Monitoring and Predicting the Global Environment

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ECMWF and the National Meteorological Services (NMSs) have strong capabilities in medium-range and seasonal forecasting, and are developing a system for the prediction of severe weather. ECMWF and the NMSs are also working with collaborators in Europe and elsewhere to improve the use of forecast products in the monitoring and forecasting of natural hazards: floods, droughts, chemical transport hazards, coastal zone hazards.

ECMWF and the NMSs of the Member States are developing a comprehensive exploitation of satellite data to monitor and forecast important aspects of the state of the atmosphere, the ocean circulation, the ocean surface waves and the land surface. ECMWF and the NMSs are also developing a comprehensive exploitation of satellite data to monitor trace gases (Ozone, CO_2, and potentially N_2O, CH_4, CO). The environmental monitoring capabilities will be developed in the operational system, as new satellite systems come on-stream.

The following discusses some of the modelling and data assimilation developments that will be required to monitor and predict the global environment.

The GMES background and context

European policymakers have increasing needs for environmental information and environmental predictions to improve the ability of society to cope with natural hazards, and to meet and verify treaty obligations. The EU is developing an initiative, Global Monitoring for Environment & Security (GMES), to address the policymakers' needs. ESA and the EU are developing proposals for related and new Earth Observation capabilities. CNES and EUMETSAT are preparing new missions relevant to GMES. On the wider international scene, the recent Goody Report urges NESDIS to develop a more comprehensive operational capability to monitor and detect changes in atmospheric composition. Similar concerns of coping with climate change and with extreme weather events animate a great deal of NASA's Earth Observing System programme.

The GMES-priority areas where the weather community can help advance the GMES agenda are summarised here:

- GLOBAL ATMOSPHERE MONITORING delivering regular assessments of state of the atmosphere with particular attention to aerosols, ozone, UV radiation and specific pollutants
- GLOBAL OCEAN MONITORING in support of seasonal weather predictions, global change research, commercial oceanography and defence.
- GLOBAL MONITORING to assess carbon fluxes and stocks in the biosphere.
- SYSTEMS FOR RISK ASSESSMENT delivering operational support to weather-related risk management (early warning, impact assessment and reaction) in European sensitive areas for: floods; forest fires; oil spills; and support for humanitarian aid

As an example of the capabilities of the weather community relevant to the GMES priorities, ECMWF has research and development programmes in the following areas,

Global modelling, and assimilation of remotely sensed data on

- the dynamics and thermodynamics of the free atmosphere including all aspects of the hydrological cycle
- the dynamics of ocean surface waves
- the dynamics and thermodynamics of ocean circulation
- the physics of the interactions of the atmosphere with the land surface
- the dynamics of atmospheric trace gas composition (CO_2)
- atmospheric reactive gas composition
- Development of information systems for Severe Weather forecasting
- Seasonal Forecasting

A key concern of the GMES project is to provide operational services. On the R&D side of the GMES initiative, the 6th Framework Programme is likely to fund large co-ordinated RTD proposals in 2003-2007 to develop operational services for GMES. The EU's planning documents indicate that the EU expects to fund the operational continuation of GMES services in the period beyond 2007. By its nature ECMWF is an operational entity with a strong research commitment. ECMWF's research is driven by the need to improve operational performance, and all research projects are undertaken with a view to an operational implementation.

ECMWF will continue its strong R&D programme for operational forecasting, which includes de-facto monitoring of the global hydrological and energy cycles. One envisages that ECMWF in partnership with the European science base, could extend its existing modelling and data assimilation framework to address GMES global monitoring of greenhouse- gases and aerosols and then GMES global monitoring of reactive gases. In the initial phase of the GMES development, one may envisage development of an experimental monitoring and assimilation system which could run daily, but perhaps with a delay of some weeks behind real time to facilitate a comprehensive data collection; the resolution is envisaged to be similar to that used for seasonal forecasting. The software would be built as an extension of the operational medium-range software, so that developments useful to medium-range work can be readily migrated into the operational environment.

