



Annual Report 2009

**European Centre for
Medium-Range Weather Forecasts**



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Foreword by the Director

2009 was another year showing significant achievements at ECMWF. The research programme continued to play a key role in the remarkable advancement of operational weather forecasting capabilities and in making best use of satellite and in situ observations of the Earth. ECMWF was able to keep its worldwide reputation and leadership in global numerical weather prediction.

The performance of the forecasting systems remained at a high level throughout the year. The implementation of two new cycles of the Integrated Forecasting System in March and September was an important step towards increasing the use of satellite data, including the operational use of data from Jason-2. These changes had a positive impact on the skill of the forecasts. In particular, this meant that both ECMWF's deterministic and ensemble forecasting systems have maintained their lead over other global centres.

The Centre's high-performance computing facility (HPCF), one of the most powerful in Europe, continued to provide a very reliable service to ECMWF operations and users. In addition, a new supercomputer was successfully brought fully into operation, bringing the computing resources to the expected 20 teraflops sustained. During 2009 Member States' usage of the ECMWF's HPCF resources reached a new milestone when the usage for one single day surpassed 1 million units for the first time.

ECMWF and its Member States are paying attention to their impact on carbon emissions. Operating in the field of atmospheric sciences, which has provided the basic insights that have alerted the world to the global warming issue, makes us especially aware of these considerations. In recent years much effort has been put in to minimizing this impact, in particular as part of the supercomputer procurement process and the cooling infrastructure upgrade. In addition in 2009, the Technical Advisory Committee decided to establish a Subgroup on 'Green Computing' to advise ECMWF on moving towards having a more environmentally friendly HPCF installation. The Subgroup will focus on considering energy efficiency and low carbon footprint, and providing a forum for sharing experiences in the field of green computing.

Education and training is an important activity at ECMWF, contributing to maintaining the high level of the atmospheric science throughout Europe. 2009 was particularly busy in this matter with an unusually high number of workshops addressing some key areas of current NWP development. In addition, ECMWF hosted several events and meetings for the meteorological community.

The GEMS project, which was concerned with developing preliminary global and regional atmospheric chemistry monitoring and forecasting, was brought to a successful completion. It had achieved its main objectives and is being continued by its successor project Monitoring Atmospheric Composition and Climate - MACC, a collaborative project (2009-2011) funded by the European Commission under the 7th Framework Programme

and coordinated by ECMWF. MACC will run until late in 2011, when it should be ready to emerge as a fully operational atmospheric service under Europe's Global Monitoring for Environment and Security (GMES) programme.

Through its core activities, ECMWF contributed significantly to climate change studies. The Centre's reanalyses are suitable for studies of long-term variability in climate. ERA-Interim, the most recent global atmospheric reanalysis at ECMWF, started being updated in near-real time on a monthly basis on 1 April. Daily and monthly products were made available as part of the ERA-Interim dataset, for the period 1 January 1989 to 31 August 2009.

ECMWF implemented major upgrades to the service for members of the World Meteorological Organization. In particular, high-resolution analysis and model data from the deterministic forecasting system can be downloaded with a spatial resolution increased from 2.5°x2.5° to 0.5°x0.5° latitude/longitude.

A key ingredient to the success of ECMWF is the high level of expertise and dedication of its staff. This has ensured that ECMWF continues to be at the forefront of applying the latest research and technological developments to meet the increasingly demanding needs of our Member States. I was particularly pleased that several of our research staff, or former staff, were honoured in 2009 for their contribution to the development of NWP.

A stylized handwritten signature in black ink, consisting of a long horizontal stroke with a loop at the end and a shorter vertical stroke intersecting it.

Dominique Marbouty
Director, ECMWF



Statement by the President of the Council

It was a great pleasure for me to serve as President of the ECMWF Council in 2007, 2008 and 2009. During this period, ECMWF was able to demonstrate once again the important role it plays in supporting the activities of national meteorological and hydrological services in Member and Co-operating States, particularly in forecasting severe weather several days or even weeks ahead thereby allowing early warnings to the public. In fact, I am not exaggerating in stating that the Centre is a flagship in the context of the European meteorological infrastructure.

The ECMWF governing bodies have been particularly busy in 2009, with working groups involved in providing guidance on the future developments of telecommunication, verification and supercomputing.

Also, the Council gave the go ahead to renewing the co-operation agreement with the African Centre of Meteorological Applications for Development (ACMAD) as well as with the European Space Agency, and to concluding a co-operation agreement with the government of Bulgaria. In addition, the Council agreed on the introduction of a reduced maximum charge licence for national meteorological and hydrological services using ECMWF products for non-commercial purposes, and extended the list of ECMWF products declared as 'essential' which are provided without restriction to WMO Members.

With full support from the Council, ECMWF is playing an increasingly important role vis-à-vis the European Commission, notably in the context of the initiative 'Global Monitoring for the Environment and Security' (GMES). The project 'Monitoring Atmospheric Composition and Climate' (MACC), funded under the European Union's Seventh Framework Programme and coordinated by ECMWF, is developing core operational atmospheric environmental services for GMES. ECMWF's reanalysis activities are another asset for monitoring the climate and contributing to climate change research.

Very good news came from the depositary of the ECMWF Convention: the Secretariat of the Council of the European Union informed ECMWF that Belgium, Ireland, Turkey and Portugal had notified their acceptance of the amendments to the ECMWF Convention. This brings the number of registered acceptances to 17 at the end of 2009. When 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, and broaden the possibility for activities funded by third parties.

As reflected in this annual report, in 2009 there have been many achievements of benefit to the operational activities of Member and Co-operating States.

As outgoing President of the ECMWF Council, I am confident that ECMWF, in close collaboration with its Member States, will maintain its leading role in global numerical weather prediction. In this way it will continue to deliver high-standard products to its Member and Co-operating States as well as playing a full role in supporting the activities of the international meteorological community.

Finally, I would like to congratulate the Director of ECMWF and the extremely qualified staff working at the Centre on the progress made during 2009.

Adérito Vicente Serrão
President, ECMWF Council

Major achievements

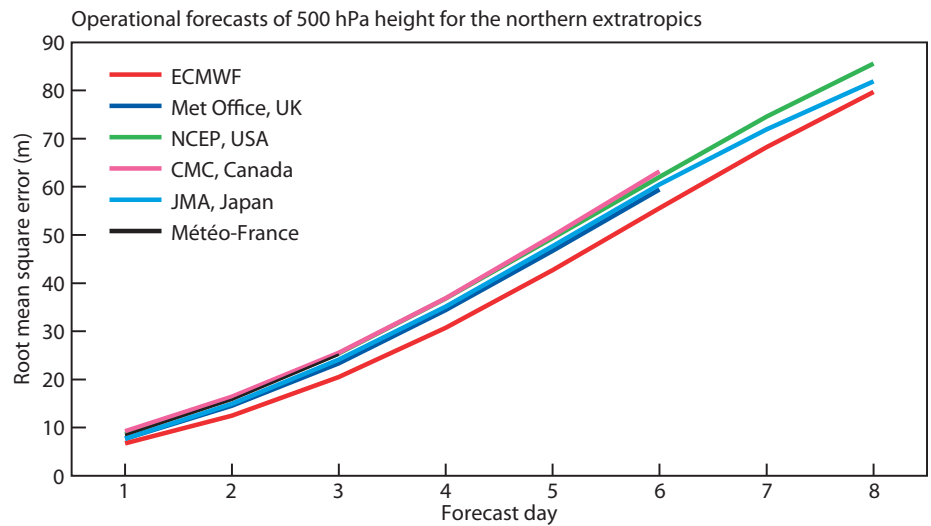
During 2009 there have been many achievements in terms of developing ECMWF's forecasting system, bringing to fruition high-quality research and development activities, and enhancing operational support. The following are just some of the major achievements over the last year.

Overall, the performance of the Centre's forecasting system remained at a high level throughout this year. For the deterministic forecasting system the performance was similar to that of the previous year. This means that ECMWF's lead over other global centres has been maintained.

As for the deterministic forecasting system, the performance of the probability forecasts from the Ensemble Prediction System (EPS) has been maintained with a marked lead over other global ensemble systems. Also, the monthly forecasting system has continued to perform well, in particular at the forecast range 12–18 days.

Results show that the ECMWF forecasting system has been able to forecast Madden-Julian oscillation (MJO) events. These are 30–60 day fluctuations of atmospheric pressure over the equatorial Indian and western Pacific oceans. This is an important milestone in developing monthly forecasts.

During 2009, ECMWF has achieved significant improvements in satellite data usage. This includes breakthroughs towards the assimilation of satellite data in all-sky conditions.



Comparison of the performance of various global forecasting centres during 2009. The verification scores from six global forecasting centres show that ECMWF maintained its lead over other centres in 2009. For the score shown, the lower its value the better the forecasts.

Some recent research developments are of particular relevance to the improvement of the forecasting system for high-impact weather. For example, when an intense winter storm (named Klaus) caused significant destruction across southern France and northern Spain, the Extreme Forecast Index indicated that there was a high risk of strong winds on 24 January, based on the three-day EPS forecast. Another example of an early forecast of an extreme weather event was the heavy rainfall in southern Europe during September and October 2009, causing localised flooding.

Through its core activities, ECMWF contributed significantly to climate change studies: the Centre's reanalyses are suitable for studies of long-term variability in climate. It has been demonstrated that the representation of essential climate variables in ERA-Interim is of sufficiently high quality that important indicators of climate change can now be reliably estimated and monitored using reanalyses.

The annual-range forecast of sea-surface temperature in the Central/Eastern Tropical Pacific predicted the possibility of a substantial El Niño event in the second half of 2009 as early as November 2008. This long-range prediction was of interest to the meteorological community and suggested additional monitoring of the El Niño phenomenon would be beneficial.

During 2009, a new high-performance computing facility was brought fully into production, consisting of two identical, independent IBM Cluster 1600 super-computers and storage clusters. This facility is one of the most powerful computer systems in Europe. In addition, a new automated tape library was installed that will greatly enhance capacity and accessibility.

The performance of the Regional Meteorological Data Communication

Network during 2009 was very good, with a 100% availability over almost the whole period. The network saw a number of configuration changes of existing connections as well as an expansion to other continents.

These achievements just give an insight into the activities of ECMWF in 2009. More details about all these achievements, as well as many others, can be found in the following chapters.



New automated tape library. The automated tape library is part of ECMWF's data handling system. The new library will allow a large number of concurrent retrieval requests and very high tape exchange rates.

Key events of the year

15 January

A symposium in honour of Tony Hollingsworth, former Head of Research at ECMWF, was organised during the American Meteorological Society annual conference held in Phoenix, Arizona. Tony had died in July 2007.

10 March

The implementation of Cycle 35r2 of the Integrated Forecasting System (IFS) was an important step towards increasing the use of satellite data, with the direct 4D-Var assimilation of microwave imager radiances in areas affected by cloud and rain. Also the operational use of Jason-2 data was implemented.

1 April

The operational forecasting suite began running routinely on the first of the POWER6 clusters, which was processing about 135,000 parallel jobs and over 600,000 serial jobs per day.

1 April

ERA-Interim started being updated in near-real time, on a monthly basis.

31 May

The GEMS project finished. It had achieved its main objectives and it was continued by its successor project MACC (Monitoring Atmospheric Composition and Climate), a collaborative project (2009–2011) funded by the European Commission under the 7th Framework Programme and coordinated by ECMWF.

25–26 June



On the invitation by its President, Adérito Vicente Serrão (Portugal), the Council held its 71st session in the Azores. The Council unanimously authorised the Director to renew the co-operation agreement with the African Centre of Meteorological Applications for Development (ACMAD) and to conclude a co-operation agreement with the government of Bulgaria.

1 July



Two ECMWF staff members were awarded prizes by the Royal Meteorological Society of the United Kingdom; Adrian Simmons was awarded the Symons Gold Medal and Tim Palmer the Adrian Gill Prize.

22 July

Prof Nikola Sabotinov, President of the Bulgarian Academy of Science, and the Director of ECMWF signed a co-operation agreement.

8 September

ECMWF upgraded the service for members of the World Meteorological Organization (WMO) to download high-resolution analysis and model data from the deterministic forecasting system. The spatial resolution was increased from 2.5°×2.5° to 0.5°×0.5° latitude/longitude.

8 September

The new IFS Cycle 35r3 was implemented; it included several important changes that resulted in a significantly positive impact on the skill of the forecasting system.

25 September

The experimental IFS Cycle 36r1 for the deterministic forecasting system started running (higher-resolution forecasting system).

28 September to 2 October

The EMS Silver Medal was awarded to Lennart Bengtsson, a former Director of ECMWF, during the annual meeting of the European Meteorological Society (EMS) in Toulouse.

30 September

Phase I of the new IBM high-performance computing facility (HPCF) was accepted. The configuration is composed of two identical POWER6 compute clusters. The service of the Centre's 'old' computer system was terminated.

7 October



The new automated tape library was installed and formal acceptance tests were started.

13 October

ECMWF implemented the increase in spectral resolution of the limited-area wave model to 36 directions and 36 frequencies.

12 November

Daily and monthly products were made available as part of the ERA-Interim dataset, for the period 1 January 1989 to 31 August 2009.

19 November

Member States' usage of the ECMWF's HPCF resources reached a new milestone. The usage for one single day surpassed 1 million units for the first time.

8–9 December



The Council's 72nd session was held at ECMWF. Some major decisions were made, including authorising the Director to extend the co-operation agreement with ESA for another five years, agreeing on the introduction of a reduced maximum charge licence for national meteorological and hydrological services (NMHSs) using ECMWF products for non-commercial purposes, and extending the list of ECMWF products declared as 'essential'.



Evolution of the forecasting system

ECMWF has a worldwide reputation for providing the most accurate medium-range, global weather forecasts. The wide-ranging programme of research and development at ECMWF continues to play a key role in the remarkable advancement of weather forecast skill and the use of satellite and in-situ observations. As well as upgrades to the forecasting system that enhance the atmospheric and marine forecasts, progress has been made in preparing for the forthcoming horizontal resolution increase to T1279 for the deterministic forecasts and T639/T319 for the Ensemble Prediction System.



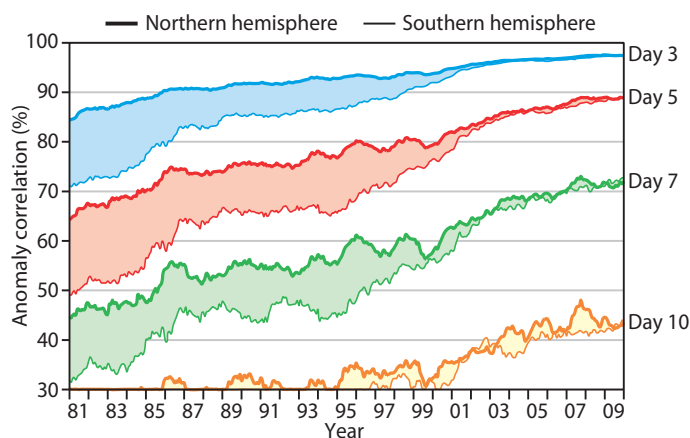
Performance of the deterministic forecasting system

Forecasts improved steadily from 1980 as a result of improvements in the global observing system, more powerful computers, and advances in the science of ECMWF's data assimilation system and forecasting model. Seven-day forecasts in the northern hemisphere are now more accurate than the five-day forecasts were 25 years ago. This represents a two-day extension of the lead time of skilful forecasts.

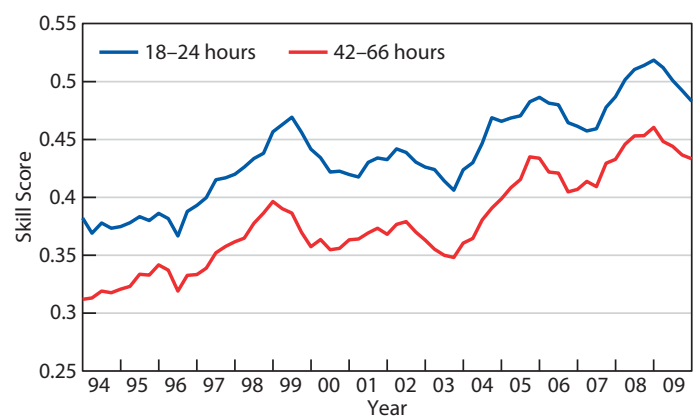
In the southern hemisphere, the improvement has been even more marked. In the early 1980s, because of the lack of observations, the three- and five-day predictions for the southern hemisphere were quite inferior to those for the northern hemisphere. Twenty-five years later, forecasts for both hemispheres were of similar accuracy – representing a gain of about four days in the lead time of accurate southern hemisphere predictions, mainly thanks to the use of satellite data.

Looking at the evolution during the last few years, we see that the accuracy of the upper-air forecasts has generally maintained the level of previous years, while the skill of the forecasts of precipitation continues to increase. Consideration is being given to using precipitation as an additional parameter to monitor long-term performance trends.

In general, the performance of the deterministic forecasting system during 2009 was similar to that of the previous year. This means that ECMWF's lead over other global centres has been maintained.



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



Improving accuracy of precipitation forecasts from the deterministic forecasting system. Time series of the skill of forecasts of precipitation exceeding 10 mm/day verified against European weather stations (SYNOP reports). Results are for precipitation accumulations for 18–24 hours and 42–66 hours.

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 many Member States and Co-operating States to run their own limited-area models.

Upgrades to the forecasting system in 2009

The ECMWF forecasting system is regularly upgraded to enhance the global atmospheric and marine forecasts provided to Member States. Before an upgrade comes into operations it is tested in research mode and then in a pre-operational trial. In 2009 two new cycles of the forecasting system were implemented.

10 March 2009 (Cycle 35r2)

The new cycle included direct assimilation of microwave imager data in all sky conditions. This replaced the previous implementation which involved a processing step for data in cloudy and rainy areas, thereby unifying the treatment of this data in all conditions. Also a revised snow scheme was implemented.

On 12 March, this cycle was also used for the first time in the monthly extension of the Ensemble Prediction System.

Overall the new cycle was neutral in terms of verification scores for both hemispheres and the tropics. There was some improvement to the 2-metre temperature bias and slightly better performance for tropical cyclones in both position and intensity. Synoptic performance was generally similar to that in the previous cycle.

8 September 2009 (Cycle 35r3)

This cycle included a parametrization for non-orographic gravity waves that improved the circulation in the stratosphere of the model. The introduction of a new approach for the quality control for conventional observations led to fewer incorrect rejections in extreme cases where the observations differed substantially from the short-range forecast. Also the assimilation system was extended to estimate (and correct for) systematic model errors in the stratosphere. The use of satellite radiance data in the infrared was extended to overcast situations.

This cycle showed clear benefit in the northern hemisphere; tropospheric scores showed statistically significant improvement. The improvement for the European area was smaller, with weaker statistical significance. The southern hemisphere impact was essentially neutral. An increased negative temperature bias is present at around 100 hPa, but there is evidence that the quality of the analysis of temperature in the stratosphere was improved.

The main change to the Ensemble Prediction System included in this cycle was a revised version of the stochastic physics. The impact of the change was primarily seen in improved probabilistic scores for temperature at 850 hPa in the tropics.

Views of the Technical Advisory Committee – October 2009

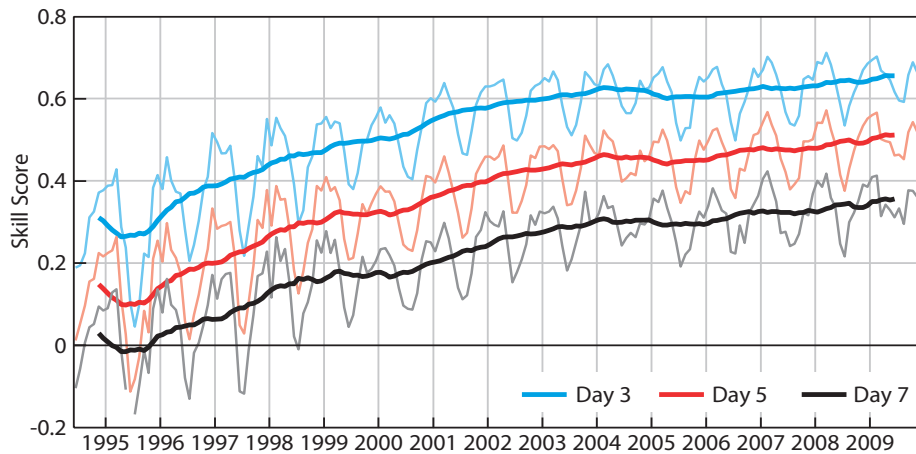
Extract from the Report of the Chair of the Technical Advisory Committee (TAC) to Council.

