement values represent 3-year averages for 2000-2002; model results represent the 2001 model year (from Vet et al., 2014).

The radiation component of GAW has concentrated its efforts on **UV radiation** resulting in many instruments and measurement guidelines being developed throughout the years. A number of regional and global calibration facilities support quality assurance of global UV radiation observations. GAW collaborates with other programs and agencies in order to produce documents related to public health and awareness. An important achievement for public information is the development of the UV Index (http://exp-studies.tor.ec.gc.ca/cgi-bin/clf2/uv_index_calculator?lang=e&printerversion=false&printfullpage=false&accessible=off) jointly with the World Health Organization (WHO), UNEP and the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

2.3.2 Cross-cutting Activities

Important GAW activities are developed in individual research programmes (coordinated and advised by expert teams) or in joint research projects. For example, the **GAW Urban Research Meteorology and Environment** (GURME) project is a component of GAW that focuses on developing improved air quality forecasting systems and contributes to a broader

urban services initiative being developed in WMO. GURME involves collaboration with the World Weather Research Programme. GURME promotes pilot projects and conducts workshops on air quality related activities. Major achievements include the development of the *System of Air Quality Forecasting and Research (SAFAR*) by the Indian Institute of Tropical Meteorology (IITM) Pune, the development of a new air quality and related services component of the Expo Multi-hazard Early Warning System for the Shanghai Expo in 2010, and the development of a new air quality forecasting service in Latin American cities (Saide et al., 2015). The *Near Real-Time (NRT) Data Application to Air Quality Forecasts* is one of two new pilot projects, one under the leadership of the Chinese Academy of Meteorological Sciences and the other one from Mexico City. The pilot projects illustrate some of the ways that research is being translated into enhanced weather and air quality services, in particularly through addressing the complex interaction of aerosol with weather and climate system.

The **GAW Expert Team on Near Real-Time Chemical Data Transfer**, which covers applications that use NRT data delivery on scales larger than urban, has established several pilot projects related to NRT data delivery within the framework of the WMO Integrated Global Observing System (WIGOS). Based on the growing importance of such modeling activities, this expert team was transformed into a new Scientific Advisory Group by EPAC SSC, which was then approved by the 17th World Meteorological Congress. This SAG will focus on a number of tasks including the improvement of models and the development of services related to dust, volcanic ash and biomass burning. The group will closely collaborate with WWRP and the Working group on Numerical Experimentation (WGNE), and will build on the example of provision of atmospheric composition related products and services in the **WMO Sand and Dust Storm Warning Advisory and Assessment System** (SDS-WAS). The SDS-WAS was established in 2007 as a joint WWRP and GAW activity in response to the intention of 40 WMO member countries to improve capabilities for more reliable sand and dust storm forecasts. SDS-WAS multi-model forecast is available online at http://sds-was.aemet.es/forecast-products/dust-forecasts/sds-was-and-icap-multi-model-products. Further development of SDS-WAS will follow its Science and Implementation Plan (Report WWRP 2015-5).

The **Group of Experts on Scientific Aspects of Marine Environmental Protection** (GESAMP) was established by the United Nations (UN) in 1969 and is an advisory body that provides the UN system with authoritative, independent, and interdisciplinary scientific advice to support the protection and sustainable use of the marine environment. WMO has supported GESAMP since its formation. GESAMP Working Group 38, The Atmospheric Input of Chemicals to the Ocean, was formed in 2007 with WMO as its lead agency. This working group undertakes studies on the impact of the temporal and spatial changes of atmospheric composition and deposition on oceanic ecosystems, marine biogeochemistry, and climate. It provides a link between the atmospheric composition and deposition community with the marine environment impact community. GESAMP WG 38 has published a number of reports and peer reviewed papers related to the atmospheric deposition of nutrients (nitrogen, phosphorus, iron) to the ocean and their impact on ocean chemical and biological processes. WG 38 has also provided advisory reports to such GAW groups as the WMO Precipitation Data Synthesis and Community Project and the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) concerning issues related to the marine environment. WG 38 and SDS-WAS also held a joint meeting where they developed advice for appropriate marine atmospheric sampling locations for dust and protocols for what should be measured there for maximum benefit to the oceanographic community. Upcoming workshops of WG 38 will be focused 1) on

the impact of ocean acidification on air/sea fluxes of atmospheric non-CO_2 climate-active species, and 2) on how the changing atmospheric acidity will affect the solubility, and thus bioavailability, of such important nutrients as iron and phosphorus when they are deposited in the ocean. WG 38 will continue to be actively involved in biogeochemical cycle efforts initiated by GAW, and WG 38 will seek GAW's advice on topics and memberships for its workshops.

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3 THE NEXT GAW DECADE

The vision for the next decade of GAW is to grow the international network of high-quality atmospheric observations across the global to local scale to drive high quality and impact science while co-producing a new generation of research enabled products and services.

The relationships between the observing-system infrastructure, the observational and model generated data, their use in underpinning science, and the translation of research to services within GAW is illustrated in Fig. 11**.** GAW will continue its focus on research and support of the observational networks that produce high-quality data to drive science. Over the 2016-2023 IP time period, GAW will place an increased emphasis on the translation of its research to produce more value added **products and services** that are relevant to society, including climate, weather forecasting, human health, mega-city development, terrestrial and aquatic ecosystems, agricultural productivity, aeronautical operations, renewable energy production and many more.

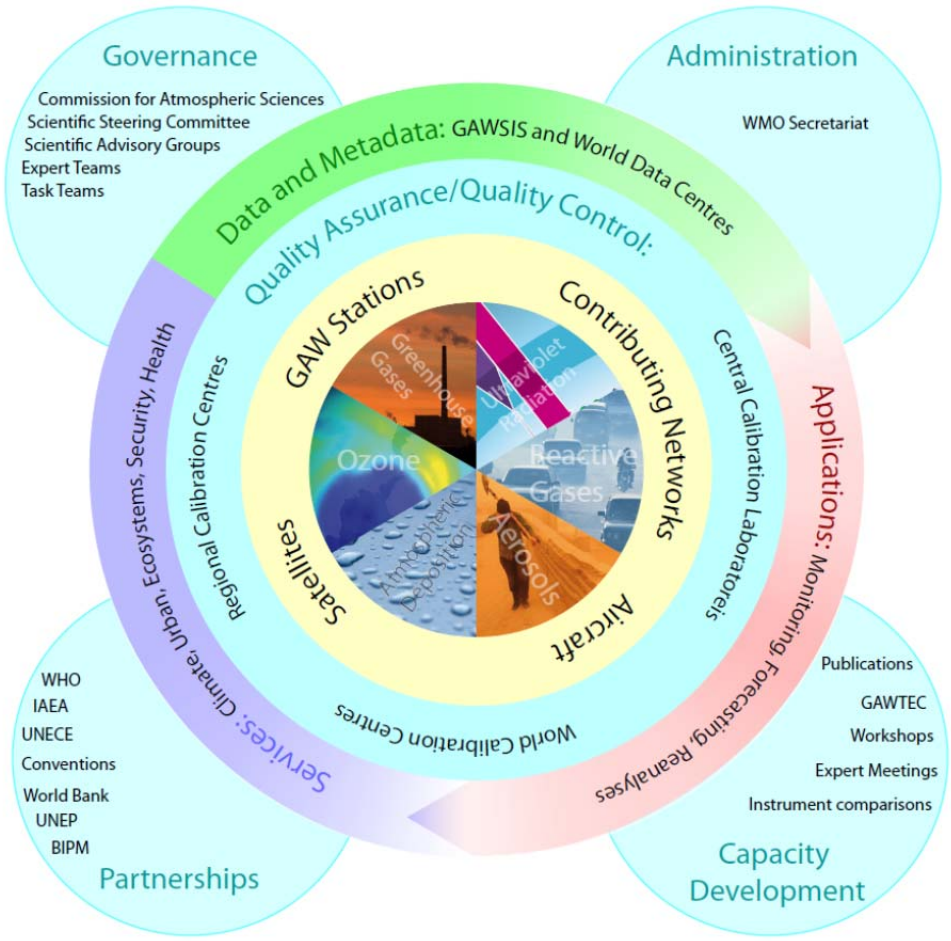

Figure 11 - The GAW program elements of Research Enabling Atmospheric Composition Services

3.1 Research Enabling Atmospheric Composition Services

The GAW mission intrinsically carries the need for complementary and integrative activities regarding measurements, scientific analysis and modeling of the chemical composition of the atmosphere. A critical strategy for the continued advancement of the GAW Programme is the broader use of GAW observations and research activities to underpin and support the development of services with high societal impact that rely on information on atmospheric composition and related parameters. These services require the use of GAW and collaborative measurements. They involve the integration of different types of observations in observation-based analysis and numerical prediction with the objective to deliver information products enabling evidence-based decision making for detecting, managing and mitigating effects on the environment, health and well-being, as well as on economies worldwide.

To ensure the development of products and services for the variety of user communities, and also to support needed cross-cutting research activities ***three broad application areas*** have been identified based on their temporal and spatial scales. They are used to streamline research and implementation strategies that build on the observations acquired under the GAW Programme:

- **Monitoring of Atmospheric Composition** - covers applications related to evaluating distributions of and analyzing changes in atmospheric composition, temporally and spatially, on regional to global scales. These applications include assessments of trends in composition, deposition, and emissions (e.g., in support of environmental conventions); re-analyses and development of climatologies; evaluation of regional and global chemical transport models and their representation of processes; evaluation of satellite-derived retrievals of atmospheric composition variables; support of treaty monitoring; and communication of findings in products such as the Antarctic Ozone and Greenhouse Gas Bulletins, and State/Health of the Atmosphere reports.

- **Forecasting Atmospheric Composition Change and their induced environmental phenomena** – covers applications from global to regional scales, with horizontal resolutions similar to global Numerical Weather Prediction (approx. 10 km and coarser), and with stringent timeliness requirements (near-real time). These applications, for example, include support for operations such as sand and dust storm warnings, haze-fog prediction and chemical weather forecasts.

- **Providing Atmospheric Composition information to support services in urban and populated areas** - covers applications that target megacities and large urban complexes (with horizontal resolution of a few km or smaller) and, in some cases, with stringent timeliness requirements. A distinguishing feature of this category of applications is their emphasis on research in support of operational services, such as air quality forecasting, which use approaches such as pilot projects and feasibility demonstrations.

A number of targeted services arise from these GAW-lead thematic application areas. An example of potential services is depicted on Fig. 12. They are expanded upon in Annex A.

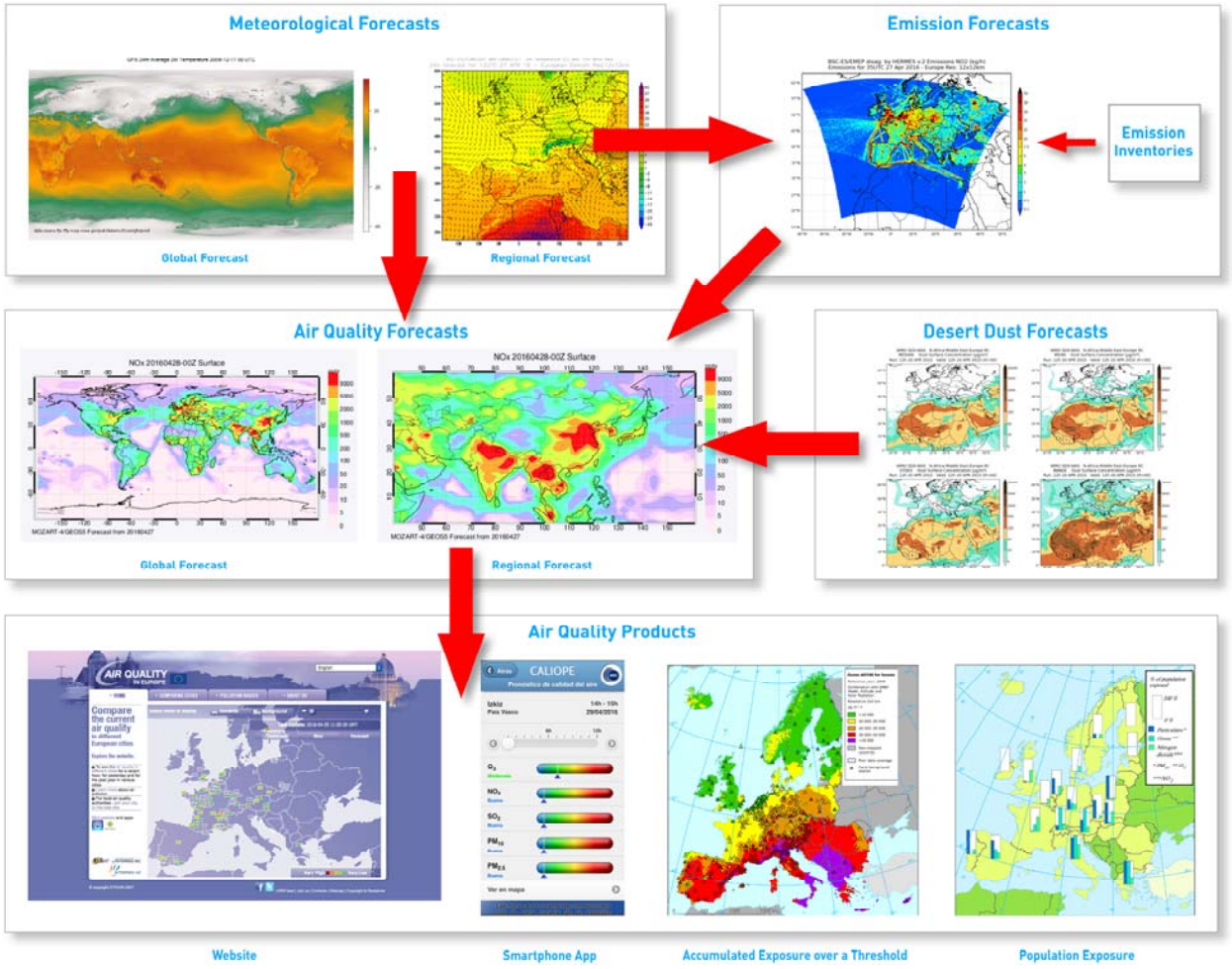

Figure 12 - Schematic overview of potential GAW data services.

