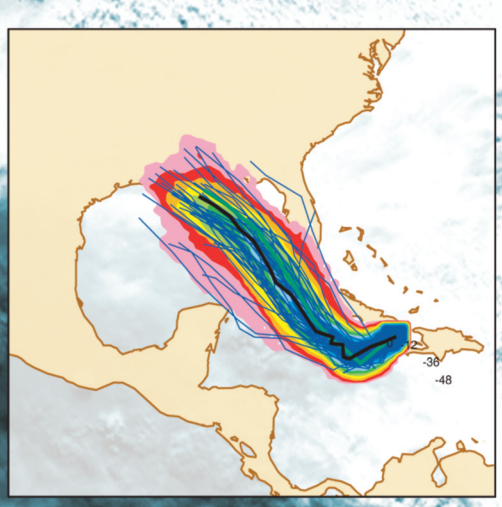
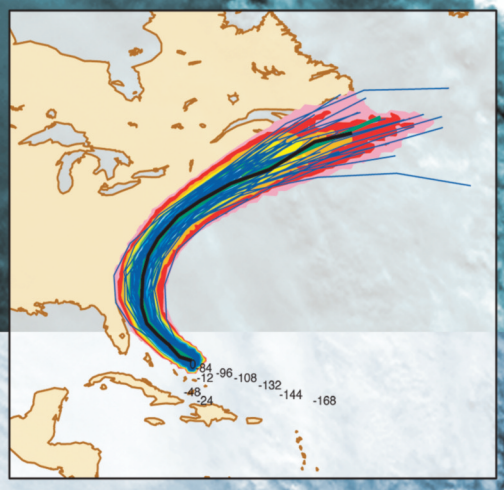
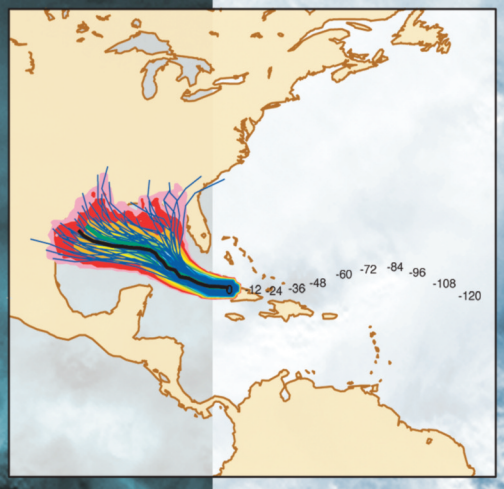
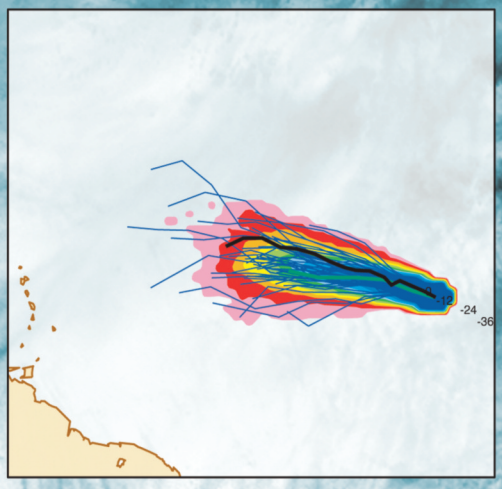
ECMWF









Annual Report 2008

European Centre for Medium-Range Weather Forecasts

Contents

Foreword by the Director

The last year has again seen significant achievements at ECMWF. The research programme has been delivered and this has resulted in improvements in the quality of the forecasts: a strength of ECMWF is the way in which staff involved in research and operational activities work together to bring high quality research through to enhancing operational capabilities.

In 2008, the performance of the forecasting systems remained at a high level throughout the year. Several severe weather events were successfully forecast several days in advance, such as the severe floods affecting Eastern Europe in the summer or major tropical cyclones such as Nargis in the Indian Ocean. For most tropical cyclones a forecast was available several days before they were named. In this context, it is worth mentioning that forecasters at the National Hurricane Center, Miami, highly appreciated the quality of the track forecasts of tropical cyclones produced by our Integrated Forecast System. Indeed, the recent upgrades in resolution and physics of the Centre's forecasting system have led to ECMWF medium-range forecasts outperforming the best multi-model consensus.

The establishment of a unified forecasting system to replace the Variable Resolution Ensemble Prediction System (VarEPS) and the Monthly Forecasting System has been an achievement requiring several years of development. This allows the Ensemble Prediction System (EPS) to provide consistent forecasts across different time ranges up to 32 days ahead and brings the coupling with the ocean early in the forecast.

The Centre's reanalysis data offer a major contribution to climate change studies. Recent work on homogenization of the observations and detailed comparisons between satellite instruments is still increasing the credibility of climate trends deduced from reanalyses. Such work will be further developed in the coming years, thanks to the continuous improvement of the assimilation techniques, in particular those associated with atmospheric chemistry, oceans and continental surfaces and to the reprocessing of past data undertaken by data providers, especially space agencies. In addition, ERA-Interim, the global atmospheric reanalysis currently in production at ECMWF, will reach real time during the first quarter of 2009. After that time it will continue to be maintained as a climate-monitoring tool with monthly updates to the product archive and data server.

The existing High Performance Computing Facility (HPCF), one of the most powerful in Europe, continues to provide a very good service to users. However, for ECMWF to retain its leadership in the world of weather forecasting, it is necessary to enhance the HPCF.

Consequently in December 2007 the Council gave its approval for ECMWF to enter into a contract with IBM UK Ltd for provision of a replacement HPCF. During 2008 preparations have been made for the installation of the new supercomputer. When fully commissioned, the HPCF will provide the computational performance needed to implement ECMWF's scientific and operational strategy.

Another important contribution is emerging with the concept of seamless systems unifying weather and climate predictions. There are important synergies between numerical weather prediction (NWP) and climate prediction. This contribution is fully recognised and ECMWF was requested by the World Climate Research Programme (WCRP) and the World Weather Research Programme (WWRP) to host their "World Modelling Summit for Climate Prediction" which aimed at identifying and developing such synergies.

A large number of workshops were convened at ECMWF during 2008 on very different subjects, such as 'Applications of GPS radio occultation measurements' (30 participants), 'Use of High Performance Computing in Meteorology' (more than 100 participants), 'Atmosphere-Ocean Interaction' (39 participants) and 'Use of GIS/OGC standards in meteorology' (over 100 participants). These events are of great value in helping shape the research and development activities at ECMWF as well as influencing development within the European meteorological community. Also ECMWF contributes to the development of meteorological expertise within Europe by running a variety of training courses.

The high-level expertise of staff at ECMWF is used for research and development aimed directly at enhancing the quality of forecasts, the range of products and operational efficiency.

The high-level expertise of staff at ECMWF is used for research and development aimed directly at enhancing the quality of forecasts, the range of products and operational efficiency. That same expertise is used to participate in a number of collaborative research programmes run by the European Union and WMO. The outcome of the programmes helps improve global forecasting, develop new technologies and improve atmospheric monitoring. This is particularly the case for ECMWF's contribution to the GMES Atmosphere Services.

At its 70th session in December 2008, the Council unanimously adopted a long-term solution to fund the Budgetised Pension Scheme by having a stepped increase in the funding. This was a momentous decision for ECMWF, since discussions to find a sustainable solution acceptable to all Member States had gone on for many years.

In April 2005 the Council unanimously agreed to amend the ECMWF Convention. By the end of 2008, 13 Member States had notified acceptance of the amendments to the Convention. At its meeting in December, the Council authorised the start of negotiations with a view to increasing the number of States that have full membership of ECMWF. This expansion will help ECMWF continue as a world leader and provide enhanced support for the development of meteorological capability within Europe.

The last year has been very successful and the foundations have been laid to build upon the past achievements of ECMWF in the coming years. As in the past, the success of ECMWF will continue to be based on the quality of the staff and the fruitful relationship between ECMWF and its Member States.

Dominique Marbouty
Director, ECMWF

ECMWF – leading the world in weather forecasting

ECMWF has a worldwide reputation for providing the most accurate medium-range global weather forecasts. It also provides monthly forecasts to one month ahead and seasonal forecasts to seven months ahead. High-quality products based on ECMWF forecasts are used by the National Meteorological Services of Member States and Co-operating States to fulfil their own national duties, particularly to give early warning of potentially damaging severe weather.

Over the past three decades ECMWF's activities and wide-ranging programme of research and development have played a pioneering role in the remarkable advancement of weather forecasting and data assimilation systems. ECMWF has dramatically improved the accuracy and reliability of weather forecasting, working in collaboration with Member and Co-operating States, the European Union and partners such as the World Meteorological Organization (WMO), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the European Space Agency (ESA).

Forecasts improved steadily from 1980 as a result of improvements in the global observing system, more powerful computers, and advances in the science of the ECMWF data assimilation system and forecast model. Seven-day forecasts in the northern hemisphere became more accurate than the five-day forecasts of 1980, and five-day forecast accuracy reached that of the three-day forecasts made 25 years earlier.

In the southern hemisphere, the improvement was even more marked. In the early 1980s, because of the lack of observations, the three- and five-day predictions for the southern hemisphere were not much better than those of the northern hemisphere for five and seven days respectively. Two decades later, forecasts for both hemispheres were of similar accuracy – a gain of about four days in the accuracy of southern hemisphere predictions, mainly thanks to the use of satellite data.

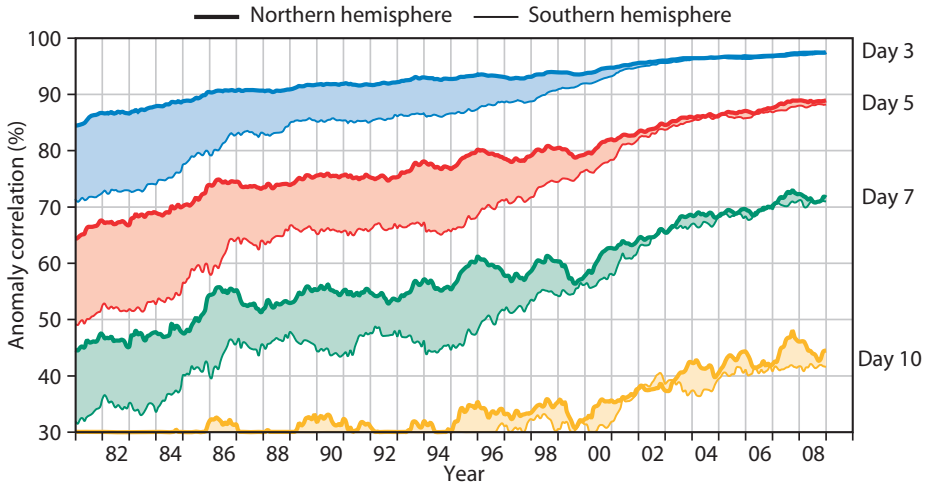
The performance of the forecasting system remained at a high level throughout this year. Following the very high level reached in 2007, good scores were maintained in 2008 in particular over Europe. As found in previous years, an important feature is the improvement for the lower scores – the enhanced quality of our forecasts relies primarily on the reduction of 'bad' forecasts.

There is a regular exchange of scores between WMO designated Global Data-Processing and Forecasting System (GDPFS) centres under the auspices of the WMO Commission for Basic Systems (CBS) using agreed standards for verification. In 2008 all centres performed well in terms of northern hemisphere forecasts of 500 hPa height, but ECMWF maintained its lead over other global forecasting centres.

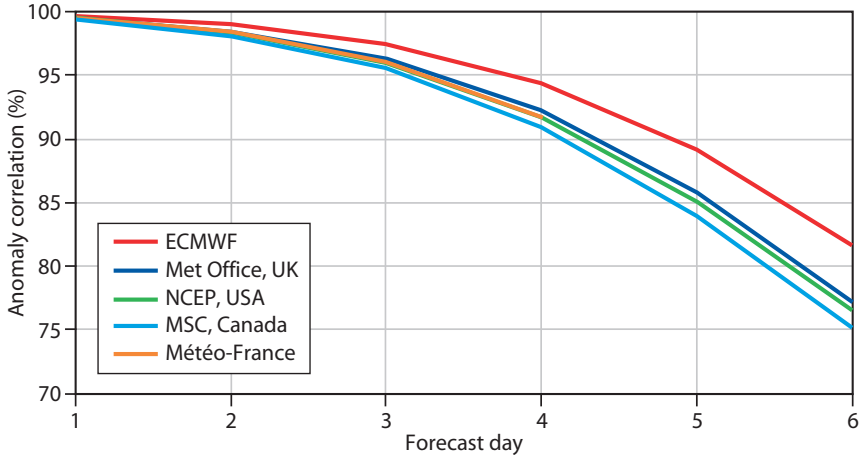
The WMO/CBS exchange of scores includes verifications against soundings from radiosondes over regions such as Europe. Assessment of various parameters (e.g. 500 hPa height errors and 850 hPa wind errors) confirms the good performance of ECMWF forecasts compared to the other centres.

As well as leading the world in weather forecasting, ECMWF's forecast products are used by scientists and researchers around the world to monitor the environment and analyse climate change.

In October 2008 the ECMWF Technical Advisory Committee "congratulated ECMWF on the very high performance levels of all its forecast systems, resulting in ECMWF maintaining its world leading position".



Improvement in the accuracy of ECMWF forecasts. *The increase in the verification scores for the northern and southern hemispheres shows that the ECMWF forecasts have steadily improved with time, with the accuracy of the forecasts for the northern and southern hemispheres now being similar. The shaded area shows the differences in forecast accuracy between the hemispheres. The score used is the anomaly correlation of forecasts of 500 hPa height.*



Comparison of the performance of various global forecasting centres during 2008. *The verification scores from five global forecasting centres show that ECMWF maintained its lead over the other centres in 2008. The score used is the annual anomaly correlation coefficient for the operational forecasts of 500 hPa height for Europe.*

Key events of the year

14–15 January
An 'SRNWP (Short-Range Numerical Weather Prediction) Interoperability Workshop', organised by the Met Office, was hosted at ECMWF.

29 January
A revised production schedule was introduced with the result that products have become available from 10 to 15 minutes earlier than before, depending on the type of product. This change was driven by requests from Member States to make certain products available earlier and so improve the usability of ECMWF products in their forecasting offices.

6–7 March
The 18th session of the Council of the European Meteorological Society (EMS) was hosted at ECMWF. Dr David Burridge, EMS President and former ECMWF Director, chaired the meeting.

11 March
The Monthly Forecasting System was integrated with the medium-range Variable Resolution Ensemble Prediction System (VarEPS). This was an important step towards the implementation of a unified forecasting system.

4 April
The first meeting of the 'Meteoalarm Impact Damage Index Working Group' was held at ECMWF. Its aim was to initiate the development of new warnings to extend the current Meteoalarm system.

10 April
ERA-Interim reanalysis products for the years 1989–1998 were made available for research and education with a latitude/longitude resolution of 1.5°. Both the ECMWF archive and the public ECMWF Data Server contain daily and monthly products from ERA-Interim for the 17-year period 1989–2005.

15 April
A range of marine forecast products to support severe weather marine forecasting was made available to WMO Members.

24–25 April
A delegation from the Chinese Meteorological Administration (CMA), led by Dr Jiao, Director General of the National Meteorological Centre and Director General of the Department of Forecasting Services and Disaster Mitigation, visited ECMWF.

30 April
The co-operation agreement between the Republic of Latvia and ECMWF entered into force, when ECMWF received the written notice that the Republic of Latvia had completed its internal procedures. The agreement was signed in Reading on 18 January 2008.

6–9 May
The 'World Modelling Summit for Climate Prediction' was hosted by ECMWF. One of the main themes discussed was how lessons learned in weather prediction can benefit climate prediction in areas such as science, computing and co-operation.

28 May
GPS radio occultation data from the GNSS Receiver for Atmospheric Sounding (GRAS) instrument onboard EUMETSAT's MetOp satellite was actively assimilated at ECMWF.

3 June
Cycle 33r1 of the ECMWF Integrated Forecast System (IFS) was implemented with important changes to the wave model, some retuning of the representation of physical processes and improved use of satellite data.

5 June
The Director gave a presentation about ECMWF's role in the European Meteorological Infrastructure to Members of the German Parliament in Berlin.

9–10 June
For the first time, a representative from the European Commission addressed a Council session. Dr Paul Weissenberg (Director for Aerospace, Security, Defence and Equipment) emphasised that the Commission regards ECMWF as an asset in the context of 'Global Monitoring for Environment and Security' (GMES).

9–10 June


16–17 September


25 November

16–18 June
A joint ECMWF/EUMETSAT GRAS-SAF workshop on the 'Applications of GPS Radio Occultation Measurements' was held at ECMWF.

23–24 June
A meeting of the EC-Earth consortium was hosted at ECMWF. The participants discussed their first results using the IFS model (Cycle 31r1) and the NEMO ocean model for the type of climate simulations and decadal predictability studies carried out under the auspices of the Intergovernmental Panel on Climate Change (IPCC).

1–4 September
The topic of the ECMWF Annual Seminar was 'Parametrization of Subgrid Physical Processes', with emphasis being placed on the interaction of parametrized processes with the resolved dynamics.

9 September
ECMWF started to receive and monitor altimeter wind and wave data from the Jason-2 satellite.

16–17 September
France, as part of its Presidency of the European Union, and the European Commission jointly held a Forum in Lille, France, to mark the launch of the first services as part of the GMES initiative. The presentation about atmospheric environmental services was given by Adrian Simmons, Coordinator for GMES Activities at ECMWF.

30 September
Cycle 35r1 of the ECMWF IFS was introduced with several changes to the representation of physical processes, such as improvements to the handling of melting snow and a new sea surface temperature analysis product.

3–7 November
The 13th Workshop on 'High Performance Computing in Meteorology' was attended by participants from meteorological services, research institutions and computer vendors.

10–12 November
The Workshop on 'Atmosphere-Ocean Interaction' addressed the requirements for ocean-atmosphere coupling from the very short time scales to the monthly time range with focus on ocean near-surface processes.

24–26 November
Météo-France, UK Met Office and ECMWF jointly organised a workshop at ECMWF on the 'Use of GIS/OGC Standards in Meteorology'. This workshop reviewed standards used in meteorology and considered ways of enhancing interoperability. Participants from various disciplines and organisations worldwide attended with representatives from commercial and public services.

25 November
His Excellency Georg Boomgaarden, German Ambassador in London, visited ECMWF. He commented: "I would like to encourage the Director and the staff to continue the excellent services ECMWF provides to the Member and Co-operating States, but also to continue its contribution to climate monitoring".

2–3 December
The ECMWF Council at its 70th session made some major decisions, such as unanimously adopting the 'Four-Year Programme of Activities' for the period 2009–2012 and agreeing an increase of Member States' contributions to the budget 2009 by 19.28% over the budget 2008. The budget increase is needed to cover, in particular, the cost of the new High Performance Computer Facility, increases in electricity prices and increasing pension liabilities. The Council also decided on a long-term solution to the funding problem in the Budgetised Pension Scheme.

22 December
Member States' usage of the ECMWF High Performance Computer Facility resources reached a new milestone with 100 million units being exceeded in 2008. The previous milestone (over 10 million units) occurred in the fourth quarter of 2004.

Evolution of the forecasting system

The wide-ranging programme of research and development at ECMWF continues to play a pivotal role in the remarkable advancement of weather forecast skill and the use of the rapidly developing satellite and in situ observations of the atmosphere. As well as upgrades to the forecasting system that enhance the atmospheric and marine forecasts, progress has been made in implementing a unified forecasting system that replaces the Variable Resolution Ensemble Prediction System (VarEPS) and the Monthly Forecasting System.

Operational prediction system

The ECMWF forecasting system produces a wide range of global atmospheric and marine forecasts.

- Deterministic forecasts of the atmosphere and ocean waves to 10 days ahead, twice per day.
- Probabilistic forecasts of the atmosphere and ocean waves to 15 days ahead, twice per day.
- Monthly probabilistic forecasts of the atmosphere and ocean waves to 32 days ahead, once per week.
- Seasonal probabilistic forecasts of the atmosphere and ocean waves to 7 months ahead, once per month, with an extension to 13 months ahead every 3 months.

Initial conditions for these forecasts come from two separate data assimilation systems:

- An atmospheric data assimilation system employing four-dimensional variational analysis (4D-Var).
- An ocean data assimilation system based on the optimum interpolation (OI) technique.

There are additional atmospheric data assimilations run to initiate forecasts for the optional project entitled 'Boundary Conditions for Limited-Area Modelling'. These forecasts are used by some Member States and Co-operating States to run their own limited-area models.

Upgrades to the forecasting system in 2008

The ECMWF forecasting system is regularly upgraded to enhance the global atmospheric and marine forecasts provided to Member States. Particular emphasis is put on providing an increasing capability for early warnings of severe weather. Before an upgrade is implemented it is tested in research mode and then in a pre-operational trial.

A Monthly Forecasting System, based on the use of ensembles, has been operational at ECMWF since October 2004. This system was run separately from the medium-range Ensemble Prediction System (EPS) which became the Variable Resolution Ensemble Prediction System (VarEPS) on 28 November 2006. On 11 March 2008 a unified system became operational. The new combined system merged VarEPS with the Monthly Forecasting System. This was an important step towards the implementation of a unified forecasting system.

Two new IFS cycles have been implemented.

- *Cycle 33r1, 3 June 2008*. This cycle included important changes to the wave model, some retuning of the representation of physical processes and improved use of satellite data. Evaluation of deterministic forecasts showed a modest but significant positive impact on northern hemisphere and European scores in the troposphere. Similar results were obtained for three weeks of EPS testing.
- *Cycle 35r1, 30 September 2008*. This cycle included several changes to the representation of physical processes, and the use of higher-resolution sea surface temperature and sea ice analyses. The new cycle shows essentially neutral scores for the extratropics, and improved scores for upper-tropospheric winds in the tropics. There is some improvement in both hemispheres for the late medium range.

IFS Cycle 33r1

This cycle had the following elements:

- Improved moist physics in tangent linear and adjoint models used in 4D-Var
- Retuned entrainment and bug fix to scaling in the freezing term in the convection scheme
- Included subgrid shear representation in the diffusion scheme
- Increased turbulent orographic form drag
- Improved soil temperature analysis in areas with 100% snow cover
- Introduced change in surface roughness for momentum and processing of 2-metre temperature and specific humidity
- Assimilated rain-affected radiances from the AMSR-E and TMI satellite instruments
- Used all four wind solutions in the assimilation of data from the QuikSCAT satellite
- Extended coverage and increased resolution for the limited-area wave model
- Improved representation of shallow water physical processes and modified advection scheme for ocean wave models
- Introduced two new wave model output quantities (maximum wave height and corresponding wave period)

IFS Cycle 35r1

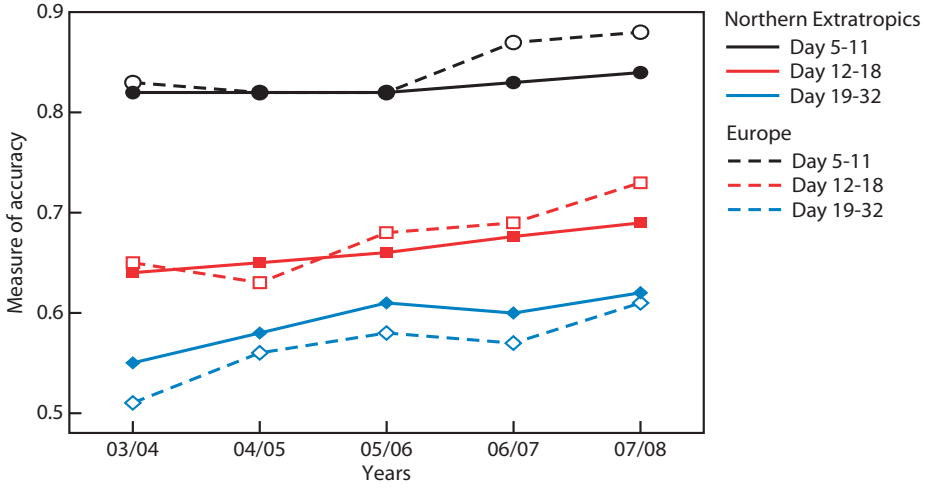
This cycle had the following elements:

- Made a correction for excessive snowfall in warm temperature conditions
- Introduced a simple representation of the diurnal cycle of the ocean surface temperature
- Modified albedo under permanent snow conditions (Greenland and Antarctica)
- Enhanced bias correction for AIRS/HIRS shortwave satellite channels
- Improved trajectory interpolation in 4D-Var
- Implemented a new version of the RTTOV radiative transfer package, RTTOV-9
- Used high-resolution sea surface temperatures from the Met Office
- Used sea ice analysis from the EUMETSAT Ocean and Sea Ice Satellite Application Facility
- Included convective contribution to wind gusts in post-processing

Ensemble Prediction System (EPS)

Forecasts from NWP models depend sensitively on the initial conditions. Also the models cannot fully represent all the complex atmospheric processes. The EPS aims at quantifying the uncertainty in the forecasts by providing forecasters with a range of possible future scenarios that can be used to estimate the probability of specific weather events occurring during the forecast period. It has been a key element of ECMWF's operational forecasting system since 1992, and has been upgraded several times.

The performance of the medium-range EPS remained consistently good during 2008 and its lead over other systems has been maintained.



Evolution of the monthly forecast scores. *The score used to measure the accuracy of the monthly forecasts shows that there has been a consistent improvement over the last five years. The yearly periods are from June to May of the following year. The accuracy is based on the area under the Relative Operating Characteristic (ROC) of the probability that the 2-metre temperature anomalies are in the upper tercile.*

Monthly forecasts

The EPS uses a coupled ocean-atmosphere model for the forecast range day 10 to 15 for the forecast starting from the 00 UTC analysis, on a daily basis. As an extension of the 15-day EPS forecast, the monthly forecast is now run once per week from 00 UTC on a Thursday. This means that the monthly forecasts benefit from the increased horizontal resolution of the atmospheric model.

