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PUBLICATION POLICY

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 The *ECMWF Newsletter* is not peer-reviewed.

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Guidance about submitting an article is available at www.ecmwf.int/publications/newsletter/guidance.pdf

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Front cover photograph – The Eyjafjallajökull volcano, Iceland, courtesy of Guðjón Reynir Jóhannesson.

A new Convention for ECMWF

On 6 June 2010 the entry into force of the amendments to the ECMWF Convention marked a major milestone in the history of the Centre. In particular the amended Convention will allow new Member States to join ECMWF.

The amendment process took more than ten years. In 1999 the ECMWF Council decided that the issue of the ECMWF Convention being 'closed' (i.e. not allowing new Member States to join) had to be addressed. This situation occurred because the list of Member States was included in the Convention itself and no process was foreseen in the Convention for enlarging the membership.

Initial attempts were made to find a solution that would avoid the lengthy process of amending the Convention. But in 2002 it became clear that this was unavoidable and Council decided to launch such a process. As the amendments have to be ratified by all Member States, this is something which can only be done very rarely. Therefore it was quickly agreed that the amendments could not be limited to the single issue of allowing more Member States.

Agreeing on the necessary changes took a further three years and on 22 April 2005 an extraordinary meeting of the Council unanimously adopted a list of proposed amendments to the Convention and recommended that the Member States adopt them. For most of them this meant ratification by their Parliament. Less than three months later the first acceptance was notified by Finland to the depositary of the Convention (the General Secretariat of the Council of the European Union in Brussels). But it took until 7 May 2010 for the last notification to reach the depositary. And 30 days later the amendments entered into force and the amended Convention became the ECMWF Convention.

As mentioned earlier the amendments are not limited to opening the possibility for Council to unanimously allow new Member States to join ECMWF, but also include other important changes.

- The ECMWF mission statement is broadened. The primary purposes of the Centre remain the development and provision of medium-range weather forecasts. But the objectives now also include "*to develop, and operate on a regular basis, global models and data-assimilation systems for the dynamics, thermodynamics and composition of the Earth's fluid envelope and interacting parts of the Earth-system*", thus including the monitoring of the Earth-system.
- The voting rights have also been revised to ensure that the Centre's governance would remain efficient with an increased number of Member States, which is expected to reach 30 within a few years.
- The possibility is now opened for the Centre to develop third-party activities, funded by the third party. This will be the framework for developing GMES (Global Monitoring for Environment and Security) core services at ECMWF.

The amended Convention will clearly allow ECMWF to further develop its co-operation with more States and with other European organisations and institutions and strengthen co-operation in meteorology in Europe.

Dominique Marbouty

New items on the ECMWF website

ANDY BRADY

Forecasting system horizontal resolution increase

On 26 January 2010, ECMWF successfully upgraded the horizontal resolution of its deterministic forecasting system and the Ensemble Prediction System (EPS), including the monthly extension to 32 days.

- http://www.ecmwf.int/products/changes/horizontal_resolution_2009/

First General Assembly of the MACC Project

The First MACC General Assembly was held at ECMWF from 11 to 15 January 2010. Its aim was to review and present the project's progress to date and plans for the coming year. Details of the Assembly including presentations are available.

- http://www.ecmwf.int/newsevents/meetings/workshops/2010/MACC/

14th Workshop on the Use of High Performance Computing in Meteorology

Every second year the European Centre for Medium-Range Weather Forecasts (ECMWF) hosts a workshop on the use of high performance computing in meteorology. The emphasis of this workshop will be on running meteorological applications at sustained teraflops performance in a production environment. Particular emphasis will be placed on the future scalability of NWP codes and the tools and development environments to facilitate this. The 14th workshop will be held from 1 to 5 November 2010.

- http://www.ecmwf.int/newsevents/meetings/workshops/2010/high_performance_computing_14th/

Corporate video about ECMWF

An online video presenting ECMWF is available in English, French and German. The video presents the story of ECMWF, how it was created, what it does and the benefits that ECMWF provides to the European and Global forecast and research communities.

- http://www.ecmwf.int/about/video/

Update of Magics and Metview web pages

Magics++ 2.10 is now available for download. Main changes are an improved Python interface and plotting of SYNOP observations.

- http://www.ecmwf.int/products/data/software/download/magics++.html

The Magics web pages have been reorganised so that the Magics++ web page is the default home page, with a sidebar link to the legacy MAGICS 6 pages which stays available. All links to old pages will continue to work.

- http://www.ecmwf.int/publications/manuals/magics/

The Metview training materials have been updated on the web and are now the versions used in the March 2010 training course held at ECMWF.

- http://www.ecmwf.int/publications/manuals/metview/training/

Changes to the operational forecasting system

DAVID RICHARDSON

Cy36r2 – changes to the EPS

A new cycle of the ECMWF forecast and analysis system, Cy36r2, was implemented on 22 June 2010. This includes a new method for providing initial-time perturbations for the EPS. In the new cycle, differences between members of an ensemble of data assimilations (EDA) will be used instead of the evolved singular vectors to create initial spread between EPS forecast members. Initial-time singular vectors will continue to be used in conjunction with the EDA perturbations. The new cycle does not include any meteorologically significant changes to the deterministic forecasting system.

Pre-operational testing shows clear improvements to the EPS spread, particularly in the first few days of the forecast. Spread for 850 hPa temperature is increased in the extra-tropics and especially in the tropics, significantly reducing under-dispersion and leading to better ensemble-mean and probabilistic scores. There is a small decrease in the spread for 500 hPa geopotential, reducing the EPS over-dispersion for this parameter. Information about operational upgrades can be found at:

- http://www.ecmwf.int/products/changes/

Cy36r2 – use of the GRIB API library

Cycle 36r2 also introduces the use of the GRIB API library for encoding of GRIB data for products from the deterministic and EPS forecasts. Details of this important technical change, including its potential impact on users, are available at:

- http://www.ecmwf.int/products/changes/grib_api/

Aksel Wiin-Nielsen

Professor Aksel Wiin-Nielsen, the first Director at ECMWF, sadly passed away on Monday, 26 April 2010. He was instrumental in the Centre's success.

A Danish national, Professor Wiin-Nielsen was ECMWF's first Director from 1 January 1974 to 31 December 1979. He put ECMWF on track to become a world leader in global Numerical Weather Prediction. On leaving ECMWF Aksel became WMO Secretary-General in 1980, and then Director of the Danish Meteorological Institute (DMI) in 1984. In that role, Aksel returned to ECMWF to attend sessions of the ECMWF Council, representing Denmark. He served as President of the ECMWF Council in 1987.

Aksel became Professor of Physics at the University of Copenhagen in 1987, and in 1995, Professor Emeritus. He continued his research interests well after his retirement. During his long career Axel received many international awards.

Staff at ECMWF are enormously grateful for Aksel's vision and leadership in setting up ECMWF. His fine legacy lives on and the firm foundation that he established has made a major factor in the Centre's continuing success. There is no doubt that a large part of the credit for the success of ECMWF as a world-renowned scientific research and operational institution is due to the initial leadership of Aksel Wiin-Nielsen.

The current Director-General, Dominique Marbouty, represented ECMWF at the funeral in Denmark on 4 May, which was also attended by WMO Secretary-General, Michel Jarraud, and the Director-General of EUMETSAT, Lars Prahm.

Corporate video about ECMWF

MANFRED KLÖPPEL

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 by going to:

- http://www.ecmwf.int/about/video

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 Hydrometeorological 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.

Landmark in forecast performance

DAVID RICHARDSON

In February 2010, ECMWF reached a landmark in the performance of its deterministic forecasting system. For the first time ever, the headline measure of skill reached the forecast range of 10 days.

ECMWF carries out comprehensive verification of its forecasting system. An overall measure of the quality of the medium-range forecasts in predicting the large-scale weather systems is given by the anomaly correlation coefficient (ACC) of the 500 hPa height forecast. A key performance indicator for the forecast system is the forecast range at which the ACC drops to 60%. In the early 1980s this level was reached at around forecast day 5. Continuous improvements to the forecast and data assimilation systems have resulted in steady improvement at around one day per decade so that on average the 60% level is now reached at around day 8. In February 2010 the average monthly ACC remained above 60% throughout the 10-day range of the deterministic forecast for both the European region and the northern hemisphere: 67% at day 10 for the northern hemisphere and 61% for Europe.

As the long-term performance record shows, there is substantial month-to-month fluctuation in the scores due partly to the variability in the atmospheric conditions. This is more prominent over smaller regions such as Europe. Winter 2009–10 has been unusual over the northern hemisphere with a strong negative phase of the North Atlantic Oscillation and Arctic Oscillation patterns. These typically are associated with cold weather in northern Europe and more active weather systems affecting south west Europe. The high scores for the ECMWF model confirm that it has performed consistently well in predicting these anomalous weather conditions.

There have been a number of severe weather events during February.

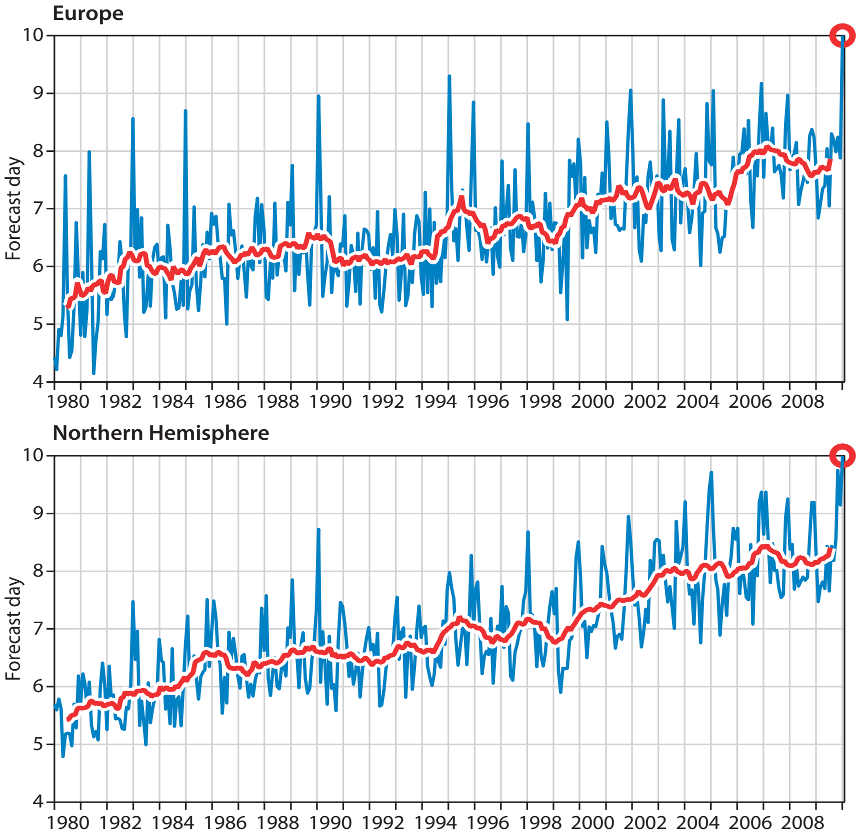
Notable over Europe were the severe winter storm Xynthia, one of the most damaging storms of the last decade, which affected much of Western Europe on 26–28 February, and a number of storms that affected south-western regions including the devastating floods in Madeira on 20 February. Prolonged cold weather and large snow accumulations affected large parts of Scandinavia and Finland. The UK and more recently Spain and southern France have also experienced disruption due to snow. ECMWF forecast from both the deterministic model and the ensemble prediction system provided consistent early warnings for these events.

A selection of ECMWF verification results is available on the following ECMWF web site:

- http://www.ecmwf.int/products/forecasts/d/charts/medium/verification/

The annual report of the performance of all the ECMWF forecast systems which includes comprehensive verification of all aspects of the models' performance is available as *ECMWF Tech. Memo. No. 606*, available from the ECMWF web site:

- http://www.ecmwf.int/publications/library/do/references/list/14



Improvement in the quality of the ECMWF forecasts. Shown are the monthly mean (blue) and 12-month running mean (red) of the forecast range at which the anomaly correlation for the operational forecasts of 500 hPa height falls below 60% for Europe (upper panel) and the extra-tropical northern hemisphere (lower panel). The final point on each curve (circled) is for February 2010 and is marked at forecast day 10. The actual score for February would be higher, but the forecast is not run beyond 10 days: the average February anomaly correlation at day 10 was 61% for Europe, 67% for the northern hemisphere.

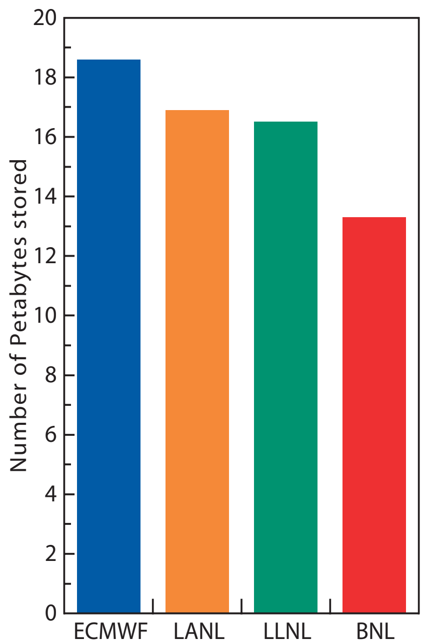
ECMWF hosts the largest HPSS archive in the world

NEIL STORER

ECMWF's data-handling system uses HPSS (the High Performance Storage System) as the data management software that underpins the meteorological archival and retrieval system (MARS) and the ECFS common file system (ECFS), the two locally developed utilities that provide the user-interface to the archive. The HPSS consortium recently released a table of organisations that use HPSS and placed them in order of the amount of data stored and the number of files stored. It should be noted, however, that some national security and defence sites that use HPSS do not publish information about their systems.

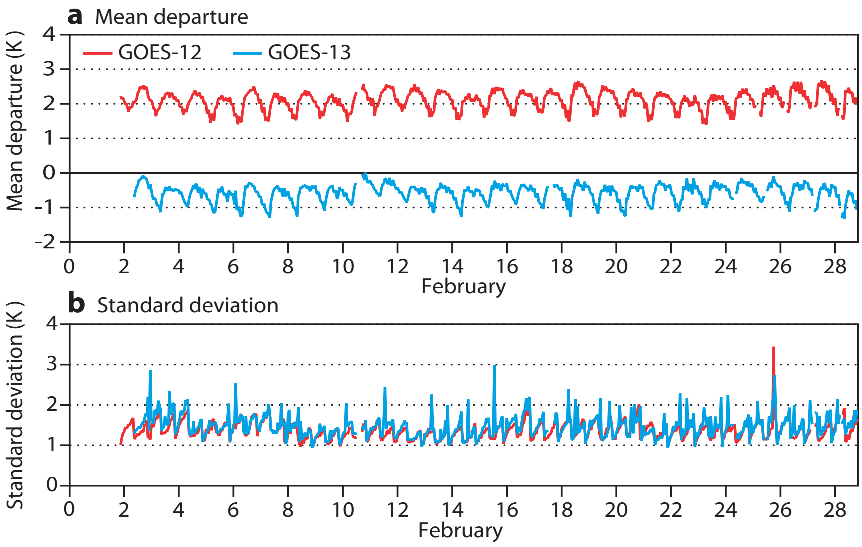
ECMWF is at the top of the list in terms of the number of Petabytes (1 PB = 10^{15} bytes = 1 million gigabytes) stored in a single HPSS system, with 18.6 PB, including secondary copies of the most important data. This places the Centre ahead of Los Alamos National Laboratory (LANL – 16.9 PB), Lawrence Livermore National Laboratory (LLNL – 16.5 PB) and Brookhaven National Laboratory (BNL – 13.3 PB).

In terms of the number of files stored, ECMWF is sixth, with 70.7 million files, preceded by LANL (133.2 million), LLNL-Secure (131.4 million), LLNL-Open (126.1 million), Argonne National Laboratory (122.3 million) and Lawrence Berkeley National Laboratory (91.6 million).



Status of the GOES-13 clear sky radiances at ECMWF

CRISTINA LUPU



Comparison of data from GOES-12 and GOES-13. (a) Time series of the mean departure of observed brightness temperature minus the corresponding model background (degrees K) for GOES-12 and GOES-13 for the water vapour channel at 6.7 μm from 2 February to 28 February 2010. (b) As (a) but for the standard deviation of the background departures. Note that the analysis and background departure statistics are reduced for GOES-13 data. Also the similarity of the standard deviation of the background departures for the GOES-13 and GOES-12 data indicates that in the water vapour channel the two sets of the data have a similar level of noise.

On 14 April 2010, GOES-13 replaced GOES-12 and has been declared operational as GOES-East in the NOAA Geostationary Operational Environmental Satellite (GOES) constellation. Currently, the GOES system consists of GOES-13 operating as GOES-East in the eastern part of the constellation at longitude 75.5° W, and GOES-11 operating as GOES-West at 135° W. In addition, GOES-12 started drifting eastward to 60° W to provide coverage for South America by June 2010.

