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GAW Report No. 207

Recommendations for a Composite Surface-Based Aerosol Network

(Emmetten, Switzerland, 28-29 April 2009)

GLOBAL ATMOSPHERE WATCH

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WORLD METEOROLOGICAL ORGANIZATION

GLOBAL ATMOSPHERE WATCH

Recommendations for a Composite Surface-Based Aerosol Network

European Network of Networks (ENAN) Workshop
Emmetten, Switzerland, 28-29 April 2009

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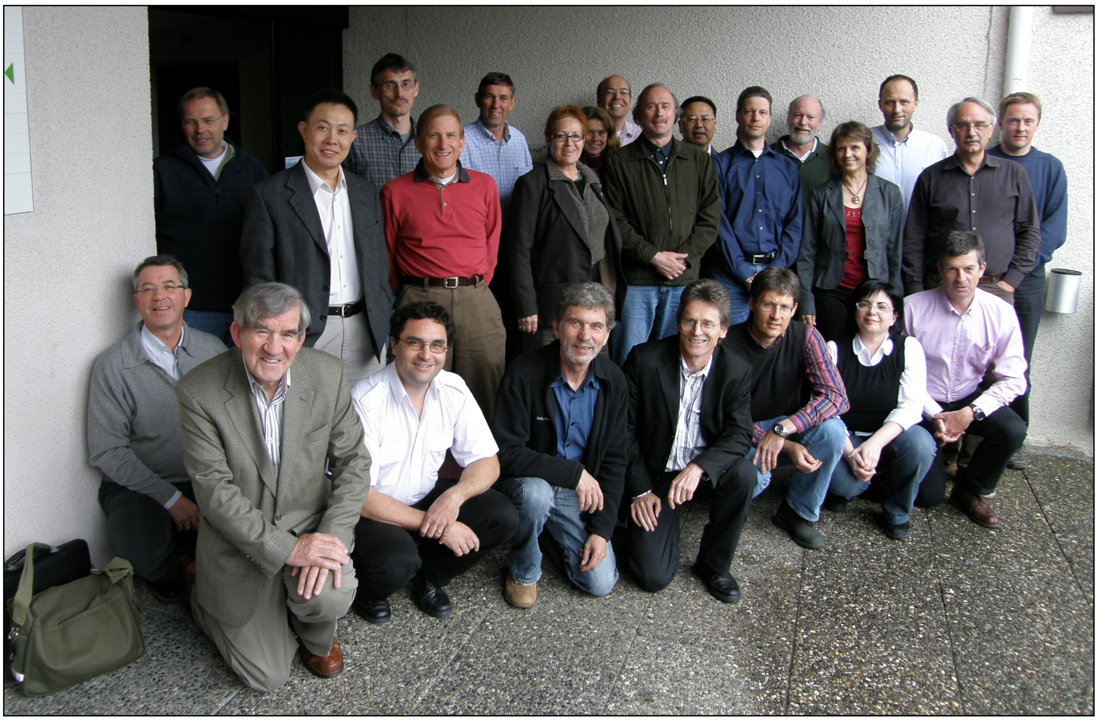

Participants attending ENAN Workshop in Emmetten, Switzerland, 28-29 April 2009

EXECUTIVE SUMMARY

The impact of aerosols on the atmosphere is widely acknowledged as one of the most significant and uncertain aspects of climate change projections. The observed global warming trend is considerably less than expected from the increase in greenhouse gases much of which is explained by aerosol effects. Aerosols impact climate through direct scattering and absorption of incoming solar radiation and trapping of outgoing long-wave radiation as well as through alteration of cloud optical properties and the formation of clouds and precipitation. Furthermore, there is growing concern for the impact of aerosols on human health and interest by many sectors such as weather prediction, the green energy industry (regarding their influence on solar energy reaching the ground) and the commercial aircraft industry (regarding the impact of volcanic ash and dust storms on operations and aircraft). Comprehensive, long-term, high quality observations of aerosols have been initiated only recently, and only in a few locations and regions. Several different regional networks are concerned with the monitoring and observations of aerosols, however, still to a large degree in an uncoordinated fashion Despite the crucial importance of aerosols as short-lived climate forcers and their importance for air quality, the networks are lacking in global, coordinated coverage. The Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO) has an important role in the coordination of aerosol measurements globally.

Current State of Aerosol Networks

Worldwide, there are numerous aerosol networks, regional or global in scope. They are divisible into two types; networks driven by environmental policy frameworks, and networks driven by project-based research. The objectives, development, maintenance and financial structure of these two types of networks are very different and there are often limited interactions between them. The global coverage was analyzed and found lacking particularly in Africa, Russia, and large parts of Asia. At present there are more than two hundred aerosol observatories in Europe measuring various aerosol properties. A major challenge is to integrate observational activities. Several European research projects are contributing to a solution. For instance, the EC project ACTRIS[1] (Aerosols, Clouds, and Trace gases Research InfraStructure Network) involves integration of the networks EARLINET, EUSAAR/EMEP and CLOUDNET (see 2.3.1). This report summarises information on about 30 key continental and global aerosols networks, the main aerosol variables measured in each network, distribution of sites, and the availability of data.

The Vision

Comprehensive integrated sustained observations of aerosols on a global scale through a consortium of existing research aerosol networks complementing aircraft, satellite and environmental agency networks.

In Europe, there are many networks that should be integrated with a large added value for policy, environmental services and advancement of science. A demonstrated integrated observing system on a European scale would accelerate integration on global scale. This observing system would foster aerosol-related process studies, validation of satellite sensors, model development and evaluation, assimilation of aerosol data into operational models, and creation of a comprehensive aerosol climatology on a global scale. It will form the non-satellite component of an Integrated Global Aerosol Observing System fulfilling the strategy originally recommended in the 2004 IGACO assessment report on Integrated Global Atmospheric Chemistry Observations, which is implemented through the GAW Programme as per the decision of the 14th Session of the WMO Commission on Atmospheric Sciences (CAS). [2] [3]

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[1] *ACTRIS: www.actris.net funded within the 7th Framework Programme.*

[2] *Barrie, L.A, P. Borrell and J. Langen, 2004, Eds, The Integrated Global Atmospheric Chemistry Observations (IGACO) THEME Report of IGOS-WMO-ESA (September 2004) (WMO TD No. 1235; GAW Report #159 www.wmo.int/gaw; ESA SP1282.*

[3] *GAW Strategic Plan 2008-2015, GAW Report No 172*

Sustained observations in the next 5-10 years will benefit from the integration of existing aerosol networks and observatories. The realisation and potential of such an integrated system will not be reached unless there is long-term sustainability of project-based research networks. This requires a long-term commitment from national and international funding agencies for research infrastructures. Research is necessary to improve observational methodologies for use by networks operated under environmental regulatory frameworks.

The integration of the many advanced European networks, many of which are also contributing networks to GAW, could be the basis for a global aerosol network. The vision for this network is to carry out comprehensive integrated sustained observations of aerosol variables through a consortium of existing aerosol networks and research infrastructures joined together as GAW contributing networks, complementing aircraft, satellite and environmental agency networks.

Integration requires the following:

i. Implement surface based supersites at which comprehensive set of *in situ and remote sensing aerosol* measurements are made together.
ii. Create surface-based observatories in climate regions not yet covered by *in situ* and/or ground-based profiling/remote sensing aerosol measurements.
iii. Link the surface-based network activities to space-borne missions. (*Validation of many satellite based remotely-sensed aerosol properties and products is still inadequate. High-quality ground-based measurements are essential for these validations. It should be emphasized that they are a small fraction of the cost of a satellite mission while adding great value to satellite observations.*)
iv. Utilize satellite observations to achieve cost effective expansion of surface-based networks (i.e. in network design).
v. Further improve standardization and harmonization of observations. Presently the same aerosol variables measured by different techniques are not necessarily providing comparable data. A quality assurance programme is needed not only for primary variables but also for advanced derived aerosol products. This is a critical issue that limits the integration and assimilation of measurements by atmospheric numerical models. On the global scale these tasks are addressed by the GAW Scientific Advisory Group (SAG) for aerosols.
vi. Ensure easy access to observation data through a common data policy and data base management structure. Several data centres exist; on the global scale data are submitted to the WMO/GAW World Data Centre for Aerosols (WDCA). The Near-Real-Time (NRT) collection and dissemination (i.e. within 1 – 3 hours of the observation) of data, using the WMO Information System (WIS), will become increasingly important, particularly during special events like heat waves, huge fires and volcanic eruptions. The World Data Centre for Remote Sensing of the Atmosphere is a one-stop shop for rapid access to atmosphere-related satellite-based data sets, information products and services. The final database structure will need to be flexible enough to accommodate a heterogeneous set of sub databases organised around specific observed parameters and/or regions. (*This requires years of preparation but it could be developed step by step once the community has agreed on the general architecture. Part of this work for European and also global data was initiated in the FP6 EC project GEOmon and is continued in ACTRIS.*
vii. Develop a coalition of research and operational observational systems. The network model will give the opportunity of spreading “best practise” for each particular instrument/variable from regional to a global scale; a good example is the approach for implementing GALION, the GAW Aerosol Lidar Network as a federated network of existing regional research and operational networks and stations.
viii. Use state-of-the-art *in situ,* aircraft and LIDAR remote sensing instruments in synergy to characterize the state of the atmosphere.
ix. Establish links to atmospheric chemistry networks and incorporate variables to strengthen implementation of the monitoring of reactive trace gases/short-lived climate forcers (VOCs, NO_{xy}, O_3). In Europe this work was initiated by EMEP already in the 1980ies and will be further developed within EMEP and ACTRIS in the near future.

The Way Forward: Implementation of a European/International Network of Networks (ENAN/INAN)

A well-defined strategy implementing integration of aerosol measurement capabilities on continental or larger scales will result in clear benefits such as improved data access and availability, improved comparability of data, more uniform data quality standards from different networks, increased synergy of measurements and prevention of unnecessary duplication. Suggested steps are:

a. Consult with network representatives and respective stakeholders on the ENAN/INAN vision.
b. Establish an ongoing engagement of networks with network principals (or representatives) acting as a high-level steering committee and providing guidance in the development of monitoring strategies for an ENAN/INAN.
c. Establish several specific working groups of network representatives involving the Aerosol SAG (Scientific Advisory Group) of the WMO-GAW programme to address specific harmonisation issues on the global scale.
d. Establish mechanisms for regular communication between networks.
e. Develop an agreement on a shared/common metadata access portal.
f. Develop common harmonised methodologies, Data quality objectives, quality assurance / quality control procedures etc. across measurement frameworks to the extent possible.
g. Facilitate expertise exchange programmes / exchange of model tools / regular intercomparison activities.

INTRODUCTION

Suspended particulate matter in the atmosphere, commonly known as aerosol by the technical and scientific community, plays a role in climate change, air quality/human health, ozone depletion and the long-range transport and deposition of toxics and nutrients. Aerosols have many sources ranging from sea spray and mineral dust that are mechanically generated by wind at the Earth's surface to sulphates, nitrates and organics produced primarily by chemical reaction of gases in the atmosphere producing non-volatile products that condense to form particles. In addition, semi-volatile substances such as certain herbicides and pesticides can simply condense on existing particles. Aerosols range in size from molecular clusters a few nm in diameter to dust and sea salt, which can be as large as tens of micrometers. The dynamics of aerosol production, transformation and removal that govern size distribution and composition are affected not only by clear air processes but also by interaction with clouds and precipitation. The complexity of aerosol processes in our environment is so great that it leads to large uncertainties in our quantitative understanding of their role in many of the major environmental issues listed above.

This report is based on a workshop on a European Network of Networks (ENAN) in Emmetten, Switzerland on 28-29 April, 2009. It was a joint initiative of the Global Earth Observation and Monitoring (GEOmon) project of the European Community's Sixth Research Framework Programme (FP6) and the Scientific Advisory Group for Aerosols of the Global Atmosphere Watch (GAW) Programme of the World Meteorological Organization (WMO). The workshop had the following goals:

- Determine the current status and achievements of aerosol monitoring networks, both in Europe and internationally.
- Identify the crucial questions and knowledge gaps concerning atmospheric aerosol for the next 5 to 10 years.
- To recommend ways that existing European and international aerosol networks can collaborate to fill these knowledge gaps.
- Establish closer collaboration and harmonisation between the aerosol networks.
- Identify schemes for funding and implementing the approaches.

Twenty-four experts from global and regional networks (Annex II) discussed the present status of coordination of European networks and their context within global programmes. The report provides recommendations for future development of aerosol observations on a continental scale in Europe.

The recommendations of this report are practical steps that when implemented will greatly enhance the contribution of a plethora of observations of aerosol properties. This will be of highest importance for an improved assessment of the aerosol impact on climate and air quality, as well as for the development of predictive capability of weather, climate and the environment. This in turn serves the goal of the sponsors of this workshop towards a wide variety of socio-economic benefits.

Acknowledgments

We acknowledge the European Science Foundation (INTROP Programme: Interdisciplinary Tropospheric Research: from the Laboratory to Global Change) for support of the workshop in Emmetten, April 2009. Furthermore we acknowledge the support of the European Commission through the GEOmon (Global Earth Observation and Monitoring) Integrated Project under the 6th Framework Programme (contract number FP6-2005-Global-4-036677) as well as the support from the World Meteorological Organisation (WMO) in the context of the Global Atmosphere Watch (GAW) Programme.

1. MOTIVATION FOR A COMPOSITE NETWORK

1.1 The need for long-term measurements of aerosol variables

Aerosol impact on climate is repeatedly mentioned as one of the most uncertain aspects of climate change (IPCC, 2007). The observed global warming trend at the surface is considerable less than expected from the increase in greenhouse gases partly explained by aerosol effects. Aerosols mask the warming caused by the increase in greenhouse gases by around 30% (Ramanathan and Xu, 2010) or maybe even more (IPCC, 2007). Additionally, impact of aerosols on human health is a growing matter of concern, particularly in urban areas. On a worldwide basis, the annual number of premature deaths caused by cardiovascular and pulmonary diseases following ambient air particulate matter (PM) exposure is estimated to be substantial at 800 000 (World Health Organization (WHO), 2002).

The issues of climate change and improvement of air quality have moved to the top of the global political agenda in many parts of the world. Over the last decade, scientists have made significant progress in understanding the causes and implications of our changing environment (Monks et al., 2009). However, many aspects of the global atmospheric system remain uncertain and not fully understood. Emissions of greenhouse gases and emissions and changes in aerosols and short-lived gases due to human activities have altered the atmosphere in ways that strongly affect the atmospheric composition and climate. It is expected that emissions will continue to stay at an elevated level as a result of fossil fuel burning, tropical deforestation and other industrial activities.

Accurate prediction of future changes of the atmosphere requires information on past and present atmospheric composition. The scientific findings over the last decades have clearly highlighted the need for a more comprehensive approach to assess atmospheric change processes. This includes the necessity for multi-criteria information, the use of advanced monitoring techniques, a strong interface with state-of-the-art atmospheric modelling, and the establishment of long-term global and regional atmospheric observations to quantify and understand the current perturbation of the atmospheric cycles of aerosols and of reactive gaseous species.

Ensuring such long-term observations, however, bears some inherent difficulties: Citing Nisbet (2007), monitoring is “science’s Cinderella, unloved and poorly paid. Monitoring does not win glittering prizes. Publication is difficult, infrequent and unread”. Thus, sustaining a long-term, ground-based programme that demands high analytical standards remains challenging.

While a number of conclusions drawn at the end of this report also apply to short-lived trace gases, this report exclusively relates to aerosols, specifically tropospheric aerosols (also referred to as particulate matter, PM). As outlined above, tropospheric aerosols are of great importance because of their impact on human health, climate, visibility, and on continental and maritime ecosystems, requiring dedicated monitoring of their concentrations and properties at a global scale. There is a need to understand regional to intercontinental transport of aerosols in order to formulate more efficient policies for monitoring of aerosols and their precursors, and for emission abatement strategies.

Contrary to the situation for greenhouse gases and despite the perpetual demand for being adopted as a scientific priority for decades, comprehensive, long-term, high quality observations of aerosols have only been initiated recently, and then only in a few locations. This is mainly a response to international conventions and protocols, a framework called for in the report on Integrated Global Atmospheric Chemistry Observations (IGACO, 2004), to the Integrated Global Observing Strategy (IGOS), its successor the Global Earth Observation System of Systems (GEOSS) and in the case of Europe, to EU research and regulatory policies. Routine aerosol monitoring has mostly remained limited to regulated variables such as PM10 or PM2.5 (mass concentration of particles with an aerodynamic diameter smaller than 10 and 2.5 mm, respectively), which as the IGACO (2004) report points out, clearly is not sufficient for climate or air quality studies as well as for understanding ozone depletion and drivers of the oxidizing capacity of the atmosphere.

In fact, at the same time, more detailed observations of aerosol variables have been an essential activity of atmospheric researchers that have developed instrumental tools (such as advanced analytical techniques) and platforms (for example: instrumented passenger aircraft, ground-based *in-situ* and remote sensing stations, earth observation satellites) that provide essential information on the state of the atmosphere. However, unlike meteorological parameters which have routinely been observed by meteorological services for decades and for which global satellite observations have existed for 30 years or more, integrated global systems to measure atmospheric composition and aerosol related variables are considered to be at an embryonic stage of development (IGACO, 2004; WMO, 2007a). Furthermore, the need for long-term observations of aerosols properties was unambiguously stated in the latest IPCC Fourth Assessment Report (IPCC, 2007).

Specific issues relate to the following scientific questions:

1) Assessment of climate effects of aerosols requires a better understanding of aerosol radiative forcing, aerosol-climate feedbacks and emission trends.
2) Assessment of air pollution requires understanding of the evolution of aerosol concentrations, the transport from urban to synoptic scale, the health impact of different aerosol particle sizes and aerosol compositions, as well as links between aerosol properties and gaseous chemistry in different environments.
3) Evaluation of aerosol related assessments of emission policies require integrated higher-level benchmark data sets than what are available in conventional databases.

1.1.1 What does integration of observations mean?

Atmospheric aerosols are complex systems of various sizes, different chemical compositions and properties, and they closely interact with gases. Various measured aerosol variables complement each other. There are both ground-based *in situ* [4] observations (typically providing e.g. chemical, optical and physical properties of the ambient aerosols) and ground-based remote sensing observations (typically providing e.g. aerosol profiles, column measurements like aerosol optical depth). While information from individual measurements or different individual platforms such as ground-based profiling measurements (example; lidar) and columnar data (example; sun-photometer data) are useful in their own right, combination and merging of separate data streams gives much added value towards a holistic characterisation of atmospheric parameters.

An important step towards integration is the harmonization of measured variables across networks and instruments. Aerosols cannot be characterised solely in terms of mass concentration, as a large number of variables are needed for a comprehensive description of atmospheric aerosol properties. All these variables need standard operating procedures in order to allow for comparability of the data. Measurement protocols, quality assurance, calibration and validation procedures need to be established to assure that data of known quality and with sufficient error documentation are available which can then be used for further integration at higher levels. Training and capacity building are also highly important aspects of integration.