The EPS now provides output uniformly up to 32 days ahead. Consequently, forecasting products can be provided across the different time ranges. For example, some probabilistic products, such as the Extreme Forecast Index (EFI), can be applied to the monthly range. In addition, users of monthly forecasts will have access to more skilful predictions.

The performance of the monthly forecasts during 2008 has been particularly good and generally better than in previous years. There has been a consistent improvement in the scores of the monthly forecast since 2004: the forecasts for the days 19–32 are now almost as skilful as the forecasts for days 12–18 about 5 years ago.

With the unified system the scores outside the tropics (i.e. in the extratropics) for the monthly forecasts are overall higher at all time ranges. In particular, the prediction of extreme events seems to benefit from the higher horizontal resolution of the atmospheric model. Furthermore, the new merged system is capable of providing useful warnings of extreme weather events beyond day 15.

The unified system has allowed the development of a forecast calibration system across the range of forecast time scales.

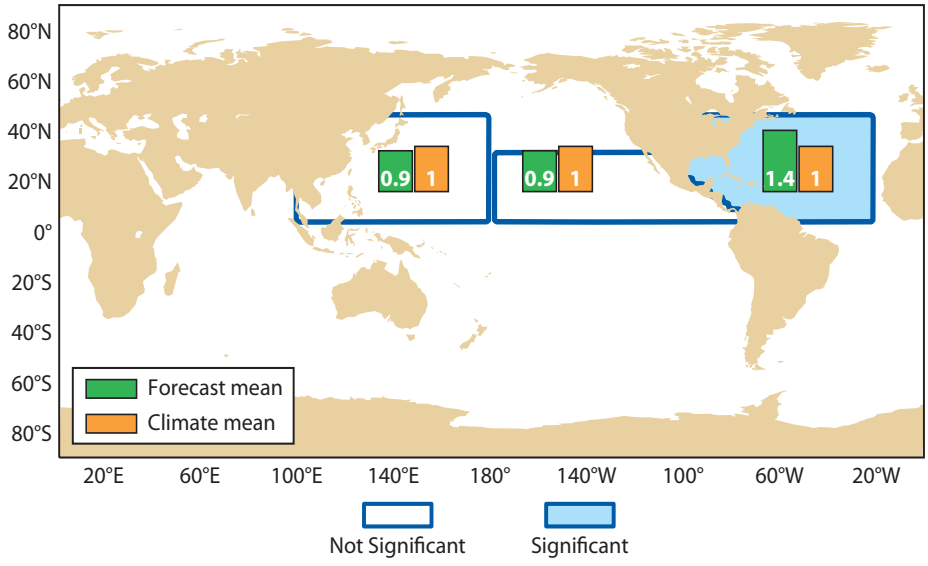
Seasonal forecasts

Seasonal forecasts can be of great benefit to decision makers in a variety of economic sectors, particularly for the management of agricultural production and water resources.

ECMWF has been running a seasonal forecast system since 1997. The most recent system (System 3) became operational in March 2007 and consists of the following.

- Atmospheric and oceanic components of the coupled model.
- Data assimilation software to create initial conditions for the ocean.
- Coupling interface linking the two components.
- Strategy for ensemble generation and the reforecasts used for calibration (correction of the systematic errors).

The set of products provided on the ECMWF website is constantly expanding. Since March 2008 several estimates of seasonal forecast skill during the past 25 years are available on the web. Also two additional tropical storms products (hurricane/typhoon frequency and Accumulated Cyclone Energy) have been made available in order to indicate the probability of occurrence of very intensive storms and their duration. These successfully predicted the active 2008 Atlantic hurricane season.



Seasonal forecast of tropical cyclone activity. *A forecast for the six-month period July-December 2008 provided a good indication of the above-normal cyclone activity that occurred in the North Atlantic. Forecasts for the east and west North Pacific indicated below-normal activity. The charts show the predicted Accumulated Cyclone Energy (ACE) for the six-month period July–December 2008 from the forecast starting in June 2008. The ACE for the North Atlantic was forecast to be 1.4 times the climatological mean and the enhancement over climatology was statistically significant.*

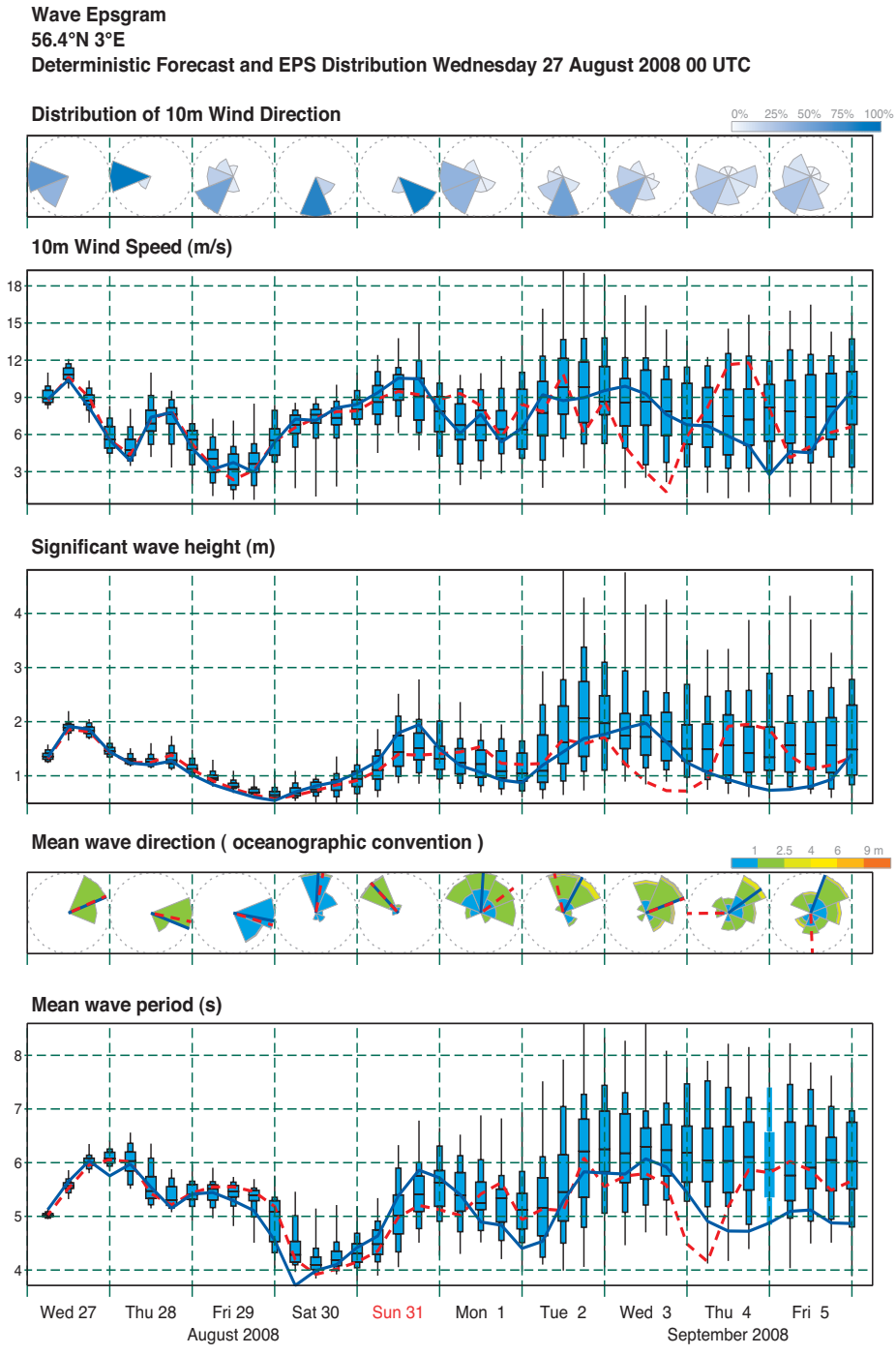
Work continued on the implementation of a new ocean model, NEMO, for ECMWF activities associated with ocean analysis and coupled long-range forecasts. During 2008, efforts were concentrated on developing the first prototype of the coupled atmosphere-ocean system. Also there has been the initial development of a variational data assimilation system for NEMO (NEMOVAR).

ECMWF is engaged in the development of a multi-model seasonal forecast system known as EUROSIP (European Seasonal to Interannual Prediction System). In addition, work to assess the skill of the multi-model ensembles is being undertaken in the EU-funded ENSEMBLES project.

Ocean wave forecasting

The ocean wave model continued to perform extremely well. Following the decision of the Council at its 68th session (December 2007), a range of wave products was made available to WMO Members on the ECMWF website. Forecasts of significant wave height and mean wave direction and period are provided to seven days from the ECMWF deterministic forecast system. In addition, probabilities of significant wave height exceeding 2, 4, 6, and 8 metres to six days are available from the ECMWF EPS.

The spatial resolution of the European shelf model was increased from 25 km to 10 km, while a more realistic version of the freak wave warning system was introduced. In addition, wave model changes included an improved version of shallow water physical processes and a modified advection scheme.



Ten-day wave EPSgram. *A new EPSgram for ocean waves was introduced into operations in March 2008 and this includes additional information that can be used for the provision of services. The EPSgram shown here is for a gridpoint in the North Sea for the forecast starting at 00 UTC on 27 August 2008. The plot shows values of 10-metre wind direction and speed, significant wave height, mean wave direction and mean wave period.*

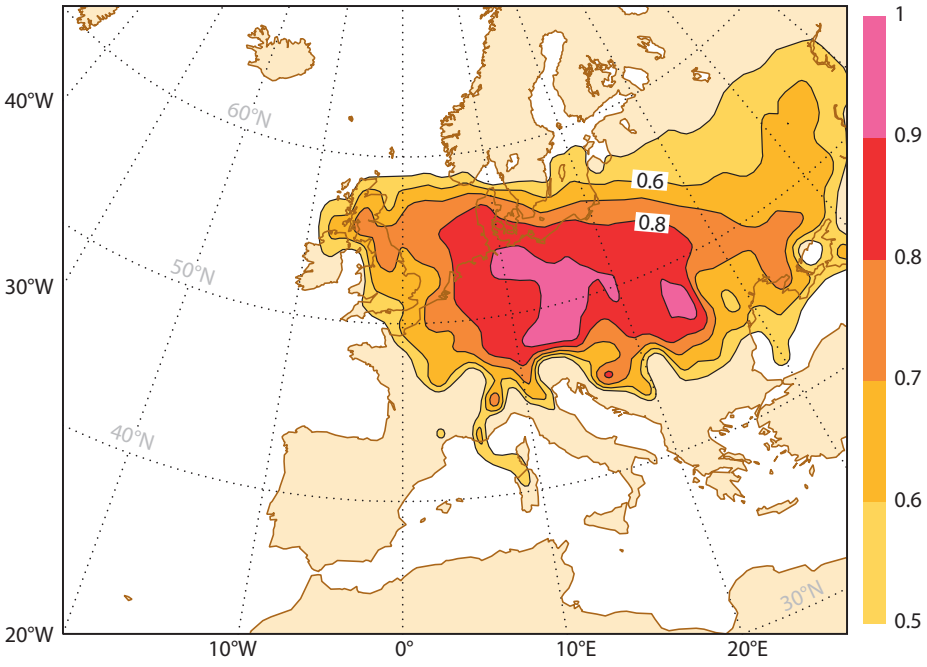
Early warning of severe weather

The ECMWF strategy puts the early warning of severe weather as one of its principal goals. This is particularly important as severe weather is predicted to become more frequent and more intense in some parts of the world under climate change. ECMWF can contribute to the development of strategies to mitigate and adapt to climate change. In particular, ECMWF's emphasis on the provision of reliable predictions of severe weather can be seen as a key contribution to help society adapt to the dangers and threats associated with global warming.

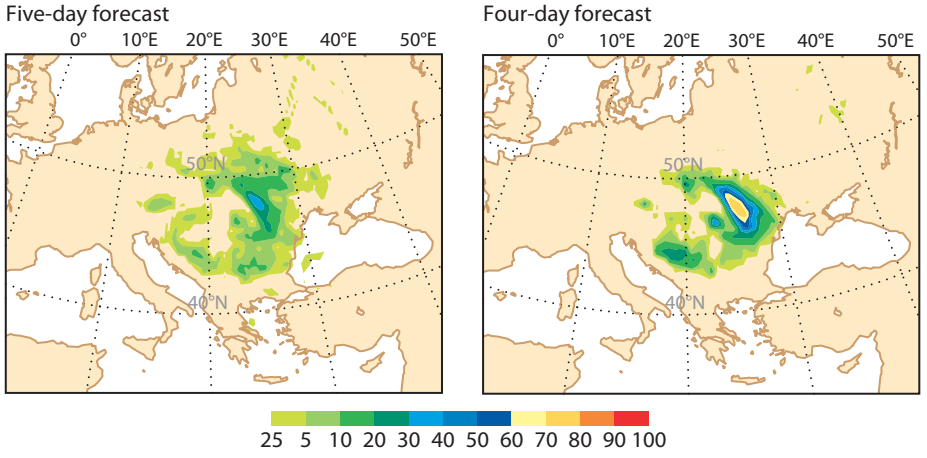
Some recent research developments are of particular importance for improving the forecasting system for high impact weather. They include the development of the Ensemble Data Assimilation (EnDA), the use of a new norm (Huber norm) for observation quality control, and recent results concerning the ability of the system to better represent blocking events.

In 2008 there were several occasions in which use of the EFI provided an early warning of severe weather. These included:

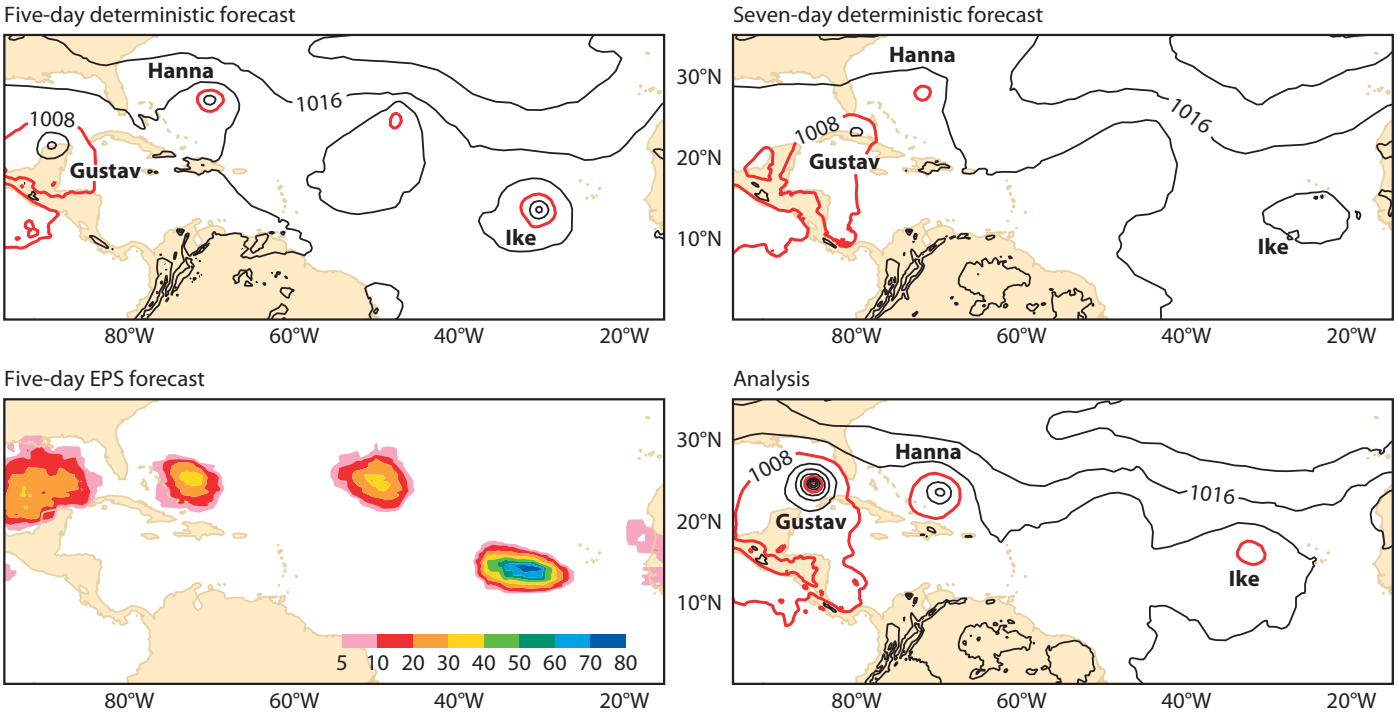
- *Winter storm Emma, 1 March 2008.* Several winter storms hit Europe in the first months of 2008. These were generally well forecast, both in the deterministic and EPS forecasts. For example, Emma caused widespread wind damage across central Europe.
- *Central and eastern European floods in July 2008.* By the end of July, heavy rain in the Carpathian Mountains triggered severe flooding in Ukraine, Moldova, Romania, Hungary and Slovakia. The ECMWF forecasting system has



Winter storm Emma, 1 March 2008. *Storm Emma killed 15 people and caused widespread damage across central Europe at the beginning of March. The EFI gave a strong warning of extreme wind gusts five days ahead. The higher values of the EFI indicate more extreme events. The signal remained consistent in the forecasts from the following days. The forecast shown was run from 12 UTC on 25 February.*



Central and eastern European floods in July 2008. *By the end of July, heavy rain in the Carpathian Mountains triggered severe flooding in Ukraine, Moldova, Romania, Hungary and Slovakia, causing serious damage: 36 people died and more than 35,000 were evacuated. The EPS provided a clear early signal for heavy rainfall. The charts show the probability forecasts from the EPS for more than 50 mm in the two-day period 24–26 July. Forecasts from 19 July (five days before event) already show up to 40% probability for heavy rainfall (left). The signal is much stronger (over 70%) in the forecast from 20 July (right).*



Forecasts for the 2008 Atlantic hurricane season when three hurricanes (Gustav, Hanna and Ike) were active at the same time. *The deterministic and EPS forecasts show that the increased hurricane activity was well captured even before the storms were officially reported. Top panels show the 5-day and 7-day deterministic forecasts of mean sea-level pressure verifying at 12 UTC on 31 August. These forecasts started before hurricanes Hanna and Ike had been officially observed. The lower-left panel shows the EPS probability for tropical cyclones to be in the region in the 24-hour period between 12 UTC on 31 August and 12 UTC on 1 September. The lower-right panel shows the verifying ECMWF analysis for 12 UTC on 31 August.*

confirmed its ability to provide early warning for severe weather events. This was particularly the case for the tropical cyclones in the Atlantic, throughout an active hurricane season. The verifications, which are now run systematically for various tropical cyclone parameters, showed significant improvement. The forecasting system also demonstrated its ability to develop tropical cyclones long before they are officially observed.

Tropical cyclone forecasts were particularly good in the 2008 season. This is a consequence of increased resolution and better representation of physical processes. The ability of the ECMWF forecasts to predict the level of hurricane activity is illustrated by the quality of the forecasts during an intensive period of the Atlantic hurricane season when three hurricanes (Gustav, Hanna and Ike) were active at the same time. This increased activity was well captured in the forecasts. On average in this period, the genesis of tropical cyclones was predicted by the model five to seven days before they were observed as tropical cyclones.

The National Hurricane Center (Miami, Florida) reports that ECMWF's predictive skill of tropical cyclone tracks has improved significantly in recent years. The most striking result is that in 2008, for the first time, ECMWF outperformed the best multi-model consensus forecast by 20% globally in the medium range (72 hours).

Tropical storm	Date first observed as tropical cyclone	Genesis first predicted in forecast from
Fay	16 August 2008	10 August (6 days before)
Gustav	25 August 2008	20 August (5 days before)
Hanna	28 August 2008	23 August (5 days before)
Ike	2 September 2008	26 August (7 days before)
Josephine	3 September 2008	29 August (5 days before)

Genesis of Atlantic tropical storms in the active period of the 2008 hurricane season.

Verification of early warning of severe weather

The ECMWF Strategy 2006–2015 puts an emphasis on early warning of severe weather and the need to develop appropriate verification. The strategy has set overall performance targets in terms of a set of headline scores (e.g. 500 hPa geopotential height for the deterministic model and 850 hPa temperature for the EPS). There is a need, however, to extend the set of headline scores that are used for long-term assessment of the performance of the ECMWF forecasting systems to include measures appropriate for severe weather. These should be based on the most important surface weather parameters and the products developed specifically to provide guidance for early warnings of severe weather, such as the EFI. During 2008 ECMWF began focusing on developing the verification of severe weather forecasts.

ECMWF's EFI was developed as a tool to identify where the EPS forecast distribution differs substantially from that of the model climate. It is an integral measure referenced to the model climate that contains all the information regarding variability of weather parameters, in location and time. Thus users can recognise the abnormality of a weather situation without having to define specific space- and time-dependent thresholds.

The EFI is widely used in Member States to provide guidance to forecasters on the possible occurrence of extreme weather events. A verification procedure has been introduced to monitor the performance of the EFI. Results show that the EFI has substantial skill to provide early warnings of extreme events, confirming the subjective experience of forecasters. Routine verification will continue to monitor the trends in EFI performance.

The verification specifically for extreme weather events causes particular problems. Sample sizes are inevitably small, the time and spatial scales of the verifying observations are limited, and standard scores used for more moderate events may not be appropriate. To address this issue, ECMWF held a meeting with experts from Member States. There is at present no clear solution for severe weather verification. However, a number of possible approaches were discussed. These included the use of new scores specifically developed for rare events. However, it was noted that current verification scores for moderate events can give useful guidance on the expected performance for more extreme situations.

Following the meeting of experts, the ECMWF Technical Advisory Committee (TAC) decided to establish a subgroup to investigate and provide recommendations on verification measures appropriate for monitoring ECMWF's progress in medium-range weather forecasting, with a particular emphasis on the progress in providing early warnings of severe weather.

Recommendations about the verification of severe weather

To discuss the verification of severe weather ECMWF held a meeting with experts from Member States on 9 and 10 September 2008. Although at present there is no clear solution for severe weather verification, a number of possible approaches were discussed.

It was noted that current verification scores for moderate events (such as are reported by ECMWF for precipitation) can give useful guidance on the expected performance for more extreme situations. Recently, new scores have been developed specifically for verification of rare events. However, there is a general lack of observations at sufficient resolution in time and space for verification of severe weather. The expert team emphasised that it is essential to have such verification data and that for operational performance monitoring these need to be available in near-real-time. There are institutional and national datasets of high-resolution observations that would be very valuable for severe weather detection and verification.

The expert team recommended that:

- Homogeneous Europe-wide datasets are created based on institutional/national observational data (e.g. from surface stations and radars), and that these datasets are made available in near-real-time for the purposes of verification, particularly of heavy precipitation and strong winds. This is non-trivial and so significant work is involved as data formats, quality control and reporting practices differ.
- The Extreme Dependency Score (EDS) is explored for the purpose of extreme weather verification, together with feature-based verification and tracking of extratropical cyclone features.
- Estimates of uncertainty are provided for scores (whenever possible).
- Funding of verification research is promoted.

A number of areas for collaboration between ECMWF and the Member States were identified, including:

- Observation data exchange.
- Comparison of results between centres.
- Development of common scores for operational verification.
- Definition of standard sets of severe weather test cases for Europe.

Use of ECMWF products during the German Antarctic expedition ANT XXIV/3

(Based on an original contribution from Deutscher Wetterdienst (DWD))

In 1981, to satisfy the conditions of accession to the Antarctic Treaty, a year-round German Antarctic research station was established on the Ekstroem Ice Shelf as a research observatory for geophysical, meteorological and atmospheric chemistry measurements, as well as a logistics base for summer expeditions.

During supply and research expeditions, the technician and meteorologist onboard the German polar research vessel Polarstern provide the crew and expedition leaders with observations and meteorological advice. The ECMWF forecasts are a key source of information.

Polarstern undertook its 24th Antarctic expedition from 10 February to 16 April 2008, navigating from Cape Town to Punta Arenas via the German Antarctic station Neumayer. It was a voyage that included going through the subtropical belt of high pressure, the south Atlantic westerly winds, and the Antarctic circulation. One of the goals was to achieve a better understanding of how the Atlantic sector of the Southern Ocean affects large-scale climatic conditions as part of the International Polar Year 2007/2008 (IPY).

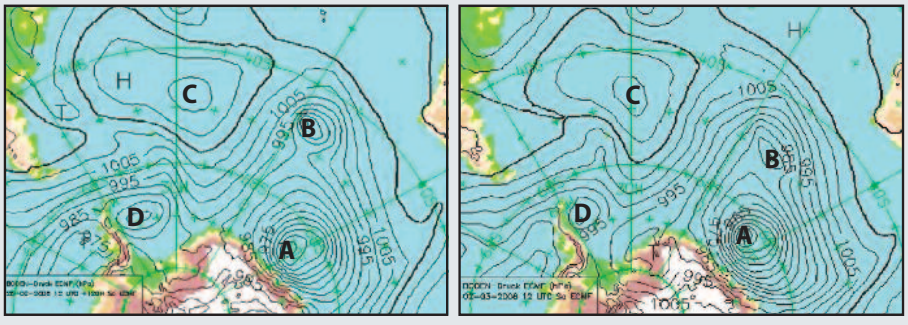
The quality of the ECMWF model was not only convincing for short-range forecasts, but also for the medium range. While the position and intensity of the pressure centres were very well forecast on the synoptic scale, deviations were noted on the smaller scale. At this scale, satellite images had to be analysed continuously in order to manually create surface pressure analyses and observations from onboard upper-air soundings had to be processed. Nonetheless, the ECMWF forecasts often proved extremely useful in that they depicted a useable trend.

