Recommendations for a future European measurement strategy (D2-5)

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REanalysis of the TROpospheric chemical composition
over the past 40 years
A long-term global modeling study of tropospheric chemistry
funded under the 5th EU framework programme
EU-Contract No. EVK2-CT-2002-00170

Document prepared on 15 July 2007

Preface

When the RETRO project was planned, there was relatively little awareness about the state and the needs of a global observing system for atmospheric composition and it was therefore regarded as a valuable task for the project to analyse the situation based on the retrospective analysis of data which was needed in the project anyway. Since then, several European and international activities have investigated this issue in great depth and detail and a multitude of reports appeared which go far beyond what could have been accomplished in a single task of a European research project. This report therefore concentrates on a few aspects which were relevant to the RETRO project in particular and it remains rather short. More information relatred to this topic can be found in the RETRO deliverable D2-2 (Integrated data base of observations) and on the web sites and in the reports of the following initiatives:

- Global Monitoring of Environment and Security (GMES) – a joint EU, ESA initiative
- Global Environmental Monitoring using Satellite and In-Situ data (GEMS) – a EU 6th framework integrated project led by the European Centre for Medium Range Weather Forecast (ECMWF)
- Protocol Monitoring for the GMES Service Element (PROMOTE)—an ESA project in support of GMES
- Global Earth Observing System of Systems (GEOSS) – an initiative of the ad hoc intergovernmental Group on Earth Observations to improve international collaboration in Earth System Monitoring
- Integrated Global Atmospheric Chemistry Observations (IGACO) – A theme report of the Integrated Global Observing Strategy (IGOS) group of the UNESCO
- Infrastructure for Spatial Information in Europe (INSPIRE) – An EU initiative to create a European Data base on geo-referenced information
- Global Earth Observation and Monitoring of the Atmosphere (GEOMON) – a 6th EU framework project to build an integrated pan-European atmospheric observing system of greenhouse gases, reactive gases, aerosols, and stratospheric ozone

Introduction

Monitoring observations of atmospheric composition are required for different purposes such as:

- assessing local and regional air quality and the effects of air quality measures
- information on stratospheric ozone depletion and compliance checking of the Montreal protocol
- assessing climate change, testing compliance with the Kyoto protocol and informing negotiations of future climate change protocols
- initialisation of numerical simulations including extended weather forecasts
- correction of atmospheric interference on satellite remote sensing of land and ocean

Due to limited resources and technical limitations, it is not possible to perform complete monitoring of the entire Earth atmosphere at all times and it is therefore necessary to prioritise between different monitoring parameters, sites and methods.

The current document is a brief discussion paper on European measurement strategies and ongoing activities on improvement of monitoring capabilities. Focus is on global and regional scale tropospheric chemistry and data that are directly relevant to the RETRO proejct. Issues such as climate gas monitoring or aerosol measurements are therefore not included.

The current document contains important input from many RETRO partners and the content has been discussed at project meetings. It should therefore be seen as a collaborative effort.

State of the art, current status of monitoring capabilities

Operational monitoring of tropospheric chemical composition in Europe is mainly accomplished through the EMEP and EIONET (AIRBASE) efforts and covers regional scale and local/urban scale gas-phase measurements respectively. Both programmes/networks are based on national funding of observations and the two programs are mainly working on coordinating and harmonising activities between the different participating countries. There is also considerable amount of cooperation and harmonisation going on between the two networks. Monitoring data from several thousand ground-based in-situ measurements throughout Europe are available. The main focus of EMEP and EIONET is related to legislation and adherence to European and international protocols and directives. Environmental concerns (e.g. protection of ecosystems) has been a key driver since EMEP started up in the seventies and EIONET in the nineties, while human health issues are becoming increasingly more important.

In addition to the above-mentioned national monitoring activities and European programmes connecting them, there are significant amounts of tropospheric composition data available from more research oriented projects and programmes throughout Europe. The MOZAIC/IAGOS and the CARIBIC projects are providing aircraft in-situ measurements of the free troposphere, the NDACC network are performing upper tropospheric chemical composition measurements with FTIR instruments, the NOAA ESRL Cooperative Sampling Network is performing additional O_3 and CO measurements in Europe and globally, and WOUDC (and NILU/Nadir in NRT) are collecting O_3 measurements in the free troposphere from ozone sondes which are launched under the auspices of the World Meteorological Organisation or the NASA funded Southern Hemisphere Additional Ozone Sondes (SHADOZ) network. All these data sources are presented in the Retro D2-2 deliverable and are not described in further detail here.