Specific data access is often restricted and prevents further integration. Providing a clear framework for data access and exchange with benefits for users and providers is a central part of integration. Once data become available, higher level products require end-user driven design of integrated data products based on mutual interactions. The need for integrated data products can be exemplified with the problem of inferring the surface levels of air pollution from satellite observations of column aerosol optical depth. Several largely disconnected data sets are needed to make satellite data more useful for local and regional air pollution now-casting and assessment.

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[4] In this paper, "in-situ" refers to measurements made by drawing a sample of air into a collection or analytical device

As an example, lidar data provide a superior view of the vertical profile of aerosol optical properties. However, few lidar data are available and technological challenges remain to be solved before such data can be used routinely. Sun photometers provide valuable, independent ground truth for satellites. However they are also limited in number and do not provide surface-specific information. Measurements of surface-related extinction coefficients from combined scattering and absorption measurements provide such ground truth for the boundary layer. However they miss information on the vertical structure and in addition need to be adapted to the ambient conditions, as *in situ* variables are typically measured under dry conditions. These extinction coefficients then need to be related to the corresponding ground level PM values, which are defined by the legal standards. This example shows the high complexity of merging these different datasets, which clearly would make the satellite data immensely more useful.

1.1.2 Integrated Global Systems

Efforts were being made to implement global observational systems, for example through the Integrated Global Observing Strategy (IGOS), and the Global Earth Observation System of Systems (GEOSS), which are briefly described below.

Integrated Global Atmospheric Observing Strategy (IGACO): Relationship to IGOS, GEOSS, GCOS

The Integrated Global Observing Strategy (IGOS) (http://www.eohandbook.com/igosp/index.htm), operating between 1998 and 2008 was a precursor of the Global Earth Observations System of Systems (GEOSS) that developed strategies of integrated global observations for particular Earth System Themes. It operated as a consortium of 13 International Bodies: CEOS (Committee on Earth Observation Satellites); FAO (Food and Agriculture Organisation of the United Nations); GCOS (Global Climate Observing System); GOOS (Global Ocean Observing System); GOS/GAW (Global Observing System / Global Atmosphere Watch (of WMO)); GTOS (Global Terrestrial Observing System); ICSU (International Council for Science); IGBP (International Geosphere–Biosphere Programme); IOC-UNESCO (Intergovernmental Oceanographic Commission of UNESCO); UNEP (United Nations Environment Programme); UNESCO (United Nations Educational, Scientific and Cultural Organisation); WCRP (World Climate Research Programme); and WMO (World Meteorological Organisation).

Through building on strategies of existing international global observing programmes IGOS strove to provide a comprehensive framework to harmonize the common interests of the major space-based and *in situ* systems for global observation of the Earth. IGACO (Integrated Global Atmospheric Chemistry Observations) was the Atmospheric Chemistry theme of IGOS. It was approved as the 4th Theme in June 2001 and IGACO's framework was adopted officially by IGOS in 2004 and was published jointly by WMO and ESA GAW Report #159 (WMO2004a, http://www.wmo.int/gaw; ESA Report ESA SP-192).

The IGACO strategy which was adopted by WMO to be implemented by GAW as well as European infrastructure initiatives is to build an integrated global atmospheric observation system that addresses various applications, by combining surface-based (in situ and remote sensing), aircraft and satellite observations with suitable data archives and models. Components of the IGACO system are shown in Figure 1.

The purpose of the IGACO system, according to its executive summary, is to provide representative, reliable and accurate information about the changing atmosphere to those responsible for environmental development and also to prediction centres for weather and the environment.

The 2004 IGACO strategy has been implemented into the WMO Global Atmosphere Watch (GAW) Programme Strategic Plan for 2008-2015 (GAW Report #172 www.wmo.int/gaw). The WMO Scientific Advisory Group (SAG) for Aerosols is working with other aerosol expert groups nationally, regionally and internationally to provide the basic aerosol system framework and to ensure that it is connected with other global observational initiatives identified in the GCOS and GEOSS strategies.

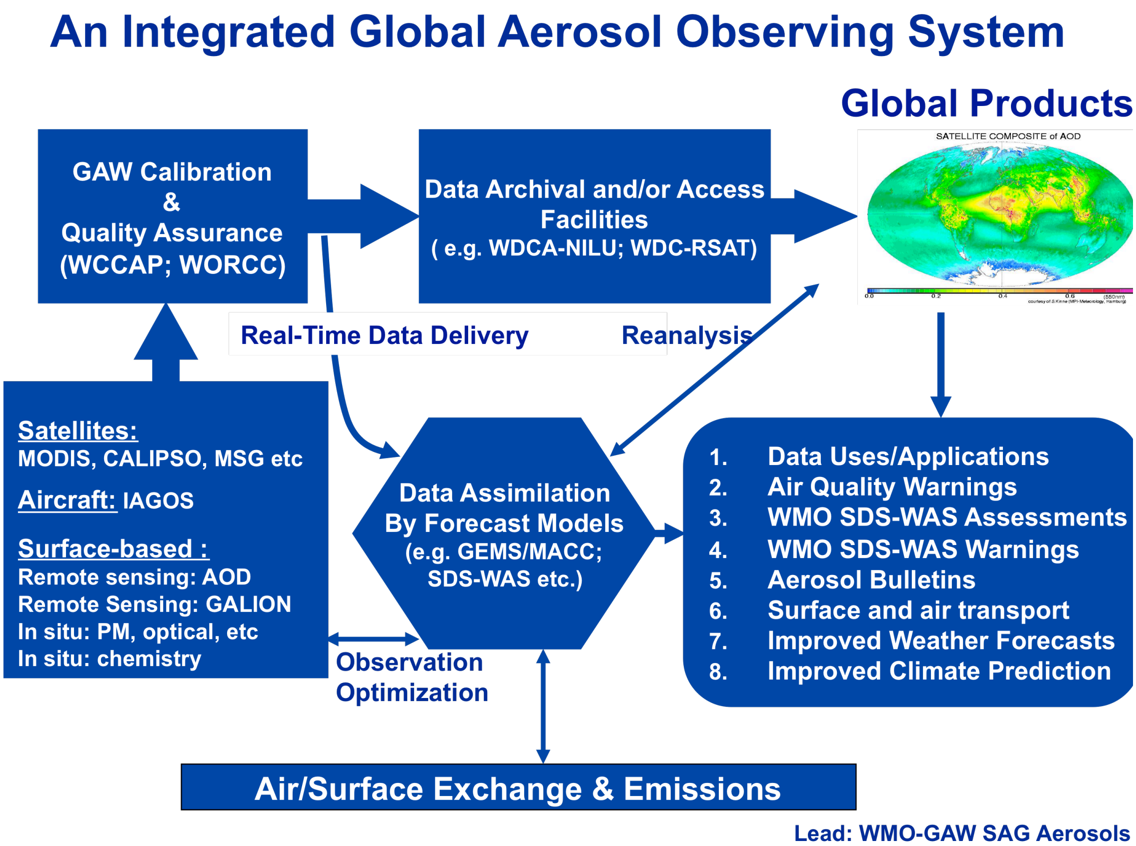

Figure 1 - Components of an Integrated Global Atmospheric Aerosol Observing System consistent with the concepts of IGACO being implemented through GAW with international partners

Global Climate Observing System (GCOS)

The Global Climate Observing System (GCOS) is an international system of observing systems and networks, established to meet national and international needs for climate observations (www.wmo.int/). GCOS is a joint undertaking of the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU). Its goal is to provide comprehensive information on the total climate system, involving a multidisciplinary range of physical, chemical and biological properties, and atmospheric, oceanic, hydrological, cryospheric and terrestrial processes. It is built on the WMO Integrated Global Observing System (WIGOS), the IOC-WMO-UNEP-ICSU Global Ocean Observing System (GOOS), the FAO-UNEP-UNESCO-ICSU Global Terrestrial Observing System (GTOS) and a number of other domain-based and cross-domain research and operational observing systems. The in situ atmospheric observing systems are largely based on the WMO Global Observing System (GOS)networks for surface and upper-air meteorological observations, and the WMO Global Atmosphere Watch (GAW) networks for atmospheric composition. It includes both *in situ* and remote sensing components, with its space based components coordinated by the Committee on Earth Observation Satellites (CEOS) and the Coordination Group for Meteorological Satellites (CGMS). GCOS is intended to meet the full range of national and international requirements for climate and climate-related observations. As a system of climate-relevant observing systems, it constitutes, in aggregate, the climate observing component of the Global Earth Observation System of Systems (GEOSS).

Global Earth Observation System of Systems (GEOSS)

The Global Earth Observation System of Systems (GEOSS) was established in 2005 following a series of ministerial-level summits. GEOSS is an intergovernmental initiative building upon existing national, regional, and international systems, with the aim of providing comprehensive, coordinated Earth observations from all platforms for the benefit of societies worldwide. GEOSS is organized around nine key societal areas: agriculture, ecosystems, biodiversity, weather, climate, water, disasters, energy, and health. Since almost all of these societal benefit areas are also ultimately the strong beneficiaries of climate observations, GEOSS provides the overall framework for further implementation of GCOS networks and systems, by fostering enhanced integration and interoperability among and between its component observing systems (e.g., through the WMO Integrated Global Observing System). It has also assumed responsibility for supporting the implementation of strategies developed by the IGOS consortium between 1998 and 2008. A 10-Year Implementation Plan for GEOSS was endorsed by nearly 60 governments and the European Commission in February 2005 (GEOSS, 2005). A 10-Year Implementation Plan for GEOSS was endorsed by nearly 60 governments and the European Commission in February 2005 (GEOSS, 2005).

The Group on Earth Observations (GEO) is coordinating international efforts to develop GEOSS.

1.2 The need for a coordinated network

In the following, an adapted summary of the GACS (Global Monitoring for Environment and Security Atmosphere Core Service Report, GACS, 2009) is presented. While this report relates specifically to Europe, individual points apply equally well on a global scale.

- Identified shortcomings relate to spatial coverage and sustainability.
  - It is recommended to optimize the spatial distribution of air quality stations
  - There is also a strong need to consolidate monitoring activities which are often supported by R&D funds (such as those carried out by ICOS, AERONET, EARLINET, ACTRIS, IAGOS, etc.) and sustain these, eventually as European contributions to international observation networks.

- Data management is another critical issue for the *in situ* observation infrastructures, and includes:
  - Timeliness (the need to establish mechanisms for near-real-time (NRT) provision of data)
  - The need for a single portal as well as the harmonization of multiple-source datasets. This latter requirement includes inter-calibration and creation of common standards for metadata & data

- European coordination mechanisms are urgently needed for:
  - Institutional issues (co-management of the infrastructure to ensure availability of observations and appropriate evolution data, co-funding approaches, international cooperation issues)
  - Technical issues (observation infrastructure consolidation and development, data quality and standardization, and data management). Concerning the latter, international frameworks are key drivers for calibration/validation and data standards.

- As regards funding, national commitment is needed for the long-term availability and sustainability of *ground-based* observational infrastructure and related data access mechanisms (including sustainable data policies). Possible areas for supranational support include (i) the filling of gaps in observation infrastructure e.g. helping relocations of sites, development of networks in Eastern Europe or outside Europe; (ii) Pan-European observation infrastructures; (iii) European contribution to international networks (through European infrastructures); (iv) Technical (e.g. Calibration / Validation facilities, Data management) & institutional coordination activities.

A composite aerosol network, such as the European Network of Networks (ENAN), initiated by the EC project GEOmon, with commitment from national and international agencies, will facilitate authoritative statements on the need and the implementation of an aerosol monitoring network. Through commonly agreed recommendations for site selection, network design, measurement parameter gap identification and integration, a federated network can provide important additional value for local and regional measurements, making them more cost-efficient. In the long-term, ENAN will facilitate easier links to other scientific fields such as the measurement of greenhouse gases and meteorological parameters. Such a composite aerosol network could provide an adequate contribution to GCOS and GEO. A European network on aerosol measurements could serve as a pilot integration exercise given the current splintering of efforts among national air pollution agencies, research institutions and European bodies such as EMEP and EEA.

1.2.1 Specific needs

1.2.1.1 Long-range trans-boundary air-pollution

Long-range aerosol transport is a very important aspect to be considered for assessing the impact of aerosol on climate on a continental and global scale as well as how aerosols influence the air quality. The relatively long lifetime of aerosol particles (several days to weeks) in the atmosphere determines the possibility of their long-range transport. One example is polluted aerosols originating from Central Europe, Central America and Asia. These aerosols can be transported over long distances, including into the Arctic. Furthermore, mineral dust transport has been documented from the Sahara region to southern and central Europe (Papayannis et al., 2008), to trans-Atlantic regions (Ansmann et al., 2009), and from desert areas in central Asia (Gobi and Taklamakan) to Eastern and South Asia (Yumimoto et al., 2009) and North America (Prospero et al., 1972, 1977). Next to mineral dust, forest fires and the burning of grassland is another important large-scale natural source of aerosol particles (Lavoué et al., 2000; Nakajima et al., 1999).

A reliable and comprehensive approach for obtaining information on the impact of aerosol long-range transport is represented by the combination of “pseudo-Lagrangian observations” from *in situ* airborne instruments with ground-based and satellite monitoring. The analysis of the aerosol long-range transport and chemical modifications along their path, from the source regions to other regions, through the lower and upper troposphere to the planetary boundary layer, needs better assessment. This is particularly important for the understanding of aerosols and their influence on health issues to support decision makers of environmental policy.

A Task Force on Hemispheric Transport of Air Pollution was established by the Executive Body of the UNECE Convention on Long-Range Transboundary Air Pollution – LRTAP – in December 2004. The Task Force was mandated to obtain a better understanding of intercontinental transport of air pollution and to provide estimates of source-receptor relationships for inter-continental air pollution. An interim assessment report – Hemispheric Transport of Air Pollution 2007 (European Commission for Europe, 2007) – was based on written contributions from some 50 international scientists. Main recommendations from the 2007 Report include: i) requirement of an integrated approach in which best available knowledge from observatories, emissions and models is combined, in order to improve our assessment of inter-continental and hemispheric transport; and ii) need for a robust observational system using multiple observational platforms and methods so as to provide data for the evaluation and improvement of chemical transport models and emission inventories. A report of the 2010 Assessment of the Task Force on Hemispheric Transport of Air Pollution is available from http://www.htap.org/ (HTAP, 2011). This is the first comprehensive assessment of the state of the science with respect to the intercontinental transport of air pollutants in the Northern Hemisphere.

At present, quantifying the impact of long-range transport of aerosol and pollutants on air quality remains challenging. A co-ordinated effort from a well established consortium of aerosol networks with harmonised observations and integrated products exploiting the various contributing networks could largely increase the potential for achieving a characterization of this impact in the next decade.

1.2.1.2 Health issues

On a worldwide basis, the annual number of premature deaths caused by cardiovascular and pulmonary diseases following ambient air particulate matter (PM) exposure is estimated to be substantial at 800 000 (World Health Organization (WHO), 2002). Thus this is of major concern globally. There is growing evidence that negative health effects are strongly related to the sources of particulate matter (e.g. through their chemical composition) (Yttri et al., 2009 and references therein). A major contributor to ambient particulate matter, the carbonaceous fraction constituting 20-70 per cent of the mass concentration, is of major concern (Hallquist et al., 2009, Jimenez et al., 2009). Large shortcomings in this area can be attributed to the lack of observations to characterize the chemical composition of the aerosol particles, particularly the carbonaceous fraction. This could be explained partly by the large number of species involved in the atmospheric formation and transformation of the carbonaceous aerosol, and by the fact that current analytical capabilities are insufficient for complete qualitative and quantitative characterization. Also, the emissions to the atmosphere of primary carbonaceous particles and gas precursors of secondary carbonaceous aerosols are poorly known.

The scientific community is still grappling with what causes the ambient aerosol toxicity. Improved monitoring and chemical characterization of aerosols is required. To do so, component speciation must be extended and more sophisticated on- and offline instruments must be employed. Such requirements are not compatible with easy-to-operate, low-cost instrumentation, but should rather be aimed at selected supersites under coordination and guidance of a network of networks. Alternatively, dedicated campaigns could be conducted across regional networks.

1.2.1.3 Weather and climate

The Earth is an interactive and complex system. The traditional separation between weather and climate studies is nowadays considered obsolete, and a synergistic research approach is recommended. At present, there is an ongoing debate on the need of observational systems designed for both weather and climate applications. Likewise, the debate will be extended to modelling issues, looking at the climate as “the averaged weather”, but also as the accumulated effect of dynamical and physical mechanisms that are closely related to the weather. Therefore, climate models need to represent these mechanisms with sufficient accuracy rather than modelling the mean conditions of the atmosphere.

It is clear that improvements in the forecasting ability of weather and climate models are strongly connected with the availability of experimental observations with high accuracy and with high temporal and spatial resolution. The research and development of new sensors, with increasing accuracies, and of data integration techniques play a fundamental role in the improvement of aerosol monitoring. Important processes related to aerosols are still inadequately represented in weather and climate models and produce large uncertainties in weather and climate projections.

The climatic effect of aerosols consists of both direct and indirect effects, the latter including influences on cloud formation and cloud properties. Despite the huge scientific focus in the last decade the overall direct, semi-direct and indirect effects are subject to wide uncertainties. There is recent progress in the understanding of the direct aerosol effect with consistent results from modelling and observational approaches (Myhre, 2009). However, large uncertainties still exist, particularly connected to the absorbing aerosol constituents (Koch et al., 2009). Moreover, effects of aerosols on cloud formation and properties like cloud lifetime and precipitation are not well understood, in part because of the lack of observations. Small human-induced perturbations to cloud characteristics via aerosol pathways can create a change in the top-of-atmosphere radiative forcing of hundreds of Wm^{-2} (Koren et al., 2010). The cloud-aerosol impacts on precipitation have recently been reviewed by Rosenfeld et al. (2008) and Stevens and Feingold (2009). Integrated products utilizing various sophisticated ground-based measurements, profiles and total column observations are central. Since the impacts of aerosols at the surface require assessment of the depth of the planetary boundary layer, aerosol profiling has a significant benefit in determining daytime heating, convection and other micrometeorological inputs to numerical models. Integration of ground-based and satellite observations would help to further support model development and testing of new and more effective aerosol parameterizations.

1.2.1.4 Water resources

A better knowledge of chemical composition and physical processes related to aerosols strongly impacts also the management of water resources. The aerosol indirect effects influence the precipitation life cycle, and the effect on precipitation in deep convective clouds needs to be considered for a correct evaluation of the water cycle. For example it is reported that aerosol/pollution coming from the major cities strongly modifies the clouds, and significantly reduces the precipitation and snowpack in the regions downwind. Therefore, this is an issue with major economic and societal implications for many populated parts of the world and it is a fairly urgent task to be addressed. Moreover, wash-out of aerosols through precipitation may have influence on the available water resources. The potential spread of infections caused by aerosol contamination of surfaces and water sources should be addressed in future aerosol studies.

1.3 Added value of a composite network

A composite network increases confidence across nations in international fora on policy decisions relating to climate change, aerosol forcing and long-range-transport, and health-related issues. Integration would allow for a quantitative synthesis from disparate networks. Understanding and quantification of long-range transport and climate effects of aerosol requires integration of vertical profiles, surface properties and column observations which currently are provided by several different networks that usually are not collocated and therefore are difficult to interpret due to local differences and gradients. Accounting for background contributions affecting urban air quality requires that data from regional scale larger networks are incorporated providing information complementary to that from urban monitoring networks. Integration allows minimising problems of individual measurement types (cost, bias, temporal and spatial gaps).