Verification using the measured and observed 12 UTC conditions for wind vector, wind sea and swell resulted in almost bias-free forecasts up to day 4. The absolute error at day 4 was 3.5 ms^{-1} for wind speed, 0.5 metres for wind sea, and 0.6 metres for swell. This is a remarkably good result.

EPSgrams provided by ECMWF were used to schedule urgent flights in the narrow window of time permitted by the weather conditions to fly out the injured victims of a serious accident. The forecasts were on the whole correct and provided valuable advice.

This expedition also made use of products from the DWD global forecasting model (GME) coupled to the ocean wave model. The satellite Internet connection also enabled results from the US-American high-resolution Antarctic Mesoscale Prediction System (AMPS) to be accessed directly.

The Antarctic ice sheet. *Polarstern loading at the edge of the Atka Bay Ice Shelf. Photograph courtesy of Wolfgang Seifert (DWD).*



Example of a good five-day forecast. *Comparison of the five-day forecast of surface pressure with the corresponding analysis for 12 UTC on 2 March 2008 shows a strong storm at 65°S, 30°E with a central pressure below 945 hPa that was well forecast (marked A). Also noteworthy is the correct position of the northern secondary low south-west of Africa (marked B), the high-pressure cell at 30°W (marked C) and the low east of the Antarctic Peninsula (marked D).*

Use of satellite observations

During 2008, ECMWF continued to improve the use of satellite data. Several additional data types were assimilated successfully. This was the case for data from the first operational GPS radio occultation instrument (GRAS) onboard EUMETSAT's polar-orbiting MetOp-A satellite. In addition, microwave imaging observations from various instruments (i.e. AMSR-E onboard AQUA and TMI onboard TRMM) were assimilated using a 1D+4D-Var assimilation scheme. The ozone observing system has been enhanced by the assimilation of data from OMI onboard AURA.

Several changes have been implemented to improve the usage of some existing data (e.g. scatterometer data from QuikSCAT and bias-corrected infrared shortwave radiances). Also a new radiative transfer model RTTOV-9 was introduced.

To prepare for further improvements in satellite data usage, ECMWF has begun monitoring of data from various types of instruments. This comprises:

- Data from the three ATOVS instruments onboard the NOAA satellites, delivered early via the Asia-Pacific Regional ATOVS Retransmission Services (RARS).
- Ozone data from GOME-2 onboard MetOp-A.
- Atmospheric winds from AVHRR onboard NOAA satellites.
- Directly broadcast atmospheric winds from MODIS onboard AQUA.
- Atmospheric winds from the Chinese geostationary satellite FY-2C.
- Water vapour data from MERIS onboard the ESA ENVISAT satellite.

Assessment of the Technical Advisory Committee

The ECMWF TAC provides the Council with advice on the technical and operational aspects of the Centre including the communications network, computer system, operational activities directly affecting Member States, and technical aspects of the four-year programme of activities. The informed scrutiny by the TAC of developments at ECMWF plays a vital role in ensuring that the forecasting system provides Member States with the right products with the right quality at the right time.

At its meeting in October 2008, the TAC indicated its satisfaction with the evolution of the forecasting system. The TAC noted the improvements in performance associated with a reduction in the number of poor forecasts, the high skill in forecasting severe weather events and improvements in the prediction of cyclone intensity and tracks. In addition, the TAC recognised ECMWF's achievements in assimilating several new types of data and revising the dissemination schedule whilst maintaining product quality and overall reliability. It was particularly pleasing that the TAC appreciated ECMWF's responsiveness to specific concerns of the Member States.

Views of the Technical Advisory Committee – October 2008

"The Technical Advisory Committee, at its 39th session:

i. congratulated ECMWF on the very high performance levels of all its forecast systems, resulting in ECMWF maintaining its world leading position;

ii. expressed its appreciation of the recently revised dissemination schedule, making products available 10 to 15 minutes earlier, while maintaining product quality and overall reliability of delivery;

iii. noted with satisfaction that the medium-range and monthly ensemble prediction systems had been merged and that the quality of forecasts in both forecast ranges had subsequently improved;

iv. welcomed the recent improvements in the model, in particular the more realistic activity levels and blocking frequency in the European Atlantic area;

v. expressed its appreciation for the continuing reduction in the number of poor forecasts produced, noting that forecasts for all months in the past year had provided useful information, on average, to day 7 for Europe and to day 7.5 for the northern hemisphere;

vi. acknowledged the value of the EFI for the Member State and Co-operating State forecasting offices and was impressed by the high skill of the forecasting systems in predicting severe weather events, such as winter storm Emma on 1 March 2008 and the floods in eastern Europe in July 2008;

vii. congratulated ECMWF for its accurate early signals of tropical cyclone genesis and for the continued improvement in the quality of its prediction of cyclone intensity and tracks;

viii. noted with satisfaction the successful assimilation of several new data types, including new data streams from the MetOp-A satellite;

ix. was encouraged by the initial results presented from trial runs with the higher horizontal resolution forecast model;

x. appreciated ECMWF's responsiveness to specific Member State concerns, for instance the earlier availability of products, the revised formulation of melting snow and wind gusts and the provision of new products, such as maximum wave height;

xi. welcomed the more representative spread/skill relationship in the EPS and the introduction of EPSgrams for waves."

Research highlights

ECMWF has a wide-ranging programme of research and development directed at improving the quality and variety of forecast products for the medium range and beyond. The benefits of the research are seen in the steadily improving performance of our forecasts and the expanding range of operational products which maintain the status of ECMWF as one of the world's leading centres for operational forecasting.

Improved variational quality control

A new variational quality control (VarQC) for conventional observations (upper-air wind and temperature as well as surface pressure and 10-metre wind) has been developed and tested in the IFS. It is based on using a Huber norm that gives more weight to outliers than the current approach. This is a robust estimation method that will allow the use of more observations with larger departures from the background field. Consequently more observations will be retained in the vicinity of extreme weather events.

Observation departure statistics have been computed for various conventional observations to determine the values for the optimal Huber norm fit for each data type. In parallel, a relaxation of the first-guess quality control was introduced for those observations and the observation errors were retuned based on the shape of the Huber norm as well as statistics for estimated observation errors. This allows more observations into the assimilation system when the Huber VarQC is activated.

The impact on analysis and forecasts of the whole Huber VarQC package has been evaluated extensively with positive results. Experiments have shown a significant impact on severe weather events such as the storms that occurred over Europe in December 1999 as well as more recent cases with poor forecast scores.

Non-hydrostatic dynamical core for the IFS

The current operational version of the IFS has a hydrostatic dynamical core. However, the hydrostatic approximation becomes increasingly less valid for horizontal resolutions with a grid spacing finer than about 10 km. ECMWF plans to run its operational model at this kind of fine resolution by the middle of the next decade, making it necessary to replace the current hydrostatic dynamical core by a non-hydrostatic version over the coming years.

Work on this project has started with the testing in ECMWF's modelling environment of the non-hydrostatic model developed by the ALADIN community for a limited-area model. This non-hydrostatic formulation has also been incorporated into the global ARPEGE/IFS model by Météo-France.

Some stability issues encountered have been resolved, allowing the non-hydrostatic model to be run successfully at all resolutions currently in use at ECMWF and with the long time steps used with the hydrostatic model. Ten-day forecasts at various resolutions as well as 13-month integrations have been run successfully. Currently the cost of the non-hydrostatic model is between 25% and 70% higher than the hydrostatic version, depending on resolution and chosen configuration.

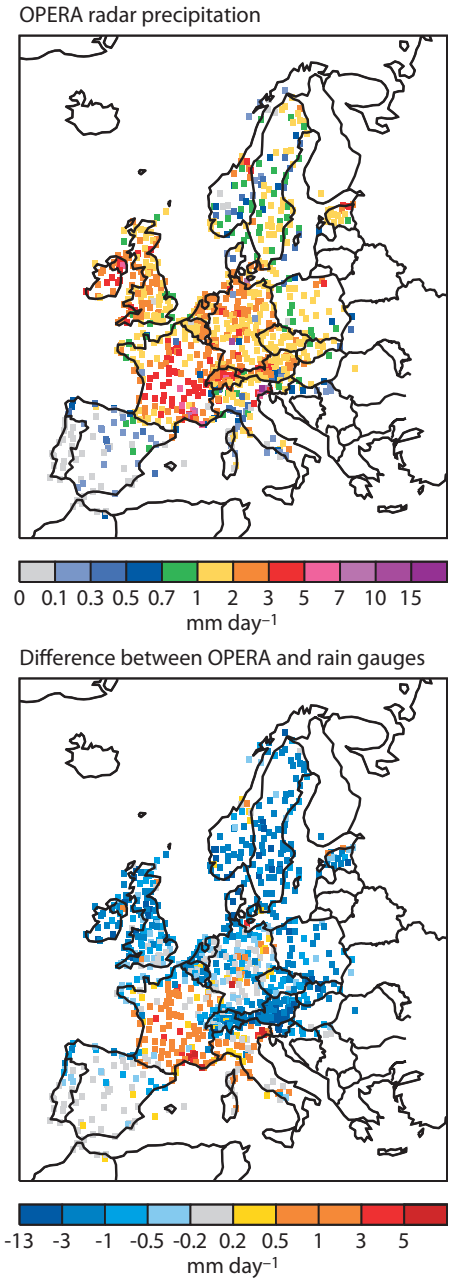
In terms of forecast scores, initial tests of the non-hydrostatic model indicated that it performed less well than the operational hydrostatic model which is part of the IFS. However, this problem has been addressed and the scores for the non-hydrostatic model are now at the same level as those of the operational hydrostatic model in the troposphere. In the stratosphere there are still performance differences between the two models.

Assimilation of ground-based precipitation radars

An investigation of the potential usage of European radar composites of precipitation rates (available every 15 minutes) obtained from the OPERA project has been initiated. As a first step there has been a statistical comparison of OPERA data with other data sources, including rain gauges, combined satellite microwave and infrared measurements, and the ECMWF model.

The first verification results suggest that the quality of OPERA data is highly dependent on country as well as on precipitation characteristics (e.g. stratiform/convective, snow/rain). The country dependence can be explained by the heterogeneities in the type of processing and quality control of radar data coming from different countries (e.g. individual radar measurements versus national composites). Overall, OPERA precipitation data systematically underestimate precipitation in snowy situations and can still be affected by anomalous propagation over the sea.

Further investigation and interaction with the OPERA community will be needed to improve the quality of OPERA composites and determine whether they can be used for data assimilation purposes at ECMWF, in a similar way to the NCEP Stage IV radar and rain gauge analyses over the USA.



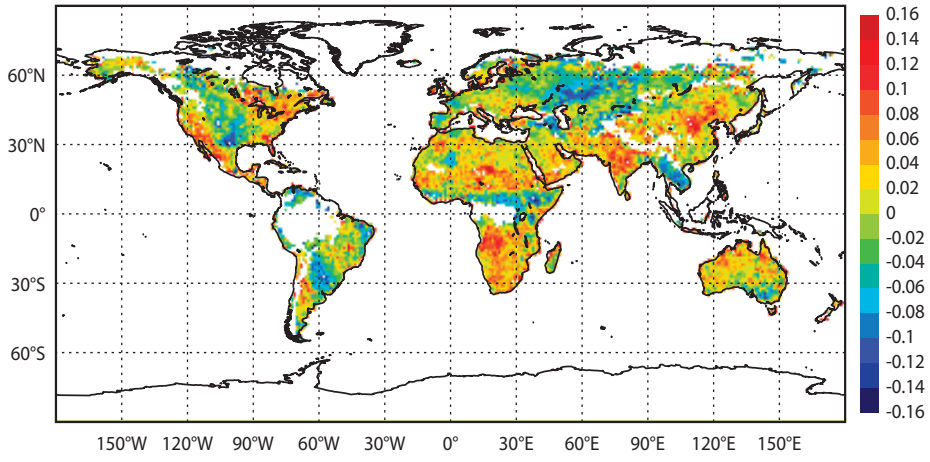
Comparison of OPERA radar rain composites with surface rain gauge measurements. *A comparison of radar and rain gauge measurements of precipitation suggests that there is a need for a more homogeneous handling of national radar data during the compositing phase of the radar data. Positive differences between OPERA and rain gauge measurements are found over France and northern Italy with negative differences elsewhere, especially over the Alps. The charts show the mean OPERA daily precipitation amounts (top) and mean differences between OPERA and rain gauge measurements (bottom) between 20 June and 31 August 2008.*

Assimilation of surface observations

The current operational soil-moisture analysis system is based on an Optimal Interpolation (OI) algorithm using screen-level variables, namely 2-metre temperature and relative humidity. Some limitations have been identified with the current OI approach and this has motivated the development of a new surface analysis scheme. In particular, it is of interest to use new satellite observations that provide direct estimates of surface soil moisture; these complement the classic input to a soil-moisture analysis.

The new scheme is a point-wise Extended Kalman Filter (EKF) for the global land surface, built on the concepts developed in the European Land Data Assimilation System (ELDAS) project. The EKF surface analysis enables the combined use of satellite, in situ and proxy observations.

The advanced scatterometer (ASCAT) on the MetOp satellite is primarily designed to measure winds over the ocean. However, there is evidence that the instrument also provides useful information about surface soil moisture over land. As part of its contribution to the EUMETSAT Hydrology Satellite Application Facility, ECMWF has implemented routine monitoring of the ASCAT soil-moisture products. It has been found that these products contain valuable information about soil moisture especially in tropical, dry and temperate climates. Experiments have shown the value of ASCAT soil-moisture assimilation using the EKF surface analysis.



Difference between ASCAT soil moisture and operational analyses. *The ASCAT soil moisture appears to be in good agreement with the model apart from the densely vegetated, mountainous and snow covered areas, where soil moisture cannot be retrieved from scatterometer data. Over large parts of the land surface, the differences are consistent with the instrument sensitivity. Some areas show larger differences and are under investigation. The map shows the mean departure between ASCAT calibrated soil moisture and the operational analysis (m^3/m^3) for the period 1–19 May 2007.*

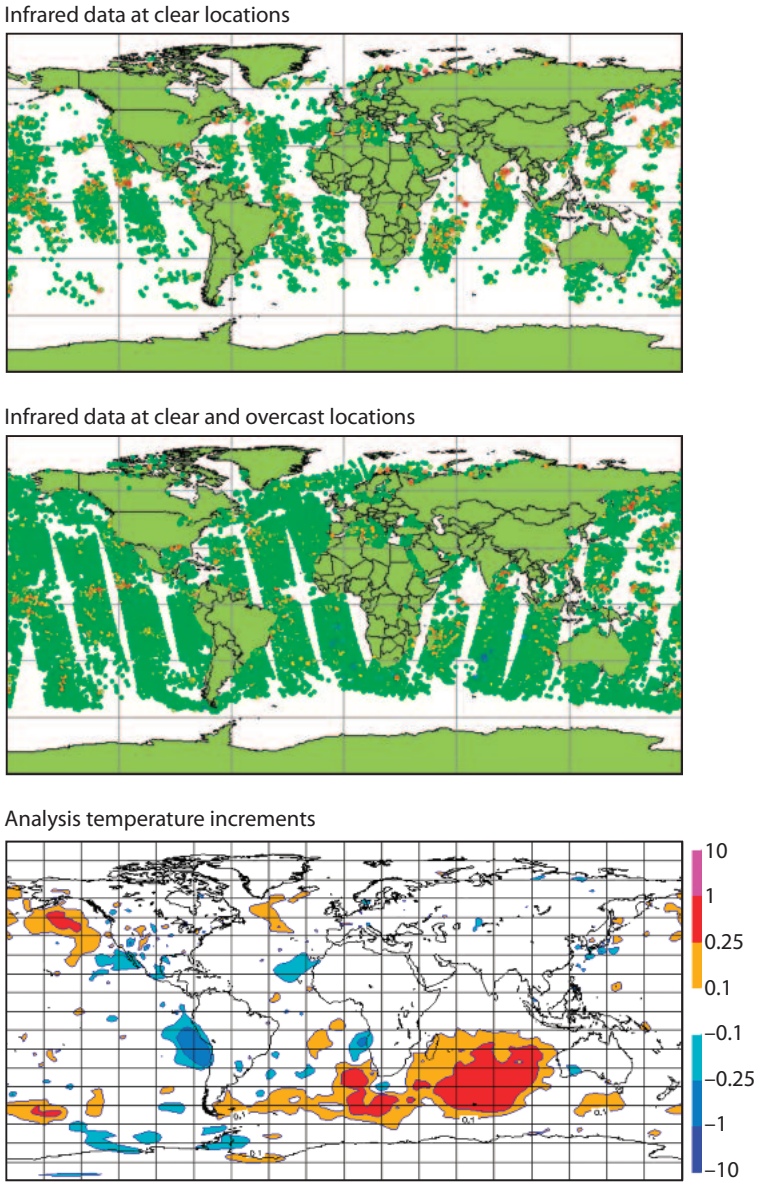
The new EKF surface analysis system opens a range of further development possibilities such as exploiting new satellite surface data and products for the assimilation of soil moisture. Short-term objectives focus on the operational implementation of the EKF surface analysis. Also data from ESA's Soil Moisture and Ocean Salinity (SMOS) mission will be assimilated using the EKF surface analysis. To this end the Community Microwave Emission Model (CMEM) forward operator has been developed and validated.

Assimilation of infrared radiances affected by clouds

The effect of clouds on infrared satellite radiance observations is dramatic. Indeed, the magnitude of the cloud signal can be far in excess of the useful information on temperature and humidity. For this reason most operational NWP centres currently focus on using cloud-free or cloud-cleared infrared radiances. However, this restriction represents a major under-exploitation of high-cost satellite instruments.

Progress is being made in using infrared radiance data in all-sky conditions. The central strategy is to extend the analysis process to include parameters that describe the cloud and simultaneously estimate these parameters, together with temperature and humidity, within the 4D-Var minimisation. In the current prototype configuration, the extra cloud variables are decoupled from the model's representation of physical processes and only cloudy data in completely overcast conditions is used. The latter significantly improves the conditioning of the cloud estimation and allows a cleaner separation of the atmospheric temperature and humidity signal down to the cloud top.

Early experiments have produced some encouraging results, suggesting that the methods will soon be operationally viable. The superior data coverage results in smaller averaged analysis increments, an improved fit to isolated upper-air soundings and reduced errors in lower tropospheric forecasts.



Positive impact of the assimilation of cloud-affected infrared radiances. *Including 'clear plus overcast' infrared radiances along with the 'clear' radiances reduces the monthly averaged analysis temperature increments thereby providing a better temperature analysis. The top and middle panels show the typical infrared data coverage (from instruments on two satellites) in 'clear' and 'clear plus overcast' conditions respectively. The bottom panel shows the difference in monthly averaged root-mean-square analysis temperature increments (at 700 hPa) when additional use is made of overcast data. The red areas indicate reduced increments.*

Ensemble Data Assimilation in support of severe weather forecasts

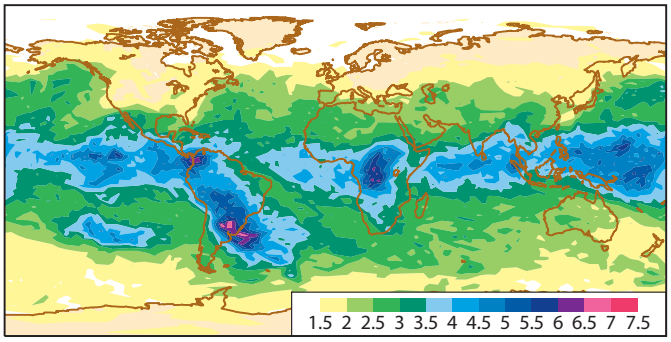
The Ensemble Data Assimilation (EnDA) has been developed further by introducing an improved representation of the spectral backscatter (SPBS) uncertainty in the model error. When the revised SPBS is combined with the improved representation of physical processes introduced in IFS Cycle 32r3, there is increased and more realistic ensemble spread in the extratropics and a reduction in the excessively large values in the tropics.

EnDA relies on an ensemble of typically ten independent 4D-Var assimilations obtained by perturbing the input observations, namely sea surface temperature and near-surface humidity, by a quantity that represents a realistic observation error. The spread, measured as the standard deviation of the ten independent short-range background forecasts, gives an estimate of the uncertainty of the background forecast for the current day.

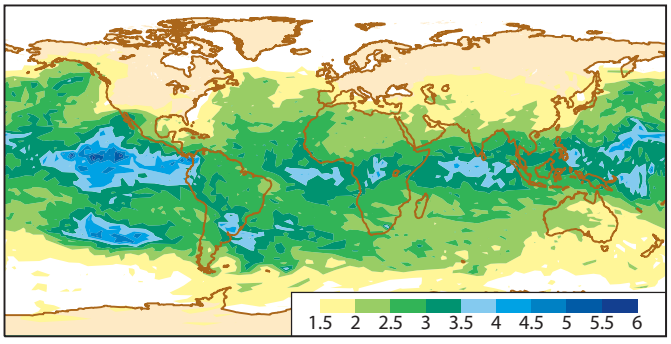
EnDA produces a set of perturbations that represent the analysis and short-range forecast uncertainties. These perturbations have been added to the initial conditions used by the EPS. This has resulted in an improved performance, especially in the tropics.

It is intended that EnDA will be implemented operationally during 2009. Additionally, experimentation is ongoing to use the EnDA perturbations in the deterministic 4D-Var system to give an accurate description of flow-dependent background errors. This will be most beneficial for unusual or extreme weather events because it allows the 4D-Var assimilation system to utilise the observations better where the background model fields are uncertain.

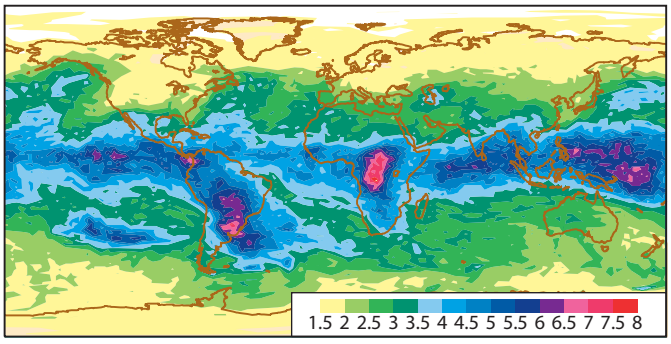
a IFS Cycle 31r1 at T255 with SPBS



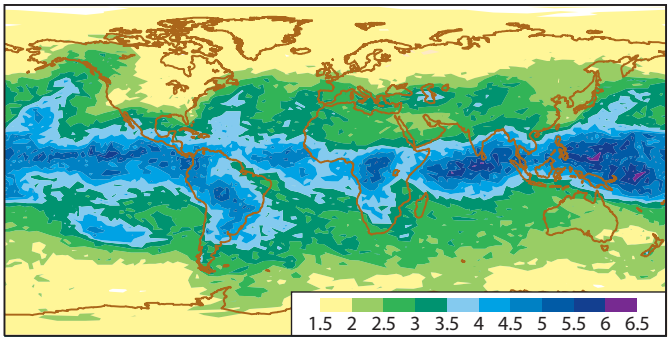
b IFS Cycle 31r1 at T255 without SPBS



c IFS Cycle 31r1 at T399 with SPBS



d IFS Cycle 32r3 at T399 with SPBS



Ensemble Data Assimilation (EnDA) provides better estimates of the average short-range forecast uncertainty. *A set of experiments has shown that it is beneficial to apply the spectral backscatter (SPBS) representation of model error uncertainty. In addition, the improved representation of physical processes introduced in IFS Cycle 32r3 combined with a revised SPBS formulation produce increased and more realistic ensemble spread in the extratropics and reduce the values that are too large in the tropics. Results are shown for the zonal wind at 200 hPa for four different configurations. a) IFS Cycle 31r1 at T255 resolution with SPBS representation of model error uncertainty. b) Like a) without SPBS. c) Like a), but at T399 resolution. d) Like c), but with IFS Cycle 32r3.*

Variational assimilation system for the ocean (NEMOVAR)

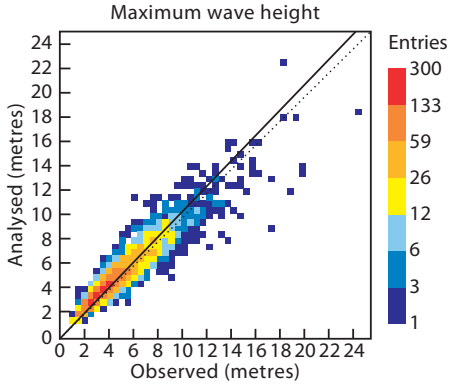
Work on developing a variational data assimilation system based on the NEMO ocean model (NEMOVAR) has continued in collaboration with CERFACS and more recently with the UK Met Office. For this purpose, a memorandum of understanding was signed with these two partners in June 2008.

The first technically working version of a 3D-Var FGAT (first guess at appropriate time) system has been completed. This represents a major milestone for the NEMOVAR development. The first experiments with the new system have been performed to verify the performance of the data assimilation system. To this end experiments for a 20-year period (1987 to 2006) with in situ observations that are externally quality controlled (prepared by the UK Met Office for the ENSEMBLES project) have been performed with various configurations of NEMO. The results of 3D-Var runs and control runs (e.g. forced ocean runs) have been compared against both the assimilated data and independent data.

Freak wave prediction and validation

The state of the sea is an important component of marine weather forecasts, and is critical for shipping, fisheries, offshore operations and coastal protection. Of particular interest to users of marine forecasts is the prediction of extreme events in terms of their maximum wave height and the corresponding wave period.