Global monitoring of greenhouse gases, and aerosols

Estimation of total column amounts of greenhouse gases

Pilot studies funded by EUMETSAT and ESA at CNRS/LMD and ECMWF, and pilot studies by NASA, have indicated the feasibility of estimating total column CO_2 using the AIRS and AMSU instruments to be launched on NASA's AQUA mission in the first half of 2002. COCO, a Framework V project in the final stages of negotiation, aims to develop an operational system to estimate total column CO_2, and to validate the results using inverse carbon modelling. Additional validation may be provided by the SCIAMACHY instrument to fly on ENVSAT towards the end of 2001. The COCO approach will use the data assimilation system to exploit the synergy between the AIRS infra-red instrument (sensitive to both temperature and CO_2) and the AMSU microwave instrument (sensitive only to temperature) to back-out the CO_2 estimates. Because the assimilation system will provide consistent wind, temperature and CO_2 estimates, it should be possible to estimate the export or import of carbon from the land to the ocean. Initially COCO will focus on CO_2 estimates over ocean where the surface radiative properties are well understood in the infrared and in the microwave. It will be possible to estimate the CO_2 exchange between atmosphere and ocean, assuming climatological information on ocean carbon concentrations. The technology being developed for the estimation of total column CO_2 can be readily adapted to provide total column estimates of other greenhouse gases such as CH_4, N_2O and CO_2.

Modelling and assimilation of the carbon cycle

One could establish an independent verification of the ocean uptake of CO_2, if one introduced a carbon cycle into the atmospheric and ocean models, as a basis for assimilating ocean colour measurements, along with the ocean satellite data currently used directly or indirectly in the ocean data assimilation: scatterometer winds, SST, altimeter sea-level heights, as well as altimeter wave data. By the end of 2002 there will be 5 ocean colour instruments in orbit (SEAWIFS, MODIS-Terra, MODIS-Aqua, MERIS-ENVISAT, OCTS-ADEOS). No plans are in place in the meteorological world for real-time use of this huge data source.

To tie down the ocean CO_2 budget by assimilating ocean colour, one needs to draw on the European science base for expertise in ocean-biology modelling, ocean-colour modelling and ocean assimilation, as well as for expertise in estimating primary production from ocean colour measurements.

For the research phase one envisages a development system running at the resolution of the seasonal forecast model. Since an advanced assimilation system can infer information on upper ocean dynamics from ocean colour measurements, there would be a direct benefit for the ocean dynamical assimilation, and thus eventually for seasonal forecasts.

Modelling and assimilation of aerosol information

All the ocean colour instruments provide a capability to estimate aerosol optical depth. The largest errors in the atmospheric clear sky radiative calculations arise from uncertainties in aerosol. The introduction of an aerosol variable (say for desert aerosol) in the atmospheric model would enable one to assimilate a good deal of the aerosol information in the ocean colour measurements. This would certainly improve the ocean colour assimilation (by quantifying a part of the signal that would otherwise be treated as noise) as well as delivering a modest forecast benefit for the atmospheric model.

Modelling and assimilation of information on the land biosphere

Development of a capability to model the radiative properties of the land biosphere is a high priority for those concerned with estimating the stocks and fluxes of carbon related to the land reservoir. It is also a high priority for meteorologists because improved modelling of the land biosphere (i) will enable meteorologists to assimilate more atmospheric sounding data over land and (ii) will lead to improved local weather forecasts. Until quite recently, our knowledge of the radiative properties of the land surface was so poor that almost all meteorological remote sounding data over land had to be discarded, because of our inability to model the radiative properties of the surface.

Satellite data on the land biosphere is available in the optical and near- infra-red (AVHRR, MODIS, MERIS, SEVIRI), in the thermal infra-red (HIRS, AIRS, IASI) and microwave (AMSU, SSMI, SSMI/S). The ESA instrument SMOS to estimate soil moisture is expected to fly in 2007. One needs to develop forward models which can simulate the satellite data, taking account of the dependence of the radiative properties of the land surface on the nature of the vegetation, on the nature of the soil and on recent meteorological events (rain, drought, snow). Effective interpretation of the 'land' satellite data thus requires an effective assimilation system. Several research initiatives are getting underway. ECMWF is a partner in the EU-funded initiative - ELDAS. ECMWF is also collaborating with EUMETSAT's Land-SAF, with ISLSCP, and with the US effort (GLDAS) on Land Data Assimilation.

Incorporation of a carbon cycle in the land, ocean and atmosphere modules of an Earth-system model, and assimilation of the range of satellite data that is or will be available, will provide global fields consistent with our understanding of the main processes in the Earth-system. ISLSCP sponsors a world-wide network of about 100 land observatories making detailed boundary layer measurements of vertical fluxes of heat, moisture, momentum and carbon. This station network would provide detailed validation and verification data on the key boundary layer exchange processes of the carbon cycle as they do at present for the water and energy cycles of Earth-system assimilations and models. The intercomparisons would thus provide a sound scientific basis for identifying shortcomings in the models, and a global basis for assessing proposed model improvements. This scientific approach has been successful in other research areas. For example, the global ocean wave assimilation uses satellite altimeter data only, while the sparse in-situ wave-buoy data provide independent and invaluable information for verification, diagnosis and development.