4 GAW OBJECTIVES AND IMPLEMENTATION

Meeting the growing need for atmospheric composition information and related services will require increased efforts and focus by GAW directed towards enhancing observing systems to provide the data needed to characterize the current state and trends in atmospheric composition. It will also be necessary to broaden the use of GAW observations and research activities to support the development of services with high societal impact that rely on information on atmospheric composition and related parameters. This will be accomplished through enhanced modeling efforts and improved information management infrastructure. Overall success and sustainability will require stronger efforts towards building collaborations, capacity and communications.

Specific priority activities are presented below.

4.1 Observations (surface, satellite, mobile)

Surface-based observations of atmospheric composition variables are a key component of the GAW strategy. The network comprises different levels of stations namely **global**, **regional**, **local**, and **mobile** operated by WMO Members, research institutions and/or agencies. Stations can be operated within other national or international networks which upon signing an agreement with the GAW Programme become **contributing networks**. Contributing networks augment the information obtained from the GAW network by covering additional regions, vertical regimes, or parameters, or through employing different measurement techniques. They thus provide added scientific expertise and support research and service activities of GAW and the broader scientific community. Figure 13 depicts different elements of the observing system as relates to meteorological parameters. A similar system is being established for atmospheric composition observations jointly by GAW and its partners. The GAW coordinated observational network contributes to WMO Integrated Global Observing System (WIGOS). General requirements for GAW stations and procedures related to station status are described in detail in Annex B.

A globally integrated system of observations must include highly accurate measurements at and near the ground in all regions of the globe. **GAW Global stations** are the flagship of the programme. Observational programmes at these stations includes a broad spectrum of GAW parameters measured following GAW QA/QC protocols, which allows them to address multiple applications. In addition to core GAW parameters, these stations perform extensive research on atmospheric composition change with an extended set of measurements (at some GAW Global stations the suite of measurements can cover more than 50 species). GAW Global stations serve as the centres of excellence, they host international research campaigns and actively participate in capacity development within GAW through the stations twinning initiatives. GAW Global stations have an excellent track record of data submissions in the GAW Data Centres and actively participate in NRT data exchange initiatives.

GAW Regional stations have less extensive measurement programmes and in many cases they were established to support specific applications (measure parameters only in one focal area). These stations are also following GAW measurement protocols which allows for data use in global assessments. There are several GAW Regional stations that do have broad measurement and research programmes, and those are encouraged to apply for the status of GAW Global stations (if all the requirements are met, see Annex B). In view of this Implementation Plan and in response to WIGOS network design principles, GAW Regional stations are encouraged to extend their measurement programmes to ensure that data can

support multiple applications. These stations should also ensure regular data submission to GAW Data Centres for all the parameters measured at the station.

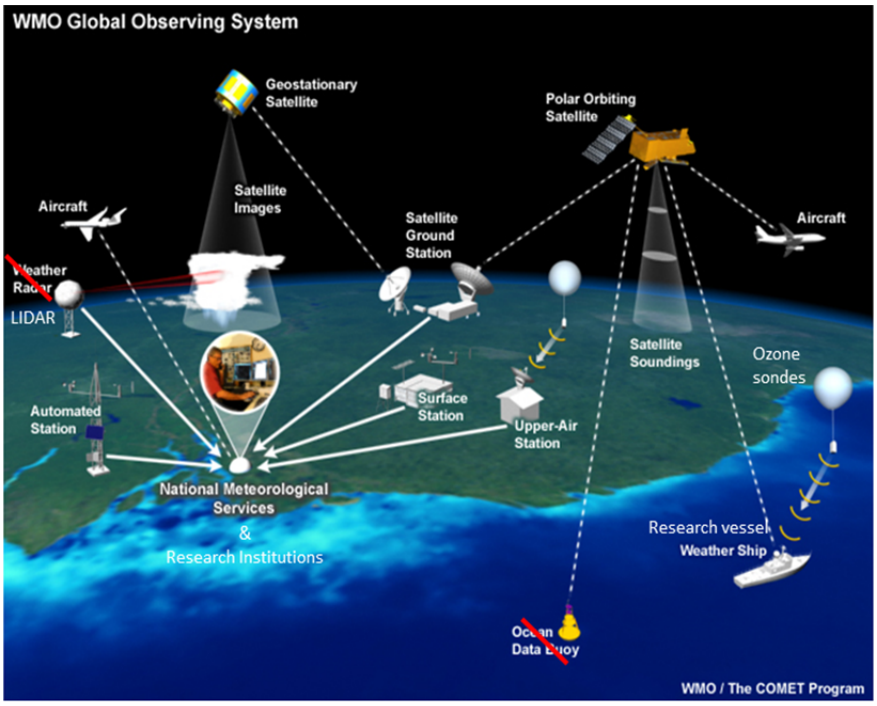

Figure 13 -WMO Global Observing System (the elements not applicable to GAW are crossed)

Local station is a new component of the GAW network. Local stations reflect the growing interest in conducting research and supporting services related to urban environments, and in other locations impacted by nearby emissions (e.g., from biomass burning). Examples of possible uses of local stations include: measurements of atmospheric composition in urban areas, determination of the increment in atmospheric composition related to nearby sources, and quantifying outflow from urban centres. These stations are also designed to be an integral component of GAW application areas with an urban focus such as air quality forecasting. Local stations complement air pollution data collected by air quality monitoring stations established by local regulatory authorities and/or may form a nucleus for building up such networks in regions which have no operational air quality monitoring in place. Local stations will provide a can be used for comparisons with regional air quality networks (serve as an anchor) - since the observations made at the GAW Local stations will be made to GAW standards, enabling when appropriate the use of observations from local networks in urban applications.

In order to obtain a complete picture of the atmospheric chemical composition, it is necessary to complement fixed-placed surface-based observations by mobile (e.g., **airborne and ship)** observations**.** A number of national aircraft monitoring networks (e.g., operated by the National Oceanic and Atmospheric Administration (NOAA) for the North America Carbon Programme, by the Japan Meteorological Agency (JMA) which conducts routine monthly aircraft observations of tropospheric greenhouse gases in the western North Pacific, and by Brazil) also contribute to the GAW observational network. These observations are augmented by

observations from various short-term research campaigns. The observing system of ground based observations would be incomplete without contribution of satellite observations that provide global coverage for many atmospheric composition parameters. So far the role of satellite observations in GAW has been quite limited. In view of many applications, the role of satellite observations will increase within the period of implementation of this plan. Satellite data on atmospheric composition are actively assimilated to improve weather forecasts, used in the air quality forecasting system as well as often used in inverse modelling for emission inventories verification.

The utility of atmospheric composition observations for use in specific analysis and applications depends on many factors. The GAW designation of a station as a global, regional, local or mobile station is an indication of the station location and also conveys information on the overall activities of the site (e.g., the number of parameters measured, history of data submission, and extent of analysis of the data). However, it is possible that a station can measure background conditions with respect to one variable while it encounters significant pollution with respect to other variables (e.g., strong influence from local ozone precursors but no CFCs or vice versa). Additional information regarding the station location with respect to local and regional pollution sources and the environment in which it is located is needed to improve the wider-spread use of GAW data. Increased efforts are needed to enhance the description of the used metadata. The standardization of such descriptions will be developed in collaboration with WIGOS.

The enhanced use of atmospheric composition information for research and applications also requires increased efforts to evolve the global atmospheric composition observing system in support of specific applications. This will be accomplished through the implementation of WIGOS and the rolling review of requirement (RRR) process (see Figure 14), where measurements should meet user requirements for quality, spatial and temporal resolution, which vary depending on the objective. The role of the RRR process is to guide Members to develop the observing system that will address their needs. The requirements formulated at the beginning of the process are technology free and help to design a system that meets requirement in a cost effective way. The RRR process was initially facilitated by the GAW Task Team on Observational Requirements and Satellite Measurements (TT-ObsReq) in partnership with the SAGs. Within the implementation period of this plan, responsibility for the RRR process will be transferred to SAGs and SSC.

The key observation-related activities within the GAW implementation period 2016-2023 are:

A-O-1. Support continued operations and the development of measurement programs at existing GAW observatories that have a solid record of achievement;

A-O-2. Make further efforts to fill gaps in global coverage of surface observations, particularly in data-poor regions like the tropics, climate and pollution-sensitive regions like the Arctic, while adapting to regional needs and seeking ways to minimize the limitations (instrumental and human resources). This entails working with the GAW observational community and contributing partners that operate networks targeting the objectives of GAW, and by improving the collaboration between the NMHSs, environmental agencies and research organizations in order to set-up new measurement sites, enhance the measurement programs at existing sites, or implement new measurement activities;

A-O-3. Investigate and develop new emerging measurement techniques and non-conventional measurement methods and the potential role these observations can play in GAW in coordination with the WMO Commission on Instruments and Methods of Observations (CIMO);

A-O-4. Enhance efforts to expand and strengthen partnerships with contributing networks, through development of statements and strategies to articulate the mutual benefits for the collaborations and stream-line processes of data reporting and exchange of QA standards and metadata;

A-O-5. Bridge across spatial scales, in particular with respect to observations of air quality relevant gases and aerosols. This involves collaboration with national and regional environmental protection agencies and the development of harmonized metadata and data exchange and quality information. Establish local stations to enable and enhance research and services in areas impacted by nearby emission sources (e.g., urban environments);

A-O-6. Further develop GAW into a three-dimensional global atmospheric chemistry measurement network through the integration of existing and stipulation of new surface-based, balloon-borne, aircraft, satellite and other remote sensing observations.

A-O-7. Enhance satellite observations as an integral part of the observing system. Work with WMO Members involved in the operation of satellites to take into consideration needs for the observations of atmospheric composition variables and share observational data with minimal delays as formulated through the user requirements in the RRR process;

A-O-8. Support the development of increased capacity to deliver near-real time (NRT) data and improve their accuracy through establishing standards and best practices, sharing experiences, and training;

A-O-9. Evolve the global atmospheric composition observing system in support of WMO application areas through the implementation of WIGOS and the rolling review of requirement (RRR) process.

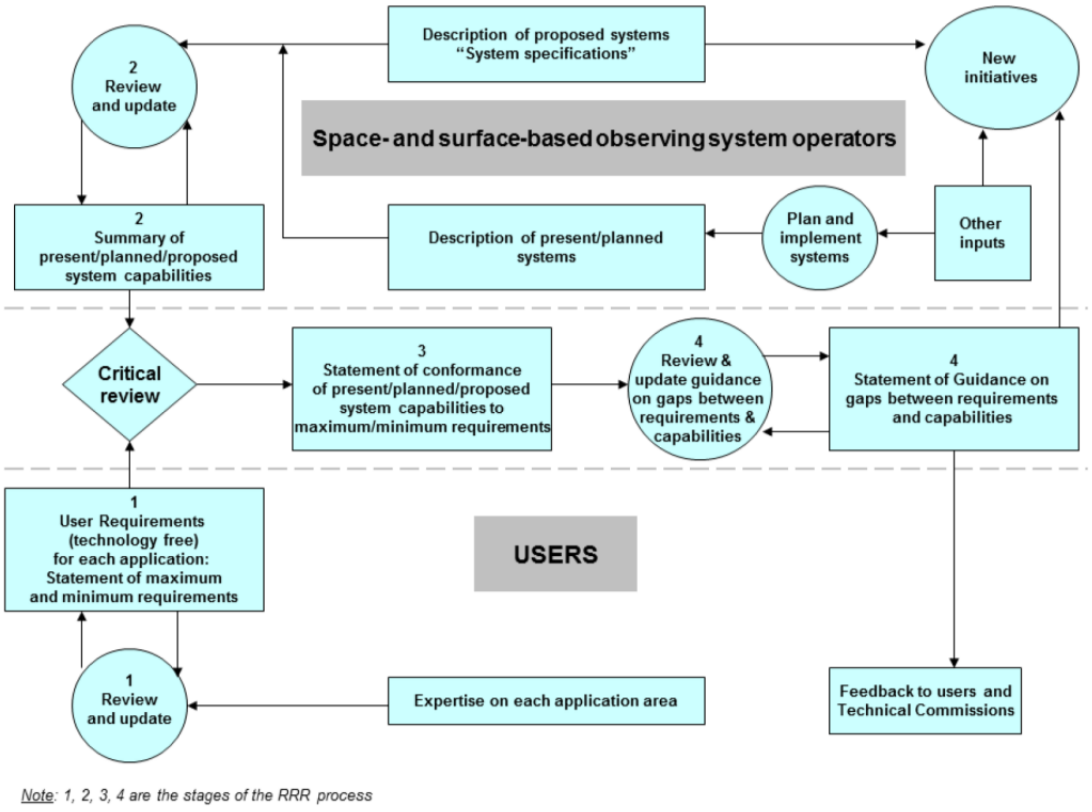

Figure 14 - The rolling review of requirement (RRR) process is used to help design observing systems to support atmospheric composition applications and services.