In addition to projects and programmes mentioned above, but still in a more research oriented mode, are the emerging tropospheric observation capabilities of Earth Observation satellites. ESA (and their participating countries), NASA and JAXA (Japan) have already atmospheric satellite missions in orbit and the China National Space Administration (CNSA) are soon launching their own mission. In Europe, projects like PROMOTE (Stage I and II) and GEMS (described in D2-2) have been and will in the future be important for enabling operational use of satellite observations for the purpose of atmospheric composition monitoring including the assimilation of these data in operational numerical weather models.

Ongoing activities to expand the monitoring capability

Operational and scientific oriented monitoring occurs through projects and programmes such as EMEP, NDACC, etc. and each of these commonly have their own strategies and plans for further development and enhancement of their effort. As an example, EMEP updates their "Monitoring Strategy and Measurement Programme" regularly and the current strategy describes how each participating country should run their monitoring programmes in the years 2004 to 2009. Similar efforts are done for e.g. the EIONET programme. Both programmes collaborate to avoid excessive overlap.

While individual programmes focus on improving and often expanding their monitoring activities, international programmes such as GMES, IGACO, GEOSS and INSPIRE try to outline the general strategy for efficient Earth System Monitoring and to make better use of the already available information. Key objectives are the integration and harmonisation of the data and making information more easily available. The latter is of special importance to the INSPIRE initiative. Based on the INSPIRE documents it can be said that access to environmental data in Europe is likely to become less restricted in the future.

Specific recommendation for future monitoring

The current document is written after completion of the RETRO project and builds on the experiences gained from the effort. Focus is on topics of relevance to the project and on lessons learned from the activities. The recommendations below are identified as relevant for the community of regional and global scale atmospheric trace gas research and monitoring.

Every analysis of the global observing system undertaken so far makes it clear that effective high-quality atmospheric composition monitoring can only be achieved through a mixture of measurements from various observational platforms (e.g. balloons, ground-based, aircraft, satellite, etc.) and their integration in numerical models (see for example the IGACO theme report). The challenge is therefore not cover the whole world with e.g. monitoring stations, but to make sure all regions of importance are covered with sufficient amounts of observations to allow assessment of the atmospheric composition (and trends) and proper model validation and/or data assimilation. Clearly, one needs to distinguish between background observations at remote sites and observations of pollution sources and their transformation at urban and rural locations. The distinction is not always clear (e.g. advection of different air masses depending on wind direction), and the required density and quality of observing platforms will also depend on the chemical properties of the species in question (long-lived substances usually require fewer observational sites but need better accuracy because of the low variability of concentrations).

For assessment of air quality records, ground-based in-situ monitoring is the standard and will probably be so for the years to come. Aircraft measurements provide valuable additional profiles of tropospheric composition while ground-based remote sensing techniques such as LIDAR and FTIR/DOAS spectrometers are only applicable for upper tropospheric and stratospheric measurements of trace gases. Current satellite instruments have very low sensitivity in the lower troposphere and atmospheric boundary layer and will mainly provide complimentary information with regards to surface air quality which are however important due to their large geographical coverage.

Ground-based in-situ monitoring
In the current EMEP monitoring strategy, focus is on ground-based in-situ monitoring. based on earlier experience, the need for a mixture of simple monitoring sites and so-called super-sites was identified. Simple monitoring stations measure a limited amount of key parameters and provide the larger geographical distribution of atmospheric species. Super-sites are much more limited in number, but provide measurements of a larger range of atmospheric compounds and often include profiling capabilities (tower measurements, LIDAR, MAX-DOAS, etc). These sites allow for more process-oriented studies and detailed model validation activities, and are especially important for the research community. Due to limited funding, it will in the future be necessary to find a balance between operating a sufficient amount of simple monitoring stations in combination with a few well equipped super-sites. The current practice where each country in Europe tries to operate at least one super-site for each field of atmospheric research/monitoring seems reasonable. Of special importance are the super-sites located at the European boundaries and it is recommended that stations such as Mace Head, Ny-Aalesund, Jungfraujoch (boundary in the vertical direction), Cabaw, etc. are ensured operation in the future. Until recently there was a lack of supersites in Southern and Eastern Europe. This makes it very difficult to assess past ozone and ozone precursor trends in the Mediterranean region which clearly marks a hot spot in Europe.

Satellite validation
Related to the discussion on normal sites vs. super-sites is the issue on satellite validation. There is a need for improved coordination and harmonisation between ground-based measurements and satellite observations. This includes issues such as adjustments of measurement times at the stations to make it possible to sample the same air-mass from space and surface. Polar orbiting satellites normally only measure over a given location once or twice per day and for parameters with high diurnal variations it is necessary to sample simultaneously. Some monitoring sites (and aircraft measurements) provide vertical information on the atmospheric composition and this is highly valuable for validation of tropospheric satellite retrievals. There is currently only limited harmonisation between satellite and ground-based (incl. aircraft) measurements programmes regarding selection of parameters, sampling periods, spatial and vertical coverage and resolution, etc. It is strongly recommended to enhance such inter-programme cooperation in the future and it is regarded essential in order to realise the strategies of e.g. IGACO (see D2-2).

