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Monitoring Atmospheric Composition and Climate

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Monitoring Atmospheric Composition and Climate

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MACC (Monitoring Atmospheric Composition and Climate) uses the modelling and data assimilation approach of numerical weather prediction to monitor the composition of the Earth's atmosphere and predict air quality with a focus on Europe. It provides data that are important for understanding climate and validating and improving the models used to predict climate change. Information important for protecting health and for efficient use of solar power generation is also supplied. MACC is developing core operational atmospheric environmental services for Europe's GMES (Global Monitoring for Environment and Security) initiative. An accompanying news item in this edition of the *ECMWF Newsletter* (page 9) discusses the role of MACC in the context of the eruption of the Eyjafjallajökull volcano in Iceland.

MACC is a project funded under the European Union's Seventh Framework Programme. It began on 1 June 2009, when it took over from the EU-funded GEMS project discussed in several earlier editions of the *ECMWF Newsletter*. MACC also continues a number of activities developed within the GMES Service Element project PROMOTE under funding from the European Space Agency.

MACC is undertaken by a 45-partner consortium drawn largely from the participants in GEMS and PROMOTE, and like GEMS is coordinated by ECMWF. Eleven of the partners are national meteorological services from ECMWF Member and Co-operating States.

Figure 1 gives an overview of the process by which MACC uses satellite and in-situ observations to produce a set of products. MACC's main components are:

- Acquisition and pre-processing of observational data, and provision of estimates of surface emissions of key species.
- Global and regional processing chains that include not only the data assimilation and modelling systems that provide the basic monitoring and forecasting products, but also systems that provide derived products.
- Interface to downstream-service providers and other users.

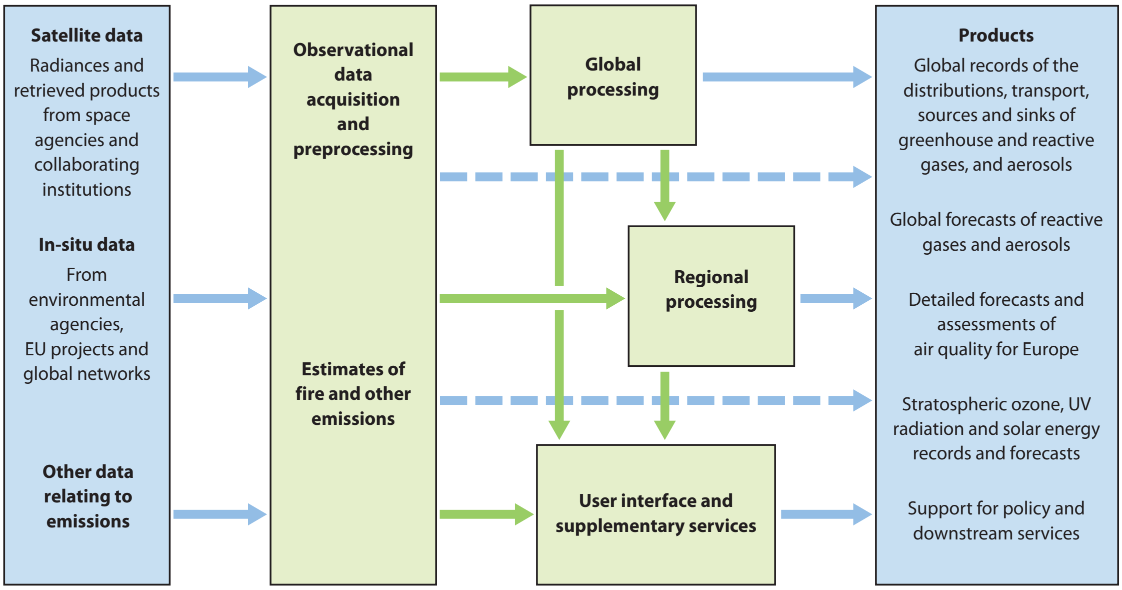

Figure 1 An overview of the MACC processing system.