4.2 Quality Management Framework

Delivery of products and services of adequate quality for the intended use fundamentally relies on the quality of underlying data. Quality Assurance and Quality Control (QA/QC) activities apply to all elements of the programme starting from assignment of the network primary standards to capacity building and training of the personnel performing the measurements. The Quality Management Framework in GAW has to be implemented using the WMO Quality Management Framework (WMO-No. 1100) applied to atmospheric composition measurements.

The following activities are included in the GAW Quality Management Framework:

- assessment of infrastructures, operations and the quality of observations at the sites,
- development of documentation in support of the quality assurance system,
- establishment and support of infrastructure for network wide implementation of quality assurance and quality control (QA/QC) actions,
- documentation of data submitted to the World Data Centres (WDCs),
- training of station personnel, and
- improvement of the quality and documentation of legacy data at the WDCs.

The elements of the GAW QA/QC procedures applied to individual stations and to the whole network are shown in Figure 15.

The requirement for traceability to one network standard is driven by the incentive that "*Collecting adequate information on the chemical composition of the atmosphere and on the consequences of the anthropogenic impact on different spatial and temporal scales is valuable and possible only if all the relevant measurements are expressed in the same units and on the same scale and if data from different countries and from different sites are comparable*."

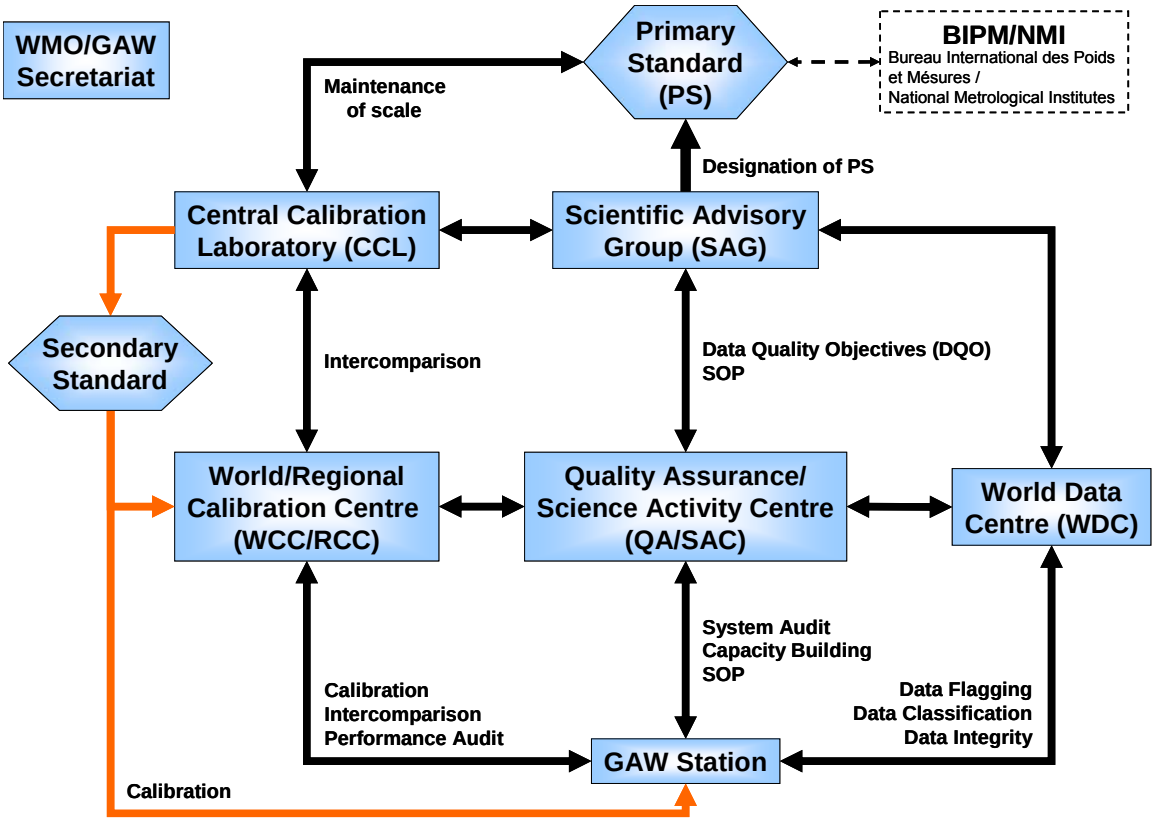

Figure 15 - Elements of the Quality Assurance system, and QA activities and workflow in GAW

Within the GAW Programme, compatibility and homogeneity of the observational network is more important than absolute calibration at the individual stations due to a number of needs, including the need to: address spatial variability of the atmospheric composition and to quantify small spatial gradients; estimate long-term trends in atmospheric composition and compare them between different countries and region; verify models and satellite measurements (done by one instrument); and calculate globally averaged concentrations for different assessments.

The objectives of the GAW QA system are to ensure that data in the WDCs are consistent, of known and adequate quality, supported by comprehensive metadata, and sufficiently complete to describe global atmospheric states with respect to spatial and temporal distribution and for use in the different applications. The details of the Quality Management Framework and supporting infrastructure are provided in Annex C.

Quality Assurance System implementation is supported by the GAW Central Facilities which are operated by the countries hosting them (the terms of reference are summarized in Section 6). These include:

- Quality Assurance/Science Activity Centres (QA/SACs) that perform network-wide data quality and science-related functions;
- Central Calibration Laboratories (CCLs) that support primary network standards and scales;
- World and Regional Calibration Centres (WCCs, RCCs) that ensure the traceability of network observations to the respective references;
- World Data Centres (WDCs) that archive the observational data and metadata;
- GAW Station Information System (GAWSIS) that serves as a database of the GAW stations and provides links to the data in WDC and contributing data centres.

For some parameters (but not all), Data Quality Objectives[2] (DQOs) have been established by the communities or by the responsible SAG. For the majority of GAW variables, measurement guidelines or standard operating procedures (SOPs) were developed by the responsible SAG, QA/SAC and/or WCC. The stations themselves have primary responsibility for the quality of the data they generate. Even after 25 years of operation, the GAW QA system continues to be incomplete, although progress has been made on all fronts. Members are encouraged to contribute resources to fill gaps not only in the observing systems, but also in the GAW QA system implementation.

The key data quality activities within this implementation period are:

A-QA-1. Standardize as much as possible DQOs and measurement methods and procedures for the primary GAW variables (see Box 8.1).

A-QA-2. Improve the quality of measurements through adjustments of methodologies, taking into consideration advancements in instrument development and calibration, and improvement of retrieval algorithms and better sharing of the metadata related to instruments calibration.

A-QQ-3. Develop homogenized guidelines for operation and calibration of instruments. Increase the value and integrity of data through thorough analysis and documentation of uncertainties of all individual measurements and provision of detailed metadata.

A-QA-4. Adopt and use internationally accepted methods and vocabulary to quantify the uncertainty in measurements [ISO, 1995; 2003; 2004]. To promote the use of common terminology, a web-based glossary is being developed (http://gaw.empa.ch/glossary/glossary.html).

A-QA-5. Continue supporting the operation, maintenance and calibration of instruments, particularly in developing countries. The continuity of instrument calibrations is an important aspect of QA/QC and the GAW Programme has made important contributions

[2] Data Quality Objective define qualitative and quantitative statements that clarify the objectives of observations, define the appropriate type of data, and specify tolerable levels of individual measurement uncertainty and/or network compatibility. DQOs will be used as the basis for establishing the quality and quantity of data needed to support decisions.

through the establishment of WCCs, RCCs and by encouraging inter-comparisons following standardized procedures. These helped to improve data quality, homogenizing data from different stations and networks. The cost of calibrations is a significant challenge, mainly in developing countries, that needs attention and creative solutions.

A-QA-6. Enhance training of personnel operating GAW stations with the aim of standardizing the operating and data control procedures for the different instruments to ensure known quality of observations.

A-QA-7. Exploit synergies originating from the use of different instruments to fill data gaps, but always ensure full consistency of the data series. Completeness of data series is important for many applications, mainly for the determination of trends.

4.3 Data Management

Observations from GAW stations and contributing networks are collected, quality-controlled and published by dedicated topical World Data Centres. These data centres include:

- World Ozone and UV Radiation Data Centre (WOUDC);
- World Data Centre for Greenhouse Gases (WDCGG);
- World Data Centre for Aerosols (WDCA);
- World Data Centre for Precipitation Chemistry (WDCPC);
- World Data Centre for Reactive Gases (WDCRG)[3];
- World Radiation Data Centre (WRDC);
- World Data Centre for Remote Sensing of the Atmosphere (WDC-RSAT).

These WDCs have been working on the harmonization of data submission and data access procedures and will continue these efforts with the joint vision of a GAW federated data management system that will allow fully interoperable access to all GAW data. Through advances in de-centralized web services and ongoing work on the standardization of metadata, the integration of individual GAW stations and contributing networks, as well as satellite data and modelling products shall be facilitated as illustrated in Figure 16. The GAW Station Information System (GAWSIS) will continue to play a central role for data discovery and detailed information on GAW stations and measurements of contributing networks. Through the new WMO OSCAR system and GAWSIS, the World Data Centres and data centres of contributing networks will become integral parts of the implementation of WIGOS, thus also facilitating data exchange across WMO programs and disciplines.

GAW will continue to liaise with other relevant actors (space agencies, environmental agencies, research networks) in order to harmonize metadata and data formats and thus facilitate the use of GAW and other data in various applications. GAW will interact with other WMO programs to ensure consistency of metadata for atmospheric composition information and work towards providing a complete service chain consisting of the discovery and provision of research driven and operational observations, model data and service applications.

[3] This data centre was established in the beginning of 2016 and is currently working with WDCGG on the transfer of historic data on Reactive Gases to it.

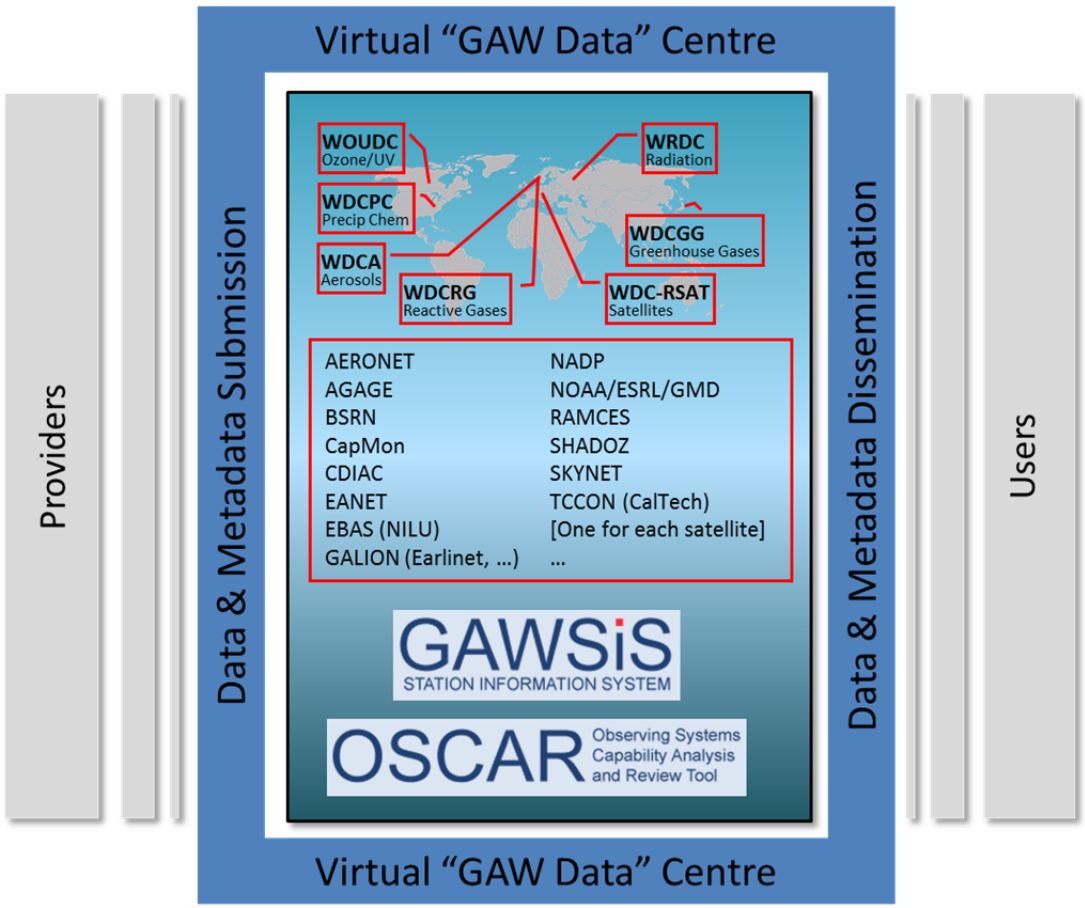

Figure 16 -The concept of the federated data management system

In order to support the application areas and activities of GAW, the adequate management and provision of data and metadata plays an essential role. The data management activities are:

A-DM-1. Establish a federated data management infrastructure including GAW Data Centres, data centers of Contributing networks, and GAWSIS.

A-DM-2. Improve open access to data and comprehensive metadata including calibration histories of ground-based, aircraft and satellite observations for the primary GAW variables.

A-DM-3. Implement a data and metadata management strategy that enables interoperable data discovery and access mechanisms and federates existing GAW data centres with data centres of contributing networks.

A-DM-4. Harmonize GAW data management activities with the WIGOS framework, in particular with regards to metadata documentation.

A-DM-5. Develop and promote support of data archiving and analysis centres that address the needs of applications and service delivery.

A-DM-6. Ensure that data collected and archived by WMO/GAW WDCs and archives of Contributing Networks are of known quality, adequate for their intended use and documented comprehensively.

