In this issue

European Centre for Medium-Range Weather Forecasts
Shinfield Park, Reading, Berkshire RG2 9AX, UK
Fax: . . . . +44 118 986 9450
Telephone: National 0118 949 9000
International . . . . +44 118 949 9000
ECMWF Web site . . . . http://www.ecmwf.int

The ECMWF Newsletter is published quarterly. Its purpose is to make users of ECMWF products, collaborators with ECMWF and the wider meteorological community aware of new developments at ECMWF and the use that can be made of ECMWF products. Most articles are prepared by staff at ECMWF, but articles are also welcome from people working elsewhere, especially those from Member States and Co-operating States. The ECMWF Newsletter is not peer-reviewed.

Editor: Bob Riddaway

Typesetting and Graphics: Rob Hine

Front cover

Partial illustration of the scope of GEO (Group on Earth Observations). The full scope of GEO is presented in Figure 1 on pages 6 and 7.

Editorial

GEO and GMES

This quarter was marked by several events which together constitute new milestones for the involvement of ECMWF in earth observation and environmental monitoring.

On 13 May 2005 the European Commission signed the contract for the GEMS (Global and regional Earth-system Monitoring using Satellite and in-situ data) project. The signing of this contract constitutes a major milestone for ECMWF as this project will allow the development of the assimilation and forecasting system towards environmental monitoring (see the article by Tony Hollingsworth in the last Newsletter, No. 103). It is also an important step in the involvement of ECMWF in the GMES initiative (Global Monitoring for Environment and Security) launched a few years ago by the European Union and the European Space Agency (ESA). GMES has several components such as atmosphere, marine and land services, and the development of risk analysis and warning services. ECMWF is primarily involved in the atmospheric component (i.e. GEMS) as coordinator. However, as a consequence of its development of an earth-system modelling facility, ECMWF is also involved as a participant in all of the other components.

On 3 and 4 May 2005, the first plenary meeting of the new GEO (Group on Earth Observations) organisation was held in Geneva, with ECMWF as one of the participants. This organisation is a follow-up to the discussions whose origin can be traced back to the Johannesburg summit on sustainable development in 2002. The goal of GEO is to develop a Global Earth Observation System of Systems (GEOSS) by achieving comprehensive, coordinated and sustained observations of the earth system, and allowing the development of applications benefiting society in various areas including disaster mitigation, energy, health and weather (see the article by Hollingsworth and Pfrang in this issue). A key aspect of this new organisation is that it involves States and International Organisations. ECMWF has been involved since the first Earth Observation summit in 2003, thus recognising its role in the process of transforming observation data into useful information. It is not surprising that GMES is usually presented as the major European contribution to GEO.

On 31 May 2005, a Co-operation Agreement was signed in Paris between ESA and ECMWF. Again, this is a confirmation of our role in earth observation which, as far as ESA is concerned, was particularly successful with ERS and will now continue with ADM-Aeolus.

Last but not least, an important characteristic of these developments is that ECMWF is involved in close partnership with its Member States. Together they contribute to the whole European Meteorological Infrastructure (EMI) which is required to address the challenge of GEO and GMES.

Dominique Marbouty

Changes to the operational forecasting system

François Lalaurette

Changes to the operational system

A new version of the model, Cy29r2, was implemented on 28 June 2005.

The main changes included in this version are:

- Assimilation of rain-affected SSM/I radiances.
- Set of changes to the AIRS assimilation (including retuned bias correction).
- Use of Meteosat-8 (MSG) winds.
- Jb statistics from the latest ensemble data assimilation.
- Refinement of the surface-pressure bias correction.
- Humidity analysis changes: reduced spin-up and stratosphere increments.
- Use of the SMHI Baltic sea-ice analysis.
- Convection changes (winds).
- Revised Gaussian sampling for the EPS perturbations.

Planned changes — major upgrade

A major upgrade in resolution is planned for the autumn, with T511L60 to become T799L91 and the Ensemble Prediction System (EPS) to increase in resolution from T255L40 to T399L62. The data assimilation will benefit from the higher resolution model and the iterations (inner loops) will be run with T255. More details (including test data) allowing Member States to prepare for this change can be found at:

www.ecmwf.int/products/changes/high_resolution_2005

New items on the ECMWF web site

Andy Brady

Updated User Guide to ECMWF Forecast Products

The *User Guide to ECMWF Forecast Products* is not like most other "user guides", which provide clear and straightforward instructions how to "plug in", "get started", "execute" and "switch off". Nor is this Guide a handbook in NWP, dynamic meteorology or weather forecasting; the aim of the Guide is to facilitate the use of traditional ECMWF medium-range forecast products, and encourage the use of newer, more advanced products such as the wave forecasts and the ensemble forecasts in the medium-range (EPS), and the monthly and seasonal forecasts.

www.ecmwf.int/products/forecasts/guide/

Workshop on representation of sub-grid processes

A workshop on the representation of sub-grid processes using stochastic-dynamic models was held from 6 to 8 June 2005. The workshop explored new ideas on the representation of sub-grid processes in weather and climate models, using computationally-cheap stochastic-dynamic systems.

www.ecmwf.int/newsevents/meetings/workshops/2005/Sub-grid_Processes/

New ECMWF data sets and services

Alfred Hofstadler

New data sets disseminated on GTS

ECMWF has added some new data sets to its GTS dissemination.

- **ECMWF seasonal sea surface temperature (SST) forecast anomalies.** Global SST forecast anomalies from the ECMWF seasonal prediction system are encoded in FM 92 GRIB edition 2 at 2.5 degree lat/long resolution. The forecast runs once a month with a basetime of 00 UTC on the first day of the month. The fields are produced and sent to the GTS on the fifteen day of each month.
- **ECMWF Tropical Cyclone Tracks.** Tropical Cyclone Tracks from the ECMWF deterministic forecast and the ensemble prediction systems are encoded in FM 94 BUFR and are made available from 00 and 12 UTC basetime. The tracks delineate the positions of tropical cyclones from the analysis to 120 hours into the forecast in 12 hourly timesteps. Products will only be generated and inserted onto the GTS if there are some observed positions of tropical cyclones or Tropical Cyclone Tracks have been detected in the forecast.

More information about these new products and all other ECMWF GTS products can be found by going to

www.ecmwf.int/products/additional/

and then following the links at the bottom of the page.

New ECMWF services on the web

Two new ECMWF services are available via the web. These services are restricted to the WMO community.

- **ECMWF EPSgrams for WMO Members**. Epsgrams are available for the capital city of each WMO Member. These are updated twice daily and are sorted by alphabetical order. The database of capital cities is still being constructed, particularly for islands. Please let us know about possible inaccuracies. The new service can be accessed at: www.ecmwf.int/products/forecasts/d/charts/medium/epsgramswmo/
- **ECMWF GTS dissemination data on the web**. As a new service ECMWF is providing access to its medium-range GTS dissemination data in FM92 GRIB on the web. More information about this new service can be found at: www.ecmwf.int/products/about/wmo_nmhs_access/

Tenth Workshop on Meteorological Operational Systems

Horst Böttger

The biennial Workshop on Meteorological Operational Systems, to be held at ECMWF on 14–18 November 2005, will be the tenth in the series. The workshop will review the state of the art of meteorological operational systems and address future trends in the use of medium-range forecast products, data management and meteorological visualisations on workstations.

Use and interpretation of medium- and extended-range forecast guidance

The ECMWF forecasting system provides the users with operational forecast guidance twice daily out to day ten, once a week out to 31 days and once a month out to six months. Both the monthly and seasonal forecasts are based on a coupled ocean-atmosphere forecasting system. The Centre plans to implement major upgrades to the forecasting system before the end of 2005. The deterministic model will move to the finer resolution of T799 (linear grid, 25 km reduced Gaussian) with 91 levels in the vertical, while the Ensemble Prediction System (EPS) will be run at T399 (linear grid, 50 km reduced Gaussian). There are also plans to upgrade the monthly forecasting system and integrate it into a unified medium- to monthly-range forecasting system. A multi-model seasonal forecast system has been implemented and products are under development. These changes to the forecasting system will be discussed at the workshop and first experiences will be reported. It is expected that users of the ECMWF forecasts will report on the use and application of the products and on their approach to medium- and extended-range weather forecasting. Contributions addressing the prediction and verification of severe weather events will be welcome.

With the planned extension of the medium-range forecasts to 15 days and the introduction of a unified forecasting system out to a month it is planned to address the user requirement for products from such a unified system in a working group.

Operational data management systems

Users of meteorological data often find that data sets of interest are scattered around and that data access is cumbersome. Web services and Grid technologies are to an increasing extent finding their way into meteorological information systems, as well as other environmental disciplines, facilitating the access to distributed data sets through user-friendly application portals.

Developing technologies and applications will be presented at the workshop together with user experience. Future requirements will be discussed in a working group, focussing on issues of interoperability (between centres and between disciplines), data catalogues, discovery mechanisms and metadata standards. A working group will also address the services that could be offered and ways to convert or abstract various data formats.

Meteorological visualisation applications

As the number of graphics file formats continues to increase, more choices are becoming available regarding functionality but also more issues arise concerning software and hardware compatibility. Developments in this area for interactive and batch production of meteorological plots will be presented and demonstrated at the exhibition. New meteorological visualisation applications and updates to existing applications will also be presented.

A working group will discuss the issues surrounding the different file formats as they relate to meteorological plots, including static and animated formats for on-screen display such as GIF and JPEG, formats for printing such as PostScript and PDF, and interactive formats such as SVG and Flash. File formats suitable for interfacing with GIS systems will also be examined.

Further information

A registration form for the workshop is now available from:
www.ecmwf.int/newsevents/meetings/workshops/2005/MOS_10/
Further information about the workshop will be put on this website, including the programme once it becomes available in the autumn.

Long-term co-operation established with ESA

Manfred Kloeppel

On 31 May 2005 Dominique Marbouty, Director of ECMWF, and Jean Jacques Dordain, Director-General of the European Space Agency (ESA), signed a Co-operation Agreement on exchange of information and expertise, which will establish long-term co-operation between these two European organisations.

Intended as an umbrella to cover activities already in place as well as future activities, the agreement pledges the exchange of information and expertise between ECMWF and ESA. In addition it establishes regular bi-lateral meetings, educational and fellowship exchanges, and fixed points of contact.

In practical terms, ECMWF is not only a leading operational user of results from ESA-developed satellites but also helps ensure data quality control, instrument calibration and validation as well as providing estimates of the performance of climate-related satellite sensors planned for the future.

ECMWF routinely assimilates near-real time data from ERS-2 and Envisat into its weather forecasts. It also validates results from these satellites' instruments on an ongoing basis, comparing their data on meteorological events to other ground and space-based sources and their numerical model outputs. In turn, the Centre uses archived ESA datasets as benchmarks to assess and improve the performance of its numerical models.

ECMWF is set to play a key role in future ESA Earth Explorer missions. The Centre has the task of processing vertical wind fields from the ADM-Aeolus mission and will be employing climate-related data from the SMOS (Soil Moisture and Ocean Salinity) mission.

ECMWF is also a major user of the Meteosat series of weather satellites, developed and built by ESA in co-operation with EUMETSAT, the European Organisation for the Exploitation of Meteorological Satellites. In addition ECMWF is currently preparing for launch of MetOp expected in April 2006. This is the first polar-orbiting joint venture between ESA and EUMETSAT.

The two organisations will also cooperate and share information on their activities for the Global Earth Observation System of Systems (GEOSS) – an international effort setting up a system to share environmental information – as well as Global Monitoring for Environment and Security (GMES), a joint initiative between ESA and the European Union to establish an independent global monitoring capability for the continent, also serving as a European contribution to GEOSS.

More information about ECMWF co-operation agreements can be found at:

www.ecmwf.int/about/basic/volume-1/cooperation_agreements/index.html

Meeting of the Scientific Advisory Committee on 3–5 October 2005

Philippe Bougeault

The Scientific Advisory Committee (SAC) normally meets once a year to consider the draft programme of activities of the Centre and to submit to Council is opinions and recommendations. The 34th session of the SAC will take place on 3–5 October 2005. Included in the agenda will be the following topics.

- Progress Report by the Head of the Research Department
- Progress Report by the Head of the Operations Department
- Verification statistics and evaluations of ECMWF forecasts
- Impact of forecast system upgrades (1995–2005)
- Progress in ocean wave forecasting
- Linearization and convergence issues in the 4D-Var
- ECMWF Strategy 2006–2015
- Consideration of the updated Four-year Programme of Activities and ceilings of expenditure for the years 2006-2009
- Detailed Research Plan 2006-2009
- Consideration of the budget including options
- Requests from ECMWF Member States for allocation of computer resources for Special Projects
- ECMWF Workshops and Seminar

The SAC is composed of 12 members appointed in their personal capacity by Council. The present Chairman is Prof Erland Källén from Stockholm University.

63rd Council session on 13–14 June 2005

Manfred Kloeppel

Chaired by Adérito Vicente Serrão from Portugal, the ECMWF Council held its 63rd session in Reading on 13–14 June 2005. Besides several decisions on financial matters, such as the use of the Budget surplus 2004, and staff matters, such as approval of Reports from the Co-ordinating Committee on Remuneration (CCR), the main results of this session were as follows.

- **Co-operation Agreements**. The Director was authorised by Council to negotiate agreements for scientific and technical co-operation with Israel and Morocco.
- **Building Programme**. The Council authorised the Director to negotiate and conclude, within the approved financial framework, a contract for a new office building.
- **Financial Matters**. The Council took note of the Auditor's Report regarding the financial year 2004 and gave discharge to the Director in respect of the implementation of the budget for 2004.

◆ **New Strategy**. The Council considered the framework of the ECMWF strategy for the period 2006-2015 and had an extended discussion on the main strategic goals to be set for the future. The Council:

- was impressed by the quality of the preparatory work;
- wished ECMWF to remain the world leader in numerical weather prediction;
- stressed that the strategy should focus on the prediction of severe weather events;
- supported ECMWF's contribution to environmental monitoring (GEMS project);
- requested the Director to strengthen collaboration with the Member States;
- encouraged strong interaction with Member States' developments in Local Area Modelling (LAM);
- requested the Director to strengthen benefits to the Member States;
- wished ECMWF to further develop relations with the European Union;
- requested the Director to make sure that the new strategy becomes affordable.

The Director was asked to prepare, for discussion by the Council in autumn this year, a strategy based on the framework which takes into account the Council's suggestions.

◆ **Products of the Centre**. The Council agreed to add some items to the catalogue of real-time products, including all web products. Also it authorised the Director to provide the Centre's multi-model seasonal forecast products to the EUROBRISA project partners.

A preliminary survey of ERA-40 users developing applications of relevance to GEO (Group on Earth Observations)

Anthony Hollingsworth and Christian Pfrang

It has been recognised that there is a need for a more comprehensive and coordinated approach to developing Earth observation systems. This led to the Group on Earth Observations (GEO) being established to implement a System of Systems to be known as GEOSS (Group on Earth Observation System of Systems).