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Input data

MACC utilizes data from the many satellites that supply information on atmospheric dynamics, thermodynamics and composition. The data are provided either by space agencies or by other institutions that extract or 'retrieve' data on physical or chemical variables from the raw satellite measurements. MACC itself undertakes some of the required satellite data retrieval for atmospheric composition. The satellite data are complemented by extensive *in-situ* data from ground-based and airborne meteorological instruments and by a more limited amount of *in-situ* data on atmospheric composition.

ECMWF's primary task for MACC in this area is the acquisition, pre-processing and archiving of the composition data that are used for global assimilation and validation in conjunction with ECMWF's holdings of meteorological data. Support is also provided to facilitate the flow of near-real-time and validated retrospective European air-quality data to the regional forecasting and assessment component of the project.

MACC also acquires and updates data related to the emissions of chemical species and particulate matter into the atmosphere. A sub-component led by ECMWF is devoted to estimating the highly variable emissions from fires, whose location and intensity are identified from satellite observations, currently from the SEVIRI and MODIS instruments operated respectively by EUMETSAT and NASA. MACC runs its fire-emission system both routinely in near-real-time to provide data for aerosol and reactive-gas forecasting and retrospectively to provide records for use in extended reanalysis and case studies. An example of significant variation in fire activity is illustrated in Figure 2, which shows substantially lower global biomass burning in 2009 than in previous years. This was mainly due to a known reduction in deforestation in Brazil last year, although relatively wet weather in Siberia also contributed.

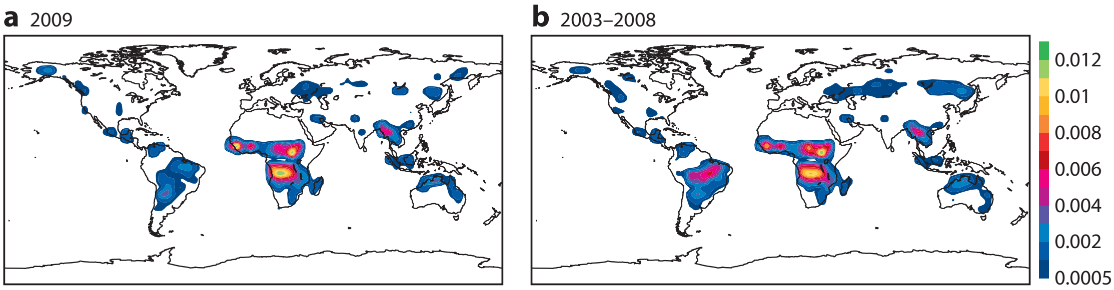

Figure 2 Fire radiative power density (Wm^{-2}) averaged for (a) 2009 and (b) 2003–2008. Global biomass burning was lower in 2009 than in previous years mainly due to reduced deforestation in Brazil. Note that, in addition to biomass burning, the maps exhibit minor features associated with gas flares such as those near the Persian Gulf.

Global monitoring and forecasting

The global component of MACC operates and refines the analysis and forecasting systems that provide the basic monitoring and forecast products for atmospheric composition. It also provides derived products related to the radiative forcing of climate, inferred corrections to sources and sinks, surface UV radiation and resources for solar power generation. Additional observational data are used for validating products.

MACC's integrated data assimilation and forecasting system for atmospheric composition and weather is based on incorporating greenhouse and reactive gases (including carbon dioxide, methane, carbon monoxide, ozone and nitrogen dioxide) and several types of aerosol (dust, sea-salt, organic and black carbon, and sulphate) into ECMWF's Integrated Forecasting System (IFS). Chemical production and loss of the reactive gases are taken at present from one of three coupled chemistry transport models maintained by partners in the project: MOCAGE from Météo-France, MOZART from Forschungszentrum Jülich (Germany) and TM5 from KNMI (The Netherlands). Development of the modelling and data assimilation components within the IFS, operation of production streams, dissemination of results and basic validation are the main tasks of ECMWF in MACC. Model development currently includes incorporation of chemistry and related modules from the transport models into the IFS to eliminate the overheads of the coupled approach.