A-DM-7. Deliver those variables pertinent to air quality and forecasting in NRT, using WMO GTS/WIS as it evolves into an open, decentralized and node-oriented structure. Continue to seize opportunities to expand the NRT delivery services for GAW variables.

A-DM-8. Together with GURME and Apps SAGs develop a strategy to manage the increasing flow of NRT data and to ensure the consistency and integrity of data throughout the data lifecycle.

A-DM-9. Develop data submission and data use procedures with the inclusion of uncertainties with the GAW data products, making it possible to select and use data in accordance to the criteria set out by the Rolling Review of Requirements (RRR) process.

A-DM-10. Continue to make best efforts towards program-wide adoption of digital object identifiers (doi) for GAW datasets to facilitate proper recognition of the data contributors in scientific analyses and reports and it will also allow for better monitoring of the actual data use.

4.4 Modeling and Re-Analysis

There is a strong need for further fostering atmospheric composition modelling components within GAW. The GAW mission intrinsically carries the need for complementary and integrative activities regarding measurements, scientific analysis and modeling of the chemical composition of the atmosphere. The required links are both in terms of improving the spatial/temporal coverage of observations and enhancing and, in some cases, even enabling the provision of related products and services. Numerical models in use worldwide and, consequently, their products and services could clearly benefit from using GAW observational data more widely to perform model evaluation, for assimilation in models, and to drive model development. Therefore, a modeling framework in GAW is needed to promote and facilitate integration of GAW observational datasets throughout physical and chemical processes and to support specific applications. Moreover, many user requirements cannot be addressed directly by observations (e.g. air quality forecasting) and they require a harmonized modeling approach to be implemented over the globe, the same way it is done for observations. It is through this modeling tool that services can be delivered to the Members.

The modeling framework in GAW will embrace the SAGs and expert groups, while recognizing and respecting the fact that different SAGs have intrinsic modeling needs. The SAG on Applications (SAG-Apps) will focus on applications that use NRT data delivery on scales larger than urban, including the development of boundary conditions for local modeling and improvement of models and development of services related to dust, volcanic ash and biomass burning plumes, and health applications. In addition, in collaboration with WIS/WIGOS which are ensuring dissemination of observational data, the SAG-Apps will review data systems that ensure possibility of service delivery. In liaison with WGNE and taking into consideration conclusions from the World Weather Open Science Conference, it will work towards improved representation of atmospheric composition in weather models. Furthermore, based on data assimilation, it will facilitate global uptake of “realistic” boundary conditions for regional to local air quality applications worldwide in liaison with SAG GURME. In addition, in liaison with WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS), Volcanic Ash Advisory Centers (VAACs) and other international activities, it will further foster the use of observations to better monitor and predict large-scale transport of dust, fire and volcanic emissions and their impacts.

The related key modeling-focused activities are:

A-M-1. Support, integrate and broaden GAW modeling activities by building upon GURME's experience, integrating the activities of the new SAG-Apps, and bridging the various other SAGs.

A-M-2. Extend the atmospheric composition related modeling activities to other activities within WMO. Join modeling actions of GAW with WWRP, WCRP, WGNE, etc., with links to the international atmospheric chemistry community through the:

- Exchange of model expertise and joint model development;
- Integration of model results and observations across thematic areas;
- Integration of observations with model development, including model evaluation, data assimilation and source attribution;
- Stimulation of the atmospheric chemistry community worldwide to engage it on model development beyond just the use of models;
- Identification of local/regional needs in terms of operational products and services;
- Guidance on design and implementation of local/regional atmospheric chemistry operational forecasting systems;
- Performance of global/regional model reanalysis in order to build up a multi-model database resources for model applications;
- Continued production of global/regional assessments via observation-modeling integration;
- Development of common reference on skill standards for chemical composition models and products for evaluation purposes.

A-M-3. Carry out research focused on improving the forecast of smoke and on providing data to verify forecast accuracy. Within GAW, the biomass burning focus will involve several SAGs (Aerosol, Reactive Gases, Apps and GURME). GAW will also collaborate with WWRP, WCRP, WGNE, IGAC and IBBI.

A-M-4. Improve modeling capabilities related to transport and chemical weather/air quality, and the integration of observations from different platforms with models (through collaboration with ICAP, Aerocom, and other programs),

A-M-5. Extend capabilities to utilize atmospheric composition data to improve emission estimates and to estimate trends in emissions, needed to support evaluation of policies.

A-M-6. Develop the Implementation Plan for the Integrated Global Greenhouse Gas Information System (IG^3IS). This system can serve as a tool for the observations-based information to help in planning and assessment of greenhouse gas emission reductions. As greenhouse gases have direct impact on climate, IG^3IS implementation will support GFCS. Network development is crucial for early detection of the biogeochemical cycle alterations in polar and tropical regions.

A-M-7. Expand the integration of model results in recurring measurement-model evaluations (e.g., total atmospheric deposition). These evaluations will be used to prioritize measurement needs; that is to identify where measurement-model differences are largest and of greatest potential importance and where measurements are needed to ascertain the cause/source of these differences.

A-M-8. Further develop and support services related to health and other air quality impacts at large scales, such as platforms focused on the global burden of disease and air quality impacts on agriculture, through collaborations with WHO, UNEP and other organizations.

A-M-9. Partner with relevant international organisations/groups on the development of the activity “Towards an Integrated Network for the Monitoring, Analysis and Forecast of Air Quality" (MAF-AQ), whose objective is to develop a prediction and downscaling capability to provide air pollution related products and services in regions of the world heavily impacted by high levels of pollutions (e.g., Latin America, Africa, Asia).

4.5 Joint Research Activities

New initiatives/activities will be undertaken by the GAW Programme to address the strategic priorities identified by CAS and WMO and to support the thematic research application and priority products and services discussed above. These initiatives involve collaboration across SAGs within GAW, with other programs within WMO (such as WWRP and WCRP) and with organisations outside of WMO including WHO, UNEP, International Global Atmospheric Chemistry Project (IGAC), the integrated Land Ecosystem-Atmosphere Processes study (iLEAPs), Stratospheric Processes and their Role in Climate (SPARC), International Convention for the Safety of Life at Sea (SOLAS) and some others. Joint research activities include:

A-JR-1. Develop an integrated research strategy focused on aerosols.

A-JR-2. Build upon the success of the GURME program (work within and external to WMO) to establish an integrated strategy to expand environmental services for urban environments.

A-JR-3. Enhance contributions to disaster risk reduction

A-JR-4. Support WMO’s activities related to the Climate and Clean Air Coalition, working jointly with the United Nations Development Programme (UNDP), United Nations Industrial Development Organisation (UNIDO), WHO, the World Bank and European Commission. GAW can provide atmospheric composition information in support of mitigations on the short-lived climate pollutants (SLCPs).

A-JR-5. Work with WWRP on enhancing the understanding of the role atmospheric chemistry plays in high impact weather. The HIWeather Project of WWRP aims to promote cooperative international research to achieve a dramatic increase in resilience to high impact weather, worldwide, through improving forecasts for timescales of minutes to two weeks and enhancing their communication and utility in social, economic and environmental applications. The research will focus on five hazard areas (urban floods, wildfires, localized extreme winds, disruptive winter weather, urban heat waves and air pollution) and GAW’s input will lead the research activities on two of the focus areas: wildfires and air pollution.

A-JR-6. Collaborate with WWRP on Sub-seasonal to Seasonal Prediction project (http://s2sprediction.net/), which aims to improve forecast skill and understanding of the sub-seasonal to seasonal timescale through producing a multi-model ensemble system database and assessing their skill in high impact case studies, and to promote its uptake by operational centres and exploitation by the applications community.

A-JR-7. Contribute to WWRP’s Polar Prediction project through fostering atmospheric composition observations in the Arctic. The collaboration will be through delivery of improved atmospheric composition and weather and climate forecasts for the Arctic.

A-JR-8. Further foster collaboration with the Working Group on Numerical Experimentation (WGNE). WGNE is developing numerical models and has a group on aerosols and a group on assimilation of atmospheric composition data to NWP models.

A-JR-9. Further foster collaborations between WMO/UNEP/WHO by continuing and expanding efforts to develop common communication messages regarding issues such as climate change, air quality, and health impacts, and collaborations through joint workshops and projects focused on topics such as new measurement technologies and urban and global scale analysis of air quality and climate change impacts. Formalize interactions through joint representation on various committees (e.g., the SSC).

A-JR-10. Continue efforts on water vapour as a cross-cutting activity and develop a strategy for observations and applications within GAW and in collaboration with other programmes.

4.6 Capacity development

Capacity development constitutes one of the strategic priorities of WMO for the financial period 2016-2019. It focuses on enhancement of the capacity of NMHSs to deliver on their mission by developing and improving competent human resource, technical and institutional capacities and infrastructure, particularly in developing, least developed and small island developing states.

In line with the WMO strategic plan, GAW includes elements of capacity development in all its activities. Within GAW, capacity development ranges from providing assistance with operational activities to topical/specialized workshops and direct partnering or twining between more experienced and less experienced countries, formal training programs and outreach. Support of operational activities includes training of technical staff on the operation of instruments and measuring systems and on quality assurance of these observations, and assistance and training in the analysis and interpretation of data. These activities are carried out through several mechanisms:

- formal training programs at the GAW Training and Education Centre (GAWTEC) supported by Germany;
- specialized training schools and workshops;
- training of the station personnel and knowledge exchange during station audit and comparison campaigns;
- twinning programmes and personnel exchange where new and established stations or labs are paired to fast-track the development of the new station to full operational status.

Informal guidance is also provided by SAGs on the thematic areas through provision of measurement guidelines and expert advice. GAW particularly enables capacity development for less developed nations by assisting with the development of plans and strategies to become full partners in global collaborative efforts.

The production of high quality data that can be compared across GAW stations is a fundamental goal of GAW requiring harmonization in data collection and analysis methods. Thus, calibration and intercomparison of instruments are major components of capacity building by GAW, and are carried out by the Central Facilities and the SAGs.

GAW also enhances global capacity by providing evaluated data and scientific information to society via statements, newsletters and publications. Evaluated statements by GAW are viewed as an important service to the general public and governments. As GAW's atmospheric services develop further this will become an increasingly important aspect of GAW's capacity development.

In addition to improvement of technical capacity, GAW also supports the development of service delivery capacity within the NMHS and other relevant agencies. GAW has promoted

capacity development in meteorological and air quality forecasting by its activities in GURME. This has been achieved via a sustained program of training workshops and pilot projects. Outcomes have included amongst others, the Indian Institute of Tropical Meteorology Air Quality Forecasting System (SAFAR), the Shanghai expo Multi Hazards Early Warning System and the adoption and operation by the Chilean National Meteorological Service of an air quality forecasting system.

The EPAC SSC ensures global representativeness in terms of region and gender in all GAW structures. EPAC SSC has developed a strategy to ensure capacity development on cross-cutting issues with WWRP, UNEP, WHO as well as between different SAGs. In support of the overarching mission of WMO, GAW supports WMO to effectively assist member countries in their quest for sustainable development. In addition, GAW supports students and young scientists to attend conferences and workshops.

Dedicated technical training is provided via GAWTEC. It has played an important role in the training of station personnel for more than 15 years and building the technical expertise within the countries and in establishing international networking. GAWTEC is located at the Environmental Research Station Schneefernerhaus (UFS) in Bavaria, Germany. The training is provided by experts from the GAW community. The GAW Global station "Zugspitze/Hohenpeissenberg" is used for some practical work. There are two GAWTEC training sessions every year with the duration of 2 weeks and about 10 trainees for each session. The major topics include measurement techniques (sampling, direct instrument measurements), analytical techniques (chemistry and physical measurement techniques), quality assurance and data analysis for GAW parameters.

Within the implementation period 2016-2023, the major capacity building activities are to:

A-C-1. Continue with the established capacity development mechanisms and look for other opportunities to ensure enhancement of the capacity of NMHSs and other GAW partner institutions to deliver high quality observations and services related to atmospheric composition.

A-C-2. Increase efforts to involve WMO Regional Training Centres in atmospheric composition training and ensure, where possible, availability of the training material in official WMO languages.

A-C-3. Identify synergies and pursue possible collaborations with other organizations and programmes (e.g. WWRP, UNEP, WHO) to exploit all possible training possibilities.

A-C-4. Develop a strategy to further engage Young Scientists (YS) within GAW through existing management mechanisms, and by working closely with WWRP/WCRP, to provide opportunities for YS to improve networking and leverage summer school opportunities.

A-C-5. Develop a strategy to provide further modeling-related training as needed.

4.7. Outreach/Communication

GAW is a research programme that through combination of observations, data analysis and modelling activities is well positioned to provide the scientific information required to enable services and support applications at the global, regional and urban scale. Outreach and communication efforts are required to share the latest scientific knowledge on the impact of human activity on atmospheric composition and in turn on climate, weather, air quality, human health, ecosystems and biodiversity. Enhanced efforts are also needed to sustain the credibility

and increase the visibility of GAW within the WMO community and other national/international bodies, the broader scientific and policy communities, as well as the general public.