Establishing the effect of aerosols on clouds and precipitation requires inputs from aerosol and meteorological networks, which would be much easier to combine when networks are harmonized and provide data in common formats for which analysis and interpretation tools are developed. Accounting for hygroscopic growth requires additional measurements, which are usually not available in a purely PM oriented network. PM mass and other microphysical and optical parameters are normally measured in their dry state, whereas the assessment of climate effects requires knowledge of microphysical, chemical and optical properties of ambient particles. Complementary enhanced chemical characterization from different networks helps to differentiate between different sources (e.g. natural, anthropogenic, regions …).

More efficient resource management will be ensured in a composite network through joint use of man power, software tools, infrastructure, data base and data access tools, outreach, and the bringing together of complementary instrumentation. Finally we can expect that on a European and international level joint human capacity building and training is more efficient in a composite network.

2. CURRENT STATE OF EXISTING AEROSOL NETWORKS

2.1 Introduction

Chapter 2 describes the status of regional and global networks measuring aerosol chemical, physical, or optical properties, and networks measuring the vertical aerosol distribution. The status includes networks targeting climate forcing and air quality issues on a global and regional scale, involving transboundary aerosol transport. The networks covered in the report are the ones presented at a workshop in Emmetten, Switzerland, in April 2009[5]. The report is limited to long-term monitoring networks, or to medium-short term projects (years) where the measurements are submitted to long-term sustainable data bases.

Currently, there are numerous international monitoring networks employing remote sensing and *in situ* aerosol observations. These networks can mainly be divided into two types; *in situ* networks driven by policy frameworks, with a relatively close relation to stakeholders, and the research based networks. The objectives, development, maintenance and financial structure of these two types of networks are very different and there are limited interactions between the networks for historical reasons. A remaining challenge is to integrate observations from the *in situ* networks with other highly relevant programmes being developed to address more detailed and in depth aerosol properties, and to exploit synergies for mutual benefit.

The chapter is divided into four main subsections: the first one describes the status of global networks, the second one describes the status of regional networks, the third section describes data centres with global data coverage, and the last section provides a brief status of the global network integration.

2.2 Global aerosol networks

There are currently a few global aerosol networks with sites distributed globally measuring the aerosol chemical, optical or physical properties. These are

- GAW aerosol networks including GAW *in situ*, GAWPFR, GALION
- AERONET
- MPLnet

2.2.1 GAW: Aerosol Networks

2.2.1.1 Global Aerosol Observatories

The goal of GAW is to ensure long-term measurements of atmospheric variables in order to detect trends and reasons for those trends. The objective of the GAW aerosol programme (http://www.wmo.int/gaw/sag/aerosol) is to determine the spatio-temporal distribution of aerosol properties related to climate forcing and air quality up to multi-decadal time scales. See also the WMO GAW Strategic Plan 2008 – 2015 (GAW, 2007a) and its addendum (GAW, 2011).

According to GAWSIS, as of June 2012 the GAW aerosol network consists of 27 'Global' Stations', which are encouraged to participate in all the GAW measurement programmes and approximately 170 regional or contributing stations. Not all GAW stations are able to measure all aerosol variables recommended by the Scientific Advisory Group for Aerosol contained in GAW Report No. 153 "WMO/GAW Aerosol Measurement procedures guidelines and recommendations", published in September 2003 (WMO, 2003). Outside Europe and North America there are 15 sites that are categorized as aerosol chemistry sites by GAW. More information can also be found at http://www.wmo.int/gaw/gawsis/.

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[5] At the workshop the goal was to provide a status of aerosol networks on a global scale with presentations of each continent by key persons. Thus there might be networks not covered in the report because the information was not available for the workshop participants.

Figure 1 - 27 GAW 'Global' Stations of June 2012 are included in the map

2.2.1.2 GAW Affiliated AOD Networks

Aerosol optical depth (AOD) is one of five core aerosol variables recommended for long-term continuous measurements in the GAW programme. See GAW Report 162: WMO GAW AOD workshop (WMO, 2004b).

The GAW-PFR network was started in 1999 as a pilot project. The GAW Scientific Advisory Group for Aerosols selected a number of existing GAW stations as candidates for the deployment of 12 Precision Filter Radiometers (PFR). The pilot network is based on mutual collaboration between GAW stations. AOD observation programmes using PFR instruments are now operating at 22 additional locations in Europe, Japan and Antarctica.

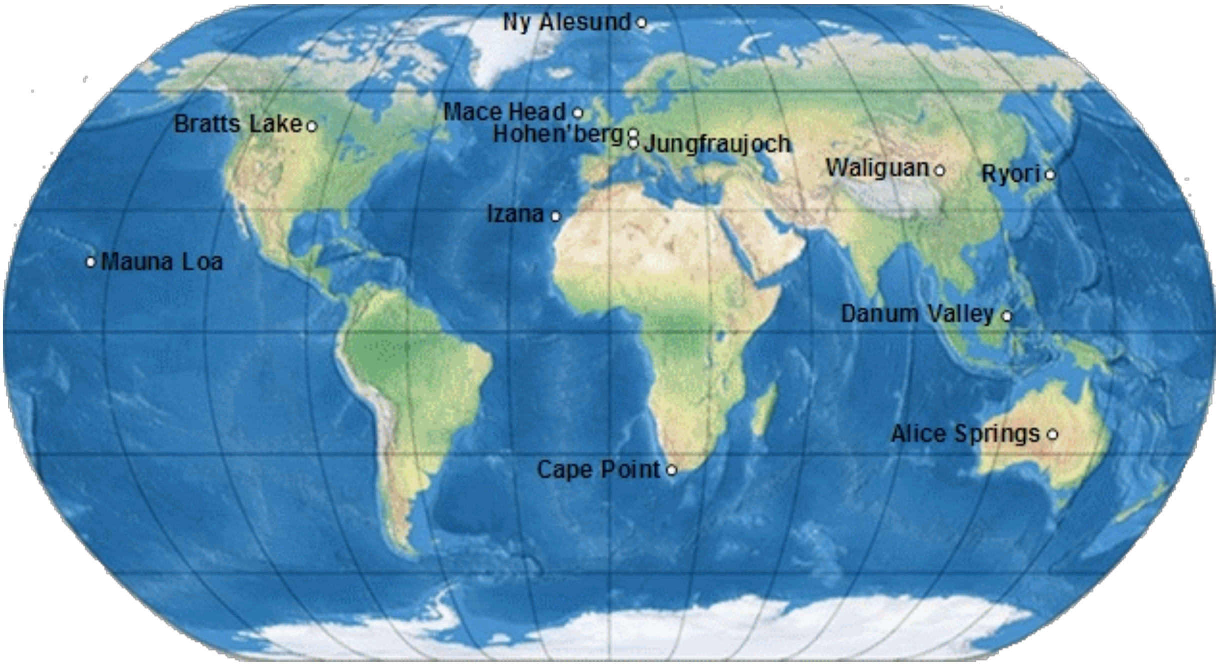

Figure 2 - The location of the original 12 GAW stations operating PFRs in 2010. In recent years there are 11 more stations contributing to the global PFR network

Additional information about GAW-PFR stations can be found at the WORCC portal under http://www.pmodwrc.ch/worcc/ or at the GAW Station Information System GAWSIS http://www.wmo.int/gaw/gawsis. In addition to these 12 stations there are 11 associated stations in Europe and Antarctica (2 in Antarctica, 1 in Greenland, 3 in central Europe, and 5 in Scandinavia).

2.2.1.3 GALION: GAW Aerosol Lidar Observations Network

One global aerosol lidar network of networks exists: The GAW Aerosol Lidar Observation Network, GALION (Figure 4). The specific objective of GALION is to provide the vertical component of the spatio-temporal distribution of aerosol properties through advanced laser remote sensing in a network of ground-based stations.

GALION is a network of networks as it is not feasible to implement a global aerosol lidar network by installing a homogeneous set of systems at a number of stations selected for optimal coverage. Instead GALION make use of existing systems at established stations, of the experienced operators of these systems, and of existing network structures. The structure and development of GALION is described in the GAW Report No. 178 (WMO, 2007b).

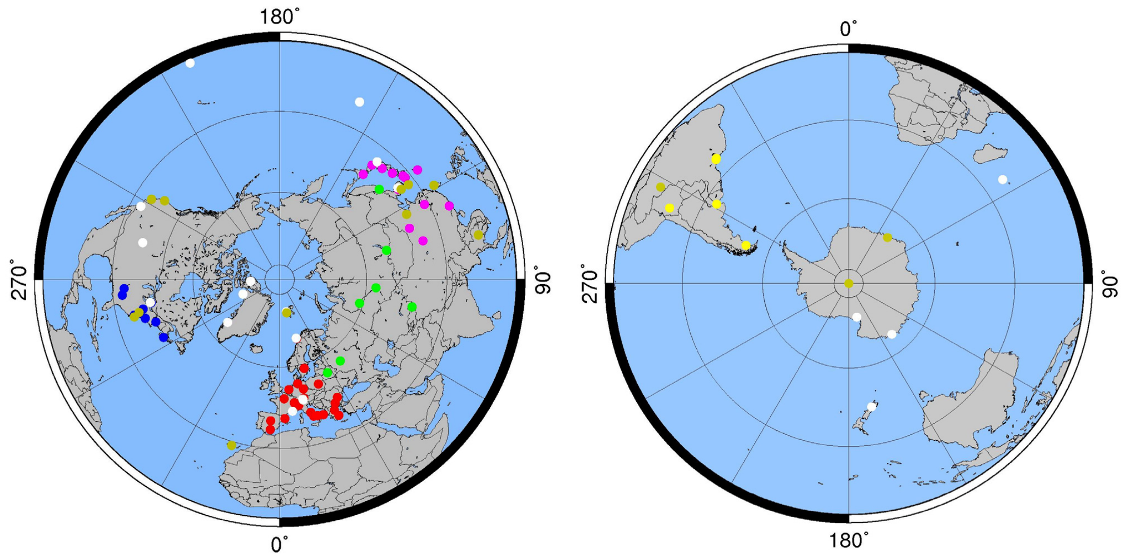

Figure 3 - Distribution of the GALION sites, in 2010. The different networks are indicated by the dot colour: AD-NET violet, ALINE yellow, CIS-LiNet green, EARLINET red, MPLNET brown, NDACC white, CLN blue. (Taken from GAW Report No. 178 (WMO, 2007b)

GALION includes EARLINET (a European research network), NDACC, ADNET in Asia and MPLNET, see 2.3.1. Other lidars (CLN, CORALNET, ALINE) contribute to GALION goals but are not at the same level of maturity or are solely regional in extent. A growing number of commercial lidar instruments is being operated in various parts of the world and will no doubt be part of the global network in the future. Finally, a large number of laser based ceilometers are appearing in the operations of meteorological services. For more details of GALION components see regional networks below.

2.2.1.4 GAW in situ aerosol monitoring network

There are many more GAW stations than the global stations shown in Figure 2 that are making *in situ* aerosol measurements. Many of these are affiliated with the Regional and Contributing networks described in Section 2.3. The NOAA/ESRL (National Oceanic and Atmospheric Administration/ Earth System Research Laboratory) provides some central services to a number of GAW Global Regional or Contributing Stations as well as independent contributors. ESRL (http://www.esrl.noaa.gov) was formed to pursue a broad and comprehensive understanding of the Earth system. This system comprises many physical, chemical and biological processes that need to be dynamically integrated to better predict their behaviour over scales from local to global and periods of minutes to millennia. Currently there are 4 U.S. sites in North America, plus 4 outside North America (South Pole, American Samoa, Mauna Loa, and Puerto Rico). The emphasis on long-term measurements of aerosol climate-forcing properties began in 1976. Now there are continuous measurements of light scattering, light absorption, and number concentration at most sites. There are also daily PM1 filter samples plus weekly PM10 impactor samples at several sites, analyzed for mass and major ions. Nine federated stations in Canada, Europe, Asia, and Africa use the same protocols for sampling and data flow (acquisition, transmission, processing, archiving), and it is anticipated to add 3-4 more in the next year. Figure 4 shows the current and planned sites.

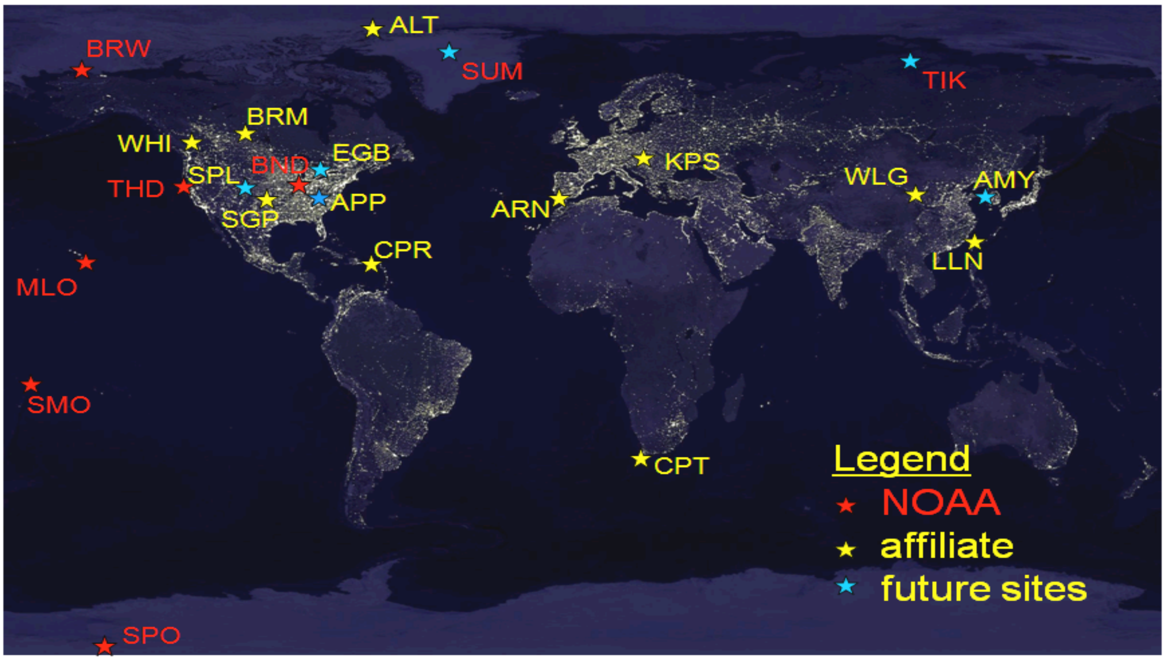

Figure 4 - GAW and independent in situ aerosol monitoring stations using central services provided by NOAA/ESRL, in the year 2010

2.2.2 AERONET: AErosol RObotic NETwork

The AERONET programme (http://aeronet.gsfc.nasa.gov) is a global ground-based remote sensing aerosol network established by NASA, and now involving LOA-PHOTONS (CNRS) and SKYNET in Asia, and is greatly expanded by collaborators from national agencies, institutes, universities, individual scientists, and partners. PHOTONS is the French part dealing with sites mainly in France, Africa and Europe. National institutions finance most of the measurements.

The programme provides a long-term, continuous and readily accessible public domain database of selected aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergisms with other databases. The network imposes standardization of instruments, calibration, processing and distribution.

AERONET collaboration provides globally distributed observations of spectral aerosol optical depth (AOD), inversion products, and precipitable water in diverse aerosol regimes. AOD data are computed for three data quality levels: Level 1.0 (unscreened), Level 1.5 (cloud-screened), and Level 2.0 (cloud-screened and quality-assured). Inversions, precipitable water, and other AOD-dependent products are derived from these data levels and may complement additional quality checks. gives an impression of the global coverage of the network and the development of the number of sites since 1994. This Figure also shows the sites with available data in the AERONET data base for 2008, 344 sites in total.

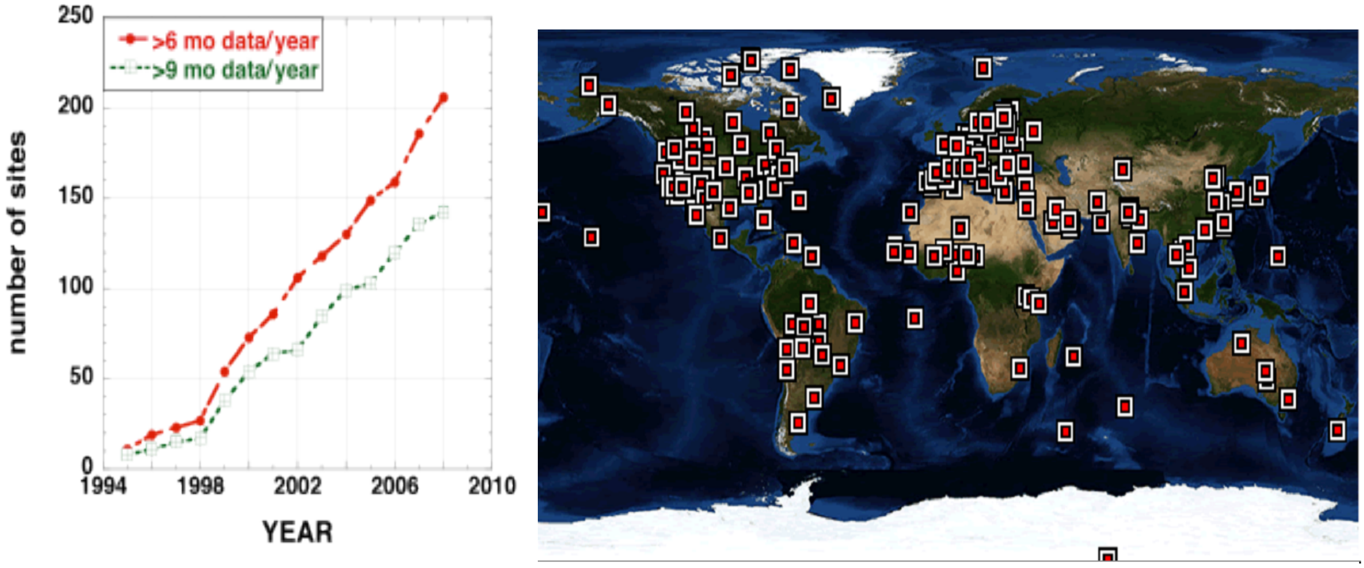

Figure 4 - Development of the number of AERONET sites since 1994 and the location of the AERONET sites that have reported data in 2008

2.2.3 MPLNET: NASA Micro-Pulse Lidar Network

The only tropospheric profiling network that can claim global coverage is the NASA Micro-Pulse Lidar Network (MPLNET, http://mplnet.gsfc.nasa.gov). MPLNET is comprised of ground-based lidar systems, co-located with some AERONET sites and distributed globally. The primary purpose of MPLNET is to acquire long-term observations of aerosol and cloud vertical structure at key sites around the world. MPLNET is composed of sites run by NASA or with help from partner research groups from around the world. In total there are around 16 currently active sites (one Arctic European). MPLNET is mainly funded by the NASA Earth Observing System (EOS), and the NASA Radiation Sciences Programme. It is part of GALION, the GAW Aerosol LIDAR Observations Network (of networks).