GOES-13 carries instruments (imager and sounder) similar to those on GOES-12, but the new spacecraft, equipped with an improved battery, will allow it to operate through eclipse periods. Images will also have improved navigation, registration and radiometric accuracy. Clear sky radiances from GOES-13 have been produced by the Cooperative Institute for Meteorological Satellite Studies (CIMSS, Madison, USA) and have been received at ECMWF in near real-time since February 2010. The GOES-13 clear sky radiances are derived for the water vapour channel at 6.7 µm and for the three infrared channels at 3.9 µm, 10.7 µm and 13.3 µm.

The GOES-13 clear sky radiances have been monitored offline from 2 to 28 February 2010 and since 16 March 2010 they are passively monitored in the ECMWF operational assimilation system (cycle 36r1 of the Integrated Forecasting System). The quality of the GOES-13 data has been investigated by comparison with data from GOES-12. Side-by-side comparison of the two sets of data shows that analysis and background departure statistics are reduced for GOES-13 data. The standard deviation of the background departure for the GOES-13 data is similar to that for the GOES-12 data which indicates that in the water vapour channel the two sets of the data have a similar level of noise.

Monitoring statistics, including time-averaged mean fields, time series of area averages and Hovmöller zonal mean fields of GOES-13 clear sky radiances, can be found at:

- http://www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/geos/GOES_13/

Following these results it has been decided to proceed with assimilation experiments to assess the impact of the clear sky radiances from GOES-13 on analysis and forecast quality. Since 29 April 2010 the GOES-13 water vapour channel has been assimilated at ECMWF whilst the infrared channel at 10.7 µm is passively monitored.

Amendments to the Convention entered into force

MANFRED KLÖPPEL

With the two chambers of the Austrian Parliament having ratified the amended Convention on 24 March and on 9 April 2010 all of the ECMWF Member States have officially accepted the amendments to the Convention adopted by the ECMWF Council on 22 April 2005.

The amended convention entered into force on 6 June 2010. This was thirty days after the notification by the Austrian government of the acceptance of the Amending Protocol to the depositary of the ECMWF Convention, the General Secretariat of the Council of the European Union, on 7 May.

The original Convention restricted ECMWF membership to the founding 18 Member States. The amended Convention enables more States, in particular existing Co-operating States, to join ECMWF as full Member States. Furthermore, it enlarges ECMWF's mission to cover the monitoring of the Earth-system and broadens the possibility for externally-funded activities.

Horizontal resolution upgrade

BOB RIDDAWAY

On 26 January, ECMWF upgraded the horizontal resolutions of its deterministic forecast and data assimilation systems and the Ensemble Prediction System (EPS), including the weekly extension to 32 days.

A new cycle of the IFS model has been introduced to implement the higher resolution upgrade. This cycle is labelled Cy36r1.

- The resolution of the deterministic model increased from T799 (25 km grid) to T1279 (16 km).
- The resolution of the Ensemble Prediction System (EPS) changed 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 resolution of the wave model increased from 40 km to 28 km. Also the representation of the wave spectrum was improved so that now there are 36 frequencies and 36 directions.

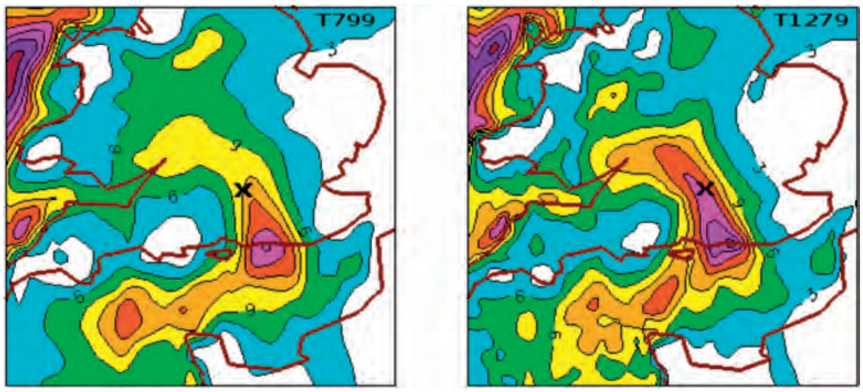
The higher resolution produces a better representation of features such as tropical storms, fronts, heavy rainfall and land/sea transitions.

The impact of the new cycle on the performance of the deterministic forecast system has been tested on more than 500 cases. Objective verification shows significant improvements for 1000 and 500 hPa height, 850 hPa temperature and wind at most levels. The location and intensity of synoptic features are improved in many cases. 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 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. However, 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.

There will be a more detailed description of the impact of the increased resolution in the summer edition of the *ECMWF Newsletter*.



Forecast of exceptional snowfall affecting southern England on 5/6 January 2010. The new high-resolution model (T1279, right) captured the exceptional snowfall event that affected southern England on 5/6 January this year very well and better than the previous model (T799, left). The panels show precipitation totals (mm liquid water equivalent) in the period 00 UTC on 5 January 2010 (T+0 h) to 09 UTC on 6 January (T+33 h). The cross marks ECMWF, where 27 cm of fresh snow was measured. This melted down to about 20 mm of rainfall equivalent, which is much closer to the T1279 forecast (~18 mm).

The funding of ERA-CLIM

DICK DEE

The ERA-CLIM project proposal, submitted in January 2010 to the European Commission, has been selected for funding in the Seventh Framework environmental research programme; it is now in the negotiation phase.

This three-year project, to be coordinated by ECMWF, is expected to kick off in January 2011 with EU funding up to 3.5 M euro. The Centre is now also receiving support for reanalysis activities from the UK National Centre for Atmospheric Science (NCAS), the UK National Centre for Earth Observation (NCEO), and the Japan Meteorological Agency (JMA). These combined resources will allow a strong growth and consolidation of reanalysis activities at the Centre.

The goal of ERA-CLIM is to prepare the input data and assimilation systems necessary for the production of a next-generation global atmospheric reanalysis spanning the entire 20th century. A large part of the project resources will be dedicated to data recovery and reprocessing efforts by partner institutions in Europe and elsewhere. Several pilot reanalyses will be delivered by ECMWF, including a century-long low-resolution atmospheric reanalysis based on surface observations only; a high-resolution land-surface reanalysis for the same period, and a comprehensive atmospheric reanalysis from 1979 to present at moderate-to-high resolution. An important feature of ERA-CLIM is that all reanalysis data, including observation feedback information, will be made publicly available via ECMWF data services.

The ERA-CLIM partner institutions are: ECMWF, the UK Met Office, Météo-France, EUMETSAT, University of Vienna, University of Bern, University of Lisbon, the Russian Research Institute for Hydrometeorological Information, and the Chilean Met Service.

New web products from the ECMWF Ensemble Prediction System

DAVID RICHARDSON

ECMWF has extended the range of weather forecast products that are available freely and with no restrictions from its web site. The new products are from the ECMWF Ensemble Prediction System (EPS) that provides guidance on the day-to-day predictability of the atmosphere. This gives an important complement to the information that is already available from the single deterministic model.

The ensemble is a set of 51 separate forecasts made by the same computer model, all started from the same initial time. The starting conditions for each member of the ensemble are slightly different. The differences between these ensemble members tend to grow as the forecasts progress. This dispersion varies from day to day, depending on the initial atmospheric conditions, and therefore gives an indication of the uncertainty in the current forecast.

The new graphical products show the ensemble mean (average over all 51 members) and ensemble standard deviation (spread) corresponding to each parameter available from the deterministic model: 500 hPa geopotential, 850 hPa wind and temperature and mean sea level pressure. These can be found at:

- http://www.ecmwf.int/products/forecasts/d/charts/medium/eps/

A detailed explanation can be found by clicking on 'show guide' on the left-hand side menu.

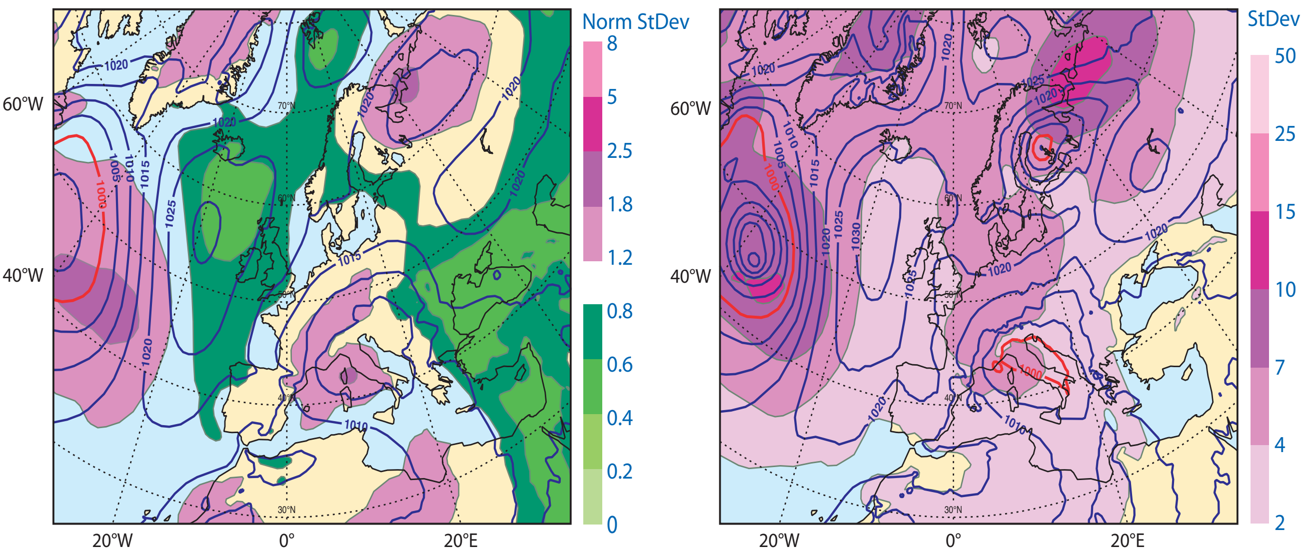
The corresponding charts from the deterministic forecast are available at:

- http://www.ecmwf.int/products/forecasts/d/charts/medium/deterministic/

This extension of the freely available 'essential' products was agreed by the ECMWF Council at its 72nd session in December 2009, as part of ECMWF's continuing efforts to promote the benefits of ensemble forecasting (for more information see page 13 of *ECMWF Newsletter No. 122*).

For more information about the full range of ECMWF products, including access to digital data, see:

- http://www.ecmwf.int/products/



Example of the new ensemble mean and spread web products. Example of the new ensemble mean and spread web products. The contours show the forecast mean sea-level pressure (MSLP) field for 6 days ahead from the ensemble-mean (left panel) and the single higher-resolution 'deterministic' forecast (right panel). The spread within the ensemble is also represented on each panel, using coloured shading. On the right panel, spread is simply represented as the standard deviation. Small values (light shading) indicate small spread differences between the ensemble members and hence high confidence, while large values indicate large differences and therefore low confidence. The shading on the left panel shows a normalised standard deviation, putting the spread into the context of the general ensemble behaviour, in that area, over the last 30 days. In this example the spread indicates relatively high confidence (green) in the high-pressure area over the UK, but more uncertainty (purple) in the low pressure areas in the Mediterranean and Atlantic.

David Burridge awarded the EMS Silver Medal

DOMINIQUE MARBOUTY

The European Meteorological Society (EMS) has chosen Dr David Burridge as Laureate of the EMS Silver Medal 2010. The EMS Silver Medal was established in 2008 to honour important contributions to the development of meteorology in Europe. Dave is honoured for his outstanding leadership and scientific contributions in the field of numerical weather prediction.

Dave spent most of his career at ECMWF which he joined at its creation in 1975. He climbed up in the Centre's hierarchy, becoming Head of the Model Division in 1979, Head of Research in 1982 and Director in 1991, a position he retained until his retirement in 2004.

The award recognises that Dave's innovative contributions to the field of numerical weather prediction were a major contribution to the establishment and maintenance of ECMWF as a world-leading forecast centre. In addition, since he left ECMWF, he has been enthusiastically, and effectively, shaping and steering the implementation of the THORPEX Programme.

As well as recognising Dave's scientific qualities and accomplishments, the award draws attention to him being an excellent advocate for the meteorological sciences; he has the capability of being able to explain convincingly scientific issues to experts, whilst being adept at conveying complex ideas to the public and the media in an understandable way. Also his outstanding people management skills are recognised.

Dave was honoured by the government of the UK when he was made a Commander of the British Empire (CBE) in 1995 for services to meteorology. In 2005 he received an honorary Doctorate of Science from the University of Reading and in 2006 he was awarded an Honorary Fellowship by the University of Swansea.

When informed about the award Dave said "I am delighted and honoured to receive this award and I regard it as also recognizing the exceptional pan-European collaboration that has made ECMWF a leading institution in numerical weather prediction. I am thankful that, during my time at ECMWF, I was fortunate to be in a key position to provide support and encouragement to ECMWF colleagues. The award is also a great personal stimulus to continue working on the THORPEX Programme which I hope will improve the prediction of high impact weather around the world."

I have been privileged to work under Dave's leadership before succeeding him, and I am particularly happy for this recognition of the scientist, the leader, the colleague and the friend. As emphasised by Dave, this award is also a recognition of ECMWF's success and, of course, the Centre is particularly honoured that it follows the awarding of the EMS Silver Medal 2009 to Dave's predecessor as ECMWF's Director, Lennart Bengtsson.

The Silver Medal ceremony, which includes a Silver Medal Lecture by David, will be held on 15 September 2010, during the EMS Annual Meeting and European Conference on Applied climatology (ECAC) at ETH in Zurich, Switzerland.

Emissions from the Eyjafjallajökull volcanic eruption affecting AIRS and IASI measurements

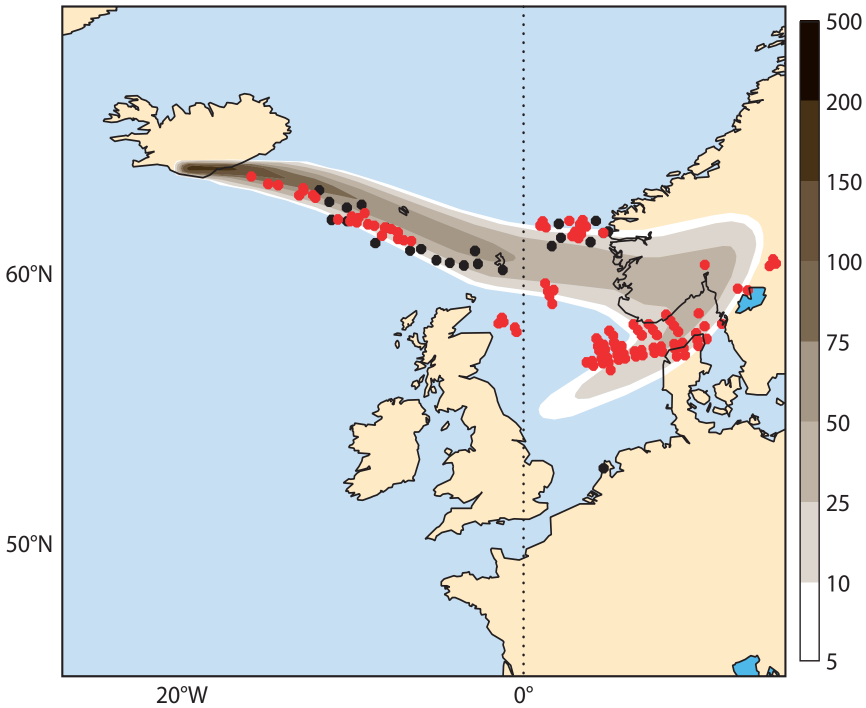
TONY MCNALLY, REIMA ERESMAA, JOHANNES FLEMMING

Extremely sensitive satellite instruments such as AIRS and IASI measure small variations in the spectrum of infrared radiation emitted by the Earth's atmosphere. These variations are used by NWP centres to infer subtle changes in atmospheric temperature and humidity, a knowledge of which can have a significant impact on reducing medium-range forecast errors. However, it is known that the cocktail of aerosol and gas emissions associated with a major volcanic eruption can produce a small, but significant disturbance of infrared spectral measurements. To prevent these disturbances being misinterpreted as erroneous temperature information, it is important to detect and reject situations where the radiance observations are believed to be strongly contaminated by aerosols. At ECMWF we have a scheme dedicated to the identification of clouds and aerosol signatures in AIRS and IASI observations.

The recent eruption of the Eyjafjallajökull volcano over Iceland in April of this year caused widespread disruption of air traffic, but this event has also been found to have an impact on data from AIRS and IASI. The figure shows the locations where aerosol signatures in the radiance data exceeded the maximum allowed level and caused observations to be rejected.

It can be seen that the AIRS and IASI rejections coincide very well with a MACC forecast that predicts the trajectory of a column integrated tracer resulting from a simulated aerosol injection at 5 km above the volcano (note that the injection source is simulated as no realistic measured values are available). While this is only a very preliminary investigation, it gives us some confidence that the aerosol detection system is working well to protect the analysis from contaminated radiance data. It also suggests that these initial simulations of the plume trajectory from the MACC system are quite realistic. More information about the MACC forecasts of the plume is given in the next news item.

We hope to perform a more comprehensive investigation of the Icelandic volcanic eruption in the near future.