GAW has several communication objectives, including:

- Communicate the state of the atmospheric chemical composition and its changes to inform Members, media, policy makers and the general public on environmental changes.
- Communicate the causes and effects that the changing state of the atmospheric chemical composition has on climate, weather, air quality, and human and ecosystem health using the latest scientific understanding and state-of-art knowledge of the earth system.
- Communicate the role and value of GAW as a coordination body delivering credible harmonized integrated (geographically and across focal areas) observations and analyses in support of global knowledge on the state of the atmospheric composition.
- Communicate the contribution of GAW in advancing the science and capacity for environmental predictions and promote the value of these predictions to the Members in addressing their mandate.
- Communicate the value of long-term systematic observations of atmospheric composition, of investments in atmospheric research and of open data sharing for creating high quality, policy and user relevant knowledge on the state of the atmospheric chemical composition.
- Promote products and services delivered by the programme and their value in fulfilling the mandate by WMO Members.
- Communicate the status of the programme implementation, on-going and planned activities to solicit the support and contribution from the Members towards programme operation and further developments.
- Highlight/encourage the participation and cooperation of scientific experts and organizations in GAW activities (including training).

Key GAW messages include:

- Atmospheric composition matters because it impacts climate, weather, air quality, human health, ecosystem biodiversity/sustainability, food security, etc.
- High quality observations and research needed for understanding of most pressing environmental issues require coordination at the global and regional scales.
- GAW-lead activities underpin and support a number of topical services with high societal impact that rely on information on atmospheric composition and related parameters, through the close integration of enhanced observation and modeling capabilities.
- GAW is tackling the research challenges faced by many centres in incorporating and exploiting atmospheric composition information in prediction systems (value for money).
- GAW observations are used for many applications and therefore are worth funding (value for money).
- GAW is a credible international scientific and technical programme.
- GAW provides guidance and demonstration for optimizing observational networks of atmospheric composition.

- GAW is the gateway to atmospheric composition data from GAW stations and other contributing monitoring networks.
- GAW provides products and services relevant to policy making.
- GAW helps to enhance the capacity of Members to fulfill their mandate.

GAW has many partners and the communication messages need to reflect the various audiences. The main communication focus groups include: WMO Members (NMHSs and other national (non-meteorological) agencies); other UN and international agencies; the atmospheric and broader science community, including early-career scientists; international and national policy making bodies; funding bodies (e.g., World Bank and other stakeholders); and the general public.

There is a multitude of tools that are used and can be further enhanced to communicate key messages to different audiences. One of such tools is publications. A number of important publications are coordinated by the GAW Programme. The timely publication of the annual Greenhouse Gas Bulletin which provides information for policy makers on the state of the greenhouse gases in the atmosphere before the meeting of the parties of the UNFCCC is one example. The publication of the WMO Antarctic Ozone Bulletins describing the ozone depletion over the continent during the Austral Spring season is another example, and continued efforts are needed to urge all Members that carry out observations in and around Antarctica to provide data in near-real time for use in these Bulletins. The Aerosol Bulletin is another example.

General information to Members about the activities of the programme is communicated through a regular Newsletter. The GAW Newsletter (e-zine) provides the community with news about past and future GAW meetings, new stations, updates from the Central Facilities and feature science news. More publications in support of application areas should be delivered by the GAW Programme in particular in the form of concise and clear newsletters or bulletins.

Key activities covered within this Implementation plan include:

A-OR-1. Modernization of WMO/GAW web pages (e.g. featured news, GAW expert profiles).

A-OR-2. Continue current publications (Bulletin and Newsletters).

A-OR-3. Develop news stories/ articles that feature GAW activities/products and that can be re-used in various communication vectors (website, newsletters, social media).

A-OR-4. Publish regular updates on pilot projects and their achievements.

A-OR-5. Develop a strategy for coordinating and disseminating statements pertaining to environmental events (e.g., volcanic eruption, extreme/record observations).

A-OR-6. Facilitate GAW presence at key scientific conferences, including via the co-sponsoring of specialized sessions.

A-OR-7. Implement an online seminar series via electronic subscription.

A-OR-8. Develop GAW-wide regular publication on the state of the atmospheric composition (*health of the atmosphere*) and why this matters with different emphases (e.g., climate, health, etc.).

The above tools and activities are to be coordinated and disseminated by the GAW Secretariat with content contributions from the GAW community.

5 PARTNERSHIP

As the GAW Programme is an integral part of the WMO activities, the major focal points and contributors within Member countries are National Meteorological and Hydrological Services. They are responsible for co-ordination of national activities on behalf of GAW, including those of research institutes and other organizations. About 100 Member countries are participating in the GAW measurement and research activities and the number is growing. The responsibility for operation of the stations and GAW Central Facilities lies with the participating countries. National responsibilities for environmental activities are frequently not entirely within the jurisdiction of the NMHSs. Inclusion of services related to atmospheric composition or improved collaboration with the other national agencies involved in such services provides an opportunity for NMHSs to increase their relevance within the country. GAW is also linked to a larger international scientific community. All GAW activities depend on collaboration, resource sharing, and interaction with many other partner organizations and networks. The major objective of this plan in relation to partnership is to build, reinforce and improve the mutually beneficial partnership with the organizations and initiatives working on the similar or closely related issues as the GAW Programme with the aim to improve the products and services delivered to Member countries.

Examples of GAW partners and collaborating organizations are listed below:

- United Nations Environment Programme (UNEP)
- World Health Organization (WHO)
- International Atomic Energy Agency (IAEA)
- World Bank
- International Oceanographic Commission
- Bureau of International Weights and Measures (BIPM)
- Committee for International Weights and Measures (CIPM)
- United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollution (UNECE-LRTAP)
- Arctic Monitoring and Assessment Programme (AMAP)
- International Commission on Atmospheric Chemistry and Global Pollution (iCACGP)
- International Global Atmospheric Chemistry Project (IGAC)
- The integrated Land Ecosystem-Atmosphere Processes study (iLEAPs)
- International Ozone Commission (IOC)
- Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)
- Stratospheric Processes and their Role in Climate (SPARC)
- International Convention for the Safety of Life at Sea (SOLAS)

Within the WMO Secretariat, the Atmospheric Environment Research Division provides the operational support for GAW. It coordinates with other WMO programmes such as the World Weather Research Programme (WWRP), the World Climate Research Programme (WCRP), the Global Climate Observing System (GCOS), WIGOS project office, the Education and Training Programme (ETR) and the other relevant entities. The Secretariat, under the institutional guidance of the appropriate WMO bodies, is in continual contact with the NMHSs in

the participating countries, WMO Technical Commissions and Regional Associations, the various GAW Central Facilities, and the relevant international organizations and programmes. Key activities covered within this Implementation Plan include:

A-P-1: Revitalization and establishment of joint activities with the partners outside of WMO related application areas as listed in this plan.

A-P-2: With the help of the partners, develop the resource mobilization strategy that will ensure continued operation of the GAW Programme with a special emphasis on the atmospheric composition related service delivery.

A-P-3: Encourage the continuous operation of the existing GAW central facilities and stations by GAW partners (including NMHSs) on the basis of commitments to WMO (Technical Regulations, vol. 1).

A-P-4: 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.

A-P-5: Encourage all NMHSs and other interested national organizations to establish internal co-operation between appropriate laboratories and institutes, especially with National Environmental Protection Agencies, Health Authorities and national development agencies.

A-P-6: Encourage partners to develop services and products related to atmospheric composition in collaboration with GAW.

6 TERMS OF REFERENCES

6.1 Scientific Advisory Groups (SAGs) and Expert Team

The following SAGs and Expert Team (ET) have been established under the GAW Programme:

- SAG on Total Atmospheric Deposition
- SAG on Reactive Gases
- SAG on UV Solar Radiation
- SAG on Aerosol
- SAG on Ozone
- SAG on Greenhouse Gases
- SAG on Near Real Time Applications
- GAW Urban Research Meteorology and Environment SAG
- ET on World Data Centres

General Terms of Reference of SAGs were defined by the Commission for Atmospheric Sciences at its 16th session in 2013 (WMO-No. 1128). Every SAG satisfies the general terms of reference. The sections below reflect specific activities related to the scientific focus of each SAG.

6.1.1 SAG on Total Atmospheric Deposition (SAG TAD)

The focus of the SAG TAD (formerly named SAG on Precipitation Chemistry) was recently expanded to include dry and total deposition in order to reflect current scientific knowledge that total (wet plus dry) atmospheric deposition characterizes the exchange process between the atmosphere and the underlying surface, while precipitation chemistry and wet deposition capture only part of this exchange. The goal of the SAG TAD is to provide a more comprehensive understanding and quantification of total atmospheric deposition, which is of critical importance for satisfying the needs of the Global Atmosphere Watch (GAW) Programme and for understanding contemporary and emerging environmental issues.

Specific activities

TAD-1. Encourage the archival and dissemination of global precipitation chemistry and deposition data via the World Data Centre for Precipitation Chemistry (http://www.wdcpc.org/) and guide WDCPC on the development of the user interface for data and products dissemination.

TAD-2. Harmonize precipitation chemistry and deposition measurement data and deposition calculation methods obtained by national and regional programs via the establishment and update of guidelines, data quality objectives and standard operating procedures (for all chemical compounds of interest), and the ongoing evaluation of and improvement of laboratory performance via the GAW Interlaboratory Comparison Studies and other related activities in collaboration with QA/SAC.

TAD-3. Assist regional programs with the implementation of new sites and field, laboratory and data management operations.

TAD-4. Establish links with other scientific topics, issues, communities, international programmes and SAGs;

TAD-5. Facilitate joint activities with other major environmental science activities including ambient aerosol and gas monitoring, atmospheric modeling, ecosystem effects research, climate research, etc.;

TAD-6. Outreach to other scientific and non-scientific communities regarding the state of science related to atmospheric deposition of major ions and other chemicals, as well as proper understanding and use of measurement data;

TAD-7. Provide training and support capacity development activities;

TAD-8. Quantify patterns and trends of the composition of precipitation and total deposition on global and regional scales;

TAD-9. Communicate availability of GAW observations to user communities, including ecosystem effects and atmospheric modeling communities;

TAD-10. Develop, improve and apply inferential methods to estimate dry deposition;

TAD-11. Research measurement-model fusion methodologies to obtain total deposition estimates;

TAD-12. Improve understanding of atmospheric deposition of chemical species of existing or emerging interest (e.g. organic acids, black carbon, metals, phosphorus, mercury, nitrogen).

6.1.2 SAG on Reactive gases (SAG RG)

The SAG on Reactive Gases will continue to focus on aspects related to tropospheric ozone chemistry with emphasis on tropospheric ozone itself and the precursor gases nitrogen oxides (NO and NO_2), carbon monoxide (CO), and selected volatile organic compounds (VOCs) as well as on sulfur dioxide (SO_2). These gases play an important role as short-lived greenhouse gases, air pollutants, and substances affecting agriculture and natural ecosystems.

Specific activities

RG-1. Promote/facilitate the expansion of reactive gases observations in undersampled regions, i.e. primarily in the tropics and in the Southern hemisphere, in order to fill large gaps in the global observation network of reactive gases.

RG-2. Improve integration of observations of reactive gases from national and regional air quality monitoring networks and GAW stations on all spatial scales into central metadata and data portals (see for example the Tropospheric Ozone Assessment Report database of surface ozone observations established in Jülich, Germany; https://join.fz-juelich.de).

RG-3. Increase efforts to obtain a fully integrated view of the tropospheric reactive gases content through integration of aircraft and satellite observations with surface measurements in model systems and data analyses.

RG-4. Maintain and improve the quality and long-term stability of reactive gases measurements via constant surveillance of available and emerging measurement techniques and the development of standard operating procedures for these.

RG-5. Extend the target species of the GAW reactive gases programme to include other substances relevant for global biogeochemical cycles (eg. nitrogen or sulfur cycle) and those substances that are important to advance our understanding of tropospheric ozone chemistry. A necessary requirement for taking up new measurements within GAW RG will depend on availability of suitable measurement technologies and calibration methods.

RG-6. Work together with the SAGs on aerosol, total atmospheric deposition and applications to develop integrated analyses targeting great global challenges such as the nitrogen cycle, air pollution impacts on agriculture and natural ecosystems, and the role of short-lived climate forcers on regional weather and climate.

RG-7. Increase the use of GAW RG observations by establishing atmospheric composition and forecasting applications (e.g. Copernicus Atmosphere Monitoring Service), and collaborating with global and regional assessment activities (e.g. TOAR, TFHTAP) and with other WMO programmes (eg. Agricultural meteorology or WWRP).

6.1.3 SAG on UV solar radiation (SAG UV)

The radiation component of GAW has concentrated its efforts on UV radiation, while specialized WMO programs have dealt with other aspects of solar radiation (for example, radiation measurements are part of the WMO Commission on Instruments and Methods of Observation (CIMO)). Objectives of the SAG UV are directed to study temporal and climatological variations in UV derived from variations in cloud cover and type, earth reflectivity (albedo), aerosols and ozone. Since UV radiation is linked to health issues, ecosystem effects and material damage, the need for quantifying these changes is of interest to many user communities.

Specific activities

UV-1. Encourage long term UV measurements as well as measurements of all parameters involved in its future changes as a consequence of global change, intense episodic events and stratospheric ozone changes.

UV-2. Promote the establishment of new monitoring site installations, particularly in regions where data is sparse or inexistent.

UV-3. Encourage the archival of UV data at the WOUDC, in Toronto, Canada, and work with the other databases to ensure delivery of integrated data products.

UV-4. Improve data quality by producing documents to help accomplish QA/QC requirements, guiding the activities of the World Calibration Center for UV, encouraging satellite data validation, and promoting intercomparisons and the establishment of new Regional Calibration Centers.

UV-5. Promote activities with other scientific communities, international programmes and SAGs.

UV-6. Contribute environmental data for atmospheric, health and ecosystems studies.

UV-7. Encourage the use of UV Index for public information.

UV-8. Follow improvement of existing instruments and development of new ones.

6.1.4 SAG on Aerosol

The goal of the SAG on Aerosol is to implement the aerosol measurement programme in GAW in order to determine the spatio-temporal distribution of aerosol properties related to climate forcing and air quality on multi-decadal time scales and on regional, hemispheric and global spatial scales.