It is expected that the ERA-40 re-analysis data for the period 1957–2003 will play an important role in achieving the objectives of GEO. Consequently an investigation was undertaken into current and future applications of the ERA-40 re-analysis data to provide a preliminary assessment of the current status of development of GEO-relevant applications. Initially we did an Internet search which identified more than 100 projects involving ERA-40 data. Subsequently, we performed a web survey of ERA-40 users and received 127 replies, with the majority of these providing positive feedback about the quality and accessibility of the ERA-40 data. These studies revealed that the ERA-40 data is being used in a wide range of areas relevant to GEO. However, there appears to be potential for more extensive use of this data in particular in areas associated with ecosystems and biodiversity.

The background and goals of GEO- and GEOSS-related activities will now be described. We will also present the results of the web survey and discuss the feedback received from numerous ERA-40 users.

GEO and GEOSS

Thirty-three nations plus the European Commission adopted, at the Earth Observation Summit I in July 2003, a Declaration of political commitment to move towards development of a comprehensive, coordinated, and sustained Earth observation system(s). There was also affirmation of the need for timely, quality, long-term, global information as a basis for sound decision making. To further these goals, they launched the intergovernmental ad hoc Group on Earth Observations (GEO) to develop a 10-Year Implementation Plan. The group, co-chaired by the United States, the European Commission, Japan, and South Africa and joined by more than 21 international organizations, began preparatory work immediately. The GEO observation system will be built as a System of Systems to be known as GEOSS (Group on Earth Observation System of Systems).

Ministers met at the Earth Observation Summit II in Tokyo, Japan, on 25 April 2004, where they adopted the Framework Document for a 10-Year Implementation Plan for this initiative.

In February 2005 in Brussels some sixty countries adopted the GEOSS Implementation Plan and created a new international entity, the Group on Earth Observations to execute the plan. They are supported in this undertaking by about forty international organisations with a mandate in Earth Observations. The GEO Framework Document, the GEOSS Implementation Plan and the Resolution creating GEOSS may be found at: http://earthobservations.org.

GEO aims to create a System of Systems to achieve "Comprehensive, Coordinated, and Sustained Earth Observations for the benefit of humankind". In the words of the GEO Framework Document "Understanding the Earth system — its weather, climate, oceans, land, geology, natural resources, ecosystems, and natural and human-induced hazards — is crucial to enhancing human health, safety and welfare, alleviating human suffering including poverty, protecting the global environment, and achieving sustainable development". Data collected and information created from Earth observations constitute critical input for advancing this understanding.

Comprehensive, coordinated and sustained Earth Observations for understanding the Earth system more completely and comprehensively will expand worldwide capacity. In addition they will provide the means to achieve sustainable development and will yield advances in many specific areas

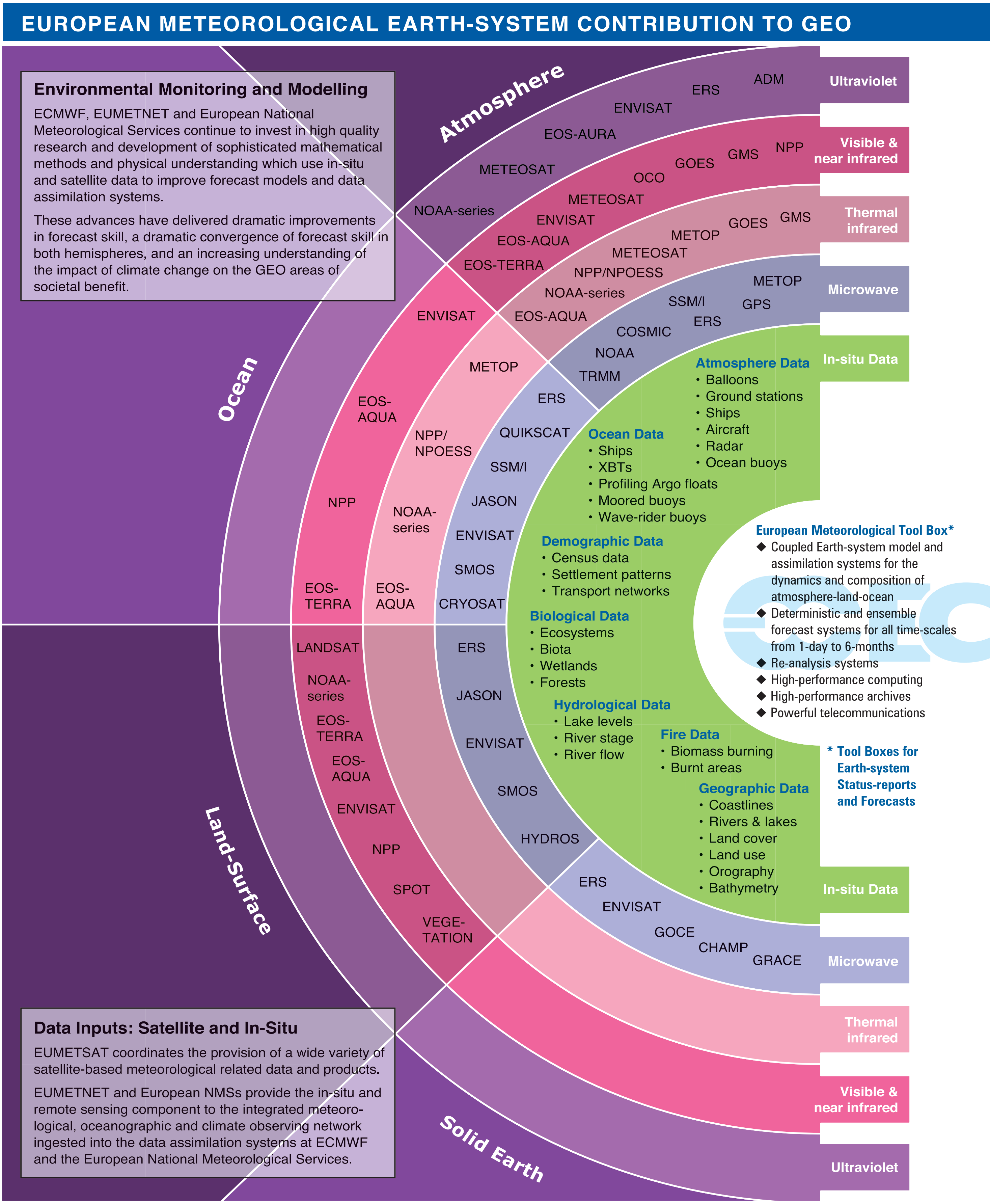
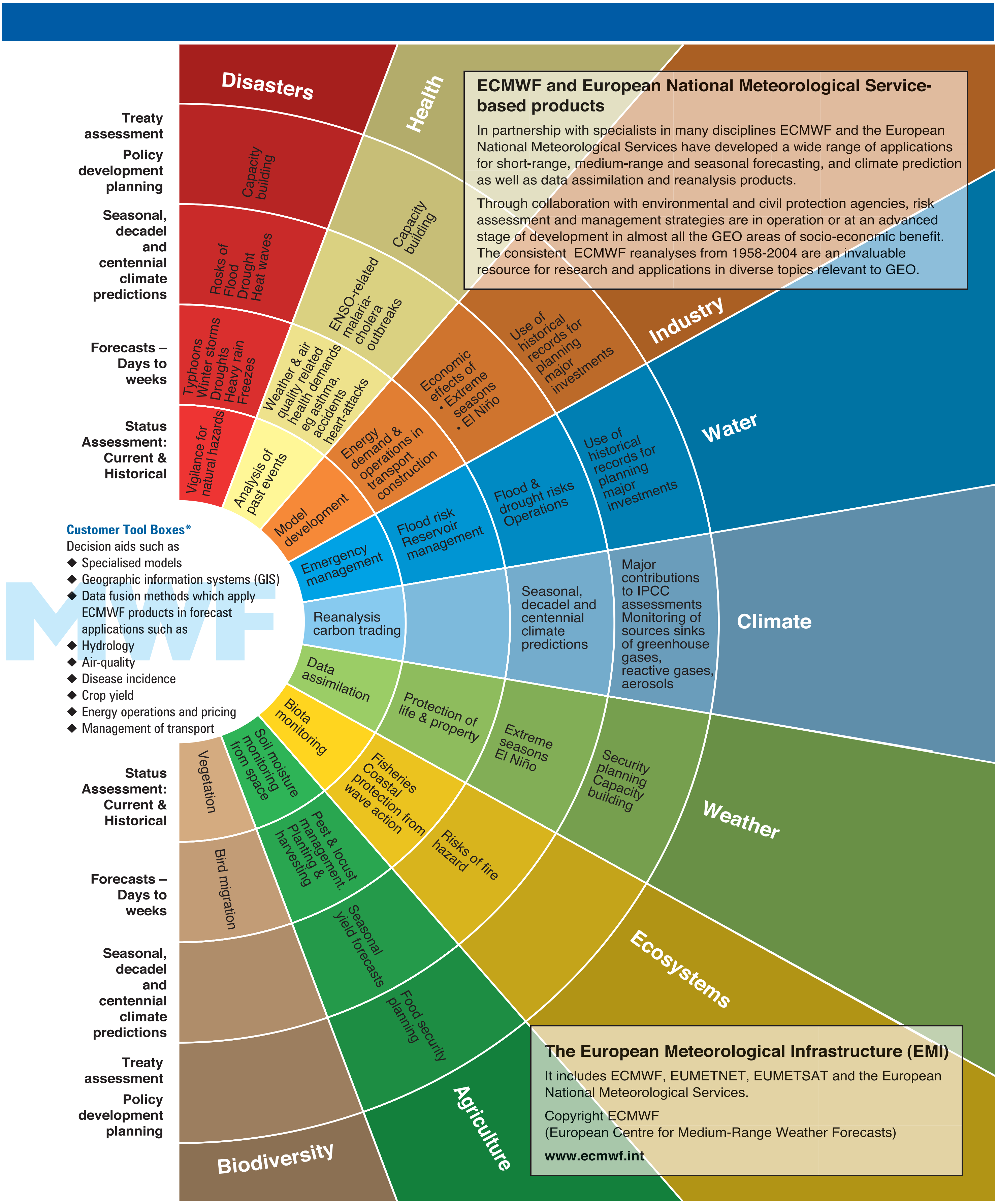


Figure 1 Illustration of the scope of GEO. On the right hand side the socio-economic benefits of GEO (stratified by time-scale) are depicted. On the left hand side the in-situ and satellite observational inputs can be found with satellite missions stratified by the frequency



bands used. European Meteorological and Customer Tool Boxes needed to transform measurements to information are shown in the centre of the figure.

of socio-economic benefit (see box). Globally, these benefits will be realized by a broad range of user communities. This will represent a fundamental step towards addressing the challenges articulated in the declarations of the 2002 World Summit on Sustainable Development and fulfilling the Millennium Development Goals agreed at the Millennium Summit in 2000.

Meeting the GEO deliverables

Figure 1 was prepared to illustrate the ambition, the complexity and the feasibility of the GEO objectives, viewed from a meteorological perspective.

- **Left-hand side**. This illustrates the diverse in-situ (green) and satellite data sources (arranged by electromagnetic frequency used) needed to achieve the diverse GEO goals. The satellite missions listed include current and planned operational and research missions.
- **Right-hand side**. This illustrates the diversity of the GEO deliverables, stratified by the areas of socio-economic benefit, and by the time-scale for which the deliverables are relevant.
- **Centre**. This illustrates the meteorological means used to transform the measurements on the left into the deliverables on the right, including current status descriptions and forecasts. Broadly speaking the means used are of two kinds: complex Earth-system models and data assimilation systems (in the left semi-circle), and specialised application models and decision aids (such as GIS) in the right semi-circle.

Socio-economic benefits

- Reducing loss of life and property from natural and human-induced disasters.
- Understanding environmental factors affecting human health and well being.
- Improving management of energy resources.
- Understanding, assessing, predicting, mitigating, and adapting to climate variability and change.
- Improving water resource management through better understanding of the water cycle.
- Improving weather information, forecasting, and warning.
- Improving the management and protection of terrestrial, coastal, and marine ecosystems.
- Supporting sustainable agriculture and combating desertification.
- Understanding, monitoring, and conserving biodiversity.

User communities

- National, regional, and local decision-makers.
- Relevant international organizations responsible for the implementation of international conventions.
- Business, industry, and service sectors.
- Scientists and educators.
- General public.

Socio-economic benefits and the user communities that will realize these benefits as a result of comprehensive, coordinated and sustained Earth Observations.

By design, Figure 1 excludes reference to geo-hazards such as volcanoes, earthquakes and tsunamis which are key aspects of GEO and GEOSS activities. It is recognised that important meteorological capabilities are needed and are available to address the consequences of such events.

Status of GEO-relevant applications

GEO requires an extremely broad and challenging range of applications of Earth Observation data. To provide a preliminary assessment of the current status of development of GEO-relevant applications, we made a web survey of current and future applications of the ERA-40 re-analysis data. The ERA-40 datasets are gridded global meteorological and surface fields available four-times daily for the period 1957-2003. Further information about ERA-40 can be found at: www.ecmwf.int/research/era/index.html.

Internet search

As a first step in November 2004, we performed an Internet search for projects involving ERA-40 data. Google was employed as a search engine using a large number of keywords like "flood" or "greenhouse gases" in conjunction with the "ERA40" keyword. The web hits were categorised into research areas and timescales of forecasts according to the overview given on the right-hand side of Figure 1. We found at least one application for each topic, and identified a large number of users in the sections climate (42 independent projects) and weather (17 independent projects). Altogether, we identified more than 100 projects involving ERA-40 data by means of the Internet search.

A clickable image-map of the right half of Figure 1 was linked to a table containing all the information retrieved in the course of the Internet survey. This information provides an overview of research areas of ERA-40 applications relevant to GEO, and incidentally facilitates communication between ERA-40 users. The data are published on the ECMWF website and can be found at:

www.ecmwf.int/research/era/era40survey/

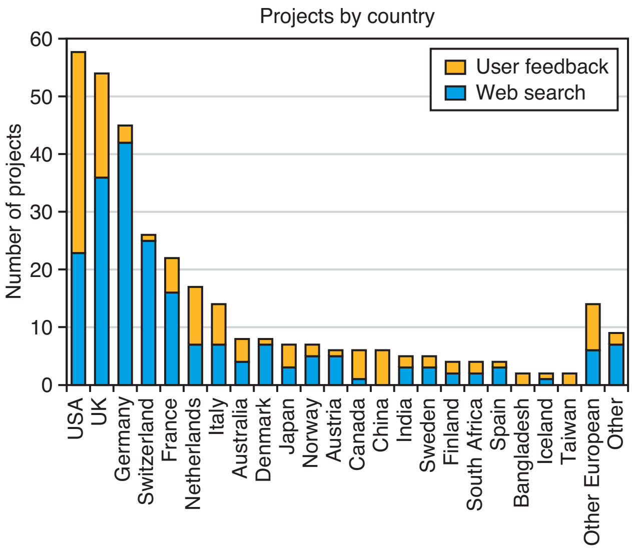


Figure 2 Number of projects by country (identified from both web survey and user feedback) using ERA-40 data.