The integrated global system is run daily to provide monitoring and four-day forecasting of the reactive gases and aerosols. It has been operated routinely and quite robustly in research mode since the summer of 2008, although this has entailed running rather more than a day behind real time. Soon, however, the global system will be moved under the control of ECMWF's operational supervisor, which will substantially improve the timeliness of products. Horizontal resolution will be increased at the same time, from T159 to T255 (125 km to 80 km) for the IFS. Full 24×7 operational support cannot be provided at this stage, but is expected to start in 2012 under a new funding regime.

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To illustrate the type of service that can be provided by MACC, Figure 3 shows a prototype dust warning index. Fine dust and other particulate matter are generally damaging to health, and severe dust storms can cause major disruption to transport and other aspects of daily life. Determining the origin of air pollution episodes and distinguishing between natural and man-made sources of pollutants is important for establishing and implementing policies to improve air quality and protect health. Transport of dust from Africa is a significant factor causing European regulatory thresholds for particulate matter to be exceeded.

The integrated MACC system is also run retrospectively by ECMWF. A production stream for monitoring greenhouse gases is run routinely about six months behind time to enable use to be made of data that arrive with a lag of several months. In addition, there is a continuing programme of reanalysis for the period from 2003 onwards when satellite data on atmospheric composition has been at its best. GEMS carried out a reanalysis for 2003–2007, and this has been extended by MACC until April 2009. An example showing interannual differences in aerosol and carbon monoxide due to Siberian fires was presented in *ECMWF Newsletter No. 120*. MACC has now started a second reanalysis for the period, using higher horizontal resolution and other improvements to the data assimilation system and input data, including emissions.

Three specialised global analysis systems for stratospheric ozone are operated by partners BIRA-IASB (Belgium), DLR (Germany) and KNMI as part of their contributions to MACC. The systems are based on assimilating data from a series of satellites into chemical transport models, and are of relatively low cost. They are run primarily to extend the data records that were established by running them during the PROMOTE project, but they also provide reference points for the performance of the newer integrated MACC system. Figure 4 presents an example of the inter-annual variability of the ozone hole that forms over the Antarctic each year.

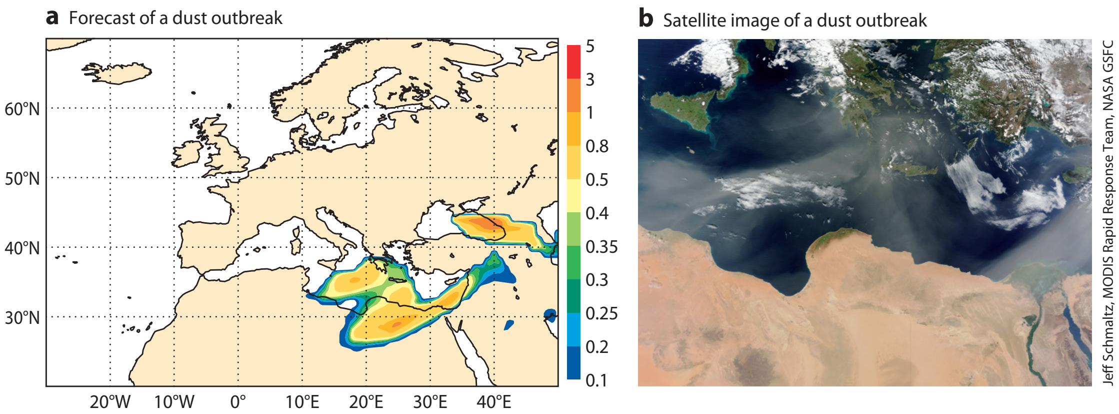

Figure 3 (a) Dust outbreaks from North Africa into the eastern Mediterranean on 18 February 2010 captured in a 33-hour forecast from the global MACC system. (b) The corresponding image from the MODIS instrument on NASA's Terra satellite. The forecast product is a prototype warning index based on scaling the dust aerosol optical depth by a measure of the deviation from climatological conditions.