Specific activities

AER-1. Coordinate and ensure that the aerosol measurement program of the GAW network is operated with the right level of quality, responding to user needs for the provision of aerosol variables as listed in GAW Report # 153.

AER-2. Promote new monitoring station installations, particularly in regions where data are sparse or inexistent and supervise the categorization of stations according to Appendix B.

AER-3. Improve data quality by producing documents to help accomplish QA/QC requirements, encouraging the stations participating in the programme to perform calibration in the World Calibration Center for Aerosol, and promoting intercomparison exercises and the establishment of new Regional Calibration Centers.

AER-4. Promote activities of the World Data Center for Aerosol, located at NILU, Norway and enforce application of the GAW/WDCA data management plan.

AER-5. Guide WDCA in providing user groups with free and open access to all data, complemented with access to innovative and mature data products, together with tools for quality assurance (QA), data analysis and research, following WIGOS policies in particular with regards to metadata documentation.

AER-5. Encourage submission of aerosol observational data to GAW WDCA and promote actions to facilitate services offered by WDCA to data providers, including training on data management.

AER-6. Promote provision of GAW aerosol data in Near Real Time in response to user needs for evaluation of Re-analysis of Climate/Chemistry model performances.

AER-7. Organize and implement the Aerosol measurement training program in coordination with GAWTEC and with contributing GAW networks.

AER-8. Promote better coordination of the regional networks worldwide and contribute to the establishment of regional networks whenever they do not exist. In particular, maintain and develop activities of the GALION network and promote establishment of an International Network for Near-Surface observations as recommended by GAW report #207

AER-9. Promote activities with other scientific communities, international programmes and SAGs.

AER-10. Develop and promote applications targeting global great challenges in particular in relation to air quality forecast and climate prediction.

6.1.5 SAG on Ozone (SAG O3)

The function of the SAG O3 is to keep the WMO and GAW informed of the developments and requirements of the world-wide community studying atmospheric ozone with respect to understanding weather, climate changes and ozone depletion. As the community consists of both data producers and users, this group acts as a conduit between the community members and the WMO so that the observational program can be supported in a manner appropriate to the WMO mission.

Specific activities

O3-1. Follow closely the scientific and technical activities and developments associated with atmospheric ozone. Inform and advise the Environmental Pollution and Atmospheric

Chemistry Scientific Steering Committee (EPAC SSC) and the WMO Secretariat on developments, priority areas and progress in this field, taking into consideration user requirements.

O3-2. Implement recommendations, tasks and projects related to ozone as defined in the GAW Implementation Plan.

O3-3. Review regularly the status of the ozone monitoring network and calibration centres operating under GAW, and advise on further improvement of the observational capacity, in order to ensure global coverage, continuous operation of stations in the long-term, quality of data, and timely data availability.

O3-4. Monitor the activities of regional calibration centres for ozone measurements and promote and assist participation of station instruments to intercomparison campaigns.

O3-5. Monitor and issue recommendations on submission of ozone data to the World Ozone and UV Data Center (WOUDC).

O3-6. Review the development of new and improvement of existing instrumentation and methods for monitoring atmospheric ozone, including processing algorithms, and, when necessary, form working groups to address specific issues.

O3-7. Develop and maintain SOPs for instruments and data processing and submission for instruments operating under GAW

O3-8. Foster synergies among stations and collaborations with other relevant monitoring networks and the satellite community.

O3-9. Support combined use of ground-, satellite-, and aircraft-based observations, as well as model simulations in order to obtain the best information on atmospheric ozone.

O3-10. Assess community needs and promote development of products and services for different application areas engaging also WMO Data Centres.

6.1.6 SAG on Greenhouse Gases (SAG GHG)

The objective of the SAG GHG is to ensure the coordination of the observational network that provides long-term "climate-quality" data on trends and spatial distributions of long-lived (LL) GHGs and related tracers. Data are used to calculate changes in radiative forcing since the pre-industrial era, to constrain LLGHG budgets of emissions and losses at global to regional spatial scales, and to verify bottom-up emission inventories and process models.

Specific activities

GHG-1. Advise EPAC SSC and WMO Secretariat on the role that Greenhouse Gases play in the climate system and in carbon cycle research. Guide the development of activities in this area of research in GAW, in particular evaluate the role of Greenhouse Gases research in support of the Global Framework for Climate Service.

GHG-2. Accommodate necessary internal consistency (compatibility) among data contributed by partners through use of common standard scales maintained by Central Calibration Laboratories, participation in standard and sample comparisons (e.g., international comparisons of standards and station audits organized by World Calibration Centers), and following practices recommended by the LLGHG measurement community at biennial meetings.

GHG-3. Strongly encourage GAW participants to maintain a data management strategy that accommodates necessary standard based metadata and facilitates annual updates at the World Data Center for Greenhouse Gases.

GHG-4. Stimulate the expansion of the in situ LLGHG measurement network at Earth's surface and vertical profiles, particularly in data-poor regions like the tropics, climate-sensitive regions like the Arctic, and other regions where observations are used to verify compliance with emission-reduction treaties.

GHG-5. Provide the necessary data for evaluation of retrievals of GHG distributions from satellite radiance measurements, which are short-term, low-precision, and subject to bias.

GHG-6. Support the development of improved atmospheric transport models, which are used to calculate fluxes from GAW measurements, with systematic and compatible measurements of the spatial distributions of transport tracers such as SF_6 and ^{222}Rn.

GHG-7. Assist in the establishment of the Integrated Global Greenhouse Gas Information System (IG3IS) working with the partner organizations and communities (including ocean, biospheric and urban communities).

GHG-8. Stimulate the development of user oriented products and services. Support outreach activities and in particular assist in the preparation and publication of the Annual Greenhouse Gas Bulletin.

6.1.7 SAG on Applications (SAG-Apps)

As a first step to enhance modeling activities, the Expert Team on Near-Real-Time Chemical Data Transfer was transformed into a SAG on Applications (SAG-Apps) focused on modeling. The main objective of the SAG-Apps is to develop a portfolio of the modeling products and services related to atmospheric composition. A more particular objective is to demonstrate the usefulness of exchanging chemical observational data in Near-Real-Time in support of monitoring and forecasting applications.

Specific activities

Apps-1. Implement the SAG-Apps and develop its activities plan with special attention to close interaction with the other SAGs.

Apps-2. Address applications that use NRT data delivery on scales larger than urban, including the development of boundary conditions for local modeling; and improvement of models and development of services related to dust, volcanic ash and biomass burning plums and health applications.

Apps-3. Work in close collaboration with WIS/WIGOS to review data system to ensure possibility of service delivery.

Apps-4. Improve NWP through better representation of atmospheric composition. This will require liaising with WGNE.

Apps-5. Based on data assimilation, facilitate global uptake of "realistic" boundary conditions for regional to local air quality applications worldwide in order to demonstrate that such boundary conditions make a quantitative difference when implementing local air quality forecasting applications. This will require liaising with SAG GURME.

Apps-6. Advise respective communities on the techniques to assimilate atmospheric composition observations to better monitor and predict large-scale transport of dust, fire and volcanic emissions and their impacts. This will require liaising with groups like SDS-WAS, IGAC&GEIA, VAACs.

Apps-7. Further develop and support health and other air quality impacts related services at large scales such as platforms focused on the global burden of disease and air quality impacts on agriculture, through collaborations with WHO, UNEP and other organizations.

6.1.8 GAW Urban Research Meteorology and Environment SAG (*GURME SAG)*

The GURME SAG will continue to focus on the development of models and associated research activities to enhance the capabilities of the NMHSs in providing urban-environmental forecasting and air quality services of high quality, illustrating the linkages between meteorology and air quality. In support of WMO's integrated urban services initiative and the creation of the SAG-Apps, the GURME SAG's focus is now centred on models and applications applicable to describe the urban environment and how these environments interact with the regional and global scales. Activities within GURME will expand beyond its experience and strengths in air quality to a broader coordination and facilitation of integrated forecasting projects for the urban environment where the health of citizens is the main driver.

Specific activities

GURME-1. Address the research barriers to advance the predictive capacity at increasing resolutions, and in the urban context in particular: through the coordination of reviews in the current state of science in urban-scale forecasting and associated monitoring, establish activities where gaps exist

GURME-2. Develop activities on those research questions/issues that transcend disciplines and require leveraging a broader community to develop improved forecasting concepts and tools to resolve complex urban environments at increasing scales; facilitate data sharing and establishment of test beds.

GURME-3. Given the integrative nature of modeling, the on-going scientific trend towards seamless predictions and the evolution of technology, actively engage other WMO advisory and working groups within WWRP, GAW and the rest of its organisation, to address this complex and multidisciplinary challenge.

GURME-4. While megacities will continue to receive particular attention, orient its research to cover the full array of urban environments that are key to the broader scientific question of urban-scale modelling.

GURME-5. Collaborate explicitly with the SAG-Apps on projects at the interface of regional and local scales and contribute actively to facilitating data assimilation efforts focused on integrated/coupled models and at finer and finer scales.

GURME-6. Continue to nurture its engagement with the health community as the main partner in assessing the needs, evaluating the benefits and communicating resulting services to society within these urban environments.

GURME-7. Build capacity through its research projects, identifying those environments that constitute gaps in the overall directions of the GURME program and encourage in its projects the development and testing of derived services. The products themselves

would take the form of forecasts, alerts and warnings and/or real-time/NRT maps or databases.

GURME-8. Forge stronger collaborations with CBS and/or individual operational centres to transition products in dissemination systems in a form that is well suited for large or targeted audiences.

6.1.9 Expert Team on World Data Centres (ET-WDC)

ET/WDC-1. Take responsibility for metadata and data management issues in support of the scientific and operational objectives of GAW.

ET/WDC-2. Work with the SAGs, WMO expert teams and partners to establish harmonised data management guidelines, including standardised data formats to allow for adequate (seamless) interoperability.

ET/WDC-3. Guide and support the further development of GAWSIS as the central catalogue of observing facilities and observations supporting GAW, linking the World Data Centres and Contributing Data Centres.

ET/WDC-4. Keep abreast of and recommend best use of changing technologies affecting information management within GAW.

6.2 GAW Central Facilities

6.2.1 Central Calibration Laboratories (CCLs)

WMO/GAW primary standards can be realized in the form of the calibration mixtures or the primary reference instrument or method of observation.

CCL-1. Host in the long term (many decades) the GAW primary standard and scale for a particular variable.

CCL-2. Serve the needs of the other quality assurance facilities and activities of GAW.

CCL-3. Prepare or commission laboratory standards required by the GAW network members for calibration purposes.

CCL-4. Supply well-calibrated reference materials in to GAW analytical laboratories as needed for conducting inter-comparisons of standards (in collaboration with the World or Regional Calibration Centres) where appropriate.

6.2.2 Quality Assurance/Science Activity Centres (QA/SACs)

QA-1. Provide an operating framework for GAW quality assurance activities and calibration facilities for a specific variable and geographical area of responsibility (world, regional, national).

QA-2. Coordinate the activities of WCCs and RCCs in the area of their responsibility.

QA-3. Provide advice and support for the local QA system at individual GAW sites.

QA-4. Where appropriate, coordinate instrument calibrations and inter-comparisons and other measurement activities.

QA-5. Perform or oversee regular system audits at GAW sites.

QA-6. Provide training, long-term technical help, and workshops for station scientists and technicians.

QA-7. Promote the scientific use of GAW data, and encourage and participate in scientific collaboration.

6.2.3 World and/or Regional Calibration Centres (WCCs, RCCs)

W/RCC-1. Assist Members operating GAW stations to link their observations to the GAW primary standard.

W/RCC-2. 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.

W/RCC-3. Maintain laboratory and transfer standards that are traceable to the primary standard.

W/RCC-4. Perform regular calibrations (where appropriate), organize comparison campaigns and performance audits at GAW sites using transfer standards in co-operation with the established RCCs.

W/RCC-5. Provide, in co-operation with the QA/SACs, training and long-term technical help for stations.

6.2.4 World Data Centres (WDCs) and Contributing Data Centres (CDCs)

WDC-1. Provide adequate archiving facilities for observational data for which GAW has global coordination responsibilities.

WDC-2. Contribute to the agreement of standards for interoperability of data archives through the Expert Team on GAW World Data Centres (ET-GAW WDCs). This also includes support for the establishment of harmonized guidelines and data formats for the submission and dissemination of atmospheric composition data, metadata and products.

WDC-3. Support and participate in the establishment of a distributed data management system involving all WDCs, the archives of Contributing Networks, and GAWSIS as the central metadata repository for discovery and access purposes.

WDC-4. 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.

WDC-5. Perform plausibility and consistency checks on submitted data, flag data problems, and provide feedback to the data providers, when necessary.

WDC-6. Continually improve the ease of access to data of known quality by evolving WDC operations in line with the development of WIGOS and with particular attention to the increasing needs for NRT data services.

7 APPLICATIONS AND SERVICES RELATED TO ATMOSPHERIC COMPOSITION

Climate change – It is recognized that variations of atmospheric composition change the budget of atmospheric radiation and drive climate change. Understanding of radiative forcing requires global observations of climate forcing agents and the processes related to their interaction with radiation. GAW's role in monitoring trends in reactive gases, greenhouse gases, ozone and aerosol has been and will remain instrumental in characterising the global impact of these constituents on the global radiation budget. Further efforts are required to improve the understanding of aerosol impacts on climate to reduce the uncertainty in the estimates of global and regional radiative forcing. The improved estimates of the radiative forcing will contribute to climate change related services. Observations are used to assess the skill of climate models (over the past decades), an essential validation step before using these models for future projections and as the basis of climate service applications. To assist Members in negotiating reduction of emissions of the climate forcers and in support of the Nationally Determined Contributions (NDCs), research is needed to characterise surface fluxes of the key greenhouse gases and to attribute them to the specific action on related emission sources. GAW will lead the development of the Integrated Global Greenhouse Gas Information System (IG^3IS) which will be able to provide such services to Member countries. IG^3IS can also be used to assess how the changes in different practices, e.g. land use changes, can help to mitigate increased quantities of carbon entering the atmosphere.