Rejected AIRS and IASI data due to excessive aerosol contamination. The locations where AIRS data (black dots) and IASI data (red dots) have been rejected due to excessive aerosol contamination during the 12 UTC 4D-Var assimilation window on 15 April. Superimposed is a 39-hour MACC forecast from 14 April (verifying with the centre of the same 4D-Var assimilation window) predicting the trajectory of simulated aerosol injection at 5 km. The units in the legend indicate only a relative magnitude of column aerosol tracer.

MACC response to the volcanic eruption in Iceland

RICHARD ENGELEN

MACC (Monitoring Atmospheric Composition and Climate) is developing services to support institutions that are providing advice and warnings related to atmospheric composition. In the case of the eruption of the Eyjafjallajökull volcano over Iceland in April and May, the direct responsibility for advice for aviation for the region lies with the London Volcanic Ash Advisory Centre at the Met Office. MACC has set up, however, a dedicated part of its website to illustrate current capabilities in terms of volcanic plume forecasting.

MACC uses its advanced data assimilation system for atmospheric composition to make pre-operational plume forecasts. Assumptions have been made about the amount of gas and ash, particle size and weight, and the height of the injection of these constituents into the atmosphere. The latter depends to a large extent on the explosiveness of the eruption. An example of a MACC forecast of the plume from the volcano is given in the previous news item about how emissions from the Eyjafjallajökull volcanic eruption affected AIRS and IASI measurements. Work is in progress to extend the current capability of gas plume forecasts to include forecasts of volcanic ash particles. At the same time, all available observations are used for validation of the plume simulations, as for instance shown in the figure, as well as for testing the impact through data assimilation.

When MACC reaches its operational phase, by 2014 at the latest, it will be able to use actual information about volcanic eruptions in combination with operational observations of atmospheric constituents, for instance from Europe's Sentinel satellite missions, to produce plume forecasts in a timely manner. These will be provided on request to the relevant institutions to help them assess the situation and provide detailed information. This would include the Volcanic Ash Advisory Centres but also agencies dealing with the impact on public health.

In the meantime, the MACC system will be used to diagnose the current event to learn how accurately the spread of the plume can be forecast, the impact of the available satellite data, and what new observations are needed for future monitoring and forecasting. More detailed forecasts as well as information about available observations can be found on our dedicated Iceland Volcanic Eruption page:

- http://www.gmes-atmosphere.eu/news/volcanic_ash/background/.

More information about MACC can be found in the article starting on page 10 of this *ECMWF Newsletter*.

Monitoring Atmospheric Composition and Climate

ADRIAN SIMMONS

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

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

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

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

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

Input data

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

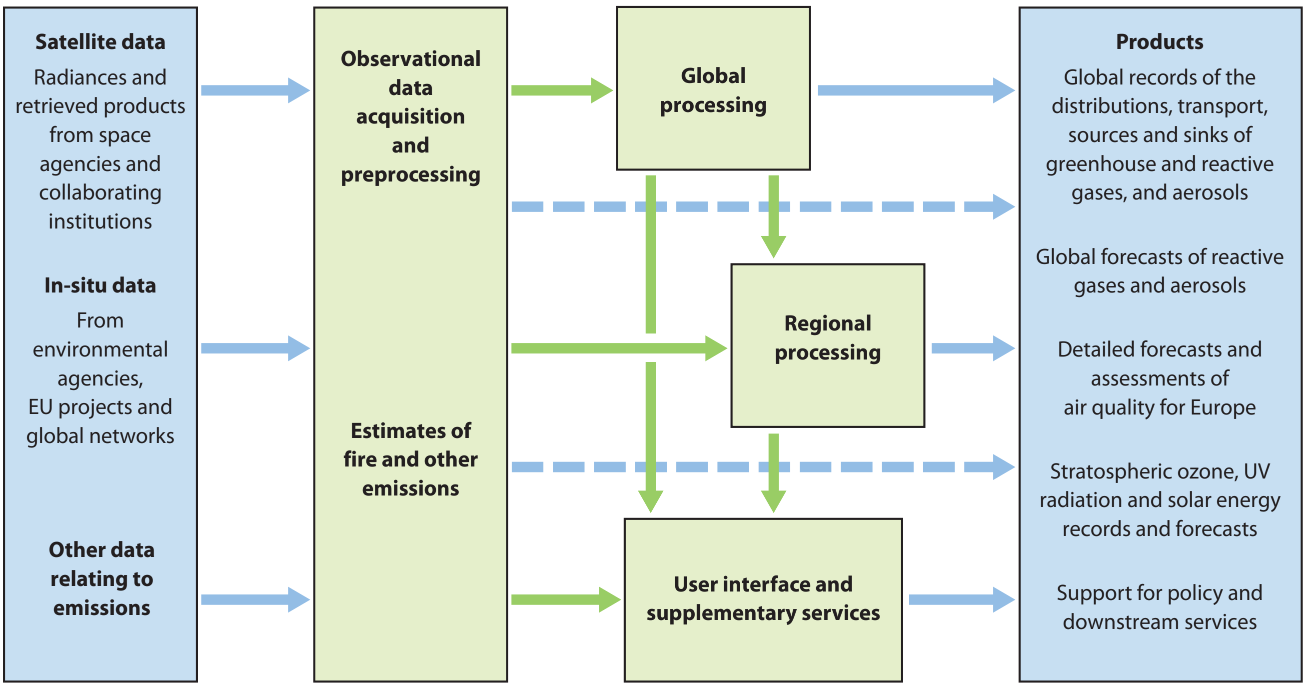


Figure 1 An overview of the MACC processing system.

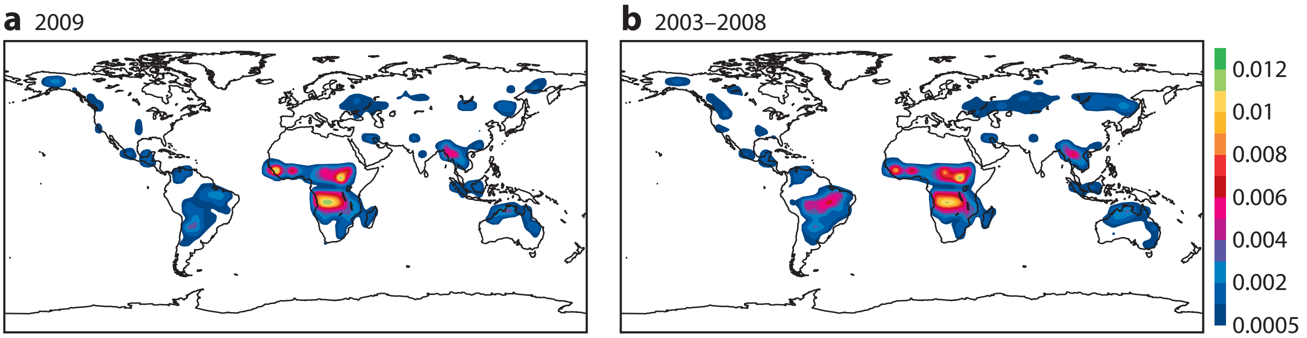


Figure 2 Fire radiative power density (Wm^{-2}) averaged for (a) 2009 and (b) 2003–2008. Global biomass burning was lower in 2009 than in previous years mainly due to reduced deforestation in Brazil. Note that, in addition to biomass burning, the maps exhibit minor features associated with gas flares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

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

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

Global monitoring and forecasting

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

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

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

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

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

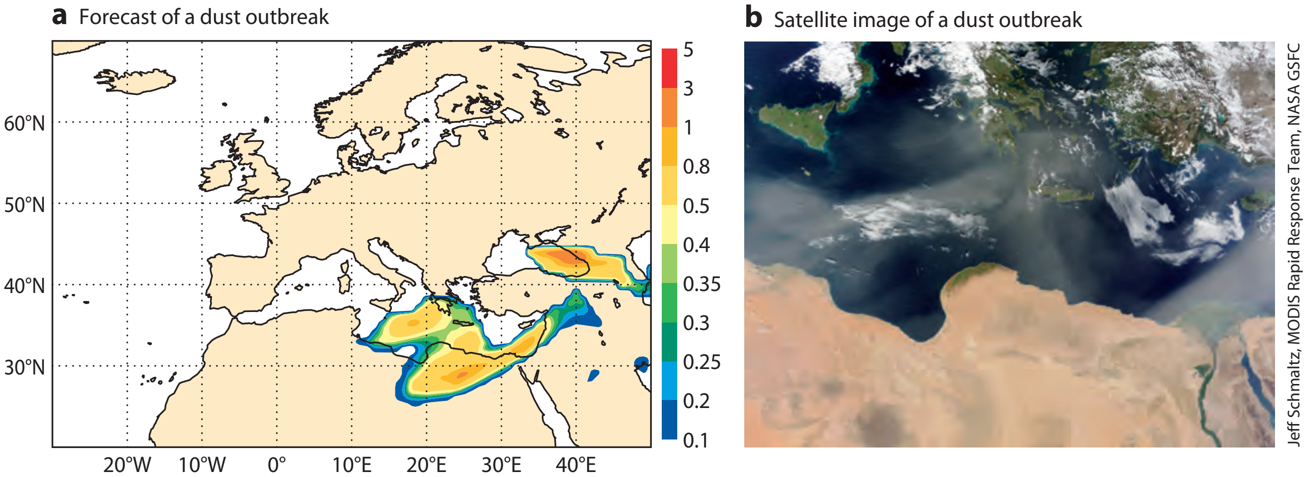


Figure 3 (a) Dust outbreaks from North Africa into the eastern Mediterranean on 18 February 2010 captured in a 33-hour forecast from the global MACC system. (b) The corresponding image from the MODIS instrument on NASA's Terra satellite. The forecast product is a prototype warning index based on scaling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

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

Regional forecasting and evaluation

MACC's regional processing component comprises an ensemble of higher-resolution chemical analysis and forecasting systems run over a common European domain by seven partners. The core ECMWF system provides the meteorological fields required by the regional systems, and the global MACC system provides chemical and aerosol boundary conditions.

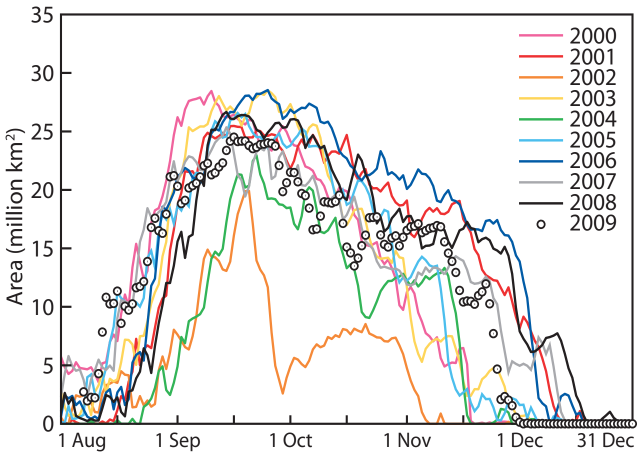


Figure 4 Area of the southern hemisphere with total ozone less than 220 Dobson Units. These records produced by partner KNMI for 2000 to 2009 are based on assimilating data from the GOME and SCIAMACHY instruments on ESA satellites. Their production is being continued in MACC.

Forecasts are produced daily for three days ahead. Retrospective analyses of validated air-quality measurements are also produced, providing a description of the background European levels of pollutants that are characterised by the influence of long-range transport. This enables evaluation of interannual variations in air quality and the effects of changes in emissions.

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

User interface and policy support

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

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

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

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

Access to products

MACC's products relating to atmospheric composition are made freely available. Graphical products, datasets and

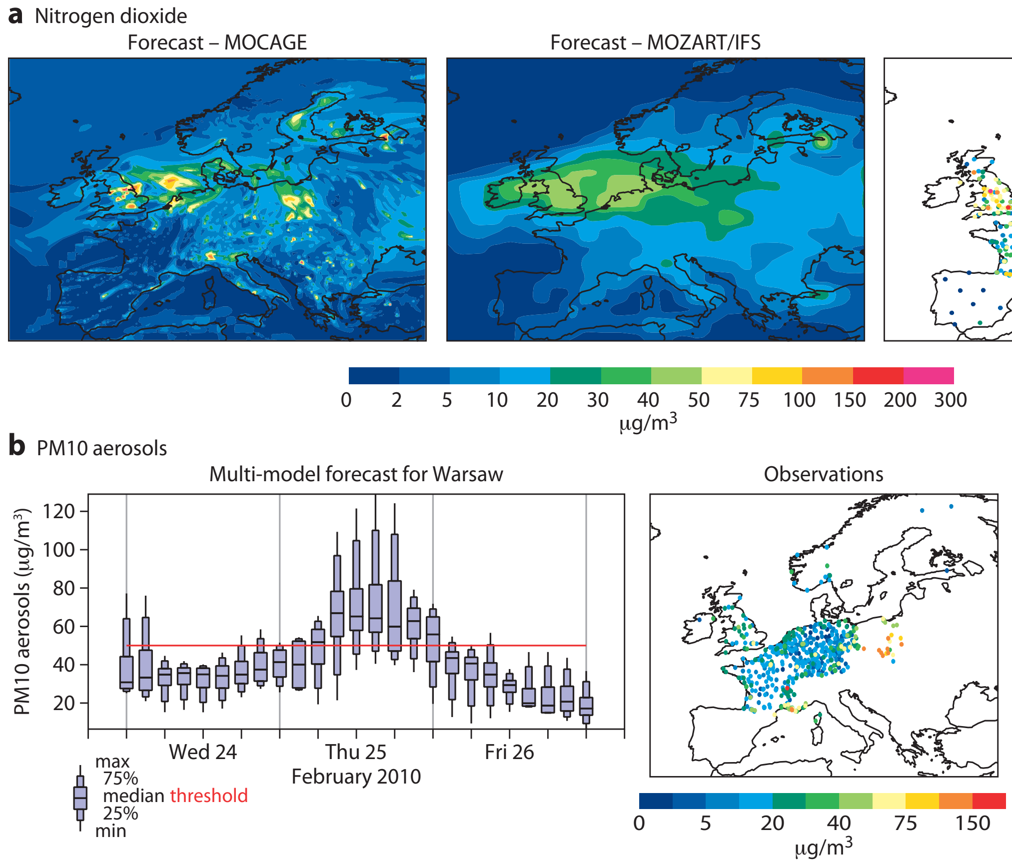


Figure 5 (a) Nitrogen dioxide distributions for 18 UTC on 25 February 2010 from the 42-hour forecasts from the MOCAGE regional model (left), the MOZART/IFS global model (centre) and the measured values (right). (b) The spread in multi-model forecasts of PM10 (particulate matter with sizes up to 10 microns)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

reports can be downloaded from the project's main website (www.gmes-atmosphere.eu) or from partner websites for which the main site acts as a portal. Other forms of dissemination are under development. Training can be provided and user feedback is encouraged.

The way forward

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

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

Support for measurement and modelling initiatives

A

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

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

Collaboration on Observing System Simulation Experiments (Joint OSSE)

ERIK ANDERSSON, MICHIKO MASUTANI

TO DECIDE how to develop the meteorological observing systems the benefit of the new observations needs to be accurately assessed; such information helps determine which systems and instruments to investment in and which will provide best value for money. Use of observing system simulation experiments (OSSEs) is a well-established technique providing objective and quantitative evaluation of future observing systems and instruments.

Simulation experiments use a model-generated proxy for the real atmosphere, commonly called the 'Nature Run'. This defines the evolution of the atmosphere over the entire experimental period. Simulated observations are generated from the Nature Run, and used in data assimilation experiments where their impact on analysis and forecast accuracy can be assessed. In such idealized experiments, the Nature Run also provides the 'truth' which all results are verified against.

An internationally collaborative effort called Joint OSSE has formed over the last several years in order to perform OSSEs (*Masutani et al.*, 2007). The Nature Run for the Joint OSSE was produced by ECMWF.

Assessing impact of future observations

OSSEs are very labour intensive projects. The Nature Run (hereafter referred to as NR) has to be produced using a state of the art NWP model at the highest resolution feasible. In addition:

- The simulation of observations from a NR requires large computing resources.
- Simulations and assimilations may have to be repeated using more than one configuration to achieve a recommendation with confidence.
- OSSEs require expert knowledge in modelling, data assimilation and observing system technology.

Consequently, efficient and effective collaboration is essential for sharing the workload and producing reliable results.

Ideally, every proposed observing system should be tested by OSSEs before being selected to be built. OSSEs can be important in influencing the configuration of an observing system and the design of a satellite instrument. Subsequently, while the instruments are being built, OSSEs can help prepare both the science and the software of NWP data assimilation systems for the new observation types.

AFFILIATIONS
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Michiko Masutani: NOAA/NWS/NCEP, Camp Springs, USA

Some institutions in the USA referred to in this article

- **JCSDA**: Joint Center for Satellite Data Assimilation
- **NASA/GLA**: NASA's Goddard Laboratory for Atmospheres
- **NASA/GMAO**: NASA's Goddard Global Modeling and Assimilation Office
- **NASA/GSFC**: NASA's Goddard Space Flight Center
- **NASA/SIVO**: NASA's Software Integration and Visualization Office
- **NCAR/CISL**: NCAR's Computational and Information Systems Laboratory
- **NCEP/EMC**: NCEP's Environmental Modeling Center
- **NESDIS/ORA**: NESDIS's Office of Research and Applications
- **NOAA/ESRL**: NOAA's Earth System Research Laboratory
- **NOAA/NCEP**: NOAA's National Centers for Environmental Prediction
- **SWA**: Simpson Weather Associates, Inc.