User feedback

As a second step, we asked ERA-40 users to contribute to our database. We sent letters via email to about 3,500 users registered at the ECMWF data server. Also the British Atmospheric Data Centre (BADC) and National Centers for Atmpspheric Research (NCAR) forwarded our request to ERA-40 users registered at their data servers. We asked ERA-40 users to send:

- A short description of projects for which ERA-40 re-analysis data was used or is intended to be used;
- Names and locations of participating research institutes if the project was conducted in collaborative work;
- A link to a more detailed project description;
- Comments on what aspects in the ERA-40 data have given the most benefit and what improvement in the data would be the most useful in the future.

We received 127 replies to date and the webpage has been updated to include complementary information about projects involving ERA-40 data.

Figure 2 shows that the largest amount of user feedback was received from researchers in the United States (28%), United Kingdom (14%) and Netherlands (8%), with responses also coming from 29 other countries. Many researchers not only reported the requested information, but also added personal comments. A large majority of replies contained positive feedback about the quality and accessibility of the ERA-40 data. Many users compared the quality of ERA-40 data with the NCEP data, and an overwhelming majority (9 out of 10 researchers) concluded that ERA-40 proved more useful. Several users requested a peer-reviewed description of the ERA-40 re-analysis and they were happy to learn that such a paper will be published in the *Quarterly Journal of the Royal Meteorological Society* (in press).

A number of suggestions for improvement were made, mainly in terms of increased resolution or a larger time span. Many users would appreciate having the time series regularly extended to the present. Users also gave an indication about the most beneficial elements of the data and which improvements would be most appreciated. Research projects, including links either to a description of the project or to institutes where the research was performed, can be found on the ERA-40 webpage.

Extension of the survey

The ultimate goal of the presented survey is to cover all areas of GEO-relevant applications of ERA-40 re-analysis data. The list is by no means considered to be complete at the current stage and we invite ERA-40 users to contribute further to our database. Nevertheless, the survey successfully demonstrates that just two years after release of the ERA-40 re-analysis, the data is already applied in a broad spectrum of areas and by a large number of researchers from all over the world, including several users from developing countries.

We hope the ERA-40 survey will prove valuable to:

- Assess the impact of the ERA-40 re-analysis project;

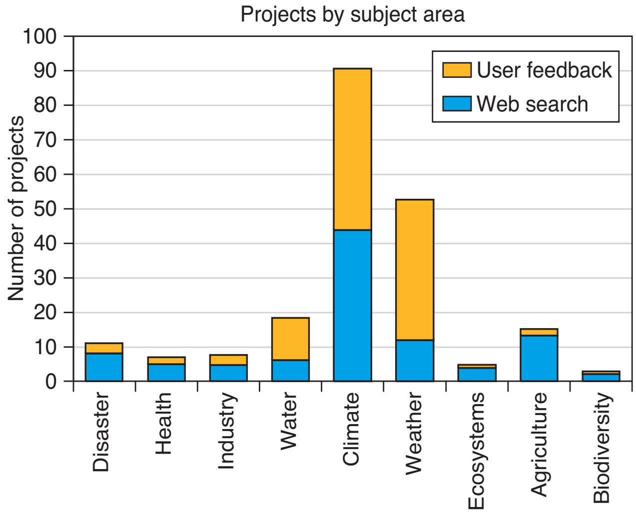


Figure 3 Number of projects categorised according to subject area (identified from both web survey and user feedback) using ERA-40 data.

- Facilitate exchange of information between ERA-40 users;
- Compile a review of research work using ERA-40;
- Make a case for a more comprehensive and longer re-analysis later this decade, which will benefit from the lessons learned from ERA-40.

If you are aware of any project using ERA-40 data not being included in the current version of the ERA-40 survey, we would be most grateful if you contact us at era40survey@ecmwf.int.

Implications for GEO

From a GEO viewpoint, the limitations of the survey are substantial, being limited to one community among many in GEO. Nevertheless the survey results are of interest. They highlight the extensive exploitation of the meteorological forecast products (on time-scales from days to inter-annual) and re-analysis products (on time-scales from days to decades) in GEO-relevant areas such as disasters, health, water resources, weather, climate, and agriculture (see Figure 3).

The survey results also suggest that there is little exploitation of the gridded meteorological fields in GEO-relevant areas such as ecosystems and bio-diversity, where one might have expected wider application. The perceived under-use may arise for reasons of unfamiliarity of the two communities or because the meteorological outreach has not extended far enough. Alternatively there may be a variety of technical reasons which need to be identified and addressed.

From the viewpoint of geographical spread, users of the ERA-40 datasets are found pre-dominantly in Europe and North America, with relatively few users in Africa and Latin America. The meteorological community and GEO may wish to consider ways and means to broaden both the geographic and the cross-disciplinary utilisation of the re-analysis products.

EPS skill improvements between 1994 and 2005

Roberto Buizza

The predictability gains of the ECMWF Ensemble Prediction System (EPS) between 1994 and 2005 have been assessed. Results show that the accuracy of medium-range EPS probabilistic forecasts over Europe has improved by about twice the rate experienced by single forecasts given by the EPS control. The analysis of the skill of mid-tropospheric forecasts at days 5 and 7 over the Northern Hemisphere indicates that single forecasts have improved by between 1 and 1.7 days/decade and that probabilistic forecasts have increased by between 2 and 3.7 days/decade. For Europe, corresponding gains amount to ~0.8 days/decade for control forecasts and ~1.5 days/decade for probabilistic forecasts. The extra predictability gains of probabilistic predictions are linked to improvements in the representation of the probability distribution function of forecast states, achieved through the years by improvements in all aspects of the ensemble system (resolution, ensemble size, introduction of evolved singular vectors in the generation of initial perturbations and stochastic physics).

Ensemble Prediction at ECMWF

The skill of single forecasts (i.e. of forecasts given by one integration, for example by the EPS control forecast) is limited for two key reasons: the presence of uncertainties in the initial conditions and the approximate simulation of atmospheric processes achieved in the state-of-the-art numerical models. A further complication is that these two sources of uncertainties limit the skill of single forecasts in a rather unpredictable way. One way to alleviate this problem is to move from a 'single' to a 'probabilistic' approach to numerical weather prediction. In other words to estimate not only the most likely forecast scenario but also the time evolution of an appropriate probability density function in the atmosphere's phase space. An ensemble of forecasts can be used to estimate the probability density function of forecast states.

Since 19 December 1992, ECMWF has been producing operationally global ensemble forecasts precisely to provide an estimate of the probability distribution function of forecast states. Initially, the ECMWF EPS included only a simulation of initial uncertainties, but since October 1998 the EPS included also a stochastic scheme designed to simulate the random model errors due to parameterized physical processes. Table 1 lists the key upgrades of the ECMWF from the implementation of a 33-member T63L19 system (spectral truncation T63 with 19 vertical levels) in December 1992.

EPS configuration operational since November 2000

Each ensemble member is defined by the time integration of a version of the ECMWF model that includes stochastic perturbations to simulate the effect of random model errors, starting from perturbed initial conditions. The use of stochastic perturbations and of singular vectors to generate the initial perturbations are two key features of the ECMWF EPS that distinguishes it from the two leading global ensemble systems implemented at the Meteorological Service of Canada and the National Centers for Environmental Prediction of the United States.

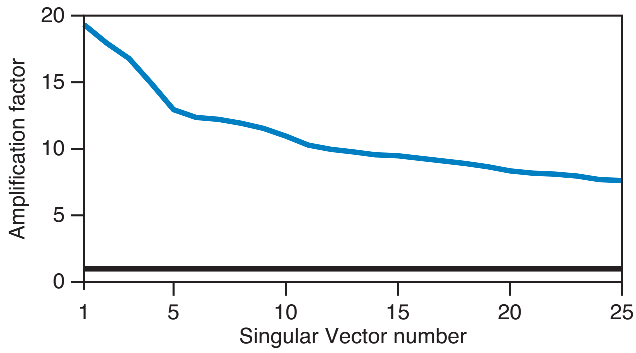


Figure 1 Amplification rates (i.e. singular values) of the leading 25 singular vectors used in the operational EPS started at 12 UTC on 1 December 2003, ranked from the fastest growing singular vector (number 1) to the 25th one (number 25). These singular vectors were computed at T42L40 resolution, with simplified dry physics, a 48-hour optimisation time interval, and final time total energy norm maximized over the Northern Hemisphere extra-tropics (latitude 30°N).

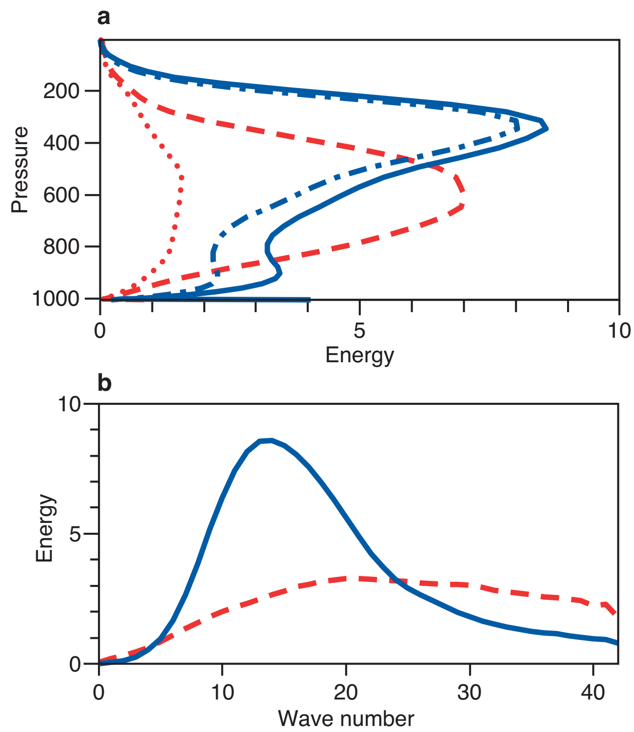


Figure 2 (a) Average initial-time total (red dashed line) and kinetic (red dotted line) energy, final-time total (blue solid line) and kinetic (blue chain-dashed line) energy vertical cross section. (b) Average initial-time (red dashed line) and final-time (blue solid line) total energy spectra. The averages have been computed considering the leading 25 singular vectors used in the operational EPS started at 12 UTC on 1 December 2003.

Date	Description	Singular Vector Characteristics						Forecast Characteristics				
		HRES	VRES	OTI	Target Area	EVO SVs	Sample Method	HRES	VRES	Tend	Ensemble Size	Model Uncert
Dec 1992	Operational Implementation	T21	L19	36 h	Globe	No	Simm	T63	L19	10 d	33	No
Feb 1993	SV Local Projection Operator	"	"	"	NHx	"	"	"	"	"	"	"
Aug 1994	SV Optimization Interval	"	"	48 h	"	"	"	"	"	"	"	"
Mar 1995	SV Horizontal Resolution	T42	"	"	"	"	"	"	"	"	"	"
Mar 1996	Extratropical SVs	"	"	"	(NH+SH)x	"	"	"	"	"	"	"
Dec 1996	Resolution/Members	"	L31	"	"	"	"	T_L159	L31	"	51	"
Mar 1998	Evolved SV	"	"	"	"	Yes	"	"	L31	"	"	"
Oct 1998	Stochastic Physics	"	"	"	"	"	"	"	"	"	"	Yes
Oct 1999	Vertical Resolution	"	L40	"	"	"	"	"	L40	"	"	"
Nov 2000	Forecast Horizontal Resolution	"	"	"	"	"	"	T_L255	"	"	"	"
Jan 2002	Tropical SVs	"	"	"	(NH+SH)x+TC	"	"	"	"	"	"	"
Sep 2004	Sampling	T42	L40	48 h	(NH+SH)x+TC	Yes	Gauss	T_L255	L40	10 d	51	Yes

Table 1 List of key changes introduced in the ECMWF EPS configuration. Columns list the horizontal resolution (HRES, expressed in terms of spectral truncation), the vertical resolution (VRES, expressed in terms of number of vertical levels), the optimization time interval used (OTI, in hours) and the target area used to compute the singular vectors (Target Area), the use of evolved singular vectors (EVO SVs), the sampling method used to generate the initial perturbations (Sample), the forecast length (Tend, in days), the number of ensemble members (Ensemble Size) and whether model uncertainty is simulated or not (Model Uncert).

Singular vectors identify perturbations of maximum growth during a finite time interval, named the optimization time interval: small errors in the initial conditions along these directions would amplify most rapidly, and affect the forecast accuracy. Singular vectors are usually located in regions of strong barotropic and baroclinic activity. At initial-time, they have most of their energy confined in the small scale and are confined vertically in the lower troposphere. During the optimization time interval, they change shape and grow in scale, and vertically propagate upward. As an example, Figure 1 shows the amplification rate (i.e. the singular value) of the leading 25 Northern-Hemisphere singular vectors used in the EPS started at 12 UTC on 1 December 2003. The corresponding average vertical distribution of total energy and the total energy spectra for these singular vectors are given in Figure 2. These two figures summarize two of the key characteristics of the singular vectors.

- The decreasing spectra of singular values, with all the first 25 singular vectors showing an amplification rate in terms of total energy greater than 10, and the leading singular vectors showing a 15-20 amplification rate.
- The upward energy propagation during the optimization time interval coupled with the conversion of initial-time potential energy into final-time kinetic energy, and the upscale energy propagation from the small- to the large- (synoptic) scales.

The EPS configuration operational in 2005 (Table 1) includes 50 perturbed members and one unperturbed member (the control forecast) run at TL255L40 resolution. The control starts from the unperturbed analysis, while the 50 perturbed members start from perturbed initial conditions. These are generated by adding to the unperturbed analysis a linear combination of the leading singular vectors growing to have maximum energy, at optimization time, inside three sets of area covering the whole globe. During this linear combination, the leading singular vectors are re-scaled to have amplitude comparable to analysis error estimates.