2.3 Regional aerosol networks

The section provides a brief overview of the regional networks that was presented at the workshop in Emmetten. The information collected through the workshop is combined and illustrated in four global maps showing the regional networks measuring different categories of aerosol variables

- A global overview of regional networks measuring chemical properties
- A global overview of regional networks measuring optical and physical properties
- A global overview regional networks measuring aerosol profiles
- A global overview regional networks measuring aerosol optical depth

Each map in Figure 7 to Figure 10 shows the approximate area covered by the various networks for each category of variables. The networks typed in bold, are international networks covering more than one country. Web addresses to each network and aerosol variables covered by the respective network are included in Annex I.

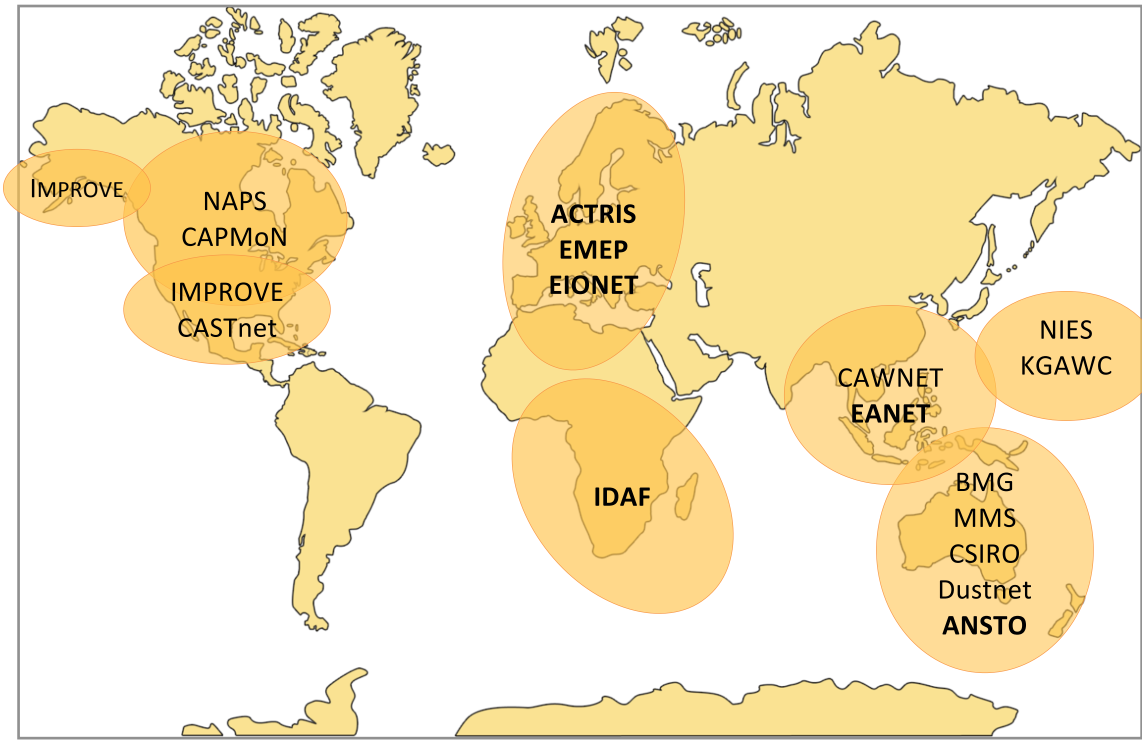

Figure 5 - Regional networks measuring aerosol mass in PM10, PM2.5 and/or PM1, with inorganic and/or organic chemical speciation in one or more size fractions. Networks typed in bold are regional networks covering more than one country

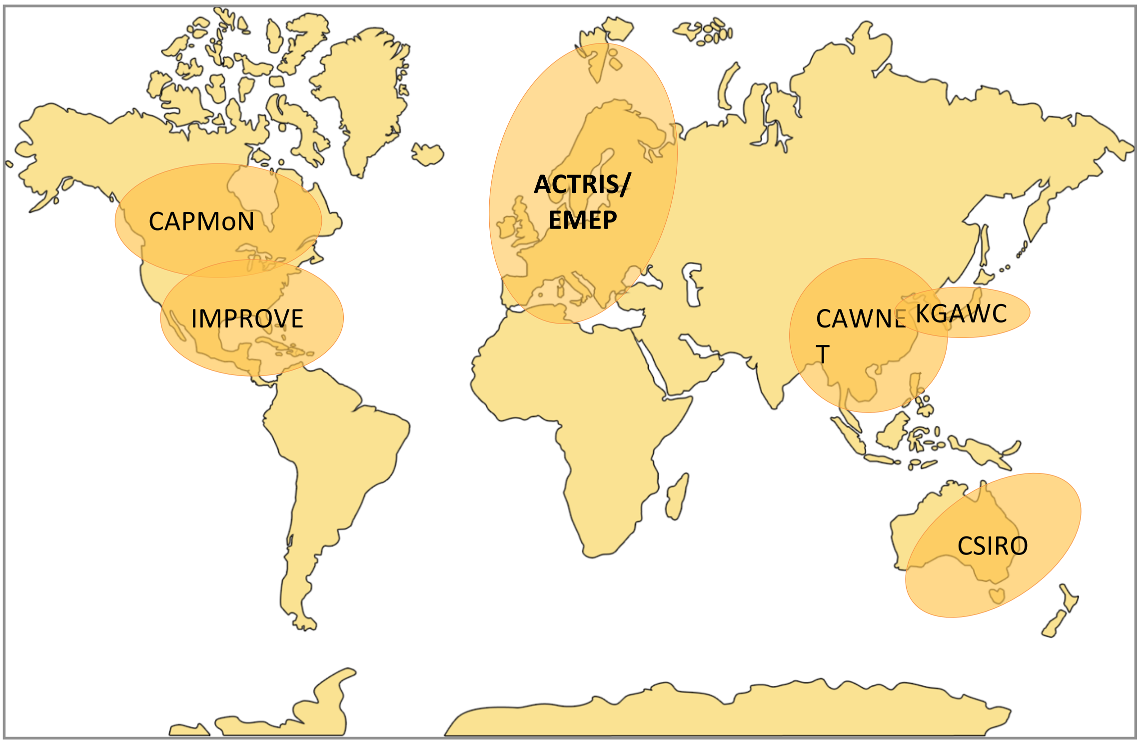

Figure 6 - Regional networks measuring optical and physical properties. Networks typed in bold are regional networks covering more than one country

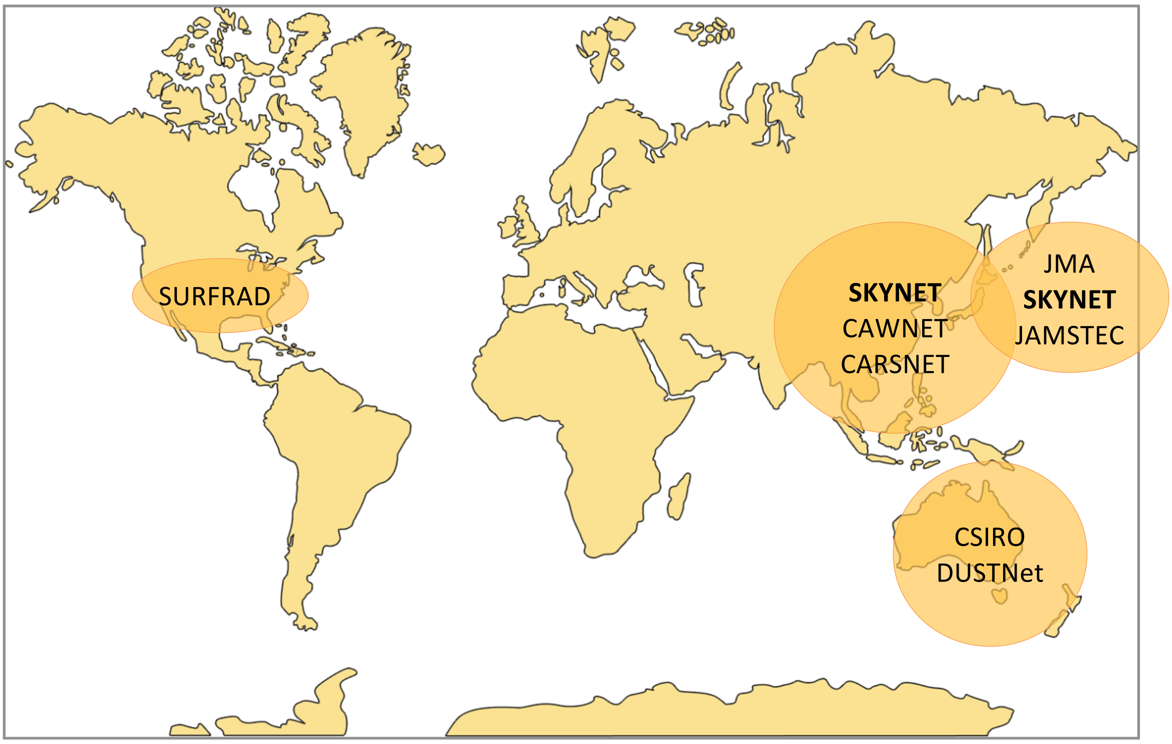

Figure 7 - Regional networks measuring aerosol optical depth. (In addition there are strong global networks described in section 2.2)

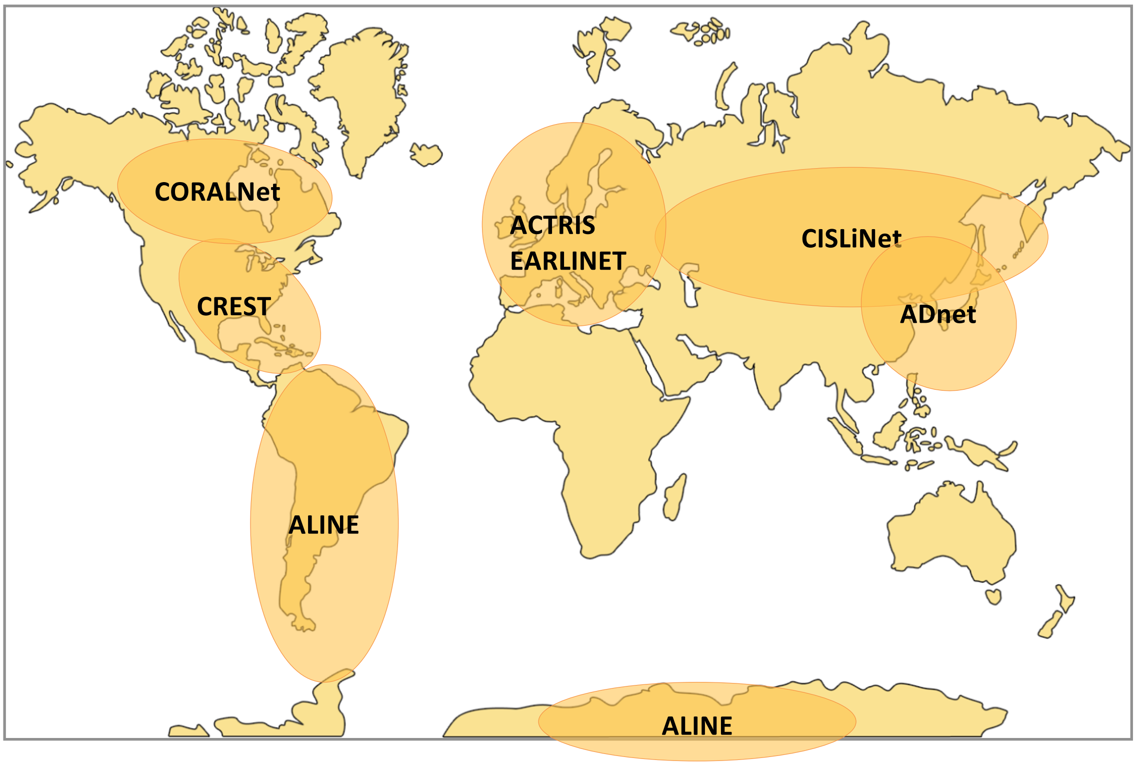

Figure 8 - Regional networks measuring aerosol profiles. In addition there is also MPLNET which is a global network

The maps highlight the potential for regional network integration, and possible coordinated expansion of central networks in certain regions. The maps also visualize the areas with few international networks, and a low level of regional atmospheric monitoring performed in a coordinated way. Note that measurements of aerosol optical depth are well covered by global networks as described in section 2.2.2. Thus a lack of observations is particularly evident in some regions for the *in situ* optical and physical properties (scattering, absorption, size distribution etc.) of aerosols. There are also large areas with no networks indicated. This is partly due to the fact that there are few regional networks in the areas (like on the African continent and in Russia) or there might be several small networks with low level of coordination and little or no interaction with international networks and frameworks (like in some regions in Asia and South America). The results and status of these networks are difficult to determine.

It is important to exploit and take advantage of satellite observations complementary to the surface observations (Hoff and Christopher, 2009). Large areas with no information and large areas where observations are not accessible to the wider community can be covered with satellite observations. Although satellites provide lower accuracy than ground-based observations, they cover large geographical areas using the same sensors and the same retrieval methods. Regional to global scales are covered daily with several instruments, but only for cloud free areas. The satellite retrieval is made with algorithms that are validated with ground-based data, particularly AERONET, and it is presumed that these algorithms are valid for a wider area. Thus developed networks and high quality surface measurements are needed to evaluate the satellite observations. It is advisable to set up stations with both *in situ* and remote-sensing instruments in such large areas at well-selected locations (possibly based on satellite measurements) to provide ground truth for validation and evaluation of the remote-sensing data (satellite and AERONET) to ensure that the assumptions made in the retrieval processes are valid for that area.

2.3.1 Brief overview of European aerosol networks

Currently there are several international monitoring networks in Europe employing remote sensing and *in situ* aerosol observations. These networks can mainly be divided into two types: *in situ* networks driven by policy frameworks, with relatively close relation to stakeholders, and research based networks. The objectives, development, maintenance and financial support of these two types of networks are very different resulting in limited overall interactions between the two types of networks.

EMEP, European Monitoring and Evaluation Programme, http://www.emep.int/

EMEP is a scientifically based and policy driven programme under the Convention on Long-range Transboundary Air Pollution for international co-operation to solve transboundary air pollution problems. Currently more than 100 EMEP sites are distributed around Europe. There are national obligations, and national authorities finance most of the measurement activities. The development of the network and measurement programme is described in Tørseth et al., 2012.

The EMEP sites are regional background sites, and around 80 sites reported aerosol observational data in 2009. In addition there are extensive measurements of other variables like ozone, acidification and eutrophication variables. All data from EMEP are subjected to national quality assessment prior to submission to EBAS (the EMEP database). The submitted data are further assessed by the EMEP-CCC (NILU) in collaboration with the data originators before they are reported on an annual basis. EMEP data are freely available for non commercial use and through its web-site most of the observations can be accessed. The first EMEP aerosol data were reported in the late 1970's, but aerosol measurements were intensified in 1990s and included in the EMEP programme around 2000. Around 50 sites reported PM10 and ca 25 sites reported PM2.5 in 2007. Many sites also reported speciation of inorganic particulate matter like SO_4^{2-}, NO_3^-, and NH_4^+. EC/OC is measured at a few sites.

EIONET, European Environment Information and Observation Network, http://air-climate.eionet.europa.eu

EIONET is a partnership network of the European Environment Agency (EEA) and its member and cooperating countries. EIONET is neither a formal network with common measurement practice and protocols, nor a joint future strategy. It is a network of experts from national environmental agencies. An air quality database system, AirBase, is developed under EIONET and the European Topic Center of air and climate change. The data is mainly based on national monitoring networks. The focus of EIONET is on European air quality issues. The parameters reported are mainly PM10, but also PM2.5 and/or PM1 mass. No optical properties, detailed chemical speciation of aerosols, or physical parameters such as number size distribution are available. In 2007 there were 2348 stations reporting PM10, ~250 stations of these are categorized as rural background. AirBase http://air-climate.eionet.europa.eu/databases/airbase/index_html.

EUSAAR: European Supersites for Atmospheric Aerosol Research, http://www.eusaar.net/

The objectives of EUSAAR was the integration of measurements of atmospheric aerosol properties performed in a distributed network of 20 high quality European ground-based stations, collocated with EMEP, and largely constituting the EMEP level 2 sites. The focus was aerosol chemical, physical (size distribution, mass) and optical properties (light scattering/absorption coefficient, optical depth). This was an EU-funded project carried out under the programme "Structuring the European Research Area - Support for Research Infrastructures". The project ended in 2011. All data from the project were reported to EBAS (http://ebas.nilu.no/). A comprehensive effort was performed within the EUSAAR project to develop and optimise a unified protocol on artefact-free sampling of OC and thermal-optical analysis of EC and OC, as well as harmonization for measurement of aerosol particle size distribution, for subsequent adoption by the EMEP TFMM. EUSAAR and EMEP have regular interactions, and all EUSAAR sites are EMEP sites. The activities is continued and further developed in ACTRIS.

EARLINET: European Aerosol Research LIdar NETwork, http://www.earlinet.org

EARLINET was established in February, 2000 as a research project supported by the European Commission. After the end of the FP5 EC-funded project, EARLINET continued to operate as a voluntary association of research institutions with specific interest in atmospheric aerosol research. The main objective is to establish a qualitatively and quantitatively significant database for vertical distributions of atmospheric aerosols over Europe. On March 2006, the five years EC Project EARLINET-ASOS (Advanced Sustainable Observation System) started on the basis of the EARLINET infrastructure. The EARLINET-ASOS project has strongly contributed to optimize the operation of the network by defining and using common standards for instruments, operation procedures, observation schemes, data processing including advanced retrieval algorithms, and dissemination of data. The network activity is based on scheduled measurements, a rigorous quality assurance programme addressing both instruments and evaluation algorithms, and a standardised data exchange format. Lidar observations within the network are performed on a regular schedule of one daytime measurement per week around noon, when the boundary layer is usually well developed, and two night time measurements per week, with low background light, in order to perform Raman extinction measurements. This data set is used to obtain unbiased data for climatological studies. In addition to the routine measurements, further observations are devoted to monitor special events such as Saharan dust outbreaks, forest fires, photochemical smog, and volcanic eruptions. Data are available from the web-page after registration.

ACTRIS: Aerosols, Clouds, and Trace gases Research InfraStructure Network, http://www.actris.net

ACTRIS started in April 2011 aiming at integrating knowledge from a large set of European ground-based stations equipped with advanced atmospheric probing instrumentation for aerosols, clouds, and short-lived gas-phase species. The main objectives of ACTRIS are to provide long-term observational data relevant to climate and air quality research on the European scale produced with standardized or comparable procedures throughout the network. The project also includes development of new methods, measurements protocols, and integration tools to fully exploit the use of multiple atmospheric techniques at ground-based stations. ACTRIS offers access to the infrastructures and sites for the scientific community, also for the training of students.

ACTRIS is an infrastructure network, and the research component of the existing measurement networks, EARLINET, EMEP, and Cloudnet[6]. Hence ACTRIS is contributing to further development and strengthening of these networks, and the quality of their measurements. As such, ACTRIS is the combined successor of EARLINET and EUSAAR, also involving EMEP.