Based on Monte Carlo simulations with the two-dimensional version of the nonlinear Schrödinger equation, a new parametrization of the kurtosis of the sea surface was introduced. Kurtosis (a measure of whether the distribution is peaked or flat relative to a normal distribution) now depends on the Benjamin-Feir Index (BFI) and on the directional width of the wave spectrum. In addition, the effects of bound waves and shallow water were introduced. Since the probability distribution function of the surface elevation (including its dependence on BFI and angular width) is known, it is relatively straightforward to obtain the maximum wave height and the corresponding wave period. These two output parameters are of great practical value for indicating extreme events. A limited set of buoys is used to routinely measure the maximum wave height.



Comparison of analysed ECMWF maximum wave height with buoy observations. *The scatter diagram shows that the model is able to provide accurate estimates of large waves.*

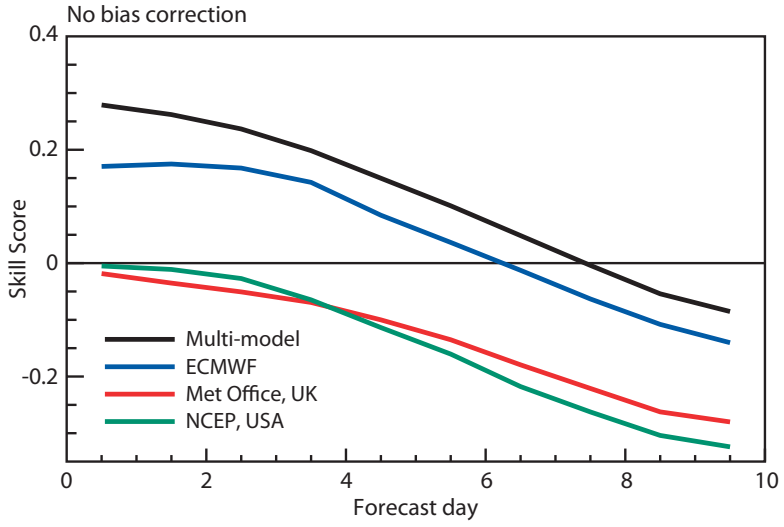
Use of TIGGE data as a benchmark for the ECMWF EPS

TIGGE, the THORPEX Interactive Grand Global Ensemble, is a key component of THORPEX (itself a component of the World Weather Research Programme) to accelerate the improvements in the accuracy of one-day to two-week high-impact weather forecasts. TIGGE facilitates the benchmarking of the ECMWF EPS with other operational ensemble forecasts and with multi-model ensembles that consist of members taken from several ensembles in TIGGE.

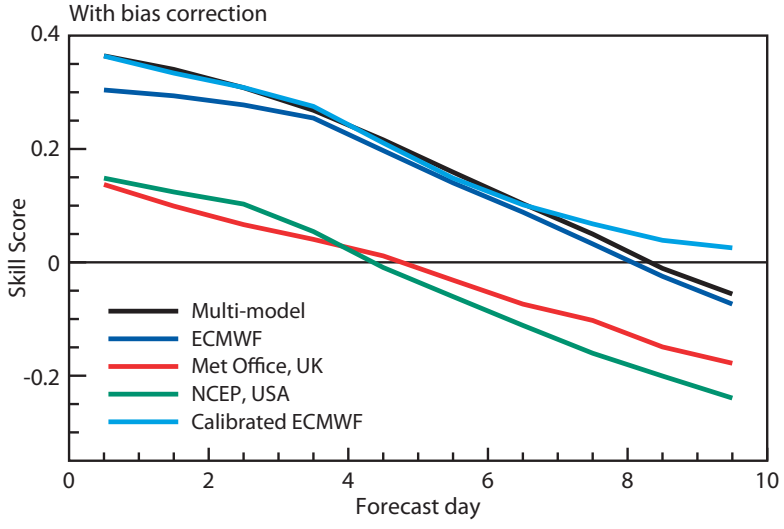
Results show that the multi-model ensemble, which consists of several ensembles including the ECMWF EPS, is only marginally more skilful than the ECMWF ensemble for 500 hPa geopotential height in the mid-latitudes. For 850 hPa temperature in the tropics, the skill of the multi-model is higher than that of the ECMWF EPS. Various upgrades are in preparation that will increase the spread of the ECMWF ensemble in the tropics. Also they should eliminate the gap in skill in the tropics between the ECMWF EPS and multi-model ensemble.

For 2-metre temperature over Europe, verified against observations, a multi-model ensemble consisting of ensembles from ECMWF, UK Met Office and NCEP performs better than each single-model ensemble. This is mainly because the inclusion of different models reduces the overall bias of the multi-model ensemble.

An evaluation of different multi-model combinations, created by excluding individual models from the full TIGGE multi-model ensemble, has shown that the ECMWF EPS is the single most beneficial contribution to the multi-model ensemble.



Comparison of a multi-model ensemble with three single ensembles. *These results show that forecasts from a multi-model ensemble perform better than each single ensemble from ECMWF, UK Met Office and NCEP, with the Skill Score of the ECMWF ensemble being close to that of the multi-model ensemble. The forecasts of 2-metre temperatures are verified against 250 European stations for 60 days in June and July 2008. The Skill Scores are based on the Continuous Ranked Probability Skill Score (1: perfect forecast, 0: as good as climatological distribution).*

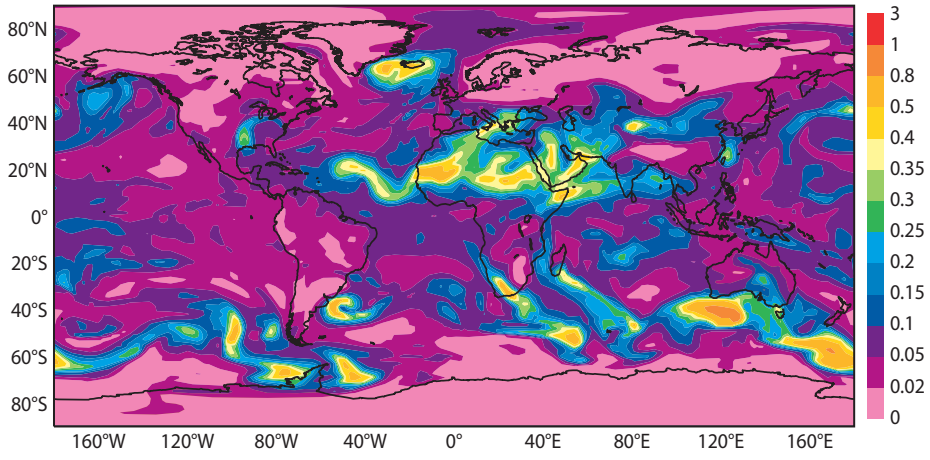


Impact of using bias-corrected ensemble forecasts. *Comparison of these results with those in the above figure shows that using bias-corrected forecasts improves the performance of the multi-model ensemble and that of each single ensemble from ECMWF, UK Met Office and NCEP. Now the Skill Score of the ECMWF ensemble is almost the same as that of the multi-model ensemble. If ECMWF forecasts are calibrated using data from the ensemble re-forecast suite, the single ECMWF ensemble performs better than the multi-model.*

Developments of the GEMS system

The EU-funded GEMS project is developing comprehensive data analysis and modelling systems for monitoring the global distributions of atmospheric constituents important for climate, air quality and ultraviolet radiation, with a focus on Europe. Recent developments of the GEMS system have included the following.

Establishment of a near-real-time production stream assimilating data on atmospheric composition. The system currently assimilates various kinds of data from satellite instruments: aerosol optical depth from MODIS onboard AQUA, carbon monoxide from IASI onboard MetOp, and ozone from the same sources as used in ECMWF's operational system. It will be expanded gradually to assimilate data on other species as they become available in near-real-time and are validated. Assimilation of the ozone data brings a big improvement to the representation of the ozone hole. This is needed for consistent provision of the associated ultraviolet radiation product, which has yet to be migrated to use the distributions of ozone and aerosol generated by the GEMS system. Assimilating the MODIS aerosol data improves the match between aerosol forecasts and independent validating data from the AERONET ground-based measurements.



GEMS semi-operational aerosol forecasts. *Semi-operational aerosol forecasts are now available as illustrated by the forecast of the optical depth at 550 nm of sea-salt and desert-dust aerosols. The forecast shows plumes of Saharan dust extend into southern Europe and the Atlantic Ocean. The landfall of Hurricane Ike is marked by a maximum in sea-salt aerosol in the southern USA and Gulf of Mexico. The 48-hour forecast is valid at 00 UTC on 14 September 2008 and is based on a near-real-time assimilation of MODIS data.*

Near-real-time running of a fire analysis system. This system is based on Fire Radiative Power data from the SEVIRI instrument onboard the MSG satellites (provided by the Land Surface Analysis Satellite Application Facility) and the MODIS instruments onboard the Terra and Aqua satellites. The system is initially being run to provide information on the spread of long-lived tracers from biomass burning, but will eventually be used to provide near-real-time emissions for use in the full GEMS data assimilation and forecasting system.

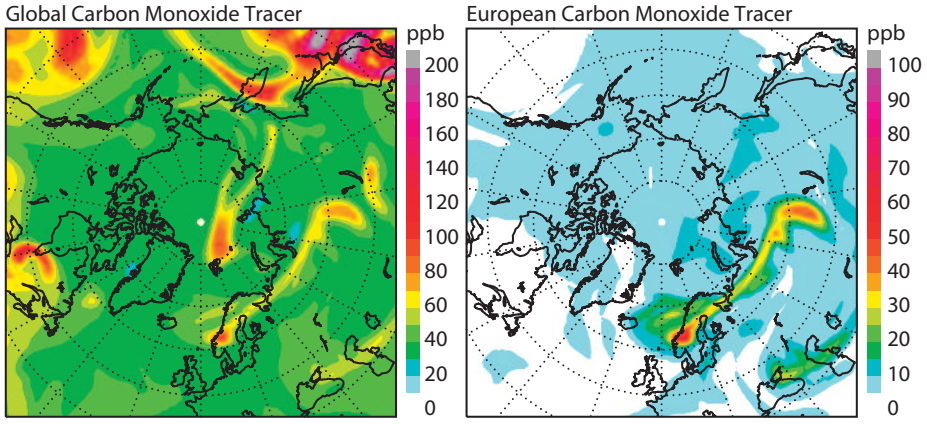
Routine verification of the ensemble of European regional air-quality forecasts run by GEMS partners. The daily verification of the forecasts against near-surface air-quality measurements is providing the partners with information that has prompted several system improvements and gives a basis for the generation of weighted ensemble products. The same verification has been applied to the forecasts from the lower-resolution coupled global system, which compares well with the better of the regional systems.

Support for the POLARCAT campaign during the International Polar Year

As part of the GEMS project, global 72-hour forecasts of reactive gases have been published on ECMWF's web pages in near-real-time since May 2007. The forecasts are produced by a system which couples the chemical transport model MOZART-3 to ECMWF's IFS.

POLARCAT is a core activity of the International Polar Year using observations and modelling to quantify the impact of trace gases, aerosols and mercury transported to the Arctic and their contribution to pollutant deposition and climate change in the region. POLARCAT performs a series of aircraft experiments at different times of the year to follow pollution plumes of differing origin.

To support flight planning and analysis of the POLARCAT campaign, the product portfolio of the coupled forecast has been extended. Several more chemical species from MOZART-3 have been included and four region-specific CO tracers with emissions from North America, Europe, South Asia and East Asia as well as a tracer with global emissions have been implemented in the IFS. The region-specific tracers will help to trace the origins of CO in the Arctic.



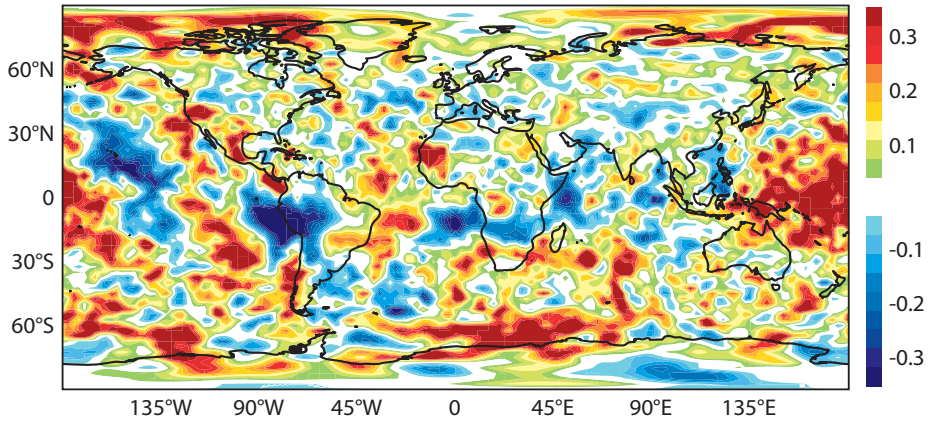
GEMS near-real-time forecasts of reactive gases. *Near-real-time forecasts of reactive gases are available as illustrated by a forecast of a global CO tracer (left) and the CO tracers with emissions from Europe (right). A pronounced CO plume travelling across the Arctic from eastern Siberia towards Scandinavia is present in the global tracer field. The source of this plume can be traced back to East Asia since it is present only in the East Asia tracer. The plumes are based on a 54-hour forecast of CO concentrations in parts per billion at 500 hPa, valid at 06 UTC on 8 April 2008. Note the difference in colour scale for the global and regional tracers.*

Evaluation of the impact of a loss of MetOp instruments

One of the goals of the ECMWF strategy is "to contribute towards the optimization of the Global Observing System (GOS)". In cooperation with EUMETSAT and EUCOS, a series of Observing System Experiments (OSEs) were performed in 2008, dedicated to examining the various components of the space and terrestrial components of the GOS.

OSEs were performed to evaluate the impact on NWP forecast skill of a potential loss of individual or groups of instruments onboard the MetOp satellite. A reference observing system has been defined that closely resembles the satellites and instruments expected to be available in the EUMETSAT Polar System (EPS) and Post-EPS period (2010–2020). MetOp instruments are then denied from this reference system.

Results obtained for two-month periods in summer 2007 and winter 2008 indicate that the simultaneous loss of all MetOp sounders would produce a significant deterioration of forecast skill. The 500 hPa root-mean-square forecast errors would increase by 3–4% in the northern and by 6–7% in the southern hemisphere, lasting well into the medium forecast range. Similarly, it was found that a loss of ASCAT would translate into a deterioration of short-range wind speed forecasts by 10% and of wave height analyses by 5%.

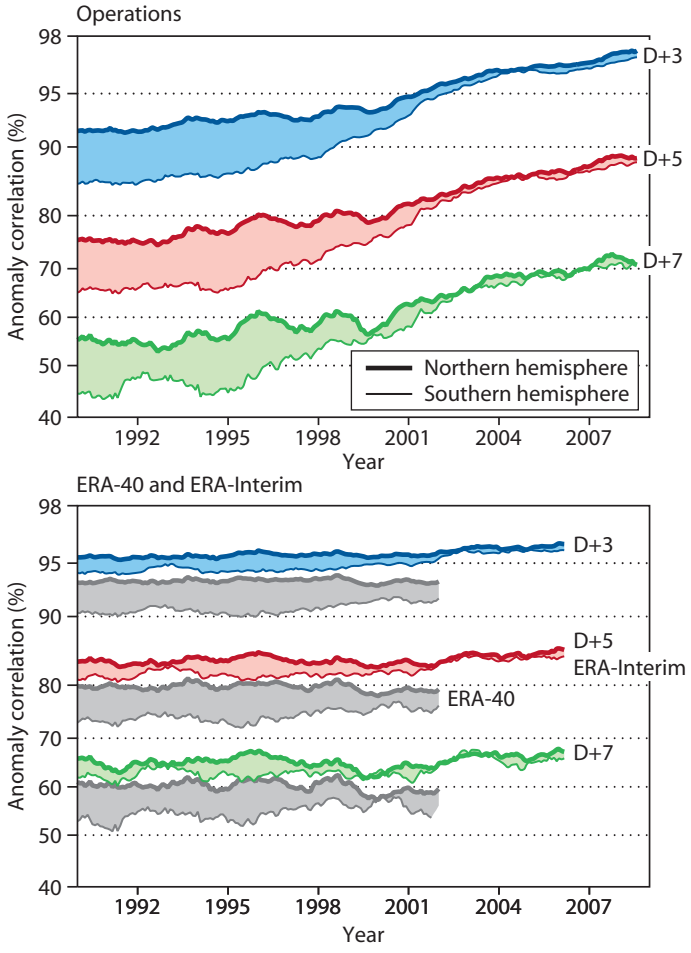


Impact of the loss of MetOp instruments. *Experiments have shown that the information from sounders onboard the MetOp satellite has a positive global impact on the forecasts. The chart shows the root-mean-square forecast error difference between the reference observing system and an observing system without any of the MetOp instruments. The positive values (marked in red) indicate where the MetOp sounders had a positive impact. The results are shown for the normalised 24-hour forecast of 500 hPa geopotential height for a two-month period in summer 2007.*

Given the large contribution of satellite data to analysis quality in general, this potential loss is considered significant. The results of the study highlight the important contribution of MetOp instruments to the GOS used by operational NWP.

Contribution to climate studies

ECMWF's core mission is to develop its global weather forecasting system, run it operationally and distribute the results to its Member States. However, through its core activity, ECMWF is contributing significantly to climate change studies.



Quality of the ERA-Interim reanalysis. *The impressively uniform quality of the ERA-Interim reanalysis is illustrated by the verification scores for 3-day, 5-day, and 7-day forecasts in the northern and southern hemispheres for operational forecasts (top) and ERA-40 and ERA-Interim forecasts (bottom). A clear improvement of ERA-Interim relative to ERA-40 is also evident. All forecasts are verified against their own analyses. The score used is the mean anomaly correlation for forecasts of 500 hPa geopotential height. Note that a non-linear scale has been used for score to magnify the differences at high values.*

Reanalysis

ECMWF's activities in the area of global atmospheric reanalysis provide a major contribution to climate change studies. Reanalysis is the reprocessing of past observations with a modern data assimilation system. As a natural by-product of the forecast and analysis system developed for numerical weather prediction, it was originally aimed at:

- Studying the evolution of the observing system and evaluating the impact on the quality of the forecast.
- Testing forecasting techniques over a long period and developing model calibrations.

Three major reanalyses have been produced at ECMWF that exploit the substantial advances made in the forecasting system and technical infrastructure since operations began in 1979. The first of these, ERA-15 (1979–1993), was completed in 1995 and the second extended reanalysis, ERA-40 (1957–2002), in 2002. The latest reanalysis project at ECMWF is ERA-Interim, which covers the data-rich period of 1989 to 2008 and will be extended forward in time for several years to come.

Reanalyses have become indispensable to many core activities at ECMWF. They are currently used, for example, to:

- Validate long-term model simulations.
- Define baseline diagnostics for model development.
- Provide climatology needed for forecast verification.
- Calibrate the seasonal forecasting system.
- Provide forcing data for ocean assimilation.
- Develop forecaster aids such as the Extreme Forecast Index.

Products from ECMWF reanalyses are also widely utilised by Member State users and the scientific community at large, for numerous applications that require an observational record of the state of the Earth-system. Since the reanalyses are generated using a fixed, state-of-the-art data assimilation system, they are much more suitable for the study of atmospheric and oceanic processes and predictability than operational analyses produced for NWP purposes.

Reanalyses are now universally recognised as a key resource for studies of long-term variability and climate. The improving quality of recent reanalysis products is reflected in the IPCC's Fourth

ERA-40 article designated as a 'Current Classic'

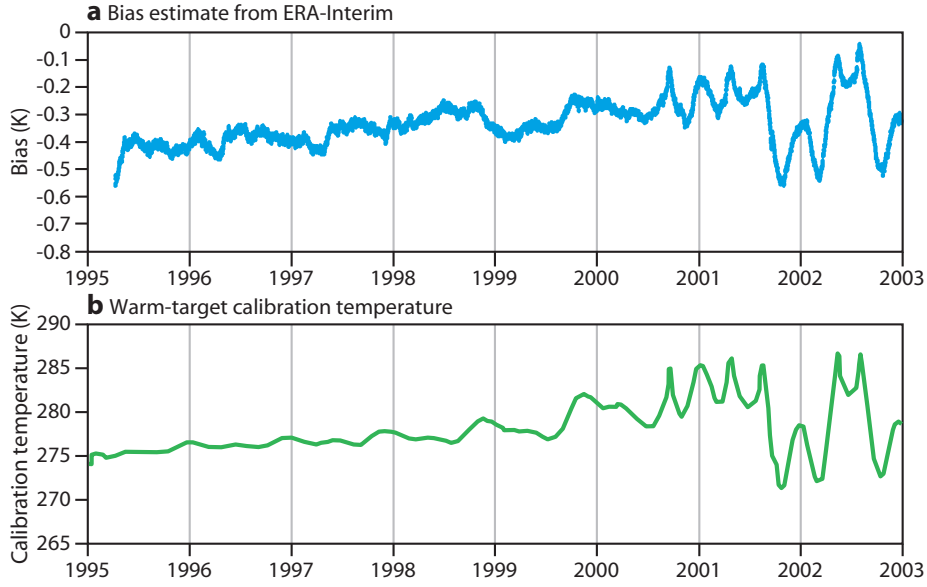
An article entitled 'The ERA-40 re-analysis' published in the Quarterly Journal of the Royal Meteorological Society (2961–3012, Part B, October 2005) has been designated as a 'Current Classic' in the field of Geoscience. The article was selected for this accolade by ScienceWatch.com, which tracks trends and performance in basic research based on the number of citations an article receives from other articles. More information about the 'Current Classics' is available at **sciencewatch.com/dr/cc/09-febcc**.

The high number of citations for the article about ERA-40 is a direct indication of the usefulness and quality of the ERA-40 products. Indeed, the positive experience of users has led to innovative and complementary ways to use the products.

Assessment Report published in 2007, which contains many references to the ECMWF reanalysis, ERA-40. Ongoing work on the homogenisation of observations and the correction of biases in satellite data has already led to major improvements in the representation of climate signals and trends. Further advances can be expected due to the continuous improvement of modelling and assimilation techniques, in particular those associated with atmospheric chemistry, oceans and continental surfaces.

ERA-Interim reanalysis products spanning the last two decades (1989–2008) are now available to users in Member States. A subset of the data has been made available on the public ECMWF Data Server, at a 1.5° spatial resolution, including several fields that were not available for ERA-40. Since March 2009 ERA-Interim has been running in real time, providing new opportunities for climate monitoring. A subset of the current reanalysis monitoring information, together with some additional climate monitoring indices recommended by WMO, will be included on the ERA-Interim website. Based on internal evaluations and comparisons with other reanalyses, the quality of ERA-Interim products is generally good and its long-term homogeneity has improved considerably over that of ERA-40.

ERA-Interim represents an important step toward the next global reanalysis that ECMWF plans to undertake subject to external funding. If it goes ahead, the project would produce a climate-oriented reanalysis from the 1930s to the present and so provide reliable estimates of regional temperature and humidity trends over the reanalysis period. It is intended that the scope of such reanalysis activity would be progressively extended through cooperation with the relevant institutes in the Member States to include atmospheric chemistry, the oceans and the continental surfaces. This would provide access to, amongst other things, a detailed history of the ozone hole and an accurate account of the most severe droughts of the last century in various parts of the world. Nevertheless, the funding of this activity remains unclear.



Comparison of warm-target temperatures onboard NOAA-14 with estimates produced statistically by the variational bias correction system in the ERA-Interim reanalysis. *The close correspondence between the two curves shows that the variational bias correction system is able to correct complex, rapidly varying instrument errors based on information available from other data sources used in reanalysis. Top panel: globally averaged bias estimates, in degrees Kelvin, for MSU channel 2 brightness temperature data from NOAA-14 produced statistically by the variational bias correction system in the ERA-Interim reanalysis. Bottom panel: Recorded warm-target temperatures onboard NOAA-14, used for self-calibration of the MSU instrument, from an article by Grody et al. (2004). The variations are due to a drift in the satellite orbit and explain the observed changes in instrument bias. This is independent information not used in ERA-Interim.*

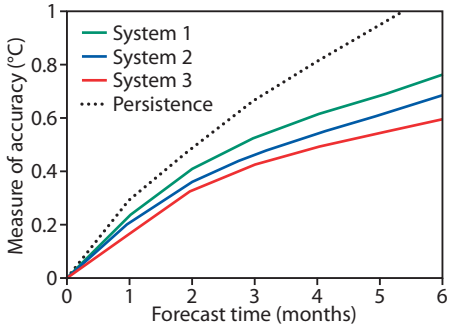
Seasonal/decadal forecasts

Forecasting the coupled atmosphere-ocean climate system on time scales of a few months ahead has been one of ECMWF's core activities for almost ten years. The scientific basis for seasonal predictability lies in the slowly evolving components of the climate system, like the ocean or land surface, that act as boundary conditions for the atmosphere with its shorter intrinsic time scales. A prime example of a coupled atmospheric and oceanic phenomenon on seasonal time scales is the El Niño event in the tropical Pacific.

ECMWF's seasonal forecast system (System 3) became operational in March 2007 and provides the Member States with an enlarged range of operational products, including a formal dissemination of real-time forecast data, raw data in ECMWF's main repository of meteorological data (MARS) and a set of graphical products on the web. System 3 uses the IFS Cycle 31r1 and runs at a T159L62 resolution. The real-time forecasts are initialised every month and comprise a 7-month forecast based on 41 ensemble members and, once per quarter, a 13-month 'El Niño outlook' based on a reduced number of ensemble members. In order to be able to assess statistically the quality of the forecast system in the past, a set of re-forecasts over the last 25 years is also provided.