Figure 3 shows the EPS ensemble-mean forecast and the ensemble standard deviation, which is a measure of the ensemble spread, at initial and at three forecast times, for the EPS started on 1 December 2004. The ensemble standard deviation at initial time shows the areas where the EPS initial perturbations were located, and their average amplitude (see Figure 3(a)). Note that the initial perturbations were located in regions of strong gradient (e.g. the exit of the North Atlantic jet stream) and intense baroclinic activity (e.g. the area of cyclonic depression over Spain). During the subsequent forecast the perturbations grow following the atmospheric flow (see Figures 3(b), 3(c) and 3(d)). These results illustrate how the ensemble standard deviation varies geographically with the forecast time. More specifically, its

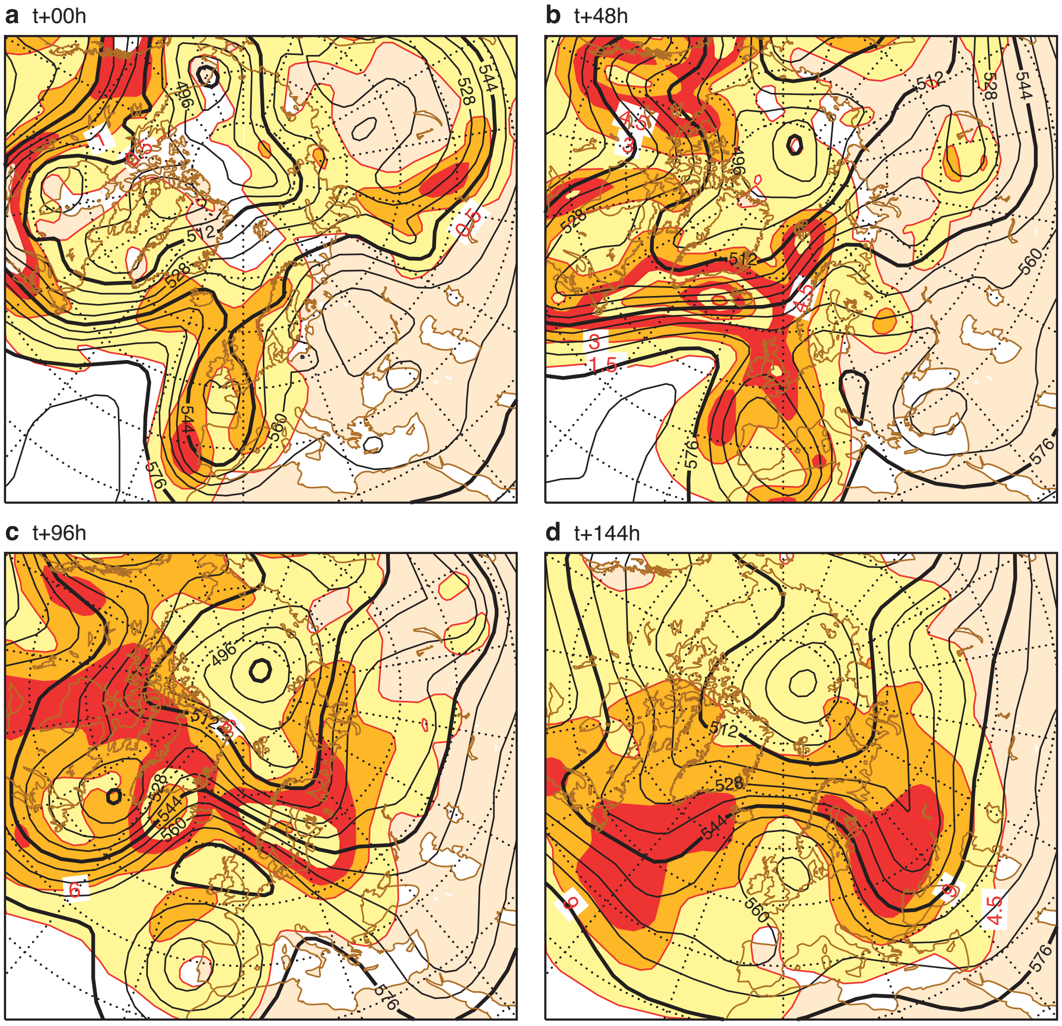


Figure 3 (a) Initial time ensemble mean (which coincide with the unperturbed analysis) and standard deviation. (b) Ensemble mean and standard deviation at forecast day 2. (c) Ensemble mean and standard deviation at forecast day 4. (d) Ensemble mean and standard deviation at forecast day 6. Fields shown refer to the 500 hPa geopotential height field of the EPS started at 12 UTC on 1 December 2003. Contour interval for ensemble mean is 80 m; contour shading for the ensemble standard deviation are: 5 m at initial time, 15 m at day 2, 30 m at day 4 and 45 m at day 6.

variation can be used to estimate predictability: regions with small standard deviation (i.e. with small ensemble spread) should be more predictable than regions with large values, since in these regions the verifying analysis should be closer to the forecast states. Considering Europe, for example, the ensemble standard deviation is small compared to the other regions during the early forecast range (Figure 3(b)), but starts being relatively large on day 4 of the forecast (Figure 3(c)).

EPS performance from May 1994 to April 2005

EPS forecasts are used to generate 'single' products (e.g. the forecasts given by the EPS control or the ensemble-mean) and probabilistic products, such as the probability of occurrence of some selected events (e.g. the probability of occurrence of positive anomalies, or of positive/negative anomalies great-than/smaller-than one standard deviation of monthly variability). The accuracy of single and probabilistic forecasts of the 500 hPa geopotential height fields has been assessed over the Northern Hemisphere and Europe, from 1 May 1994 to 30 April 2005. Probabilistic forecasts have been assessed using 3 skill measures: the area under the relative operating characteristic curve (ROCA), the Brier skill score (BSS) and the ranked probability skill score (RPSS).

For each skill measure, first a linear regression line has been determined, and then the slope of the linear regression curve has been translated into predictability gains measured in terms of days-per-decade (d/de). In other words, the predictability gain of the time t forecast gives a measure of the trend in skill between 2005 and 1994. For example, a gain of 1 day/decade for a 5-day forecast means that the improvement in skill between 1 May 1994 and 1 May 2004 of the 5-day forecast is equal to the average difference between the skill of 4.5-day and a 5.5-day forecast during that period.

Considering for example 7-day forecasts over the Northern Hemisphere, Figure 4 shows the time evolution of the skill of the control and the ensemble-mean forecasts in terms of anomaly correlation coefficient. Results indicate a continuous improvement, equivalent to a predictability gain of

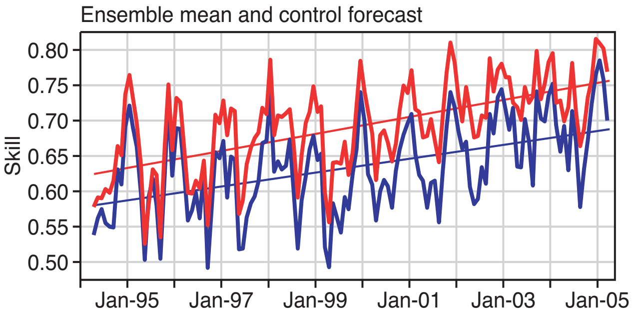


Figure 4 Monthly average anomaly correlation coefficient of the control (blue line) and the ensemble-mean (red line) 7-day forecasts of 500 hPa geopotential height fields over the Northern Hemisphere. Straight lines show linear regression curves.

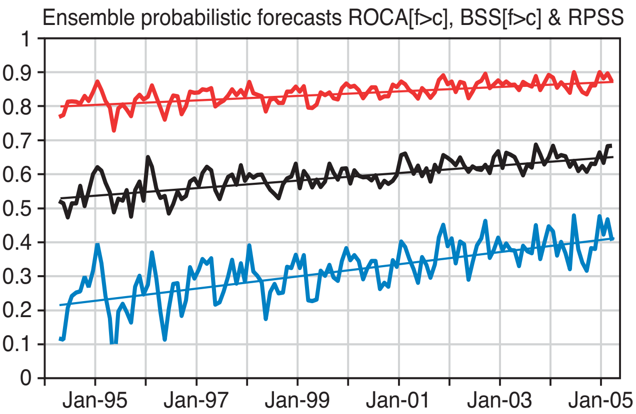


Figure 5 Monthly average area under the relative operating characteristic curve (red line) and Brier skill score (blue line) of the 7-day probabilistic forecasts of positive anomalies, and ranked probability skill score (black line) of the 7-day probabilistic forecasts of 500 hPa geopotential height fields over the Northern Hemisphere. Straight lines show linear regression curves.

1.06 d/de (days per decade) and 1.68 d/de, respectively, for the control and ensemble-mean. The corresponding results for the skill of probabilistic forecasts measured in terms of ROCA, BSS and RPSS, are given in Figure 5. In this case the predictability gains range between 1.98 and 2.90 d/de.

Figure 6 summarizes the predictability gains of the single and probabilistic forecasts achieved between 1994 and 2005 at forecast day 5 and 7 and for the Northern Hemisphere and Europe. *Results indicate that for both the Northern Hemisphere and Europe the predictability gains of medium-range EPS probabilistic forecasts has improved by about twice the value shown by EPS single control forecast*.

The improvement of ensemble forecasts first of all indicates that the EPS benefits from ameliorations of the ECMWF data assimilation and forecast model. But it also indicates that changes introduced in the EPS (Table 1) played an important role in improving the prediction of the probability distribution function of forecasts states. Although it is difficult to clearly identify which of the changes of the EPS configurations had the largest impact on the EPS scores, published works suggest that the improvements shown in Figure 6 are mainly due to three causes.

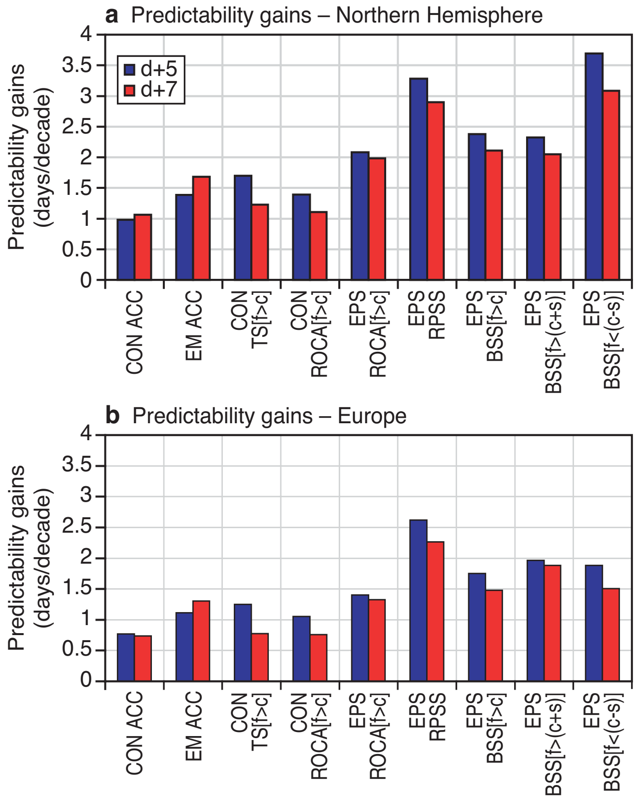


Figure 6 (a) Gains in predictability of five-day (blue bars) and seven-day (red bars) forecasts of 500 hPa geopotential height fields over the Northern Hemisphere, computed from different forecasts. (b) As top panel but for Europe. **CON ACC**: control anomaly correlation coefficient. **EM ACC**: ensemble-mean anomaly correlation coefficient. **CON TS[f>c]**: control threat score of positive anomalies. **CON ROCA[f>c]**: area under the relative operating characteristics of the probabilistic forecast of positive anomalies given by the control. **EPS ROCA[f>c]**: area under the relative operating characteristics of the probabilistic forecast of positive anomalies given by the EPS. **EPS RPSS**: ranked probability skill score of the EPS. **EPS BSS[f>c]**: Brier skill score of the probabilistic prediction of positive anomalies. **EPS BSS[f>(c+s)]**: Brier skill score of the probabilistic prediction of positive anomalies greater than one standard deviation. **EPS BSS[f>(c-s)]**: Brier skill score of the probabilistic prediction of positive anomalies less than one standard deviation.

- Increases of the EPS resolution in 1996 and 2000.
- Increase in the ensemble size in 1996.
- Introduction of evolved singular vectors and of stochastic physics in 1998.

EPS future upgrades

Work is in progress to improve the current system in three key areas.

- **Simulation of initial uncertainties** — Work in this area includes developments in the definition of the norm used to compute the singular vectors, in the use of moist, higher-resolution singular vectors, and in the combination of ensemble data assimilation and singular vectors.
- **Simulation of model imperfection** — Work in this area focuses in the revision of the scheme designed to simulate the effect of near-grid scale and sub-grid scale processes.

- **System design** — Work in this area involves changes in the ensemble resolution and forecast length, including the possibility to run the each single forecast with variable resolution (with a T_L399 resolution up to forecast day 7, and with a T_L255 resolution from the truncation time to forecast day 14).

The ECMWF EPS is based on the Integrated Forecasting System/Arpege software, developed in collaboration by ECMWF and Météo-France, and is the result of the work of many ECMWF staff members and consultants. Without their contributions the ECMWF EPS would not have reached the mature development stage and accuracy that it has reached now: their work is fully acknowledged.

FURTHER READING

On singular vectors: Buizza, R. and T.N. Palmer, 1995: The singular-vector structure of the atmospheric general circulation. *J. Atmos. Sci.*, **52**, 1434–1456.

On stochastic physics: Buizza, R., M. Miller and T.N. Palmer, 1999: Stochastic simulation of model uncertainties. *Q. J. R. Meteorol. Soc.*, **125**, 2887–2908.

On the original EPS configuration: Molteni, F., R. Buizza, T.N. Palmer and T. Petroliagis, 1996: The new ECMWF ensemble prediction system: methodology and validation. *Q. J. R. Meteorol. Soc.*, **122**, 73–119.

On the EPS configuration operational since November 2000: Buizza, R., D.S. Richardson and T.N. Palmer, 2003: Benefits of increased resolution in the ECMWF ensemble system and comparison with poor-man's ensembles. *Q. J. R. Meteorol. Soc.*, **129**, 1269–1288 .

On the latest EPS change: Ehrendorfer, M. and A. Beck, 2003: Singular vector-based multivariate normal sampling in ensemble prediction. *ECMWF Technical Report Number 416*. Available at ECMWF, Shinfield Park, Reading RG2 9AX, UK (www.ecmwf.int/publications/library/).

On the comparison of the performance of the ECMWF, MSC and NCEP ensemble systems: Buizza, R., P.L. Houtekamer, Z. Toth, G. Pellerin, M. Wei and Y. Zhu, 2005: Assessment of the status of global ensemble prediction. *Mon. Wea. Rev.*, **133**, 1076–1097.

CO_2 from space: estimating atmospheric CO_2 within the ECMWF data assimilation system

Richard Engelen

In 2001 a report by the Intergovernmental Panel on Climate Change (IPCC) noted that "*the atmospheric concentration of CO_2 has increased from 280 ppmv in 1750 to 367 ppmv in 1999 (31%). Today's CO_2 concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The rate of increase over the past century is unprecedented, at least during the past 20,000 years.*"

Currently, the global mean atmospheric concentration is about 380 ppmv. Interestingly enough, this is less than could be expected based on anthropogenic emissions. Somehow, the land and ocean take out half the amount of CO_2 that is injected in the atmosphere by the anthropogenic emissions. Accurate quantification of the processes responsible for this so-called 'missing sink' is not yet available.

Within the COCO project, funded by the European Commission, ECMWF has implemented a CO_2 estimation within the data assimilation system to monitor atmospheric CO_2 concentrations. European research groups will use these estimated concentrations to improve their surface flux estimates in order to solve the 'missing sink' problem.

More than a year of satellite data from the Advanced Infrared Sounder (AIRS) has now been processed and results are very promising. Comparisons with independent observations show that the data assimilation system is able to estimate tropospheric column CO_2 with an accuracy of better than 1%. Although these estimates are not sensitive to the boundary layer concentrations, the wealth of spatial information will help to improve the flux inversions that are currently based on the surface flask network. Recent comparisons show that for the first time we have a dataset that is able to evaluate differences between CO_2 climate model simulations on a global scale. Within the EU-funded GEMS (Global and regional Earth-system Monitoring using Satellite and in-situ data) project the CO_2 analysis system will be extended to a full 4D-Var system that will be able to assimilate CO_2 information from various instruments. Further information about GEMS can be found in the spring 2005 edition of the ECMWF Newsletter.