Routine aircraft measurements
During three successive EU projects, the MOZAIC programme was highly successful to establish a 10-year database of tropospheric composition measurements from passenger aircraft flights. In order to further develop these unique measurement capabilities and transform the programme from a research mode into a firm part of the monitoring network, the EU funded the IAGOS design study in FP6. At present, IAGOS is bidding to become a part of the European Research Infrastructure (ESFRI), where the fleet of aircraft equipped with monitoring instruments shall be expanded from presently 5 to 20 over the next decade. It will be essential to also secure funding for the continued operations of these instruments. The data from the passenger aircraft

flights will in the future be transmitted in near realtime and can thus be used to routinely evaluate numerical model predictions of the tropospheric composition, such as those undertaken in the GEMS project. Later on these data might also be used directly in the data assimilation of a yet to be defined GMES Atmospheric Service.

Similar to the concept of simple monitoring and more complex supersites for ground-based observations, the measurements from MOZAIC/IAGOS provide greater coverage for fewer species, and they are augmented by the far less frequent observations from the CARIBIC research programme, which measures many more substances. Both components are needed to ensure a reasonable coverage of free tropospheric composition measurements.

Harmonisation of quality assurance methods
Current operational and research oriented monitoring activities, networks or programmes initiate their own measurement programmes and their own systems for ensuring the quality of their data. This includes operation of the sites, routines for calibration of instruments, instrument inter-comparisons, laboratory analyses, validation procedures, metadata reporting, use of quality-control flags, retrieval and data processing algorithms, etc. Due to the use of different standards, it is sometimes difficult to compare measurements of the same parameter from different networks/programmes and use of such measurements for satellite or model validation purposes is even harder. It is strongly recommended that networks/programmes improve their cooperation with other networks/programmes in the future. The recently started GEOMON project will to a certain extent enable much of this intra network harmonisation of quality assurance methods, but further initiatives are probably required in the future in order to realise integrated observations along the lines of the IGACO strategy.

Related to the topic of quality assurance is the reporting of data quality and the need for standardisation of such documentation. For users such as the modellers involved in the RETRO project, it is very important that data are of known quality. Since it is impossible to maintain close links between the data users and all the people performing the actual measurements, it is crucial that data quality information is readily available together with the actual data and that this information is provided in standardized form (use of common terminology and metrics). For most observations in the RETRO database, there was not sufficient information of data quality available from the original data archives, but a description of the datasets and recommendations for optimal use was given in the D2-2 deliverable. For trend analyses, it is generally not sufficient that observations are reported together with their standard deviation. Additional information from the quality assurance procedures is required (such as calibration info, lab inter-comparison exercises, instrument inter comparison exercises, etc.). Improved documentation of data quality and harmonisation of reporting methods is strongly suggested. It is strongly suggested that most of this information is stored together with the actual data since this reduces the chances of loosing crucial information. Self-describing file formats, such as the HDF and netcdf formats implemented in the RETRO database, are useful for this purpose, but more standardisation of reporting methods for quality assurance information is needed. Data or data-files should furthermore provide simple guidance to users on proper use of data and information on applicability and representativeness (which is sometimes only known by the local operator of a monitoring station) should preferably be included. It may be of great value to further develop standardized filtering procedures in order to distinguish background air masses from polluted ones, identify episodes of boundary layer influence at mountain sites, etc. How such filtering is best accomplished (e.g. by means of separate sub sets of the data stored independently, options for interactive data access or via quality-control flags) remains to be investigated, but a unified solution would greatly enhance the usability of such information.

Parameters

From a RETRO perspective, a limited number of parameters are needed in order to validate global models and to derive robust information on trends and interannual variability of the atmospheric composition. NO_x, CO and VOC concentrations, needed to validate the emission inventories and the regional-scale and long-range transport in the models, are not sufficiently sampled on a global basis and it is recommended to increase the density of measurements for these species. Surface ozone and ozone in the free troposphere are reasonably well covered in the northern hemisphere, but there are not enough data available for the tropics and in the southern hemisphere. With the present funding structures for monitoring activities which are generally based on national budgets it is unlikely to achieve sufficient global coverage of NO_x, CO, VOC and O_3 concentrations in the foreseeable future. In order to improve this situation, some monitoring activities in developing countries (e.g. in Africa) must be funded from the richer industrialized nations, possibly under joint international or European efforts. It is important to realize that this involves a lot more than the funding of a station and its instrumentation. Sustained operations and a comprehensive data quality assurance programme require at least equal amounts of money and are essential elements of a possible future strategy of global monitoring.