The Joint Center for Satellite Data Assimilation (JCSDA), Washington, recognized that it is very important that future observing systems be tested by OSSEs. Now NCEP/EMC, NASA/GMAO, JCSDA, ECMWF, NESDIS/ORA, NASA/SIVO, NASA/ GLA, SWA, NOAA/ESRL (Boulder), KNMI, and others are working together to further this goal. The Japan Meteorological Agency, Météo-France and the Met Office (UK) are also participating in this effort (*Masutani et al.*, 2007).

Joint OSSE Nature Runs

The starting point of an OSSE is the Nature Run, which serves as 'truth' for the simulations. The team behind the Joint OSSE decided to use a long forecast from ECMWF, forced with daily sea-surface temperature and sea ice, as the NR. It is unavoidable that the NR gradually diverges from the real atmosphere during the first few weeks of the forecast. This is not a concern within the context of an OSSE, provided that the climatological statistics of the simulation match those of the real atmosphere.

The main NR is a 13-month forecast using cycle 30r1 of ECMWF's Integrated Forecasting System (IFS) with T511 horizontal resolution (40 km) and 91 levels in the vertical; the output is saved every 3 hours. The initial condition is the operational analysis on 12 UTC on 1 May 2005 and the NR ends at 00 UTC on 1 June 2006.

The T511 NR was evaluated, and very realistic hurricanes (Figure 1) and mid-latitude cyclone statistics were reported

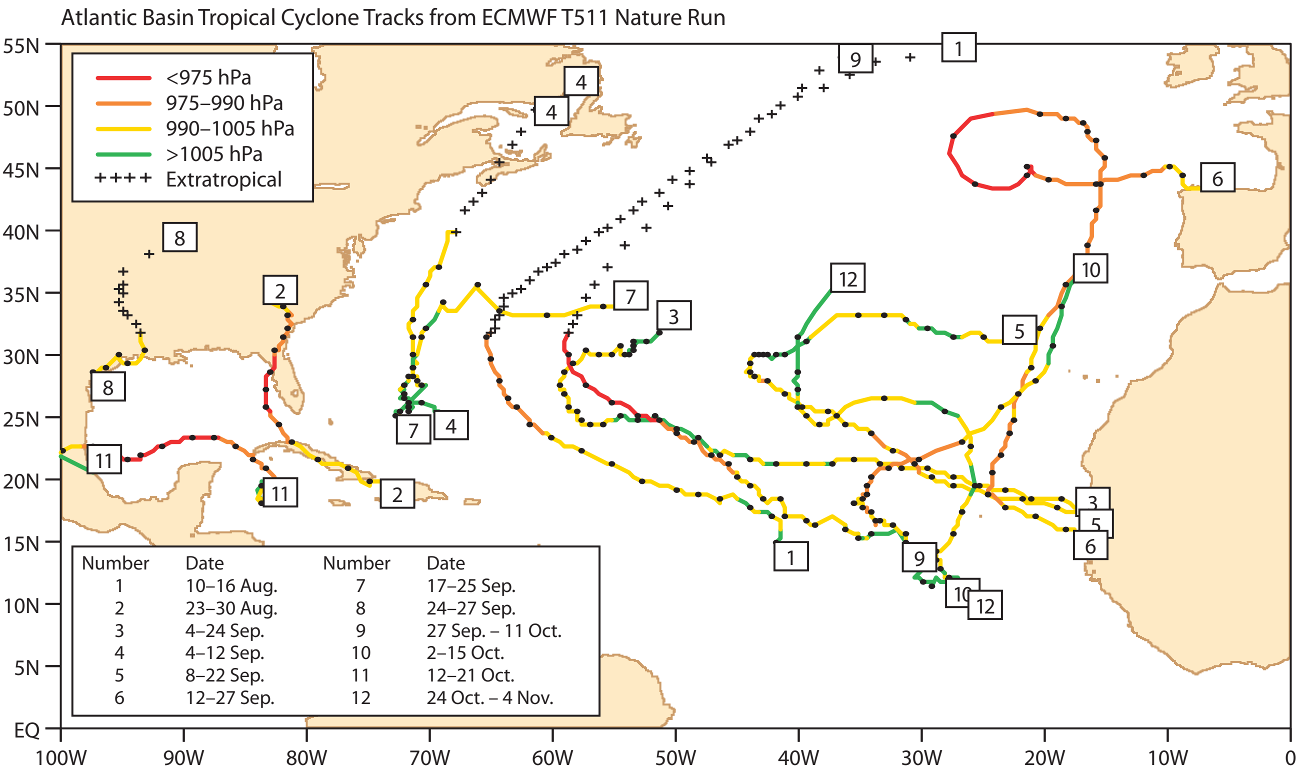

Figure 1 Atlantic tropical cyclones in the Nature Run 'hurricane season'. The tracks are shown in different colours reflecting the centre pressure in the full resolution T511 surface fields. Crosses indicate extratropical storms. From *Reale et al.* (2007).

(*Masutani et al.*, 2007; *Reale et al.*, 2007). The cloud distribution is much more realistic than in the previous NR (*Masutani et al.*, 1999). Statistics of the mid-latitude jet were also studied and found to be realistic. Further reports on the validation of T511 NR are available at:

http://sivo.gsfc.nasa.gov/OSSE/nature_run_validation.html

they include studies of how well it captures the South American and African monsoons, and tropical and mid-latitude cyclones.

Two high-resolution NRs at T799 horizontal resolution with 91 vertical levels have been generated to study data impact on forecasting hurricane and mid-latitude storms. A hurricane period from 27 September to 1 November was selected. A period from 10 April to 15 May was selected to study mid-latitude storms.

The NRs are accompanied by an additional dataset of low-resolution pressure and isentropic level data on a latitude-longitude grid, also provided by ECMWF, to speed up the diagnostic and evaluation processes. Selected surface variables from the T511 NR and all surface variables from the T799 NR are provided on a regular latitude-longitude grid. Furthermore, a time series of selected variables on a regular grid is also provided. The gridded data is used for verification purposes only and observations must be simulated from the full-resolution model-level data.

Data distribution, usage and credit

The complete data for the T511 NR and T799 NR is saved at ECMWF, NCEP, NASA/GSFC, and NOAA/ESRL. Also verification data for the T511 NR is saved at the NCAR/CISL Research Data Archive and Japan Meteorological Agency.

NR data is available from ECMWF for the ECMWF registered users, from NASA/GSFC in the USA, and from the NCAR/CISL Research Data Archive. Access to the complete NRs is available from the NASA/GSFC portal system. Currently the data is available from:

http://sivo.gsfc.nasa.gov/OSSE/index.html

Access to the data from this site requires an account, which is available to the research community. This data must not be used for commercial purposes and re-distribution rights are not given. ECMWF and Joint OSSE must be given credit in any publications in which this data is used.

Methodology

For OSSEs, the NR is a proxy for the real atmosphere. It is from the NR dataset that simulated observations are generated. As with real observations measured in the real atmosphere, simulated observations are assimilated both with and without certain observing systems included. Forecasts are then executed from these assimilations. The output from both the assimilations and forecasts are evaluated in a variety of ways. The results of the evaluation can be used to either calibrate the OSSE system to enhance realism, or to tune various components of the system to improve performance.

In the initial iterations through this cycle, comparisons are made between experiments using simulated and real observations, both using the same data assimilation system and forecast model. Inconsistencies in results between the simulated world and real world may necessitate a calibration of one or more components of the OSSE system. Calibration may involve, for example, improving the errors that are applied to the simulated observations or enhancing certain NR fields to achieve greater realism.

After the initial calibration is performed, the OSSE system is ready for actual experiments with new observing systems. At this point, another iterative process will commence in which simulated observations from new instruments are introduced. Results of assimilations and forecasts with and without these new observations are evaluated. The NR provides the truth data against which all of these simulated experiments are verified.

Progress in simulation of observations and precursor assimilation

Conventional and radiance data has been simulated from the T511 NR for an entire year at NOAA/NCEP. This data is available to Joint OSSE participants. The observations are being produced with simulated observational errors, which roughly correspond to the types of random errors found in real observations. This is an essential component of the impact assessment: if the errors are too small then the resulting OSSE results will show unrealistic benefit from the data.

Since the spatial drift of radiosondes (RAOBs) is considered in the NCEP data assimilation system, it has to be simulated in the NRs as well. The drift was not significant for previous OSSEs with a low resolution NR, though it becomes significant at the resolution scales of T511 (40 km) or T799 (25 km). Extensive discussions on representativeness errors have been organized under the auspices of the Joint OSSE.

The current state of the OSSEs is as follows.

- Simulations of an Unmanned Aircraft System (UAS) are funded and the simulation is in progress at NOAA/ESRL.
- Simulations of a Doppler Wind Lidar satellite system are funded and in progress at KNMI, NASA and SWA.
- KNMI is seeking funding to simulate scatterometer data.

The challenge

It is a challenging task to evaluate the realism of impacts from OSSEs as the results are affected by uncertainties in an OSSE, the differences between the NR and real atmosphere, the process of simulating data, and the estimation of observational errors. The choice of evaluation metrics also affects the conclusions drawn.

Consistency in results is important. However, it is also important to be able to evaluate the source of the errors and uncertainties. As more information is gathered we can perform more credible OSSEs. If the results are inconsistent, the cause of the inconsistency needs to be investigated carefully. NCEP's OSSEs have demonstrated that carefully conducted OSSEs are able to provide useful recommendations to influence the design of future observing systems (wind lidars). OSSEs are able to provide guidance on where more observations are required and where the model needs to be improved.

OSSEs will be conducted by various scientists with different interests. Some are investigating the potential applications of particular prospective instruments. Others may want to aid in the design of the global observing system.

At the current time, the American space agencies are getting involved in prioritising and funding the most urgent impact simulations from their perspective. Now that the Joint OSSE framework has been built and validated, there is a wide range of possibilities for its application.

FURTHER READING

Masutani, M., K. Campana, S. Lord & S.-K. Yang, 1999: Note on Cloud Cover of the ECMWF nature run used for OSSE/NPOESS project. *NCEP Office Note No.427*.

Masutani, M., E. Andersson, J. Terry, O. Reale, J.C. Jusem, L.-P. Riishojgaard, T. Schlatter, A. Stoffelen, J.S. Woollen, S. Lord, Z. Toth, Y. Song, D. Kleist, Y. Xie, N. Priv, E. Liu, H. Sun, D. Emmit, S. Greco, S.A. Wood, G.-J. Marseille, R. Errico, R. Yang, G. McConaughy, D. Devenyi, S. Weygandt, A. Tompkins, T. Jung, V. Anantharaj, C. Hill, P. Fitzpatrick, F. Weng, T. Zhu & S. Boukabara, 2007: Progress in Joint OSSEs. In *AMS Preprint Volume for 18th Conference on Numerical Weather Prediction*, Parkcity UT, 25–29 June 2007.

Reale, O., J. Terry, M. Masutani, E. Andersson, L.P. Riishojgaard & J.C. Jusem, 2007: Preliminary evaluation of the European Centre for Medium-Range Weather Forecasts' (ECMWF) Nature Run over the tropical Atlantic and African monsoon region. *Geophys. Res. Lett.*, **34**, L22810, doi:10.1029/2007GL031640.

The list of OSSE related references are available at:
http://www.emc.ncep.noaa.gov/research/JointOSSEs/references/

NASA OSSE home page:
http://sivo.gsfc.nasa.gov/OSSE/index.html

THORPEX OSSE home page:
http://www.emc.ncep.noaa.gov/research/THORPEX/osse

The new Ensemble of Data Assimilations

LARS ISAKSEN, JAN HASELER,
ROBERTO BUIZZA, MARTIN LEUTBECHER

AN ENSEMBLE of Data Assimilations (EDA) system will be introduced at ECMWF with cycle 36r2 of the Integrated Forecasting System (IFS). The EDA system consists of an ensemble of ten independent lower-resolution 4D-Var assimilations that differ by perturbing observations, sea-surface temperature fields and model physics. The computing cost is significant, similar to running the deterministic analysis suite.

The main justification for implementing the EDA is that it quantifies analysis uncertainty.

- It is the first system implemented at ECMWF that provides estimates of analysis uncertainty. A properly designed EDA will complement the data assimilation system with important information about the quality of the deterministic analysis.
- It can be used to estimate flow-dependent background errors in the deterministic 4D-Var assimilation system; this will potentially improve the medium-range forecast. Flow-dependent background errors will be introduced in the second phase, in the autumn of 2010.
- It can improve the representation of initial uncertainties for the Ensemble Prediction System (EPS). When the EDA is introduced in IFS cycle 36r2, EDA-based perturbations will replace evolved singular vectors (SVs) to generate the EPS initial conditions. This change will improve the EPS skill, especially over the tropics.

The application of EDA in EPS will be described in an accompanying article by *Buizza et al.* in this issue of the *ECMWF Newsletter* (pages 22 to 28).

The EDA is expected to become an important part of the ECMWF data assimilation system, with the introduction of a hybrid 4D-Var/EDA system. Also, in the coming years, the EPS and EDA are expected to be further integrated to the benefit of both systems.

Rationale for developing an EDA system

The EDA is based on a perturbed lower-resolution version of the operational analysis system. If the perturbations of observations and model physics are realistic, the EDA will provide good estimates of analysis uncertainty. Because four-dimensional data assimilation, similar to that used for the operational analysis, is an integral part of EDA it has the potential to provide very valuable information about analysis uncertainty of the operational assimilation system. This is difficult to obtain by other means. The system will also provide short-range forecast error uncertainty. Many applications would benefit from accurate estimates of the uncertainty in analysis and short-range forecast errors. This could provide guidance for the quality of ECMWF's short-range forecasts. The EDA can also be used to improve the data assimilation system and the EPS.

In data assimilation, one of the crucial aspects is the estimation of the background error variances. To a large degree these are static in the operational 4D-Var system. This is unrealistic, especially for extreme events, where the background error variances can be underestimated significantly.

The EDA system is able to produce flow-dependent estimates of analysis uncertainty and background error uncertainty based on the ensemble spread, measured as the standard deviation of the difference between independent short-range background forecasts (*Fisher*, 2003; *Tan et al.*, 2007). This information gives an estimate of the error-of-the-day and can also be used for the estimation of seasonally varying background errors. Recent research at ECMWF has shown a beneficial impact from using the EDA errors of the day in the operational high-resolution 4D-Var. This is expected to be implemented in the second half of 2010.

Currently, covariance statistics of background error are generated from an offline EDA that is run over a period of one month. Only rarely are the statistics updated, and a single set of statistics is used for all seasons. The availability of an operational EDA will allow more frequent updates of background error statistics, with the possibility of accounting for seasonal variation of error covariances.

Characteristics of the EDA system

4D-Var at ECMWF is based on the incremental approach to minimising a cost function. The first minimisation (inner loop) takes place at low resolution to produce preliminary low-resolution analysis increments with a simplified representation of linearized model physics. The subsequent loops are at higher resolution with a more advanced linearized model physics applied. The comparison of observations against model fields takes place at a high resolution with all the non-linear aspects included (outer loop). This incremental approach provides considerable flexibility in the use of computer resources.

Isaksen et al. (2007) describe the design of the EDA in detail, based on analyses run with a T255 outer loop and T95/T159 inner loops and 91 vertical levels. In the EDA, for each observation, perturbations are defined by randomly sampling a Gaussian distribution with zero mean and standard deviation equal to the estimate of the observation error standard deviation. For cloud-track wind observations, perturbations are horizontally correlated. Sea-surface temperature fields are also perturbed, with correlated patterns as currently used in the Seasonal Forecasting System. At the first assimilation cycle, the randomly-perturbed observations are the only source of difference between the perturbed analyses, while for the subsequent cycles differences will evolve in the first-guess fields and contribute to the analyses spread. Model error is simulated by stochastically perturbing the model tendencies using same method applied in the EPS –

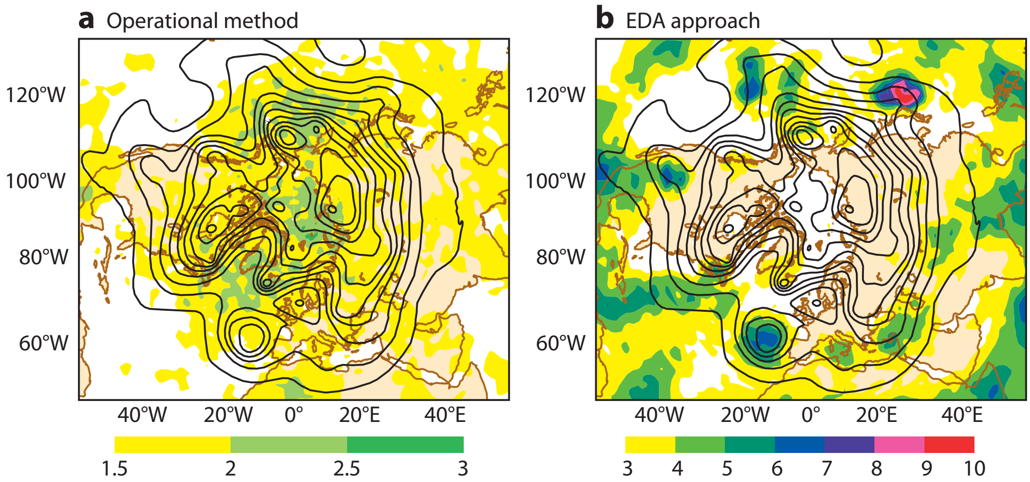

Figure 1 Background error standard deviation estimates for 850 hPa zonal wind at 00 UTC on 16 October 2006 using (a) the operational randomization method of *Fisher & Courtier*, 1995 (maximum value 2.97 ms^{-1}) and (b) the EDA approach based on 2 times the standard deviation of 10 ensemble members using T255 outer loop and T95/T159 inner loop (maximum value 9.99 ms^{-1}). Both panels have 500 hPa geopotential height field overlaid (8 dm contouring). The factor of two makes the average global EDA spread more realistic.

the method used is described later in the section on '*The operational EDA configuration*'.