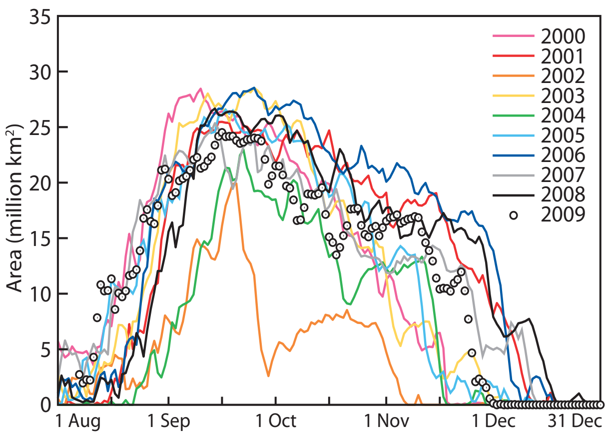

Figure 4 Area of the southern hemisphere with total ozone less than 220 Dobson Units. These records produced by partner KNMI for 2000 to 2009 are based on assimilating data from the GOME and SCIAMACHY instruments on ESA satellites. Their production is being continued in MACC.

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Regional forecasting and evaluation

MACC's regional processing component comprises an ensemble of higher-resolution chemical analysis and forecasting systems run over a common European domain by seven partners. The core ECMWF system provides the meteorological fields required by the regional systems, and the global MACC system provides chemical and aerosol boundary conditions. Forecasts are produced daily for three days ahead. Retrospective analyses of validated air-quality measurements are also produced, providing a description of the background European levels of pollutants that are characterised by the influence of long-range transport. This enables evaluation of interannual variations in air quality and the effects of changes in emissions.

Figure 5a illustrates the detailed forecasts of air quality that can be provided by a high-resolution regional model and Figure 5b shows an example of how the concept of the Epsgram developed for medium-range ensemble weather forecasting has been extended to shorter-range regional prediction of pollutants.

User interface and policy support

The remaining component of MACC provides the interface to intermediate service providers and end users, runs service-chain test cases and supports the development of policy for the control of atmospheric pollution. Boundary conditions from the global system may be used not only to support MACC's regional component, but also to drive other European models or models for other regions of the world.

MACC includes a service-chain test case that uses regional modelling to study links between dust outbreaks and the occurrence of meningitis in the Sahel region of Africa. Other test cases evaluate the capability of MACC's core service lines to support downstream services for urban air-quality forecasting and other types of health warning.

Policy support is undertaken in liaison with the European Environment Agency, national and regional environment agencies and other interested bodies. It includes agreements on data exchanges, preparation of scenarios and predictive tools to be run on demand in extreme situations and provision of agreed input to assessment reports.

Examples of the support MACC provides for international measurement and modelling initiatives is shown in Box A.

Support for measurement and modelling initiatives — A

MACC supports the American HIPPO observational campaign by providing near-real-time forecasts of carbon monoxide, ozone, and aerosol. HIPPO is measuring cross sections of a comprehensive suite of atmospheric trace gases approximately pole-to-pole, from the surface to the tropopause, five times during different seasons over a three-year period. Its data will be used to evaluate and improve MACC's global analysis and forecasting system.

MACC supports the AQMEII coordinated evaluation of European and North American regional air quality modelling. AQMEII promotes exchange of information on practices, inter-community activities and identification of research priorities, with a focus on policy needs. MACC is providing boundary data on atmospheric composition for comparisons of regional model performance over North America and Europe.