Currently more than 60 European sites are included in ACTRIS, providing measurements of aerosol chemical, physical (size distribution, mass) and optical properties (light scattering/absorption coefficient), aerosol backscatter and extinction profiles, and a wide range of reactive traces gases (VOCs and NO_{xy}). All data are delivered to a common data centre, http://actris.nilu.no.

2.3.2 Brief overview of American aerosol networks

There are several extensive networks covering the North American continent, but fewer in South America. Also, very few networks are coordinating measurements across national borders with harmonised methods at an international level, the exceptions being the US-Canada collaboration on light scattering and absorption included in 2.2.1.4 and the American AERONET sites in 2.2.2.

IMPROVE: Interagency Monitoring of Protected Visual Environments, http://vista.cira.colostate.edu/improve/

This network includes 110 sites distributed in federally-protected areas (National Parks, wilderness areas, etc) in the USA. Recognizing the importance of visual air quality, the US Congress included legislation in the 1977 Clean Air Act to prevent future and remedy existing visibility impairment (Regional Haze Rule). To aid the implementation of this legislation, the IMPROVE programme was initiated in 1985. This programme implemented an extensive long-term monitoring programme to characterize visibility reduction in the National Parks and Wilderness Areas and attribute the visibility reduction to sources. Currently the monitoring programme includes 110 sites, and 24-hr filter sampling every 3 days is performed and analyzed for PM10 mass, PM2.5 mass, ions, EC/OC, elements, absorption. The network also includes 34 nephelometers measuring light scattering at ambient RH. The IMPROVE monitoring network data undergoes extensive quality control and assessment procedures and analyses. Data from IMPROVE are freely available from http://vista.cira.colostate.edu/improve/Data/IMPROVE/improve_data.htm.

CASTNET: Clean Air Status and Trends Network, http://www.epa.gov/castnet/

CASTNET is a North-American regional long-term environmental monitoring programme administered and operated by US Environmental Protection Agency (EPA). Developed from the existing National Dry Deposition Network (NDDN), CASTNET was established in 1991 under the Clean Air Act Amendments. The regional monitoring network was formed to assess trends in acidic deposition due to emission reduction regulations, such as the Acid Rain Programme and NO_x Budget Trading Programme. CASTNET has since become the nation's primary monitoring network for measuring concentrations of air pollutants involved in acidic deposition affecting regional ecosystems and rural ambient ozone levels. In 2008, there were a total of 82 operational CASTNET sites located in or near rural areas and sensitive ecosystems collecting data on ambient levels of pollutants where urban influences are minimal. There are weekly samples of particulate matter (SO_4^{2-}, NO_3^-, NH_4^+, K^+, Ca^{2+}, Mg^{2+}, Na^+, Cl^-) and also of selected gases. For quality assurance, site audits are performed once every six months and biennially by the CASTNET contractor and a third party auditor, respectively. Data from CASTNET are freely available from http://java.epa.gov/castnet/clearsession.do

[6] *Cloudnet: http://www.cloud-net.org/*

SURFRAD: Surface Radiation Network http://www.srrb.noaa.gov/surfrad/

SURFRAD is a NOAA-operated network, established in 1993, that monitors the surface radiation budget at seven sites in the US. Aerosol optical depth is measured at all sites. Data from SURFRAD are freely available at ftp://aftp.cmdl.noaa.gov/data/radiation/surfrad/.

CREST: Lidar Network (CLN), http://crest.ccny.cuny.edu

The NOAA Cooperative Remote Sensing Center for Science and Technology (CREST) sponsors a confederation of university lidars on the east coast of the United States, Canada, and Puerto Rico. Little coordination of North American lidar capabilities has evolved probably largely due to the multi-agency funding and varied research goals for U.S. and Canadian lidar facilities. CLN evolved from a confederation called REALM (Regional East Aerosol Lidar Mesonet) started in 2002. NOAA-CREST has provided several years of support to the lidars at CCNY, UMBC, Hampton University and University of Puerto Rico at Mayaguez. Separate lidar groups at University of Alabama Huntsville and Dalhousie University in Canada have agreed to be included in CLN. There are also linkages with the Howard University and University of Wisconsin lidar groups, although they are not formally part of CLN. There is no ongoing core funding for the effort and it is truly a collaborative activity of lidar researchers. Funding for parts of the programme has been made available from the two NOAA sponsored centres, the Center for Atmospheric Sciences and the Center for Remote Sensing Science and Technology (CREST, the network sponsor). CLN will continue to depend on financial support from agencies such as NASA, NOAA and EPA in the future. Data from the partners in CLN is available from six separate websites and the CREST link above is being revised to provide more effective connection to the partner sites.

NAPS: National Air Pollution Surveillance Network, http://www.ec.gc.ca/rnspa-naps/

NAPS was established in 1969 as a joint programme of the federal and provincial governments to monitor and assess the quality of the ambient air in Canadian urban centres. The network supports air quality forecasting/reporting and regulatory requirements. Measurements of PM10 and PM2.5 have been a part of the programme since 1984 at 22 sites nationally. Sample filters are analyzed for 50 elements by EDXRF and ions by IC. Since 2000, PM speciation is done at 6 sites analyzing for ammonia, nitrate, and EC/OC.

CAPMoN: The Canadian Air and Precipitation Monitoring Network, http://www.ec.gc.ca/rs-mn/

CAPMoN is a non-urban air quality monitoring network with regional representative sites not affected by local sources of air pollution. There are currently 28 measurement sites distributed in Canada and 1 in the U.S.A. The objectives are to monitor changes in the optical and chemical properties of atmospheric aerosol across Canada and the impact on climate and precipitation. There are measurements of light absorption, light scattering, particle number concentrations, aerosol inorganic ions, and EC/OC. From 1984 onwards there are open face filters for aerosol and precipitation for major ions, from 2004-2007 there are PM2.5 measurements and EC/OC analysis. Data and meta data are available for non commercial use, and most data are available from the web site after registration.

AEROCAN: The Canadian Sun-Photometer Network, http://pages.usherbrooke.ca/aerocan/

AEROCAN provides aerosol optical depth measurements at 9 representative sites across Canada. All sites are included in AERONET and constitute the Canadian AERONET part (see section 2.2.2 about AERONET).

CORALNet: The Canadian Operational Research Aerosol Lidar Network http://www.coralnet.ca/

The Canadian Operational Research Aerosol Lidar Network (CORALNet) was established in 2008 to look at the degree of long-range transported aerosols. CORALNet is currently composed of five lidar systems (four are currently active) strategically located at sites across Canada. These sites were chosen to cover the entire country and to maximize the ability to monitor both long-range transport events as well as regional air quality issues. The sites from west to east are University of British Columbia, Bratt's Lake, Centre For Atmospheric Research Experiments (Egbert), University of Sherbrooke and Acadia University. The first of the sites, CORALNet-UBC began collecting data on April 16th, 2008. Every 10 seconds the system provides vertical aerosol profiles from near ground to 20 km into the sky. It operates 24 hours a day, seven days a week except during precipitation events and when aircraft fly over the site. The system is operated remotely and the data, which are updated every hour, are publicly available on the website. The data are available upon log in.

ALINE: The American Lidar Network

The American Lidar Network is an informal agreement among existing lidar groups in Latin America. The main goals of ALINE are developing a lidar community, conducting capacity building activities among young scientists in the region, and promoting cooperation between the few existing groups. A series of regular workshops every two years have been conducted, the first one in 2001. This has contributed to exchanges and some cooperation among the lidar groups in the region. A general agreement has been reached to formalize the network. Several steps have been taken in that direction. The network consists currently of 7 aerosol lidars. There is no common web page for the network, but information with contact persons, agendas and outcome of joint workshops is available from http://www.lidar.camaguey.cu/.

2.3.3 Brief overview of African aerosol networks

There are very few regional networks on the African continent and the global networks GAW and AERONET make significant contributions to aerosol knowledge in this region.

IDAF: Monitoring Network of Atmospheric Chemistry in Africa, http://idaf.sedoo.fr/

IDAF is an *in situ* network initiated in 1994 by French and African scientists. Currently the programme is maintained and operated on a voluntary basis. The IDAF programme is an initiative of IGBP/IGAC/DEBITS[7] in Africa and the objectives are to estimate, from measurements of wet and dry deposition fluxes, chemical species (especially N, C (OA) and S) at regionally representative sites. Objectives also include trying to achieve the relative contributions of natural and anthropogenic sources and to determine relevant chemical and physical factors that regulate these deposition fluxes and to develop schemes for regional and global atmospheric chemistry models. The measurement programme consists of:

- Rainwater sampling for chemical analysis to estimate wet deposition
- Measurement of SO_2, NO_2, HNO_3, NH_3 concentrations to estimate dry deposition fluxes
- Collection of aerosol samples for chemical analysis to estimate dry deposition fluxes
- Chemical aerosol analysis : Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+} , Cl^-, NO_3^-, SO_4^{2-}, $HCOO^-$, CH_3COO^-, $C_2H_5COO^-$, $C_2O_4^{2-}$-, total carbonates
-

There are data freely available from their web site: http://idaf.sedoo.fr/ in general most data are from the late 1990's.

The IDAF programme is sustained by the IRD (Institut de Recherche pour le Développement) and the French Minister of Foreigner Affairs.

An important contribution to the aerosol measurement at the African continent is the AERONET sites. In 1993 there was one site, Capo Verde, and one site was established in Ouagadougou in 1994. In 1997, there were 10 sites and as many as 37 sites in 2008. The map shown in Figure 9 illustrates the IDAF sites together with the AERONET and GAW sites.

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[7] *International Geosphere Biosphere Programme: IGBP*
International Global Atmospheric Chemistry: IGAC
Deposition of Biogeochemically Trace Species DEBITS

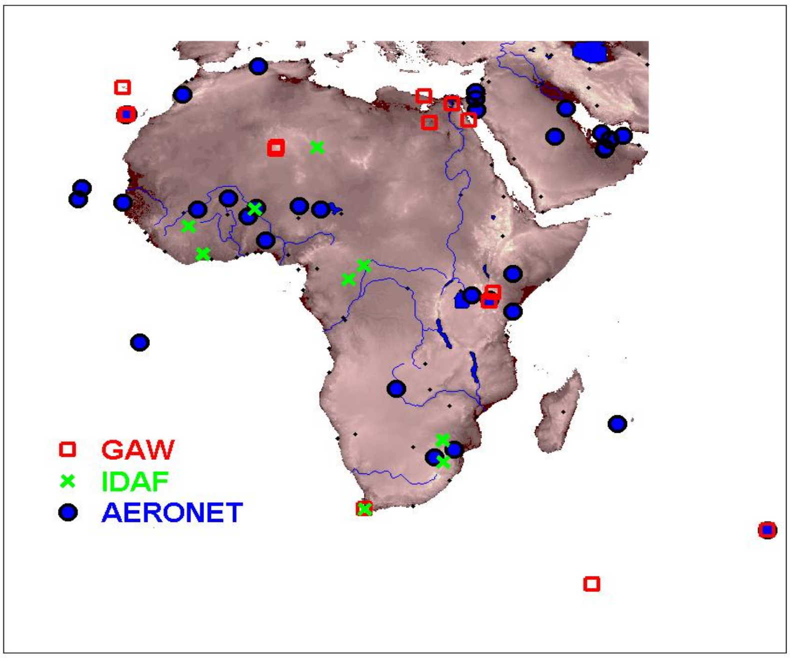

Figure 9 - The map shows the IDAF sites, and the location of AERONET and GAW sites on the African continent in the year 2009

2.3.4 Brief overview of Asian aerosol networks

Urban scale networks receive the majority of resources and are highly regulated in this region, compared to the regional and global networks. However, there are some regional networks coordinating measurements across the national borders. These networks have few sites each, but are important. This section also contains a brief description of some national networks covering parts of Asia. Also valuable clusters of sites run by national meteorological departments are included for some regions even if these are not formal networks.

The regional networks EANET, SKYNET, CISLiNET and ADNet are described first, followed by a section divided in national networks/clusters. It is worthwhile to emphasise the importance of global networks like GAW and AERONET in this region.

EANET: The Acid Deposition Monitoring Network in East Asia, http://www.eanet.cc/

EANET started in 1998 as an intergovernmental initiative to create a common understanding on the state of acid deposition problems in East Asia. Thirteen countries in East Asia are participating in EANET at present. The UNEP Regional Resource Centre for Asia and the Pacific (UNEP RRC.AP) located in Thailand is the Secretariat and the Acid Deposition and Oxidant Research Center (ADORC) located in Japan is the Network Center. 41 sites measured aerosol properties in 2006, most of them with time-series longer than 10 years. The sites are categorized as urban (13), rural (11) and remote (17). There are measurements of PM10, (and PM2.5 at some sites) at 20 sites and concentrations of SO_4^{2-}, NO_3^-, NH_4^+, and Ca^{2+} at all these sites. Many sites are also equipped with radiation measurements and measurements of trace gases, e.g. SO_2 and O_3. A central activity of the network is quality assurance and quality control (QA/QC) activities including development of QA/QC programmes, development of standard operational procedures, inter-laboratory comparison projects and implementation of technical support and capacity building activities. The map in Figure 10 shows the distribution of sites; red dots are urban sites, black dots are rural and remote sites. Reports and further descriptions are available from their web-pages.

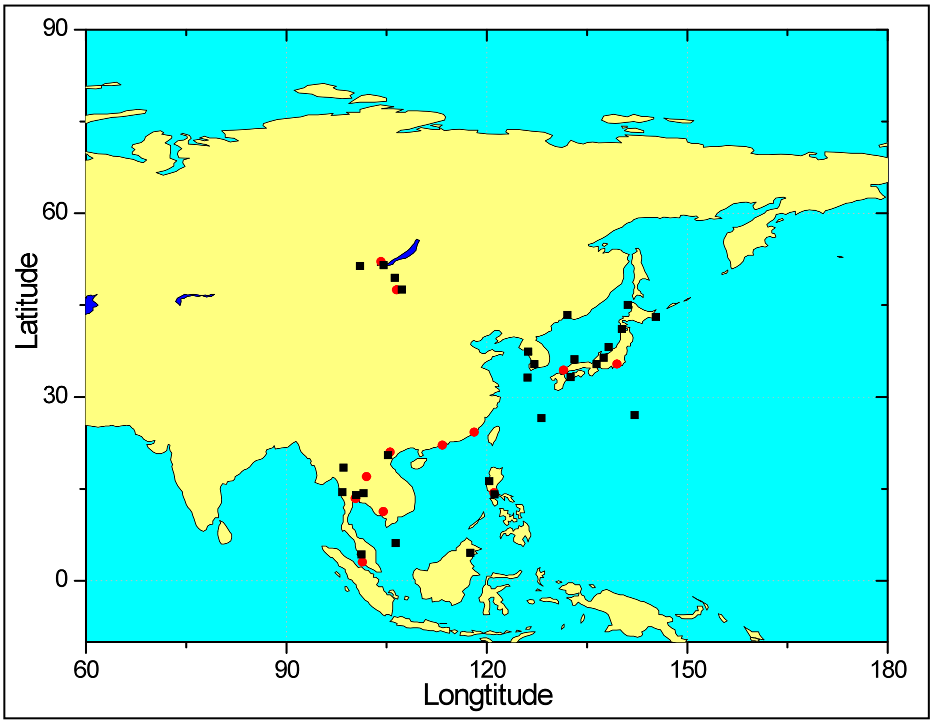

Figure 10 - The sites included in EANET measuring inorganic composition and PM10 in 2006. Red dots are urban sites; black dots are rural and remote sites

SKYNET: atmospheric radiation and weather observation network
http://atmos.cr.chiba-u.ac.jp/

SKYNET is an observation network designed to understand aerosol-cloud-radiation interactions in the atmosphere. The SKYNET is a research-based voluntary activity, which is supported by many researchers and collaborators. Several programmes support SKYNET, but there is no long-term funding. Currently there are 17 sites included in SKYNET, and the sites are located mainly in Eastern Asia from Mongolia to Thailand as well as in Japan. The main instruments consist of a sky radiometer and radiation instruments such as a pyranometer and pyrgeometer at a basic site, while a super site has more extended instruments for analyzing atmospheric aerosol parameters, cloud and radiation. There are limited *in situ* aerosol measurements. Data are freely available from the network's web page.

CISLiNet: Commonwealth of Independent States Lidar Network
http://www.cis-linet.basnet.by/

The networks are based on the project "Atmosphere aerosol and ozone monitoring in CIS regions through the lidar station's network (CIS-LiNet)" established in 2005 by lidar teams from Belarus, Russia and Kyrgyz Republic. The project is funded by ISTC[8]. The objective is to create scientific and methodological foundations in order to develop a lidar network in the CIS regions, and perform joint atmospheric investigations with AERONET, EARLINET and AD-Net at the Eurasian continent. Currently there are 6 stationary lidar sites, 1 mobile site and 1 shipboard lidar in Vladivostok. Data, instrument details and reports are available from their web-page and details, maps and site descriptions are also included in the GAW Report No. 178 (WMO, 2007b) describing GALION.

[8] *The International Science and Technology Center (ISTC) is an intergovernmental organization connecting scientists from Russia, Georgia and other countries of the Commonwealth of Independent States (CIS) with their peers and research organizations in Canada, EU, Japan, Republic of Korea, Norway and the United States.* http://www.istc.ru/

ADNet: Asian Dust and Aerosol Lidar Observation Network
http://www-lidar.nies.go.jp/AD-Net/

Asian Dust Network (AD-Net) is an international virtual community established in 2001, based on four years of spring campaigns for rapid communication of Asian dust events since 1997. Since 1999, the community expanded and included various fields of the atmospheric sciences, e.g., lidar, radiation, and other ground chemical and physical measurements, transport modelling, and satellite remote-sensing. Currently there are 20 lidar sites distributed in Mongolia, Japan, Korea and China included in the network. All lidar data except for the Chinese lidar data are available from http://www-lidar.nies.go.jp/; there are no aerosol *in situ* data available.

2.3.4.1 China

CAWNET: China Meteorological Administration (CMA), China meteorological administration Atmosphere Watch NETwork, http://www.cma.gov.cn/en/

The China Meteorological Administration (CMA) also has covered areas such as atmospheric composition analysis and warnings, sand/dust storm monitoring and forecasting etc. since the year 2000. CAWNET is the atmospheric integrated observation system set up in China incorporating sky-, space- and ground-based subsystems. CAWNET includes operational observation of hourly surface PM10 (some sites include PM2.5, PM1), visibility, aerosol light absorption and aerosol light scattering. The network has operational analyses of 24-h sulphate, nitrate, ammonium, EC, OC and dust at 14 stations by filter sampling. The data are not publically available and the network has no unique web page, but an overview of sites and other relevant information can be found in the publications by Zhang and his co-workers (Zhang et al., 2008a; Zhang et al., 2008b).

Additionally the Ministry of Environmental Protection of P.R. China publishes yearly reports on the state of the environment in China available from http://english.mep.gov.cn/. Some relevant information might be found in the data centre: (in Chinese) http://datacenter.mep.gov.cn/. CMA also operates 7 GAW stations including measurements of hourly surface O_3 and reactive gases (NO_x, CO, SO_2) and operational observation of GHGs, and on-line measurements at 4 stations.