An important limitation of current or imminent observations is the inability to sense fluctuations of CO_2 amounts in the planetary boundary layer. Proposals are under discussion to develop either active or passive satellite sensing capabilities to remedy the shortcoming. Experience with assimilation of AIRS, SCIAMACHY and IASI data for green-house gas monitoring may be helpful in refining the requirements for new instruments or missions. When such missions eventually fly, their data will be immediately exploitable in the Earth-system assimilations.

Global Monitoring Of Reactive Gases

Atmospheric chemical data assimilation has traditionally used chemical transport models, driven by gridded winds and temperatures from an independent source such as a meteorological data asssimilation system. Atmospheric chemical data contains information on the advecting winds. This was one motivation for developing an interactive dynamical-chemical assimilation system for ozone in the framework of ECMWF's 4D-Var variational assimilation system

Dynamical-Chemical Assimilation System for Ozone

With support from ESA and EU (Framework IV project SODA), ECMWF and Meteo-France have developed a capability to model the three-dimensional distribution of ozone, and to assimilate data on ozone from the following instruments presently in orbit or to be launched in the near future:

SBUV, TOMS, HIRS	on NOAA satellites
GOME	on ERS and METOP
SCIAMACHY	on ENVISAT

This meteorological/ozone assimilation system will be used to support the calibration and validation of real-time data from the GOMOS, MIPAS and SCIAMACHY instruments on ENVISAT, and eventually for the assimilation of the products from these instruments. No plans are in place for use of data from NASA's chemistry mission AURA, due for launch in 2002-2003.

The ozone assimilation system is also being used in a simpler 3D-Var context to provide a 23-year assimilation (1979-2002) of all available satellite data on ozone as part of the EU-supported ERA-40 reanalysis project.

Useful satellite data on ozone first became available in 1979. The ERA-40 project will assimilate both SBUV and TOMS data on ozone for the period of record. The full reanalysis will cover the period 1958-2002. Prior to 1979, the ozone field in the model will evolve freely, unconstrained by observations.

The ozone assimilation system will become operational at ECMWF in the autumn of 2001, around the time of the expected ENVISAT launch. The assimilation will use the real-time ozone data from ENVISAT and from the NOAA satellites. As such, the system will provide valuable products for operations (e.g. UV_B forecasting) and for research. Ground-based Dobson spectro-photometer ozone data could be included in the system (either by real-time delivery of the data, or by a delayed mode run of the assimilation). Inclusion of the Dobson spectro-photometer data would make the assimilation fields a useful adjunct in the monitoring of the Montreal convention. A further scientific development of considerable interest is the direct variational assimilation of limb-sounding radiances from instruments such as MIPAS. This would provide a better net result than the use of MIPAS retrieved profiles.

Coupled dynamical – chemical assimilation

Many chemical data assimilation activities use chemical transport models driven by specified winds. Unlike an interactive dynamical-chemical assimilation, they get no benefit from the wind information in the chemical data. The interactive dynamical-chemical assimilation approach could be extended from ozone alone to the entire NOx family of ozone precursors and perhaps also to the family of precursors of sulphate aerosol. This would offer substantial operational and scientific benefits by providing the most accurate possible wind and chemistry fields.

If a semi-Lagrangian model is used for the assimilation, then the marginal cost of the chemical advection computation is negligible. The additional costs are thus mainly memory and the costs of the chemical-interaction calculations.

Chemical – weather forecasting

There is a large demand across Europe for accurate forecasts of air quality at times of environmental stress. Such forecasts are normally a national responsibility, and are usually made with specialised regional models which require meteorological and chemical boundary conditions, analogous to the requirements of regional meteorological forecast models.

The availability of a global assimilation and forecast system providing consistent global analyses and forecasts of the meteorological, chemical and aerosol fields would offer substantial operational and scientific benefits.

The proposals just outlined involve comprehensive global monitoring of the atmosphere, the ocean and the land at resolutions in the range 40-150 km corresponding to the range of models used for forecasting on medium-range, monthly, seasonal and decadal time-scales. Success in the enterprise will require the participation from wide spectrum of talent across the European science base. Success will also require improvement of the science of the atmospheric, ocean and land models to the point where they can realistically simulate the observations. This immediately guarantees the use of the scientific advances in improved models for forecasts and simulations. It also guarantees that periodic reanalyses of the available data (e.g. for studies of low-frequency variability or trends) will benefit from the new science developed in the monitoring programmes.