In regard to its overall view of the operational forecasting system, the Committee:

- congratulated ECMWF on the very high performance levels of all its forecast systems during the previous year and on its continued leading position in relation to other centres;*
- noted that the skill of the ensemble prediction system had continued to improve and was impressed by the results of recent work on the TIGGE dataset, which showed the ECMWF ensemble to be the best in the world;*
- noted with satisfaction that ECMWF wave forecasts remain the best in the world; also noted the importance of freak wave forecasts and that further progress is needed in this area;*
- was encouraged by the promising results from the use of cloud-affected and surface-affected radiances in the data assimilation;*
- welcomed the development work on interactive EFI products and stressed the great potential value of such products for the early detection of high impact weather events;*
- very much appreciated the introduction of new verification statistics for the EFI, showing a positive trend in performance over recent years;*
- with respect to deterministic forecasts of weather parameters:*
 - *welcomed the marked improvement in the skill of precipitation forecasts;*
 - *noted that, although the accuracy of snowfall forecasts has been improved, there is still an overprediction of snow in certain conditions;*
 - *noted, with some concern, a significant cold bias over Europe at night during the last winter and spring;*
 - *appreciated the value of the wind gust predictions but queried whether there is sufficient differentiation in their treatment over land and sea.*

EFI: Extreme Forecast Index

TIGGE: THORPEX Interactive Grand Global Ensemble



Performance of the Ensemble Prediction System (EPS). The skill of the EPS has continued to improve. The figure shows the monthly score and 12-month running mean of the Ranked Probability Skill Score (RPSS) for EPS forecasts of 850 hPa temperature over the extratropical northern hemisphere.

Ensemble Prediction System

The Ensemble Prediction System (EPS) aims at quantifying the impact of uncertainties in initial conditions and the inability of models to fully represent complex atmospheric processes. Output from the EPS provides forecasters with a range of possible forecasts 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 EPS probability forecasts have performed well during 2009. As with the deterministic forecasting system, the EPS performance during the winter months has been maintained at a high level.

A research project using the TIGGE (THORPEX Interactive Grand Global Ensemble) archive of forecasts from ten global ensemble prediction systems has shown that the ECMWF EPS forecasts are the most skilful (see page 25).

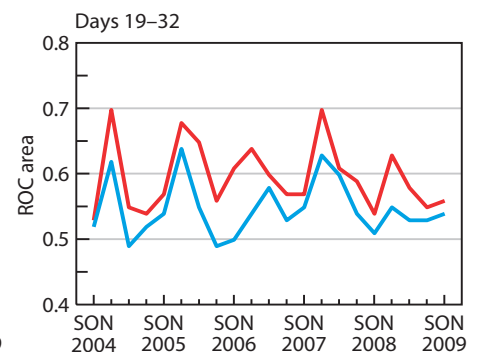
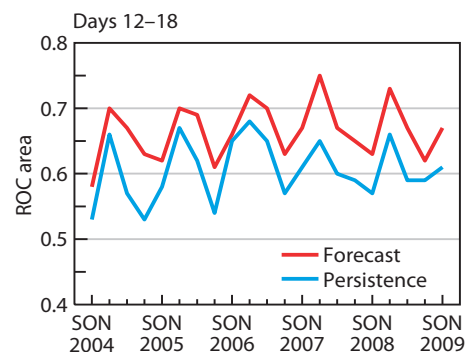
Monthly forecasts

The monthly forecasting system has continued to perform well at forecast range 12–18 days. At days 19–32 the skill over the winter months was not as good as in previous years. This may be explained solely by the year-to-year variability, since the skill of the forecasts based on previous conditions (known as persistence forecasts) was also poor for the most recent winter season.

The probabilistic performance of the monthly forecasting system in predicting unusually warm conditions (i.e. warm temperature anomalies) over the northern hemisphere has consistently outperformed

persistence by a substantial margin for each season over the past year. Overall, the cold conditions observed over Europe between December 2008 and January 2009 were well predicted.

Results show that the ECMWF forecasting system has been able to forecast Madden-Julian oscillation (MJO) events. These are 30–60 day fluctuations of atmospheric pressure over the equatorial Indian and western Pacific oceans; they are characterised by large-scale regions of enhanced and suppressed convection. This is an important milestone in developing monthly forecasts as such events play a key role at this range.



Performance of the monthly forecasts. The monthly forecasts outperform the persistence forecasts. The score used represents the trade-off between hits and false alarms across a range of thresholds, with the higher the value the better. The red curve shows the score for the monthly forecasting system for forecast days 12–18 (7-day mean) and 19–32 (14-day mean). As a comparison, the blue curve shows the score for persistence of the preceding 7-day or 14-day period of the forecast. The results are based on the area under the Relative Operating Characteristic (ROC) curve for the probability that the 2-metre temperature will be in the upper third of the climate distribution. Scores are calculated for each three-month season since autumn (September–November) 2004 for all land points in the extratropical northern hemisphere.

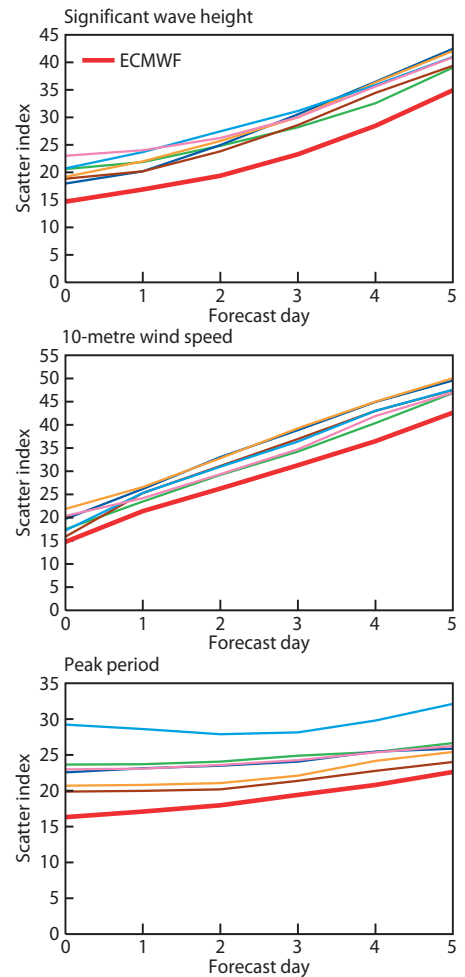
Seasonal forecasts

Since the beginning of the year, the ECMWF seasonal forecasts consistently predicted the change to El Niño conditions that developed during spring 2009 and persisted into the following year. Despite uncertainty over the amplitude of the El Niño, for most forecasts the values of observed sea-surface temperature anomalies in the Central/Eastern Tropical Pacific (the Niño 3.4 region) were within the range indicated by the ensemble distribution.

Though results were less satisfactory for summer 2009 over western Europe, the seasonal forecasts gave a useful indication of warmer than average conditions over eastern and southern Europe during summer 2009. This is consistent with the spatial distribution of the seasonal forecast skill based on the 25 years of past performance currently available on the ECMWF website.

Ocean wave forecasts

The ocean wave model continued to perform well. A comprehensive set of wave verification charts is now available on the ECMWF website, including comparisons with other centres. These results show that ECMWF's wave forecasts have consistently lower errors than other centres throughout the forecast. Also the gap is larger for the wave forecasts than for the driving winds from the atmospheric model, indicating that the wave model itself makes a substantial contribution to the improvement relative to other centres.



Verification of different wave model forecasts

The results show that ECMWF has consistently lower errors than other centres for the forecasts of wave height, 10-metre wind speed and peak wave period. Note that the gap is larger for the wave forecasts (top and bottom panels) than for the driving winds from the atmospheric model (middle panel); this indicates that the wave model itself makes a substantial contribution to the improvement relative to other centres. The scatter index is the standard deviation of error normalised by the mean observed value based on a consistent set of observations from wave buoys. The results are for forecasts from 00 UTC and 12 UTC for September to November 2009.

Use of satellite observations

During 2009, ECMWF has achieved significant improvements in satellite data usage. This includes two main breakthroughs towards the assimilation of satellite data in both clear and cloudy conditions. Microwave observations are currently assimilated in all sky conditions, and selected overcast cloudy scenes from infrared radiances are being assimilated. Other data has also been assimilated successfully. This was the case for data from ATOVS (Advanced TIROS Operational Vertical Sounder) onboard the NOAA-19 satellite, humidity channels from MetOp and day-time total-column water vapour over land from ENVISAT.

To prepare for further improvements in satellite data usage, ECMWF has implemented the passive monitoring of ozone data from AURA and the soil moisture derived from MetOp measurements.

Early warning of severe weather

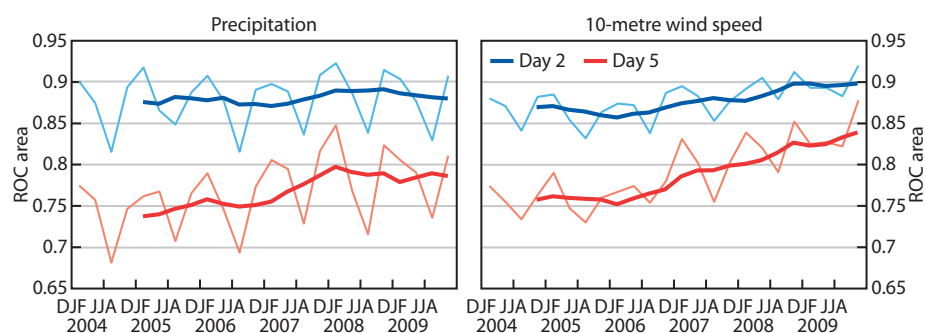
ECMWF's strategy has the early warning of severe weather as one of its principal goals. This is particularly important as severe weather is predicted to become more frequent and more intense in some parts of the world under climate change. ECMWF can contribute to the development of strategies to mitigate 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 relevance to the improvement of the forecasting system for high-impact weather. They include the development of the ensemble data assimilation, the use of a

new approach for observation quality control, and recent results concerning the ability of the system to better represent blocking events.

The Extreme Forecast Index (EFI) was developed at ECMWF as a tool to provide general guidance on potential extreme events. By comparing the EPS distribution of a chosen weather parameter with the model's climatological distribution, the EFI indicates occasions when there is an increased risk of an extreme event occurring.

The EFI has been verified using observations over Europe. For all parameters, there has been a clear improvement in the ability of the EFI to detect extreme events since 2004/05, especially for the 5-day range.



Verification of Extreme Forecast Index (EFI) for precipitation and 10-metre wind speed over Europe. The verification results for both parameters show that there has been a clear improvement in the ability of the EFI to identify extreme events, especially for the 5-day forecast. An extreme event is taken as an observation exceeding the 95th percentile of station climate. The ability of the EFI to detect extreme events is assessed using the area under the Relative Operating Characteristic (ROC) curve. This is a measure of the trade-off between hits and false alarms across a range of thresholds. The curves show the ROC area calculated for each 3-month season from winter (December–February) 2003/04 to autumn (September–November) 2009 for day 2 and day 5. Thick curves show running mean of seasonal scores averaged over four seasons; the last point is for the average from winter 2008/09 to autumn 2009.

Record waves in San Sebastian, Spain. A buoy located about 35 km north of the Spanish coast recorded a peak wave height of 26.13 metres associated with storm Klaus (22–23 January 2009). Also gusts in excess of 190 km/hour were recorded over land near the coast. ECMWF's Extreme Forecast Index (EFI) gave an early warning of a risk of strong winds several days in advance. Source 20minutos.es.



Examples of good predictions of extreme weather

Extremely cold period in January

Extreme cold affected much of central Europe during the first week of January 2009. In Germany, the week 5–11 January was one of the coldest for ten years with temperatures below -25°C in places. ECMWF's monthly forecast provided a consistent and clear-cut early warning of this event. Even the forecast from mid-December, three weeks ahead of the event, managed to successfully highlight the main risk areas.

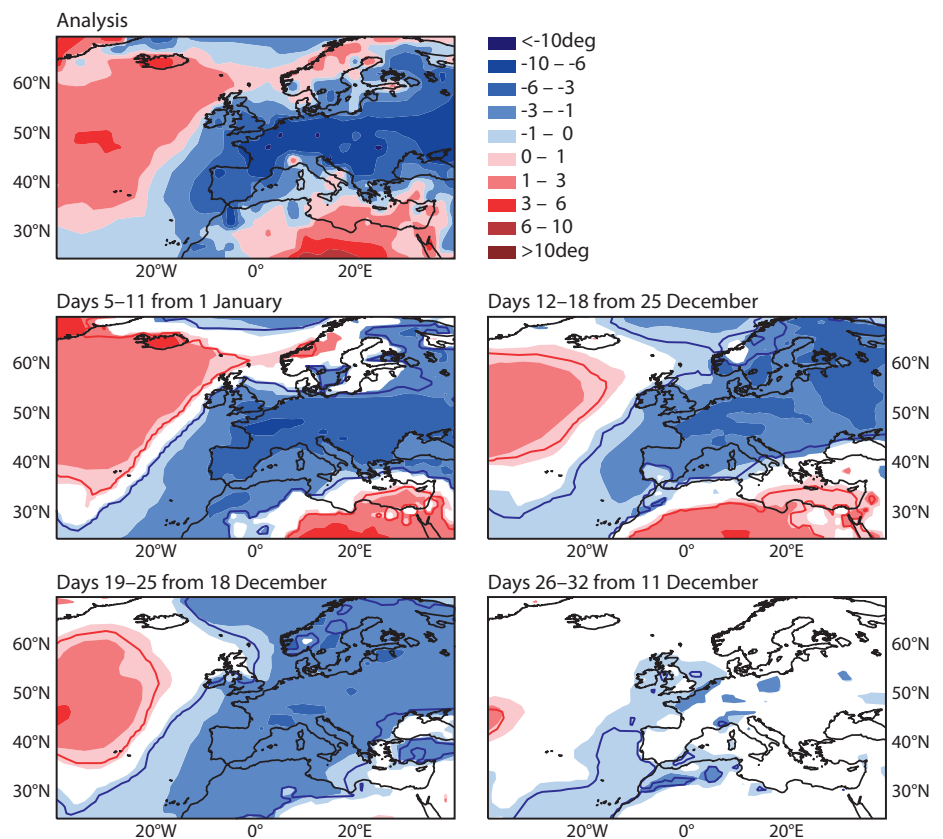
Storm Klaus in January

An intense winter storm (named Klaus) caused significant destruction across southern France and northern Spain on 24 January 2009. The storm developed in the Atlantic on 22 and 23 January and moved very rapidly in the strong westerly flow, crossing France and affecting the western Mediterranean. The EFI indicated that there was a high risk of strong winds on 24 January, based on the EPS forecast from 00 UTC on 21 January. As forecast, the most extreme winds were reported across south-west France from Biscay to the Mediterranean.

Heavy rainfall in September and October

Several heavy rainfall events, causing localised flooding, occurred in southern Europe during September and October 2009. On 21 October a frontal system, together with the low-level flow over the Mediterranean, resulted in heavy rainfall, especially in south-east France. On 22 October, a low deepened over the Gulf

of Lyon and moved eastwards causing more heavy rainfall in parts of France, Italy and Greece. Totals of more than 50 mm were widely reported in these areas, with some reports of over 100 mm in south-east France on 21 and 22 October. The large-scale development and the heavy precipitation were well forecast three days ahead by both the deterministic model and the EPS.



Monthly forecast of extremely cold weather in the first week in January 2009. The charts show that the cold weather for the week 5–11 January, as indicated by the average temperature deviation from climate (anomalies, in degrees Celsius), was predicted three weeks ahead. The top-left panel shows the verifying analysis and the four panels below show the successive monthly forecast for that week one to four weeks ahead: top-left is one week ahead, top-right is two weeks ahead, bottom-left is three weeks ahead and bottom-right is four weeks ahead.

Verification statistics and evaluations of ECMWF forecasts

Each year ECMWF produces a comprehensive set of verification statistics and evaluations of its forecasts. The report covering the period 2008–2009 is available at www.ecmwf.int/publications/library/do/references/show?id=89453.

Hurricane season

The 2008 North Atlantic hurricane season was very active. In contrast, the seasonal forecast from June 2009 predicted reduced activity for 2009. The North Atlantic season began late with the first named storm not occurring until mid-August (latest start since 1992); in total there were nine named storms and only three hurricanes during the season, confirming the forecast for overall activity to be substantially below normal.

The seasonal forecast from June 2009 predicted increased activity in the West Pacific. Verification shows that July to October was indeed an active period for that area; cyclones included typhoon Morakot, which caused devastation (mainly from flooding and associated landslides) in the

Philippines, China and Taiwan. Morakot was consistently well forecast by the ECMWF systems, with indications of the track crossing Taiwan up to 10 days ahead and probability of the track crossing the north of Taiwan exceeding 50% at 5 days ahead.

At shorter range the deterministic forecast predicted extreme rainfall up to 1,000 mm in 24 hours (almost 2,500 mm in 24 hours was recorded in some places). Typhoons Ketsana and Parma brought further severe flooding to the Philippines and to Vietnam and China. The skill of the deterministic and EPS forecasts for all tropical cyclones over the past year has matched the extremely good performance of 2008.

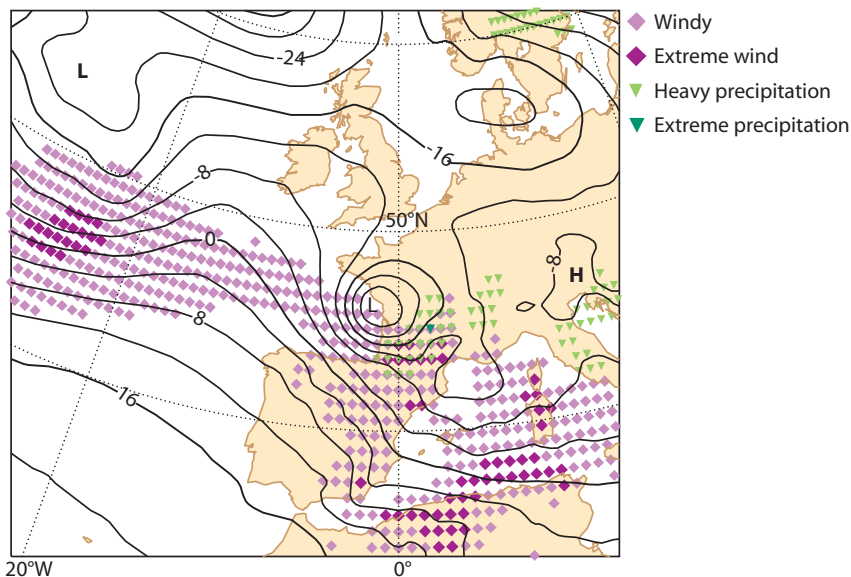
Development of verification methods

The ECMWF Strategy 2006–2015 places emphasis on early warning of severe weather and the need to develop appropriate verification. The strategy has set overall performance targets in terms of 500 hPa geopotential height for the deterministic model and 850 hPa temperature for the Ensemble Prediction System.

There is a need 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.

Operational verification is already performed for a selection of surface weather variables, including precipitation, wind and temperature. However, verification specifically for extreme weather events causes particular problems. Sample sizes are inevitably small, and the time and spatial scales of the verifying observations are limited. Also standard scores used for more moderate events may not be appropriate.

ECMWF's Technical Advisory Committee established a subgroup to make 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.



Early warning for winter storm Klaus, 24 January 2009. The Extreme Forecast Index (EFI) gave strong warning of extreme wind gusts (purple symbols) and heavy rainfall (green symbols) three days ahead (based on the EPS forecast from 00 UTC on 21 January). Filled-in symbols indicate more extreme events. Contours show the analysed 1000 hPa height field for 06 UTC on 24 January, when the storm struck the French coast.

Product development

Simulated satellite images

Simulated satellite images can be generated from the model forecast fields using the same radiative transfer algorithm (RTTOV) as in the operational data assimilation. This means that pictures can be produced that are equivalent to the infrared and water vapour images available from geostationary satellites. Forecast-simulated satellite images are now produced out to five days and are displayed on the ECMWF website.

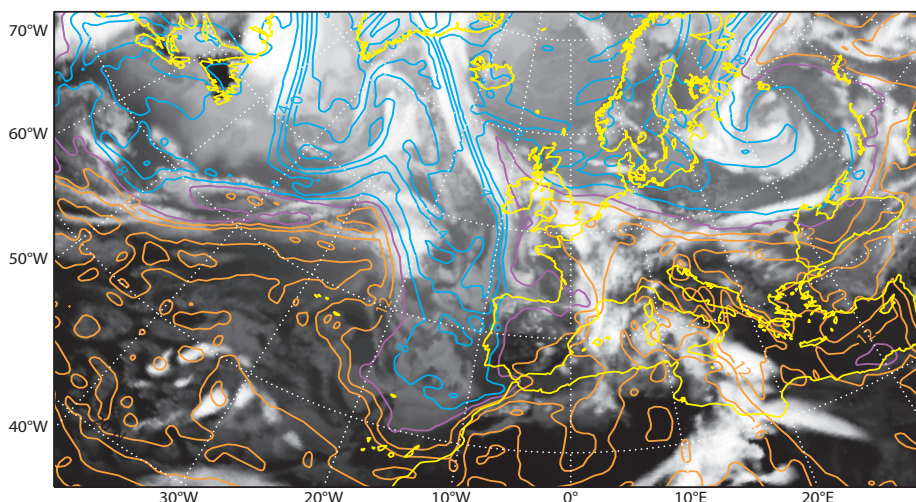
As the simulated image products are in a format that is very familiar to that used by forecasters, the products can easily be compared with the actual satellite cloud images.