Carbon cycle

In 1957 Charles Keeling and colleagues started observing atmospheric CO_2 concentrations at Mauna Loa, Hawaii, and at the South Pole. Concentrations have risen from 313 ppmv (parts per million by volume) in 1957 to 380 ppmv in 2004, an increase of about 20% in 50 years. It is now clear that this increase in atmospheric CO_2 is largely due to anthropogenic emissions, such as combustion processes, cement production, and biomass burning. Since these early observations, a network of accurate flask measurement sites has been set up to obtain a better idea of the variability of atmospheric CO_2. From these observations and from our knowledge of the amount of anthropogenic emissions an interesting result arose: only half the amount of anthropogenic emissions accumulates in the atmosphere. The other half is somehow absorbed by the ocean and/or land biosphere. This phenomenon is now widely known as the missing sink (see Figure 1).

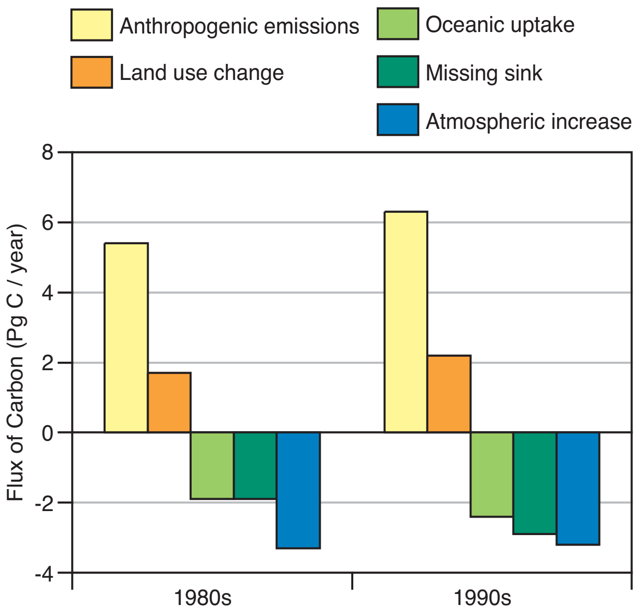


Figure 1 Anthropogenic perturbations to the natural atmospheric carbon cycle in Petagram Carbon per year for the 1980s and 1990s. The missing sink represents the part of the budget that can not be explained with current knowledge about the carbon cycle.

Much of the carbon cycle research has been focused on the possible processes that can account for the missing sink. Bottom-up approaches try to build better flux models for both the ocean and the natural biosphere. At the same time top-down methods have used the flask observations together with atmospheric transport models to infer flux estimates. The main problem with the latter approach, the flux inversions, is the data sparseness. Only about 100 surface flask sites exist today and the inversion problem therefore strongly relies on the atmospheric transport model being used. This has not helped research groups reach consensus as to which processes are responsible for the uptake of anthropogenic emissions. Observing atmospheric CO_2 with satellite instruments is therefore regarded as a very promising way forward to improve flux inversions. However, there are currently no satellite instruments that have been specifically designed to observe CO_2.

Both the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA) are building designated CO_2 instruments that will use solar reflection in the near infrared to observe atmospheric CO_2 concentrations (Orbital Carbon Observatory, OCO, and GOSAT, respectively). These instruments will potentially provide accurate observations, but they also suffer from poor reflectivity over ocean, aerosol interference, and the need for solar radiation. Meanwhile, the AIRS instrument flying on board of the NASA Aqua satellite observes the infrared part of the spectrum at high spectral resolution.

Important absorption bands in the infrared part of the spectrum consist of CO_2 absorption lines. Traditionally, these CO_2 absorption lines have been used to infer atmospheric temperatures from the measurements assuming the CO_2 concentration to be fixed. It is possible, though, to estimate both temperature and CO_2 from these observations by either adding other absorption bands (e.g. water vapour) or making assumptions about for instance the vertical profile of CO_2 (e.g. well-mixed profile). Another possibility is to add observations from other instruments that provide information about the temperature profile as is routinely done in a numerical weather prediction (NWP) data assimilation system. However, the amount of independent CO_2 information is small and can easily be obscured by the other signals and/or the noise in the observations and the radiative transfer modelling. Also, measurements in the infrared are generally not sensitive to atmospheric CO_2 in the lower part of the troposphere. This is an important restriction, because most of the variability of CO_2 occurs in the boundary layer. However, the infrared option is attractive because it guarantees continuity in time with instruments such as the European Infrared Atmospheric Sounding Interferometer (IASI) and the American Cross-track Infrared Sounder (CrIS) being launched in the next few years. It also has the advantage over near-infrared observations that there is no restriction to daytime observations.

CO_2 estimation set-up

ECMWF has been operationally assimilating observations from the AIRS instrument since October 2003. The measurements constrain temperature and water vapour by assuming constant CO_2 mixing ratios. Within the COCO project we have added CO_2 to the minimization state vector in an experimental configuration to prove the feasibility of this approach. Instead of including CO_2 in the forecast model, which would require extensive coding to transport tracers around as well as defining proper background statistics, CO_2 was added to the state vector as a column variable for each AIRS observation location. Then the output of one analysis cycle consists of all the relevant atmospheric fields (temperature, winds, humidity, etc.) together with CO_2 tropospheric column estimates at all the AIRS observation locations that go into the assimilation. Because CO_2 is not part of the assimilation transport model, there are no forecasts for CO_2. Consequently CO_2 information from one analysis cycle cannot be used in the next analysis cycle. Also, to generate global fields, individual estimates have to be gridded in for instance 5° by 5° boxes for a certain time period.

A set of only 18 AIRS spectral channels (out of 324 available channels) sensitive to tropospheric CO_2 was used to estimate the tropospheric CO_2 columns. These channels were chosen to minimize the effect of water vapour and ozone absorption. Because the signal of CO_2 in the observed radiances is so small, it is easily obscured by uncertainties in the water vapour and ozone distributions. For the background constraint a global mean value of 376 ppmv was chosen with a background error standard deviation of 30 ppmv. The analysis error was estimated based on the background error, the observation error, and the sensitivity of the observations to atmospheric CO_2. This sensitivity largely depends on the temperature lapse rate and the depth of the tropospheric layer (i.e. the height of the tropopause).

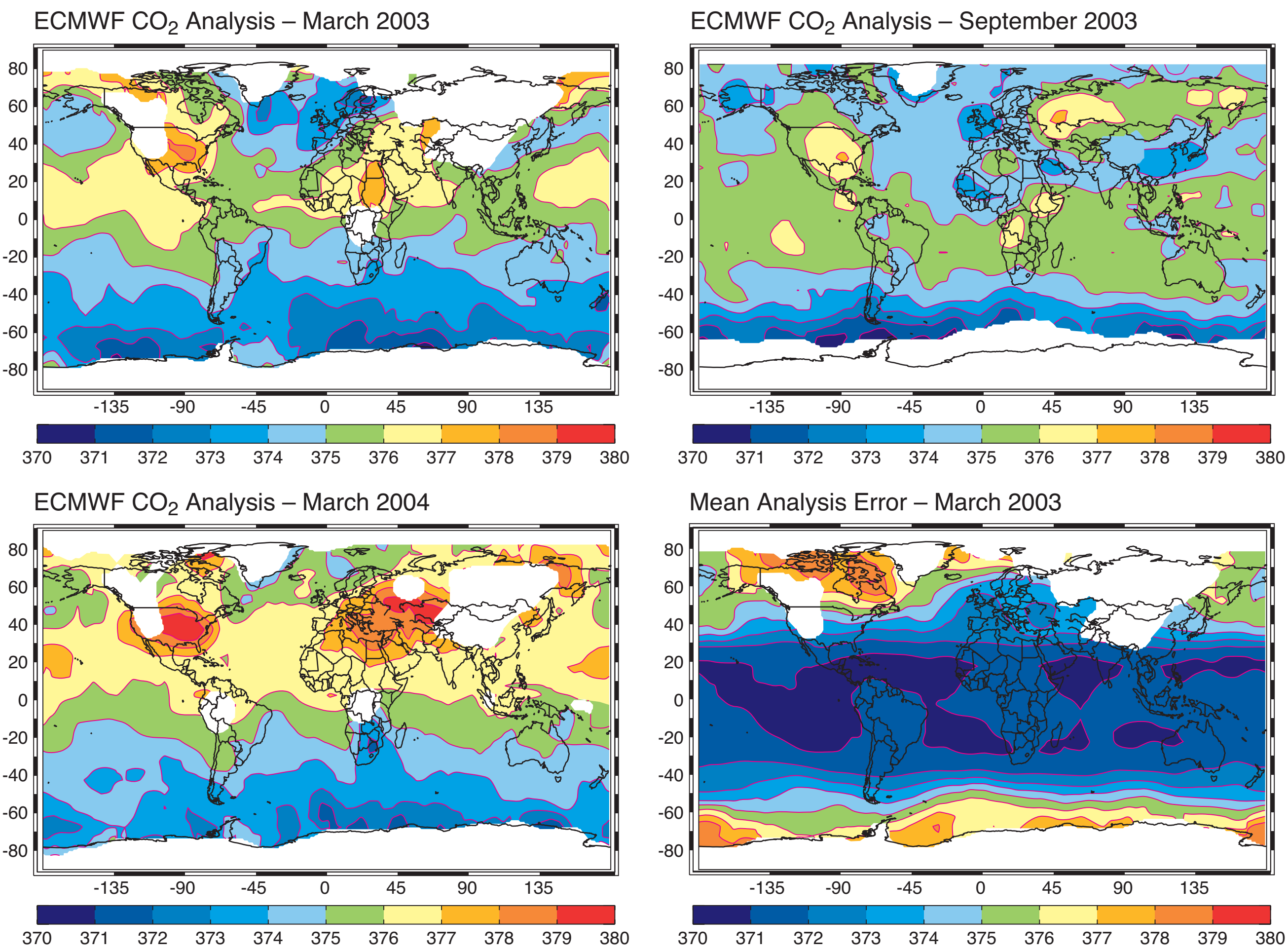


Figure 2 Monthly mean CO_2 analysis results for March 2003, September 2003, and March 2004 as well as the monthly mean analysis error for March 2003. Units are ppmv of CO_2.

Results of analysing AIRS data

More than one year of AIRS data has been processed and Figure 2 shows monthly mean results for March 2003, September 2003, and March 2004. The fourth panel shows the monthly mean analysis error for March 2003. White areas represent areas with extensive cloud cover throughout the month.

The largest signal in atmospheric CO_2 concentrations comes from the terrestrial biosphere. Vegetation absorbs CO_2 by photosynthesis and emits CO_2 through respiration. Plant litter on and in the soil releases CO_2 as well due to decomposition. A strong seasonal cycle is produced, although the annual net biosphere flux is very close to zero. The terrestrial biosphere also creates a latitudinal gradient in the atmospheric concentrations due to the large amount of land in the northern hemisphere compared to the southern hemisphere. This latitudinal gradient is amplified by the anthropogenic emissions that mainly originate from the northern hemisphere. Both the seasonal cycle and the latitudinal gradient are visible in the results of Figure 2. It is encouraging to see that the assimilation is capable of producing these spatial and temporal variations without having that information in the background.

March 2004 shows generally higher CO_2 concentrations than March 2003, representing the upward trend in global atmospheric CO_2. The difference between March 2003 and March 2004 at the location of Hawaii is 1.6 ppmv compared to the 1.4 ppmv observed at the Mauna Loa flask station. The monthly mean error shows the clear dependence of the analysis error on the temperature lapse rate as well as the thickness of the tropospheric layer. Errors are smallest in the tropics were the tropopause is high and the temperature lapse rate is large, while they increase at higher latitudes where the tropopause is lower. The relatively low errors over Europe are caused by a higher tropopause (deeper tropospheric layer) in the sub-tropical air mass.

Validation of the analyses

The presentation of monthly mean results is interesting by itself, but an important check of the validity of our analysis results is by comparing these results to independent observations of atmospheric CO_2. There are only very few data sources for 2003 and we can generally not use the surface flask data. This is because our estimates represent a layer between about 700 hPa and the tropopause, while the surface flasks are sampled in the boundary layer. Only if we are sure that the full tropospheric CO_2 profile is well-mixed would a comparison be useful. However, Dr Hidekazu Matsueda and colleagues at the Japanese Meteorological

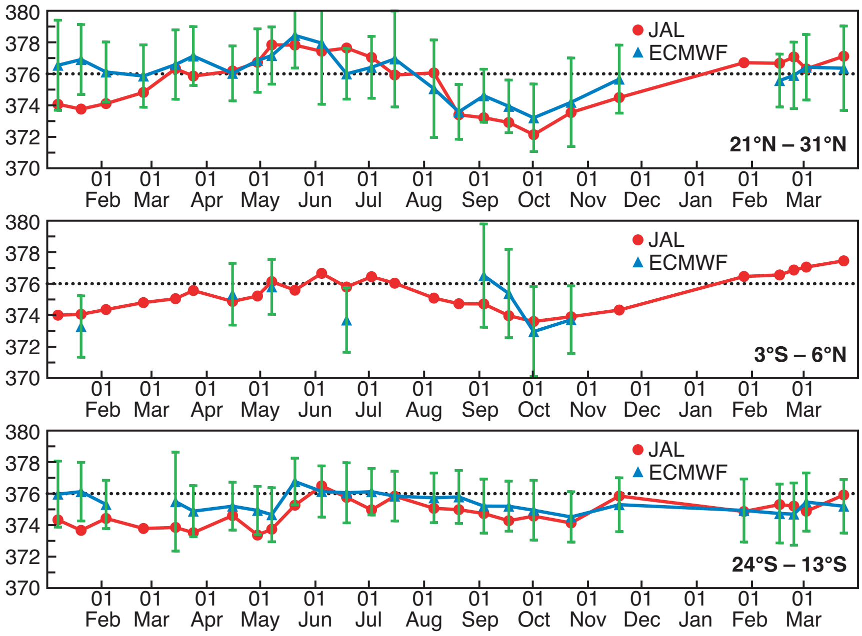


Figure 3 Comparison of ECMWF CO_2 estimates (blue triangles) with JAL observations (red dots) for three different latitude zones from January 2003 to March 2004. The CO2 background value is denoted by the dotted line. Mean analysis errors are denoted by the green error bars. Missing ECMWF data are caused by extensive cloud cover in the area. Units are ppmv of CO_2.

Agency have been measuring CO_2 on board commercial flights of the Japanese Airlines (JAL) flying between Japan and Australia. These observations consist of automatic flask samples gathered at altitudes between 8 and 13 km on bi-weekly commercial flights. For 2003, there were 21 flights available for our comparisons.