Isaksen et al. (2007) demonstrated the EDA system's ability to produce flow-dependent spread and deliver promising results for some extreme meteorological events. The EDA produces a realistic horizontal distribution of analysis error and background error, with small values over the data rich areas of the USA, Europe and Australia.

Figure 1 shows a snapshot of background error estimates for 850 hPa zonal wind on a day in October 2006 for the northern hemisphere extra-tropical region from the operational randomization method (*Fisher & Courtier*, 1995) and the standard deviation of a ten member EDA. The EDA values have been scaled to get more realistic global average amplitude of variances. It is clear that the day-to-day background error estimates for wind have very different structures and amplitudes for the operational method (Figure 1a) and the EDA (Figure 1b). The operational method takes some account of flow curvature, but primarily samples the static background error variances, taking account of the observation coverage.

It is seen from Figure 1 that the EDA method results in more flow-dependent variability of the background error variances. The largest values are seen east of Japan where an extra-tropical low is developing. The EDA method really captures the dynamically active regions, like extra-tropical lows and troughs; an ability that to a large extent is lacking for the operational method.

The impact of EDA resolution and ensemble size has been investigated for the case used in Figure 1. Some results are now described that focus on the region near Japan that is dynamically very active. For the low-resolution assimilation system with one T95 inner loop (Figure 2c) there is a clear flow dependence, but this is not the case when the operational randomization method is used (Figure 2a). Also, the low-resolution assimilation system (Figure 2c) delivers less focussed, but still similar results compared to a higher-resolution system with two (T95 and T159) inner loops (Figure 2b). Both use a T255 outer-loop resolution.

Comparing Figures 2c and 2d, one can see the impact of increasing the number of ensemble members from 10 to 50. The patterns are very similar, but the result of the 50-member ensemble is smoother with fewer spikes and also reduces regions with very low variance. The 50 members are basically giving a statistically better sampling of the forecast errors, but they also describe flow-dependent features at a higher resolution. The results shown in Figure 2 suggest that computer resources may be better spent on more members with a simpler low-resolution version of the 4D-Var system. But more research investigating case studies of extreme events will have to be performed before the final conclusions can be drawn on this subject.

The capturing of flow dependence for all three ensemble-based versions shown in Figure 2 is clearly visible. The smoothing property of using 50 members is also marked. Indeed, the amplitudes and structures are surprisingly similar for the low- and higher-resolution analysis system. This may well be due to the fact that all systems for these experiments used a T255 outer-loop resolution. It is at this stage and resolution that the observations are perturbed. The uncertainty information is also propagated in time with the same T255 model resolution.

The EDA is most beneficial for extreme events. As an example, consider the Category-3 Hurricane Emily on 20 July 2005 just before it made landfall in Mexico. Figure 3a shows the precipitation measured by the local weather radar. The EDA spread (i.e., the standard deviation of the ten, in this case T399 members) for zonal wind at approximately 850 hPa is given in Figure 3b. Typical standard deviations in the region would be 2–3 ms^{-1}, but the flow-dependent estimates from the EDA system yield standard deviations up to 13 ms^{-1}. Note that the spread is concentrated in the vicinity of Hurricane Emily, identified by the mean sea level pressure contours.

The ability of the EDA system to identify regions of large background error associated with extreme events has the potential to significantly improve quality control decisions and give higher weight to observations used in the analysis from such regions.

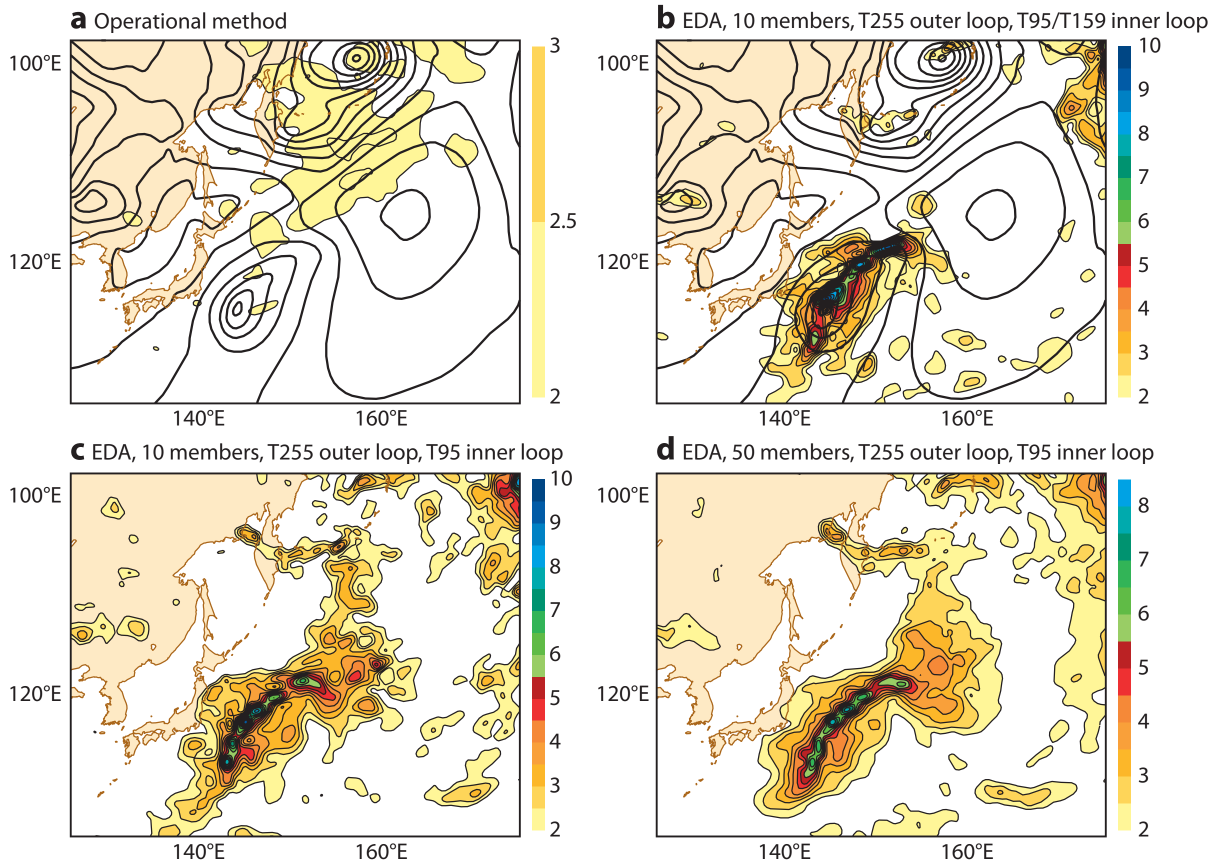

Figure 2 850 hPa zonal wind background error estimates valid at 00 UTC on 16 October 2006 for a baroclinic area near Japan. (a) The operational cycling randomization method (global max. 2.8 ms^{-1}). (b) The 10-member T255 outer loop with T95/T159 inner loop (global max. 13.8 ms^{-1}). (c) The 10-member T255 outer loop with T95 inner loop (global max. 13.9 ms^{-1}). (d) The 50-member T255 outer loop with T95 inner loop (global max. 12.0 ms^{-1}). Panels (b), (c) and (d) all use 2 times standard deviation of the ensemble members. The factor of two makes the average global EDA spread more realistic.

Deciding the operational configuration

It is important to note that the EDA system is designed to serve the needs of applications in the data assimilation system and the needs of the EPS. This has major implications for the design of the Ensemble of Data Assimilations that will become operational.

To be able to use the system to calculate background error statistics and estimate flow-dependent background errors, the EDA system must be designed to be sufficiently similar to the operational 4D-Var assimilation system. So it requires the same number of vertical levels (91 at present). The horizontal resolution cannot be significantly lower than the operational 4D-Var resolution in order to get a flow-dependent impact on extreme events and analysis uncertainty estimates that describe the operational 4D-Var system. Also, for reasons of consistency, a 4D-Var configuration in the EDA is preferable to a 3D-Var configuration.

When EDA products are used to calculate initial uncertainties for the EPS it will require vertical interpolation from 91 to 62 levels and horizontal interpolation from T399 to T639. It has been decided not to force the EPS and the EDA resolutions to be the same. This leaves more flexibility in the future system design of EPS and EDA. If the resolution of the EDA becomes an issue for the EPS the situation needs to be revisited. However, the computer codes have been designed to cater for any resolution change, as this may be required for research experiments or future operational configurations.

The performance and computing costs of a number of potentially suitable low-resolution configurations were investigated to choose an assimilation system that was close in skill to the operational system, but still significantly cheaper. The investigations described above, performed at T255, showed that a 10 member EDA system gave similar ensemble spread patterns to a 50-member EDA system, though with more noise. Because noise-filtering methods are available it was decided to choose 10 members for the initial operational implementation.

It was also seen that a higher-resolution outer loop was the main contributor to increased, more detailed ensemble spread and more accurate analysis uncertainty estimates. For the same inner-loop resolution, it was found that an increase in outer-loop resolution from T255 to T399 also improves the forecast scores significantly. The investigations showed that a T95 inner loop is not capable of representing tropical cyclones and other extreme events accurately. On the other hand, the use of a T255 inner loop added significant extra computing costs without a significant gain in EDA variance estimates.

It turned out to be more beneficial to increase the outer-loop resolution combined with use of a moderate inner-loop resolution. It should be kept in mind that because the EDA

a Radar image **b** Ensemble spread

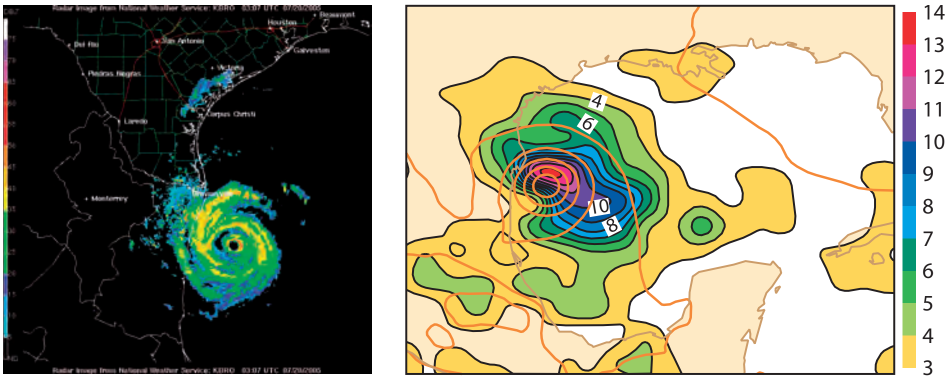

Figure 3 Atlantic hurricane Emily on 20 July 2005 near the coast of Mexico. (a) Radar image from National Weather Service. (b) Ensemble spread for zonal wind at 850 hPa near Hurricane Emily; the maximum value is 13.4 ms^{-1}. The mean sea level pressure contours are overlaid.

system only produces 15-hour forecasts (not 10-day forecasts) the cost of increasing the outer loop and forecast resolution from T255 to T399 is relatively small.

The operational EDA configuration

Based on these investigations it was decided to use the following configuration for the operational EDA system.

- The EDA system is run at T399L91 resolution with a control (unperturbed) analysis and 10 perturbed analyses.
- The analyses are 12-hour 4D-Var, with two minimizations, first at T95, then at T159 with advanced linearized physics.
- The EDA is run twice daily, with the midnight analyses using observations from 2101 UTC to 0900 UTC and the midday analyses using observations from 0901 UTC to 1500 UTC.
- The observations used are those which have already been extracted for the operational high-resolution delayed cut-off 12-hour 4D-Var analysis, so the EDA analyses can run as soon as these observations become available.
- Unperturbed observations are used for the control analysis, while the other members use observations which have been modified by a random perturbation which is proportional to the observation error.
- For Atmospheric Motion Vector (AMV) observations, the perturbations are horizontally correlated.
- Input sea surface temperature fields are perturbed using the same method as for the seasonal forecasts.

In the EDA it is important to represent model error to account for the fact that the forecast model is not perfect. To simulate the impact of model uncertainty, the stochastically perturbed parametrization tendency (SPPT) scheme is used; this perturbs the total parametrized tendency of physical processes. Positive results have also been obtained with the stochastic backscatter (SPBS) scheme that is based on the idea of backscatter of kinetic energy from unresolved scales (see *Palmer et al.*, 2009 for a review of ECMWF work on stochastic parametrization schemes). To date, however, the use of the SPPT scheme alone gave the best performance (work is in progress to assess the impact of also introducing a backscatter scheme).

On average, if the EDA spread is measured in terms of the 700 (850) hPa temperature standard deviation, the SPPT scheme increases the global average by 19% (23%), and if the EDA spread is measured in terms of the 700 (850) hPa the kinetic energy standard deviation is increased by 33% (39%).

It is interesting to see the geographical distribution of model error impact on short-range forecast uncertainty implied by the stochastic methods. Figure 4 shows the zonally averaged EDA spread for temperature (Figure 4a) and zonal wind (Figure 4b) valid on 14 October 2008 when SPPT is used. The impact of SPPT on the spread can be assessed by calculating the ratio of EDA spread from an experiment with SPPT applied compared to EDA spread from an experiment without model error parametrization. It is clear that the increase in spread due to SPPT is significant for both temperature (Figure 4c) and zonal wind (Figure 4d) throughout the atmosphere. The largest SPPT impact for temperature is at the top of the planetary boundary layer, especially in the stratocumulus regions. For wind the largest impact is near 700 hPa in the tropics. The SPBS only perturbs the wind field directly, so the increased spread in temperature (Figure 4e) is small. The increased wind spread for the SPBS scheme (Figure 4f) is mainly located in the planetary boundary layer, where the convection is most active. It is clear that the SPPT scheme provides more widespread perturbations than the SPBS. The larger level of spread looks reasonable and gives the best improvement of the EPS system.

Figure 4 confirms that the SPBS and SPPT methods complement each other, but the new tendency stochastic physics is the more effective of the two methods. Further testing will be performed with both methods applied. This is linked to the medium term goal of unifying the model error representations in the EPS and EDA.

Future developments

A well-designed EDA system will enable improved estimates of analysis uncertainty. This will be a potentially valuable output from the Centre's data assimilation system.

For the EDA, the short-term improvements will take account of horizontal correlations for radiance observation errors, use OSTIA instead of NOAA/NESDIS sea-surface temperatures (as already is the case in the operational 4D-Var), and improve the perturbations applied to the surface observations and parameters. Further investigations will be performed to assess the benefit of more ensemble members, various model error representations and different assimilation configurations. Finally, a significant effort is ongoing to develop and implement the use of flow-dependent background error in the deterministic 4D-Var system.