Extratropical feature tracking products

In response to requests from Member States and Co-operating States, a range of products to identify and track extratropical cyclonic features has been developed. A software package originally developed at the UK Met Office has been upgraded and implemented for the ECMWF forecasting systems. This now runs in real time and provides products on the ECMWF test website.

Other developments

- A new main web page has been created for the ECMWF ocean wave products and an extended set of verifications for the wave forecasts. This makes it easy to access all the available information for ocean waves from one page.
<http://www.ecmwf.int/products/forecasts/wavecharts/>
- A new interactive web product based on the Extreme Forecast Index (EFI) is now available. The main page is an 'anomalous weather' chart that summarises EFI information for wind, temperature and precipitation. By clicking on a location on the chart, users can find more detailed information.
<http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/interactive/globalefi/>
- ECMWF routinely monitors all the observations used by the data assimilation system to initialise the forecasts. Plots showing the global, spatial distribution of available data are provided on the ECMWF website.
<http://www.ecmwf.int/products/forecasts/d/charts/monitoring/coverage/dcover/>
- Time series of the total available number of observations for different data types over recent months are available. For conventional observing systems, a monthly monitoring report is produced, which includes information on data quality.
http://www.ecmwf.int/products/forecasts/monitoring/mmr/GDMR_PDF_Archive.html



Example of satellite image simulated from a model forecast. The simulated satellite image shows a band of frontal cloud extends from Ireland to Greenland (strong gradient in potential temperature), while the area of cloud over southern England, France and Germany (away from the potential temperature gradients) is associated with convection. The simulated satellite image and the 850 hPa wet-bulb potential temperature are for the forecast valid at 18 UTC on 14 May 2009 that started at 12 UTC on 13 May. Contours show forecast 850 hPa wet-bulb potential temperature for the same time.

Preparations for the increase in horizontal resolution

Preparations for the implementation of higher-resolution forecasts in 2010 progressed well*. The following changes will be made to the horizontal resolution.

- The resolution of the deterministic model increases from T799 (25 km grid) to T1279 (16 km).
- The resolution of the Ensemble Prediction System increases from T399 (50 km) to T639 (32 km) for the first 10 days of the forecast and from T255 (80 km) to T319 (65 km) for day 10 onwards.

The higher-resolution configurations of all components of the forecasting system were first technically tested using an earlier cycle of the IFS. A substantial number of individual global forecast cases were examined to identify any numerical, dynamical or physical problems. Also, several periods of data assimilation and forecasts were studied to see the impact of the increased resolution on objective scores, including those for weather parameters.

Elements of the forecast suite that needed to be made highly efficient were identified and further optimised in collaboration between the Operations and Research Departments. Test data from the deterministic model and EPS was made available in the Meteorological Archival and Retrieval System (MARS) to the users.

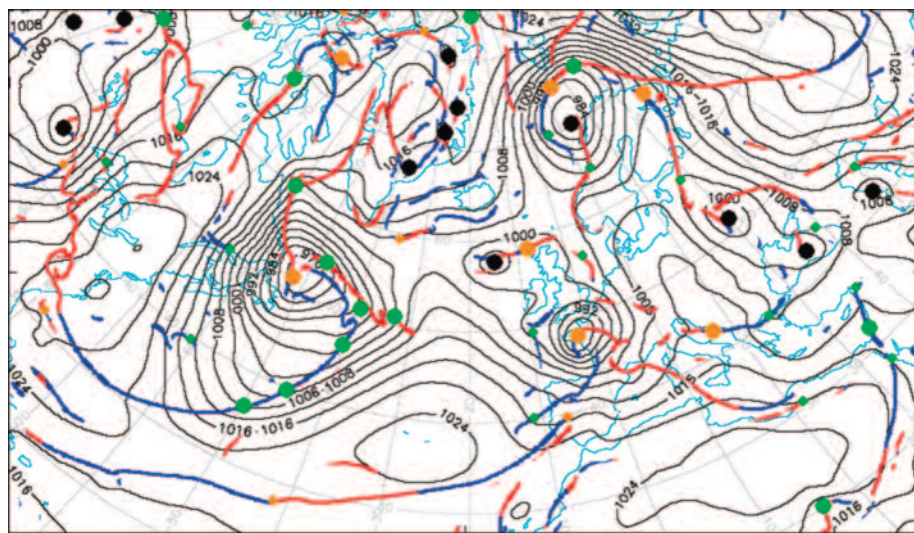
To support the higher-resolution forecasts, the interpolation software package was updated. This is used to retrieve data from MARS. Also hardware and software aspects concerning how to handle and visualise high-resolution fields on ECMWF's desktop computers have been investigated.

Impact of increased horizontal resolution

By the end of the year the impact of the new cycle on the performance of the deterministic forecasting system had been tested on more than 500 cases. Objective verification shows statistically significant improvements for 1000 hPa and 500 hPa height for Europe and for both extratropical hemispheres out to day 7. Also there is a systematic improvement of temperature at 850 hPa. In many cases the location and intensity of synoptic features are improved. The frequency of occurrence of intense rainfall events has increased, resulting in better agreement with observations.

The higher-resolution wind fields are better at representing features such as tropical storms, fronts and land/sea transitions, which translates into better wave forecasts. Tropical cyclone track and intensity forecasts are generally improved in the higher-resolution system, based on the relatively small sample available.

The overall benefit of the T639 version of the Ensemble Prediction System (EPS) is reflected in the results for the probability scores, which are consistently improved for 500 hPa height anomalies and 850 hPa temperature anomalies. EPS spread is in general unchanged. The EPS ensemble-mean errors are consistently lower, resulting in some overestimation of spread in terms of 500 hPa height and a better-tuned spread in terms of 850 hPa temperature.



Example of new extratropical feature tracking product. The cyclonic features on the 'automated synoptic chart' are marked by the coloured circles (green: diminutive frontal wave; orange: frontal wave; black: barotropic low), and warm and cold fronts are marked by red and blue lines respectively. Mean sea level pressure is in black. Weaker frontal features are denoted by smaller spots. The results are shown for the 5-day deterministic forecast from 00 UTC on 5 February 2009. Storm Quinten, located near the coast of France, caused widespread damage to northern France from wind gusts of over 30 ms^{-1} and disruption from heavy snow and flooding over England.

* The implementation of the high-resolution forecasts took place on 26 January 2010.



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 that maintain the status of ECMWF as the world's leading centre for operational global forecasting.



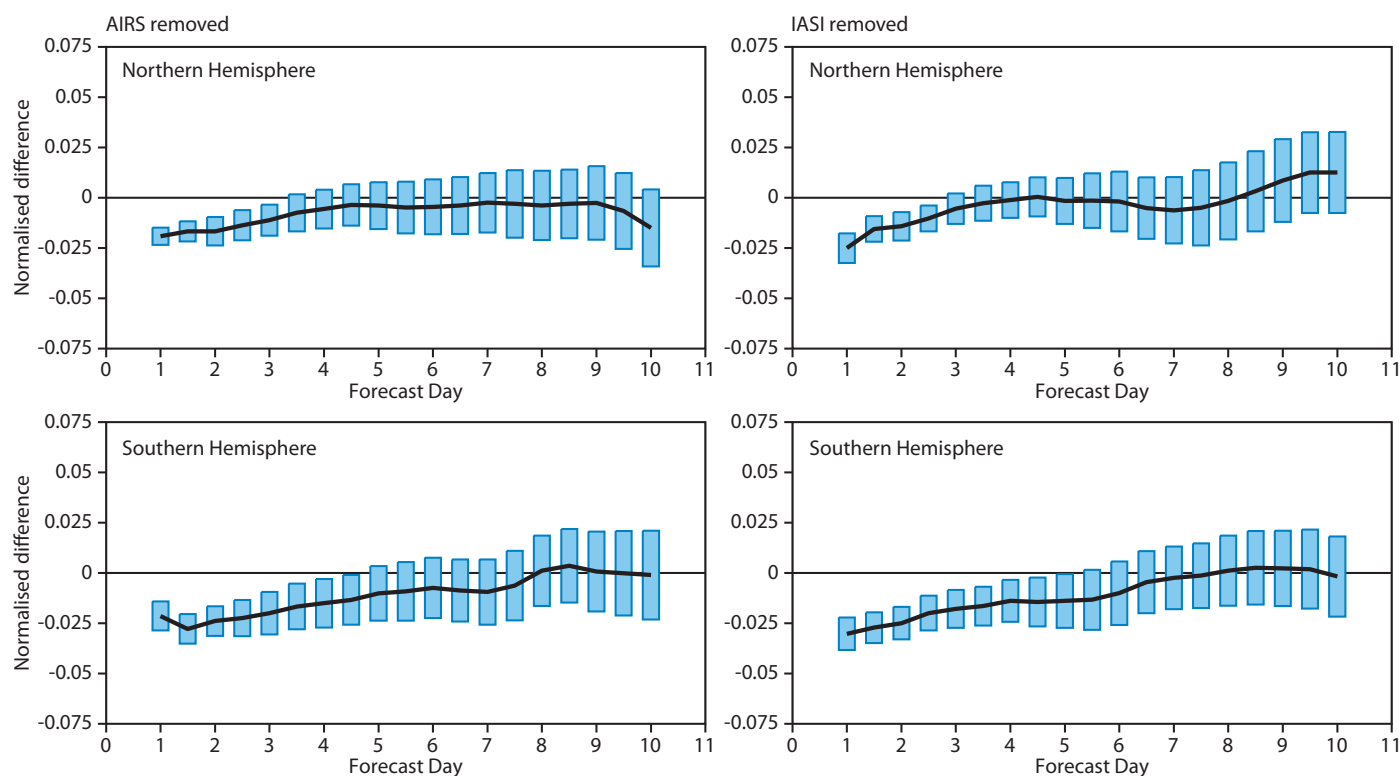
AIRS: Atmospheric Infrared Sounder
IASI: Infrared Atmospheric Sounding Interferometer

Impact of advanced infrared sounders

AIRS and IASI are two advanced infrared sounders carried on satellites. An extensive observing system experiment covering a full year, aimed at assessing the impact of AIRS

and IASI data, has been conducted. The scenarios tested included the loss of AIRS and IASI (both separately and together) from the current observing system. The results are consistent with previous studies and confirm that the loss of AIRS and IASI

data would result in a significant degradation of forecast skill that lasts until day 3–4 in the northern hemisphere and day 4–5 in the southern hemisphere.



Impact of advanced infrared sounders. The results show that removing AIRS (left panels) or IASI (right panels) has a clear negative impact on forecast skills in both the northern hemisphere (top panels) and southern hemisphere (bottom panels). Each system is verified against the ECMWF operational analyses and the vertical error bars indicate the 95% confidence intervals. The measure is the normalised root mean square forecast error difference between the experiment without the sounding data and the control for 500 hPa geopotential height evaluated over 365 cases (7 August 2008 to 6 August 2009).

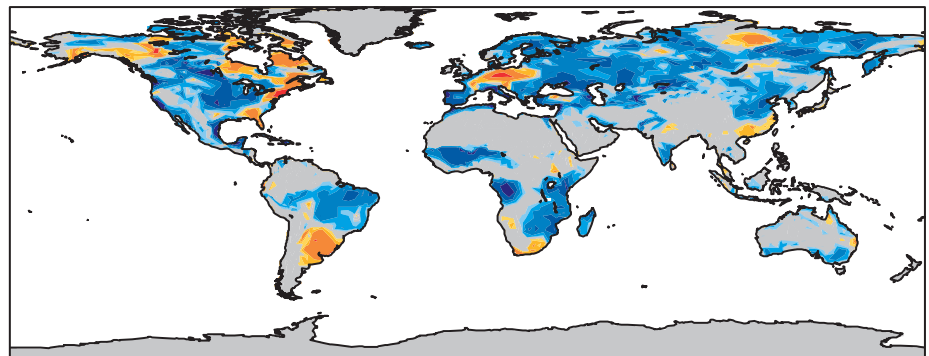
Soil moisture assimilation and SMOS preparation

Significant scientific and technical work has taken place to prepare for the operational implementation of the extended Kalman filter (EKF) surface analysis. The new analysis scheme provides the opportunity to exploit new satellite surface data and soil moisture products. It is computationally far more expensive than the simple operational optimum interpolation (OI). However, the EKF can be run without delaying the final analysis by separating observations and fields for the surface and upper-air analyses so they can now be run concurrently.

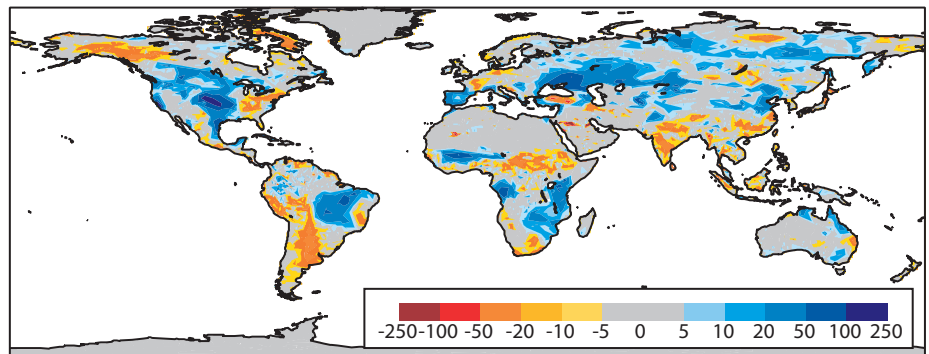
In preparation for the Soil Moisture and Ocean Salinity (SMOS) mission that was launched in November 2009, the Community Microwave Emission Model (CMEM) was used to investigate the sensitivity to soil roughness parametrization. The use of the CMEM follows the 'all-sky' radiance approach adopted for the other microwave sensors.

Comparison of the optimum interpolation (OI) and extended Kalman filter (EKF) soil moisture analyses. Although the same observations are used in the two data assimilation schemes, using the EKF soil moisture analysis allows drastically reduced soil moisture increments compared with the OI analysis. Shown are the soil moisture analysis increments in mm for July 2009 using the OI soil moisture analysis (top) and EKF soil moisture analysis (middle) for the accumulated root zone (top metre of the soil layer). Also shown is the difference between EKF and OI analyses (bottom).

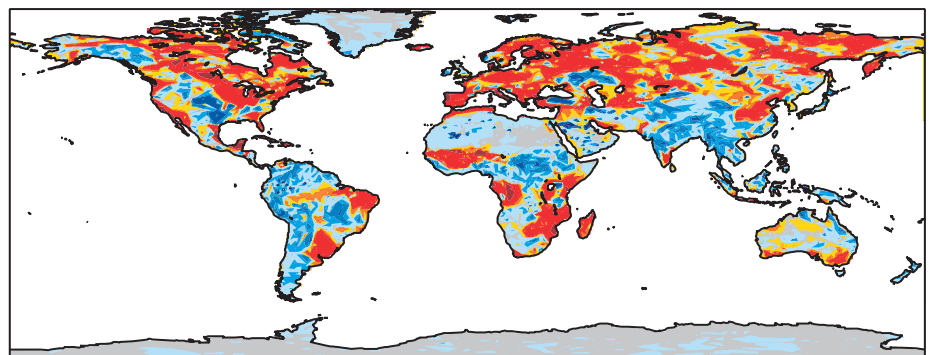
OI soil moisture analysis increments



EKF soil moisture analysis increments



Difference between EKF and OI analysis increments

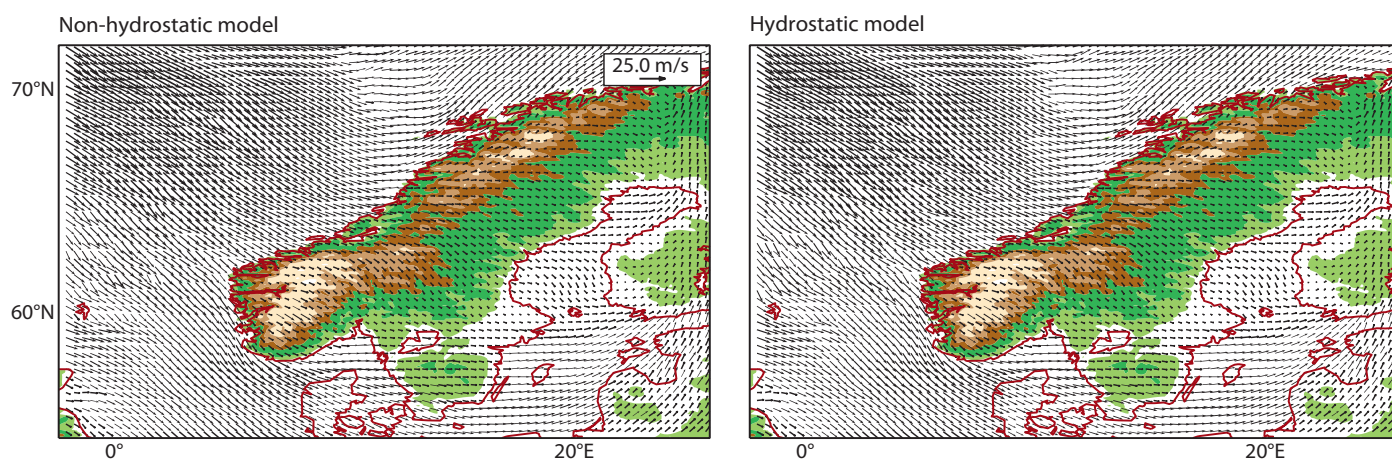


Hydrostatic versus non-hydrostatic core

ECMWF plans to implement a horizontal resolution of ~10 km by 2015 for its assimilation and deterministic forecasting system, beyond which a non-hydrostatic dynamical core will be required. Rather than developing such a dynamical core for the Centre's future operational forecasting applications from scratch an alternative approach was taken. It was decided to evaluate the accuracy, efficiency and robustness of the non-hydrostatic model formulation developed by the ALADIN group and made available by Météo-France in the global IFS/Arpège model.

The tests performed ranged from 13-month simulations at T159 (~125 km) horizontal resolution to medium-range forecasts at T2047 (~10 km). These assessed the performance of the non-hydrostatic model in the hydrostatic regime, all the way to idealised ultra-high resolution simulations in the non-hydrostatic regime on a reduced-size planet. Experiments with the T2047 horizontal resolution indicate that the differences between the hydrostatic and the non-hydrostatic simulations are still not significant at this resolution.

Based on the performance of the non-hydrostatic model in terms of skill, it can be concluded that this non-hydrostatic dynamical core is a possible choice for future, globally-uniform high-resolution applications at ECMWF. An assessment of moist simulations at non-hydrostatic scales is ongoing. Issues with the efficiency of the non-hydrostatic model still need to be addressed before it is fit to be used as the dynamical core of the operational model at all resolutions.

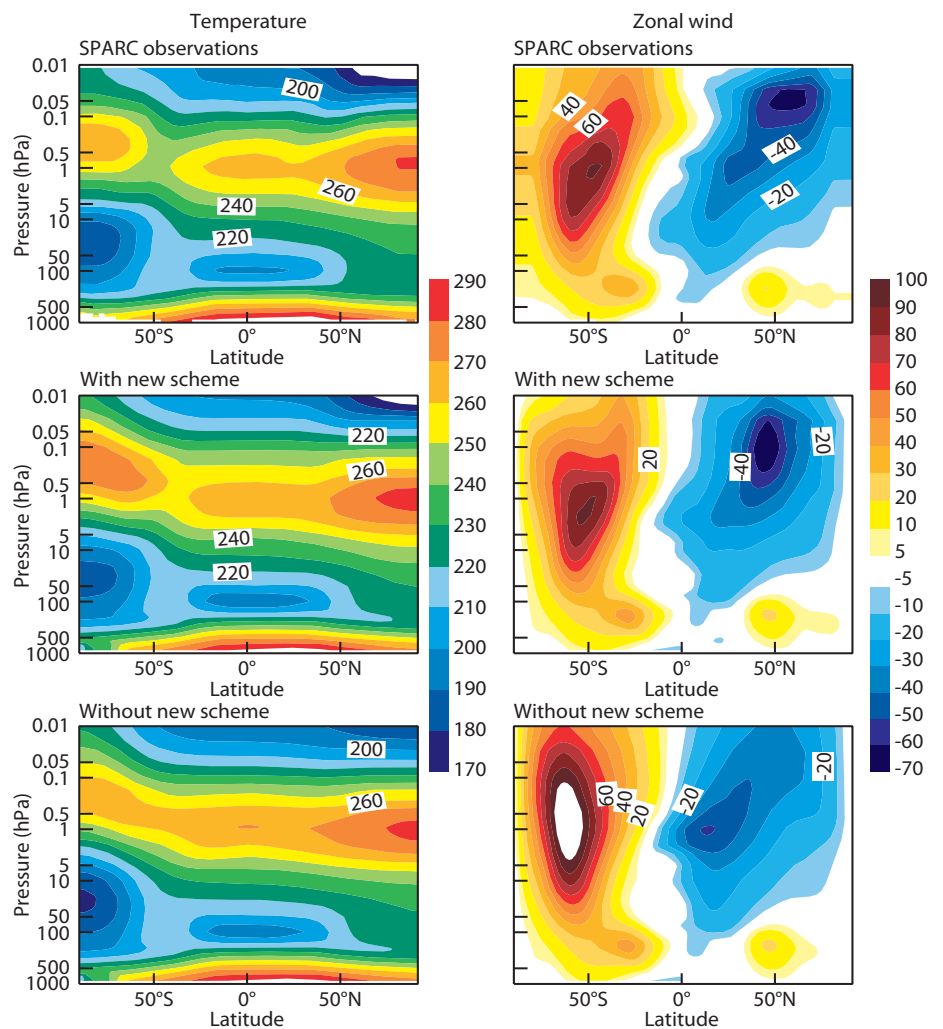


Test of the non-hydrostatic dynamical core. Shown is a comparison of the north-westerly flow impinging on the Scandinavian peninsula simulated with the non-hydrostatic (left) and the hydrostatic (right) models at T2047 horizontal resolution (~10 km). Differences between the hydrostatic and the non-hydrostatic simulations are not significant at 10-km resolution and there is no indication that the semi-Lagrangian advection algorithm provides an inferior solution in the presence of a more complex topography. The simulations are 24-hour forecasts from 00 UTC on 18 March 1998.