Figure 3 shows the CO_2 annual cycle for both the flight observations and the assimilation estimates. For the full processed period (1 January 2003 to 31 March 2004), CO_2 analysis estimates were sampled in 6° by 6° boxes around the locations of the flight observations and over a period of 5 days around the date of those observations. We then generated three plots that represent the northern hemisphere region, the equatorial region, and the southern hemisphere region, by averaging the respective box averages for each region together. The figure shows that the analysis estimates follow the JAL observed annual cycle quite well. All differences fall within the one standard deviation error bars and are of the order of 1 ppmv in most cases. There is a clear improvement compared to the background, which is 376 ppmv throughout the year. The main anomaly can be seen in both the northern hemisphere and the southern hemisphere in January and February, in which period the analysis estimates are consistently higher than the JAL observations.

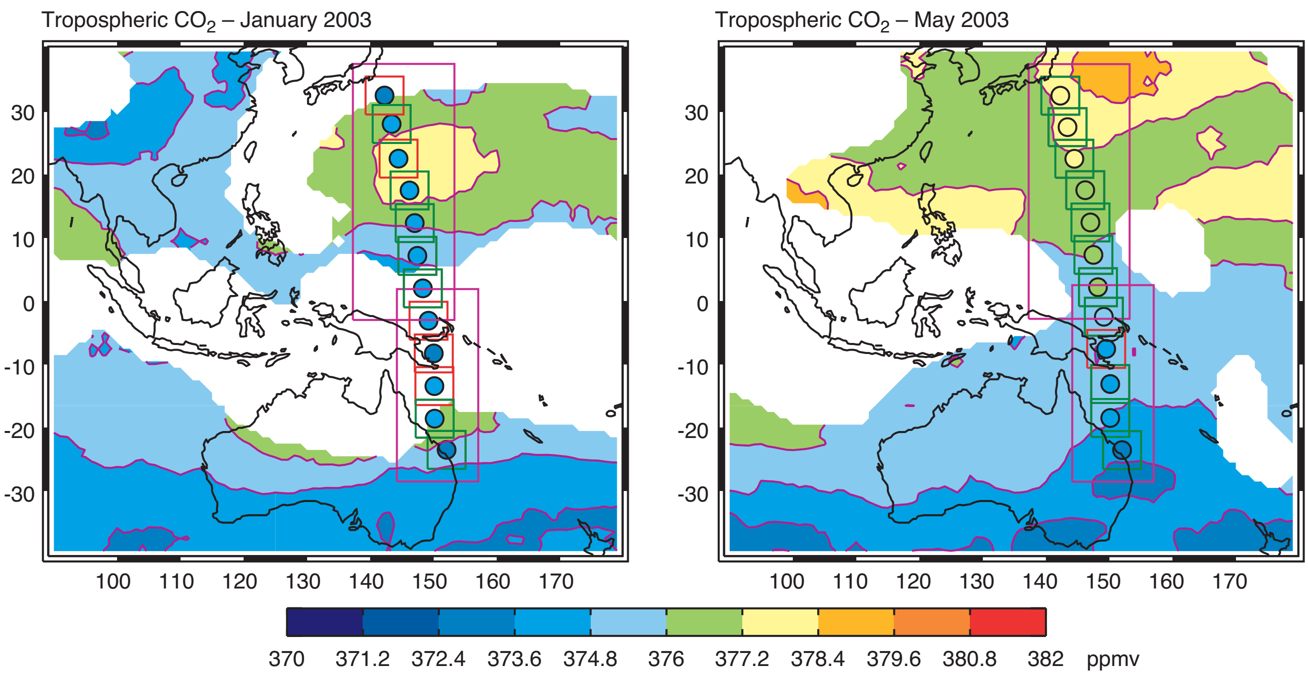


Figure 4 Comparison of ECMWF CO_2 estimates with Japanese Airlines (JAL) observations (filled circles in same colour scale) for 20 January and 20 May 2003. Units are ppmv of CO_2.

Figure 4 shows geographical comparisons with the JAL data for January and May 2003. The figure for 20 January 2003 is an example of a bad match between the JAL observations and the analysis results, while the figure for 20 May 2003 is an example of a good match. We suspect the main problem area in the January plot is affected by undetected thin cirrus clouds. Although the signal of these undetected clouds is negligible in terms of the temperature analysis, it causes the average CO_2 field to be high compared to the surrounding area. This difference in the cloud detection between January 2003 and May 2003 is most likely caused by the effect of the GOES-9 satellite on the moisture fields of the ECMWF analysis. The normal geostationary satellite over the Pacific area was GMS-5, but continuing problems with the onboard imager required a replacement by the GOES-9 satellite in May 2003. Therefore, during the critical (in terms of amount of convection over the Pacific) months of January, February and March the geostationary constraint on the humidity field was lacking. This is a cautionary example showing the impact of seemingly unrelated satellite instrument changes on the CO_2 estimates. Continuous validation of the results is therefore of great importance.

The next phase

On 1 March 2005 the EU-funded GEMS project started with the aim to develop an operational environment monitoring system. Within this project the CO_2 data assimilation will be upgraded to a full 4D-Var data assimilation system. Work is now underway to add CO_2 as a tracer variable to the forecast model. We are also defining proper background statistics that will be very important for the interpretation of the satellite observations. It is envisaged that this system will provide even better results than the relatively simple assimilation system, here described. The main output will be three-dimensional CO_2 fields every 12 hours constrained by observations from AIRS, IASI, CrIS, and possibly OCO and GOSAT. These fields will then be used by some of the partners of the GEMS project to improve their flux estimates and hopefully get a better idea of the processes behind the missing sink.

FURTHER READING

Engelen, **R.J.**, **E. Andersson**, **F. Chevallier**, **A. Hollingsworth**, **M. Matricardi**, **A.P. McNally**, **J.-N. Thépaut** and **P.D. Watts**, 2004: Estimating atmospheric CO_2 from advanced infrared satellite radiances within an operational 4D-Var data assimilation system: Methodology and first results. *J. Geophys. Res.*, **109**, D19309, doi:10.1029/2004JD004777.

Engelen, **R.J.** and **A.P. McNally**, 2005: Estimating atmospheric CO_2 from advanced infrared satellite radiances within an operational 4D-Var data assimilation system: Results and validation. *J. Geophys. Res.*, in press, doi:10.1029/2005JD005982.

Improved prediction of boundary layer clouds

Martin Köhler

You are having a sunny summer picnic when suddenly low cloud moves in. Instantly, your skin feels a cooling from the drastic change in radiation. Sunlight is reduced by 50 to 70% or 200 to 300Wm^{-2}. Yet infra-red radiative cooling is also reduced by 50 to 100 Wm^{-2}, because the cloud above emits more black body radiation than the colder clear sky. The air temperature sinks by 1°C per hour, the wind picks up and you start to pack up to go home.

It comes as no surprise that low cloud has a commanding impact on climate as well as climate change. If one could magically cover an additional 4% of the globe with low cloud, the global warming resulting from the potential doubling of CO_2 could possibly be offset. On the other hand, if the amount of low cloud decreased there could be an unpleasant positive feedback which would accelerate global warming. Unfortunately, current global climate models are split into those that increase low cloud in climate change scenarios and those that produce a decrease.

Turning our attention to weather forecasting, the quality of cloud forecasts still lags significantly that of temperature and circulation above the planetary boundary layer (PBL). Figure 1 compares the skill of ECMWF forecasts relative to persistence for a few typical variables. Cloud appears to be the most difficult to forecast, with the boundary layer variables (i.e. two-metre temperature and ten-metre wind speed) only a little better. Much better predicted are temperature and wind at 850 hPa just above the boundary layer and, quite encouragingly, six-hour accumulated precipitation. Apparently, it is easier to forecast the dynamically forced precipitation than the small residual — the cloud. The errors in cloud forecasts produce errors in the radiation calculations and these in turn affect the PBL temperatures and winds. This skill comparison of a diverse set of variables comes with caveats such as that persistence is a better forecast benchmark for cloud than for precipitation. Yet, this figure illustrates the difficulty of getting good cloud predictions from accurate circulation forecasts.

At ECMWF considerable work has been invested recently in developing an improved representation of low cloud. As a result the simulation of marine stratocumulus improved drastically. Continental stratus also benefited as witnessed specifically in the blocking period of December 2004 over Europe. This article outlines the key aspects of the new planetary boundary layer parametrization scheme which has been incorporated into the ECMWF Integrated Forecast System (IFS) in April 2005. Some of the improvements in cloud cover are highlighted.

New treatment of stratus and stratocumulus

What are the physical processes needed to adequately model stratus and stratocumulus in particular? And why has it proved so difficult to develop successful parametrizations?

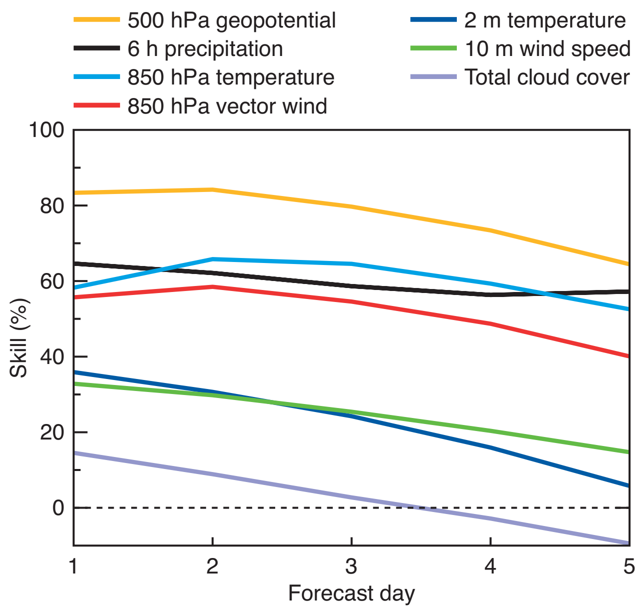


Figure 1 Forecast skill versus persistence against observations of various atmospheric variables over Europe for the year 2004 at 12 UTC. The observations are radiosondes for 500 hPa and 850 hPa variables and SYNOP stations for the rest. Note that SYNOP cloud observations have significant errors and for cloud and precipitation it is questionable how representative local observations are for the model scale. With RMSE as the root mean square error of forecasts or persistence, the skill is defined as

$$1 - \frac{RMSE\ (forecast)}{RMSE\ (persistence)}$$

Those low clouds are known to cap well-mixed boundary layers. The required vigorous mixing is mainly forced by the strong radiative cooling at the cloud top. This would cool the entire PBL by 10°C per day if not balanced by surface fluxes and entrainment of warm air through the cloud top. Assuming that the stratocumulus topped PBL is a turbulent well-mixed layer there are just three budgets one has to solve: mass, water and heat.

- The mass budget governed by subsidence and cloud-top entrainment predicts the cloud top height.
- The water and heat budgets determine cloud base and cloud water.

The key factors are surface fluxes, cloud top entrainment, solar warming and infra-red cooling.

Writing these three PBL budgets is straightforward, yet many global models strongly underpredict marine stratocumulus clouds. Generally, the problems these models have can be separated in two categories: inadequate representation of physics and inaccurate numerics. Examples of physical problems are a lack of mixing up to cloud top and there being no scientific consensus about cloud top entrainment. Another region of current inconclusive research is the transition from stratocumulus with unbroken cloud decks to trade cumulus with just a few tens of percent of cloud cover. Numerical difficulties arise from the PBL top moving through model levels and the interaction of PBL, convection, cloud and radiation schemes. Maintaining numerical stability whilst using long time-steps is another typical challenge for transport schemes used to simulate low-level cloud.

The main aim in upgrading the PBL parametrization was to improve low-level cloudiness and pave the way towards the unification of the PBL and shallow convection schemes. To achieve that goal the following ingredients were deemed necessary: (a) moist conserved variables, (b) a combined mass-flux/diffusion solver, (c) a treatment of cloud variability, and (d) a treatment of the transition between stratocumulus and shallow convection.

Figure 2 illustrates the approach chosen, which is based on a flux decomposition into diffusion and mass-flux terms. This decomposition goes back to work by Siebesma and Cuijpers at KNMI in 1995, who showed that any vertical flux of a scalar quantity can be split into three contributions: the mass-flux, the sub-core flux and the environmental flux terms. This can be understood by reference to Figure 3. The mass-flux approach (red line) accounts for the strongest updraughts. Then the small perturbations (blue) along the

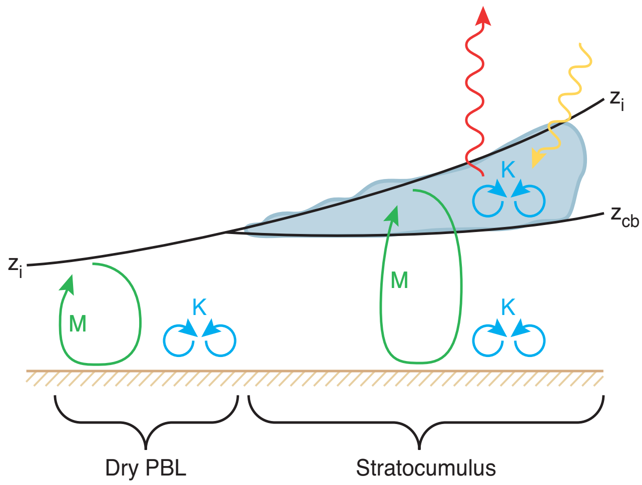


Figure 2 Transition of a dry PBL to stratocumulus. The parametrization of the associated convective transports in the new scheme are illustrated in blue for the diffusion component K and in green for the mass-flux component M. Yellow and red arrows denote solar and infra-red radiation respectively. z_i is the inversion height and z_{cb} is the cloud base height. See text for explanation.

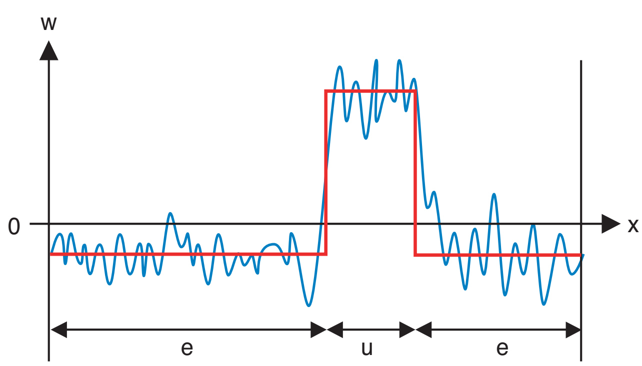


Figure 3 Two box decomposition of vertical velocity w between mass-flux component (red line) and perturbations against the mean environment (e) and updraught (u) (blue line). The perturbation components are being parametrized with a diffusion approach.

red line can be described with a diffusion approach. This combined mass-flux/diffusion methodology allows for a more accurate description of the fluxes than either approach by itself. Additionally, these two traditional transport approximations can be combined as desired for specific cloud regimes. Therefore, this combined approach is ideally suited to unifying PBL parametrization, which often uses pure diffusion techniques, with convection parametrization, typically based on mass-flux techniques.

Cloud cover and cloud water are treated in the new parametrization scheme by predicting the variance of total water, that is cloud water plus water vapour. If the shape of the probability density function of total water is assumed, the conversion between the prognostic variables water vapour and cloud water on the one hand and total water and total water variance on the other hand can be represented.