CARSNET: China Aerosol Remote Sensing NETwork

CARSNET consists of 37 sites with CIMEL sunphotometer measurements, 26 of which are kept running operationally. All the data are transferred to CMA once a day, but are not freely available. The calibration system including solar and sky measurements has been completed so far. A recent publication links the observations of CARSNET to AERONET (Che et al., 2009).

2.3.4.2 Japan

JMA: Japan Meteorological Agency, http://www.jma.go.jp/

JMA implements services with the goal to prevent and mitigate natural disasters, ensure safety of transportation, develop industry, and improve public welfare. As a part of this, JMA routinely measures radiation, AOD, and aerosol profiling at one site at Ryori, but they do not report any *in situ* aerosol measurements. Currently very little aerosol data or meta data are available through their web page, but JMA hosts the WMO World Data Centre for Greenhouse Gases, WDCGG.

NIES: National Institute for Environmental Studies, http://www.nies.go.jp/

NIES has evolved from studying problems such as pollution, to long-term global-scale issues such as climate change. The main interest is monitoring of long-range transport of pollutants and dust from the Asian continent. There are two stations; Hedo on Okinawa Island and one on Fukue Island. There are also Skynet observations at these sites. Under the NIES “Priority Programme on the Asian Environment” they plan to develop methods to establish *in situ* observational sites for multi-constituent/continuous observation of atmospheric gases and aerosols and to expand the lidar and *in situ* observational network of Asian Dust to include Mongolia and

Southeast Asian regions. Currently, very little aerosol data or meta data are available through their web page.

2.3.4.3 Korea

KGAWC: Korea Global Atmosphere Watch Center

http://www.climate.go.kr/home/Eng/htmls/kgawc/sub1.html

KGAWC is a part of the Korean Meteorological Administration and KGAWC operates two sites measuring aerosol properties: Anmyeon-do and Gosan. The measurement programme is comprehensive including continuous measurements of mass and chemical inorganic analysis (weekly resolution), size distribution (weekly) and optical properties (light scattering and absorption coefficient with 5 minutes time resolution at several wavelengths). Both sites also include a Cimel instrument (aerosol optical depth) and Anmyeon-do is also equipped with a lidar measuring aerosol profiles during campaigns (a NASA MPLNet). Both sites are included in GAW and AERONET. The access to the data is limited (except for the AERONET data).

2.3.4.4 Malaysia and Indonesia

BMKG: Badan Meteorologi Klimatologi dan Geofisika and MMD: Malaysian Meteorological Department: http://www.bmkg.go.id/BMKG_Pusat/Home.bmkg

There are two Global GAW sites measuring aerosol properties in this region operated by the national meteorological departments: Danum Valley in Malaysia and Bukit Kotatabang in Indonesia. Both are measuring PM10 and scattering coefficient at one wavelength, and Danum Valley is also measuring the absorption coefficient at one wavelength. Both sites are run continuously, and the data are available through GAW.

Information about 7 sites measuring PM10 in Malaysia is available from:

http://www.met.gov.my/index.php?option=com_content&task=view&id=748&Itemid=956 and by contacting environ@met.gov.my.

2.3.4.5 Australia and New Zealand

There are few coordinated regional networks in this region, and very few *in situ* observations are available. Generally, the observations are parts of the global networks of GAW and AERONET. Not all are long-term monitoring networks, but rather research sites run by organisations.

CSIRO: The Commonwealth Scientific and Industrial Research Organisation, http://www.csiro.au/

CSIRO is Australia's national science agency. Several research based networks and sites are operated under CSIRO, also in collaboration with the Bureau of Meteorology, BoM, http://www.bom.gov.au/. The GAW site at Cape Grim is very well equipped measuring CCN concentration, light scattering and absorption coefficient, inorganic components, number concentration, and condensation particle number. The data are available from WDCA. CSIRO established the AGSNet in 1998 in affiliation with AERONET. These data are available through the AERONET data base.

ANSTO: The Australian Nuclear Science and Technology Organisation, http://www.ansto.gov.au/

ANSTO is a public research organisation responsible for delivering specialised advice, scientific services and products to government, industry, academia and other research organisations. The aerosol sampling programme has been running for almost 20 years. Aerosol samples are routinely collected at approximately 15 sites distributed in Australia and Asia twice a week, for a 24-hour time period. Each individual filter is analysed for more than 20 different chemical species. Samples are analysed and results interpreted and reported. The data are not publically available. More information is provided by Jodi Colbran, Jodi.COLBRAN@ansto.gov.au. It is possible to view data on fine particle pollution from 4 sites along the New South Wales (Australian) coast at:

http://www.ansto.gov.au/discovering_ansto/what_does_ansto_do/live_weather_and_pollution_data/aerosol_sampling_program.

Furthermore Dustnet is a 29 year record from 13 sites measuring (event samples, with incomplete cover) for TSP mass by HiVol sampler, carried out with research funding by Grant McTainsh. The contact for these data is Dr Grant McTainsh, Griffith University (g.mctainsh@griffith.edu.au).

2.4 Status of data centres

The major challenges for integrated data centres are related to harmonised and on-time data delivery, consistency between data centres, and supporting users in their access to multiple datasets. This includes: getting an overview of existing datasets; selection of appropriate datasets; easier access to data (faster downloads, improved data extraction); improved access to data handling (formats); support with data inter-comparison and collocation; support with data visualization. Overall, the goal of data centres should be to support scientists in preparing and providing data sets in a user-friendly manner, and to ensure preservation of archives of long-term aerosol measurements.

2.4.1 Data centres for ground-based measurements

For an observational network, the data centre not only has a practical function, i.e. collecting, archiving, and disseminating the observed data, but it also could have an outreach function. The data centre serves as a permanent address of the network, and creates the visibility needed to help ensure a network's continuing financial support. While network activities such as defining uniform operating procedures and reporting protocols have limited duration, annual or more frequent reporting of data to the data centre can serve as a reminder of belonging to a network.

Without claiming completeness, Table 1 gives a list of data centres for ground-based aerosol measurements and their key features.

From a user's perspective, the fragmented landscape of data centres creates a challenge when trying to obtain a comprehensive picture of aerosol parameters observed for a given air mass. Temporal resolution of data, metadata, and file formats may vary significantly across networks. It is unlikely that the fragmented nature of data centres will change in the near future.

To try and improve the situation, the inter-operability of data centres has come into focus. Corresponding initiatives aim to harmonise data formats, metadata items and metadata vocabulary and vocabulary definitions between data centres, while maintaining visibility to each individual programme and/or data centre. A natural component of this approach is to develop and maintain data directories overarching the data centres. The directories are meant to list the datasets available, permit searching them, and linking to the source data centre where the actual data are archived and where they can be obtained. The most comprehensive attempt in this direction is probably the WMO Information System (WIS) and its contributors, such as GAWSIS (http://www.wmo.int/gaw/gawsis) and the GEOmon Distributed Database (http://geomon.nilu.no/). While certain core elements of the system, such as terminology and metadata exchange format (ISO 19115) have already been defined for WIS, other parts of the infrastructure still need to be specified and implemented.

Table 1 - Data Centres for Ground-Based Aerosol Measurements and their Key Features

Data centre	Network included	Variables observed	Coverage	Data Access	Format
http://aeronet.gsfc.nasa.gov	AERONET	Aerosol optical depth, Ångström-coefficient, products	global	open	custom ASCII
www.earlinet.org	EARLINET	Aerosol backscatter and extinction profiles	regional	Open, but the use of data is regulated through a data protocol	NetCDF
http://www.eea.europa.eu/themes/air/airbase	EIONET	mass fractions, chemical composition	regional	open	custom CSV
http://ebas.nilu.no	EMEP / EUSAAR / ACTRIS	Physical, optical, chemical properties	regional	open	NASA-Ames + rules for additional metadata
	EUCAARI	Physical, optical, chemical properties	regional	restricted	NASA-Ames + rules for additional metadata
	GAW aerosol	Physical, optical, chemical properties	global	open	NASA-Ames + rules for additional metadata
	IDAF	Chemical properties	regional	restricted	NASA-Ames + rules for additional metadata
	CapMon	Chemical properties	regional	restricted	NASA-Ames + rules for additional metadata
	IMPROVE	Chemical properties, mass fractions, visibility, optical properties	regional	restricted	custom CSV
http://gaw.empa.ch/gawsis (metadata)	GAW WDCA GALION EMEP, AERONET others	metadata of observations within GAW aerosol scope	global	open access to metadata	ISO19115
http://vista.cira.colostate.edu/improve/Data/data.htm	IMPROVE	Chemical properties, mass fractions, visibility, optical properties	regional	open	custom CSV
http://mplnet.gsfc.nasa.gov	MPLNET	Aerosol backscatter and extinction profiles	global	open	
http://loaphotons.univ-lille1.fr	PHOTONS	Aerosol optical depth, Ångström-coefficient, polarisation	regional	open	custom ASCII
http://actris.nilu.no *	ACTRIS Data Centre	All aerosol variables	global	open, but use of data might be regulated trough data protocols	includes many contributing data bases with aerosol data in various formats

**Developed during the EC project GEOmon (http://www.geomon.eu/).The data centre is maintained and further developed in ACTRIS.*

2.4.2 *Data centres hosting satellite aerosol data*

There are currently four activities to support integrated access to satellite aerosol datasets from several instruments.

The NASA **GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure (Giovanni**) exploration tool focuses on support to easily obtain information on the atmosphere around the world without a need to learn data formats to retrieve and process data. The user can try various combinations of parameters measured by different instruments. All the statistical analysis is done via a regular web browser: http://giovanni.gsfc.nasa.gov/ Giovanni works with aerosol (and other atmospheric data) data from NASA missions (OMI/AURA, MODIS/Terra, MODIS/Aqua, TOMS, HALOE/UARS, MISR/Terra, SeaWIFS/OrbView-2) and MERIS/ENVISAT plus additionally ground-based and model data from the U.S. Environmental Protection Agency. Giovanni provides various graphical outputs (area plots, time plots, Hovmöller plots, image animation, different cross sections), various output formats including GIS and batch mode download. Also multi-parameter plots can be made (area, time, scatter, differences, correlations, anomalies).

EPA's **Remote Sensing Information Gateway (RSIG)** was developed as a prototype system under the EPA-GEO (Global Earth Observations) Advance Monitoring Initiative to demonstrate the ability to share and integrate Earth observation data with partners at NASA and NOAA using a distributed architecture (Szykman et al., 2010; http://badger.epa.gov/rsig/). Similarly, the NASA-EPA 3-D Air Quality System decision support project was focused on improved access to NASA satellite data for the air quality community. In 2008, the EPA subsumed the goals and objectives of the 3-D AQS project under the development of the RSIG. EPA's Remote Sensing Information Gateway is now an operational web-based tool (www.epa.gov/rsig) that enables users to access a variety of distributed environmental datasets, including 3-dimensional air quality data sets in a highly efficient manner. Satellite data sets available via RSIG include Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol optical depth and cloud optical thickness along with Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) total aerosol backscatter, key A-Train data relevant to air quality research and analysis.

The **Cloud-Aerosol-Water-Radiation Interactions (ICARE) Thematic center** is a structure created in 2003 by CNES, CNRS, INSU, the University of Lille, and the Nord-Pas-de-Calais Regional Council to coordinate the French research community in fields related to aerosols, clouds, water cycle, and their interactions with radiation. ICARE aims to provide data, products, and services to the community. ICARE operationally produces, archives and distributes selected products requested by the ICARE community, with primary focus on a few key missions supported by CNES (e.g., PARASOL, CALIPSO,…) and collects selected remote sensing and ground-based data from other data providers. Its focus is to provide development services to scientists, especially operational processing, to provide tools, services, and documentation to the users community, to facilitate product dissemination to potential new users, and to provide distant computing resources to ICARE users (SSH access). Access is provided at http://www.icare.univ-lille1.fr. One major focus lies on data from the A-Train (MODIS, PARASOL, CALIOP, CloudSat), and MSG-SEVIRI. A user-friendly interface allows the display of multiple products over a user-defined region of interest. Further tools provide a link to the AERONET sun photometer database.

The **World Data Center for Remote Sensing of the Atmosphere (WDC-RSAT)** hosted by DLR's German Remote Sensing Data Center with mandates of ICSU, WMO and CEOS, pursues the mission to provide a portal for easy access to satellite data and derived information products along all evolution levels of the value adding chain. The main focus lies on the delivery of a harmonized overview and data access portal for all satellite products (initially aerosol and ozone) – a "one-stop shop" for satellite products. By this "one-stop shop" the user is supported in obtaining an overview of available products for their region, period, application and making appropriate choices. Collaboration is established with NASA, NOAA, national satellite product providers (KNMI, LOA, FMI, DLR, universities Bremen, Bern). Access is provided at http://wdc.dlr.de. The main information level is a standardized overview for each satellite aerosol product collection which summarizes its major specifications and provides a direct data access link either at WDC-RSAT or to a partner site of the PI. Minimal pre-conditions for inclusion into the "one-stop shop" are online availability of a continental / annual dataset (not just a case study) with online information on algorithm, product, validation status and an agreement by the PI to collaborate. A high level (i.e. data collection level) search tool is under development.

In summary, it can be said that there are several data centres that contain satellite aerosol data: Individual data centres holding their own data set(s) and few integrated data centres providing access / links to other data sets. There is some copying of datasets between individual data centres. The integrated data centres share partly common goals, but have different foci (goals, sensors, users). They have links to partly overlapping sensors and they include more than aerosol data. They provide and develop tools and continue to work for further harmonization and extension. Collaboration of integrated data centres has been initiated (tools, formats, metadata, interoperability): WDC-RSAT hosts since May 2010 the CEOS Atmospheric Composition Portal in collaboration with NASA (a.o. Giovanni) and is iterating another MoU with CNES/CNRS to link ICARE to the WMO-GAW WDC-RSAT. The joint vision is to fully exploit the potential of satellite data by supporting easy access and joint analysis of multiple satellite aerosol datasets.

2.5 Status of network integration and interaction

2.5.1 Global perspectives

Chemical, physical and optical properties: The global integration of measurements of chemical, physical and optical properties is currently very low. These measurements draw upon the activities of several contributing regional networks, e.g. EMEP, BSRN. This explains the high density of sites in Europe and parts of the US reporting to GAW. Establishing the comparability of measurements across these networks is an important task for GAW. The data flow of EMEP and GAW aerosol data is harmonised to avoid duplication of efforts.

An important issue - the lack of harmonized methods for certain variables measured at surface sites - will benefit from global integration. The measurement protocols used e.g. in IMPROVE (in the US) and EMEP (in Europe) for measuring chemical properties are different. Thus results from the networks in the various regions are not necessarily comparable. Observations in Australasia networks tend to be (strongly) decoupled from other networks, even inside the countries. There is some *de-facto* harmonization through similar "accepted" methodologies (e.g. PM10, PM2.5) or common instrumentation e.g. TEOM, CPC, but there is little uniform end to end system auditing.

Aerosol Optical Depth: With respect to networks measuring aerosol optical depth, these networks are better distributed globally, and integration between the networks is much better. The GAW-PFR network represents a cornerstone of the global AOD observations as participating networks at the WMO 2004 workshop in Davos concluded that "*contributing networks should become traceable to WORCC through inter-comparison of representative instruments or co-location at specific GAW sites*". A complete description of the outcome of this workshop is described in GAW Report No. 162 (WMO, 2004b).

Aerosol profiling: The GAW network GALION is a network of networks designed to contribute to global integration of these types of observations. Through the GAW Report No. 178, there is an implementation plan where collaboration between networks has been initiated, see also section 2.2.1.3 of this report.

2.5.2 Regional perspectives

2.5.2.1 Status of network integration in Europe

In Europe a remaining challenge is to integrate observations from the *in situ* networks that focus on regulatory issues (e.g., EMEP) with other highly relevant programmes. The sites included in research driven infrastructures and networks like EUSAAR, EARLINET and AERONET (see section 2.2.2) are mainly connected to universities and research institutes, both with respect to location and personnel. Compared to the *in situ* networks, these observations are often more complex, but with a weaker, not sustainable financial support, and thus time series are often shorter and not continuous. There is a need to improve the coordination and interaction between these networks, although partial integration also exists between some ground-based *in situ* measurements and remote sensing sites. ACTRIS is considerable step in the direction of improved integration of observation in Europe. ACTRIS is a EU-funded infrastructure that consists of atmospheric supersites combining observations from a set of various measurement platforms and methods targeting aerosols, clouds and short-lived trace gases (see section 2.3.1). ACTRIS is building on the networks EARLINET, EMEP/EUSAAR, Cloudnet. The map in Figure 11 shows the distribution of European network sites across the networks. The EUSAAR sites are the EMEP levels 2 sites with comprehensive aerosol *in situ* observations. Most of these are also included in ACTRIS, together with EARLNET and additional EMEP sites.

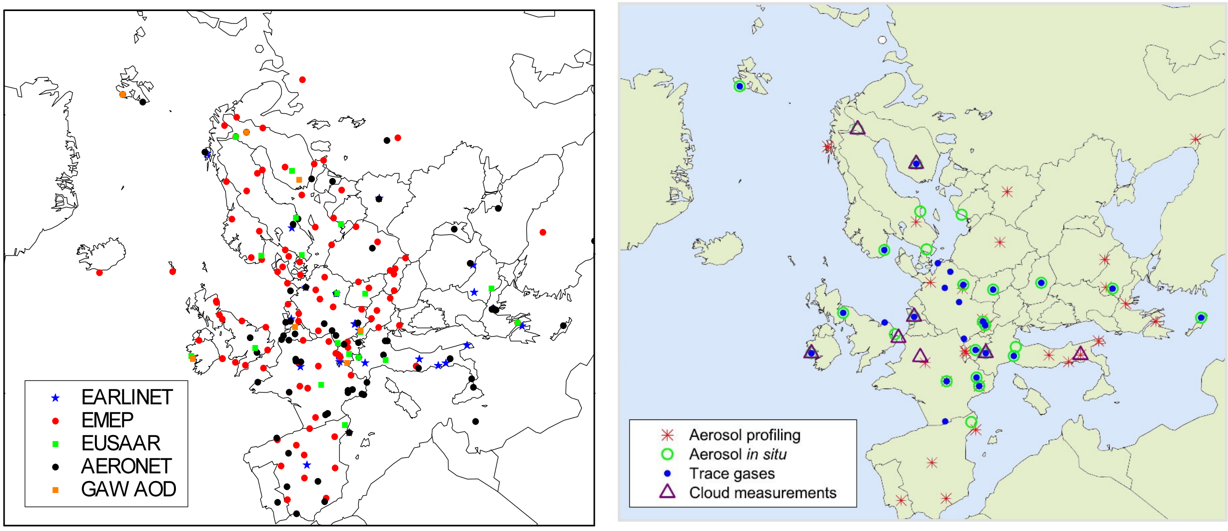

Figure 11 - Distribution of the European network sites included in EARLINET, EMEP, EUSAAR, AERONET and WMO GAW, reporting aerosol variables to their associated databases in 2010. The ACTRIS infrastructure of 2012 is shown to the right

The most striking result comparing the coverage of European aerosol measurement networks is that it is rather the exception than the rule that sites for ground-based *in situ* measurements (EMEP and EUSAAR) overlap with sites for ground-based remote sensing of the aerosol column and profiling (AERONET and EARLINET). This is also the case within the infrastructure project ACTRIS, shown in the map to the right. Considerable synergy effects between these measurements are known, and closer collaboration should improve the sharing of *in situ* and columnar data from the respective networks. One possible approach for improving the situation is a coordinated expansion of the networks emphasizing collocation of ground-based remote sensing and *in situ* instruments, both for aerosol chemical and microphysical properties. An example is the expansion of AERONET in Europe during the last years. In 2000 there were about 28 AERONET sites in Europe, while in 2006 the number had increased to 69, with some of the new instruments being co-located with EARLINET sites. There are also a few AERONET instruments recently located at EMEP sites, but the interaction is still low between these networks and a more formalized and regular contact between the networks will be highly beneficial. It is noted that there is a limitation to the number of AERONET sites that can be set-up in Europe due to the limited availability of Meteosat channels that are used to transfer the data to NASA. Furthermore, EARLINET and AERONET are complementary in that AERONET measured the column AOD whereas EARLINET provides information on the vertical structure of the aerosol optical properties in the atmospheric column but not in the lower 500-1000 m. Hence both networks need to be used together to provide the complete information to obtain optical closure and the correct information on climate effects of aerosols.