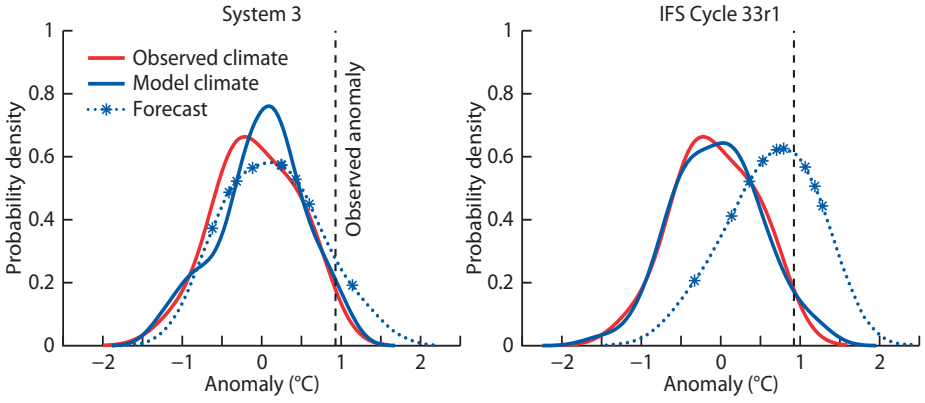
The skill of the seasonal forecasting system differs widely over different parts of the globe. In the tropics, where internal atmospheric variability plays a relatively minor role, the predictability a few months ahead is higher than in the extratropics, where the chaotic nature and large internal variability of the atmosphere diminish predictability on longer time scales. For example, the seasonal forecasting system is very good at predicting El Niño related sea surface temperature anomalies in the tropical Pacific.

Predictions of circulation anomalies for the extratropics a few months ahead are more difficult and, so far, not yet very successful. However, there are encouraging signs that with improved models, useful forecasts in the extratropics will be possible. For example, the summer of 2003 was the warmest summer on record in large parts of central and southern Europe. The current seasonal forecasting system showed very little sign of a warm summer over southern and central Europe for this year. However, it was found that further developments of the atmospheric convection and radiation parametrization schemes, as well as a better land-surface representation in a recent cycle of the IFS, led to a much improved forecast of the anomalous high temperatures over southern Europe in the summer of 2003. This example highlights the need for improved representation of physical processes in the model to fully exploit the potential for seasonal predictions.



Progress in forecasting sea surface temperatures in the tropical Pacific. *The evolution of the forecast error for the average sea surface temperature (SST) anomaly shows the improvement in forecasting SSTs going from System 1 through System 2 to the current System 3. The black dotted line indicates the corresponding error of a simple statistical forecast based on persistence. The results are shown for the root-mean-square forecast error for the average SST anomaly in the region 5°N to 5°S, 170°W to 120°W (the Niño3.4 region) for the period 1987–2002.*

Seasonal forecasts, which can be verified against observations, have recently been suggested as a test bed for climate change predictions where verification is inherently impossible. The idea is to use information about the reliability of multi-model seasonal forecasts to calibrate regional multi-model climate projections on centennial time scales (e.g. from the IPCC). In a seamless prediction system, the reliability of coupled climate model forecasts made on seasonal time scales can provide useful quantitative constraints for improving estimates of trustworthiness of regional climate change projections.



Seasonal forecasts for June–August 2003 of 2-metre temperature over southern Europe. *The forecasts using System 3 gave no indication that summer 2003 would be unusual, though use of a recent version of the IFS, Cycle 33r1, indicated a high probability for a very warm summer in 2003. The figures show a comparison of the probability density functions (pdf) for temperature anomalies from the current operational System 3 (left) and a more recent version of the IFS, Cycle 33r1 (right). The red solid curve indicates the observed climate according to ERA-40/operational analyses over the 1991–2005 period (leaving out the year 2003). The observed anomaly for 2003 of 0.93 °C is shown by the vertical line. The solid blue curves are estimates of the model climatological pdf showing for both model versions a very good agreement with the observations in general. The dotted curves are the forecast pdfs for June–August 2003, with the asterisks indicating individual ensemble members.*

In the framework of several EC-funded projects, notably ENSEMBLES (see page 44), ECMWF has started to explore predictability on interannual and decadal time scales in a seamless approach. Fully initialised global forecasts using essentially the same coupled system as for seasonal forecasts are being produced over a ten-year lead time for a set of past start dates to analyse the ability to issue skilful near-term climate predictions. This research is still at an early stage.

EC-Earth

EC-Earth is a project run by a consortium of ten Member States under the leadership of KNMI. Its purpose is to build from the ECMWF coupled model system a complete Earth-system simulation capability and use it for decadal and longer time-scale integrations in support of, for example, IPCC assessment reports.

ECMWF provides technical support to the project. In 2008, the first version of the EC-Earth-system was developed based on the atmospheric model from the ECMWF IFS Cycle 31r1 coupled to the NEMO ocean model, and this has been made available to EC-Earth organisations. Integrations from this coupled system have been shown to have minimal climate drift on decadal time scales. Future versions will be based on more recent cycles of the building blocks.

These developments have synergy with ECMWF's core missions, as the next seasonal forecast model will also use the NEMO ocean model. Moreover, collaboration with EC-Earth partners has influenced the changes made to the representation of physical processes recently implemented in the IFS (e.g. the representation of lakes and snow pack).

World Modelling Summit for Climate Prediction. *Attendance at the summit was very high, with 140 participants from 19 countries representing the global weather and climate community.*

World Modelling Summit for Climate Prediction

The World Modelling Summit for Climate Prediction, jointly organised by the World Climate Research Programme (WCRP), the World Weather Research Programme (WWRP), and the International Geosphere-Biosphere Programme (IGBP), was hosted by ECMWF from 6 to 9 May 2008, and fully funded through wide-ranging international sponsorship.

The goal of the meeting was to address the threat of the consequences of global climate change by developing a strategy to revolutionise climate prediction for the 21st century. A key task was to identify synergies between NWP and climate prediction problems, a process sometimes called the 'seamless systems approach'. Examples of such synergies are as follows:

- Many of the key feedbacks which lead to uncertainty in climate predictions are associated with processes such as clouds, convection or boundary-layer turbulence, whose intrinsic time scales lie within the domain of NWP.
- The future generations of computers require new optimised dynamical cores able to run efficiently on very large arrays of processors. This is a problem common to NWP and Climate Science and convergence towards common software tools is needed to avoid duplication of efforts. This approach would allow the much needed increase of resolution for climate predictions.
- NWP will also benefit from developments in climate prediction, in particular in addressing model errors.

During the opening session, introductory talks were given by distinguished speakers such as Michel Jarraud (Secretary-General of WMO), Rajendra Pachauri (Chair of the IPCC, recorded) and Jeff Sachs (Earth Institute). This was followed by a number of presentations related to the main themes of the summit:

- The current status of weather and climate modelling and strategies for seamless prediction.
- Strategies for next-generation modelling systems.
- Prospects for current high-end computer systems.
- Strategies for model evaluation and experimentation.
- Strategies for revolutionising climate prediction.

These themes were discussed in more depth during the breakout group sessions on the third day of the summit, and on the final day a draft of the summit declaration was developed in the plenary session. The declaration is available from wcrp.ipsl.jussieu.fr/Workshops/Modelling Summit/.

Overall it was felt that the summit was a very successful event, not least in providing a strong emphasis on the successful and co-operative development of NWP.

The summit attracted considerable interest amongst the scientific and more general media. A press briefing held in London was attended by journalists from major UK print media, TV stations and international news agencies. Furthermore, the scientific journal Nature reported on the summit in its issue published on 15 May with an editorial and two other articles.

Computing

Running ECMWF's complex weather forecast models in relatively short time scales requires supremely powerful computers and instant access to massive amounts of data. Central to ECMWF's activities are its supercomputers and its unique archive of meteorological data, collected over three decades and stored in the Data Handling System.

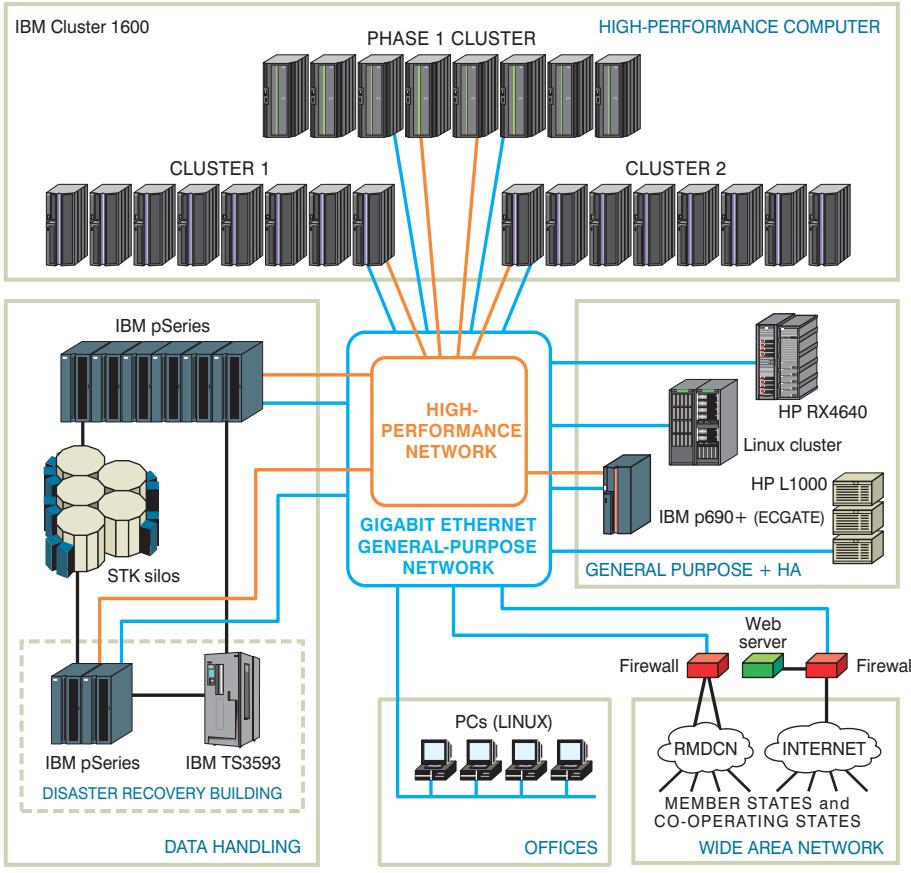
High Performance Computing Facility

ECMWF has a long history of high performance computing (HPC) in a production environment for weather forecasting, going back to the installation of its first supercomputer in 1978. Over time, various architectures have been used, including CRAY vector shared memory systems, Fujitsu VPP vector distributed memory systems, and, since 2003, IBM scalar SMP clusters. From the beginning, ECMWF has ensured that its codes are portable and has invested considerable resources in ensuring that they remain suitable for most prevailing HPC architectures, which has made it possible to migrate relatively easily from one type of system to another.

ECMWF's current High Performance Computing Facility (HPCF), one of the most powerful in Europe, comprises two identical independent IBM Cluster 1600 supercomputers based on POWER5 processor technology.

Use of ECMWF's high performance computer resources is allocated to three main activities: 50% to research, 25% to producing forecasts and 25% to the activities of the Member States.

The current operational system provides a very good user service, with availability in the region of 99.9%. Good use is made of the system, with almost a million jobs being run on it each week and over 98% of the total resources being utilised by parallel jobs.



ECMWF's computer configuration in September 2008. *Cluster 1 and Cluster 2 are part of the current operational system. Phase 1 cluster is the first stage of the new supercomputer system.*

A major activity during 2008 was preparation for the installation of the new IBM supercomputer. Following an invitation to tender and the approval of the Council at its 68th session (December 2007), ECMWF entered into a contract with IBM UK Ltd for the supply of a replacement HPCF which will provide the computational performance needed to implement ECMWF's scientific and operational strategy.

The new HPCF will be supplied in two phases: Phase 1 will cover the period 2009

to early 2011, while Phase 2 will cover the period 2011 to mid-2013. Each phase will be delivered and installed in two stages.

The staged installation with a parallel run of the existing and the new HPCF ensures that, at any time, ECMWF can rely on two operational clusters to consistently run the operational suite of jobs to the required deadlines. In 2008, the first stage of Phase 1 was installed, comprising one compute cluster and one I/O cluster, both of which are based on IBM's POWER6 processor architecture and use Infiniband technology as the fabric for the interconnect. The second stage, which has a system architecture identical to that of the first, will be installed in 2009.

The main activities this past year have been the preparations for the installation of the new IBM supercomputer, the installation itself and the testing of the system prior to putting it into normal operation. Besides installing the computer hardware, major changes have had to be made to ancillary equipment to cope with the increased demands for power and cooling. This has necessitated very careful planning and close liaison between groups within ECMWF and the vendors of the various types of equipment.

User support

Significant efforts were made to provide a steadily increasing number of Member State and Co-operating State users with support for and advice on the use of ECMWF's computing facilities. New Co-operating States were helped when starting to use the ECMWF computing and archiving resources.

Several Member State users were assisted and advised on their usage of the IBM Phase 4 HPCF. Usage of HPCF resources by Member States continued to remain high with several countries using a very large share of their allocation.

"Ecgate", a separate general-purpose server, is increasingly being accessed by users from the Member States and the Co-operating States.

Support is also provided through various educational and training activities that are described elsewhere in the Annual Report.

- Computer User Training Course.
- Forecast Products Users' Meetings.
- Workshop on High Performance Computing in Meteorology.

ECMWF's current High Performance Computing Facility (HPCF). *One of the most powerful in Europe, comprises two identical independent IBM Cluster 1600 supercomputers based on POWER5 processor technology.*

Data Handling System

ECMWF's Integrated Forecast System generates a large amount of data – observations, analyses and results from research experiments. Some of this data needs to be archived for a relatively short period of time, but some forever. It is an invaluable asset used by researchers in meteorological and environmental studies, as well as for educational and commercial purposes. The ease with which this data can be accessed is frequently commented upon by visiting scientists and other users of the facilities. The huge volume of data, amounting to about 10 petabytes (1016 bytes), is stored in the Data Handling System (DHS), on about 20,000 magnetic tape cartridges.

The data, tape drives and disk caches are managed by the High Performance Storage System (HPSS). This is a scalable hierarchical system that has been developed over the years by IBM and US Department of Energy laboratories, with contributions from universities and research organisations worldwide, including ECMWF. Users access the data via applications that have been developed by ECMWF.

- *MARS, the Meteorological Archival and Retrieval System*: a unique resource that enables users to access and retrieve a wealth of data via an interface that uses meteorological terms as keys.
- *ECFS, the ECMWF Common File System*: a utility with commands that resemble Unix remote copy commands, enabling users to store and retrieve data that is not structured in a way required by MARS.

About one fifth of the data constitutes a secondary copy of the most important data and this resides in the Disaster Recovery System that is located some distance away from the primary copy. The tape cartridges holding the secondary copies and the LTO-3 drives that read and write the data reside in an IBM TS3595 automated tape library, while the cartridges holding the primary copies reside in five StorageTek 'powderhorn' silos. These silos have been exceedingly reliable, but are now approaching end of life – one of them is over 20 years old. Their replacement is the subject of an invitation to tender that was issued at the end of 2008.

Configuration of 'Stage 1A' installed in 2008

- Stage 1A, comprising a compute cluster and an I/O storage cluster.
- 240 compute nodes, each with 32 POWER6 symmetric multi-threaded processors and 64 GB of memory; 8 pre-/post-processing nodes, identical to the compute nodes but with 256 GB of memory; 9 network I/O nodes that connect the cluster to the I/O storage fabric.
- Each of the I/O storage clusters has 18 basic I/O units, each comprising two POWER5 servers (for resiliency) and 168 disks of 300 GB capacity. The disks are in a RAID-6 configuration, which protects data even if two disks in an array of 10 were to fail.
- There are two different types of Infiniband fabrics: the one connecting the compute nodes and the pre-/post-processing nodes is based on IB4x-DDR technology and is the fabric over which data travels as a consequence of requests from the Message Passing Interface (MPI) within parallel programs; the other connects the compute clusters and the I/O server clusters and is based on IB4x-SDR, over which data travels that is written to or read from the disks.
- There is considerable replication of components in the system ranging from the dual-subsystems down to primary and secondary disk adapters. This provides the resiliency required of a system that is used to produce forecasts to a tight delivery schedule.

Data and product distribution

The efficient distribution of a wide variety of data and products produced by ECMWF is essential to support operational activities as well as research and development. By the end of 2008, ECMWF disseminated 5,460,000 analysis and forecast products each day to Member States and Co-operating States via its privately managed network and website, and to non-members via the WMO's Global Telecommunications System (GTS).

MARS and Data Services

The Meteorological Archival and Retrieval System (MARS) is the main repository of meteorological data at ECMWF. It contains petabytes of operational and research data as well as data from Special Projects. MARS data is freely available to registered users in the Member States and Co-operating States.

There is no public access to MARS. Data can be obtained for research and commercial use via ECMWF's Data Services section. Some datasets are freely available on the ECMWF data server, but for research purposes only.

A public data server was set up in April 2008 to provide the research community with access to the first ten years of ERA-Interim datasets. Over 170 external users have already registered. Two further data servers have been set up to support the ENSEMBLES and Year of Tropical Convection (YOTC) projects.

ECMWF handling charges for the provision of archived data have been reviewed, to take into account the evolution of the computing infrastructure. As a result, the charges have been reduced by 30% to 40%, depending on the nature of the order.

MARS serves tens of thousands of requests each day.

Web services

ECMWF's website is an important, easily accessible resource for the international meteorological and research communities that is much appreciated. Users can access computer facilities and run experiments as well as being able to obtain a wide range of information such as operational and research data, training material and data on Special Projects.

The use of the website continues to grow year-on-year, with an average growth of 51% during 2008, in terms of the number of pages served. The growth rate of pages served to registered customers (both Member State and Commercial) is almost as high at 46%.

The ECMWF web servers continued to provide a stable and reliable service throughout the year. As users from Member States increasingly rely on the timely availability of forecast products from the external website, action is being taken to enhance the availability of its services.

During 2008, the future provision of web services was planned and relevant web technologies have been researched and assessed for their suitability. This took place in preparation for a significant redevelopment of the website that will be undertaken in 2009 and 2010. The redevelopment will have two aims: to make the website highly available and to add significant new features that will enable personalisation and more comprehensive interaction with ECMWF's forecast data.

Research community

Since 2002 a public data server has been providing access to research datasets (ERA-Interim, ERA-40, DEMETER and ENSEMBLES) to the research community. There are about 11,800 registered users from over 130 countries.

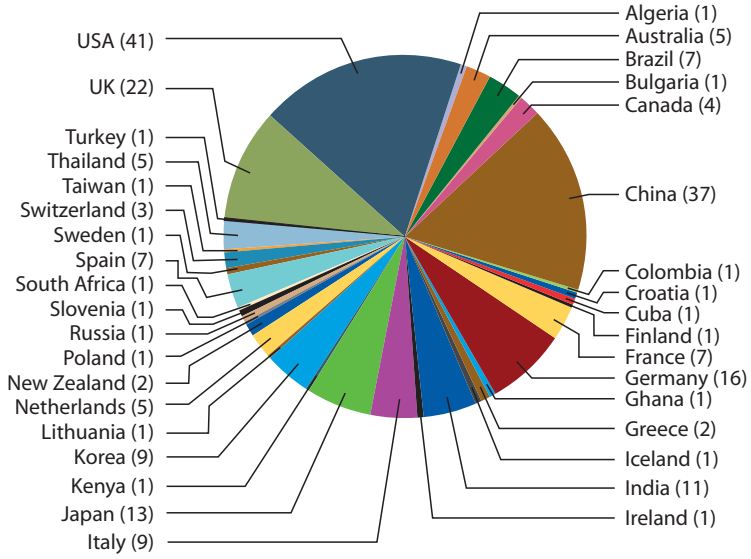
ECMWF is currently providing real-time data to the following research experiments:

- Global Land Data Assimilation System (GLDAS) since 2001
- Euro-Brazilian Initiative for Improving South American Seasonal Forecasts (EUROBRISA) since 2006
- Bangladesh floods since 2006
- Working Group on Numerical Experimentation/Surface Flux Analysis (WGNE/SURFA) since 2007
- Indian monsoon since 2008

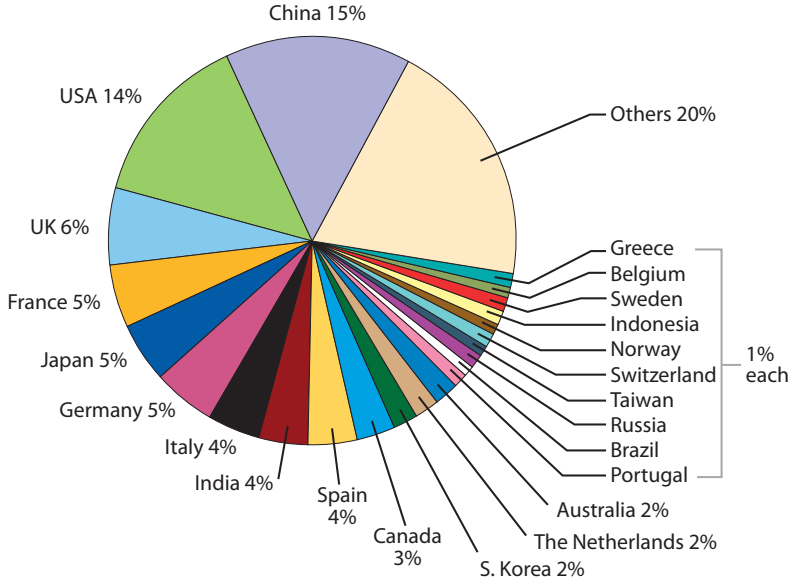
THORPEX/TIGGE

ECMWF continues to contribute actively to the WMO World Weather Research programme on THORPEX. The THORPEX Interactive Grand Global Ensemble (TIGGE) is a key component aimed at enhancing international collaboration between operational centres and academia on the development of ensemble prediction. TIGGE supports the development of a deeper understanding of the contribution of observation, initial and model uncertainties to forecast error. The project will investigate new methods of combining ensembles from different sources and correcting systematic errors. TIGGE enables scientists around the globe to access an archive of operational and research ensemble forecasts from a number of NWP centres.

The TIGGE database now contains global EPS data from ten data providers and holds more than 155 terabytes of data (1 billion fields). Tropical cyclone forecast tracks are also made available to the TIGGE community using an agreed XML format.



Use of the TIGGE database. *The chart shows the country of origin of registered external users of the TIGGE database, which contains global EPS data from ten data providers. There are 223 registered users.*



Users of the ECMWF public data server. *The chart shows the distribution by country of the 11,800 registered users of the ECMWF public data server. The data server provides the research community with access to datasets held at ECMWF.*

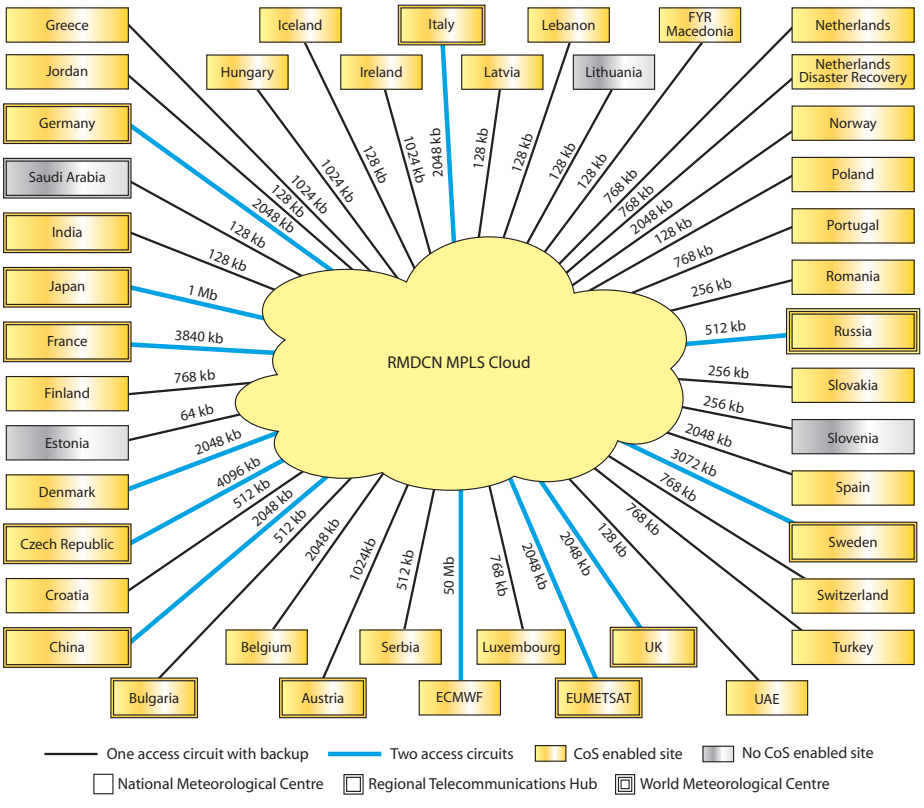
Regional Meteorological Data Communications Network

The Regional Meteorological Data Communications Network (RMDCN) has been in operation since March 2000. It provides a network infrastructure for the connections between ECMWF and its Member States and Co-operating States. In addition it serves most of the GTS connections for WMO Regional Association VI. Over time it has expanded to encompass the Far East with connections to Japan, China and India. The RMDCN is based on state-of-the-art architecture.

ECMWF manages the RMDCN project and monitors the network on behalf of the sites that are connected, following an agreement with WMO.

The RMDCN continues to provide a stable and reliable service, with monthly global availability above 99.9% over the last 18 months. At present the RMDCN is being used operationally by 40 countries plus EUMETSAT and ECMWF.