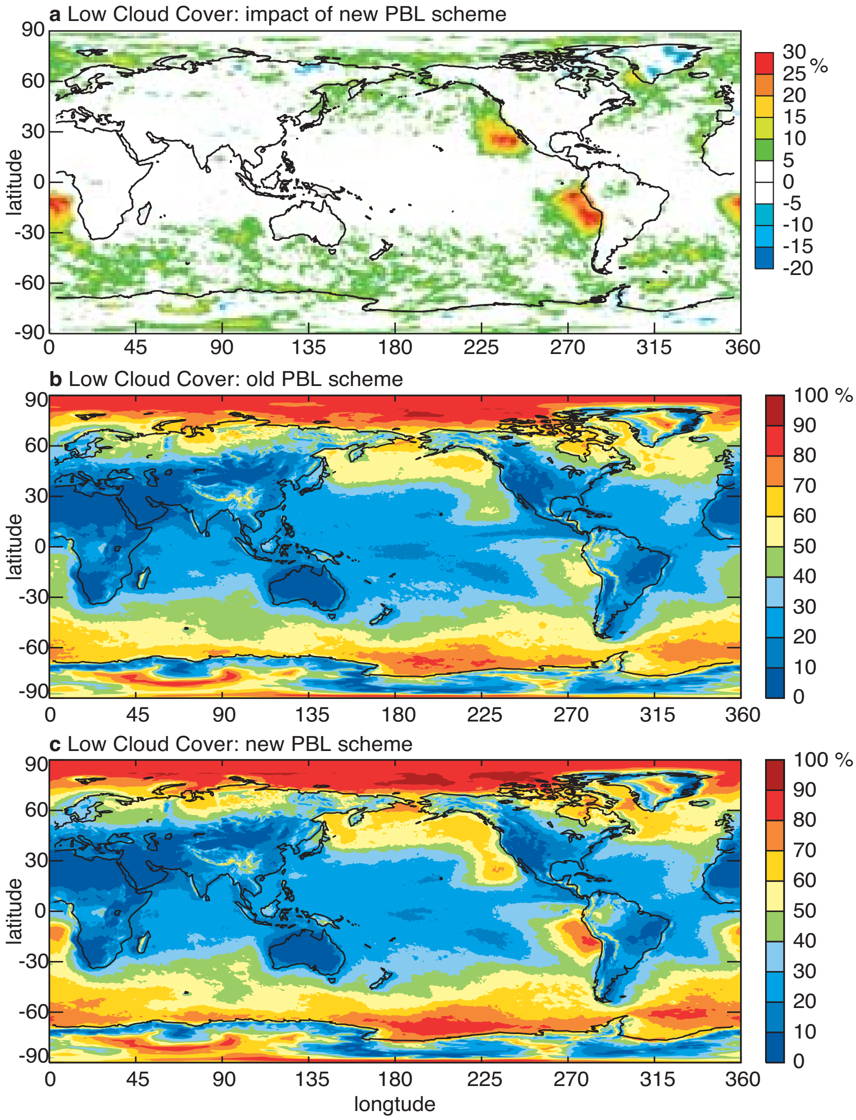


Figure 4 (a) Difference in low-cloud cover between analysis/forecast experiments using the new PBL parametrization scheme and the old scheme. The other panels give the low-cloud cover from the analysis/forecast experiments using (b) the old PBL scheme and (c) the new PBL scheme. The results represent 9.5 and 10 day forecasts from six test periods covering 7–27 July 2001, 9–22 October 2001, 1 February–1 March 2004, 1–31 July 2004, 1–31 October 2004 and 3-15 December 2004 amounting to 140 days.

The last key requirement of the new PBL parametrization is to determine the PBL cloud regime. In nature there are two typical low-cloud regimes: stratocumulus clouds, which occur in well-mixed PBLs with a large cloud fractions, and trade cumulus clouds with small cloud fractions and cloud layers that are weakly stable stratified. Various algorithms are available to distinguish between these regimes. In the end we used a criterion based on lower tropospheric stability after the work by Klein and Hartmann at the University of Washington in 1993. This criterion reflects the observation that stratocumulus clouds mostly live in atmospheres with strong inversions.

Peruvian stratocumulus

The main impact of the new moist PBL scheme was expected to be an increase in low-level cloud cover which would be more realistic in situations of cloud-topped mixed layers below inversions. Most stratus and stratocumulus live over relatively cold ocean regions favouring condensation. The ocean also supplies a near infinite heat source offsetting the cloud top cooling minus top entrainment, which together thermally force the well mixed PBLs. Therefore, the subtropical oceans west of continents associated with upwelling and the high latitude oceans are typical regions of large low-level cloud cover. In addition stratus forms over the continents during winter in anticyclonic regimes.

Testing of the new PBL included more than a thousand forecast days with the full resolution T511 model during six periods in the years 2001 and 2004. Figure 4 shows the corresponding realistic increases in cloud cover of up to 40% locally in all the typical stratocumulus and stratus regions and of around 2% to 4% globally. This improvement is rather significant for the Earth energy balance. Two of the full-resolution reanalysis periods were specifically chosen to coincide with marine stratocumulus field experiments: DYCOMS II in July 2001 in the California stratus region and EPIC in October 2001 in the Peru stratus region.

The field experiment EPIC (Eastern Pacific Investigation of Climate Processes) focused on a comprehensive study of turbulence, drizzle and aerosols in stratocumulus in the southeast Pacific Ocean. The research ship Ron Brown was located for a full week in the centre of this low-cloud region. Typically this region has thick stratocumulus clouds,

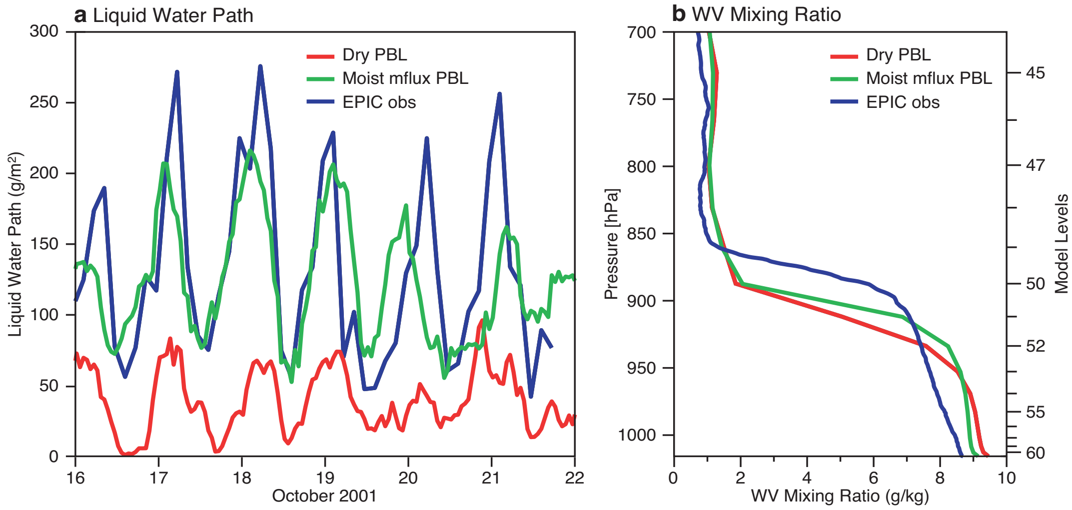


Figure 5 (a) Liquid water path evolution during the Eastern Pacific Investigation of Climate (EPIC). It included a stationary observation period at 85°W, 20°S off the coast of Peru during 16–21 October 2001. The observed liquid water path is in blue. Results of the three-hourly forecasts using the old PBL scheme are in red and those using the new PBL scheme are in green. The day 1, 2 and 3 forecasts were averaged according to verifying time to obtain a smooth curve. (b) The corresponding profiles of water vapour.

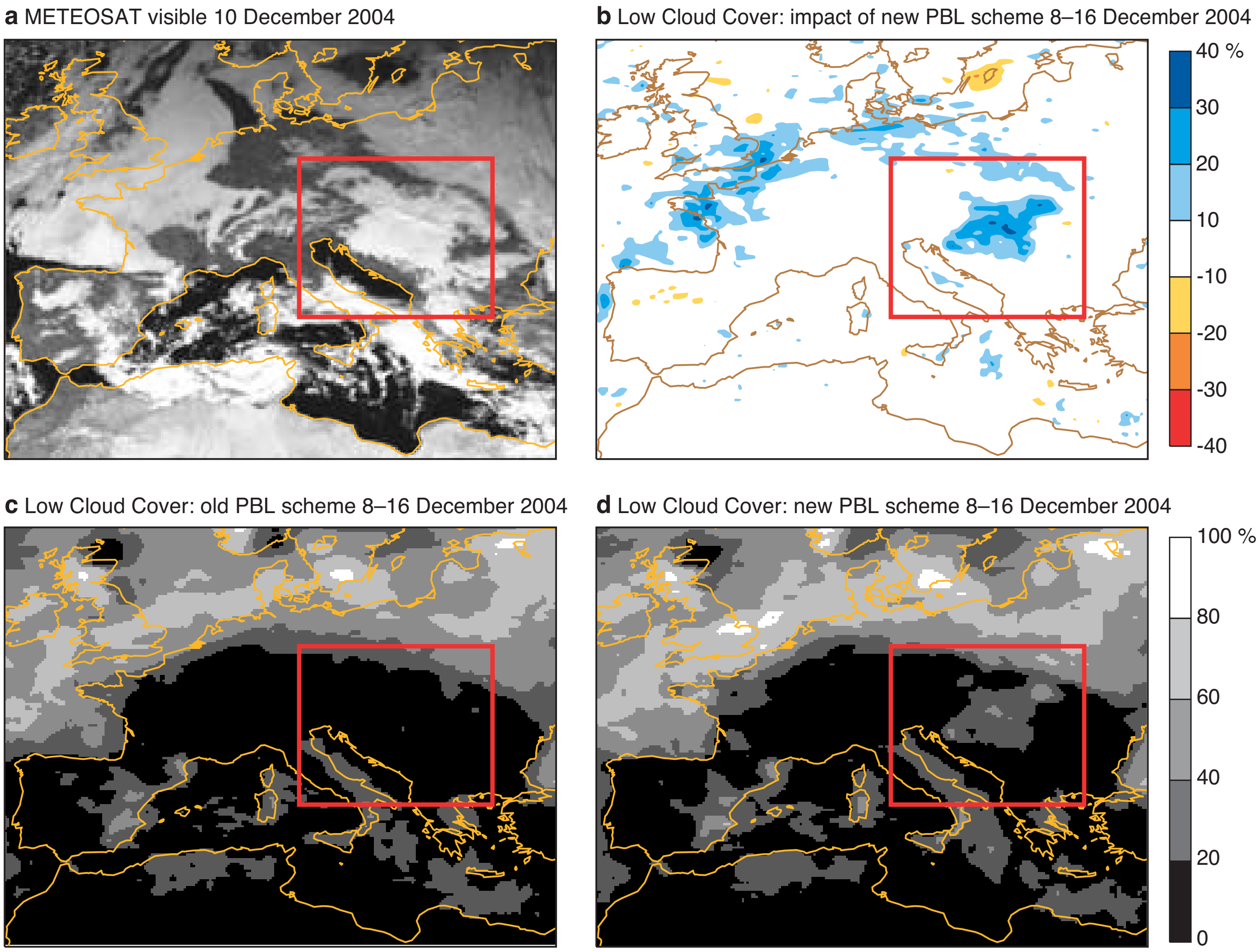


Figure 6 (a) Meteosat 7 visible image for 12 UTC on 10 December 2004 over Europe. This snapshot is characteristic for the 8–16 December 2004 period. The red rectangle includes the Hungarian plateau with the thickest stratus occurrence. (b) Low-level cloud cover difference between the new and old PBL parametrization schemes over Europe for verifying time 12 UTC on 8–16 December 2004. The day 1, 2 and 3 forecasts were averaged according to verifying time. (c) Low-level cloud cover using the old PBL scheme. (d) As (c) but using the new PBL scheme.

which play an integral part in the Equatorial Pacific air-sea interaction. Such interactions include the formation of the "cold tongue" of cool sea surface temperatures (SSTs) extending westward from Peru and the El Niño interannual SST oscillation. Figure 5 shows the vertically integrated liquid water at the EPIC location taken from short-term global T511 forecasts with the old and new PBL parametrizations. The new PBL forecasts significantly improve the magnitude and diurnal cycle of the liquid water path in this thick stratocumulus regime (Figure 5(a)). The main origins of this improvement can be traced to a more well-mixed PBL and a higher PBL top as seen from the corresponding water vapour profiles (Figure 5(b)).

European winter stratus

In December 2004 the parametrization development reached its final stage. At the same time, during a persistent anticyclonic regime the operational forecasts showed a complete lack of stratus observed over France and Hungary (thanks to Gerald Van der Grijn, ECMWF and Tamás Hirsch, Hungarian Meteorological Service). The Meteosat visible image for 10 December 2004 (Figure 6(a)) is typical for the period of 8 to 16 December in terms of the persistent thick stratus over the Hungarian plateau and the stratus along the northern coast of France. Occasionally marine stratus moved inland into France during this period. An analysis/forecast experiment for 3 to 15 December was performed with the new moist PBL parametrization incorporated into the operational model. This new scheme produced much more realistic low cloud with 30% more cloud over both the French and Hungarian cloud regimes for the full 8 to 16 December period (Figure 6(b)). While the marine stratocumulus improvements were primarily targeted with the introduction of the new scheme, an equal improvement was not expected during the challenging winter land situations.

What did we accomplish and where do we go now?

We accomplished the scientifically and technically challenging unification of two conventional approaches for the PBL and convection, the diffusion and mass-flux approaches. That allowed us to unify the two physical boundary layer regimes of the dry and stratocumulus topped PBL with great success.

The same framework is now being extended to include the trade cumulus regime, where this moist combined mass-flux/diffusion approach should be even more appropriate. Early results using a multiple mass-flux extension are very encouraging.

We might never bring the quality of cloud forecasts to the level of 500 hPa height forecasts. But this work shows that there is great potential for improving cloud prediction by careful treatment of their physical and numerical aspects, even though there are physical (e.g. regime transition) and numerical (e.g. inversion prediction) challenges ahead.

FURTHER READING

Siebesma, A.P. and **J.W.M. Cuijpers**, 1995: Evaluation of parametric assumptions for shallow cumulus convection. *J. Atmos. Sci.*, **52**, 650–666.