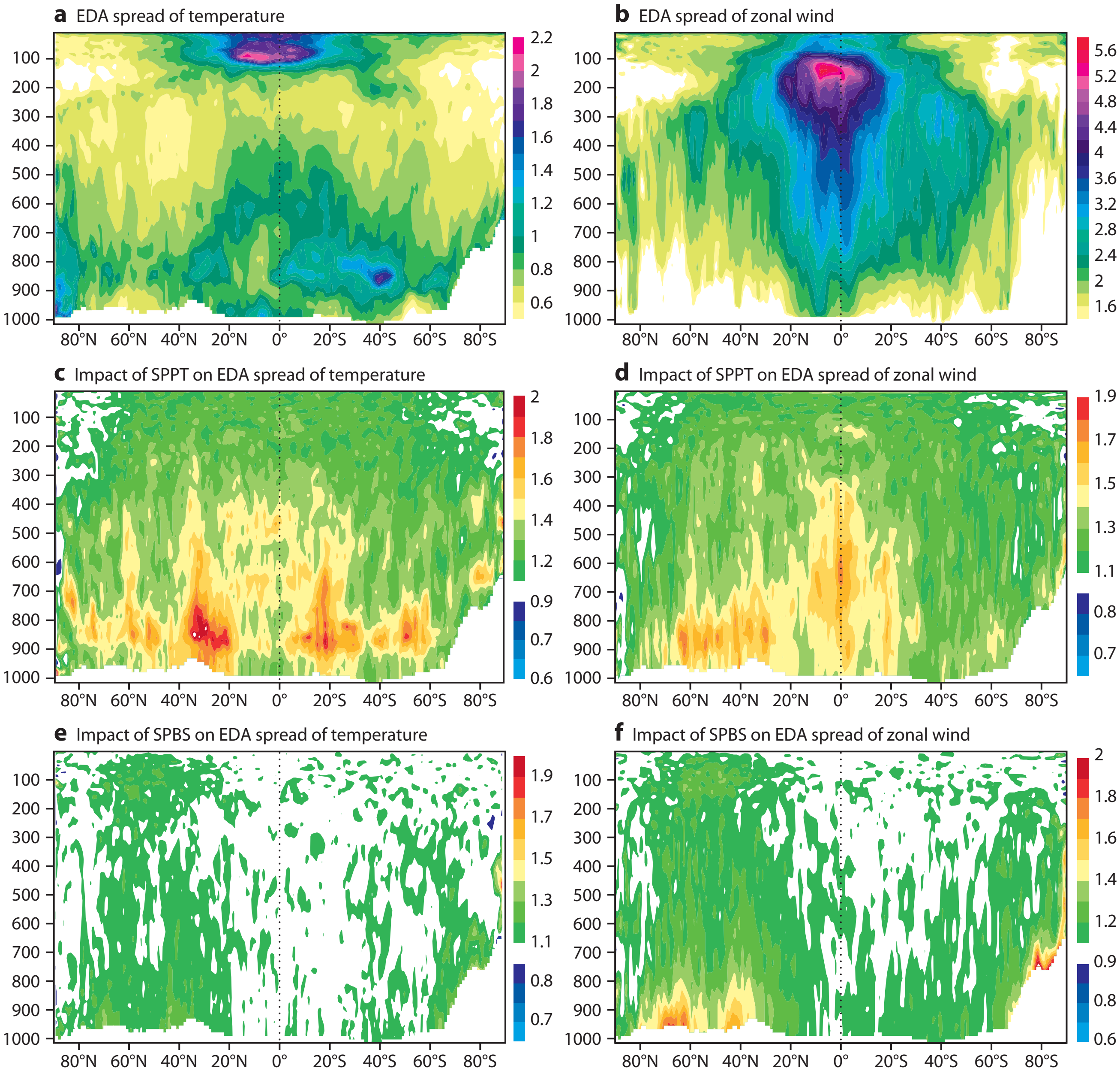

Figure 4 Impact of model error representation on EDA spread. Zonal mean values for (a) temperature and (b) zonal wind on 14 October 2008 using the operational SPPT configuration. The ratio of EDA spread for SPPT applied compared to EDA spread without model error parametrization for (c) temperature and (d) zonal wind. The same ratios for (e) temperature and (f) zonal wind when SPBS is used. As expected, the ratios are almost always greater than one.

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Combined use of EDA- and SV-based perturbations in the EPS

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THE SIMULATION of initial uncertainties is one of the key aspects in ensemble prediction. At ECMWF, since the implementation of the first version of the Ensemble Prediction System (EPS) in 1992, these uncertainties have been simulated with singular vectors (SVs), perturbations characterized by the fastest growth, measured using a total energy norm, over a finite time interval.

With the forthcoming implementation in cycle 36r2 of an Ensemble of Data Assimilations (EDA, see the companion article in this edition of the *ECMWF Newsletter*, pages 17 to 21), the methodology used to generate the EPS initial perturbations will be changed. EDA-based perturbations will replace evolved singular vectors in the generation of the EPS initial conditions. Following this change, the EPS initial perturbations will have a better geographical and vertical coverage than in the earlier system. This results in a better spread-skill relationship in the early forecast range over the extra-tropics, and for the whole forecast range over the tropics. Limited-area ensemble prediction systems (e.g. COSMO-LEPS) that use EPS initial and boundary conditions will benefit from this improvement. Over the tropics the substantial increase of the EPS spread leads to much smaller spread under-dispersion. In terms of skill, the EDA-SVINI configuration of the EPS has a higher skill than the earlier SV-based system everywhere.

This article briefly describes the new EDA-SVINI implementation and discusses some results.

The old SV-based EPS

In the old SV-based system (Figure 1a), the EPS initial perturbations are generated using SVs growing over two different time periods:

- Evolved SVs (EVO) growing optimally during the 48 hours leading to the analysis time represent uncertainties that are likely to contribute most to analysis errors.
- Initial-time SVs optimally growing during the first 48 hours of the forecast (SVINI) sample directions in phase space likely to contribute most to forecast uncertainty.

Practically, the SVs are computed separately over the northern and the southern hemisphere extra-tropics, and for up to six local regions in the tropics to improve the geographical sampling of the initial uncertainties. The initial-time and evolved SVs for the different areas are re-scaled to have initial amplitude comparable to the analysis error estimate given by the high-resolution data-assimilation system. The background research that lead to ECMWF's SV-approach to simulating initial uncertainty is briefly summarized in Box A, and more detailed information about the configuration used to compute the SV component is given in Box B.

Replacement of the evolved SVs with EDA-based perturbations in the EPS

Buizza et al. (2008), who discuss in details the rationale behind the proposed change, have shown that replacing the

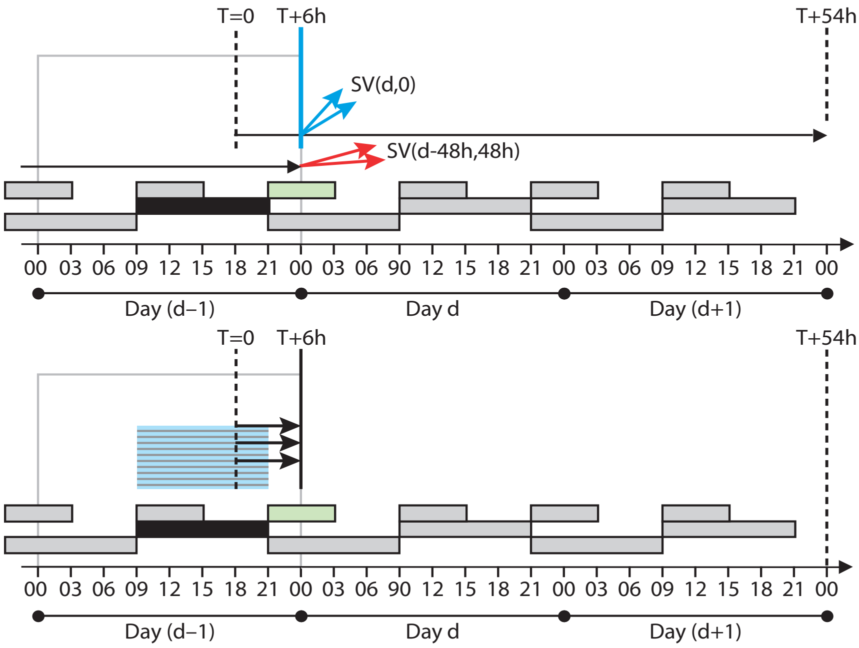

Figure 1 (from *Buizza et al.*, 2008). Schematic of the configuration used to generate the EPS initial conditions at 00 UTC. (a) The 12-hour-long black and grey boxes mark the time window of the 12-hour 4D-Var; while the 6-hour-long dark-grey and grey boxes for 21–03 UTC and 09–15 UTC mark the time window of the early-delivery 6-hour 4D-Var. The EPS unperturbed analysis at 00 UTC is defined by the 6-hour 4D-Var analysis generated by the early-delivery suite (green box). The evolved *SV(d-48h,48h)* (red vectors) are computed from 00 UTC of day *(d-2)*, and the initial-time *SV(d,0)* (blue vectors) are computed from 00 UTC of day d. The trajectory along which the *SV(d,0)* grow starts from the +6-hour forecast initiated at 18 UTC of day *(d-1)*, and the trajectory along which *SV(d-48h,48h)* grows starts from the +6-hour forecast initiated at 18 UTC of day *(d-3)*. (b) The EDA members used at day *d* (blue box with black lines) are generated by 12-hour 4D-Var cycles running between 09 UTC and 21 UTC of day *(d-1)*.

A

ECMWF's SV-approach to simulating initial uncertainty

The ECMWF SV-approach to simulating initial uncertainty using SVs was inspired by earlier work by, among others, *Lorenz* (1965) and *Farrell* (1990), who showed that these type of perturbations dominates the system dynamics over a finite time-interval. It is worth also quoting the work of *Ehrendorfer & Tribbia* (1997), who showed that if the objective of an ensemble system is the optimal prediction of the forecast error covariance matrix (optimal in the sense of maximum possible fraction of forecast error variance), then the singular vectors constructed using covariance information at the initial time constitute the most efficient means for predicting the forecast error covariance matrix. *Palmer et al.* (1998) discussed the issue of the impact of the norm definition on the SVs, and argued that the total energy norm used in the ECMWF system is a good approximation of the covariance matrix mentioned by Ehrendorfer & Tribbia.

evolved SVs with EDA-based initial perturbations leads to a better ensemble system. In the new EDA-SVINI configuration (Figure 1b):

- EDA-based perturbations are used instead of the evolved SVs to represent uncertainties that have been growing during the data assimilation cycles.
- Initial-time SVs optimally growing during the first 48 hours of the forecast (SVINI) were used to sample directions likely in phase space to contribute most to forecast uncertainty.

The EDA perturbed members are generated by (a) perturbing all observations and the sea-surface temperature field and (b) using the stochastically perturbed parametrization tendency (SPPT) scheme that perturbs the total parametrized tendency of physical processes to simulate random model error. More details on the EDA methodology can be found in the companion article by *Isaksen et al.* published in this edition of the *ECMWF Newsletter*,

In this new EDA-SVINI configuration, the EPS initial conditions are defined by adding to the unperturbed analysis an EDA-based perturbation and a linear combination of initial-time SVs. The initial-time SV component is identical to the one that was used in the old EVO-SVINI configuration except for a reduction of the amplitude by 10%. This reduction of the SVINI component is needed to achieve a better spread-skill relationship since the EDA-based perturbations have larger amplitude than the EVO component.

Each EDA-based initial perturbation is defined by the difference between one perturbed and the un-perturbed 6-hour forecasts (the first-guess) started from the previous EDA cycle (i.e. from the EDA 4D-Var analyses run during the 12-hour period preceding the most recent analysis used to generate the unperturbed analysis). The EDA-based perturbations are symmetric, thus the EPS initial perturbations are still symmetric in the new configuration.

The reason why differences between 6-hour first guesses from the preceding EDA assimilation cycle are used instead of differences between analyses, is that the EDA suite runs with a 12-hour delayed mode to achieve a timely dissemination of the EPS products. Earlier experimentation compared ensemble forecasts using EDA-based perturbations defined by analyses and perturbations defined by 6-hour forecasts from the preceding cycle. Published (*Buizza et al.*, 2008) and recent results indicated that the use of 6-hour forecast perturbations instead of analyses perturbations does not degrade the probabilistic skill of the EPS. It should be pointed out that the EDA-based perturbations are also added to the upper-level specific humidity component of the unperturbed initial conditions (this variable was not perturbed in the old EVO-SVINI configuration). The reader is referred to *Buizza et al.* (2008) for a more detailed discussion of the similarity and differences between the old SV-based and the new EDA-based configurations.

Replacement of the evolved SVs with EDA-based perturbations in the EPS re-forecast suite

Since March 2008, when the 15-day variable resolution ensemble was merged with the monthly prediction system, a key component of the EPS system has been the EPS re-forecast suite (*Hagedorn*, 2008; *Hagedorn et al.*, 2010). The EPS re-forecast suite is based on a 5-member ensemble starting from ERA-Interim analyses, and run for the same calendar day of the past 18 years. These 90 forecasts are used operationally to generate monthly anomaly products

B

The old EVO-SVINI configurations of the EPS

In the old EVO-SVINI configuration, the initial conditions are defined by adding to the unperturbed analysis a linear combination of initial-time and evolved SVs. To optimize the use of computational resources, SVs for any specific day/time are computed along a forecast trajectory, defined by the 6-to-54 hour forecast starting from a 6-hour earlier analysis (see *Leutbecher*, 2005 for more information).

For the EPS starting at time t, the initial-time SVs are the initial-time (t=0) SVs computed along a 6-to-54 hour forecast starting at t= –6 h. The evolved SVs are the final-time (t+48 h) SVs computed along a 6-to-54 h forecast starting at t= –54 h. The initial perturbations are symmetric, with the EPS even members having the opposite sign perturbation of the odd members. The coefficients that determined the linear combination and the amplitude of the SVs are computed using a Gaussian sampling method.

Over the extra-tropics (northern and southern hemispheres) the 50 leading initial-time and extra-tropical SVs are used, and over the tropics only the 5 leading initial-time SVs for each tropical target area are used (see *Leutbecher & Palmer*, 2008 for details). These perturbations are added only to the temperature and wind component of the model state vector, and to the surface pressure (no perturbations are added to the specific humidity or to any surface field). In the new EDA-SVINI configuration of the EPS only the initial-time SVs are used.

Initial conditions			EPS forecasts day 0–15/32	
Unperturbed analysis	SV-based initial perturbations	EDA-based initial perturbations	Leg A (day 0–10)	Leg B (day 10–15/32)
T639L62 (interpolated from T1279L91 operational analysis)	T42L62	T399L62 analyses interpolated from the T399L91 analyses	T639L62	T319L62

Table 1 Resolution of the components used to generate the EPS initial conditions and produce the EPS forecasts since 26 January 2010.

and to compute EPS products such as the Extreme Forecast Index (to be more precise, the EFI uses 450 forecasts, i.e. the 90 re-forecasts starting on the 5 weeks centred on the current day).

The new EDA-SVINI configuration will be used also for the re-forecast suite, but since the EDA has not been run for the past years, the re-forecast suite has to use the EDA-based perturbations computed for the current year. More precisely, since the re-forecasts are run up to 2-weeks in advance, the re-forecasts for any specific day for the past 18 years use the EDA-based perturbations from the current year minus 14 days. Extensive experimentation has indicated that the EDA-SVINI re-forecast EPS, despite using EDA perturbations from another year, has spread and skill characteristics closer to the real-time EPS than the old EVO-SVINI re-forecast EPS (not shown).

Comparison of the old EVO-SVINI and the new EDA-SVINI EPS configurations

It is worth noting that since 26 January 2010, the EPS has been running with a T639L62 (spectral triangular truncation at wave-number 639 with a linear grid and 62 vertical levels) resolution between day 0 and 10, and with T319L62 resolution from day 10 to day 15 (day 32 at 00 on Thursdays) – this is referred to as the 639v319 EPS. Table 1 summarizes the resolution of the key components of the EDA-SVINI configuration of the EPS that will become operational with model cycle 36r2 (the re-forecast suite has the same characteristics, but it includes only 4 instead of 50 perturbed members).

EPS initial perturbations

The replacement of the evolved SVs with EDA-based perturbations has a large impact on the EPS initial perturbations As an example, Figure 2 shows the initial perturbations in terms of temperature and the zonal wind component at 700 hPa for one randomly-chosen member, member number 5, of the EVO-SVINI (left panels) and the EDA-SVINI (right panels) ensembles started on 1 December 2009. Also Figure 3 shows the corresponding results for a vertical cross section. The EDA-SVINI perturbations are less localized geographically and in the vertical and provide a better coverage of the globe. This is true especially over the tropics which were sampled (by design) only in a limited fashion by the initial perturbations of the old EVO-SVINI system.

The EDA-based perturbations, computed at T399 resolution, have smaller scales than T42 SV-based perturbations

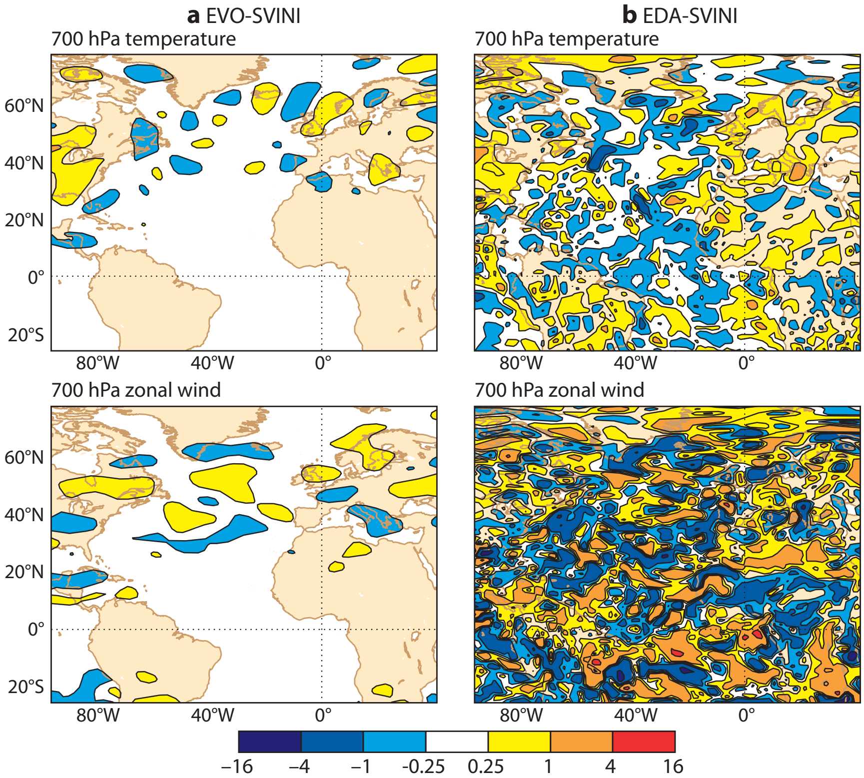

Figure 2 Initial-time perturbation of EPS member number 5 of (a) EVO-SVINI and (b) EDA-SVINI started at 12 UTC on 1 December 2009, in terms of the 700 hPa temperature (top panels) and the 700 hPa zonal wind (bottom panels).