The impact of water vapour in a changing climate is also an area of uncertainty that GAW will take into consideration. Climate change mitigation strategies now consider shorter lived climate forcers (aerosol, certain reactive gases) so that the characterization of their physical, radiative and chemical properties is now essential. GAW activities will support and further develop climate related services through improvements of observational network and supporting modeling tools. GAW will provide high-quality data and products to improve our understanding of air quality under a changing climate and will allow higher quality forecasts of future climate (of particular relevance to WCPR). The climate services developed within GAW will support implementation of the Global Framework for Climate Services.

Urban services (air quality & health) – Currently 54% of the worldwide population lives in cities and, by 2017, it is expected that more than half of the population of less developed nations will be living in cities. The urban environments will be amongst the most susceptible to weather-driven disastrous events, from flooding and air pollution to storms and severe weather, both in terms of safety and socio-economic impacts. Comprehensive prediction systems at the urban scale have the potential to help build resilience for these urban centres and provide early warning systems for a full suite of weather and environmental conditions. GAW/GURME has an important role to play in the development of these urban scale modelling systems which need to tightly couple meteorology, atmospheric composition, hydrology and climate processes. The energy efficiency component of urban services will be enhanced through the urban component of IG^3IS. While the urban health issues are of particular interest to GURME, urban systems that can be envisioned for real-time forecasting are just emerging. In coordination with WWRP amongst others, GURME will facilitate initiatives and pilot projects that advance the understanding and modelling of urban processes and their prediction. In step with the development of urban systems, GURME will work with others to define the observation systems that can support the evaluation and eventually assimilation at these scales.

Working with the relevant communities, especially WHO, is essential to make effective progress in providing information that is relevant for mitigation and adaptation policy

implementation. GAW will continue to support air pollution and related services, including environmental forecasting, and expand its efforts through collaboration with WHO and other entities to support health-related services for megacities and large urban complexes. GAW community will work towards development of observational systems (including emerging measurement techniques and new health related tracer measurements) and modeling tools that can be used by the health community for the assessment of impacts of atmospheric composition changes on humans. Further efforts will be made through joint activities with WHO to develop more comprehensive health impact indicators.

Ecosystem services – Natural ecosystems are both a source and a sink of atmospheric compounds. With the exception of carbon-cycle related studies, a few connections have been established between the communities working on atmospheric composition and on ecosystems. GAW will support consolidating knowledge on how deposition, ambient levels of trace constituents as well as radiation and meteorological parameters influence ecosystems and on feedback processes. One of the potential services will address nitrogen cycle.

Food Security – GAW needs to enforce the links between atmospheric composition research and agricultural studies, investigating for instance how deposition of atmospheric constituents (and their different cycles) my affect the health of the biosphere and in return how emissions of volatile hydrocarbons or the efficiency of dry deposition processes impact atmospheric chemical composition. GAW also recognizes that changes in atmospheric composition have numerous two-way links with agriculture (e.g., the use of fertilizer is the main reason for increasing N_2O emissions, which is a greenhouse gas as well as a threat to stratospheric ozone). Linking agriculture and atmospheric composition can serve as a basis for bio-cycle services. Joint activities between agro-meteorology and GAW activities, especially in the context of the food security focus of the Global Framework for Climate Services, will be enforced.

Conventions and treaties – Like the Montreal protocol and its amendments, the Convention on Long-Range Transboundary Air Pollution, and the United Nations Framework Convention on Climate Change (UNFCCC via GCOS) require observations of different atmospheric constituents at the global and regional scales on a long-term basis. Only long-term observations can confirm the efficacy of the actions taken by environmental conventions and protocols. Assimilation/re-analysis products are essential to develop an integrated picture of the changes and efficiency of measures implemented. GAW will enhance its activities related to policy facilitation by supporting Members to continue observations and to document the state of the atmosphere in their countries.

ANNEX B

8 STATION AND NETWORK DEFINITIONS AND OPERATIONS

8.1 Station and contributing network requirements

The designation of observation sites as global, regional, local or mobile stations provides some indication about the station location while at the same time expressing a certain comprehensiveness of the measurement program conducted at these sites.

Requirements for GAW Regional stations in particular include:

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 or at least frequently experiences advection of pollution-free air from specific wind directions.

2. There is a commitment by the responsible agency to long-term observations of at least two variables in at least one GAW focal areas (ozone, aerosols, greenhouse gases, reactive gases, UV radiation, precipitation chemistry/total deposition). To address measurements for multiple applications in more than one focal area are recommended.

3. Adequate power, air conditioning, communication and building facilities are provided to sustain long term observations with greater than 90% data capture[4] (i.e. <10% missing data).

4. Standard meteorological in situ observations (at least temperature, humidity, air pressure, and wind speed and direction), necessary for the accurate determination and interpretation of the GAW variables, are made of known quality.

5. Technical staffs are trained to operate station equipment.

6. GAW observations are of known quality, follow GAW Quality Assurance principles and procedures, linked to the GAW Primary Standard where applicable and use the measurement methods recommended[5] by GAW.

7. 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.

8. The data and associated metadata must be submitted to one of the GAW World Data Centres at least on a yearly basis documenting Year N no later than end of Year N+1. Changes of metadata including instrumentation, traceability, observation procedures, must be reported to the responsible WDC and GAWSIS in a timely manner following the WIGOS metadata standards.

9. If feasible, data are submitted to a designated data distribution system in near-real-time.

[4] Data capture referred to the total number of observations possible/feasible to perform within the period of time given the frequency of observations. It refers to minute/hourly values for continuous observations and to the total number of measurements per month for discrete sampling (e.g. flask collection or remote sensing measurement techniques).

[5] The ultimate goal is to reach GAW Data Quality Objectives where those were set up by the community.

Requirements for Global Stations

These stations primarily observe GAW variables under background conditions, i.e. without permanent significant influence from local pollution sources. In addition to fulfilling the requirement of GAW Regional stations, Global stations must fulfill the following:

1. Measure at least two variables in at least three of the six GAW focal areas with the full implementation of GAW's Quality Assurance system (Box 8.1).
2. 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.

   a. The stations should have a confirmed track record of research campaigns and/or scientific products (within last 3 years) as a Regional station.

   b. The measurements at the station have been audited or the quality of the measurements has been documented through other means of verification.

   c. The data from at least two variables in at least three focal areas have been submitted to the respective World Data Center(s) during at least three years within the data submission period of 1 year after measurement.
3. 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.
4. In case the measurements of some GAW variables are occasionally influenced by local pollution, the station shall subject the data to appropriate filter methods to extract the background concentrations and submit both a filtered and an unfiltered time series to the WDC. Also the station metadata on GAWSIS should describe the conditions under which pollution influences may be found and describe the applied filter methods.

Requirements for Mobile stations

Mobile [6] station is the station that uses moving platforms to perform atmospheric composition observations (aircraft, ship, train etc). In general the sitting requirements do not apply to this category of observations. The measurement techniques could be modified from the recommendation in GAW to ensure instruments accommodation at the platform. The Quality Assurance practices recommended for other categories of GAW stations should be followed. The goal is to achieve the observations which are compatible with the stationary platform to ensure the use of mobile stations data in global analysis and assessments.

Requirements for Local stations

Local stations reflect the growing interest in conducting research and supporting services related to urban environments, and in other locations impacted by nearby emissions (e.g., from biomass burning). GAW local stations are to satisfy the same requirements as for regional stations except for the sitting requirement.

[6] Observations using atmospheric balloons are not considered as mobile station if the launch takes place from the regular location.

Box 8.1 Recommended GAW measurement variables

- *Ozone:*
  - column (total) ozone,
  - ozone vertical profiles with a focus on the stratosphere and upper troposphere;
- *Greenhouse gases:*
  - carbon dioxide CO_2 (including Δ14C, $\delta^{13}C$ and $\delta^{18}O$ in CO_2, and O_2/N_2 ratios)
  - methane CH_4 (including δ13C and δD in CH4)
  - nitrous oxide N_2O (including isotopologues)
  - halogenated compounds and SF_6
- *Reactive gases:*
  - surface and tropospheric ozone
  - carbon monoxide (CO)
  - Volatile Organic Compounds (VOCs), including Ethane, Propane, Acetylene, Isoprene, Formaldehyde, Terpenes, Acetonitrile, Methanol, Ethanol, Acetone, DMS, Benzene, Toluene, Iso and normal Butane, Iso/normal Pentane
  - nitrogen oxides (NOx, NO and NO_2)
  - sulphur dioxide (SO_2)
  - molecular hydrogen (H_2)
- *Atmospheric total deposition*[7]*:*
  - pH of wet deposition
  - Conductivity of wet deposition
  - Alkalinity of wet deposition
  - chemical composition of wet deposition (Cl-, NO_3^-, SO_4^{2-}, NH_4^+, Na^+, K^+, Ca^{2+}, Mg^{2+}, Organic Acids, NO_2^-, F^-, PO_4^{3-})
- *UV Radiation;*
- *Aerosol*
  - 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 at various wavelengths
  - Light scattering and hemispheric backscattering coefficient at various wavelengths
  - Aerosol number concentration
  - Aerosol number size distribution
  - Cloud condensation nuclei number concentration at various super-saturations
  - Vertical distribution of aerosol backscattering and extinction
  - Detailed size fractionated chemical composition
  - Dependence of aerosol variables on relative humidity, especially aerosol number size distribution and light scattering coefficient

[7] "Total deposition" is defined here as the sum of wet plus dry deposition. Direct measurements of dry deposition are difficult to make due to the requirements for highly sophisticated methods and instrumentation (Wesely and Hicks, 2000). The best currently available method for estimating dry deposition is via an inferential technique that involves measuring ambient concentrations of gases and particles and multiplying them by model-derived dry deposition velocities (Vet et al., 2014).

Contributing Stations and Networks

Contributing stations are the stations operated as a part of the contributing network. To be recognized as a contributing network, this network should sign an agreement with GAW. Contributing stations must satisfy the requirements of Regional, Global, Local or Mobile stations except for traceability (point 6) and data submission (point 8). Contributing stations must be operated according to the protocols of contributing networks and share their data through the contributing networks data centres. It is required nevertheless that metadata are provided through GAWSIS. Where appropriate and achievable, network standards shall be directly compared with WMO standards and scales and the network QA principles should be harmonized with the GAW QA principles.

8.2 Procedures to obtain or change the status of a GAW station

The application for inclusion of the station into the GAW Programme should be done for each individual station, although common characteristics can be collected in a general introduction, if a group of stations shall be registered together. Contributing networks shall negotiate an agreement with GAW, which, at the time of signature should contain an Appendix that lists stations that will be included in the GAW network, together with their characteristics and observation programmes. These data shall also be submitted in electronic form for inclusion in GAWSIS. Stations from contributing networks may register additionally as GAW Regional, Global, or Local stations if they can prove that they adhere to the GAW QA principles and can trace their calibrations to GAW primary standards.

To become a GAW station or change the status of a station, the following steps should be performed:

1) Prior to application, the essential requirements for a GAW station should be studied to make sure that the station qualifies for one of the types. The type of the station can be suggested in the application letter but the final decision will be made based on the requirements met by the station.

2) The station shall register all station and variable metadata in the GAW Station Information System (GAWSIS) at gawsis.meteoswiss.ch The registration process assists in the creation of the application letter.

3) The application letter describing general characteristic of the station, measurement programme and motivation to join GAW coordinated observations and research should be prepared. The application should also specify how each station requirement is addressed at the station. The application letter signed by the station's responsible person should be sent (electronically or by post) to the Chief of the GAW Programme.

To update the status of the registered stations a similar letter is required.

4) The application is evaluated by the respective SAG(s) for particular parameter(s) measurements. In addition to the normal review process for Regional, Local or Mobile stations, EPAC SSC will review the applications for Global stations. Global stations will also be evaluated with respect to their data submission history and the quality of data in the respective WDCs. Unless further clarification is needed, a decision shall be sent within a month from the time the application is received.

5) As soon as a confirmation of acceptance is sent by the WMO Secretariat, the status of the station in GAWSIS will be updated and the station becomes visible to the public.

6) If the measurements have started earlier than a year ago prior to application and satisfy the requirements of the GAW Programme, then the earlier data should also be submitted to the respective World Data Centers. From the time of confirmation of station status , submission of data and metadata is required on due time (point 8 in station requirements).

The data quality and data submission will be reviewed from time to time by the SAGs and other expert groups. In case significant discrepancies are found with respect to the rules outlined above, a procedure may be initiated which can lead to a complete de-registration as a GAW station (if no data of good quality have ever been submitted). Before such procedures are initiated, clarification will be sought by the secretariat through communication with the registered station PIs.

8.3 Procedures related to the status of GAW stations in GAWSIS

The following procedures apply to the status of the stations in GAWSIS:

1) The application is launched every month that retrieves all the variables that have been measured by the station within last 27 months.

2) Application calculates how many different groups of variables[8] are measured in the above period.

3) The status of the GAW Global station is set us as follows:

- '**Operational**': Station has submitted data (data are available) to the World Data Centres for at least three groups of variables within 27 months period

- '**Partly operational'**: if a station has submitted data for less than three groups of variables within 27 months period;

- **'Non-reporting'**: if stations does not meet the requirements of "operational" or "partly-operational" it is labeled as "non-reporting".