RMDCN – Regional Meteorological Data Communication Network

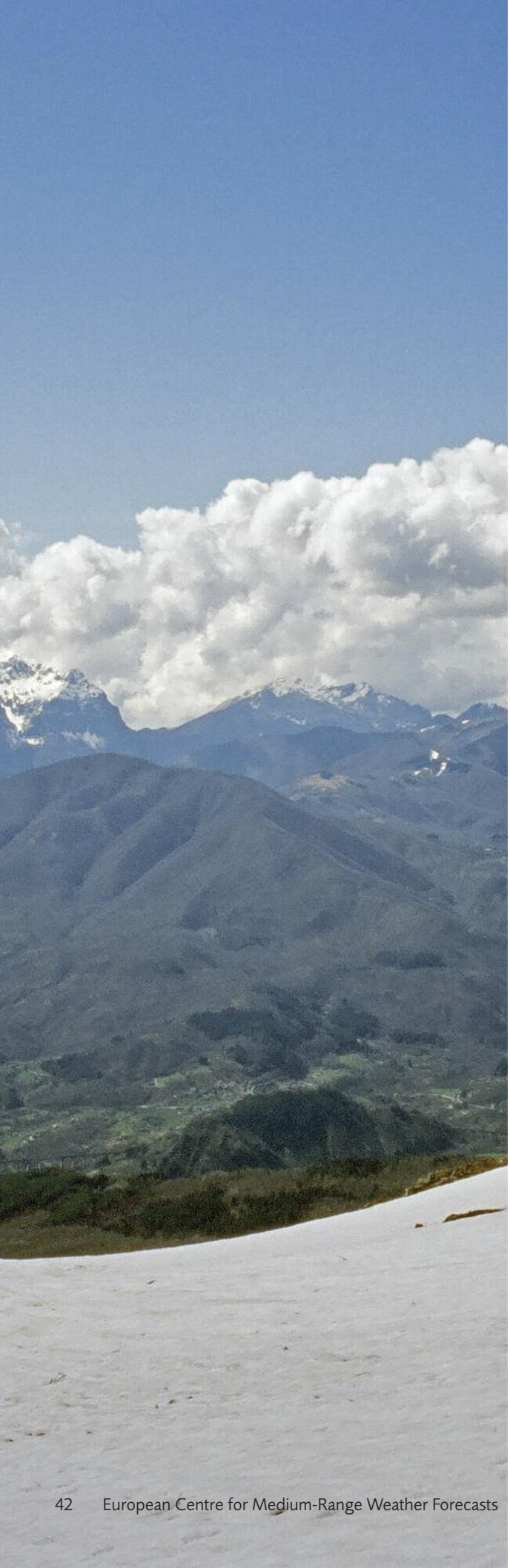


RMDCN configuration at January 2009. *The figure shows the RMDCN configuration in terms of the new MPLS IPVPN network, the types of circuit and the security levels of the 43 connected user sites. CoS refers to Class of Service that allows traffic prioritisation.*

Other activities

The Operations Department continues to support a variety of activities in addition to those described above. These include:

- *Boundary Conditions (BC) Project.* ECMWF continues the operational running of the BC suite in its updated configuration. It is now integrated into the main deterministic forecasting system using 4D-Var for the analysis system.
- *EUMETNET/EUCOS.* ECMWF is now a full partner in the EUMETNET Interoperability Programme. Its aims include defining a common interface between NWP models and post-processing, and harmonising parameters and file formats, with an emphasis on multi-model ensembles.
- *North America/Europe data exchange.* ECMWF takes an active role in facilitating the exchange of observational data between Europe and North America. The European data requirements are compiled and updated annually for discussion with the North American data providers.
- *Support for new satellite missions.* Support continues to be provided to ESA's Earth Explorer Atmospheric Dynamics Mission (ADM-Aeolus). Also ECMWF provides auxiliary data to ESA's Soil Moisture Ocean Salinity (SMOS) mission and for EUMETSAT's JASON-2 mission.



Other activities

ECMWF currently participates in a number of collaborative research programmes run by the European Union and WMO. Also it supports a variety of international meteorological activities. ECMWF's computer resources and forecasting expertise are helping to improve the accuracy of global forecasting methods, develop new technologies for utilising computer and data storage capacity across distant sites, and improve atmospheric monitoring and forecasting for the purposes of environmental and climate research.

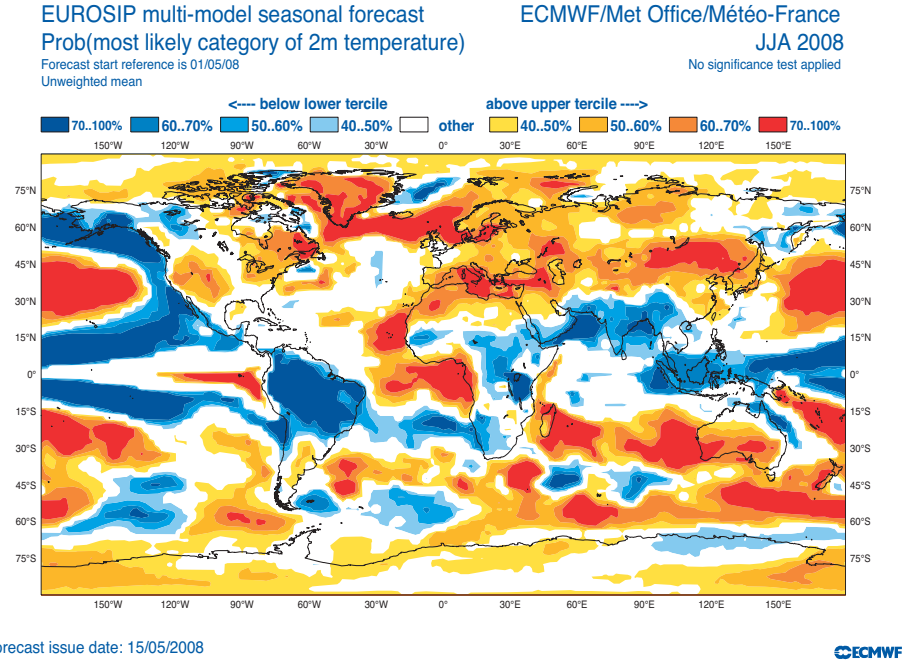
EUROSIP and EUROBRISA

The EUROSIP multi-model seasonal forecasting system continued to run reliably, and has produced graphical products based on multi-model forecasts. It is based on models run at ECMWF, Météo-France and the UK Met Office. The multi-model system provides unified data structures for archiving and disseminating seasonal forecasts, monitoring of individual models and generating multi-model products.

Météo-France System 3 became operational in May 2008, with significant improvements in forecast skill and a more comprehensive set of back integrations; this also benefited the multi-model products.

Forecasts from all three models are archived at ECMWF, and can be accessed subject to the terms of the EUROSIP data policy. In addition ECMWF produces a number of multi-model products which are created from the integrated output of the component models. During 2008, a basic set of numerical multi-model products was added to the ECMWF Catalogue. These multi-model products can be accessed just like any other ECMWF products.

Collaboration with EUROBRISA, a European-Brazilian initiative for improving South American seasonal forecasts, has given encouraging results. EUROBRISA is issuing well-calibrated real-time probabilistic seasonal forecasts for South America and is exploring the downscaling of seasonal forecasts for river flow predictions and use in hydrological and crop models.



Example of a EUROSIP forecast. *ECMWF contributes to the EUROSIP multi-model seasonal forecasting system. The chart shows the forecast for the seasonal mean 2-metre temperature June/July/August 2008 from the EUROSIP system issued in May 2008. The moderate to high probability of anomalously warm temperatures over the Mediterranean, Northern African, Central Asian and Eastern Canadian regions, indicated by the prevalence of orange/red colours, was well predicted. The EUROSIP forecasts are generally consistent with the ECMWF ones although EUROSIP probabilities have typically lower values. The forecast is presented in terms of tercile categories.*

EU-funded projects

BRIDGE

The EU-funded BRIDGE project finished at the end of 2008. BRIDGE was a two-year project to demonstrate the benefits of GRID technology for international co-operation, in particular between Europe and China. The project covers three application areas: pharmaceuticals, aeronautics and meteorology. The final project review will be held at ECMWF in April 2009.

BRIDGE provides the partners involved in the meteorological activity (ECMWF, DWD and the China Meteorological Administration) with an opportunity to address the development of the next phase of the THORPEX Interactive Grand Global Ensemble programme (TIGGE). In this next phase the data archives are distributed over a number of repositories, instead of all being held centrally, but efficient and transparent access to users is maintained.

During the project, a grid infrastructure has been deployed at each partner's site. This offers access to model outputs as well as basic analysis services and plotting facilities. Using the macro languages of METVIEW (ECMWF's meteorological data visualisation and computation software), users can chain these services to compute probabilistic products, such as clusters or EPSgrams, in a distributed fashion over the grid.

DEISA

DEISA is a consortium of leading super-computing centres in Europe that are jointly building a European supercomputing grid facility. The original DEISA project was completed in May 2008 with a very good review from the European Commission. However, the eDEISA project, originally due to finish at the end of May 2008, was extended by 12 months, and a follow-up three-year project named DEISA-2 started in June 2008. Its aim is to support and further develop the distributed high-performance computing infrastructure and services.

ECMWF will focus on the Operations and Technologies work packages of DEISA-2.

- The Operations work package covers the maintenance of the resource information system, a global file system and a common production environment that were deployed in a previous part of the project.
- The Technologies work package includes activities to provide data access and discovery services to the DEISA infrastructure; ECMWF will be mainly concerned with data grid services.

ENSEMBLES

ENSEMBLES is a project that aims to develop an ensemble prediction system for climate change based on the principal state-of-the-art, high-resolution, global and regional Earth-system models developed in Europe. The new system will provide an objective probabilistic estimate of uncertainty in the future climate at the seasonal to decadal and longer time scales. ECMWF is a key partner in ENSEMBLES.

This ensemble prediction system will be used to quantify and reduce the uncertainty in the representation of physical, chemical, biological and human-related feedbacks in the Earth-system (including water resource, land use, and air quality issues, and carbon cycle feedbacks). In addition, the project will maximise the exploitation of the results by linking the outputs of the ensemble prediction system to a range of applications, including agriculture, health, food security, energy, water resources, insurance and weather risk management.

The ECMWF contribution to ENSEMBLES has focused on formulating and testing ways of representing model uncertainty in ensemble forecasts on seasonal and decadal time scales. In doing this, ECMWF scientists have coordinated the creation of new datasets of seasonal and decadal re-forecasts for project partners and others to analyse. These datasets are archived at ECMWF, and are available in part from public data servers.

EURORISK/PREVIEW

For the EURORISK/PREVIEW project a consortium of meteorological services, hydrological institutes and industrial partners are developing integrated solutions for the early warning of severe weather. ECMWF contributes to two aspects of PREVIEW: the demonstration of the feasibility of targeted observations and the development of the European Flood Alert System.

The European Flood Alert System is being developed by the European Commission Joint Research Centre and ECMWF. It is tailored to make use of ECMWF medium-range ensemble forecasts of rainfall for the early warning of severe floods from most large European rivers. Additionally, ECMWF developed new products specifically to meet the needs of hydrologists, for example 'RiverGrams'. Work is progressing to produce these routinely and show the most important variables averaged over river basins.

Also within the EURORISK project, ECMWF developed a web-based Data Targeting System (DTS) that enables forecasters in the Member States to assess the potential impact of additional observations based on the observation sensitivity in the NWP forecasts of the day. The system allows the computation in real time of the geographic areas where additional observations are most likely to influence the forecast in the region of interest. The lead user of the DTS, based at the UK Met Office in Exeter, can use it to issue requests for additional observations from European radiosonde stations, ASAP ships and AMDAR aircraft. More than 1,200 additional radiosonde ascents were requested and deployed via the DTS in 2008.

The DTS was also used to support two THORPEX research field campaigns in 2008: the Norwegian THORPEX-IPY experiment in the Arctic and the THORPEX Pacific Asian Regional Campaign (T-PARC), focusing on tropical cyclones and their transition into mid-latitudes. Later in 2008, the DTS was also used by the MEDEX observational experiment in the Mediterranean.

Co-operation

World Meteorological Organization

ECMWF has enjoyed a long and fruitful association with the World Meteorological Organization (WMO). As well as providing WMO Members with access to a variety of ECMWF products, staff from ECMWF play an active role in the activities of WMO.

In response to a request from the WMO Secretariat, the ECMWF Council at its 68th session (December 2007) agreed to provide a range of forecast products to WMO Members in support of severe marine weather forecasting. These products were added to the web in April. A letter from the Secretary-General of WMO, dated 14 April, to all Permanent Representatives informed them of the availability of these new products and expressed his appreciation and gratitude to ECMWF and its Member States.

ECMWF supported the WMO Member States as the Regional/Specialised Meteorological Centre for global medium-range weather forecasts, focusing on early warning of severe weather. In addition specific support was provided to WMO Regional Association VI and ECMWF actively participated in its relevant bodies.

ECMWF continued to provide special monitoring and forecast products for Africa, in particular the WMO Severe Weather Forecast Demonstration Project in Southern Africa and the African Monsoon Multidisciplinary Analysis (AMMA) project in Western Africa.

Space agencies

ECMWF plays a vital role in identifying requirements for satellite observations, monitoring the quality of those observations and finding effective ways of using them. These activities are based on close and constructive relationships between ECMWF and the operational and research space agencies (e.g. EUMETSAT, ESA, NOAA, NASA and JAXA).

ECMWF holds annual, bilateral meetings with European space agencies. The meeting with EUMETSAT took place on 5 February. The use of EUMETSAT data, in particular from MetOp, was reviewed. Other items included the EUMETSAT fellowships, ECMWF's involvement in the Satellite Application Facilities (SAFs) and the contributions of both organisations to the Group on Earth Observations (GEO) and the Global Monitoring for Environment and Security (GMES) initiative. On 19 March the meeting with ESA allowed each organisation to present its plans and review the projects they have in common. ECMWF routinely monitors and assimilates observations from a number of instruments onboard ENVISAT, and will be active in using data from ESA's ADM-Aeolus and SMOS satellite missions.

In addition to the provision of ECMWF data to EUMETSAT and ESA, governed by co-operation agreements, ECMWF is currently providing real-time data to the following missions for calibration/validation purposes:

- NASA/QuikSCAT (since 1999)
- NASA/CLOUDSAT and CALIPSO (since 2007)
- NASA/AIRS (since 2001)
- UCAR/COSMIC (since 2007)

Global Monitoring for Environment and Security

The Global Monitoring for Environment and Security (GMES) initiative aims to make environmental information more readily available to scientists, policy makers and industry.

A meeting between the European Commission and the meteorological community, represented by the Directors of EUMETNET, EUMETSAT and ECMWF, took place in Brussels on 16 April. It was recognised that the European Meteorological Infrastructure (EMI) can provide important input for defining user requirements and the planning of GMES.

At the meeting of the GMES Advisory Committee (GAC) in Brussels on 25 September there was a very important outcome for ECMWF: the final report of the implementation group for the Atmosphere Core Services was supported. The current GEMS and MACC developments match the requirements outlined in the final report.

The European Commission launched a communication on GMES in November. It includes some crucial elements for the European meteorological community.

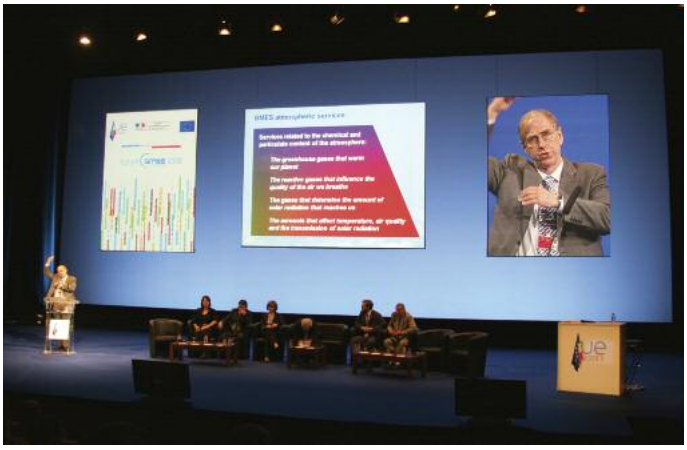
- The role of EUMETSAT as an operational space agency is acknowledged, and EUMETNET is mentioned as one of the existing relevant coordination bodies for in-situ observations.
- ECMWF is mentioned as the likely coordinator of atmospheric services.

Group on Earth Observations

The Group on Earth Observations (GEO) is leading a worldwide initiative to build a Global Earth Observation System of Systems (GEOSS) over the coming years. ECMWF has been a Participating Organization in GEO since it was initiated in 2003. GEOSS consists of a global and flexible network of providers of information that will allow a wide variety of users to have access to tools and data to support decision making.

ECMWF supported the implementation of several tasks in the GEO Work Plan associated with the societal benefit areas of weather, climate, health, energy and water. The contributions from ECMWF are mainly based on its reanalysis data, long-lasting expertise in NWP and Observing System Experiments (OSEs) and TIGGE activities. ECMWF also continued to contribute to the activities of two GEO Committees: the User Interface Working Group, and the Science and Technology Working Group.

The global network of weather monitoring instruments, databases and forecasting models is making a crucial contribution to the emerging GEOSS. In particular, GEOSS is integrating international weather data with Earth observations now emerging in fields such as biodiversity, health, energy and water management.



Adrian Simmons giving a presentation about GMES atmospheric environmental services. *ECMWF contributed to the session about core atmospheric services at an international forum in Lille on 16 and 17 September 2008. This event had been convened under the French Presidency of the European Union Council. In his presentation Dr Simmons (Coordinator for GMES Activities at ECMWF) explained how the atmospheric services combine model simulations with observations to monitor the composition of the Earth's atmosphere and predict regional air quality.*

EUMETNET SRNWP Interoperability Project

ECMWF has been an active partner in the EUMETNET Short Range Numerical Weather Prediction (SRNWP) Interoperability project since 2008. The three-year project is managed by the UK Met Office and combines efforts from the three European Limited Area Model (LAM) consortia and the European providers of lateral boundary conditions from global atmospheric models.

The first SRNWP Interoperability project meeting was held at ECMWF in December 2008. ECMWF contributed with its experience from the TIGGE project, where output from ten partners is successfully encoded in a common data format (GRIB-2). It was agreed during the meeting to also choose GRIB-2 as the common data format for field data in this project and use ECMWF's software as the primary tool for encoding and decoding.

ECMWF volunteered to set up a server for sharing sample data from all participating partners and assist with the encoding of the different datasets in GRIB-2.

GEMS/MACC

As a contribution to GMES, the EU-funded project GEMS began in 2005. It is concerned with global and regional Earth-system monitoring using satellite and in-situ data. GEMS has developed an atmospheric service that provides global monitoring of greenhouse gases, reactive gases and aerosols, and produces short- and medium-range forecasts of air quality and pollution patterns, with an emphasis on Europe. The 51-month project is coordinated by ECMWF, which is also responsible for developing and operating the global assimilation and forecasting system for atmospheric composition.

Much effort has been dedicated to the continuation of the GEMS services. This included, in particular, the negotiations for the Monitoring Atmospheric Composition and Climate (MACC) project and significant contributions to the various groups that are preparing the future GMES Atmospheric Services (GAS).

The MACC project was proposed to the European Commission in June 2007 and contract negotiations continued through 2008. MACC is a successor not only to GEMS, but also to PROMOTE, which is an ESA-funded project of the GMES Service Element. MACC is expected to start in June 2009.

MACC partners, products and services

The project Monitoring Atmospheric Composition and Climate (MACC) was proposed by a partnership that comprises 46 national institutes from 18 European States, plus ECMWF and the EU's Joint Research Centre. Partners include 11 Meteorological Services from Member and Co-operating States of ECMWF. Supporting organisations include EUMETSAT and WMO. ECMWF is the project coordinator and leader of components on global data assimilation, production and services, data acquisition and emissions from fires.

MACC will provide a range of data products and services:

- Satellite-data retrievals from various instruments for several aspects of atmospheric composition.
- Global analyses and reanalyses of greenhouse gases, reactive gases and aerosols.
- Global forecasts of reactive gases and aerosols.
- Estimates of global climate forcing, emissions and sinks.
- Regional multi-model forecasts and assessments of air quality.
- Specific services for stratospheric ozone, ultraviolet radiation and solar-energy resources and in support of health protection.
- Estimates of long-range pollutant transport, source attribution, evaluation of control strategies and support of international studies.

Education and training

Scientists and meteorologists from Member States, Co-operating States and WMO Members participate in ECMWF's extensive education and training programme to enhance their understanding of NWP and the ECMWF computer facilities.

Use of Computing Facilities

Six independent modules of the course on 'Use of Computing Facilities' were run at ECMWF.

- Introduction to SMS/XCDP (11–12 February)
- GRIB API: Library and tools (13–14 February)
- Introduction to new users/MARS (25–29 February)
- MAGICS (3–4 March)
- METVIEW (5–7 March)
- Use of supercomputing resources (22–16 September)

A total of 76 participants from 23 Member States, Co-operating States and other organisations attended the various modules. Particularly well attended was the new module on the use of the GRIB API. The module on 'Use of supercomputing resources' contained an introduction to the new IBM High Performance Computing Facility. Material presented during the various modules has been made available on the ECMWF website.

Use and Interpretation of ECMWF Products

The aim of this course is to increase the ability of participants to examine and assess ECMWF output products, and to produce user-oriented products from gridpoint data. The course was run twice from 10 to 14 March and 2 to 6 June.

An additional course was run from 13 to 17 October specifically for participants from WMO National Meteorological and Hydrological Services that are not ECMWF Member States or Co-operating States. This course had 11 participants.

Numerical Weather Prediction

ECMWF conducts an NWP training course each year. This is designed to provide meteorologists from Member States and Co-operating States with advanced training in NWP. The training course consisted of the following modules.

- Numerical methods, adiabatic formulation of models (31 March–8 April)
- Predictability, diagnostics and extended-range forecasting (9–18 April)
- Data assimilation and use of satellite data (21–30 April)
- Parametrization of diabatic processes (12–22 May)

A total of 200 applications for one or more modules of the meteorological training courses were received from 15 Member States. In addition, there were 17 applications from Co-operating States and organisations with which ECMWF has a working agreement.

	Met OP (I & II)	Met NM	Met PR	Met DA	Met PA
Member States/ Co-operating States	73	22	28	48	35
Non-Member States	0	4	6	1	0
Total applications	73	26	34	49	35
Total attendees	48	18	27	38	32

Number of attendees at the 2008 meteorological training courses.
Of the non-Member State applications, only the one for Met DA attended.
***Met OP**: Use and interpretation of ECMWF products.*
***Met NM**: Numerical methods, adiabatic formulation of models.*
***Met PR**: Predictability, diagnostics and extended-range forecasting.*
***Met DA**: Data assimilation and use of satellite data.*
***Met PA**: Parametrization of diabatic processes.*

Forecast Products Users' Meeting

Each year ECMWF organises a meeting of users of its medium-range and extended-range forecast products. In 2008 the Forecast Products Users' Meeting was held at ECMWF from 11 to 13 June. Around 50 forecast users participated, including representatives from National Meteorological Services and commercial users of ECMWF products.

From the presentations and discussions it was clear that ECMWF products are used in a wide range of official duties and commercial applications. An increasing amount of data is available to forecasters either on their own internal web or via their workstation display systems. In addition, the ECMWF website is considered a very important source of forecast information for medium-range, monthly and seasonal forecasts. There is thus a continuing requirement for a reliable web service at ECMWF, including from countries investing in their own display systems.

The use of products from the EPS continues to grow and several countries plan to develop their use of ensemble products to supplement those from the deterministic model. Users reported that the monthly forecast is being used to advise government departments, especially on hydrological issues. Also there is increased use of the seasonal forecasts, providing outlooks to the public and responding to commercial demands.

Users confirmed their requirements for the ECMWF products currently under development, including the tracking of tropical cyclones that develop during the forecast and products related to extratropical cyclones. Additional requests from users at this meeting included a further extension of the range of parameters for the EPSgrams and EFI as well as the extension of the EFI to longer forecast ranges. Also there was an interest in the development of products for additional weather parameters, such as freezing level, cloud base and visibility.

New products implemented in 2008 and presented at the Users' Meeting

- Additional pressure levels for deterministic model
- Vertical velocity in model coordinates ("etadot")
- New wave products (maximum wave height)
- Ensemble mean and spread added to the web
- EPSgrams: new parameters (wind direction, waves), revised precipitation scale
- Two additional seasonal tropical storm products to give a more detailed outlook for the tropical cyclone season
- Monthly-mean SST area averages located over the Pacific, Atlantic and Indian Oceans from seasonal forecast
- Revised set of EUROSIP seasonal forecast products

Product development in progress and requests for new products made at the meeting

- Tracking of tropical cyclones developing during forecast
- Review of clustering: options for classification of forecasts by weather types or regimes
- Percentiles (EPS and model climate)
- Clickable EFI map to show EPS and climate distributions at a point
- Climate information on EPSgrams and EFI maps
- More parameters for EPSgrams and EFI; extension of EFI beyond day 5
- Extra-tropical cyclone products
- Collaboration with Meteoalarm on heat wave indices
- Additional weather parameters e.g. freezing level, cloud base, visibility
- Coupling of Limited Area Wave model to EPS
- Soil moisture levels 1 and 2 for monthly and seasonal forecasts

Other requests

- Zoomable maps: display more detail for smaller regions on web plots
- More information on impact of model changes on weather parameters

Seminar on 'Parametrization of Subgrid Physical Processes'

Increasingly, models are being developed and used at higher resolutions. However, many physical processes remain unresolved and need to be parametrized. Even the highest resolution limited-area models still need a parametrized representation of shallow convection, turbulence, microphysics, radiation and land surface processes. Schemes for deep convection and subgrid orography will still be needed in the foreseeable future for global NWP and climate models. Such issues were considered at this year's seminar that was held from 1 to 4 September.