Non-orographic gravity wave drag

Non-orographic gravity waves are generated by mechanisms such as deep convection, frontal instabilities, shear zones and thermal contrasts. These waves are generally unresolved or under-resolved by the model, and/or their generating mechanisms cannot be represented by the model. As a result, a new parametrization scheme was implemented on 8 September (IFS Cycle 35r3) to represent the non-orographic gravity wave drag in the middle atmosphere (i.e. stratosphere and mesosphere).

The introduction of this scheme has generally improved the representation of the northern and southern polar vortex in the middle atmosphere. Also the temperature structure in the upper stratosphere and mesosphere is improved. Another important impact of the new scheme is that it provides a much better representation of the quasi-biennial oscillation that occurs in the tropical stratosphere and lower mesosphere.

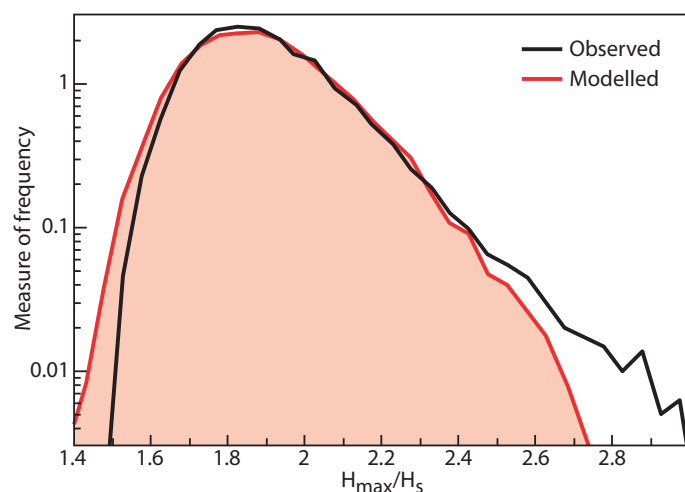


Impact of introducing non-orographic gravity wave drag. With the non-orographic gravity wave drag scheme both the strength and the inclination of the polar winter middle atmosphere are a better fit to the observations. The figure shows the average July cross-sections of zonal-mean temperature (K) and zonal wind (ms⁻¹) for SPARC (Stratospheric Processes and their Role in Climate) observations (top), and simulations with (middle) and without (bottom) the new non-orographic gravity wave drag scheme. Simulation results are six-year averages. SPARC data north and south of 80°N and 80°S is constant and interpolated. Contour intervals are 10 K and 10 ms⁻¹.

Freak wave prediction

The wave model performance during 2007–2008 has been monitored extensively. Forecast validation against buoy data and against the verifying analyses confirms that the quality of the wave forecast continues to be very high. The comparison of performance with other operational centres shows that the ECMWF wave forecasting system has a clear lead over the other centres (see page 12).

The recently introduced maximum wave height parameter has been subjected to further extensive validation against maximum wave height observations which are available from a limited set of buoys only. The results indicate that the present freak wave warning system is effective. However, there is a discrepancy between model and observed probability distribution functions for really extreme states; this requires further analysis.



Verification of freak wave forecasts. The modelled and observed probability distribution functions are similar for most values of the ratio of maximum wave height (H_{max}) and significant wave height (H_s). In engineering practice a sea state is considered extreme when this ratio is greater than 2.2. Extreme sea states above 2.2 are well represented, but really extreme states above 2.7 still require analysis. The number of collocations is about 16,000 taken over a two-year period. The measure of frequency used for the graph is $\log_{10}(\text{pdf})$ where pdf is the probability distribution function.

Views of the Scientific Advisory Committee – October 2009

Extracts from the Report of the Chair of the Scientific Advisory Committee (SAC) to Council.

- The SAC notes with satisfaction the milestones achieved towards increasing the resolution of the forecasting system. The resolution of T1279L91 (16 km horizontal grid spacing) has been successfully tested, significantly improving the forecast skills.
- The SAC congratulates the Centre for the excellent management of the GEMS project which was important to secure the succeeding MACC (Monitoring Atmospheric Composition and Climate), which is expected to become the core of the planned GMES atmospheric service and is therefore of strategic importance for the Centre's relation to the European Commission.
- The pioneering work of the Centre on stochastic processes for representing model uncertainty in ensemble prediction is noted with pleasure. The SAC strongly endorses this approach.
- The SAC points out that the reanalysis projects of the Centre have become an important tool for diagnosing and monitoring climate variability and change, and are widely used by the scientific community.

Simulation of the Madden-Julian oscillation

The Madden-Julian oscillation (MJO), a 30–60 day oscillation, is a major source of variability in the tropics in the time range exceeding one week but less than a season. It is a near-global-scale, quasi-periodic eastward moving disturbance over the equatorial belt. The anomalous rainfall is usually first evident over the western Indian Ocean, and then propagates eastward across the Indian Ocean, the Maritime Continent, and then the western Pacific. The wet phase of enhanced convection and precipitation is followed by a dry phase where convection is suppressed.

The MJO has a very significant impact on the Indian, Australian and African monsoons. It also plays an active role in the onset and development of an El Niño event and has an impact on tropical cyclogenesis. The MJO affects the weather over Europe, through its impact on the North Atlantic oscillation (NAO). Therefore, it is important for a monthly forecasting system to have skill in predicting the evolution of the MJO.

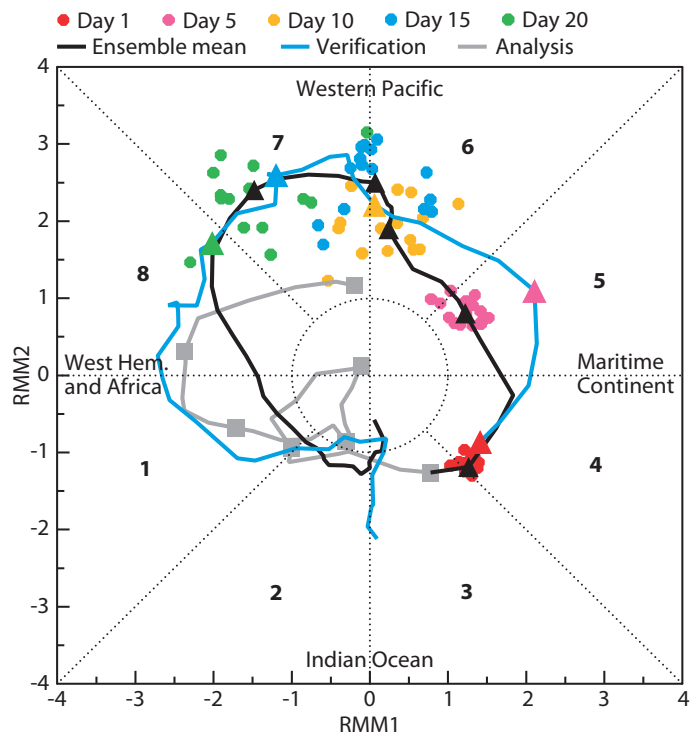
Simulation of the Madden-Julian oscillation (MJO). The distance from the origin indicates the strength of the MJO (an MJO event is outside the inner circle), and the changing angle effectively indicates the propagation of the MJO around the equator. The 46-day ensemble-mean forecast (black line) starting on 15 May 1997 and the corresponding analysis (blue line) from ERA-Interim show that this MJO event was well predicted. Each dot represents an individual ensemble member for day 1 (red), 5 (magenta), 10 (orange), 15 (blue) and 20 (green). The triangles show the verification at day 1, 5, 10, 15 and 20. The grey line shows the past 30 days of analysis. RMM1 and RMM2 are indices used to plot the MJO; RMM refers to 'Real-time Multivariate MJO'.

In earlier versions of the ECMWF monthly forecasting system, the MJO was not well represented. The situation is much improved in the recent versions.

The ECMWF forecasting system is generally able to accurately predict the evolution of an MJO event. Overall the model displays skill to predict the MJO for up to about 20 days. This is, however, not always the case. Sometimes the MJO events predicted by the recent versions of the IFS tend to propagate too slowly and

often die crossing the Maritime Continent. On the other hand, the tropical rainfall patterns associated with different phases of the MJO are realistically reproduced by the model.

Model simulations support recent observation findings on the link between the MJO and the NAO. As a consequence the reliability of monthly forecasts over Europe is increased during active MJO events.



Ensemble prediction intercomparison

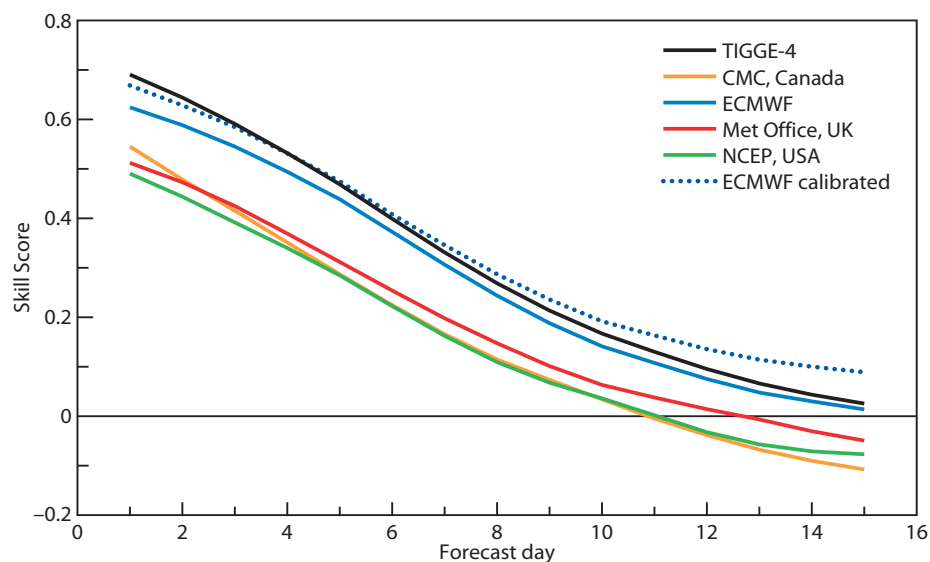
The TIGGE (THORPEX Interactive Grand Global Ensemble) archive, providing access to forecasts from ten global ensemble prediction systems, establishes a new benchmark for forecasts from the ECMWF Ensemble Prediction System (EPS). Comparing the ECMWF EPS with all other single-model systems demonstrates a clear overall superiority of the ECMWF system.

A TIGGE multi-model composed of all single models does not provide significantly better forecasts than the ECMWF EPS on its own. However, combining only the four best single models (ECMWF, Met Office, CMC and NCEP) can improve the forecasts compared with the single ECMWF EPS, in particular for surface variables like 2-metre temperature. This suggests that work is needed in the EPS to perturb land-surface variables, as discussed in the four-year programme.

Based on previous work, which demonstrated that calibrating the ECMWF EPS with the re-forecast dataset can significantly improve its performance, it was investigated whether the ECMWF EPS calibrated in this way is as good as, or even better than, the TIGGE multi-model.

Results indicate that the performance of the calibrated ECMWF EPS indeed becomes more than competitive with the TIGGE multi-model performance.

Further investigations showed that both the multi-model and calibration procedure correct in a similar way for similar deficiencies (i.e. both techniques are similarly successful in reducing systematic errors and correcting for spread deficiencies).



Comparison of the ECMWF EPS with other ensemble systems. The ECMWF EPS outperforms other individual ensemble systems. A multi-model combination of the four best ensemble systems ('TIGGE-4') is slightly better than the EPS, but the calibrated EPS regains the lead ('ECMWF calibrated'). The results are based on the Continuous Ranked Probability Skill Score (CRPSS) for December–February 2008/09 for the 2-metre temperatures over the northern extratropics.

CMC: Canadian Meteorological Centre
NCEP: National Centers for Environmental Prediction



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. It does not include carrying out climate simulations. However, through its core activity, ECMWF is contributing significantly to climate change studies.



ERA-Interim reanalysis in near-real time

Reanalysis is the reprocessing of past observations with a modern data assimilation system. Since reanalyses are produced with fixed, modern versions of data assimilation systems used for NWP, they are more suitable than operational analyses for studies that require an observational record of the state of either the atmosphere or its underlying land and ocean surfaces. For example, reanalyses are suitable for studies of long-term variability in climate.

The ERA-Interim project was initiated in 2006 to prepare for a new, more ambitious ECMWF reanalysis to succeed ERA-40, which covered the period 1957 to 2001. The main goal of the project is to use lessons learned from ERA-40 to address some well-documented weaknesses in existing first- and second-generation reanalysis products.

Substantial progress towards this goal has been made in ERA-Interim, largely because of improvements in the forecasting model and advances in data assimilation achieved at ECMWF during recent years. The overall quality of ERA-Interim products exceeds that of ERA-40 in terms of, for example, the fit to observations and the skill of re-forecasts initialised from reanalysed fields. In addition, it has been demonstrated that the representation of essential climate variables in ERA-Interim is

of sufficiently high quality that important indicators of climate change can now be reliably estimated and monitored using reanalysis.

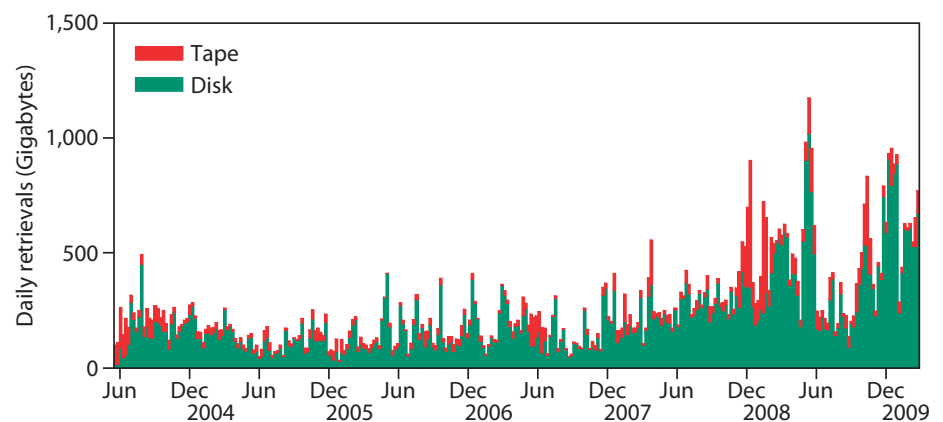
The ERA-Interim reanalysis produced at ECMWF has now completed 21 years of data assimilation, from 1989 to 2009. The reanalysis is being continued in near-real time, lagging the operational forecasting system by about five days. ERA-Interim daily and monthly averaged products are available on MARS (ECMWF's archival and retrieval system) and are updated on a monthly basis as the reanalysis progresses forward in time.

ERA-Interim products are already used extensively at ECMWF for research and diagnostic studies, and for many other purposes such as calibrating the seasonal forecasting system and providing the

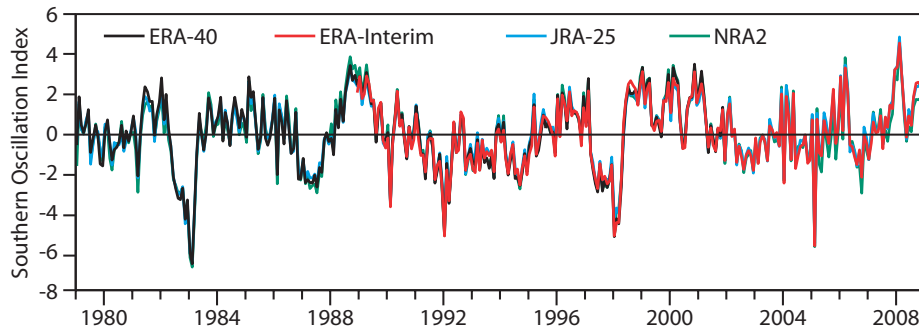
climatology needed for operational verification. Users from the academic and wider scientific community increasingly rely on ECMWF reanalysis data for their work, and many have been eagerly awaiting the availability of ERA-Interim products in near-real time.

ECMWF reanalysis data has always served a large number of users, giving high visibility to ECMWF's activities. This is exemplified by the fact that an article on 'The ERA-40 re-analysis' by Sakari Uppala and others published in 2005 was recently identified as one of the most highly cited papers in the field of Geosciences based on the Essential Science Indicators used by the Thomson Reuters company.

The high demand for ECMWF reanalysis products by Member State users is well illustrated by recent MARS usage statistics.



Usage of reanalyses. The graph shows daily retrievals from the MARS reanalysis server, in gigabytes. The number of retrievals has been growing steadily.



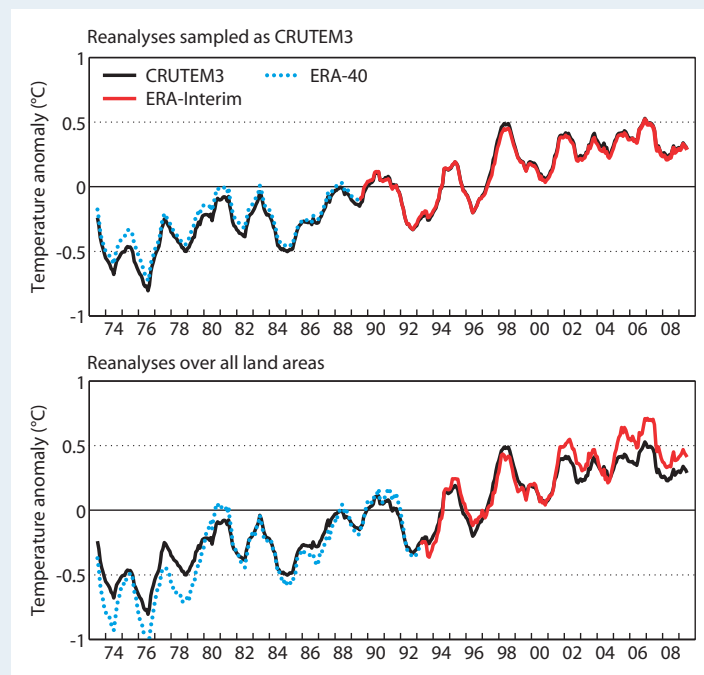
Example climate monitoring product. The figure shows the Southern Oscillation Index, which assesses the phase of El Niño/La Niña phenomena. The results are based on monthly averaged data from ERA-40 and ERA-Interim as well as the Japanese 25-year reanalysis (JRA-25) and the NCEP/Department of Energy reanalysis (NRA2).

On a typical day more than 7,000,000 reanalysis fields are retrieved from MARS, and this number is still growing. In addition, more than 12,000 users have registered on the ECMWF Data Server for public access to ERA-40 data; for ERA-Interim this number already exceeds 2,500.

The rapidly growing interest in climate is expected to lead to increased demand for high-quality reanalysis products. The nature of the users and the type of information they require will evolve as well. ERA-Interim already generates a range of web-based climate monitoring products. These include time series of global and regional mean temperature and precipitation, and standard measures of the large-scale atmospheric circulation. One such measure is the Southern Oscillation Index, which assesses the phase of the El Niño/La Niña phenomena.

Reanalysis – climate trends

A comparison has been made between the surface temperature trend over land areas estimated with ERA-40, ERA-Interim and the Hadley Centre/University of East Anglia surface temperature dataset (CRUTEM3). When the reanalysis data is sampled at the locations contained in CRUTEM3, the temperature evolutions of the two datasets agree very well. If all land areas are included, however, the ERA data shows a stronger warming trend in recent years than the CRUTEM3 data. As the reanalyses use many more surface temperature observations than CRUTEM3, as well as measurements from other instruments (including satellites) over sparsely populated regions, it can be assumed that the reanalysis data produces a more representative estimate of the global surface temperature trend than can be derived from the CRUTEM3 data.



Use of reanalysis for climate monitoring. Comparison of temperature trends over land areas. Temperature data from the Hadley Centre/University of East Anglia (CRUTEM3) and two reanalyses (ERA-40 and ERA-Interim) is shown. In the top panel the datasets are sampled at the same spatial points and are in very good agreement. All land points are included in the reanalysis curves in the bottom panel, which then shows a stronger warming trend.