The networks have common topics of interest: analysis of atmospheric change and its relation to climate and air quality. The density of sites in Europe is currently relatively high, and closer collaboration between existing networks and sites is perhaps a more efficient way of increasing the networks' potential. Strengthening of the interactions between the networks by an integrated European network based on the existing structures will improve the situation in Europe considerably. In this way the high competences developed in each network might be better utilized across the networks. The potential of co-locating instruments, harmonization of methods and carrying out campaigns can also be stimulated and encouraged through a joint network. This could also be a good strategy leading to possible new observations at existing sites e.g. observations of aerosol precursor gases and secondary aerosol products. Closer network integration can also lead to new and integrated products and methods and provide common tools to better interpret raw data and facilitate easier use of data for end users. This, to a large extent, does not exist today and will be particularly useful in the assessment of climate change, as well as in the evaluation of climate and air pollution mitigation strategies.

2.5.2.2 Status of network integration in America

CASTNET monitors air quality and deposition in cooperation with other national networks. In particular CAPMon operates 28 measurement sites throughout Canada and one in the United States. IMPROVE measures aerosol pollutants near more than 30 CASTNET sites. The map shows IMPROVE sites together with CASTNET sites; 10 sites are overlapping.

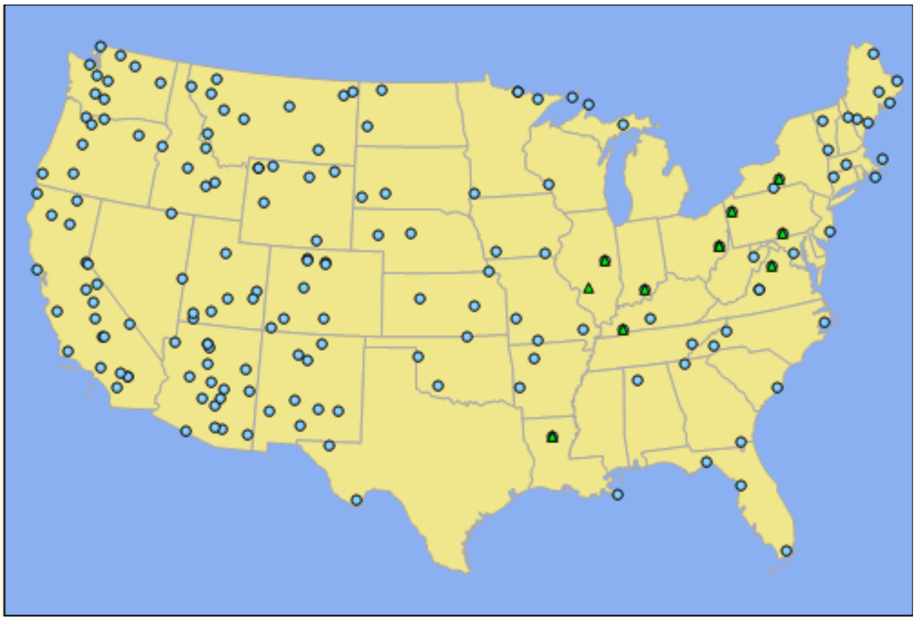

Figure 12 - The map shows IMPROVE sites (blue) together with CASTNET sites (green); 10 sites are overlapping in the year 2009

In general the network interactions are not optimal. A closer interaction between the *in situ* networks is believed to be beneficial. There are weak contacts and little collaboration with networks in South America.

2.5.2.3 Status of network integration in Asia

Australasian regional and global networks tend to be strongly decoupled from other networks, even within a single country. Some *de-facto* harmonization through similar in "accepted" methodology (e.g. PM10 and PM2.5) or common instrumentation like TEOM exists. However, a principal weakness is low uniform end-to-end system auditing. There have been attempts to harmonise measurements through GAW, but there is not sufficient international exchange of expertise. In the Australasian region, column properties using sun photometers have reasonably good coverage. There are still many gaps in spatial coverage.

3. THE VISION OF THE NEAR FUTURE: 5-10 YEARS FROM NOW

In Chapters 1 and 2, motivations for a composite aerosol network and an overview of the existing aerosol networks at both continental and global scale have been presented. In this chapter we present the vision of what we want to achieve in the next years, starting from the present status of the observing system for aerosol. The main specific targets to be addressed are presented, while the implementation part is covered in Chapter 4.

3.1 Introduction

At present, in Europe there are many different existing networks (Chapter 2) that could be integrated with a large added value for the support of decision makers in policy issues as well as for scientific use of the collected data. This integrated observing system on a European scale could act as a basis for a global scale network. This will be the non-satellite component of earth-system observations, contributing to GEO, focusing first on aerosol and then hopefully to be extended to other atmospheric parameters.

The vision is for provision of long-term sustained and consistent observations of aerosol properties on a global scale through a consortium of existing aerosol networks complementing satellite and environmental agencies.

This observation system should be dedicated to supporting studies in specific areas such as long-range transboundary air pollution, weather-climate and water resources. Specific targets to be addressed should include: defining observational gaps and the filling of those gaps; standardisation of measurement methods; standardisation of data archival protocols; improved data quality; known data quality and its uncertainty; an improved data delivery/data management system to multiple users including researchers.

This observing system should foster aerosol-related process studies, validation of satellite sensors, model development and evaluation, assimilation of aerosol data into operational models, and creation of comprehensive aerosol climatology on a global scale. These activities require a coalition of research and an operational/regulatory observational system, coordinated by GAW.

3.1.1 Long-term sustained and consistent observations of aerosol properties on the global scale

For long-term observations, the system should be sustainable. In the last 10 years, significant progress has been made in this direction, mainly by developing networking activities, as shown in Chapter 2, but a lot of work still needs to be done. At present, less than 15 stations worldwide have observation records for aerosol properties besides optical depth spanning over more than 10 years, which clearly limits derivation of trends (Collaud Coen et al., 2012, Asmi et al., 2012).

Sustained observations in the next 5-10 years will surely benefit from the integration of existing aerosol networks and observatories because these will take advantage of the best practice approaches developed within each network for each specific aerosol variable from the relevant aerosol community. The integration of these networks will be coordinated by GAW and will facilitate a relatively less expensive multidisciplinary approach that is crucial for a better aerosol characterisation, and a better understanding of aerosol processes and their impact on climate, weather and air quality.

However, the construction of such an integrated system will strongly depend on the creation of long-term sustainability of research based initiatives. The full potential of such an integrated system will not be reached unless there is long-term sustainability of research-funded contributions, requiring corresponding long-term commitment from national and international funding agencies. This will be necessary to ensure the generation of comprehensive (space and time), homogenous data sets to motivate and support policy decisions in areas such as public health, transport, and climate change.

Research is necessary to improve observational methodologies and to transfer these to other operational networks. The integration of research networks requires the provision of consistent datasets of observations performed using state-of-art measurement technology and data processing.

The integration of European networks could act as a basis for the implementation of a federated network for aerosol observations at the global scale. The main outcome, in a 10-year period, could be a ground-based observational system complementing satellite observations and integrated with numerical models. The basis for this effort is formulated in the EU FP6 project GEOmon.

Space-based measurements have the advantage of obtaining global spatial coverage, but these observations alone are not sufficient. Satellite observations do not have a sufficient temporal coverage to study many processes and they need ground-based measurements for calibration and validation (GCOS, 2006). Ground-based observations are also necessary for the long-term monitoring of parameters that cannot be retrieved from space observations. For example, it is very challenging to distinguish natural and anthropogenic aerosols from ground-based observations and even more so from satellite data. Validation programmes for advanced satellite-data products are still under development and initial assessments indicate some systematic errors (e.g. Hoff and Christopher, 2009). In the next 5-10 years, a strong improvement of these validation programmes is expected. In particular, in an integrated ground-based observational system, ground-based profiling techniques, such as the advanced multi-wavelength lidar technique capable of classifying different aerosol types on the basis of their optical and microphysical properties, can be considered as an ideal bridge between *in situ* and satellite measurements in order to fill gaps in the interpretation of physical mechanisms related to atmospheric aerosol and to ensure a fuller exploitation of satellite and *in situ* operational data on a global scale.

3.2 Specific targets of a composite network

3.2.1 Define and fill gaps

Detailed knowledge of optical, microphysical, and radiative properties of aerosol particles is of vital importance in order to understand their role in atmospheric processes as well as their impact on human health and the environment. Despite the considerable improvements in aerosol particle characterization made in the last decade or more, our knowledge of aerosol particle properties is still quite limited.

We need a strategy, to be implemented in the next 5-10 years, for an integrated approach of characterizing particles by including ground-level and airborne *in situ* measurements, ground-based remote sensing and remote measurements, and space-borne observations in combination with advanced modelling (Diner et al., 2004; GEOSS http://www.earthobservations.org/geoss.shtml).

One of the main targets here is to identify gaps and to promote actions to fill those gaps.

Technological gaps

A fairly exhaustive review of actual gaps in existing technologies for aerosol observations and suggestions on how to fill them was presented by Laj et al. (2009). An important gap is represented by a lack of overlap among different observational techniques at any one site. One example is optical properties derived from lidar observations, which measures profiles starting at a few hundred meters above ground, and *in situ* ground-based optical properties. Another example is observations of ambient and dry aerosols, which often are not comparable and a conversion is necessary. The European situation can be taken as an example of the challenges. At present there are more than 200 sites spread around Europe measuring various aerosol properties coordinated under different networks, as described in Chapter 2. The various aerosol networks have developed over a considerable time period and are partly a result of expansions of existing monitoring networks, and partly represented by networks focusing solely on one of a selected set of aerosol properties. This results in a fairly dense but non-homogeneous coverage and also not having a significant overlap among different observational techniques at the same site, with only few exceptions.

Sites for ground-based *in situ* measurements rarely overlap with sites for ground-based remote sensing observations. Clearly, there is a need for more stations adopting the coupling of these techniques. The same holds for sites measuring AOD by sunphotometry and aerosol vertical profiles by lidar. The most promising approach for improving the described situation is likely a coordinated expansion of the networks fostering the collocation of ground-based remote sensing and *in situ* instruments.

If co-location of measurements is not feasible at each site, there should be at least a few anchor stations where co-location can be encouraged. We should make use of existing networks/stations already providing multi-annual aerosol data. Such stations could be encouraged to form a network where users are given the tools to visualize and select different aerosol parameters, measured at their stations. Such a system has been initiated within GEOmon and is being brought further in the EU FP7 project ACTRIS.

Geographical gaps

Beside technological/co-location gaps we should also consider geographical gaps. A global, ground-based observational system for aerosols could be designed so that most of the climatic regions are well characterized by ground-based *in situ* and profiling measurements. The expansion should be done with a clear knowledge of the requirements for geographical distribution of stations and to foster the creation of stations in climate regions not yet covered by *in situ* and/or ground-based profiling measurements. This can be based on the outcome of future possible science driven design studies performed to identify optimum locations and technical specifications for the new stations. Depending on the outcome of such suggested design studies, new institutions may become interested to build and operate the new stations under their responsibility. The involvement of the end users, and mainly of the modelling community, will be fundamental to define priorities and recommendations. New stations require funding, which is a key driver for establishment of new stations and indeed for the sustainability of existing stations.

The ground-based network activities also need to be linked to space-borne missions. Validation of many satellite based remotely-sensed aerosol properties and products is still inadequate. High-quality ground-based measurements will continue to be required for these validations. Suitable instrument technologies are lacking, particularly in view of aerosol-cloud interaction processes. We also need novel data analysis algorithms that make best use of the data that are available from various measurement platforms of the different networks.
For instance, validation studies of data from satellites and/or ground-based networks cannot in fact be achieved with one single instrument type, nor with one single network alone. Only the synthesis of various instruments and networks will in the future provide higher-order data products that will narrow or close the gap (differences, deviations) that nowadays exist between parameters that are derived with satellites sensors and from ground-based instrumentation.

3.2.2 Standardization, data of known uncertainty and adequate for the intended use

Network activities are based on scheduled measurements, rigorous quality assurance programmes addressing both instruments and evaluation algorithms, and standardized data exchange formats. These procedures are expected to be further improved in the next 5-10 years for each network and for different aerosol parameters.

A strong effort should be made in the coming decade to harmonise the different datasets and achieve a high standard for quality assurance programme also for advanced aerosol products derived from the integration of different observing ground-based and profiling techniques.

The usefulness of data products is strictly related to correct and detailed estimation of measurement uncertainties. This is a crucial issue and needs to be well defined in order to facilitate the comparison, integration and assimilation of measurements from different instruments and networks into numerical models. To this end, harmonisation of methods to calculate measurement uncertainties will need to be undertaken within the next 5 years or so, and subsequently applied to an integrated network.

In view of the quality of data products the networks will need to develop tools (novel algorithms that are implemented into software packages) that will allow us to carry out uncertainty analysis at a skilful level. It is well known that such tools for error analysis either do not exist for some of the networks, or that error estimates are based rather on a “common sense decision” than on a mathematically sound basis. This gap needs to be closed in future network activities, even more so, with involvement of different networks. In this context, it is absolutely mandatory that open source documentation exists in which any potential data user can easily follow the methodologies that are applied to determine the measurement/retrieval uncertainty of data products.

3.2.3 Data delivery/data management system to multiple users

Data dissemination encompasses at least the following aspects: data policy, data format, data dissemination, tracking of usage of data, and metadata.

Easy access to observation data is a pre-requisite for a successful network. A common data policy and data base management structure is beneficial, with the main aim of open and free access to metadata and collected data across networks. In order to facilitate data exchange as well as communication, improved systems for data discovery and dissemination are desired.

In order to foster data use, a dialogue with the user community is essential and user requirements for the operation of the observational system need to be further developed. It should be noted that different users will require multiple data products on different spatial/temporal scales and with different demands concerning accuracy and availability (delayed, near real time, real time data). At the same time, monitoring techniques are constantly being improved; offering shorter time delays and higher time resolution, and these capabilities should be reflected in the development of data dissemination systems.

The final database structure will need to be flexible enough to accommodate a heterogeneous set of sub databases organised around specific observed parameters and/or regions. This heterogeneity reflects the scattered distribution of funding sources for aerosol parameter observation networks, where each funding source requires visibility, e.g. through its own database and webpage. This situation is unlikely to change in the foreseeable future. There are currently at least three noteworthy attempts towards building a common access framework for a distributed set of databases hosting atmospheric observations. ESA and NASA are currently working on a common metadata profile, vocabulary, and metadata exchange protocols for their observation databases for satellite validation, the ESA Campaign Database and the NASA Aura Validation Data Centre. The EU FP6 project *Global Earth Observation and Monitoring* (GEOmon) has built a common access portal for at least 16 globally distributed databases. This is being brought further in the new EU FP7 project, ACTRIS and available from http://actris.nilu.no. At the global scale, the WMO has started its WMO Information System (WIS) project, where the structure has been defined but communication formats and protocols still need to be worked out and implemented. Rather than building its own umbrella infrastructure, the aerosol community should work with these existing initiatives. ESA’s next generation validation data centre, “Generic Environment for Calibration/validation Analysis (GECA)” is focusing solely on satellite calibration and validation, and will make use of the existing data centres.

A primary pre-requisite for data use is data discovery. Metadata portals that allow users to search for data archived in different locations, and engines that support the transformation of data into different formats need to be developed. GAWSIS and the GEOmon Distributed Data Base may serve as role-models and are building blocks for global initiatives such as WIS.

While regional or parameter-oriented initiatives may retain their identity and visibility by maintaining their own data archives, they should ensure that their data are registered and searchable with one or more umbrella infrastructures, and that existing or standardized data formats and naming conventions are used in favour of new ones. Regional and parameter-oriented initiatives may also be used as test-bed for new applications and services for later adaption at the international scale. One such example is the EU FP6 project “European Supersites for Atmospheric Aerosol Research” (EUSAAR) (see chapter 2.3.1). EUSAAR developed a near-real-time (NRT) data collection and dissemination infrastructure for advanced ground-based aerosol observations. By involving international partners and stakeholders, the EUSAAR data centre and NRT infrastructure was accepted as the World Data Centre for Aerosol (WDCA, http://www.wmo.int/gaw/wdca) of the WMO Global Atmosphere Watch (GAW) programme. This is continued and further developed within the EU FP7 project ACTRIS. In terms of ground-based observations of aerosol properties, ACTRIS covers microphysical and optical parameters, lidar profiling, and cloud properties. Building on previous infrastructures such as EARLINET, EUSAAR, and Cloudnet, as well as the WDCA, ACTRIS works on a data umbrella infrastructure for common access. By involving international stakeholders, ACTRIS will extend the number of parameters covered by WDCA, including NRT, and help support the GAW Aerosol Lidar Observation Network (GALION).

The establishment of such a data management system is a huge task, it will require years of preparation but it could be developed step by step once the community has agreed on the general architecture; this is mainly because a data management system should be implemented in a flexible and sustainable way allowing easy (low cost) and continuous upgrades.

3.2.4 Near Real Time (NRT)

Many of the methods for observing atmospheric aerosol properties from the ground that are currently used in observation networks have a temporal resolution down to a couple of minutes or, depending on sampling statistics, even seconds. At the same time, network projects like EARLINET and EUSAAR have implemented not only agreed procedures on how to operate the respective instruments, but also agreed methods on how to process the raw data to arrive at the respective physical parameter provided by the instrument, which includes a hierarchy of data formats for establishing traceability. Furthermore, most networked stations are equipped with online access, originally intended for maintaining the instruments without personally accessing the site. These are the essential ingredients for streamlining the whole data processing chain to a degree as to collect the data at a data centre and disseminate them in near-real-time (NRT), i.e. within 1 – 3 hours of the observation.