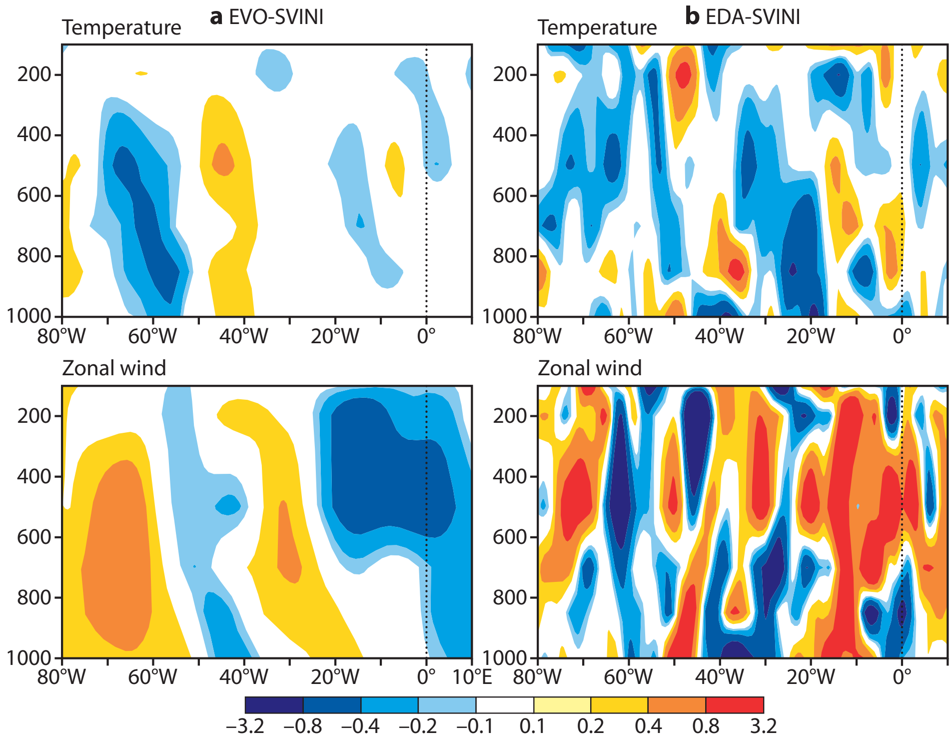

Figure 3 As Figure 2 but for a vertical cross section at latitude 50°N between 80°W and 10°E of the perturbation of EPS member number 5 of (a) EVO-SVINI and (b) EDA-SVINI at 12 UTC on 1 December 2009, in terms of temperature (top panels) and zonal wind (bottom panels).

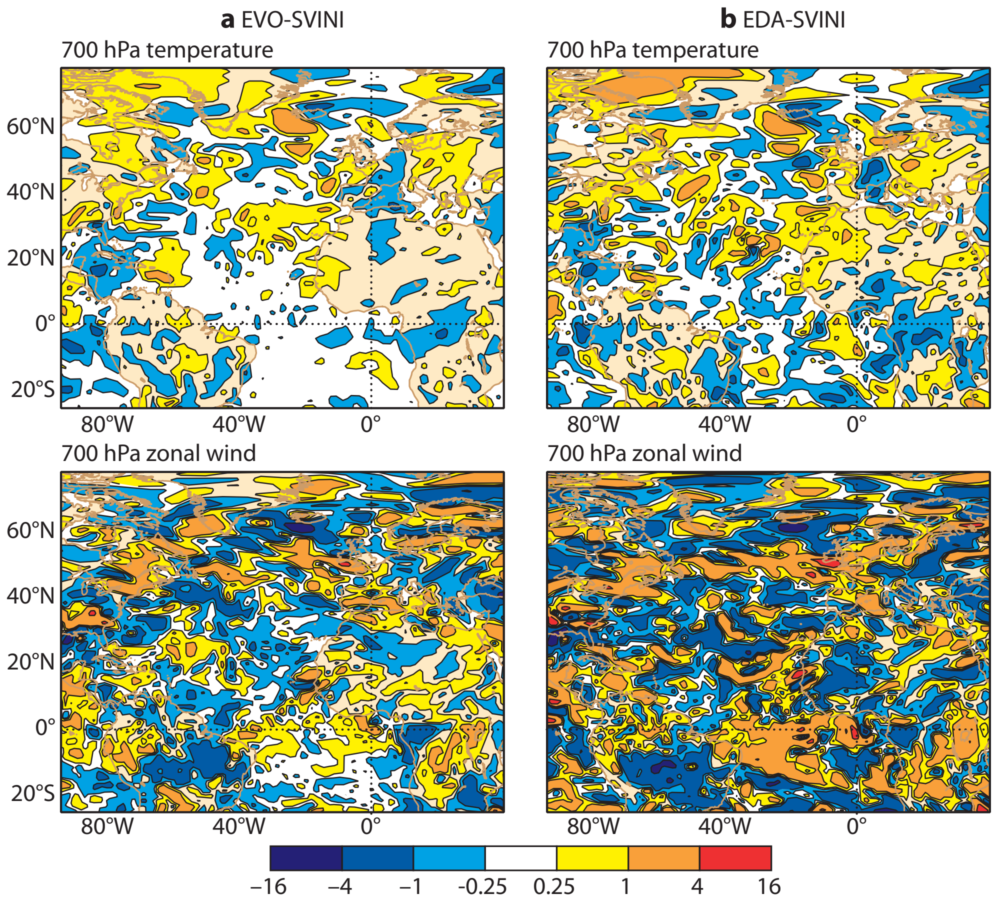

Figure 4 As Figure 2 but for the t+24 hour perturbation of EPS member number 5 of (a) EVO-SVINI and (b) EDA-SVINI started at 12 UTC on 1 December 2009, in terms of the 700 hPa temperature (top panels) and the 700 hPa zonal wind (bottom panels).

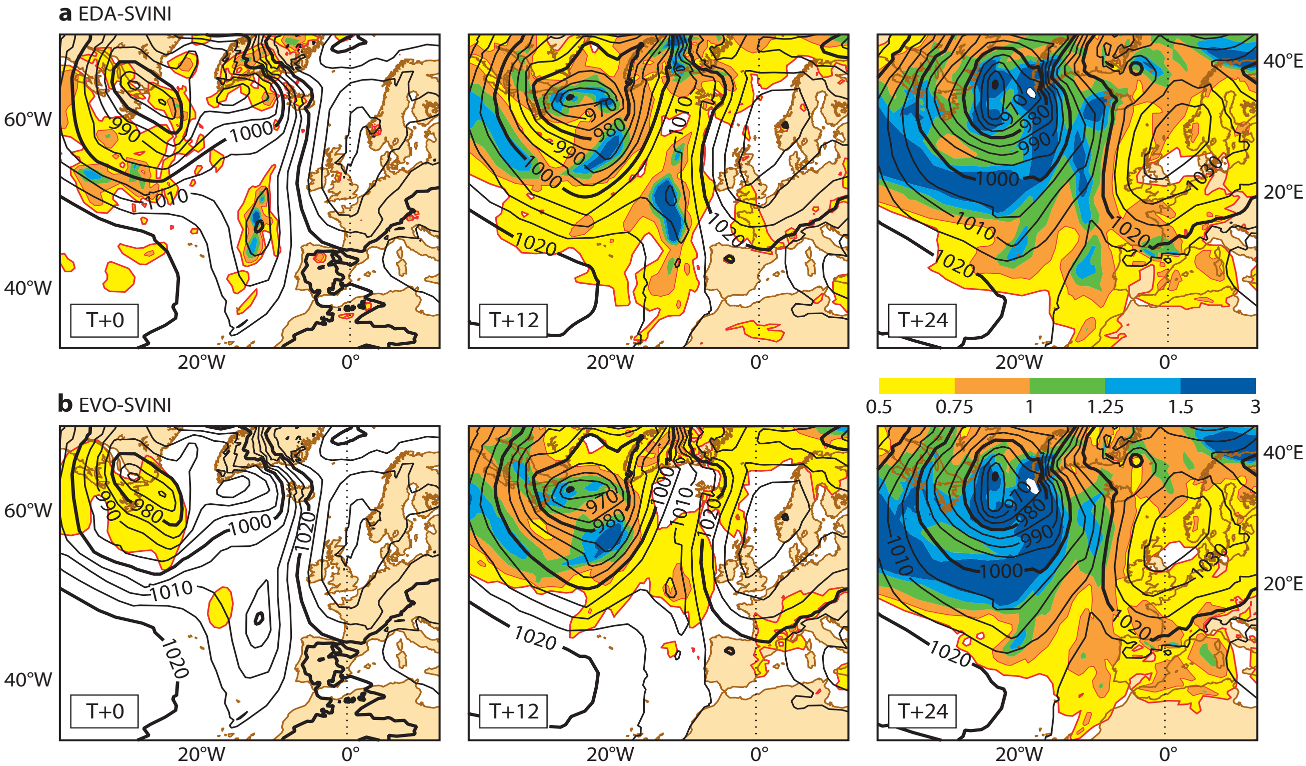

Figure 5 Ensemble-mean (black contours) and standard deviation (coloured shading) in terms of mean-sea-level-pressure (MSLP) of (a, top panels) EDA-SVINI and (b, bottom panels) EVO-SVINI ensembles at initial time (left panels), at T+12 hour (middle panels) and at T+24 hour (right panels) for EPS forecasts started on 11 December 2009. The contour interval for the ensemble-mean fields is 5 hPa; the shading for the standard deviation is for 0.5, 0.75, 1.0, 1.25, 1.50 and 3 hPa.

and a less evident vertical tilt with height. In addition, the EDA-based perturbations grow slower than SV-based perturbations, which explains why an ensemble with only EDA-based initial perturbations would have too little spread and a poorer performance than an EDA-SVINI ensemble (see *Buizza et al.*, 2008). By contrast, the blend of EDA-based perturbations and the initial-time SVs combines the benefits of both sets of diverse perturbations, and provides a superior performance to EVO-SVINI.

The effect of the modified initial perturbations is detectable over the extra-tropics during the first 48 hours and over the tropics for the first week. The EDA-SVINI perturbations start with a larger initial amplitude than the EVO-SVINI perturbations but after 24 hours their amplitude is close to the amplitude of the EVO-SVINI perturbations, especially over the extra-tropical regions where the SVINI component starts dominating the perturbation growth (Figure 4). This is the reason why from this forecast time on, in the regions sampled by initial-time SVs, the perturbations from the two ensembles have similar structures (e.g. south-east of Greenland (20°W, 60°N) or south-east of Cuba (60°W, 10°N)). But in the regions not sampled by the initial-time SVs (e.g. over most of the tropics) the EDA-SVINI initial perturbations provide a better geographical coverage. After 48 hours, over the extra-tropics the difference becomes, on average, smaller and gradually disappears in the medium-range (say around forecast day 7).

Member States' users of EPS initial and boundary conditions for limited area ensemble prediction systems over Europe will benefit from the increased spread over the extra-tropics in the early forecast range. This can be seen in Figure 5; this example shows the ensemble spread at initial time and at T+12 and T+24 hours for the EPS started at 12 UTC on 11 December 2009. The EDA-SVINI has a larger initial spread at 20°W where the EDA perturbed analyses differ slightly in the positioning and intensification of a low-pressure system, which propagates in time and leads to larger spread at T+24 hours west of Spain.

EPS spread and skill characteristics

The difference in the characteristics (amplitude, scale, growth rate, coverage) of the initial-time perturbations affects the average ensemble spread, as can be seen in Figure 6. This shows the 10-day average (forecasts with initial date from 1 to 19 December 2009, every other day) spread of the EVO-SVINI and the EDA-SVINI ensembles in terms of the 850 hPa temperature and the 700 hPa kinetic energy. The EVO-SVINI initial perturbations (left panels) are much more localized and have a smaller amplitude than the EDA-SVINI initial perturbations (right panels).

Figure 7 shows the average impact on 639v319 ensemble forecasts of the 850 hPa temperature, based on the comparison of EVO-SVINI and EDA-SVINI initial perturbations for 88 cases (from 5 October to 31 December 2009). As already mentioned in the introduction, in the EDA-SVINI ensemble, the amplitude of the SVINI perturbations has been decreased by 10% to improve the spread and skill relationship.

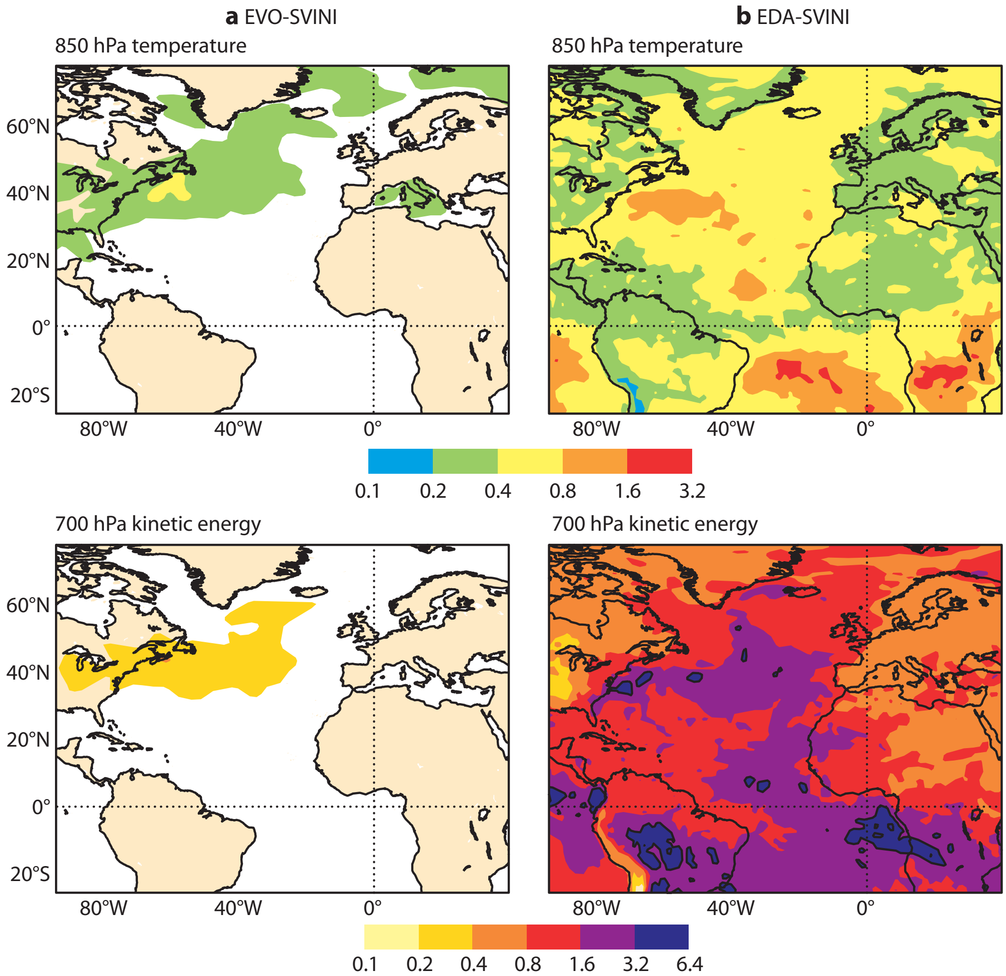

Figure 6 Ensemble spread: 10-case average (1 to 19 December 2009, every 2 days) standard deviation at initial time of an (a) EVO-SVINI ensemble and (b) EDA-SVINI ensemble, measured in terms of the 850 hPa temperature (top panels, K) and the 700 hPa kinetic energy (lower panels, ms^{-1}).

The EDA-SVINI ensemble has, on average, a better-tuned ensemble spread and a higher skill. Over the extra-tropics, there is a clear increase in ensemble spread during the first 48 hours: this reduces the spread under-estimation of the old ensemble system by about 50%. There is also a small positive impact on the error of the ensemble-mean and on the skill of probabilistic scores measured by the continuous rank probability skill score (CRPSS): although small, differences are statistically significant at the 5% level up to forecast day 6 over the northern hemisphere, and up to forecast day 10 over the southern hemisphere.