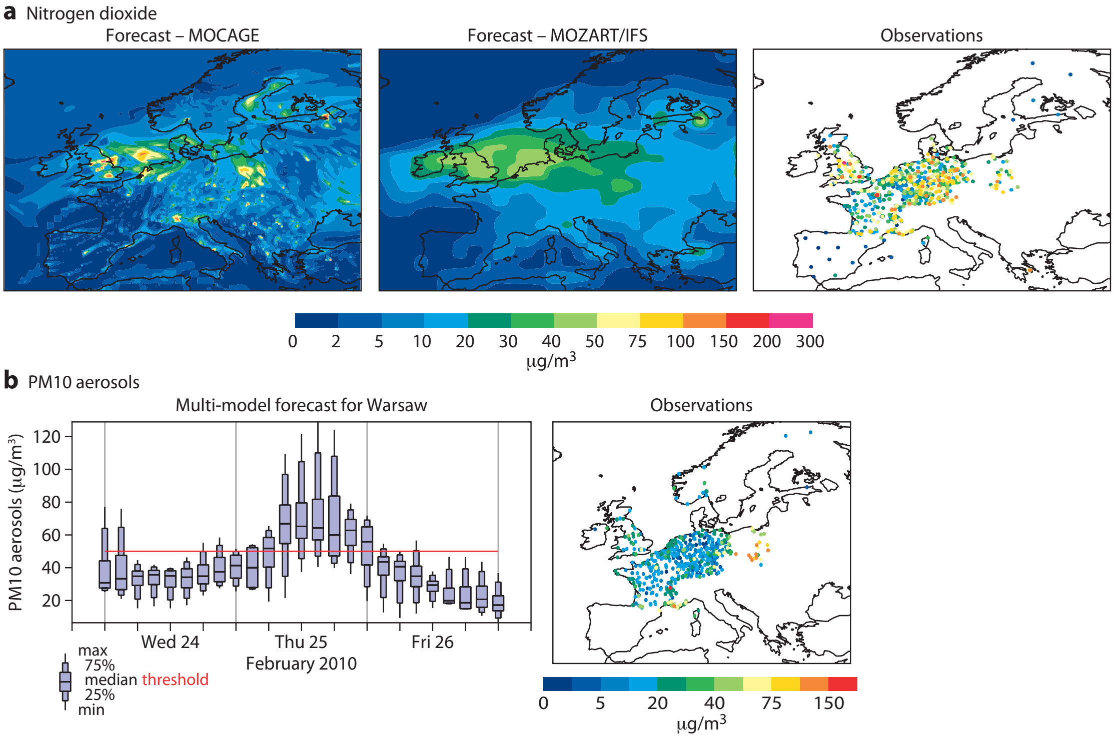

Figure 5 (a) Nitrogen dioxide distributions for 18 UTC on 25 February 2010 from the 42-hour forecasts from the MOCAGE regional model (left), the MOZART/IFS global model (centre) and the measured values (right). (b) The spread in multi-model forecasts of PM10 (particulate matter with sizes up to 10 microns) for Warsaw over the three-day period commencing 00 UTC on 24 February 2010 (left) and the measured values of PM10 at 12 UTC on 25 February (right).

Access to products

MACC's products relating to atmospheric composition are made freely available. Graphical products, datasets and reports can be downloaded from the project's main website (www.gmes-atmosphere.eu) or from partner websites for which the main site acts as a portal. Other forms of dissemination are under development. Training can be provided and user feedback is encouraged.

The way forward

MACC is engaged in an ongoing process of consolidating and refining its analysis and forecasting systems, completing the migration of components from GEMS and PROMOTE, and establishing supplementary new services. It continues to expand its capability to monitor the quality of its products on a systematic basis. Also MACC is developing its interaction with users to ensure that their requirements are known and met, and that their feedback on products is received and acted upon. This will include a focus on the downstream-service projects that are being established under GMES to provide much of the delivery of targeted services to end users. MACC in turn provides feedback on the quality of the input data it uses, and helps to define the requirements for new observing systems, in particular the GMES Sentinel satellite missions. Bringing all this to fruition also requires funding to be secured and governance arrangement to be put in place for sustained future operation.

MACC is unique worldwide in the breadth of what it is doing and in the integration of its activities. Its success derives from its ability to use the expertise and infrastructure of the many members of the consortium, and builds upon the pioneering work of GEMS and PROMOTE. Meeting future challenges will require continued effective cooperation between national meteorological services, environmental and space agencies, universities and research institutes within Europe, and continued interaction with the wider international community engaged in observation and research in atmospheric composition.

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