EC-Earth

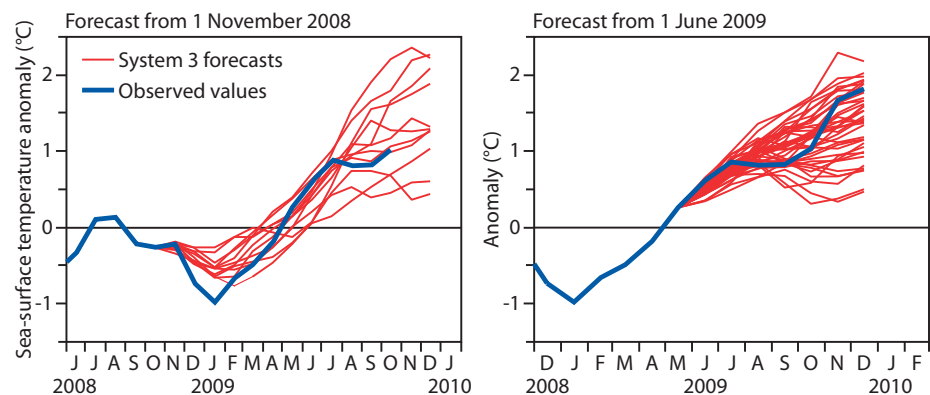
ECMWF collaborates with the EC-Earth consortium that is developing a new fully coupled atmosphere-ocean-land-biosphere model, usable for seasonal to decadal climate prediction and climate projections. The aim is to implement the emerging concept of 'seamless prediction' and to contribute with climate scenarios to the next IPCC report.

EC-Earth is a project run by a consortium of scientists from Member States under the leadership of KNMI (Koninklijk Nederlands Meteorologisch Instituut). It is building upon ECMWF's coupled model system to develop a climate model for decadal and longer timescale integrations. ECMWF provides technical support to the project with a consultant who works in the Seasonal Forecast group at ECMWF, fully funded by EC-Earth.

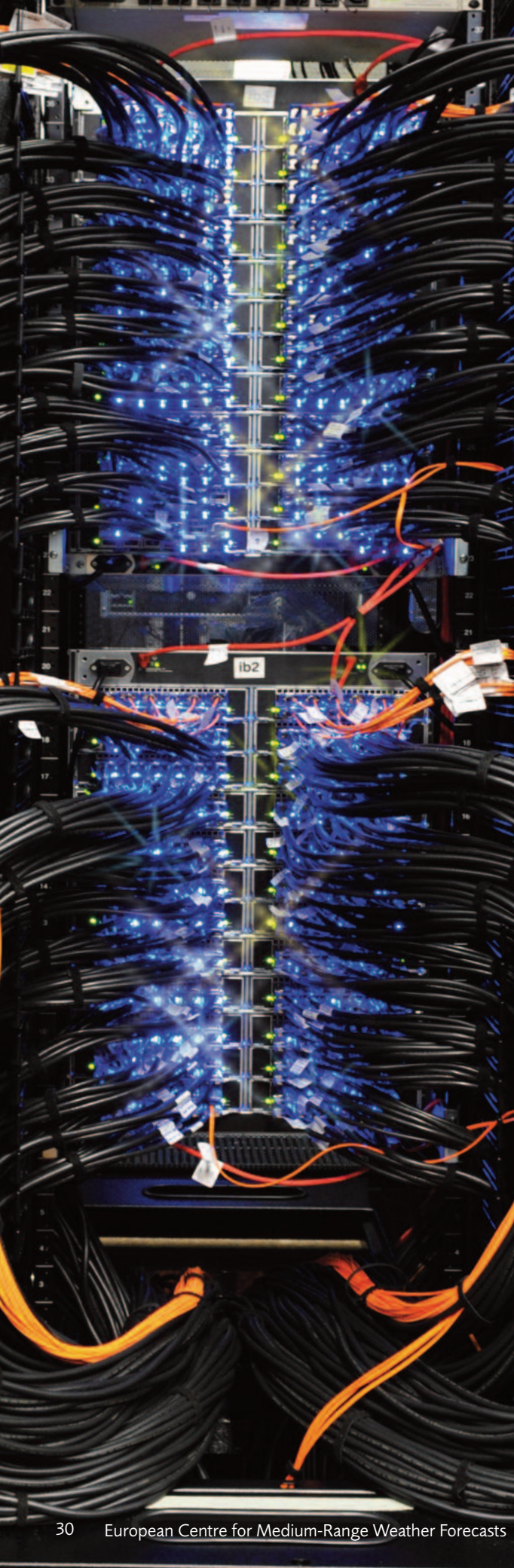
El Niño prediction 2008/2009

Every quarter the operational seasonal forecast is extended to 13 months. The annual-range forecast of sea-surface temperature in the Central/Eastern Tropical Pacific (the region known as Niño 3.4) predicted the possibility of a substantial El Niño event in the second half of 2009 as early as November 2008. This long-range prediction was of particular interest and suggested additional monitoring of the El Niño phenomenon would be beneficial.

As the operational annual-range forecasts are only run once per quarter, it was agreed to run a parallel suite in research mode to produce annual-range forecasts for those months not covered by operations. This necessitated producing a substantial set of hindcasts as well as the real-time forecasts. The results showed that the seasonal forecasting system (System 3) was very consistent in predicting the likelihood of a substantial warm event.



Annual-range forecast of El Niño. The possibility of an El Niño in late 2009 was already evident using the annual-range forecasts of sea-surface temperature anomaly in the Niño 3.4 region from 1 November 2008 using System 3 (left). Also shown is the seven-month forecast from 1 June 2009 for comparison (right).



Computing

Running ECMWF's complex weather forecasting models to a relatively tight schedule requires extremely powerful computers and instant access to massive amounts of data. Central to the Centre's activities are its supercomputers and its unique archive of meteorological data that has been collected over three decades and stored in the data handling system.



High-performance computing facility (HPCF)

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 IBM scalar SMP clusters. From the beginning, ECMWF has ensured that its codes are portable. Also it 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 has been using IBM computer systems to produce operational forecasts since 2003. Its current high-performance computing facility (HPCF) is one of the most powerful in Europe.

During 2009, a new HPCF was brought fully into production, consisting of two identical, independent IBM Cluster 1600 supercomputers and storage clusters, all with POWER6 servers. This replaced the previous facility, which was based on POWER5+ architecture, and is the first of two phases under a contract with IBM – the result of an invitation to tender for a replacement HPCF that was issued in 2007. The follow-on system that will replace this new one will be installed in 2011. It too will

comprise two identical, but distinct compute clusters and storage clusters and will be based on IBM's next-generation processor, POWER7.

The new POWER6 system, known as 'Phase 1', was delivered in two stages, the installation of which had to be carefully planned and executed to ensure that the service provided and products delivered to ECMWF's users were not disrupted. The first stage of Phase 1 was installed in 2008 and began providing a service to the users at the end of 2008; the second stage was installed in spring 2009. The operational suite of jobs, which produce the products

HPCF – facts and figures

- 2 identical clusters
- 544 32-way p6-575 servers
- 17,408 SMT-2 cores
- 20 teraflops sustained
- 325 teraflops theoretical peak
- 38 terabytes of memory
- 6,048 disk drives (each 300 gigabytes)
- 1.2 petabytes of usable disk space

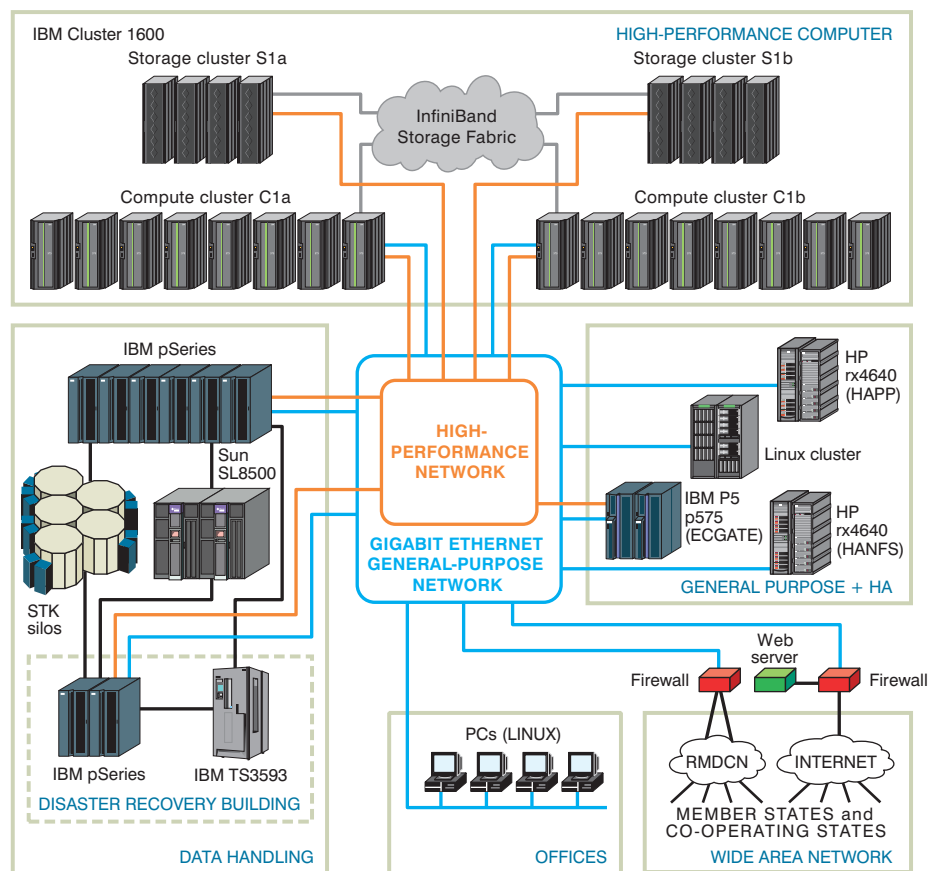
delivered to ECMWF's Member States, Co-operating States and other customers, was migrated fully to the new system on 1 April 2009, and shortly thereafter, the service was opened fully for use by the Member States.



Part of ECMWF's high-performance computing facility (HPCF). The HPCF consists of two identical, independent IBM Cluster 1600 supercomputers and storage clusters.

The availability of the new HPCF over 2009 as a whole was almost 99% and actually reached 99.9% for the month of August. Users are very pleased with the quality of the service it provides and are making good use of the facilities, running almost a million jobs each week, with over 96% of the computing resources used by parallel jobs.

Phase 1 comprises two identical POWER6 compute clusters, each with 272 32-core p6-575 servers, as well as two identical storage clusters, each of which holds about 0.6 petabytes of data. InfiniBand is used as the high-performance interconnect within each of the compute clusters. All four clusters are connected to an InfiniBand network that enables each compute cluster to access data in multi-cluster filesystems that reside on either of the storage clusters. This system, which has a theoretical peak performance of 325 teraflops, delivers an aggregated sustained performance of about 20 teraflops on the various components of ECMWF's IFS codes.



ECMWF's computer configuration as of December 2009. The diagram shows how the major components, including the HPCF, are interconnected via the local area network. The HPCF is currently one of the most powerful computer systems in Europe.



ECMWF's new automated tape libraries (ATLs) during construction. Each ATL from Sun can host 10,000 one-terabyte tape cartridges. Photographs, Neil Storer, ECMWF.



Data handling system

Weather forecasting makes use of, and generates, very large volumes of data – observations, analyses and research experiments – that needs to be stored for long periods. The data represents a valuable asset and incomparable archive of worldwide meteorological information from the past 30 years. It is used by researchers in meteorological and environmental studies, and is also available for educational and commercial purposes.

For many years ECMWF has operated a dedicated data handling system (DHS) in which all ECMWF users can store and retrieve data needed to perform a wide variety of research and development activities. The ease with which data in the DHS can be accessed is regularly commented upon by visiting scientists and other users of the system.

IBM's high-performance storage system (HPSS) is the underlying data management system in which all of the data in the DHS resides. Users do not use HPSS directly, but access the data via one of two applications that have been developed by ECMWF:

- **Meteorological Archival and Retrieval System (MARS):** a unique resource which allows research and operational staff to access and retrieve a wealth of meteorological data.
- **ECMWF Common File System (ECFS):** a facility which allows users to store data that is not suitable for storing in MARS.

At the end of 2009 the volume of primary data residing in the DHS was almost 13 petabytes, residing on approximately 18,000 IBM 3592 tape cartridges. In addition, more than 4 petabytes of back-up copies are kept in the disaster recovery system. On the DHS, there are one hundred tape drives, which process a total of almost 10,000 tape mounts per day. Additional servers and disk subsystems are added each year to the DHS configuration to ensure that it continues to provide an excellent service to the users. There have been very few problems with the DHS over the past year and the system continues to perform very well.

In the first half of 2009, an invitation to tender was conducted for the replacement of two core components of ECMWF's DHS: the IBM enterprise-class tape drives and the StorageTek automated tape library (ATL) complex. The latter has been providing a service for almost 20 years but will no longer be maintained after 2010. Following the decision by the Council in June, a contract was concluded with Sun Microsystems Ltd.

Two SL8500 ATLs, almost one hundred Sun T10000B tape drives and 6,000 1-terabyte tape cartridges were installed in October. A third ATL, together with additional tape drives and cartridges, will be installed in January 2010. Throughout 2010 all of the data that exists on the IBM 3592 tape cartridges will be migrated to this new system. This will be a major exercise since it has to be completed without impacting unduly on the quality of service provided to the users of the DHS. Once the migration process is complete, the IBM tape drives and the STK silos in which they reside will be decommissioned.

DHS – facts and figures

Old system (until end 2010)

5 STK 9310 ATLs
100 IBM 3592 tape drives
Capacity: 27,000 tape cartridge slots
Data volume: 13 petabytes on 20,000 tape cartridges

New system

2 Sun SL8500 automated tape libraries (ATLs)
90 Sun T10000B tape drives
Capacity: 20,000 tape cartridge slots
No operational data (end 2009)

Disaster recovery system

IBM TS3500 ATL
20 LTO-3 tape drives
4 petabytes of backup data (secondary copy)
11,500 tape cartridges

User support

Significant efforts have been made to provide a steadily increasing number of users from Member States and Co-operating States with support and advice on the use of the Centre's computing facilities.

Several Member State users and persons responsible for Member State time-critical applications received assistance and advice for migrating to the new IBM HPCF. Usage of HPCF resources by Member States has doubled in 2009, with some countries using a considerable part of their 2009 allocation.

ECMWF continues to run several Member State time-critical applications: TEPS/LAMEPS (Norway), COSMO-LEPS (Italy), MOTHS (UK), LBC for ALADIN-France. All these suites have been migrated from the old IBM system to the new IBM HPCF.

In addition to these suites, ECMWF runs about 900 jobs from 126 different users triggered by 60 events. These jobs are monitored by ECMWF operators and relevant actions are taken in the event of their failure. Using this option, Austria is running an ALADIN Limited Area Ensemble Forecasting System (ALADIN-LAEF) twice a day and Portugal is running a different version once a day. Austria has started archiving its model output into MARS.

The Member State server ECGATE has continued to provide a stable and reliable service for users from Member States. However, the system is heavily used and needed to be upgraded in preparation for the implementation of the high-resolution forecasting system. Consequently in late 2009 the system was replaced by a cluster of 6 IBM P575+ nodes with about 50 terabytes of disk space. The replacement system provides users from Member States with the same computing environment, but significantly increased computational and storage resources.



COSMO/LEPS: COSMO Limited Area Ensemble Prediction System
HPCF: High Performance Computing Facility
LBC: Lateral Boundary Conditions
MARS: Meteorological Archival and Retrieval System
MOTHS: Measurement of Tropospheric Humidity
TEPS/LAMEPS: TEPS/Limited Area Ensemble Prediction System

Other developments

- **General-purpose network.** The general-purpose network has undergone a major redesign. The reason for this was to simplify the design and introduce better safety mechanisms into the configuration. The new design has proved to be more stable than the previous one and provides a very good service.
- **Internet access.** The Internet access was upgraded to 600 Mb/s (with a back-up connection at the same speed) in early 2009. Also two new servers were installed to support dissemination over the Internet. This has improved performance, not only for destinations served by the Internet but also for destinations using the RMDCN (Regional Meteorological Data Communication Network).
- **Technical infrastructure.** The programme of refurbishment and enhancement for ECMWF's technical infrastructure has continued. In particular, electrical and mechanical services have been provided with the capacity to support the new HPCF and to improve the resilience of the technical infrastructure. Special consideration has been given to separating electrical and mechanical services so that the equipment in each computer room is supplied from different circuits.

Computing and energy efficiency

About 95% of ECMWF's energy consumption is attributed to its HPCF and the associated cooling requirements. Consequently, ECMWF is focusing its efforts on improving the energy efficiency of the technical infrastructure needed to support the HPCF.

Supercomputer manufacturers are conscious of the need to increase the energy efficiency of their systems to keep within the power and cooling constraints of current data centres and also of the need to reduce the energy bills for such facilities. On a 'compute performance per power consumption' rating, ECMWF's current HPCF is about twice as efficient as the system it replaced in 2009, and its successor system (Phase 2 of the current contract) is expected to be about three times as efficient as the current Phase 1.

ECMWF has chosen to install energy-efficient infrastructure equipment for many years, but the technologies now available mean that new equipment is much more energy-efficient than older devices. Whenever equipment approaches the end of its useful life at ECMWF, the energy savings to be gained from its replacement are assessed when deciding the optimum time for its substitution.

When it became necessary to extend the Centre's chilled water facility to provide sufficient cooling for the new HPCF system, the decision was taken to install a new chilled water system, separate from the existing one, to provide a degree of resilience and to exploit more energy-efficient chilling technologies. The chillers chosen for this, based on the Turbocor design, were put into operation in 2009; averaged over a year they are about twice as energy-efficient as the oldest chillers on site. Having established this, and because the two oldest chillers are due for replacement, two more such chillers will be installed in 2010.

Technical Advisory Committee Subgroup on Green Computing

In October 2009, following the meeting of its Subgroup on High-Performance Computing Facilities, the Technical Advisory Committee decided to establish a new Subgroup on Green Computing with the following objectives:

- To advise ECMWF on moving towards an environmentally-friendly HPC installation, with particular focus on energy efficiency and low carbon footprint.
- To provide a forum for sharing experiences in the field of green computing.



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 2009, ECMWF disseminated 9,800,000 analysis and forecast products per day to Member States and Co-operating States via its privately managed network and website, and to non-members via WMO's Global Telecommunications System. The total number of products generated and disseminated daily to Member States, Co-operating States, research projects and commercial customers amounts to 13,000,000.



Daily product dissemination in 2009

13 million products with a volume of 545 gigabytes.
 33 gigabytes of monthly forecasts (once per week).
 32 gigabytes of seasonal forecast products (once per month).

Product dissemination

During 2009 the product generation and dissemination system was migrated to the new high-performance computing facility (HPCF). It was enhanced to handle the increased frequency of extended-area European wave model products as well as the provision of increased resolution data to national meteorological and hydrological services of WMO Members. In addition, the dissemination system was modified to allow Member States and Co-operating States the option of requesting model-level fields in a new format (GRIB edition 2). As fields are available in both GRIB editions 1 and 2, users will be able to test that their operational systems can handle data in the new format.

In addition to its service to Member States and Co-operating States, ECMWF disseminates real-time products to 35 commercial users. Of these, 24 hold a contract with a Member State, with data delivery delegated to ECMWF.

Users of the ECMWF public data server.

The chart shows the distribution by country of the 6,450 registered users of the ECMWF public data server. The data server provides the research community with access to datasets held at ECMWF. The European research community is under-represented because many research teams have direct access to the archive.

MARS and Data Services

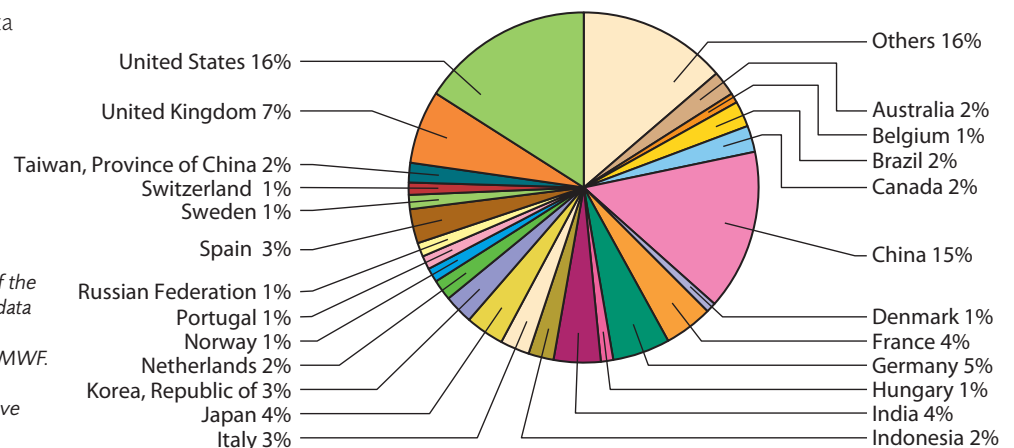
The Meteorological Archival and Retrieval System (MARS) is the main repository of meteorological data at ECMWF. It contains operational and research data as well as data from Special Projects. MARS data is freely available to registered users in the Member States and Co-operating States. MARS has been extended to support the archiving of new data, such as data from JASON-2 and output from the ensemble data assimilation system, the ALADIN-LAEF model and the new extended-area European Wave Model.