At the seminar emphasis was put on the interaction of parametrized processes with the resolved dynamics. Increasingly, parametrization work focuses on how processes interact with each other and the dynamics, and whether the feedbacks are represented realistically. This is particularly relevant at very high resolution where part of the process (e.g. convection) might be resolved. Interactions and feedbacks act at all scales from planetary and synoptic scales to mesoscales. Examples include cloud/radiation interaction with the general circulation, boundary layer turbulence with cyclones, land surface processes with precipitation at the mesoscale and the interaction of convection with tropical variability. Consideration was also given to the role of cloud-resolving models in studying interactions and developing parametrization schemes, and the need for stochastic components in schemes.

Workshops and meetings

Workshops and meetings provide the opportunity for experts from around the world to get together to exchange ideas, discuss the latest research and debate future developments. These events help guide the research and development activities at ECMWF.

Events organised by ECMWF

Meetings of Security Representatives and Computing Representatives

The annual meetings of the Security Representatives and the Computing Representatives took place at ECMWF from 13 to 16 May 2008.

Security Representatives represent their organisation in matters relating to computer and network security, and receive information about ECMWF's security arrangements. Twenty-three external participants attended the Security Representatives' Meeting. Technical issues were addressed as well as various aspects of security (e.g. Security Policy, Quality Management).

The Computing Representatives' Meeting provided a forum where views and experiences were exchanged between ECMWF and the Member States and Co-operating States. It was attended by 25 delegates who represent their organisation in matters relating to the use of ECMWF computing facilities. Recent changes and the future development of ECMWF's computing service were discussed, as well as developments in the computing facilities in the delegates' organisations. Two specific discussions on 'Experiences in the transition from Research to Operations' and on 'Disaster mitigation' were held.

Applications of GPS Radio Occultation Measurements

A joint ECMWF/EUMETSAT GRAS-SAF workshop on 'Applications of GPS Radio Occultation Measurements' was held at ECMWF from 16 to 18 June. The workshop brought together many of the leading international experts in the use of GPS radio occultation measurements for reanalysis/climate studies and operational NWP.

It was recognised that GPS radio occultation measurements are an important new addition to the global observing network: they have good vertical resolution, an all-weather capability and long-term stability. Also, forecast impact studies at a number of operational NWP centres have demonstrated that they provide useful temperature information. The measurements can be assimilated without bias correction and therefore have the potential to improve the bias correction of satellite radiance measurements. Recent studies have also shown that they provide useful information on the height of the planetary boundary layer. Furthermore, the long-term stability of the GPS radio occultation measurements suggests that they will have important applications in detecting a climate signal and model testing.

The topics for the workshop included the status of current and future missions, the latest developments in assimilation methods employed at the operational centres, the retrieval of planetary boundary layer information and recent work on reanalysis and climate applications.

Participants in the ECMWF/EUMETSAT GRAS-SAF Workshop. *The workshop was attended by 15 invited lecturers, 2 ECMWF lecturers, and 13 participants from the Member States and many from ECMWF.*

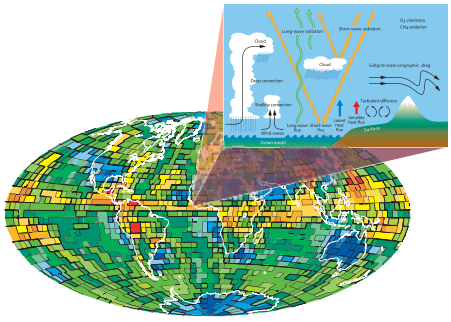
Use of High Performance Computing in Meteorology

Every second year ECMWF hosts a workshop on 'Use of High Performance Computing in Meteorology'. The 13th workshop in this series took place from 3 to 7 November 2008 and was attended by over 100 participants from Meteorological Services, research institutions and computer vendors, coming from 25 different countries in Europe, Asia, Africa, the Americas and Australia.

The emphasis of this workshop was on running meteorological applications at sustained teraflops performance in a production environment, and in particular on the future scalability of NWP codes and the tools and development environments to facilitate this.

At the workshop there were 36 presentations covering a wide range of topics including:

- High performance computing at various forecasting centres.
- Current and future products from vendors of supercomputers.
- Developments in parallel computing techniques.
- Tools to exploit the power of supercomputers.



Workshop on 'Use of High Performance Computing in Meteorology'. *This is the logo for the workshop which illustrates the computational imbalance in IFS physics for a T799 model running with 2048 processors over a six-hour period. See the text for more information.*

Atmosphere-Ocean Interaction

A workshop on 'Atmosphere-Ocean Interaction', which took place from 10 to 12 November 2008, addressed the requirements for ocean-atmosphere coupling from the very short time scales to the monthly time range with focus on ocean near-surface processes.

Questions discussed included:

- Which processes need to be taken into account (e.g. ocean waves, currents, diurnal cycle of SST, ocean mixed layer dynamics and horizontal resolution of sea surface temperatures)?
- What is the impact of air-sea processes on atmospheric phenomena, including extreme events (e.g. tropical cyclones, extratropical explosive genesis, monsoons and Madden-Julian Oscillation)?
- Which models are the most appropriate at different time scales, and what are the implications for seamless forecasting?

About 35 leading scientists from outside ECMWF participated in the workshop. The workshop had the usual format with presentations followed by working groups that considered (a) atmosphere-ocean interaction processes and (b) impact of air-sea interaction on the atmosphere. Consideration was given to three time scales: short to ten days, monthly, and seasonal.

Workshop on 'Use of GIS/OGC Standards in Meteorology'. *The workshop involved representatives from commercial and public services including OGC, WMO, INSPIRE, EUROCONTROL and National Weather Services.*

Use of GIS/OGC Standards in Meteorology

Météo-France, the UK Met Office and ECMWF jointly organised a dedicated workshop on the 'Use of GIS/OGC Standards in Meteorology'. The workshop was held at ECMWF from 24 to 26 November 2008, and was a great success with over 100 participants from various disciplines and organisations worldwide.

The aim of this workshop was to review the use of OGC (Open Geospatial Consortium) standards in geo-sciences in Europe and worldwide and to promote collaboration between meteorological services in order to define a set of common standards that will enhance interoperability.

The outcome of the workshop is the establishment of a roadmap for further collaborations within the meteorological community and the setting up of testbeds to guarantee the interoperability of OGC compliant web services for meteorological data and visualisation. This work should lead to a set of recommendations to WMO.

Events hosted by ECMWF

Meteoalarm

The first meeting of the Meteoalarm Impact Damage Index Working Group was held at ECMWF on 4 April 2008. It was convened by the Meteoalarm Program Manager, Michael Staudinger, and attended by experts from six National Meteorological Services involved in Meteoalarm, and representatives from ECMWF.

The aim of the meeting was to initiate the development of new warnings to extend the current Meteoalarm system. It was agreed that the initial work would focus on early warnings (up to six days ahead) of extreme heat likely to affect health. Several of the experts at the meeting agreed to develop a suitable index.

World Modelling Summit for Climate Prediction

The 'World Modelling Summit for Climate Prediction' was hosted by ECMWF from 6 to 9 May 2008. The event was fully funded through wide-ranging international sponsorship.

The purpose of the summit was to:

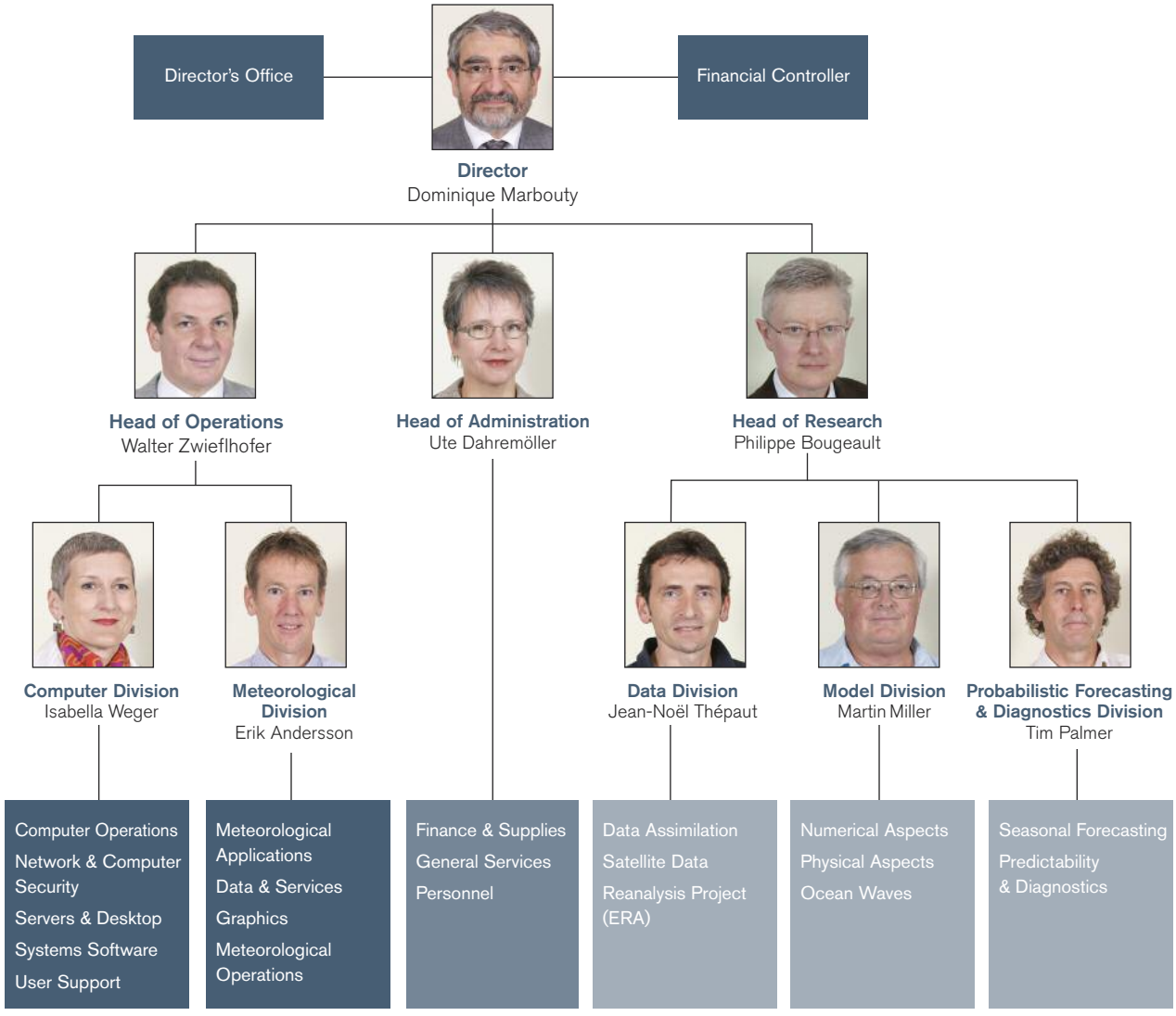
- Bring together leading scientists from all over the world to rigorously assess and discuss the capabilities of current model systems to fulfil the great expectations society has of them for guiding future adaptation and mitigation activities.
- Develop a visionary strategy that will enable and accelerate progress in the modelling and prediction of regional climate change and variations on time scales from days to decades.
- Recommend a realistic roadmap for how this revolution in climate prediction can be achieved for the benefit of society.

More information about the summit can be found on page 33.

Administrative matters

To ensure that ECMWF can fulfil its strategic aims, it is necessary that appropriate facilities and funding are in place. In addition the recruitment and retention of staff, coupled with staff exchanges between ECMWF and its Member States, play a key role in maintaining ECMWF as the world leader in global weather forecasting.

ECMWF's Organisation at 31 December 2008



Personnel

ECMWF's Director, appointed by the Council, is responsible for implementing the organisation's objectives and oversees three departments: Operations, Research and Administration.

At the end of December 2008, ECMWF employed 154 staff members and 75 consultants. In addition, there were 35 contractors on site. During the year, 6 staff members were recruited, 3 staff members left the organisation and 5 staff members retired.

ECMWF employs many talented European meteorologists to ensure that the increasingly challenging and demanding needs of the Member States and other users of ECMWF products continue to be met. In addition the Centre has highly-capable staff with a wide variety of expertise who support operational activities and administration.

Recruitment

ECMWF operates an equal opportunities policy. Staff and consultants are recruited solely on the basis of their qualifications and experience, regardless of their gender, marital status, race or religion.

The proportion of female staff employed at ECMWF at the end of 2008 was 50% for B-grades and 17% for A-grades. In comparison with 2007, these figures are stable and show a significant increase in A-grades compared to 2002.

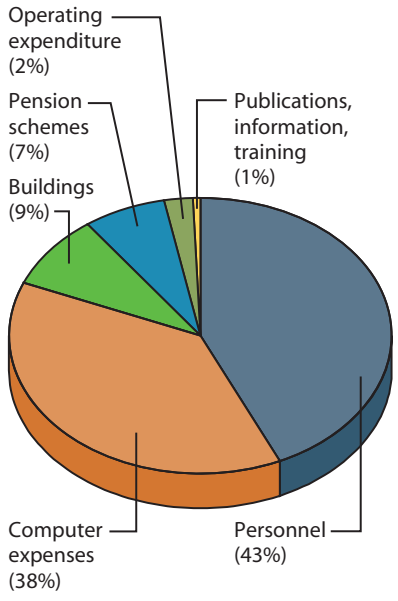
Year	B-grades	A-grades
2002	51%	11%
2003	47%	13%
2004	48%	14%
2005	49%	16%
2006	50%	17%
2007	49%	17%
2008	50%	17%

Proportion of female staff employed by ECMWF during the period 2002–2008.

Finance

ECMWF's budget for 2008 was £31,934,700. This included contributions from Member States and Co-operating States amounting to £30,491,200 and miscellaneous revenue of £1,443,500. The main expenditure was on the high performance computer infrastructure and on staff.

The Centre is in the process of setting up a simple activity-based costing system which will deliver its first results in 2009. As well as being used as a management tool, the results will be used as a basis for calculating direct and overhead costs for externally funded projects.



Expenditure 2008 by category.

Pension matters

When the Centre was set up in 1975, it was decided to enter the staff contributions to the Budgetised Pension Scheme as revenue in ECMWF's budget, as ECMWF had no pensioners at that time. The Member States' contributions were only notional.

Now, 30 years later, more and more ECMWF staff are retiring , and ECMWF already pays benefits to 72 pensioners. The increasing number of pensioners leads to a constant increase in pension payments for which no reserve has been built up. According to actuarial studies, ECMWF would require additional annual budget increases in the region of 2% to 3% just to cover the increase in pension payments for staff covered in the Budgetised Pension Scheme. This was considered to be unsustainable in the long term and was perceived as a serious threat to the financial stability of the Centre.

The problem of funding the Budgetised Pension Scheme has been extensively discussed in various committees. The Finance Committee, at its session in April 2008, agreed to set up a working group chaired by Detlev Frömming (Germany) to consider this problem in more depth. The Working Group analysed different payment scenarios which were all based on the results of the last actuarial study.

At its session in October 2008, the Finance Committee considered the report from the Working Group on Pensions. A majority of delegations stressed the importance of not postponing the decision and recommended that the Council should adopt a long-term solution to fund the Budgetised Pension Fund.

At its 70th session in December 2008, the Council unanimously adopted an increase in funding of £2,150,000 in each of the years 2011, 2021 and 2031 to fund the Budgetised Pension Scheme. The Council requested the Secretariat to review the underlying assumptions for this solution on a regular basis, also taking into account future actuarial studies, and to report to the Council on the findings.

This stepped increase in funding constitutes a long-term solution to the funding problem in the Budgetised Pension Scheme as these increases will be sufficient to cover the annual increases in pension payments provided that the underlying assumptions for calculation of the future liabilities of the scheme are correct. This is an important decision for ECMWF, as it will significantly reduce ECMWF's year-on-year annual budget requirements and bring them more in line with annual inflation.

Amendments to the Convention

ECMWF was founded on 1 November 1975 with the purpose of developing a European capability for medium-range weather forecasting and providing medium-range weather forecasts to its Member States. The Convention establishing ECMWF sets out its core objectives and duties. It restricts membership to the founding 18 Member States.

In April 2005 the Council, ECMWF's governing body, in a landmark decision unanimously agreed to amend the Convention to facilitate ECMWF's activities as leading provider of global medium-range weather forecasts. All Member States must notify their acceptance of the amendments to the depositary of the ECMWF Convention, the Secretariat of the Council of the European Union, before the amendments can enter into force. By the end of 2008, 13 Member States had done so.

- Finland: 12 July 2005
- Denmark: 17 March 2006
- Norway: 23 June 2006
- United Kingdom: 22 December 2006
- The Netherlands: 19 March 2007
- Switzerland: 3 May 2007
- Italy: 2 July 2007
- Spain: 6 July 2007
- Luxembourg: 12 July 2007
- France: 23 July 2007
- Sweden: 4 September 2007
- Germany: 29 January 2008
- Greece: 6 March 2008

Once ratified by all the current Member States, the amended Convention will:

- Allow new Member States to join the organisation.
- Enlarge ECMWF's mission to cover the monitoring of the Earth-system.
- Broaden the possibility for activities funded externally.

Appendices

ECMWF's Member States and Co-operating States

Member States

Austria, Belgium, Denmark, Germany, Greece, Finland, France, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

Co-operating States

Croatia, the Czech Republic, Estonia, Hungary, Iceland, Latvia, Lithuania, Montenegro, Morocco, Romania, Serbia, Slovakia and Slovenia.

Co-operating States have full access to ECMWF real-time products, archive data and software tools, as well as access to ECMWF training facilities.

Co-operation agreements

ECMWF has co-operation agreements with the following organisations:

- World Meteorological Organization (WMO)
- European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)
- African Centre of Meteorological Applications for Development (ACMAD)
- ALADIN (Météo-France)
- Joint Research Centre (JRC) of the European Commission
- Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO)
- Executive Body of the Convention on Long-range Transboundary Air Pollution (CLRTAP)
- European Space Agency (ESA)

Council and Committees

As ECMWF's governing body, and comprising two representatives from each Member State, the Council adopts measures that implement the Convention. Its responsibilities include admission of new members, authorising the Director to negotiate and conclude co-operation agreements, determining the annual budget and the scale of financial contributions of the Member States, adopting the Financial Regulations and the Staff Regulations and pursuing the Centre's long-term strategy and programme of activities.

ECMWF Council 69th session in Reading on 9 and 10 June 2008

For the first time, a representative from the European Commission addressed a Council session. Dr Paul Weissenberg (Director for Aerospace, Security, Defence and Equipment) emphasised that the European Commission regards ECMWF as an asset in the context of the 'Global Monitoring for Environment and Security' (GMES). He noted that the core atmospheric services could be built upon the Centre's leadership.

The Council:

- Underlined the need to demonstrate vis-à-vis the European Commission that the European Meteorological Infrastructure (EMI), comprising ECMWF, EUMETSAT and European National Meteorological Services (EUMETNET), should play a prominent role within GMES.
- Unanimously authorised the Director to negotiate an agreement for scientific and technical co-operation with Tunisia.
- Unanimously agreed to add monthly forecasts to the catalogue of archived data and approved some additions to the catalogue of real-time products.

ECMWF Council 70th session in Reading on 2 and 3 December 2008

The Council:

- Unanimously authorised the Director to start negotiations on full membership with those States that have concluded a co-operation agreement for eventual accession to the ECMWF Convention and with EU Member States that wish to accede to the ECMWF Convention.
- Unanimously adopted the updated "Four-Year Programme of Activities" for the period 2009–2012.
- Agreed that Member States' contributions to the budget 2009 would increase by 19.28% over the budget 2008.
- Unanimously adopted the Member States' scale of contributions for the years 2009–2011.
- Decided on a long-term solution to the funding problem in the Budgetised Pension Scheme.
- Agreed that the ECMWF funded RMDCN basic package for Member States be upgraded.
- Unanimously approved that, during GMES pre-operations, access by the GMES Core Services to ECMWF data and products required as input for the services will be free of information charge on the understanding that each consortium member within those services signs a licence with ECMWF.

Member States' representatives to Council Sessions

President: Adérito Vicente Serrão (Portugal) **Vice-President:** Wolfgang Kusch (Germany)

Participants in the 69th and 70th sessions of Council

State	Representatives	Advisers
Austria	Fritz Neuwirth	
Belgium	Henri Malcorps	Werner Verschueren
Denmark	Peter Aakjaer, Leif Laursen	Carsten Simonsen
Finland	Petteri Taalas, Juhani Damski	Mikko Alestalo
France	Pierre-Etienne Bisch, Philippe Veyre	
Germany	Wolfgang Kusch, Detlev Frömming	Franz Berger
Greece	Odysseas Galanopoulos, Ioannis Papageorgiou, Theagenis Charantonis	
Ireland	Declan Murphy, Liam Campbell	
Italy	Massimo Capaldo, Pierluigi Cascioli	Domenico Scordato
Luxembourg	Claude Alesch	
The Netherlands	Frits Brouwer	
Norway	Anton Eliassen, Roar Skålin	
Portugal	Adérito Vicente Serrão, Teresa Abrantes	
Spain	Jesus Patan, Beatriz Navascues, Manuel Palomares	
Sweden	Maria Ågren, Ilmar Karro	
Switzerland	Daniel Keuerleber-Burk, Alex Rubli, Peter Binder	
Turkey	Mustafa Eldemir, Mehmet Caglar, Fatïh Büyükkasabbaşi	
United Kingdom	John Hirst, Alan Dickinson	Alastair Price

Policy Advisory Committee (PAC)

The PAC provides the Council with opinions and recommendations on any matters concerning ECMWF policy submitted to it by the Council, especially those arising out of the Centre's four-year programme of activities and long-term strategy.

Chair: Fritz Neuwirth (Austria)
Vice-Chair: Maria Ågren (Sweden)

Participants in the 26th session of the PAC

State	Representatives
Austria	Fritz Neuwirth
Finland	Mikko Alestalo
Germany	Wolfgang Kusch Detlev Frömming* Franz Berger*
Italy	Sergio Pasquini
The Netherlands	Piet de Wildt
Spain	Manuel Palomares
Sweden	Ilmar Karro
United Kingdom	Mike Gray

* Advisers

Finance Committee (FC)

The FC provides the Council with opinions and recommendations on all financial matters submitted to the Council and exercises the financial powers delegated to it by the Council.

Chair: Monika Köhler (Austria)
Vice-Chair: Sergio Pasquini (Italy)

Participants in the 80th and 81st sessions of the FC

State	Representatives
Austria (observer)	Monika Köhler
France	Christine Mengus
Germany	Detlev Frömming
Greece (observer)	Efstratios Karnahoritis
Italy	Sergio Pasquini Antonio Bartolini
The Netherlands (observer)	Piet de Wildt
Spain (observer)	Manuel Palomares
Sweden (also representing Denmark, Ireland, Norway, and Finland)	Eva Edelind
Switzerland (also representing Austria, Belgium, The Netherlands, and Luxembourg)	Peter Morscher
Turkey (also representing Greece, Portugal and Spain)	Fatïh Kocaman, Gülçiçek Őzkan, Alper Güser
United Kingdom	Paul Mundy Alastair Price Mike Gray

Scientific Advisory Committee (SAC)

The SAC provides the Council with opinions and recommendations on the draft programme of activities of the Centre drawn up by the Director and on any other matters submitted to it by the Council. SAC members are appointed in their personal capacity and are selected from among the scientists of the Member States.

Chair: Gerhard Adrian
Vice-Chair: Martin Ehrendorfer, Heikki Järvinen

Participants in the 37th session of the SAC

Members
Gerhard Adrian
François Bouttier
Luigi Cavaleri
Martin Ehrendorfer
John Eyre
Hans Huang
Heikki Järvinen
Hennie Kelder
Jochem Marotzke
Ernesto Rodriguez-Camino
Julia Slingo
Michael Tjernström

Technical Advisory Committee (TAC)

The TAC provides the Council with advice on the technical and operational aspects of the Centre including the communications network, computer system, operational activities directly affecting Member States, and technical aspects of the four-year programme of activities.

Chair: Alan Dickinson (United Kingdom)
Vice-Chair: Bernard Strauss (France)

Participants in the 39th session of the TAC

State	Representatives
Austria	Georg Kaindl
Belgium	Daniel Gellens
Denmark	Leif Laursen
Finland	Juhani Damski
	Kimmo Aaltonen
France	Jean-Marie Carrière
Germany	Dieter Schröder
Greece	Anastassios Anthis
Ireland	Paul Halton
Italy	Massimo Ferri
The Netherlands	Toon Moene
	Hans den Braber
Norway	Jens Sunde
	Roar Skålin
Portugal	Vanda Costa
Switzerland	Stefan Sandmeier
	Thomas Egli
Sweden	Mikael Hellgren
	Håkan Borg
United Kingdom	Alan Radford
	Alan Dickinson
	Nick Grahame
Co-operating State representatives	
Croatia:	Čedo Branković
Hungary:	Istvan Ihász
Serbia:	Ljiljana Dekic
Slovakia:	Jozef Vivoda

Advisory Committee for Data Policy (ACDP)

The ACDP provides the Council with opinions and recommendations on matters concerning ECMWF Data Policy and its implementation.