- The station can be declared "Closed" by the station PI. This status can be rewritten by either operational or partly operational, if station starts submitting data. "Closed" stations cannot be labeled as "non-reporting".

4) All other GAW station can have a status "Closed", "Operational" (if data for at least one group of variables are submitted within 27 months) or "non-reporting".

Effective January 2012, information on stations registered in GAWSIS that have no measurement programme listed in GAWSIS and no record of any data submission to one of the recognized data centres will be archived but no longer be displayed in GAWSIS, after consultation with the GAW Country Contact.

When the station status is changed to "Non-reporting" the application creates a ticket and triggers an e-mail message to station contact and GAW Country Contact informing them about the status of the station. The copy of the mail is sent to WMO Secretariat. Station status will be checked routinely and will be re-activated upon data submission.

[8] See Table 8.1 for the list of GAW variables

All stations which were listed as “intermittent” in the previous version of GAWSIS (before May 2016) are set to “reporting”. All stations which were listed as “unknown” with a measurement programme are set to “reporting” or “non-reporting” based on their data submission record.

ANNEX C

9 QUALITY ASSURANCE ELEMENTS AND PROCEDURES

9.1 GAW quality assurance principles

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

- Full support of the GCOS Climate Monitoring Principles[9].
- Network-wide use of only one reference standard or scale (primary standard). In consequence, only one institution is responsible for this standard.
- Full traceability to the primary standard of all measurements made by Global, Regional and Local GAW stations and network standards of contributing networks where such standards are established.
- The definition of data quality objectives (DQOs).
- Establishment of guidelines on how to meet these quality targets, i.e., harmonized measurement techniques published as Measurement Guidelines (MGs) and Standard Operating Procedures (SOPs) and implemented at the stations.
- Use of detailed log books for each parameter containing comprehensive meta information related to the measurements, maintenance, and 'internal' calibrations.
- Regular independent assessments (system and performance audits).
- Timely submission of data and associated metadata to the responsible World Data Centre or a contributing network data center as a means of permitting independent review of data by a wider community.
- Regular statistical and scientific analysis of data in the GAW data archives in order to ensure correctness, long-term consistency, and comparability of the archived measurement data.

9.2 GAW Central Facilities

Table 9.2 - GAW Central Facilities (green colour indicates the Central Facilities with agreement in place)

Variable	Quality Assurance /Science Activity Centre	Central Calibration Laboratory	World Calibration Centre	Regional Calibration Centres	World Data Centre
CO_2	JMA# (Asia, South-West Pacific)	NOAA-ESRL	NOAA-ESRL (round robin) Empa (audits)		JMA#
CO_2 Isotopes		MPI-BGC			JMA#

[9] https://www.wmo.int/pages/prog/gcos/documents/GCOS_Climate_Monitoring_Principles.pdf

CH_4	Empa (Americas, Europe, Africa) JMA# (Asia, South-West Pacific)	NOAA-ESRL	Empa (Americas, Europe, Africa) JMA# (Asia, South-West Pacific)		JMA#
N_2O	UBA	NOAA-ESRL	KIT/IMK-IFU		JMA#
SF_6		NOAA ESRL	KMA		JMA#
CFCs, HCFCs, HFCs					JMA#
Surface Ozone	Empa	NIST	Empa	OCBA (South America)	NILU
CO	Empa	NOAA-ESRL	Empa		JMA#
VOCs	UBA	NPL (Ethane, Propane, n-butane, n-pentane, Acetylene, Toluene, Benzene, Isoprene) NIST (monoterpenes)	KIT/IMK-IFU		NILU
NO_X	UBA	NPL (NO)	FZJ (IEK-8) (NO)		NILU
SO_2					NILU
H_2		MPI-BGC			JMA#
Precipitation Chemistry / Wet Deposition	NOAA-ARL (Americas)	ISWS	ISWS		NOAA-ARL
Total Ozone	JMA# (Asia, South-West Pacific)	NOAA-ESRL (Dobson instruments) EC (Brewer instruments)	NOAA-ESRL (Dobson instruments) EC (Brewer instruments)	Dobson instruments: BoM (Australia & Oceania) NOAA-ESRL JMA# (Asia) DWD-MOHp(Europe) CHMI-SOO-HK (Europe) OCBA (South America) SAWS (Africa) Brewer instruments: IARC-AEMET (Europe) Filter instruments: MGO	EC (Ground based observations) DLR### (Satellite based observations)
Ozone Profile	FZJ(IEK-8)	FZJ(IEK-8)	FZJ(IEK-8)		EC
UV Radiation			PMOD/WRC	NOAA-ESRL (Americas)	EC

Aerosol Physical Properties	UBA		IfT		NILU (ground based observations) DLR### (satellite based observations)
Aerosol Optical Depth		PMOD/WRC (Precision Filter Radiometers)	PMOD/WRC		NILU (ground based observations) DLR### (satellite based observations)
Aerosol Chemical Properties					NILU
Solar Radiation##		PMOD/WRC	PMOD/WRC		MGO

exchange of letter between JMA and WMO
all facilities are established through EC resolutions
agreement has expired

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
CHMI	Czech Hydrometeorological Institute
DLR	German Aerospace Centre, Oberpfaffenhofen, Wessling, Germany
DWD	German Meteorological Service (Deutscher Wetterdienst)
EC	Environment Canada, Toronto, Ontario, Canada
EML	Environmental Measurements Laboratory, Department of Energy (DoE), New York City, New York, USA
Empa	Swiss Federal Laboratories for Materials Testing and Research, Dübendorf, Switzerland
FZJ (IEK-8)	Forschungszentrum Jülich, Institute for Energy and Climate Research: Troposphere (IEK-8), Jülich, Germany
IARC-AEMET	Izaña Atmospheric Research Centre- State Meteorological Agency of Spain
IfT	Institute for Tropospheric Research, Leipzig, Germany
ISWS	Illinois State Water Survey, Champaign, Illinois, USA
JMA	Japan Meteorological Agency, Tokyo, Japan
KIT/IMK-IFU	Karlsruhe Institute of Technology (KIT), Institute for Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Garmisch-Partenkirchen, Germany
KMA	Korea Meteorological Administration (KMA), , Seoul, Korea
MGO	A.I. Voeikov Main Geophysical Observatory, Russian Federal Service for Hydrometeorology and Environmental, St. Petersburg, Russia
MOHp	Meteorologisches Observatorium Hohenpeißenberg, Germany
MPI-BGC	Max Planck Institute for Biogeochemistry, Jena, Germany
NILU	Norwegian Institute for Air Research, Kjeller, Norway
NIST	National Institute for Standards and Technology, Gaithersburg, MD, USA
NOAA-ARL	National Oceanic and Atmospheric Administration (NOAA), Air Resources Laboratory (ARL), College Park, Maryland, USA
NOAA-ESRL	National Oceanic and Atmospheric Administration (NOAA) , Earth System Research Laboratory (ESRL), Global Monitoring Division , Boulder, Colorado, USA
NPL	National Physical Laboratory, UK
OCBA	Observatorio Central Buenos Aires, Argentina
PMOD/WRC	Physikalisch-Meteorologisches Observatorium Davos/World Radiation Centre, Davos, Switzerland
SAWS	South African Weather Service, Pretoria, South Africa
SOO-HK	Solar and Ozone Observatory, Hradec Kralove, Czech Republic
UBA	German Environmental Protection Agency, Berlin, Germany

9.3 Procedure for designation of GAW Central Facilities

Table 9.2 lists the facilities and organisations responsible for each measurement variable as of January 2016. There are still a number of variables that do not have a complete set of Central Facilities assigned to them in the GAW Programme, and GAW welcomes applications from interested organizations. Institutions offering to establish a Central Facility for

the GAW Programme are requested to submit an application to the GAW Secretariat, addressing in particular the following requirements:

Requirements of GAW Central Facilities

- A confirmed capacity to run a Central Facility in accordance with the respective Terms of Reference;
- Long-term experience in performing the activities assigned to the particular type of Central Facility;
- Availability of high level laboratory and equipment, and trained personnel dedicated to performing the required work and to running the facility;
- Annual reporting to the Secretariat using a template provided. The reporting depends on the kind of Central Facility as specifically described in the Terms of Reference and the respective agreement;
- If relevant to the task, a willingness to participate in BIPM key comparisons;
- Other relevant information (e.g., connection with GAW stations, support of exchange/ twinning programmes in GAW etc.);

The organization operating the Central Facility shall minimize the cost of their services to the network or provide it free of charge where possible, and shall strive to perform to the best of their knowledge, taking into account the current state of the art.

Applications submitted to the GAW Secretariat are evaluated by the respective SAGs that will make a recommendation for decision by EPAC SSC. Designations of Central Facilities in general have no time limitation.

Central Calibration Laboratories, and World and Regional Calibration Centres designated within the GAW Programme are not necessarily operated by National Metrological Institutes and may thus not be eligible automatically for key comparisons organized by BIPM. If an institution operating a Central Facility (e.g., a CCL or a WCC) is not yet eligible for key comparisons as organized by BIPM, a nomination should be sought. One of the mechanisms is the establishment of a side agreement with BIPM through the already existing agreement between BIPM and WMO. An agreement is signed with institutions responsible for each individual Central Facility, which specifies the mutual rights and obligations of the Parties.

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ABBREVIATIONS AND ACRONYMS

AGU	American Geophysical Union
BoM	Bureau of Meteorology (Australia)
BSRN	Baseline Surface Radiation Network
CARIBIC	Civil Aircraft for the Regular Investigation of the Atmosphere based on Instrument Container
CAS	Commission for Atmospheric Sciences
CCAC	Climate and Clean Air Coalition
CCL	GAW Central Calibration Laboratory
CHMI	Czech Hydrometeorological Institute
CIMO	Commission on Instruments and Methods of Observation
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CONTRAIL	Comprehensive Observation Network for Trace Gases by Airliner
DLR	German Aerospace Center
DQOs	Data Quality Objectives
DRR	Disaster Risk Reduction
DWD	German Meteorological Service
EC	Environment Canada
ECMWF	European Center for Medium-Range Weather Forecast
EML	Environment Measurement Laboratory (New York)
Empa	Swiss Federal Laboratories for Material Testing and Research
EPAC SSC	Environmental Pollution and Atmospheric Chemistry Scientific Steering Committee
ET	Expert Team
GALION	GAW Aerosol Lidar Observation Network
GAW	Global Atmosphere Watch
GAWSIS	GAW Station Information System
GAWTEC	GAW Training and Education Center
GCOS	Global Climate Observing System
GEO	Group on Earth Observation
GESAMP	Joint Group of Experts on the Scientific Aspects of Marine
GFCS	Global Framework for Climate Services
GURME	GAW Urban Research Meteorology and Environment
IAGOS	In-service Aircraft for a Global Observing System
iCACGP	international Commission on Atmospheric Chemistry and Global Pollution
ICAO	International Civil Aviation Organization
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IG^3IS	Integrated Global Greenhouse Gas Information System
IGAC	International Global Atmospheric Chemistry Project
IGBP	International Geosphere Biosphere Programme
IITM	Indian Institute of Tropical Meteorology
iLEAPS	Integrated Land Ecosystem Atmosphere Processes Study
IPCC	Intergovernmental Panel on Climate Change

IZO	Izana Observatory, Tenerife
JMA	Japan Meteorological Agency
KMA	Korean Meteorological Administration
LLGHG	Long-lived Greenhouse Gases
MACC	European Monitoring Atmospheric Composition and Climate
MGO	A.I. Volekov Main Geophysical Observatory (St. Petersburg)
MGs	Measurement Guidelines
MOHp	Hohenpeißenberg Meteorological Observatory
MOZAIC	Measurement of Ozone and Water Vapour on Airbus in-service
MPI	Max Planck Institute
NHMS	National Hydrological and Meteorological Services
NILU	Norwegian Institute on Air Research
NIST	National Institute on Standards and Technology, USA
NOAA	National Oceanic and Atmospheric Administration, USA
NRT	Near Real-Time
NWP	Numerical Weather Prediction
OCBA	Observatorio Central Buenos Aires
PMOD	Physikalisch-Meteorologisches Observatorium Davos
QA/QC	Quality Assurance / Quality Control
QA/SAC	GAW Quality Assurance / Science Activity Center
RCC	Regional Calibration Center
RRR	Rolling Review of Requirements
RTC	Regional Trainings Center
SAFAR	System of Air Quality Forecasting and Research, India
SAG	Science Advisory Group
SAWS	South African Weather Service
SDS-WAS	WMO Sand and Dust Storm Warning Advisory and Assessment System
SOLAS	International Convention for the Safety of Life at Sea
SOO-HK	Solar and Ozone Observatory (Hradec Kralove)
SOPs	Standard Operating Procedures
SPARC	Stratospheric Processes and their Role in Climate
TAD-SAG	Total Atmospheric Deposition SAG
ToR	Terms of References
TCCON	Total Carbon Column Observing Network
TT-ObsReq	GAW Task Team on Observational Requirements and Satellite Measurements
UBA	German Environmental Protection Agency
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
UV	Ultraviolet
VAAC	Volcanic Ash Advisory Center
WCC	World Calibration Center

WCRP	World Climate Research Programme
WDC	World Data Center
WGNE	Working Group on Numerical Experimentation
WHO	World Health Organization
WIGOS	WMO Integrated Global Observing System
WMO	World Meteorological Observation
WOUDC	World Ozone and Ultraviolet Radiation Data Center
WRC	World Radiation Center
WWOSC	World Weather Open Science Conference
WWRP	World Weather Research Programme