Developing and validating Grid Technology for the solution of complex meteorological problems

Matteo dell'Acqua and Guillaume Aubert

At its fourteenth Congress held in 2003, the World Meteorological Organization (WMO) approved the concept of a WMO Information System (WIS). The WIS will provide a single coordinated global infrastructure for the collection and sharing of information in support of all WMO and related international programmes. It will be based on three main components and a network able to interconnect them: National Centre (NC), Global Information System Centre (GISC) and Data Collection and Production Centre (DCPC). Further information about WIS, can be found at:

www.wmo.int/web/www/FWIS-Web/homefwis.html

As a first step towards the establishment of the WIS, the Regional Association VI of WMO decided to create a project for the development of a prototype GISC. Deutscher Wetterdienst (DWD), Météo-France and the UK Met Office volunteered to jointly design and implement a Virtual GISC (V-GISC) shared by their Services and to include ECMWF and EUMETSAT as DCPCs in the concept. They proposed that ECMWF lead a sub-project of the EU-funded SIMDAT project (Data Grids for Process and Product Development using Numerical Simulation and Knowledge Discovery), with the view to preparing the necessary elements of the V-GISC.

SIMDAT

SIMDAT is a four-year European FP6 Integrated Project. The SIMDAT contract was signed on 1 September 2004. The project aims at developing generic Grid Technology for the solution of complex data-centric problems and validating the effectiveness of the Grid Technology in several application sectors.

Development of large-scale products and services poses complex problems. The processes used to develop these products and services typically involve a large number of independent organisational entities at different locations grouped in partnerships and supply chains. Offering connectivity plus interoperability, Grids are a major enabler of improved collaboration and of virtual organisations; they are needed to connect diverse data sources and to enable flexible, secure and sophisticated levels of collaboration.

The four application sectors selected to cover the full range of issues to be addressed in design, development and production of complex products and services are aerospace, automotive, pharmacy and meteorology. For each application

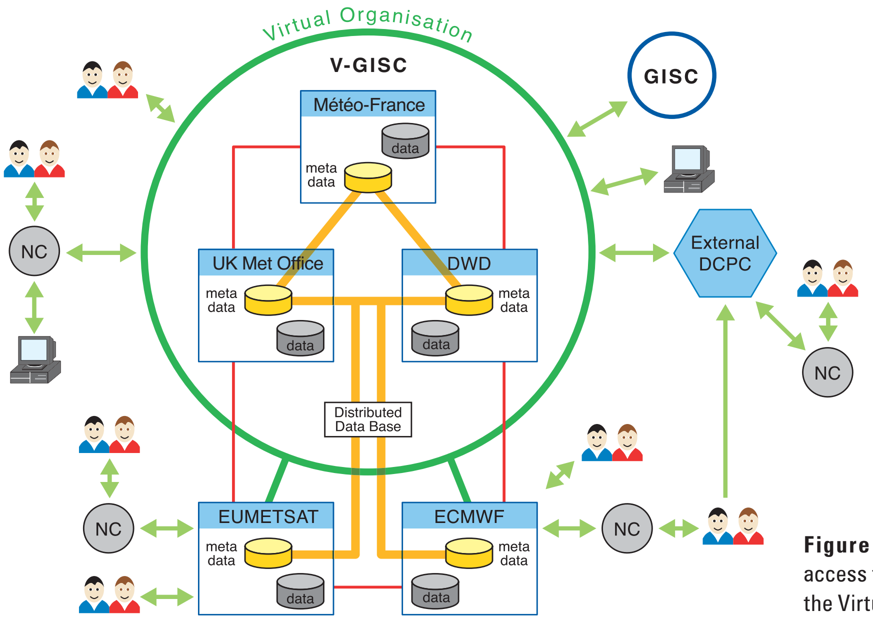


Figure 1 The SIMDAT Infrastructure will provide access to distributed meteorological databases through the Virtual Global Information System Centre (V-GISC).

sector a complex problem has been identified as a use-case for the project. The consortium also comprised leading software and process system developers and Grid technology specialists.

Seven key technology layers have been identified as important to achieving SIMDAT's objectives.

- ◆ An integrated Grid infrastructure, offering basic services to applications and higher-level layers.
- ◆ Transparent access to data repositories on remote Grid sites.
- ◆ Management of Virtual Organisations.
- ◆ Scientific workflow.
- ◆ Ontology (i.e. specification of conceptualization).
- ◆ Integration of analysis services.
- ◆ Knowledge services.

Virtual Global Information System Centre (V-GISC)

V-GISC The objective of SIMDAT for the meteorology sector is to develop a virtual information centre to support research and operational activities of the European meteorological community. This virtual centre will offer users a consistent view of all meteorological data distributed in the real-time and the archive databases of the partners, and provide a secure, reliable and efficient mechanism to collect, exchange and share these distributed data.

ECMWF, in cooperation with Météo-France, DWD, the UK Met Office and EUMETSAT, and with the help of SIMDAT technology specialists, plans to develop and deploy a common system for the collection and sharing of distributed meteorological data. The V-GISC partners will form a cluster, with partners enjoying equal rights and supporting one another. By the use of Grid technologies and standards and protocols for metadata, data discovery, transport and on-line browsing, the V-GISC infrastructure will improve the load distribution and availability of the system. In addition it will provide a uniform external interface to the users allowing them to easily locate, access and use the diverse distributed forms of data and their associated metadata.

ECMWF hosted the first SIMDAT/V-GISC workshop from 6 to 9 December 2004. The workshop reviewed the technical and functional requirement of the WIS and started to identify and capture the requirements of the V-GISC. The initial datasets that will be available through the virtual centre were also discussed during the workshop.

V-GISC infrastructure

The project will develop an infrastructure that brings together the data of the partners and provide access to distributed meteorological databases through the virtual organisation. Figure 1 shows the infrastructure within the WIS architecture. Users and systems can either access the V-GISC or can access directly the National Centres or the Data Collection and Production Centres. The V-GISC will be seen as a normal GISC and will fulfil the WIS technical requirements. Consequently the V-GISC will:

- ◆ Improve visibility and access to data through a comprehensive discovery service based on metadata development;
- ◆ Add value to existing data sets;
- ◆ Offer a subscription services and a variety of reliable delivery services;
- ◆ Provide a global access control policy managed by the partners and integrated into their existing security infrastructure.

V-GISC architecture

The project will develop Grid-based software to collect and exchange data. Metadata systems, delivery and access tools will be developed to provide users with Grid services linking data discovery across distributed databases to dataset delivery. Figure 2 shows the conceptual architecture of the V-GISC. Users search and retrieve data, subscribe to services, subject to authentication and authorization, through a distributed portal located on each partner's site. The following services are available.

- ◆ **Virtual database Service**: it is the core of the system and provides a single view of partners' databases.

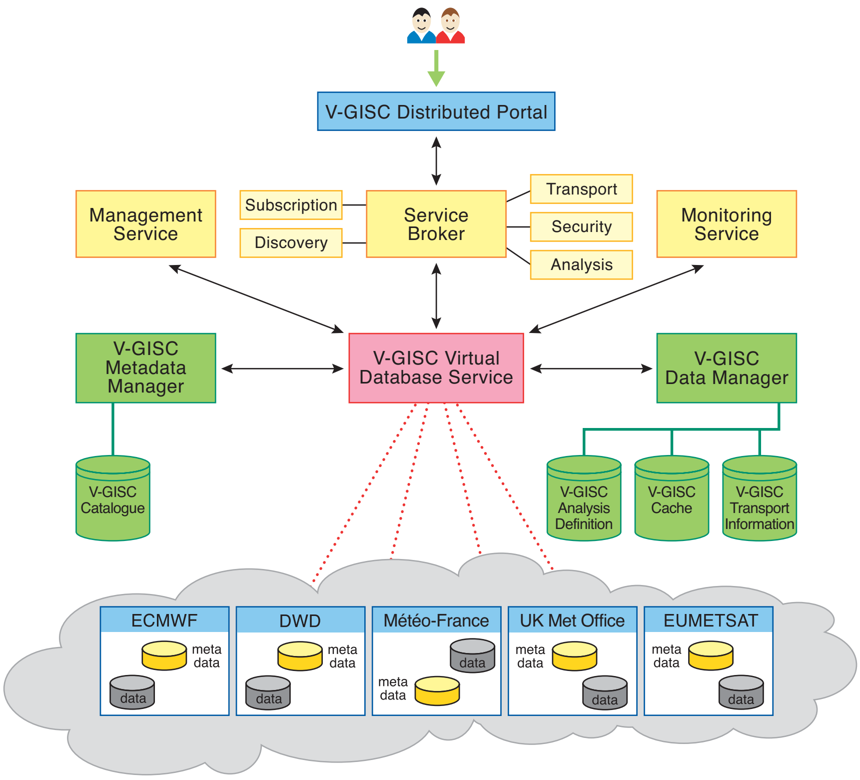


Figure 2 The conceptual view of the Virtual Global Information System Centre (V-GISC).

- **Discovery Service**: provides data searching facilities.
- **Subscription Service**: provides delivery scheduling.
- **Transport Service**: provides data acquisition and delivery mechanisms.
- **Analysis Service**: provides post-processing facilities.
- **Security Service**: verifies user identity and provides authorization credentials (data policy).
- **Management Service**: provides administrator with management facilities.
- **Monitoring Service**: provides operators and users with monitoring facilities.

To validate that the V-GISC can be built on a distributed and loosely coupled Grid architecture a demonstrator is being developed by the partners. The initial list of data to be accessible through the demonstrator was agreed between the partners during the second SIMDAT/V-GISC workshop held at ECMWF in March 2005. These data will be discoverable through the V-GISC catalogue that conforms to WMO Core Metadata Profile. Grid technologies and web services will be used to offer external interfaces to the virtual centre and to federate the partners' legacy data repositories.

International impact

The results of the SIMDAT project should become the foundations for the Virtual Global Information Systems Centre, an innovative service of the centres involved. The software developed within SIMDAT will be made freely available to the WMO community. It is expected that the project will develop standards for the WIS. Meteorological centres from other WMO Regional Associations could then use the outcome of this project to build virtual organisations.

ECMWF Calendar 2005/2006

2005

Sep 5–9	Seminar – Global Earth-System Monitoring
Oct 3–5	Scientific Advisory Committee (*34th Session*)
Oct 5–7	Technical Advisory Committee (*35th Session*)
Oct 10–14	Training Course – Use and Interpretation of ECMWF Products (for WMO Members)
Oct 17–18	Finance Committee (*75th Session*)
Oct 21	Advisory Committee on Data Policy (*7th Session*)
Oct 19–20	Policy Advisory Committee (*22nd Session*)
Oct 26	Advisory Committee of Co-operating States (*11th Session*)
Nov 8–11	Workshop – Bias Estimation and Correction in Data Assimilation (ECMWF/NWP-SAF Workshop)
Nov 14–18	Workshop – Meteorological Operational System (*10th Workshop*)
Dec 6–7	Council (*64th Session*)

2006

Jul 5–6	Council (*65th Session*), Norway
Nov 27–28	Council (*66th Session*)

ECMWF publications

(see http://www.ecmwf.int/publications/library/ecpublications/)

Technical Memoranda

468 **Bormann, N.** & **S.B. Healy**: A fast radiative transfer model for the assimilation of limb radiances from MIPAS: Accounting for horizontal gradients. *15 June 2005*

464 **Janssen, P.A.E.M.** & **M. Onorato**: The shallow water limit of the Zakharov Equation and consequences for (freak) wave prediction. *12 May 2005*

462 **Leutbecher, M.**: On ensemble prediction using singular vectors started from forecasts. *15 April 2005*

461 **Coelho, C.A.S., D.B. Stephenson, M. Balmaseda, F.J. Doblas-Reyes** and **G.J. van Oldenborgh**: Towards an integrated seasonal forecasting system for South America. *22 June 2005*

ERA-40 Project Report Series

23 **Haimberger, L.**: Homogenization of radiosonde temperature time series using ERA-40 analysis feed-back information. *June 2005*

22 **Betts, A.K., J.H. Ball, P. Viterbo, A. Dai** & **J. Marengo**: Hydrometeorology of the Amazon. *February 2005*

Index of past newsletter articles

This is a list of recent articles published in the ECMWF Newsletter series. Articles are arranged in date order within each subject category. Articles can be accessed on the ECMWF public web site

www.ecmwf.int/publications/newsletter/ index.html

Useful names and telephone numbers within ECMWF

Telephone

Telephone number of an individual at the Centre is:

International: +44 118 949 9 + three digit extension
UK: (0118) 949 9 + three digit extension
Internal: 2 + three digit extension

e.g. the Director's number is:
+44 118 949 9001 (international),
(0118) 949 9001 (UK) and 2001 (internal).

E-mail

The e-mail address of an individual at the Centre is:
firstinitial.lastname@ecmwf.int
e.g. the Director's address is: D.Marbouty@ecmwf.int

For double-barrelled names use a hyphen
e.g. J-N.Name-Name@ecmwf.int

Internet web site

ECMWF's public web site is: http://www.ecmwf.int

	Ext
Director	
Dominique Marbouty	001
Deputy Director & Head of Administration Department	
Gerd Schultes	007
Head of Operations Department	
Walter Zwieflhofer	003
Head of Research Department	
Philippe Bougeault	005

Switchboard

ECMWF switchboard	000

Advisory

Internet mail addressed to Advisory@ecmwf.int
Telefax (+44 118 986 9450, marked User Support)

Computer Division

Division Head	
Isabella Weger	050
Computer Operations Section Head	
Sylvia Baylis	301
Networking and Computer Security Section Head	
Matteo Dell'Acqua	356
Servers and Desktops Section Head	
Richard Fisker	355
Systems Software Section Head	
Neil Storer	353
User Support Section Head	
Umberto Modigliani	382
User Support Staff	
John Greenaway	385
Paul Dando	381
Dominique Lucas	386
Carsten Maaß	389
Pam Prior	384

Computer Operations

Call Desk	303
Call Desk email: cdk@ecmwf.int	
Console – Shift Leaders	803
Console fax number +44 118 949 9840	
Console email: newops@ecmwf.int	
Fault reporting – Call Desk	303
Registration – Call Desk	303
Service queries – Call Desk	303
Tape Requests – Tape Librarian	315

Software libraries (eclib, nag, etc.)

John Greenaway	385

	Ext
Meteorological Division	
Division Head	
Horst Böttger	060
Meteorological Applications Section Head	
Alfred Hofstadler	400
Data and Services Section Head	
Baudouin Raoult	404
Graphics Section Head	
Jens Daabeck	375
Meteorological Operations Section Head	
François Lalaurette	420
Meteorological Analysts	
Antonio Garcia Mendez	424
Federico Grazzini	421
Anna Ghelli	425
Claude Gibert (web products)	111
Laura Ferranti (seasonal forecasts)	601
Meteorological Operations Room	426

Data Division

Division Head	
Adrian Simmons	700
Data Assimilation Section Head	
Erik Andersson	627
Satellite Data Section Head	
Jean-Nöel Thépaut	621
Re-Analysis Project (ERA) Head	
Saki Uppala	366

Probabilistic Forecasting & Diagnostics Division

Division Head	
Tim Palmer	600
Seasonal Forecasting Section Head	
David Anderson	706

Model Division

Division Head	
Martin Miller	070
Numerical Aspects Section Head	
Mariano Hortal	147
Physical Aspects Section Head	
Anton Beljaars	035
Ocean Waves Section Head	
Peter Janssen	116

GMES Coordinator

Anthony Hollingsworth	824

Education & Training

Renate Hagedorn	257

ECMWF library & documentation distribution

Els Kooij-Connally	751