During the 2010 eruption of the Eyjafjallajökull volcano on Iceland, the need for such a service became apparent even for the sceptical observer. The resulting plume of volcanic ash spread across the whole of Europe causing severe disruptions of air traffic. Data on location, stratification, and relative density of the plume were available, e.g. from the EARLINET ground lidar network, but not readily accessible for decision making by government authorities or for assimilation into dispersion models that could have predicted plume spreading more accurately. Similar scenarios for using surface-based *in situ* observations of aerosol properties exist, e.g. wildfires or desert dust outbreaks. Last but not least, operational weather forecast models will benefit from assimilating such data for improving quantitative precipitation forecast, or offering forecast of air quality.

At the political level, first initiatives towards implementing near-real-time services for data on atmospheric aerosol properties have been taken. The INSPIRE directive of the European Commission names near-real-time availability of geo-scientific data as a tool for policy making and a goal. The Convention on Long-Range Transport of Air Pollution (CLRTAP-EMEP) has included it in its strategic plan. Also at the international level, the WMO is dedicated to near-real-time dissemination of atmospheric observations in the implementation of the WMO Information System (WIS). The feasibility of implementing NRT data delivery for observations that used to be research level only a few years ago has been shown by the EUSAAR project. EUSAAR has implemented NRT services for surface-based *in situ* observations of particle size distribution and aerosol optical properties, and the service has been adopted and extended by the WMO GAW programme. The scope of these NRT services is continued and extended in the ACTRIS project to include more stations and variables. Also the NASA AERONET programme continues to provide NRT data of aerosol optical depth from its global network of surface-based stations, although the delay is larger than defined above.

For advancing the above mentioned initiatives, at least two challenges, one political and one scientific, need to be addressed. If NRT services are thought as important for decision making by government authorities, implementation is essential. On the other hand, the service relies heavily on research-grade voluntary programmes such as ACTRIS and others as well as regulatory monitoring groups that are reluctant to release or disseminate data until they are fully quality controlled. An important but challenging task will be the strong encouragement of all partners and their sponsoring agencies to support NRT delivery of observations at these stations. It will be a central task of WMO and their environmental partners to point this out to their Member governments and highlight the importance of continued support for NRT delivery of observations at these stations. The scientific challenge lies in assimilating the data into forecast models. Stations providing or potentially providing advanced aerosol properties such as size distribution or optical properties are sparsely distributed spatially, and this situation is unlikely to change due to the cost of making the measurements. In order to make best use of this NRT service, techniques for assimilating sparse datasets into forecast models will need to be a research focus.

3.3 Coalition of research and operational observational system

The success of this ENAN/INAN initiative depends critically on co-operation between research and operational aerosol networks. A continuous flow of know-how will be transferred among the research communities and to operational networks. New stations will be supported using the expertise of the network through different initiatives. The use of mobile facilities will provide a unique opportunity for training activities in the new stations and for increasing their expertise at a state-of-the-art level. Demonstrations and field campaigns will be a perfect opportunity to ensure that their development is in compliance with network objectives.

The model of a federated network will give the opportunity of spreading “best practise” for each particular instrument/parameter from regional to a global scale; a good example is the approach for implementing GALION, the GAW Aerosol Lidar Network as a federated network of existing lidar networks (Ad-NET, ALINE, CISLiNet, EARLINET, MPLNET, NDACC and CLN) (GAW Report No. 178, WMO, 2007b). Federation of different existing networks (different instruments/parameters) at regional/continental scale will improve the observing capability, providing most advanced aerosol products. In this case, state-of-the-art *in situ* and remote sensing instruments will be used in synergy in order to characterize the state of the atmosphere, with unprecedented accuracy and detail of aerosol optical and microphysical properties. The research and development of new sensors, with increasing accuracies, and of data integration techniques play a fundamental role in the improvement of the study and monitoring of aerosol physical properties. Improvements in processing algorithms for advanced data product releases are necessary. Fundamental to this scope is the development of physically consistent aerosol microphysical and radiation parameterizations. This is also important for performing satellite validation and data assimilation in aerosol numerical models.

The ground-based aerosol observational systems’ personnel should cooperate with modellers for the development of physical to optical transfer functions to bridge the gap between observables (*in situ*, ground-based and satellites) and models as well as lay the foundations for aerosol data assimilation. A first step is related to the development of products suitable for the different purposes of model evaluation, reanalysis and data assimilation. For the assimilation of ground-based data, different products should be delivered both for the development of new techniques and for their assimilation in existing operational aerosol models.

Simultaneously, several satellites orbit the Earth with remote sensing instruments that provide a top-down view of the corresponding atmospheric variable. The combination of the databases collected by an integrated aerosol ground-based observation network and from satellite sensors has the potential of providing a complete picture of the four-dimensional state of the atmosphere. Their complementary nature and synergistic use should significantly contribute to providing a more comprehensive description of the atmosphere.

The new European research infrastructure IAGOS-ERI (www.iagos.org) will use *in situ* instruments permanently installed aboard a number of commercial long-range aircraft in order to measure vertical profiles of trace gases and aerosol size distribution throughout the troposphere. The data will form an important complement to vertical information provided by remote sensing and can provide an important linkage between ground-based sites in different regions of the world.

On a longer time scale, it would be possible to establish links to other atmospheric networks. Strategies for quality assurance programmes, standardisation, training and education including data management, developed for a ground-based aerosol observational system could be exported to further networks dealing with different atmospheric parameters (GEOSS http://www.earthobservations.org/geoss.shtml).

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4. IMPLEMENTATION OF A EUROPEAN / INTERNATIONAL NETWORK OF NETWORKS (ENAN/INAN)

Observations of atmospheric aerosols are undertaken by several networks all aiming at the systematic conduct of long-term observations at various locations in a defined region following established protocols related to site representativeness, QA/QC and data dissemination. The networks can be classified into 3 broad categories namely AOD networks, surface-based lidar networks and surface-based *in situ* aerosol physico-chemical properties networks. In some cases these may overlap, and commonly a site location may contribute observations in support of several networks. There is however a great potential for improving the integration of observations across the various networks, and there is further a need to develop cost-efficient monitoring capacity in regions currently inadequately covered. This chapter presents views expressed during the Emmetten workshop on steps that can be taken to improve the interaction between individual networks.

The discussions concluded that any international or continental scale network of networks that can bring together a much larger set of independent networks should be approached by developing some sort of an informal federation of those existing networks. This is essential as these operate on existing funding sources, have established monitoring commitments and have structures to facilitate communication, coordination, harmonisation, capacity building, etc. These networks all need to respond to the directions of their individual stakeholders, and their implementation will always rely on national capabilities (funding, competence etc). Thus, establishing a closer collaboration across networks through some additional efforts is seen as the way forward. This could be organised as a global network of contributing networks under GAW.

A well defined strategy leading to a more efficient integration of aerosol measurement capabilities on continental or larger scales will results in clear benefits such as improved data access and availability, improved comparability of data, more uniform data quality standards from different networks, increased synergy of measurements and prevention of unnecessary duplication. Even moderate resources invested towards developing synergies could significantly enhance such an integration.

The review of the various regional and global aerosol networks at the Emmetten workshop which is further detailed in this report highlighted significant regional gaps. In some areas there are no observations, and in some areas no information was available to the participants, which in itself indicates quite strongly the less than optimal engagement that currently exists between aerosol measurement networks globally. The report presents a view of the existing aerosol networks worldwide that do not detail the operational status of stations within a specific network. A common situation worldwide is that station operators are facing difficulties maintaining their infrastructure at a high level of operation, even within established networks. This issue may become more and more problematic in the future.

Recommendation for implementation and development of the European Networks of Networks/ International Networks of Networks: ENAN/INAN

The Emmetten workshop developed an initial vision for the operation and scope of a network of aerosol networks, and an initial outline of steps towards its implementation.

- Consult with network representatives and respective stakeholders to discuss the ENAN/INAN vision.
    - Based on the outcome of these consultations, identify appropriate mechanisms and formal procedures to develop adequate mandates, and to secure resources to initiate its implementation

- Establish an ongoing engagement of networks with network principals (or representatives) acting as a high-level steering committee and providing guidance in the development of monitoring strategies for an ENAN/INAN.

- Establish several specific working groups of network representatives involving the Aerosol SAG (Scientific Advisory Group) of the WMO-GAW programme to address specific harmonisation issues on the global scale.
    - Set up working groups to develop, coordinate and action specific engagement & harmonisation activities – work with project office and individual networks to implement activities
    - Objectives of the working groups: confirm/develop shared vision and implementation plan - revitalise AOD integration, start development of forum for overall integration, initiate surface network cooperation, data access, technology, communication issues, act as primary contacts for national funding support and programme objectives

- Establish mechanisms for regular communication between networks.
    - Facilitate joint activities e.g. workshops and campaigns
    - Facilitate shared planning of new site locations, co-location and shared operations (large scale facilities)
    - Coordinate the expansion of the networks by collocating instruments to existing monitoring sites of other networks
    - Coordinate the expansion of the networks by establishing new sites in regions with few or complete lack of observations

- Develop an agreement on a shared/common metadata access portal. This requires continuous effort and a long-term scope. GAWSIS can be developed into a suitable metadata portal to provide a comprehensive overview of what is available globally, specifically through a future component of WIS[9]. The GEOmon distributed data base developed in EU FP 6 is a good example of a useful structure, but is lacking the long-term perspective.

- Develop common harmonised methodologies, DQOs, QA/QC procedures etc. across measurement frameworks to the extent possible.

- Facilitate expertise exchange programmes / exchange of model tools/ regular intercomparison activities.

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[9] *An example currently under development is illustrating the possibilities: http://gaw.empa.ch/gawsis -> select 'Global AOD' as the component.*

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Overview of Main Aerosol Variables Measured in the Networks

	Particulate mass [i)]	Chemical speciation[ii)]	Optical, physical properties	Aerosol optical depth	Retrieval products[iii)]	Aerosol profile variables	Web address
ACTRIS	✓*	✓*	✓*			✓*	http://www.actris.net/
ADNet						✓	http://www-lidar.nies.go.jp/AD-Net/
AEROCAN				✓	✓		http://pages.usherbrooke.ca/aerocan
AERONET				✓	✓		http://aeronet.gsfc.nasa.gov
AGSNet				✓	✓		
ALINE						✓	
ANSTO	✓	✓					http://www.ansto.gov.au/:
CAPMoN	✓	✓					http://www.ec.gc.ca/rs-mn/default.asp?lang=En&n=752CE271-1
CARSNET				✓	✓		Che et al., 2009
CASTNET	✓						http://www.epa.gov/castnet
CAWNET	✓	✓					http://www.cma.gov.cn/english/ http://2011.cma.gov.cn/en/ (in Chinese)
CISLiNet						✓	http://www.cis-linet.basnet.by/
CREST				✓		✓	http://crest.ccny.cuny.edu
EANET	✓						http://www.eanet.cc/

	Particulate mass i)	Chemical speciation ii)	Optical, physical properties	Aerosol optical depth	Retrieval products iii)	Aerosol profile variables	Web address
EARLINET					✓	✓	http://www.earlinet.org
EIONET	✓	✓					http://air-climate.eionet.europa.eu:
EMEP	✓	✓*	✓*				http://www.emep.int/
GAW AOD			✓	✓			http://www.wmo.int/, http://www.pmodwrc.ch/worcc/
GAW GALION						✓	http://www.wmo.int/, GAW Report No. 178 (WMO, 2007b)
GAW *in situ*	✓	✓*	✓*		✓*		http://www.wmo.int/, http://gaw.tropos.de/
IDAF	✓*	✓*					http://idaf.sedoo.fr/spip.php?rubrique3
IMPROVE	✓	✓	✓*				http://vista.cira.colostate.edu/improve/
MPLNET				✓	✓	✓	http://mplnet.gsfc.nasa.gov
NAPS	✓						http://www.ec.gc.ca/rnspa-naps/
NIES	(✓)	(✓)					http://www.nies.go.jp/
NOAA ESRL	✓	✓	✓	✓			http://www.esrl.noaa.gov/gmd/aero/
SKYNET			✓*	✓	✓		http://atmos.cr.chiba-u.ac.jp/
SURFRAD				✓	✓		http://www.srrb.noaa.gov/surfrad

** Not all variables at all sites.*
i) PM10 and in some cases or at selected sites also PM1, PM2.5
ii) Inorganic and/or organic speciation
iii) Size distribution (0.05-15mm radius range), single scattering albedo, soot content, aerosol water

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AEROCOM	Stefan Kinne	MPI Met.
AERONET / PHOTONS	Philippe Goloub	U. Lille
AERONET / PHOTONS	Alexander Smirnov	NASA
EARLINET / GALION	Gelsomina Pappalardo	IMAA CNR
EARLINET	Müller, Detlef	IfT
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List of Abbreviations

ACTRIS	Aerosols, Clouds, and Trace gases Research Infrastructure Network
AD-NET	Asian Dust and Aerosol Lidar Observation Network
ADORC	Acid Deposition and Oxidant Research Center
AEROCAN	The Canadian Sun-Photometer Network
AERONET	Aerosol Robotic Network
ALINE	The American Lidar Network
ANSTO	The Australian Nuclear Science and Technology Organisation
AOD	Aerosol Optical Depth
BIRA-IASB	Belgian Institute for Space Aeronomy
BMKG	Badan Meteorologi Klimatologi dan Geofisika
BoM	Bureau of Meteorology
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CAPMoN	The Canadian Air and Precipitation Monitoring Network
CARSNET	China Aerosol Remote Sensing Network
CASTNET	Clean Air Status and Trends Network
CAWNET	China meteorological administration Atmosphere Watch Network
CCC	Chemical Co-ordinating Centre
CCNY	The City College of New York
CEOS	Committee on Earth Observation Satellites
CGMS	Coordination Group for Meteorological Satellites
CISLiNet	Commonwealth of Independent States Lidar Network
CLN	CREST Lidar Network
CMA	China Meteorological Administration
CNES	Centre National d'Etudes Spatiales
CNRS	Centre National de la Recherche Scientifique (National Center for Scientific Research)
CORALNet	The Canadian Operational Research Aerosol Lidar Networkhttp
CPC	Cloud Particle Counter
CREST	Cooperative Remote Sensing Center for Science and Technology
CSIRO	The Commonwealth Scientific and Industrial Research Organization
DEBITS/AFRICA	Deposition of Biogeochemically Trace Species, Africa
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EANET	The Acid Deposition Monitoring Network in East Asia
EARLINET	European Aerosol Research Lidar Network
EC/OC	Elemental Carbon/Organic Carbom
EEA	European Environment Agencys
EIONET	European Environment Information and Observation Network
EMEP	European Monitoring and Evaluation Programme
ENAN	European Network of Networks
ENAN/INAN	European Network of Networks / International Network of Networks
EPA	Environmental Protection Agency
ESA	The European Space Agency
ESRL	Earth System Research Laboratory
EU	European Union
EUSAAR	European Supersites for Atmospheric Aerosol Research
FAO	Food and Agriculture Organisation of the United Nations
FMI	Finnish Meteorological Institute
GACS	Global Monitoring for Environment and Security Atmosphere Core Service
GALION	GAW Aerosol Lidar Observations Network
GAW	Global Atmosphere Watch
GAWSIS	GAW Station Information System

GCOS	Global Climate Observing System
GEOmon	Global Earth Observation and Monitoring
GEOS	Global Earth Observation Systems
GEOSS	Global Earth Observation System of Systems
Giovanni	NASA GES-DISC Interactive Online Visualization ANd aNalysis Infrastructure
GMD	Global Monitoring Division (NOAA/ESRL)
GOOS	Global Ocean Observing System
GOS	Global Observing System
GTOS	Global Terrestrial Observing System
HALOE	Halogen Occultation Experiment
IAGOS	In-Service Aircraft for Global Observing System
ICARE	Cloud-Aerosol-Water-Radiation Interactions
ICOS	Integrated Carbon Observations System
ICSU	International Council for Science
IDAF	IGBP/IGACO/DEBITS Africa, DEBITS: Deposition of Biogeochemically Trace Species
IGACO	Integrated Global Atmospheric Chemistry Observations
IGBP	International Geosphere – Biosphere Programme
IGFA	International Group of Funding Agencies for Global Change Research
IGOS	Integrated Global Observing Strategy
IMPROVE	Interagency Monitoring of Protected Visual Environments
INSU	Institut National des Sciences de l'Univers, the French institute for universe sciences
INTROP	Interdisciplinary Tropospheric research
IOC-UNESCO	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
JAMSTEC	Japan Agency for Marine-Earth Science and Technology
JMA	Japan Meteorological Agency
KGAWC	Korea Global Atmosphere Watch Center
KNMI	Koninklijk Nederlands Meteorologisch Instituut
LOA	Laboratoire d'Optique Atmosphérique
LRTAP	UNECE Convention on Long-Range Transboundary Air Pollution
MMD	Malaysian Meteorological Department
MODIS	Moderate Resolution Imaging Spectroradiometer
MoU	Memorandum of Understanding
MPLNET	NASA Micro-Pulse Lidar Network
NAPS	National Air Pollution Surveillance Network
NASA	National Aeronautics and Space Administration
NDACC	Network for the Detection of Atmospheric Composition Change
NIES	National Institute for Environmental Studies
NOAA	National Oceanographic and Atmospheric Administration
NRT	Near-real-time
PARASOL	Polarization & Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar
PFR	Precision Filter Radiometers
PI	Principal Investigator
PM	Particulate matter
QA/QC	Quality Assurance and Quality Control
REALM	Regional East Aerosol Lidar Mesonet
RSIG	EPA Remote Sensing Information Gateway
SAGE II	Stratospheric Aerosol and Gas Experiment II
SAGE III	Stratospheric Aerosol and Gas Experiment III
SAM II	Stratospheric Aerosol Measurement
SKYNET	Atmospheric radiation and weather observation network
SUFRAD	Surface Radiation Network
TEOM	Tapered Element Oscillating Microbalance
UMBC	University of Maryland, Baltimore County
UNEP	United Nations Environment Programme

UNEP RRC.AP	UNEP Regional Resource Centre for Asia and the Pacific
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WCRP	World Climate Research Programme
WDCA	World Data Centre for Aerosols
WDC-RSAT	World Data Centre for Remote Sensing of the Atmosphere
WHO	World Health Organization
WIDAC	World Integrated Data Archive Centre
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WMO	World Meteorological Organisation
WORCC	World Optical Depth Research and Calibration Center

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102. Report of the Workshop on Precipitation Chemistry Laboratory Techniques, Hradec Kralove, Czech Republic, 17-21 October 1994 (WMO TD No. 658).

103. Report of the Meeting of Experts on the WMO World Data Centres, Toronto, Canada, 17 - 18 February 1995, (prepared by Edward Hare) (WMO TD No. 679).

104. Report of the Fourth WMO Meeting of Experts on the Quality Assurance/Science Activity Centres (QA/SACs) of the Global Atmosphere Watch, jointly held with the First Meeting of the Coordinating Committees of IGAC-GLONET and IGAC-ACE, Garmisch-Partenkirchen, Germany, 13 to 17 March 1995 (WMO TD No. 689).

105. Report of the Fourth Session of the EC Panel of Experts/CAS Working Group on Environmental Pollution and Atmospheric Chemistry (Garmisch, Germany, 6-11 March 1995) (WMO TD No. 718).

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119. Report on BoM/NOAA/WMO International Comparison of the Dobson Spectrophotometers (Perth Airport, Perth, Australia, 3-14 February 1997), (prepared by Robert Evans and James Easson) (WMO TD No. 828).

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