MARS is being enhanced to support the archiving and retrieval of data from the observation database (ODB). Given the increasing volume of satellite observations, efficiency is a primary concern for the design.

Public data servers have been upgraded to satisfy the high demand for ECMWF data within the research community. Also a new service is now available offering analysis and near-real-time data from GEMS (see page 43). This means that there are now eight datasets offered via the data servers.

The reanalysis dataset, ERA-Interim, has been extended to cover more than 20 years of data, from 1989 to 2009. Production has now reached current time. The data is made available with a two-month delay so that it can be checked before being released. There are more than 2,700 users registered for the ERA-Interim data server.

A revised standard licence agreement for use of ECMWF products has been adopted. This replaces the previous different licence agreements and takes into account current business practice at ECMWF and in the Member States.



Web services

ECMWF's website is a major, easily accessible and much appreciated resource for the international meteorological and research communities. Users can access computer facilities and run experiments as well as accessing a wide range of information such as operational and research data, training material and data on Special Projects. The ECMWF web servers continue to provide a stable and reliable service.

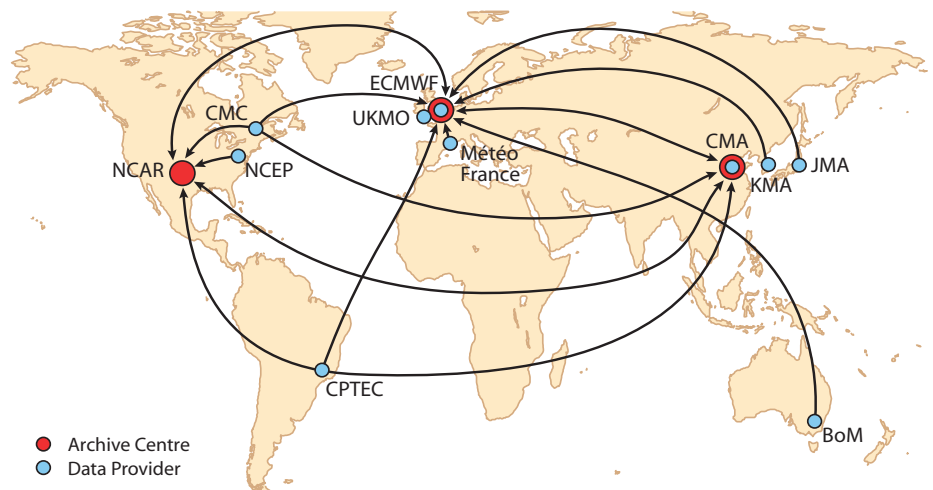
ECMWF has started a project to re-engineer web-based services. The aim is to provide highly interactive graphical products to forecasters who have access to the ECMWF web products. Users will be able to customise products by interacting directly with plots, including actions such as zooming and panning. For example, they could change the event threshold of probability maps and have some control over the graphical attributes (e.g. isolines and shading) of plots. Products will be provided in such a way that they can be integrated into a user's own Geographic Information System (GIS) software.

The technology to be used for the re-engineered services is highly available, scalable and fast.

THORPEX/TIGGE

ECMWF has continued to be involved in the TIGGE project, both as a contributor to the development and provision of the necessary infrastructure and as a data provider. The current service consists of feeding the TIGGE data repository with research and operational forecasts from various centres in near-real time. Tools have been developed to access this archive and to provide consistent data access.

Data started to be fed operationally into the TIGGE data archive in October 2006. The database now contains three years of global EPS data and holds more than 260 terabytes (1.7 billion fields). There are around 690 registered users from 60 different countries.



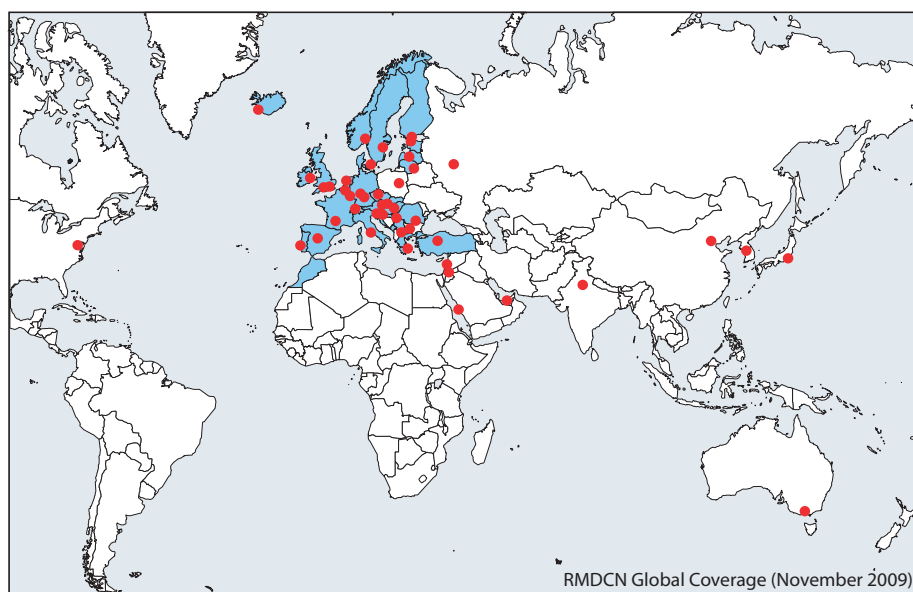
TIGGE data exchange. The figure shows the ten producing centres and three archiving centres. ECMWF uses the TIGGE archive to compare its own Ensemble Prediction System (EPS) with the other ensemble prediction systems.

Regional Meteorological Data Communication Network

The Regional Meteorological Data Communication 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 has most of the Global Telecommunication System (GTS) connections for WMO Regional Association VI. Over time it has expanded to encompass other geographical areas with connections to North America, Asia and Australia. ECMWF manages the project and monitors the network on behalf of the connected user sites following an agreement with WMO.

The performance of the RMDCN during 2009 has been very good and it achieved almost 100% availability throughout the year.

In 2009, the RMDCN saw a number of configuration changes of existing connections as well as an expansion to other continents. The connections to 12 sites have been upgraded to a mission-critical configuration to provide enhanced resilience and two major WMO IMTN (Improved Main Telecommunication Network) sites in the USA and Australia joined the network. At the end of 2009 there were 47 sites connected to RMDCN.



RMDCN network coverage. By the end of 2009 43 National Meteorological Centres, EUMETSAT (two sites) and ECMWF used the RMDCN operationally. There is also a disaster recovery site for one of the NMCs connected to the network.

GTS datasets available to NMHSs of WMO Members

The Council, at its 70th session (December 2008), agreed to make the GTS datasets available to national meteorological and hydrological services of WMO Members at a spatial resolution of 0.5° latitude/longitude. These datasets have been made available in GRIB-2 from ECMWF's data server. The previously available GRIB-1 datasets at lower resolution are still accessible via the GTS, EUMETCast and ECMWF's data server. It is envisaged that, in the near future, this new service will be extended to provide the full functionality of a Data Collection or Production Centre that forms part of the WMO Information System.

The newly generated higher-resolution datasets (in GRIB-2) will also be offered to Deutscher Wetterdienst, UK Met Office and Météo-France for insertion into the GTS, and to EUMETSAT for dissemination to members of the WMO Regional Associations for RA-VI (Europe) and RA-I (Africa) via the EUMETCast service.

The ECMWF Council unanimously adopted the 'Oslo Declaration' as a guideline for formulating ECMWF's data policy. This led to a review of the list of ECMWF products declared 'essential', meaning that they are available on a free and unrestricted basis.

ECMWF products designated as 'essential'

The Council considered the ECMWF products that are made available to NMHSs of WMO Members. Of these only a few are classified as 'essential': 500 hPa geopotential height, 850 hPa winds and mean sea-level pressure from the deterministic model for forecast ranges of 72 hours and longer. At its 72nd session the Council decided to include the following in the 'essential' products.

- 500 hPa geopotential height, 850 hPa winds and mean sea-level pressure available at H+00, H+24 and H+48.
- 850 hPa temperature in 24-hour time steps from H+00.
- Ensemble mean and ensemble standard deviation (spread) from the Ensemble Prediction System (EPS) for 500 hPa geopotential height, 850 hPa winds, 850 hPa temperature and mean sea-level pressure in 24-hour time steps from H+00.

WMO Regional Association	Number of Members
I	36
II	26
III	8
IV	22
V	10
VI	18

The number of WMO Members, by region, that were allocated a web password in 2009.

Boundary Conditions for Limited-Area Modelling

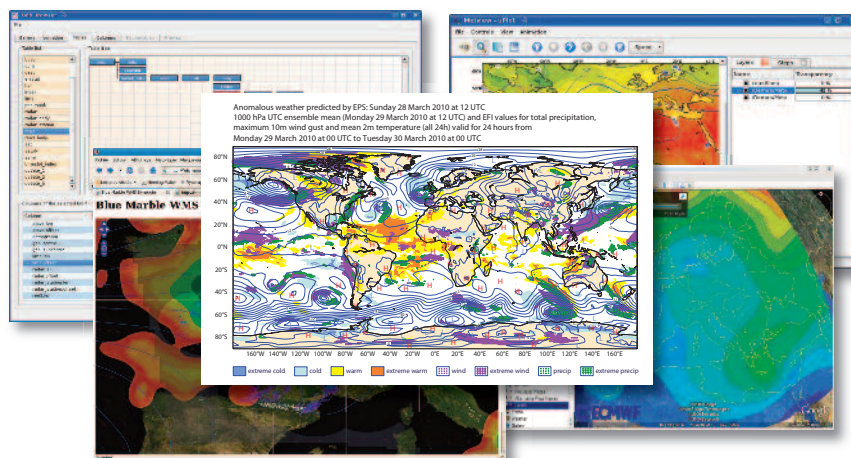
The Optional Project 'Boundary Conditions for Limited-Area Modelling' (BC) was established in June 1999 to provide participating States with boundary conditions. The production of the boundary conditions is currently fully integrated with the main high-resolution global deterministic atmospheric analysis and forecasting systems, with four daily runs at 00, 06, 12 and 18 UTC.

Most ECMWF Member States and Co-operating States are participating in the BC Project. Results from the project are widely used for the operational running of limited-area forecasting systems in participating countries. At the end of 2009 some 1,030,400 products were generated each day and the volume disseminated amounted to about 41 gigabytes.

According to the guidelines for the BC project, a review is due to take place in 2010. In preparation for this review a subgroup of ECMWF's Technical Advisory Committee has been formed to investigate possible improvements to the BC analysis and forecasting systems, review the project guidelines and formulate recommendations on the future development of the project.

Examples of work done by the Graphics Section.

Metview 4 with its new data examiner (top left) and visualisation module (top right); successful tests between ECMWF and Météo-France to overlay map layers provided by Magics++ and Synergie using Open Geospatial Consortium (OGC) web standards (bottom left); support for new products such as the interactive EFI (middle) and support for new presentation media such as Google Earth® (bottom right).



Graphics

In its mission to make ECMWF forecast data more easily available, ECMWF provides tools to process and visualise meteorological data. For this purpose effort is put into developing and maintaining the Magics visualisation library and the Metview meteorological workstation environment.

The well-established meteorological plotting library Magics is currently in the process of being replaced by the newly developed Magics++. The new library has undergone developments in response to requirements from Metview and the Web Re-Engineering Project (WREP). Magics++ now has a stronger web-orientation. Many Member States use Magics++ and much of their feedback has influenced its development.

Metview also underwent much development in 2009 and an updated internal test version was released. This new version integrates Magics++, which enables Metview to offer more interaction with the displayed data. Furthermore, features have been added to support ECMWF's work in the monitoring of incoming observations.

Other meteorological activities

Support continues to be provided to a variety of activities in addition to those already described. These include:

- **Seasonal forecasts.** Seasonal forecast data is now being provided to the WMO Lead Centre for Long-Range Forecast Multi-Model Ensembles (LC-LRFMME), jointly hosted by NCEP (USA) and KMA (Korea).
- **WMO Severe Weather Forecast Demonstration Project (SWFDP).** ECMWF continues to support the SWFDP in southern Africa by providing a set of forecast products for participating WMO Members on the ECMWF website. ECMWF also provides a corresponding set of products for the SWFDP in the south-west Pacific.
- **EUMETNET/EUCOS.** ECMWF has been a 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. It has been agreed to use GRIB-2 as the common data format for field data in this project and ECMWF's software as the primary tool for encoding and decoding.
- **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 have been compiled and updated, and then discussed with the North American data providers.

EUCOS: EUMETNET Composite Observing System

EUMETNET: European Meteorological Network

KMA: Korea Meteorological Administration

NCEP: National Centers for Environmental Prediction



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. The Centre's computing resources and scientific expertise are contributing to international research efforts through a wide net of collaboration. The purpose of the international research programmes is to enhance atmospheric monitoring and forecasting and to advance the science in general.



Achievement of the GEMS objectives

The GEMS project achieved its basic objectives:

- To extend the ECMWF global data assimilation and forecasting system to include greenhouse gases, faster reactive gases and aerosols.
- To organise the cooperative running of regional air-quality forecasting systems for Europe, utilising boundary conditions from the global system.
- To demonstrate the capability of the global and regional systems by running them routinely in near-real time.
- To produce a retrospective global reanalysis for 2003–2007.
- To run regional systems retrospectively for 2003.
- To carry out extensive validation of the project's global and regional products.

EU-funded projects

GEMS/MACC

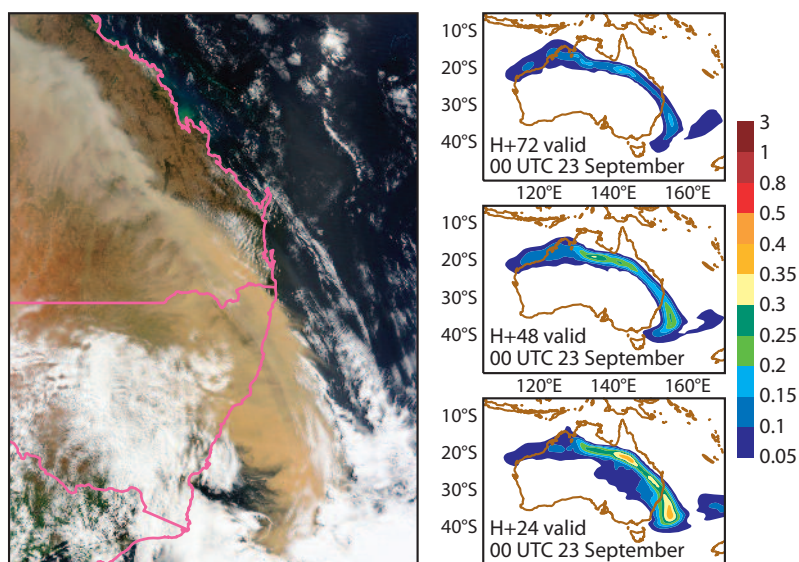
The GEMS project, which was concerned with global and regional Earth-system monitoring using satellite and in-situ data, started on 1 March 2005 and concluded on 31 May 2009. GEMS achieved its objectives of building and demonstrating the operation of global and regional analysis

and modelling systems that monitor and predict variations in atmospheric constituents; these variations force climate change and influence air quality, ultraviolet radiation and solar energy resources. Thirty-two partners were involved in total, with ECMWF developing and operating the core global component and supporting the regional component with data handling, validation and display of results.

The final assembly of the GEMS project was an open scientific meeting with 115 participants held from 31 March to 3 April at Forschungszentrum Jülich, Germany. It provided the occasion for a comprehensive presentation of the results of the project and the main lines of future operation and development.

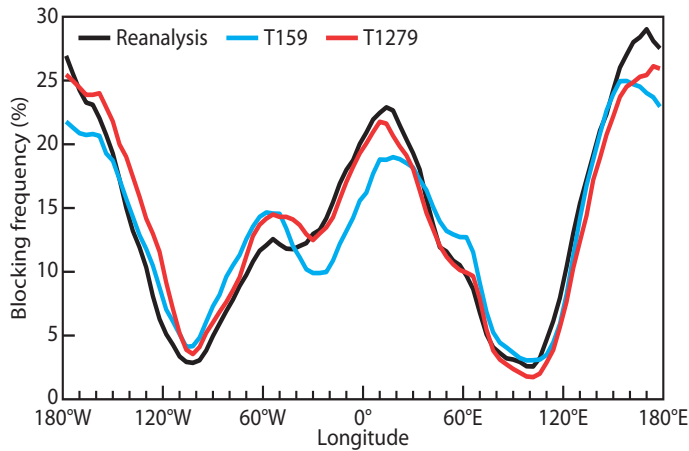
The MACC (Monitoring Atmospheric Composition and Climate – www.gmes-atmosphere.eu) project is a successor not only to GEMS but also to PROMOTE, which was an ESA-funded project of the Atmosphere GMES Service Element that concluded at the end of 2009. Most of the partners and activities in GEMS are continuing in MACC, which has 48 partners in all, 11 of which are national meteorological services. Like GEMS, MACC is coordinated by ECMWF.

Compared with GEMS, MACC is taking a more operational approach to the running of its systems and has a stronger focus on the interface with users and downstream service providers. It began on 1 June 2009 and will run until late in 2011, when it should be ready to emerge as a fully operational atmospheric service under Europe's GMES (Global Monitoring for Environment and Security) programme.



A severe dust storm affected Sydney and other parts of Australia in September. The position of the dust band is captured well in each of the forecasts, indicating that the controlling meteorology is predicted accurately out to at least three days ahead. The predicted system nevertheless becomes more intense as the forecast range shortens. This suggests that underestimation of dust in background forecasts is corrected by assimilating data that detects the incipient storm. Illustrated are the optical depths of dust aerosol in three-, two- and one-day MACC forecasts for 00 UTC on 23 September 2009, and a corresponding image from the MODIS instrument on NASA's Terra satellite. (Credit: Jeff Schmaltz, MODIS Land Rapid Response Team, NASA GFC)

GEMS: Global Earth-system Monitoring using Satellite and in-situ data
PROMOTE: Protocol Monitoring for the GMES Service Element



Impact of increasing horizontal resolution on the frequency of occurrence of blocking days. Increasing the horizontal resolution from T159 to T1279 leads to significant improvements in the simulated frequency of occurrence of blocking days. The results shown are for winters (December, January, February) during 1960–2007.

ATHENA

It is widely believed that increasing the resolution of weather and climate models to accurately resolve mesoscale phenomena in the atmosphere can dramatically improve the fidelity of the models in realistically simulating the atmosphere. Following the World Modelling Summit at ECMWF in May 2008, the US National Science Foundation (NSF) recognised the importance of this issue and realised that a resource was available that could be used to test the benefit of employing very high resolutions. The NSF offered the dedicated use of the Athena supercomputer, over a period of six months from 1 October 2009 to 31 March 2010.

The 'Athena Project' is an international collaboration including groups from Japan, the USA and ECMWF. As part of the project ECMWF is carrying out long integrations covering the period 1960–2007 to investigate the impact of increased resolution on the climate of the ECMWF model, including severe and other high-impact weather events. Preliminary results show that increasing the horizontal resolution to T1279 (16 km grid) leads to significant improvements in the simulated frequency of occurrence of Euro-Atlantic blocking events.

ENSEMBLES

ENSEMBLES was a five-year project (concluded in December 2009) on ensemble-based predictions of climate changes and their impacts. ECMWF was one of the key partners amongst the more than 60 European research institutions that participated. One of the project's main objectives was the development of an ensemble prediction system based on global models developed in Europe to produce probabilistic estimates of uncertainty in future climate at seasonal to decadal and longer timescales.

In ENSEMBLES new approaches to account for model uncertainty were tested to assess whether they could be considered powerful alternatives to the well-established but intrinsically pragmatic and ad hoc multi-model ensemble. To this end, an experiment exploring three methodologies was run.

It was found that, overall, the multi-model ensemble gives the best forecast scores on seasonal to annual timescales. However, the perturbed parameter and stochastic parametrization techniques are competitive new physical approaches. They provide promising indications that a similar level of performance to the multi-model ensemble can potentially be achieved through the application of systematic techniques for the sampling of uncertainties in a single-model system.

AMMA

The field experiment of the African Monsoon Multidisciplinary Analysis (AMMA) project during the 2006 wet monsoon season provided an unprecedented amount of radiosonde/dropsonde data over the West African region. These soundings are the only source of data that can provide three-dimensional information on the structure of the atmosphere over continental West Africa.

The usage and impact of this invaluable dataset in the ECMWF analyses and forecasts have been explored by comparing analysis experiments with the pre-AMMA radiosonde network and the enhanced AMMA network. The results show that the extra AMMA radiosoundings have a significant impact in the low-level temperature over the Sahel and in the structure of the African easterly jet. However, the impact of the extra AMMA data on the forecasts disappears after 12 to 24 hours due to systematic model biases that are under investigation.



Radiosonde launch from Niamey airport as part of the AMMA project. The African Monsoon Multidisciplinary Analysis (AMMA) project aims to enhance understanding of the West African monsoon and its variability. This will lead to improved predictions of the West African monsoon and its impacts. Photo courtesy of Douglas J. Parker (University of Leeds).