Chair: Colin Cuthbert (United Kingdom)
Vice-Chair: Klaus Haderlein (Germany)

Participants in the 9th session of the ACDP

State	Representatives
Austria	Monika Köhler
Denmark	Søren E. Olufsen
Finland	Lea Leskinen
France	Philippe Santoni
Germany	Klaus Haderlein
Greece	Theodoros Kolydas
Ireland	Joseph Bourke
Italy	Paolo Capizzi
The Netherlands	Ton Donker
	Frank Lantsheer
Norway	Lillian Svendsen
Spain	Manuel Palomares
Sweden	Marcus Flarup
United Kingdom	Colin Cuthbert
	Alastair Price
Co-operating State representatives	
Croatia	Branka Ivancan-Picek
Slovakia	Vladimir Pastircak

Advisory Committee for Co-operating States (ACCS)

The ACCS provides the Council with opinions and recommendations on the Centre's programme of activities, and on any matter submitted to it by the Council.

Chair: Ivan Čačić (Croatia)
Vice-Chair: Ion Sandu (Romania), Laszlo Bozo (Hungary)

Participants in the 14th session of the ACCS

Co-operating State representatives	
Croatia	Ivan Čačić, Čedomir Brankovič
Estonia	Rein Kärner
Hungary	István Ihász
Latvia	Inita Stikute
Slovakia	Martin Benko
Slovenia	Jožef Roškar

Publications in 2008

(Visit: www.ecmwf.int/publications/)

Technical Memoranda published in 2008

543 **Orr**, **A.** and **P. Bechtold**: Improvement in the capturing of short-range warm season orographic precipitation in the ECMWF model. *March 2008*

546 **Vidard**, **A.**, **M.A. Balmaseda** and **D. Anderson**: Assimilation of altimeter data in the ECMWF ocean analysis system. *March 2008*

547 **Richardson**, **D. J. Bidlot**, **L. Ferranti**, **A. Ghelli**, **G. van der Grijn**, **M. Leutbecher**, **F. Vitart** and **E. Zsoter**: Verification statistics and evaluations of ECMWF forecasts in 2006–2007. *January 2008*

548 **Park**, **Y-Y.**, **R. Buizza** and **M. Leutbecher**: TIGGE: preliminary results on comparing and combining ensembles. *January 2008*

549 **Lopez**, **P.**: A 5-year 40 km resolution global climatology of super-refraction for ground-based radar meteorology. *January 2008*

550 **Casado**, **M.J.**, **M.A. Pastor** and **F.J. Doblas-Reyes**: Euro-Atlantic circulation types and modes of variability in winter in ERA-40 and NCEP reanalysis. *January 2008*

551 **Jung**, **T.** and **M. Leutbecher**: Scale-dependent verification of ensemble forecasts. *January 2008*

552 **Janssen**, **P.A.E.M.**, **S. Abdalla**, **L. Aouf**, **J.-R. Bidlot**, **P. Challenor**, **D. Hauser**, **H. Hersbach**, **J.-M. Lefevre**, **D. Vandemark**, **P. Queffeulou** and **Y. Quilfen**: 15 years using altimeter sea state products. *February 2008*

553 **Taylor**, **J.W.**, **P.E. McSharry** and **R. Buizza**: Wind power density forecasting using ensemble predictions and time series models. *February 2008*

554 **Hersbach**, **H.**: CMOD5.N: A C-band geophysical model function for equivalent neutral wind. *April 2008*

555 **Wilkinson**, **J.M.**, **R.J. Hogan**, **A.J. Illingworth** and **A. Benedetti**: Use of a lidar forward model for global comparisons of cloud fraction between the ICESat lidar and the ECMWF model. *February 2008*

556 **Bechtold**, **P.**, **M. Koehler**, **T. Jung**, **F. Doblas-Reyes**, **M. Leutbecher**, **M.J. Rodwell**, **F. Vitart** and **G. Balsamo**: Advances in simulating atmospheric variability with the ECMWF model: from synoptic to decadal time-scales. *February 2008*

557 **Pappenberger**, **F.**, **J. Bartholmes**, **J. Thielen** and **E. Anghel**: TIGGE: Medium range multi model weather forecast ensembles in flood forecasting (a case study). *January 2008*

558 **Pappenberger**, **F.** and **R. Buizza**: The skill of ECMWF precipitation and temperature predictions in the Danube basin as forcings of hydrological models. *December 2008*

559 **Buizza**, **R.**: Comparison of a 51-member low-resolution (TL399L62) ensemble with a 6-member high-resolution (TL799L91) lagged-forecast ensemble. *March 2008*

560 **Doblas-Reyes**, **F.J.** , **A. Weisheimer**, **M. Déqué**, **N. Keenlyside**, **M. McVean**, **J.M. Murphy**, **P. Rogel**, **D. Smith**, **T.N. Palmer**: Addressing model uncertainty in seasonal and annual dynamical ensemble forecasts. *November 2008*

561 **Fisher**, **M.**, **J. Nocedal**, **Y. Tremolet** and **S.J. Wright**: Data assimilation in weather forecasting: a case study in PDE-constrained optimization. *April 2008*

562 **Daget**, **N.**, **A.T. Weaver** and **M.A. Balmaseda**: An ensemble three-dimensional variational data assimilation system for the global ocean: sensitivity to the observation- and background-error variance formulation. *June 2008*

563 **Balsamo**, **G.**, **P. Viterbo**, **A. Beljaars**, **B. van den Hurk**, **M. Hirschi**, **A.K. Betts**, **K. Scipal**: A revised hydrology for the ECMWF model: Verification from field site to terrestrial water storage and impact in the Integrated Forecast System. *April 2008*

564 **Matricardi**, **M.**: The generation of RTTOV regression coefficients for IASI and AIRS using a new profile training set and a new line-by-line database. *May 2008*

565 **de Rosnay**, **P.**, **M. Drusch**, **A. Boone**, **G. Balsamo**, **B. Decharme**, **P. Harris**, **Y. Kerr**, **T. Pellarin**, **J. Polcher** and **J.-P. Wigneron**: The AMMA Land Surface Model Intercomparison Experiment coupled to the Community Microwave Emission Model: ALMIP-MEM. *July 2008*

566 **Drusch**, **M.**, **T. Holmes**, **P. de Rosnay** and **G. Balsamo**: Comparing ERA-40 based L-band brightness temperatures with Skylab observations: A calibration/validation study using the Community Microwave Emission Model. *July 2008*

567 **Rodwell**, **M.J.** and **T. Jung**: Understanding the local and global impacts of model physics changes: an aerosol example. *December 2008*

568 **Betts**, **A.K.**, **M. Köhler** and **Y. Zhang**: Comparison of river basin hydrometeorology in ERA-Interim and ERA-40 with observations. *July 2008*

569 **Lopez**, **P.**: Comparison of OPERA precipitation radar composites to CMORPH, SYNOP and ECMWF model data. *August 2008*

570 **Balmaseda**, **M.A.** and **D.L.T. Anderson**: Impact on initialization strategies and observations on seasonal forecast skill. *August 2008*

571 **Benedetti**, **A.**, **J.-J. Morcrette**, **O. Boucher**, **A. Dethof**, **R.J. Engelen**, **M. Fisher**, **H. Flentjes**, **N. Huneeus**, **L. Jones**, **J.W. Kaiser**, **S. Kinne**, **A. Mangold**, **M. Razinger**, **A.J. Simmons**, **M. Suttie**, and the GEMS-AER team: Aerosol analysis and forecast in the ECMWF Integrated Forecast System: Data assimilation. *August 2008*

572 **Engelen**, **R.J.**, **S. Serrar**, and **F. Chevallier**: Four-dimensional data assimilation of atmospheric CO2 using AIRS observations. *August 2008*

573 **Morcrette**, **J.-J.**, **O. Boucher**, **L. Jones**, **D. Salmond**, **P. Bechtold**, **A. Beljaars**, **A. Benedetti**, **A. Bonet**, **J.W. Kaiser**, **M. Razinger**, **M. Schulz**, **S. Serrar**, **A.J. Simmons**, **M. Sofiev**, **M. Suttie**, **A. Tompkins**, **A. Untch**, and the **GEMS-AER team**: Aerosol analysis and forecast in the ECMWF Integrated Forecast System: Forward modelling. *September 2008*

574 **Cloke**, **H.L.** and **F. Pappenberger**: Operational flood forecasting: a review of ensemble techniques. *October 2008*

575 **Dee**, **D.** and **S. Uppala**: Variational bias correction in ERA-Interim. *October 2008*

576 **Drusch**, **M.**, **K. Scipal**, **P. de Rosnay**, **G. Balsamo**, **E. Andersson**, **P. Bougeault** and **P. Viterbo**: Exploitation of satellite data in the surface analysis. *October 2008*

577 **Morcrette**, **J.-J.**, **A. Beljaars**, **A. Benedetti**, **L. Jones** and **O. Boucher**: Gustiness as predictor for lifting sea-salt and dust aerosols in the ECMWF IFS. *October 2008*

578 **Richardson**, **D.S.**, **J. Bidlot**, **L. Ferranti**, **A. Ghelli**, **M. Janousek**, **M. Leutbecher**, **F. Prates**, **F. Vitart** and **E. Zsoter**: Verification statistics and evaluations of ECMWF forecasts in 2007–2008. *October 2008*

579 **Janssen**, **P.A.E.M.**: On some consequences of the canonical transformation in the Hamiltonian theory of water waves. *November 2008*

Seminar and Workshop Proceedings

- **Seminar on Parametrization of Subgrid Physical Processes**, 1–4 September 2008
- **GRAS-SAF Workshop on Applications of GPS Radio Occultation Measurements**, 16–18 June 2008
- **ECMWF Workshop on Ensemble Prediction**, 7–9 November 2007

ECMWF Newsletters

- **Winter** 114, **Spring** 115, **Summer** 116, **Autumn** 117

Global Data Monitoring Reports

- Published monthly by ECMWF

ESA Contract Reports

Abdalla, **S.** and **H. Hersbach**: The technical support for global validation of ERS Wind and Wave Products at ECMWF (July 2007–June 2008). Final Report for ESA contract 20901/07/I-EC. *November 2008*

Dragani, **R.**: Monitoring and assimilation of SCIAMACHY, GOMOS and MIPAS retrievals at ECMWF. Final Report for ESA contract 17585/CCN-1: Technical support for global validation of ENVISAT data products. *July 2008*

Peer reviewed publications

Balmaseda, **M.A.**, **A. Vidard**, and **D.L.T. Anderson** (2008): The ECMWF Ocean Analysis System: ORA-S3. *Mon. Wea. Rev.*, **136**, 3018–3034

Balmaseda, **M.A.**, **L. Ferranti** and **F. Molteni** (2008): The ocean component at ECMWF: towards a seamless prediction system. *CLIVAR Exchanges*, **44**, 36–38

Bechtold, **P.**, **M. Köhler**, **T. Jung**, **F. Doblas-Reyes**, **M. Leutbecher**, **M.J. Rodwell**, **F. Vitart**, **G. Balsamo** (2008): Advances in simulating atmospheric variability with the ECMWF model: From synoptic to decadal time-scales. *Q. J. R. Meteorol. Soc.*, **134**, 1337–1351

Bell, **W.**, **S.J. English**, **B. Candy**, **N. Atkinson**, **F. Hilton**, **N. Baker**, **S.D. Swadley**, **W.F. Campbell**, **N. Bormann**, **G. Kelly** and **M. Kazumori** (2008): The assimilation of SSMIS radiances in Numerical Weather Prediction models. *IEEE Trans. Geosci. & Remote Sensing*, **46**, 884–900

Benedetti, **A.** and **M. Janisková** (2008): Assimilation of MODIS cloud optical depths in the ECMWF model. *Mon. Wea. Rev.*, **136**, 1727–1746

Berner, **J.**, **F.J. Doblas-Reyes**, **T.N. Palmer**, **G. Shutts** and **A. Weisheimer** (2008): Impact of a cellular automaton backscatter scheme on the systematic error and seasonal prediction skill of a global climate model. *Philos. Trans. R. Soc.*, **A366**, 2561–2579, 10.1098/rsta.2008.0033

Branković, **Č.**, **B. Matjačić**, **S. Ivatek-Šahdan** and **R. Buizza** (2008): Dynamical downscaling of ECMWF ensemble forecasts for cases of severe weather: ensemble statistics and cluster analysis. *Mon. Wea. Rev.*, **136**, 3323–3342

Buizza, **R.** (2008): The value of probabilistic prediction. *Atmos. Sci. Lett.*, **9**, 36–42, DOI: 10.1002/asl.170

Buizza, **R.** (2008): Comparison of a 51-member low-resolution (TL399L62) ensemble with a 6-member high-resolution (TL799L91) lagged-forecast ensemble. *Mon. Wea. Rev.*, **136**, 3343–3362

Casado, **M.J.**, **M.A. Pastor** and **F.J. Doblas-Reyes** (2008): Euro-Atlantic circulation types and modes of variability in winter. *Theor. Appl. Climatol.*, **94**, 8, 10.1007/s00704-008-0036-2

Ferro, **C.A.T.**, **D.S. Richardson** and **A.P. Weigel** (2008): On the effect of ensemble size on the discrete and continuous ranked probability scores. *Meteorol. Appl.*, **15**, 19–24

Gutierrez, **J.M.**, **C. Primo**, **M.A. Rodriguez** and **J. Fernandez** (2008): Spatiotemporal characterization of ensemble prediction systems – the Mean-Variance of Logarithms (MVL) diagram. *Nonlinear Processes Geophys.*, **15**, 1, 109–114

Hagedorn, **R.**, **T.M. Hamill**, and **J.S. Whitaker** (2008): Probabilistic forecast calibration using ECMWF and GFS ensemble reforecasts. Part I: Two-meter temperatures. *Mon. Wea. Rev.*, **136**, 2608–2619

Hagedorn, **R.**, **T.M. Hamill** and **J.S. Whitaker** (2008): Probabilistic forecast calibration using ECMWF and GFS ensemble reforecasts. Part II: Precipitation. *Mon. Wea. Rev.*, **136**, 2620–2632

Holmes, **T.**, **M. Drusch**, **J.-P. Wigneron** and **R. de Jeu** (2008): A global simulation of microwave emission: Error structures based on output from ECMWF's operational Integrated Forecast System. *IEEE Trans. Geosci. & Remote Sensing*, **46**, 3, 846–856

Iversen, **T.**, **J. Kristiansen**, **T. Jung** and **J. Barkmeijer** (2008): Optimal atmospheric forcing perturbations for the Cold Ocean Warm Land pattern. *Tellus A*, **60A**, 528–546

Fernández, **J.**, **C. Primo**, **A.S. Cofiño**, **J.M. Gutiérrez** and **M.A. Rodríguez** (2008): MVL spatiotemporal analysis for model intercomparison in EPS: application to the DEMETER multi-model ensemble. *Clim. Dyn.*, 10.1007/s00382-008-0456-9

Jolliffe, **I.T.** and **C. Primo** (2008): Evaluating rank histograms using decompositions of the chi-square test statistic. *Mon. Wea. Rev.*, **136**, 2133–2139

Jung, **T.** and **M. Leutbecher** (2008): Scale-dependent verification of ensemble forecasts. *Q. J. R. Meteorol. Soc.*, **134**, 973–984

Kelly, **G.**, **P. Bauer**, **A. Geer**, **P. Lopez** and **J.-N. Thépaut** (2008): Impact of SSM/I observations related to moisture, clouds and precipitation on global NWP forecast skill. *Mon. Wea. Rev.*, **136**, 2713–2726

Leutbecher, **M.** and **T.N. Palmer** (2008): Ensemble forecasting. *J. Comput. Phys.*, **227**, 3515–3539, doi:10.1016/j.jcp.2007.02.014

Orr, **A.** and **P. Bechtold** (2008): Improvement in the capturing of short-range warm season orographic precipitation in the ECMWF model. *Meteorol. Atmos. Phys.*, **99**, 9, DOI 10.1007/s00703-008-0288

Palmer, **T.N.**, **F.J. Doblas-Reyes**, **A. Weisheimer** and **M. Rodwell** (2008): Towards "seamless" prediction: Calibration of climate-change projections using seasonal forecasts. *Bull. Am. Meteorol. Soc.*, **89**, 459–470

Pappenberger, **F.**, **J. Bartholmes**, **J. Thielen**, **H.L. Cloke**, **R. Buizza** and **A. de Roo** (2008): New dimensions in early flood warning across the globe using grand-ensemble weather predictions. *Geophys. Res. Lett.*, **35**, L10404, DOI:10.1029/2008GL33837

Pappenberger, **F.**, **K. Scipal** and **R. Buizza** (2008): Hydrological aspects of meteorological verifications. *Atmos. Sci. Lett.*, **9**, 43–52, (DOI:10.1002/asl.171)

Parker, **D.J.**, **A. Fink**, **S. Janicot**, **J.-B. Ngamini**, **M. Douglas**, **E. Afiesimama**, **A. Agusti-Panareda**, **A. Beljaars**, **F. Dide**, **A. Diedhiou**, **T. Lebel**, **J. Polcher**, **J.-L. Redelsperger**, **C. Thorncroft** and **Posselt**, **D.J.**, **G.L. Stephens** and **M. Miller** (2008): CLOUDSAT: Adding a new dimension to a classical view of extratropical cyclones. *Bull Am. Meteorol. Soc.*, **89**, 5, 599–609

Primo, **C.**, **M.A. Rodriguez** and **J.M. Gutierrez** (2008): Logarithmic bred vectors. A new ensemble method with adjustable spread and calibration time. *J. Geophys. Res.*, **113**, D05116,

Ringer, **M.** and **S.B. Healy** (2008): Monitoring twenty-first century climate using GPS radio occultation bending angles. *Geophys. Res. Lett.*, **35**, L05708, doi:10.1029/2007GL032468

Scipal, **K.**, **M. Drusch** and **W. Wagner** (2008): Assimilation of a ERS scatterometer derived soil moisture index in the ECMWF numerical weather prediction system. *Adv. Water Resources*, **31**, 1101–1112

Tan, **D.G.H.**, **E. Andersson**, **J. deKloe**, **G.-J. Marseille**, **A. Stoffelen**, **P. Poli**, **M.-L. Denneulin**, **A. Dabas**, **D. Huber**, **O. Reitebuch**, **P. Flamant**, **O. Le Rille** and **H. Nett** (2008): The ADM-Aeolus wind retrieval algorithms. *Tellus A*, **60A**, 191–205

Thielen, **J.**, **J. Schaake**, **R. Hartman** and **R. Buizza** (2008): Aims, challenges and progress of the Hydrological Ensemble Prediction Experiment (HEPEX) – a summary of the 3rd HEPEX workshop held in Stresa 27–29 June 2007. *Atmos. Sci. Lett.*, **9**, 29–35 (DOI:10.1002/asl.168)

Wedi, **N.P.** and **P.K. Smolarkiewicz** (2008): A reduced model of the Madden-Julian Oscillation. *Int. J. Numer. Methods Fluids* , **56**, 1583–1588

Wilson, **G.A.** (2008): The AMMA radiosonde programme and its implications for the future of atmospheric monitoring over Africa. *Bull. Am. Meteorol. Soc.*, **89**, 1015–1027

Woollings, **T.**, **B.J. Hoskins**, **M. Blackburn** and **P. Berrisford** (2008): A new Rossby wave-breaking interpretation of the North Atlantic Oscillation. *J. Atmos. Sc.*, **65**, 609–626

Externally funded projects and services

Project Acronym	Project Name	ECMWF role	Date		Funded by	ECMWF budget (€)	Total budget (€)
			From	To			
ADM/AEOLUS	Development and production of aeolus wind data products	Subcontractor	01/08/2008	30/09/2011	ESA	1,026,923	n/a
AMMA	Observation techniques and mission concepts for analysis of the global carbon cycle	Contractor	01/05/2005	31/12/2009	EC	372,780	11,700,000
ARM	Model validation studies	Contractor	15/04/2007	14/04/2010	US DOE	$566,296	n/a
BOSS4GMES	Building operational sustainable services for GMES	Contractor	01/12/2006	01/06/2009	EC	149,997	11,800,000
BRIDGE	Bilateral research and industrial development enhancing and integrating GRID enabled technologies	Contractor	01/01/2007	31/12/2008	EC	250,724	1,700,000
DEISA	Distributed European infrastructure for supercomputing applications	Contractor	01/05/2004	30/04/2008	EC	709,800	14,000,000
DEISA2	Distributed European infrastructure for supercomputing applications 2	Contractor	01/05/2008	30/04/2011	EC	480,000	10,237,000
EC-EARTH	EC-Earth	Contractor	01/11/2007	31/10/2009	KNMI	256,000	n/a
eDEISA	Extended distributed European infrastructure for supercomputing applications	Contractor	01/06/2006	31/05/2008	EC	131,200	4,500,000
ENSEMBLES	Ensemble-based predictions of climate change and their impacts	Contractor	01/09/2004	31/08/2009	EC	1,124,475	15,000,000
ENVISAT II	Technical support for global validation of ENVISAT data products	Contractor	01/08/2008	31/12/2010	ESA	689,325	n/a
EPS IASI	Support of ECMWF to EPS/IASI phase 4	Contractor	01/01/2008	31/12/2009	EUMETSAT	293,125	n/a
ERA	ERA	Subcontractor	01/09/2007	31/08/2010	NCAS/NERC	£165,984	n/a
ERS validation II	Technical support for global validation of wind and wave products (ERS II)	Contractor	01/07/2008	30/06/2010	ESA	239,997	239,997
EUMETSAT fellowships	Fellowships	Contractor	Ongoing		EUMETSAT	n/a	n/a
EURORISK PREVIEW	Presentation, information and early warning pre-operational services to support the management of risks	Contractor	01/04/2005	31/12/2008	EC	320,000	14,300,000
GEMS	Global regional Earth-system monitoring using satellite and in-situ data	Coordinator	01/03/2005	31/05/2009	EC	4,691,000	12,500,000
GEOMON	Prototype system for atmospheric composition monitoring for climate applications by the combination of ground-based with satellite observations	Contractor	01/02/2007	31/01/2009	EC	28,800	6,621,740
GlobeMODEL	GlobeModel	Subcontractor	01/01/2007	31/05/2008	ESA	24,668	249,689
GRAS-SAF	The continuous development and operations phase of a EUMETSAT Satellite Applications Facility on GRAS meteorology	Subcontractor	01/03/2007	29/02/2012	EUMETSAT	610,000	4,200,000
H-SAF	Satellite Application Facility on support to operational hydrology and water management	Subcontractor	01/09/2005	31/08/2010	EUMETSAT	220,000	3,000,000
JRC HPC facilities	Provision of flexible dedicated high performance computing facilities	Contractor	01/08/2006	31/03/2009	JRC	433,182	433,182
NWP SAF CDOP	Development and Implementation of certain activities within a EUMETSAT Satellite Application Facility on numerical weather prediction	Subcontractor	01/03/2007	28/02/2012	EUMETSAT	988,510	4,900,316
Post EPS	Optimisation of the oxygen and water vapour sounding channels	Contractor	06/06/2007	30/09/2008	ESA	140,348	249,961
QuARL	Quantitative assessment of the operational value of space-borne radar and lidar measurements of cloud and aerosol profiles	Contractor	01/09/2008	30/08/2010	ESA	499,373	499,373
SAFEWIND	Multi-scale data assimilation, advanced wind modelling and forecasting with emphasis to extreme weather situations for a safe large-scale wind power integration	Contractor	01/09/2008	31/07/2012	EC	416,000	3,992,400
SMOS DA	Study methods and techniques to best assimilate SMOS data into ECMWF's operational numerical weather forecasting system	Contractor	02/02/2007	30/09/2009	ESA	354,149	354,149
THOR	Thermohaline overturning – at risk?	Contractor	01/11/2008	31/10/2011	EC	392,000	9,964,773
UKMO-EPS	Maintenance of software to implement ensemble seasonal predictions using various configurations of the Met Office Unified Model	Contractor	01/08/2005	31/01/2009	UK Met Office	n/a	n/a

Glossary

AERONET	Aerosol Robotic Network
AMDAR	Aircraft Meteorological Data Relay
ASAP	Automated Shipboard Aerological Programme
BOM	Bureau of Meteorology (Australia)
CERFACS	European Centre for Research and Advanced Training in Scientific Computation
DHS	Data Handling System
DWD	Deutscher Wetterdienst (German National Meteorological Service)
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
EFI	Extreme Forecast Index
EMI	European Meteorological Infrastructure
EPS	Ensemble Prediction System
ESA	European Space Agency
EU	European Union
EUCOS	EUMETNET Composite Observing System
EUMETNET	European Meteorological Network
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GIS	Geographic Information System
GMES	Global Monitoring for the Environment and Security initiative
GOS	Global Observing System
GPS	Global Positioning System
GTS	Global Telecommunication System (WMO)
hPa	hectaPascal (unit of pressure)
HPCF	High Performance Computing Facility
HPSS	High Performance Storage System
IFS	Integrated Forecast System
IPCC	Intergovernmental Panel on Climate Change
JAXA	Japan Aerospace Exploration Agency
KNMI	Royal Dutch Meteorological Institute
MACC	Monitoring Atmospheric Composition and Climate
MAGICS	Meteorological Application Graphics Integrated Colour System
MARS	Meteorological Archival and Retrieval System
MetOp	Meteorological operational satellite (polar-orbiting)
MSC	Meteorological Service of Canada
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration (USA)
NCEP	National Centers for Environmental Prediction (USA)
NEMO	Nucleus for European Modelling of the Ocean
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OGC	Open Geospatial Consortium
OPERA	Operational Programme for the Exchange of Weather Radar Information
OSE	Observing System Experiment
RMDCN	Regional Meteorological Data Communications Network
RTTOV	Radiation Transfer Model for TOVS (TIROS Operational Vertical Sounder)
THORPEX	The Observing System Research and Predictability Experiment
TIGGE	THORPEX Interactive Grand Global Ensemble
UTC	Coordinated Universal Time
VarEPS	Variable Resolution Ensemble Prediction System
WMO	World Meteorological Organization

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