EUROSIP and EUROBRISA

The EUROSIP multi-model system is constructed from Met Office, Météo-France and ECMWF seasonal forecast data. This system provides unified data structures for archiving and disseminating seasonal forecasts, monitoring individual models and generating multi-model products.

The Met Office seasonal forecasting system underwent radical changes in summer 2009. The biggest changes were (a) the move to a lagged-average approach and (b) real-time generation of hindcasts. To maintain a coherent and straightforward-to-use EUROSIP archive, the Met Office data is preprocessed and archived in such a way that it appears to have originated from a single ensemble started from the 1st of the month.

EUROBRISA is a European-Brazilian initiative for improving South American seasonal forecasts, led by CPTEC (Centro de Previsão de Tempo e Estudos Climáticos, Brazil) with ECMWF as one of the partners. A new EUROBRISA forecasting system has been implemented; it consists of an empirical (statistical) model, and four coupled ocean-atmosphere models from ECMWF (System 3), UK Met Office (GloSea 4), Météo-France (System 3) and CPTEC. This project helps with the evaluation of ECMWF's seasonal forecasts for South America.

Cooperation

WMO

Following the Council's decision at its 70th session (December 2008) to increase the resolution of products for WMO members, ECMWF's datasets for the Global Telecommunication System (GTS) are now available at high resolution (0.5° latitude/longitude) for the WMO community. These datasets are also provided to Deutscher Wetterdienst and the UK Met Office for insertion into the GTS, and to EUMETSAT, via the WMO Regional Associations I and VI, for distribution via EUMETCast. A letter from the Secretary-General of WMO, dated 29 January 2009, thanked ECMWF and its Member States for this important step.

Other important activities included the following.

- ECMWF continues to provide special monitoring and forecast products for Africa, in particular the WMO Severe Weather Forecast Demonstration Project in Southern Africa and the AMMA project in Western Africa.
- Seasonal forecast data is now being provided to the WMO Lead Centre for Long-Range Forecast Multi-Model Ensembles (LC-LRFMME) jointly hosted by NCEP (USA) and KMA (Korea).

Provision of real-time data for research experiments

ECMWF has provided real-time data for the following research experiments.

- Global Ocean Data Assimilation Experiment (GODAE, since 2003)
- International Research Institute for Climate and Society (IRI, since 2004)
- Euro-Brazilian Initiative for Improving South American Seasonal Forecasts (EUROBRISA, since 2006)
- Bangladesh floods (since 2006)
- WGNE Surface Flux Analysis (SURFA, since 2007)
- Indian monsoon (since 2008)
- FAAM Contrails Spreading into Cirrus (COSIC, since 2009)
- Program to Evaluate High Resolution Precipitation Products (PEHRPP, since August 2009)

Also data was provided over the summer to the CAVIAR research experiment carried out by the University of Reading.

- ECMWF was involved in the 3rd World Climate Conference that took place in Geneva from 31 August to 4 September. Contributions were made to the expert segment, as seasonal forecasting, reanalyses and seamless prediction were important themes.

Space agencies

The annual, bilateral meeting with EUMETSAT took place on 11 February. The use of EUMETSAT data, in particular from the MetOp satellite, 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 activities of Group on Earth Observations (GEO) and Global Monitoring for Environment and Security (GMES).

EUMETSAT has requested data support for a range of projects conducted on its behalf by the Centre National d'Etudes Spatiales (CNES). A special suite has been implemented to provide real-time data to CNES on a daily basis for it to improve the processing of ocean surface data from the Jason-2 satellite. Data requests for other projects are being processed.

Support continues for ESA's Earth Explorer Atmospheric Dynamics Mission (ADM-Aeolus). Also ECMWF provides auxiliary data to ESA's Soil Moisture Ocean Salinity Mission (SMOS) and other projects.

On 3 April an ECMWF delegation visited ESA for the annual bilateral meeting that is part of a co-operation agreement between the two organizations. There is a close working relationship enabling data access, monitoring, exploitation and feedback on data quality and impact from the ESA Earth Observation Programmes.

The meeting gave both organisations the opportunity to present their activities and plans, review the status of the different bilateral contracts, and identify areas of possible further cooperation and support. For example, climate monitoring and generation of Essential Climate Variables (through reprocessing and reanalysis activities) was identified as an area where collaboration between ECMWF and ESA should expand.

Data exchange was agreed with the Indian Space Research Organisation (ISRO) concerning its Oceansat-2 scatterometer. Provision of data to ISRO started in September. Discussions with the China Meteorological Administration (CMA) have resulted in the real-time reception of data from its FY-3A satellite.



ESA's Soil Moisture Ocean Salinity Mission (SMOS). ECMWF, in close collaboration with ESA, is heavily involved in the early validation of the SMOS data with a clear view to future operational assimilation.

Provision of real-time data to space agencies

In addition to providing data to EUMETSAT and ESA, governed by co-operation agreements, ECMWF provides real-time data to space agencies and other satellite data producers on the condition that it receives observations for use in its forecasting system and that the use of ECMWF data is restricted to satellite data processing (in particular calibration/validation).

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

- NASA/GLDAS (since 2001)
- NASA/QuikSCAT (since 1999)
- NASA/CLOUDSAT (since 2007)
- NASA/AIRS (since 2001)
- UCAR/COSMIC (since 2007)
- NASA/OCO (since 2008)
- NIES/GOSAT (since 2008)

Attendees at the GEO Plenary which was held in Washington, DC, USA, 17–18 November.
 Photograph, Manfred Klöppel, ECMWF.



Global Monitoring for Environment and Security (GMES)

GMES aims to make environmental information more readily available to scientists, policy-makers and industry, and to create a European shared information system for exchanging a wide range of information.

Various workshops organised to develop the requirements for future GMES Climate Services clearly underlined the need for regularly updated reanalyses, both global and regional. This is very much in line with the idea that GMES should be the proper framework for the development of reanalyses as a tool for research and climate monitoring. Discussions have started with the GMES Bureau concerning the framework for the future GMES Atmospheric Core Services (GACS), and with the MyOcean team concerning a possible involvement of ECMWF in the coordination of the Marine Core Services (MCS).

Group on Earth Observations (GEO)

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 the initiative was started in 2003. ECMWF continued to contribute to the activities of the Science and Technology Working Group and User Interface Working Group.

ECMWF supports the implementation of several tasks of the GEO 2009–2011 Work Plan in the societal benefit areas weather, climate, health, energy and water. This has mainly been through contributions based on provision of reanalysis data, ECMWF's long-standing expertise in NWP and observing system experiments (OSEs), and ECMWF's TIGGE activities.

EUMETNET

ECMWF is a member of the EUMETNET SRNWP (Short Range Numerical Weather Prediction) Interoperability project. ECMWF maintains a data repository for boundary condition data in the agreed standard data format. Partners in the project are supported in coding their data in the standard format with the help of the ECMWF GRIB Application Programming Interface (the GRIB API).

ECMWF continues to support EUCOS (EUMETNET Composite Observing System) activities by supplying observation monitoring information on both radiosondes and European wind profilers to the EUCOS operations managers. ECMWF also ran its data targeting system during October to December 2009 to support the MEDEX/EUCOS observation experiment in the Mediterranean region.



Education and training, workshops and meetings

Scientists and computer specialists from Member States, Co-operating States and WMO Members participate in ECMWF's extensive education and training programme to enhance their understanding of numerical weather prediction and the ECMWF computer facilities. In addition, 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.

Number of attendees at the meteorological training courses in 2009.

There were a total of 167 applicants from Member States and Co-operating States for one or more modules of the meteorological courses.

MET OP: Use and interpretation of ECMWF products.

MET OP WMO: Use and interpretation of ECMWF products for WMO national meteorological and hydrological services.

NWP PR: Predictability, diagnostics and extended-range forecasting.

NWP NM: Numerical methods, adiabatic formulation of models.

NWP DA: Data assimilation and use of satellite data.

NWP PA: Parametrization of diabatic processes.

	Met OP (I & II)	Met OP WMO	NWP PR	NWP NM	NWP DA	NWP PA
Member States/ Co-operating States	80	0	24	16	35	26
Non-Member States	0	40	6	8	6	5
Total applications	80	40	30	24	41	31
Total attendees	49	9	30	24	41	31

Training courses

Use of computing facilities

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

- Use of supercomputing resources (2–6 February)
- GRIB API: Library and tools (9–11 February)
- Introduction to SMS/XCdp (11–13 February)
- Introduction for new users/MARS (23–27 February)
- MAGICS (2–3 March)
- Metview (4–6 March)

A total of 81 participants from 25 Member States, Co-operating States and other organisations attended the various modules. Once again the module on the usage of GRIB API was particularly well attended.

Material presented during the various modules has been made available on the ECMWF website.

Use and interpretation of ECMWF products

The objective of this course is to assist Member States and Co-operating States with advanced training in the use of operational products from the ECMWF forecasting system. It is directed towards those staff in the meteorological services who are (or will be) using ECMWF products either directly as forecasting staff, or in research and development work, and is aimed at maximising the benefits to users of the Centre's products. Courses were given from 9 to 13 March and 1 to 5 June.

As in previous years ECMWF organised an additional course for participants from WMO national meteorological and hydrological services which are not ECMWF Member States or Co-operating States. This took place from 12 to 16 October. There were some 40 applications. WMO funding provided financial support for eight candidates (from Botswana, Mauritius, Mozambique, Samoa, Seychelles, Solomon Islands, Vanuatu and Zambia) who are participants in WMO Severe Weather Demonstration Projects. Four candidates (from Brazil, Canada, Fiji Islands and Hong Kong) had their own funding. Additional places were available but these could not be filled because of lack of alternative funding for travel.

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 this year consisted of the following modules.

- Predictability, diagnostics and extended-range forecasting (16–25 March)
- Numerical methods, adiabatic formulation of models (30 March–3 April)
- Data assimilation and use of satellite data (20–29 April)
- Parametrization of diabatic processes (11–21 May)



Seminars, workshops and meetings organised by ECMWF

Workshop on the use of IASI data

A workshop on the assimilation of IASI data in NWP, co-sponsored by ECMWF and the EUMETSAT NWP-SAF, took place from 6 to 8 May. IASI provides high vertical resolution information on temperature and water vapour, and allows the extraction of information on a number of atmospheric composition species and trace gases.

Nearly two years after IASI data was first disseminated to the NWP community, experts and observers from major NWP centres, atmospheric research centres and space agencies, representing more than ten countries, participated in the workshop. The focus of the workshop was on reviewing the progress made in the use of IASI and the consolidation of its impact in NWP. Provision of guidance about future paths for a more aggressive and optimal exploitation of this instrument was particularly important.

Meetings of Security Representatives and Computing Representatives

The annual meetings of the Computing Representatives and the Security Representatives took place from 11 to 14 May. These meetings provided the opportunity for exchanging information and enhancing cooperation for the provision of IT infrastructures and services between ECMWF, Member and Co-operating States, and other organisations.

Workshop on diagnostics of data assimilation system performance

The workshop from 15 to 17 June considered techniques to measure the performance of the assimilation system in NWP. In particular, methodologies were presented that evaluate the analysis optimality with respect to all the analysis input parameters. Also, consideration was given to adjoint techniques to assess the impact of observations in the short-range forecast. Working groups were formed to discuss objective evaluation of the assimilation system, diagnostics tools and diagnosing model and forecast error.

Presentations were given by 12 invited lecturers and 4 ECMWF lecturers, and some 24 invited observers attended the workshop.

Forecast product users' meeting

The meeting for users of the forecast products took place from 10 to 12 June with 42 participants representing 17 national meteorological services and 9 commercial customers from the Member States and Co-operating States.

There was a review of changes to ECMWF's operational forecasting system over the past year and plans for future developments. Also, the introduction of new and improved products was discussed. Participants from Member States described their use of ECMWF products and their assessment of ECMWF forecasts in the past year. They were generally very happy with the quality of the forecasts, but highlighted concerns about the snow cover and night-time temperature biases that had affected Central Europe the previous winter. Requirements for the new products that ECMWF is developing were confirmed, and there were some requests for additional products.

Event	Presentations and proceedings
Workshop on the use of IASI data	www.ecmwf.int/newsevents/meetings/workshops/2009/IASI_data/
Workshop on diagnostics of data assimilation system performance	www.ecmwf.int/newsevents/meetings/workshops/2009/Diagnostics_DA_System_Performance/
Forecast product users' meeting	www.ecmwf.int/newsevents/meetings/forecast_products_user/
Workshop on meteorological operational systems	www.ecmwf.int/newsevents/meetings/workshops/2009/MOS_12/
Seminar on diagnosis of forecasting and data assimilation systems	www.ecmwf.int/newsevents/meetings/annual_seminar/2009/
ECMWF/GLASS workshop on land surface modelling, data assimilation and the implications for predictability	www.ecmwf.int/newsevents/meetings/workshops/2009/Land_surface_modelling/

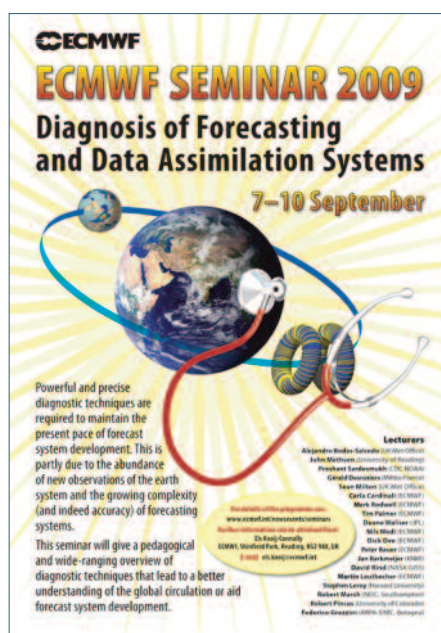
Access to information about workshops and seminars. Presentations and proceedings of workshops and seminars are available from the ECMWF website.

Diagnosis of forecasting and data assimilation systems

The Annual ECMWF Seminar was held from 7 to 10 September. Its aim was to consider the powerful and precise diagnostic techniques that are required to maintain the present pace of forecasting system development. The abundance of new observations of the Earth system and growing complexity (and indeed accuracy) of forecasting systems have influenced the need for such techniques.

Invited and ECMWF expert speakers provided a wide-ranging overview of diagnostic techniques that can lead to a better understanding of the global circulation or aid forecasting system development. Diagnostics targeting observations, data assimilation, NWP, seasonal and climate forecasting and ensemble prediction were discussed.

There were 13 invited lecturers and 7 ECMWF lecturers; the seminar had 61 participants.

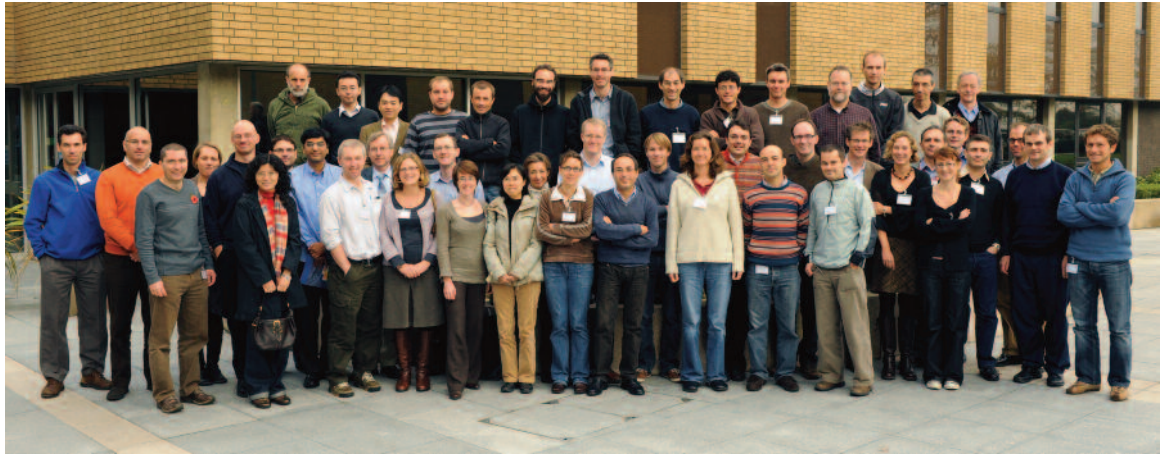


Workshop on meteorological operational systems

Every second year ECMWF hosts a workshop on meteorological operational systems. The 12th workshop took place from 2 to 6 November. It had nearly 60 participants from meteorological services, WMO, EUMETSAT, research institutions and commercial weather services coming from 22 countries in Europe, Asia and the Americas.

The focus of the workshop was on observation handling. The state-of-the-art was reviewed and consideration was given to future trends in the role of observations in verification of medium-range forecast products, data management and meteorological visualisations on workstations. The discussion focussed on the challenges of dealing with a greater variety of observation types, handling increasing data volumes and obtaining homogeneous, high-resolution observations for verification. The prospects for exchanging graphical information via web services using international standards were emphasised.

Participants at the ECMWF/GLASS workshop on land surface modelling, data assimilation and the implications for predictability.



ECMWF/GLASS workshop on land surface modelling, data assimilation and the implications for predictability

The workshop was organised in cooperation with the Global Land/Atmosphere System Study (GLASS), which is part of the WCRP/GEWEX (World Climate Research Project/Global Energy and Water Cycle Experiment). About 50 leading scientists from outside ECMWF participated in the workshop that was held from 9 to 12 November.

There was a review of recent research on land/atmosphere modelling, land data assimilation, new observations and the role of soil moisture and snow in predictability in the sub-seasonal time range. Also the role of verification and benchmarking was discussed.

The working groups were asked to make recommendations about priorities for further research at ECMWF and in the GLASS community. There was endorsement of the Centre's plans for further integration of the atmospheric model and the land data assimilation system and the use of new soil-moisture related observations (e.g. SMOS).

Seminar on Object-Oriented Prediction System

On 18 November a seminar was held to discuss re-structuring the computer code in the Integrated Forecasting System (IFS) based on the concept of an Object-Oriented Prediction System (OOPS). The meeting attracted considerable attention, both with ECMWF staff from all three departments as well as Member State visitors.

The main purpose of the proposed changes is to make the Integrated Forecasting System easier to work on and more efficient in terms of development work. Presentations were given describing the new ideas and their consequences for future model development work. In a separate discussion session all participants contributed with views and ideas that will help with making a decision about how to proceed with OOPS.

Workshop on the use of GIS/OGC standards in meteorology

From 23 to 25 November the second workshop on the use of GIS/OGC standards in meteorology was held in Toulouse. This workshop was jointly organised by Météo-France, UK Met Office and ECMWF. There were over 140 participants from various organisations across the world.

The presentations and working group discussions reflected the progress achieved after last year's workshop at ECMWF. It was clear, however, that more work needs to be done to achieve interoperability; concrete plans to achieve this in the next years have been proposed.

Within OGC (Open Geospatial Consortium), a MetOcean Domain Working Group (DWG) was established to resolve issues in applying OGC standards in meteorology. The signing of a Memorandum of Understanding between OGC and WMO will raise awareness of the work of the MetOcean DWG within the meteorological community.

Members of the WMO CBS Co-ordination Group on Forecast Verification.



Events hosted by ECMWF

EFAS workshop

The 4th annual workshop about the European Flood Alert System (EFAS) was held on 29 and 30 January. The 43 participants came from 24 national and regional water authorities across Europe. The EFAS team informed participants about the progress achieved during 2008 in terms of early warnings and system development. There was also a session dedicated to training on probabilistic products and lessons learned from national EPS-based flood forecasting systems.

IFS-Arpège coordination meeting

The annual, bilateral IFS-Arpège co-ordination meeting took place on June 24. The IFS-Arpège NWP software is jointly developed by ECMWF and Météo-France, and common model cycles are created on a regular basis (typically every year). The status of the current IFS common cycle was discussed. Scientific and technical plans for both organisations were also considered. This meeting included observers from the HIRLAM and ALADIN consortia, which have a strong interest in the development of the code.

CBS: Commission for Basic Systems
EFAS: European Flood Alert System
EUMETNET: European Meteorological Network
HIRLAM: High Resolution Limited Area Model

Meeting of the WMO CBS Co-ordination Group on Forecast Verification

The first meeting of the WMO CBS Co-ordination Group on Forecast Verification was held from 24 to 26 November. The meeting proposed that there should be an updating of the procedures used by global NWP centres to produce the standard set of scores that are exchanged monthly. In addition, the establishment of a Lead Centre for Deterministic NWP Verification was proposed.

EUMETNET Council at ECMWF

A EUMETNET Council meeting took place on 9 December. Its purpose was to adopt the financial regulations required from 1 January 2010. They were drafted on the basis of ECMWF rules, adapted to the specific rules of an Economic Interest Grouping (EIG). EUMETNET provides a framework for organising cooperative research and development programmes between the 26 European national meteorological services that are members.

HIRLAM Council at ECMWF

HIRLAM is an international research programme involving European meteorological institutes. The HIRLAM Council met on 9 December. The main item was a preliminary report from the review team appointed by the HIRLAM Council. Cooperation between HIRLAM and ECMWF is leading towards better interoperability and complementarity.

Meeting about North America-Europe data exchange

The 22nd North America-Europe Data Exchange Meeting took place from 9 to 11 December. Participants represented Deutscher Wetterdienst, EUMETSAT, Météo-France, UK Met Office and WMO, as well as meteorological organisations from Australia, Canada and the USA. The requirements for observational data on both sides of the Atlantic were discussed. The various distribution channels and telecommunication links were also reviewed. As a result, several new datasets have become available for use by the NWP centres.

EC-Earth meeting

A meeting within the EC-Earth consortium took place on 10 and 11 December. The goal of EC-Earth is to develop an Earth-system model based on the ECMWF seasonal prediction system. Research groups from universities and meteorological institutes in several Member States are taking part in the project. The meeting attracted about 40 external participants and among the topics discussed were simulation of sea ice, resolution dependence of climate simulations, and aerosol process description in climate models. It was noted that the performance of the most recent version of the EC-Earth model is on the same level as global climate models from leading climate research centres.



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 highly qualified and motivated 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.



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 2009, ECMWF employed 155 staff members and 75 consultants. During the year, nine staff members were recruited, four staff members left the organisation and three staff members retired.

Changes in some senior management positions have occurred: Erland Källén was appointed as Head of the Research Department from 6 July 2009. He replaced Philippe Bougeault, who left ECMWF on 1 April 2009. Furthermore, the Council appointed Walter Zwiefelhofer as the new Deputy Director with effect from 1 April 2009.

A key ingredient to the success of ECMWF is the high level of expertise and dedication of the staff. This has ensured that ECMWF continues to be at the forefront of applying the latest research and technological developments to meet the increasingly demanding needs of Member States.

Proportion of female staff employed by ECMWF during the period 2005–2009.

Employment

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

The proportion of female staff employed at ECMWF as at the end of 2009 was 51% for B-grades and 17% for A-grades. The corresponding figures for 2008 were 50% and 17%.

For staff and consultancy positions, 17 vacancies were published. For the 14 for which recruitment was completed, there were 506 applications, of which 340 (67%) were from male applicants and 166 (33%) from female applicants. Out of the 166 female applications, 57 of them were for a secretarial position. For scientific and technical positions the applicants were predominantly male.

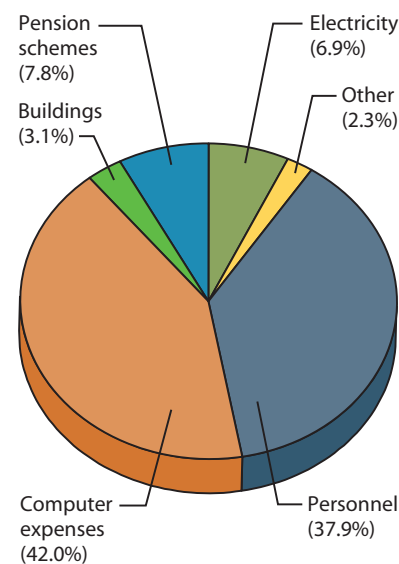
Out of the staff and consultants that were recruited, 84% were male and 16% were female.

Year	B-grades	A-grades
2005	49%	16%
2006	50%	17%
2007	49%	17%
2008	50%	17%
2009	51%	17%

Finance

At its meeting in December 2008, the Council agreed that Member States' contributions to the budget for 2009 would increase by 19.28% over the budget for 2008. This increase was mainly due to the already agreed increase of £3.5 million in the money stream for the HPC and additional requirements for electricity.

ECMWF's budget for 2009 was £37,610,200. This included contributions from Member States and Co-operating States amounting to £36,440,700. The main expenditure was on the high-performance computer (HPC) infrastructure and staff.



Expenditure 2009 by category.

Awards

The EMS Silver Medal was awarded to Lennart Bengtsson, a former Director of ECMWF, during the annual meeting of the European Meteorological Society (EMS) in Toulouse.

The Royal Meteorological Society made the following awards.

- Adrian Simmons received the Symons Gold Medal for distinguished work in connection with meteorological science.
- Tim Palmer received the Adrian Gill Prize for a significant contribution in a field that is at the interface between atmospheric science and related disciplines.

Pension matters

In 2009, an actuarial study for the Budgetised Pension Scheme was conducted by the Joint Pension Administration Section of the Co-ordinated Organisations.

The scope of the study was to carry out an actuarial projection to estimate the long-term contribution required and to ensure the long-term financial equilibrium of the scheme. As a result, the contribution rate of the staff to the Budgetised Pension Scheme was increased to 9%.

Towards a greener ECMWF

ECMWF is committed to being as energy-efficient and environmentally friendly as possible. To this end, ECMWF has established a working group to explore systematically the options available for improving energy efficiency. The working group has started to investigate all areas where there is significant potential to reduce energy consumption. The aim is to make the best possible use of all energy. Furthermore, ECMWF has put significant emphasis on reducing waste and has managed to achieve a reduction of general waste by 50% in 2009.

Premises

During the 35 years since its inception in 1975, ECMWF has undergone quite significant developments. ECMWF premises are no longer sufficient to host the growing number of activities and the increasing number of staff. Consequently, some additional facilities and buildings, as well as a substantial refurbishment of the older buildings, are urgently required.

The ECMWF Finance Committee has established a working group that will analyse the ECMWF conference centre requirements, with special emphasis on the need to accommodate an increasing number of Member States. It will also analyse the requirements for additional facilities and for refurbishments needed now and in the future for the old office building. It will take into account the ongoing discussions in the Technical Advisory Committee concerning green computing and draw up a comprehensive building and refurbishment plan for consideration by the Finance Committee and the Council.

Corporate video about ECMWF

A corporate video about ECMWF has been produced. Its aim is to inform interested audiences about the organisation, its objectives and its wide spectrum of activities in the field of numerical weather prediction. The video can be viewed in English, French and German.

The video points out the socio-economic benefits of ECMWF products to a wide spectrum of applications in ECMWF's Member and Co-operating States, above all for use by national meteorological and hydrological services as a complement to their national short-range activities. It also reveals the role ECMWF plays in the context of the European meteorological community.



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, the Centre'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 they can enter into force. By the end of 2009, 17 Member States had done so.

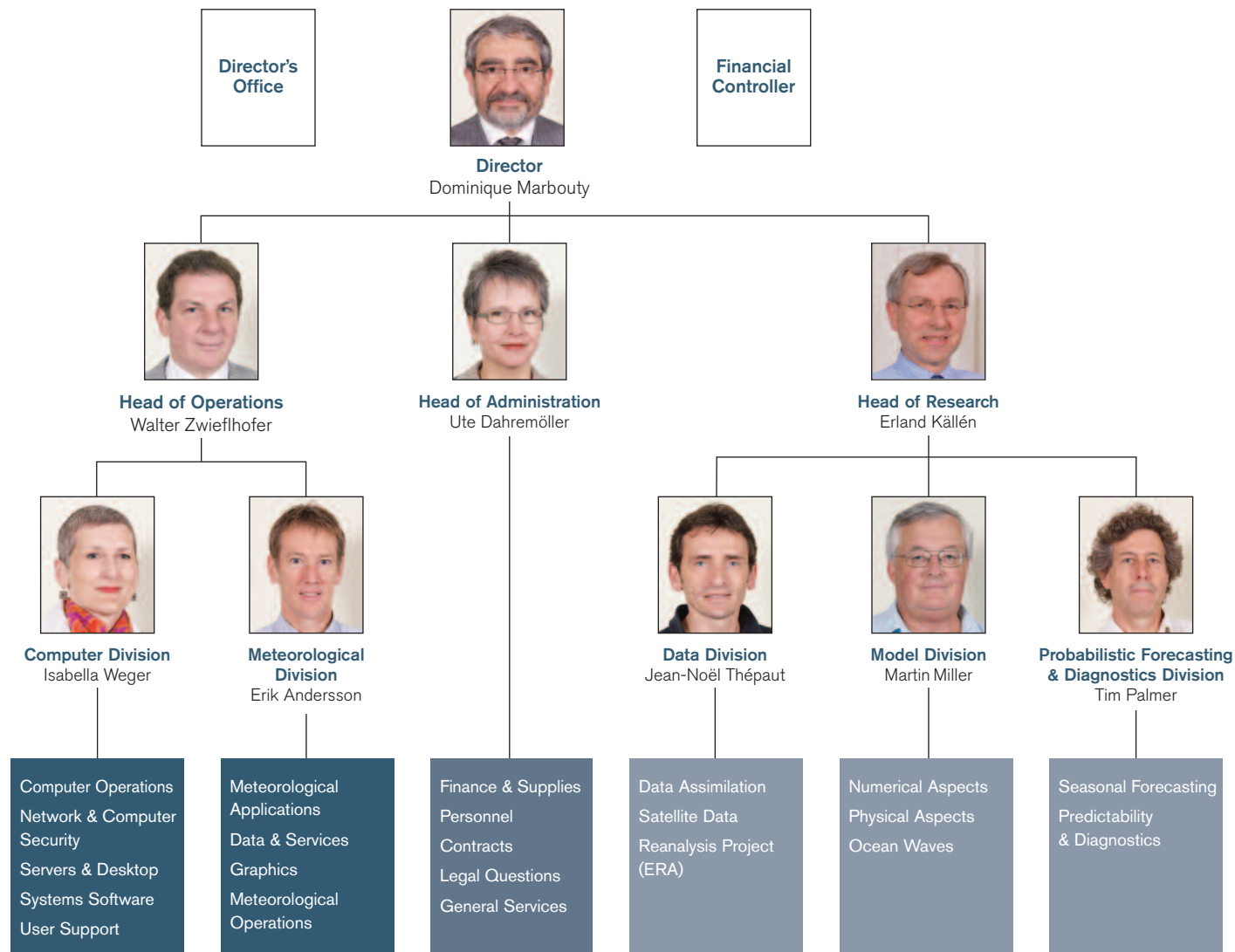
When ratified by all the current Member States, the amended Convention will:

- 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.

Intellectual property rights (IPR)

ECMWF puts great emphasis on safeguarding and properly managing its intellectual property rights (IPR). Consequently, internal guidelines about IPR were issued in July 2009. These guidelines outline 'dos' and 'do nots' about aspects of IPR at ECMWF. They apply to all ECMWF staff (staff members, consultants and graduate trainees). They are especially relevant for staff involved in source code and software development and software and data distribution. The intention of the guidelines is to raise awareness of the IPR implications of such activities.

The Centre's organisation on 31 December 2009



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, 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, 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)

The Council

As ECMWF's governing body, and comprising 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 71st session

By invitation of its President, Dr Adérito Vicente Serrão from Portugal, the ECMWF Council held its 71st session in Ponta Delgada in the Azores on 25 and 26 June 2009.

The main results of this session were as follows.

On co-operation

The Council unanimously approved the extension of the existing licence agreement between ECMWF and EUROBRISA, allowing Brazil's Centro de Previsão de Tempo e Estudos Climáticos, CPTEC, to receive real-time, multi-model, seasonal forecasts from ECMWF, until June 2012; authorised the Director to renew the co-operation agreement with the African Centre of Meteorological Applications for Development (ACMAD); authorised the Director to conclude a co-operation agreement with the Government of Bulgaria.

On the use of ECMWF products

The Council unanimously adopted the revised standard licence agreement for use of ECMWF products, and the revised 'Rules governing the distribution and dissemination of ECMWF real-time products'.

ECMWF Council 72nd session

The main results of this session were as follows.

On co-operation

The Council unanimously authorised the Director to extend the co-operation agreement with ESA for another five years.

On financial matters

The Council unanimously agreed on the introduction of an Activity Based Costing (ABC) system and the implementation of 'International Public Sector Accounting Standards' (IPSAS).

On the use of ECMWF Products

The Council unanimously agreed on the introduction of a reduced maximum charge licence for national meteorological and hydrological services using ECMWF products for non-commercial purposes and on extending the list of ECMWF products declared as 'essential'.

Member States' representatives to Council sessions



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

State	Representatives	Advisers
Belgium	Henri Malcorps, Heidi Langenus	
Denmark	Peter Aakjaer, Leif Laursen	
Germany	Wolfgang Kusch, Franz Berger	Detlev Frömming
Greece	Odysseas Galanopoulos, Ioannis, Papageorgiou, Theagenis Charantonis	
Spain	Ricardo Riosalido, Manuel Palomares	
France	François Jacq, Philippe Veyre	
Ireland	Tom Sheridan, Liam Campbell	
Italy	Massimo Capaldo, Pierluigi Cascioli	Costante de Simone
Luxembourg	Claude Alesch	
The Netherlands	Frits Brouwer	
Norway	Anton Eliassen, Roar Skålin	
Austria	Fritz Neuwirth, Ernst Rudel	
Portugal	Adérito Vicente Serrão, Teresa Abrantes	
Switzerland	Daniel Keuerleber-Burk, Alex Rubli, Peter Binder	
Finland	Petteri Taalas, Juhani Damski, Mikko Alestalo	
Sweden	Lena Häll Eriksson, Ilmar Karro	
Turkey	Ali Karatas, Mehmet Caglar, Mehmet Fatih Büyükkasabbaşı	
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-Chairs: Maria Ågren (Sweden),
 Alain Ratier (France)

State	Representatives
Germany	Wolfgang Kusch Franz Berger Detlev Frömming* Gisela Seuffert*
Greece	Aglaia Vrachnou
Spain	Manuel Palomares
France	Alain Ratier
Ireland	Declan Murphy
Italy	Massimo Capaldo
The Netherlands	Piet de Wildt
Austria	Fritz Neuwirth
Switzerland	Alex Rubli
Finland	Mikko Alestalo
Sweden	Ilmar Karro
United Kingdom	Alan Dickinson Mike Gray Alistair Price*

* Advisers

Finance Committee (FC)

The FC provides the Council with opinions and recommendations on all financial and administrative 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)

State	Representatives
Germany	Detlev Frömming Gisela Seuffert
Spain	Manuel Palomares (also representing Greece, Portugal and Turkey)
France	Christine Mengus Philippe Santoni Véronique Martin
Italy	Sergio Pasquini Antonio Bartolini
The Netherlands	Piet de Wildt (also representing Austria, Belgium, Luxembourg and Switzerland)
Austria (observer)	Monika Köhler
Sweden	Eva Edelid (also representing Denmark, Ireland, Norway, and Finland)
United Kingdom	Paul Mundy Alistair Price Abigail Mewse 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: Heikki Järvinen

Members
Gerhard Adrian
Jan Barkmeijer
François Bouttier
John Eyre
Hans Huang
Heikki Järvinen
Piero Lionello
Jochem Marotzke
Ernesto Rodriguez-Camino
Julia Slingo
Michael Tjernström
Robert Vautard

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)

State	Representatives
Belgium	Daniel Gellens
Denmark	Leif Laursen
Germany	Dieter Schröder
Greece	Anastassios Anthis
Spain	Eduardo Monreal
France	Bernard Strauss
Ireland	Paul Halton
Italy	Massimo Ferri
The Netherlands	Toon Moene
Norway	Jens Sunde
Austria	Georg Kaindl
Switzerland	Stefan Sandmeier
Finland	Pertti Nurmi
Sweden	Mikael Hellgren
United Kingdom	Alan Dickinson

Co-operating State representatives

Croatia	Čedo Branković
Hungary	Istvan Ihász
Serbia	Ljiljana Dekić
Slovenia	Jure Jerman

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)

State	Representatives
Germany	Klaus Haderlein
Greece	Theodoros Kolydas
Spain	Francisco Pascual Manuel Palomares
France	Philippe Santoni
Ireland	Joseph Bourke
The Netherlands	Frank Lantsheer
Norway	Lillian Svendsen
Austria	Monika Köhler
Finland	Lea Leskinen
Sweden	Marcus Flarup
United Kingdom	Colin Cuthbert

Co-operating State representatives:

Slovakia	Vladimir Pastircak
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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: László Bozó (Hungary)

Co-operating State	Representatives
Czech Republic	Ivan Obrusnik
Estonia	Jaan Saar Rein Kärner
Croatia	Ivan Čačić
Latvia	Inita Stikute
Lithuania	Vida Augulien
Hungary	István Ihász
Slovenia	Jožef Roškar
Slovakia	Martin Benko

Externally funded projects and services

Project Acronym	Project Description	Funding Agency	ECMWF role	Dates		ECMWF Budget (€)	Total Budget (€)
				From	To		
ADM AEOLUS	Development and production of aeolus wind data products	ESA	Subcontractor	01/10/04	30/06/12	1,220,511	n/a
AMMA	Observation techniques and mission concepts for analysis of the global carbon cycle	EC	Contractor	01/05/05	31/12/09	372,780	11,700,000
ARM	Model validation studies	US DOE	Contractor	15/04/07	14/04/10	\$566,296	n/a
BOSS4GMES	Building operational sustainable services for GMES	EC	Contractor	01/12/06	31/01/10	149,997	11,800,000
Combine	Comprehensive modelling of the Earth system for better climate prediction and projection	EC	Contractor	01/05/09	30/04/13	296,200	7,922,680
DEISA2	Distributed European infrastructure for supercomputing applications 2	EC	Contractor	01/05/08	30/04/11	480,000	10,237,000
EC-EARTH	EC-Earth	KNMI	Contractor	01/11/07	31/12/10	353,500	n/a
EFAS	Feasibility study on the benefit of using calibrated weather forecasts for medium-range flood warnings	JRC	Contractor	01/01/09	31/03/10	50,000	n/a
ENSEMBLES	Ensemble-based predictions of climate change and their impacts	EC	Contractor	01/09/04	31/12/09	1,124,475	15,000,000
ENVISAT II	Technical support for global validation of ENVISAT data products	ESA	Contractor	01/08/08	31/12/10	689,325	n/a
EPS IASI	Support of ECMWF to EPS/IASI phase 4	EUMETSAT	Contractor	01/01/08	31/12/09	293,125	n/a
ERA	ERA	NCAS/NERC	Subcontractor	01/09/07	31/08/10	£165,984	n/a
ERS validation II	Technical support for global validation of wind and wave products (ERS II)	ESA	Contractor	01/07/08	30/06/10	239,997	n/a
EUMETSAT fellowships	Fellowships	EUMETSAT	Contractor	Ongoing		190,000/year	n/a
GEMS	Global environment monitoring using satellite and in-situ data	EC	Coordinator	01/03/05	31/05/09	4,691,000	12,500,000
Geoland2	Towards an operational GMES Land Monitoring Core Service	EC	Contractor	01/09/08	31/08/12	514,991	25,393,432
GEOMON	Prototype system for atmospheric composition monitoring for climate applications by the combination of ground-based with satellite observations	EC	Contractor	01/02/07	31/01/09	28,800	6,621,740
GRAS-SAF	The continuous development and operations phase of a EUMETSAT Satellite Application Facility on GRAS meteorology	EUMETSAT	Subcontractor	01/03/07	29/02/12	610,000	4,200,000
H-SAF	Satellite Application Facility on support to operational hydrology and water management	EUMETSAT	Subcontractor	01/09/05	31/08/10	220,000	3,000,000
JRC HPC facilities	Provision of flexible dedicated high performance computing facilities	JRC	Contractor	01/08/06	31/03/09	433,182	n/a
MACC	Monitoring atmospheric composition and climate	EC	Coordinator	01/06/09	31/10/11	3,642,898	11,700,000
MyOcean	Development and pre-operational validation of upgraded GMES Marine Core Services and capabilities	EC	Contractor	01/01/09	31/03/12	65,000	33,800,000
NWP SAF CDOP	Development and implementation of certain activities within a EUMETSAT Satellite Application Facility on numerical weather prediction	EUMETSAT	Subcontractor	01/03/07	28/02/12	988,510	4,900,316
NWP study	Study on the impact of future developments of the space-based observing system on Numerical Weather Prediction	EUMETSAT	Contractor	01/08/09	31/08/10	119,410	n/a
Post EPS	Refinement of spectral and radiometric requirements for a Post-EPS microwave imaging mission	EUMETSAT	Contractor	01/07/09	31/12/10	149,979	n/a
QuARL	Quantitative assessment of the operational value of space-borne radar and lidar measurements of cloud and aerosol profiles	ESA	Contractor	01/09/08	30/08/10	499,373	n/a
SAFEWIND	Multi-scale data assimilation, advanced wind modeling and forecasting with emphasis on extreme weather situations for a secure large-scale wind power integration	EC	Contractor	01/09/08	31/07/12	416,000	3,992,400
SMOS DA	Study methods and techniques to best assimilate SMOS data into ECMWF's operational numerical weather forecasting system	ESA	Contractor	02/02/07	31/03/10	354,149	n/a
THOR	Thermohaline overturning – at risk?	EC	Contractor	01/12/08	30/11/12	392,000	9,964,773
UKMO-EPS	Maintenance of software to implement ensemble seasonal predictions using various configurations of the Met Office Unified Model	UK Met Office	Contractor	01/08/05	31/01/09	£421,585	n/a
VALOR	Value of the rapid array for climate prediction	NERC	Subcontractor	01/04/09	31/12/11	£136,300	£901,245

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European Centre for Medium-Range Weather Forecasts (ECMWF)
Shinfield Park
Reading RG2 9AX
United Kingdom
Tel: +44 (0) 118 949 9000
Fax: +44 (0) 118 986 9450
Email: (e.g. info@ecmwf.int)
Website: www.ecmwf.int
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