The positive impact on the ensemble spread and skill is more evident over the tropics, where the use of the EDA-based perturbations has a large impact on the ensemble spread. Over this region, the EDA-SVINI ensemble-mean has a smaller root-mean-square-error that is statistically significant (at the 5% level) and the probabilistic forecast has a higher continuous ranked probability skill score up to forecast day 9.

Similar conclusions can be drawn from other probabilistic accuracy measures, such as the area under the relative operating characteristic curve or the Brier skill score (not shown).

Future developments of the EPS

Work will continue in four key areas to further improve the skill of the EPS:

- ***EDA membership***: the potential benefit of using a larger ensemble of perturbed analyses (25 or 50 instead of 10) will be assessed.
- ***EDA-based land-surface perturbations***: spread of the EPS in the boundary layer and for surface variables will be assessed more thoroughly, and the potential use of EDA-based perturbations to perturb surface variables (e.g. soil moisture and soil temperature) will be investigated.
- ***Combination of EDA- and SV-based perturbations***: possible ways to combine the EDA- and the SV-based perturbations different from the one implemented in the EPS will be explored, with the final aim to provide a better tuned and more skilful ensemble system for the entire forecast range and for the whole vertical structure of the atmosphere.
- ***Stochastic model error***: revised and new stochastic schemes are under final development and will be tested in the EPS and the EDA to improve the simulation of model uncertainties.

Progress in these areas will be reported in due course.

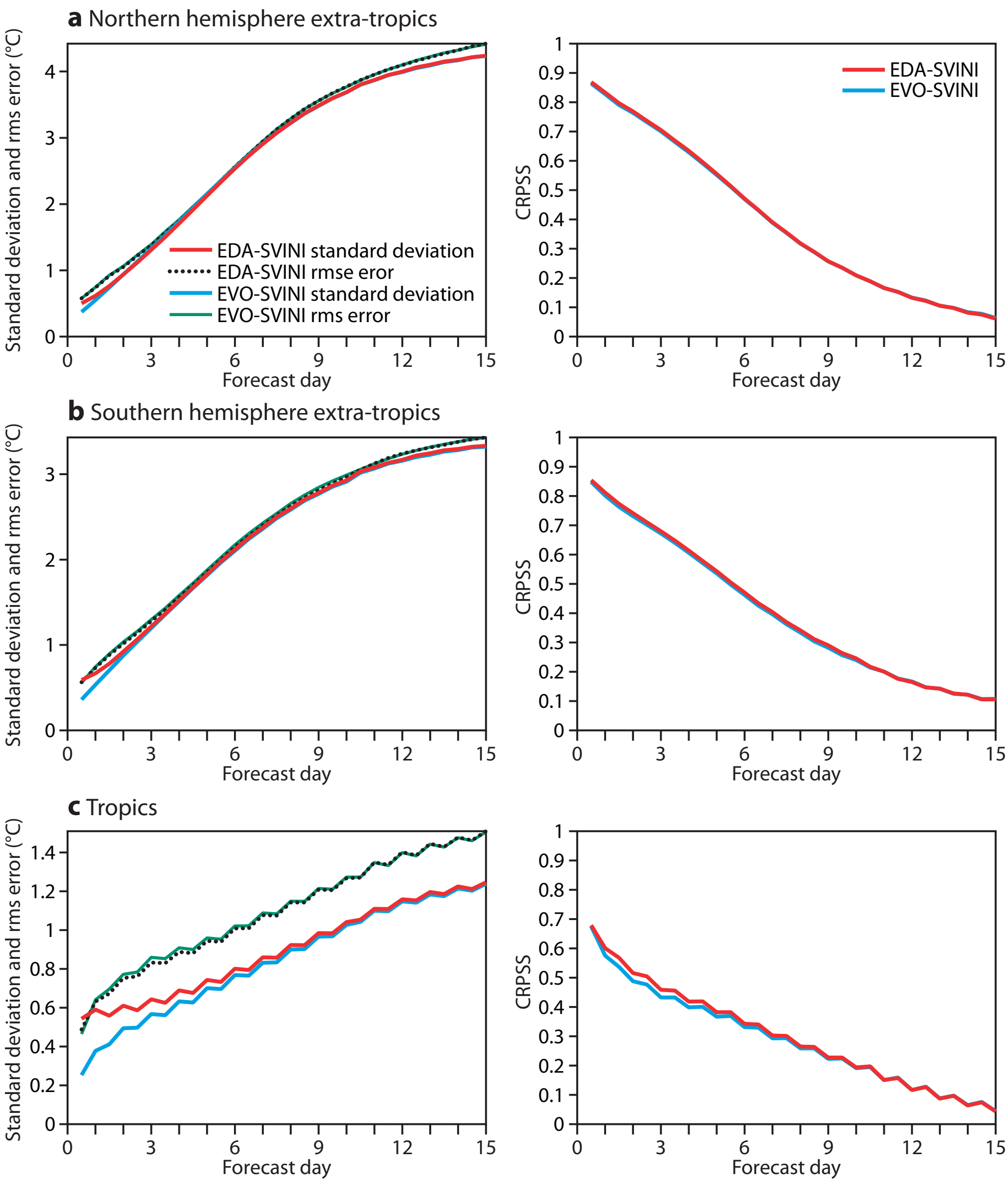

Figure 7 Average (88 cases from 5 October to 31 December 2009) statistics for the 850 hPa temperature over (a) northern hemisphere extra-tropics, (b) southern hemisphere extra-tropics, and (c) tropics. Left: root-mean-square error of the ensemble-mean forecast of the EDA-SVINI and the EVO-SVINI ensembles, and standard deviation of the EDA-SVINI and the EVO-SVINI line) ensembles. Right: continuous rank probability skill score (CRPSS) of the EDA-SVINI and the EVO-SVINI ensembles.

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Update on the RMDCN

THE RMDCN TEAM
(AHMED BENALLEGUE, TONY BAKKER, RÉMY GIRAUD)

2009 HAS been a busy year for the RMDCN (Regional Meteorological Data Communications Network). In October 2008 the TAC Subgroup on the RMDCN reported to the ECMWF's Technical Advisory Committee (TAC) on its findings of the investigations concerning the future of the RMDCN. The TAC considered the report and concluded that the current contract for the provision of the RMDCN service represented good value for money and that, at this stage, an invitation to tender is not recommended. It also recommended a limited expansion of the RMDCN to countries outside WMO Regional Association (RA) IV and an upgrade of the basic RMDCN package. The ECMWF Council, at its 70th meeting in December 2008, unanimously agreed to the following.

(a) The ECMWF funded RMDCN basic package for Member States will be upgraded to the following configuration.

- Mission Critical set-up with 2 Mbps access lines.
- 1.5 Mbps IP (Internet Protocol) bandwidth.
- Service management and help desk charges.
- Redistribution charges (where applicable).

(b) The following categories of countries will be considered as potential future members of the RMDCN.

- ECMWF Member States and Co-operating States.
- RA VI countries not currently connected to the RMDCN.
- Countries operating MTN (Main Telecommunications Network) centres in the framework of the IMTN (Improved Main Telecommunications Network), including future Global Information System Centres.

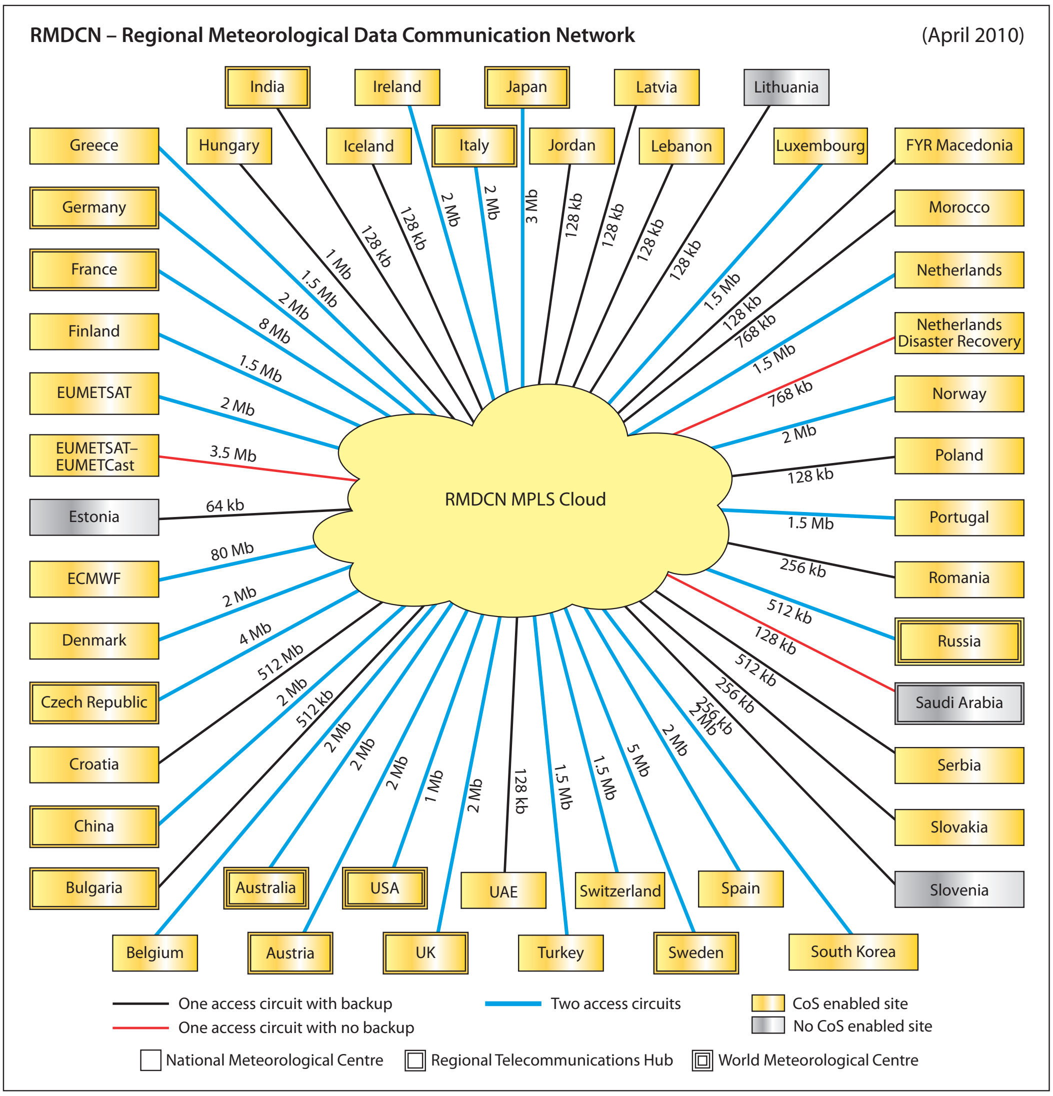

Figure 1 RMDCN configuration in April 2010.

◆ Countries outside RA VI connected to a RA VI country as part of the Global Communications Network (GTS), upon request by the RA VI country concerned.

Basic package upgrade

The 2008 Price Review resulted in a considerable reduction of the charges. The TAC Subgroup proposed to reinvest these savings and upgrade the basic package of ECMWF Member States connections which is funded out of the ECMWF budget. It was agreed that the connections should be upgraded to a Mission Critical set-up (i.e. a diverse dual connection) with an access circuit speed of 2 Mbps and an IP bandwidth speed of 1.5 Mbps. Consequently the connection of ECMWF was upgraded from 50 Mbps to 80 Mbps IP bandwidth. In addition, ECMWF Member States that already have connections at 1.5Mbps or higher were asked if they wished to reinvest the savings to increase their connections. Table 1 shows the current configurations for the ECMWF Member States.

Changes for other ECMWF Member States and Co-operating States

Sweden investigated various options for the upgrading of its RMDCN connection. Following discussions with ECMWF and OBS (Orange Business Services, the operator of the network) regarding diversity implications, Sweden ordered an upgrade to 5 Mbps IP bandwidth. This upgrade was implemented in March 2010.

Météo-France replaced their RETIM (satellite broadcasting system) service with a EUMETCast-based (EUMETSAT's broadcast system for environmental data) solution and requested an upgrade of its connection to 8 Mbps. This also required the installation of an RMDCN connection to Usingen, Germany, where the ground station for the EUMETCast service is located. This site was connected with a speed of 3.5 Mbps. The upgrade for Météo-France and the installation of the connection in Usingen were completed in October 2009.

When Morocco became a Co-operating State of ECMWF it started investigating a connection to the RMDCN in order

Country/Site	Access Speed (bps)	IPVPN Port Speed (bps)	Resiliency	CoS	Load Balancing	NAS Backup Speed (bps)
Austria	2M	2M	Mission Critical	Gold	No	N/A
Belgium	2M	2M	Mission Critical	Gold	No	N/A
Denmark	2M	2M	Mission Critical	Gold	No	N/A
ECMWF	100M	80M	Mission Critical	Gold	Yes	N/A
Finland	2M	1.5M	Mission Critical	Gold	No	N/A
France	8M	8M	Mission Critical	Gold	No	N/A
Germany	2M	2M	Mission Critical	Gold	No	N/A
Greece	2M	1.5M	Mission Critical	Gold	No	N/A
Ireland	2M	2M	Mission Critical	Gold	No	N/A
Italy	2M	2M	Mission Critical	Gold	No	N/A
Luxembourg	2M	1.5M	Mission Critical	Gold	No	N/A
Netherlands	2M	1.5M	Mission Critical	Gold	No	N/A
Netherlands-DR	2M	768k	N/A	Gold	No	N/A
Norway	2M	2M	Mission Critical	Gold	No	N/A
Portugal	2M	1.5M	Mission Critical	Gold	No	N/A
Spain	2M	2M	Mission Critical	Gold	No	N/A
Sweden	8M	5M	Mission Critical	Gold	No	N/A
Switzerland	2M	1.5M	Mission Critical	Gold	No	N/A
Turkey	2M	1.5M	Mission Critical	Gold	No	N/A
United Kingdom	2M	2M	Mission Critical	Gold	No	N/A

Table 1 RMDCN configuration for ECMWF Member States at April 2010 (Member States with orange background were upgraded to a Mission Critical configuration as part of the Basic Package Upgrade). ***Access Speed***: Speed of the physical connection to the network. ***IPVPN Port Speed***: IP Bandwidth available. ***CoS***: Class of Service (Gold: three Classes of Service defined, Silver: one Class of Service). ***Load Balancing***: Possibility of using the two physical connections to share the traffic load. ***NAS Backup Speed***: Speed of the available backup using ISDN.

Country/Site	Access Speed (bps)	IPVPN Port Speed (bps)	Resiliency	CoS	Load Balancing	NAS Backup Speed (bps)
ECMWF Co-operating States						
Croatia	512k	512k	Enhanced	Gold	No	256k
Czech Republic	6M	4M	Mission Critical	Gold	No	N/A
Estonia	64k	64k	Enhanced	Silver	No	64k
EUMETSAT	2M	2M	Mission Critical	Gold	No	N/A
EUMETSAT-EUMETCast	4M	3.5M	N/A	Gold	No	N/A
Hungary	1M	1M	Enhanced	Gold	No	256k
Iceland	128k	128k	Enhanced	Gold	No	128k
Latvia	128k	128k	Enhanced	Gold	No	128k
Lithuania	128k	128k	Enhanced	Silver	No	128k
Morocco	1M	768k	Enhanced	Gold	No	128k
Romania	2M	256k	Enhanced	Gold	No	128k
Serbia	512k	512k	Enhanced	Gold	No	256k
Slovakia	256k	256k	Enhanced	Silver	No	128k
Slovenia	256k	256k	Enhanced	Gold	No	256k
Other States						
Australia	2M	2M	Mission Critical	Gold	No	N/A
Bulgaria	512k	512k	Enhanced	Gold	No	128k
China	2M	2M	Mission Critical	Gold	No	N/A
FYR Macedonia	128k	128k	Enhanced	Gold	No	128k
India	128k	128k	Enhanced	Gold	No	128k
Japan	10M	3M	Mission Critical	Gold	Yes	N/A
Jordan	128k	128k	Enhanced	Gold	No	128k
Lebanon	128k	128k	Enhanced	Gold	No	128k
Poland	128k	128k	Enhanced	Gold	No	128k
Russian Federation	512k	512k	Mission Critical	Gold	No	N/A
Saudi Arabia*	512k	128k	Enhanced	Silver	No	N/A
South Korea	2M	2M	Mission Critical	Gold	No	N/A
United Arab Emirates	128k	128k	Enhanced	Gold	No	64k
USA	1M	1M	Mission Critical	Gold	No	N/A

* Saudi Arabia does not yet have a backup connection in place. Please also note that from March 2010 the connection to Saudi Arabia has been suspended.

Table 2 RMDCN configuration for ECMWF Co-operating States and other states at April 2010. The corresponding configuration for ECMWF Member States is given in Table 1. ***Access Speed***: Speed of the physical connection to the network. ***IPVPN Port Speed***: IP Bandwidth available. ***CoS***: Class of Service (Gold: three Classes of Service defined, Silver: one Class of Service). ***Load Balancing***: Possibility of using the two physical connections to share the traffic load. ***NAS Backup Speed***: Speed of the available backup using ISDN.

to receive ECMWF dissemination products and also to replace its private circuit to Météo-France. Following discussions with ECMWF and Météo-France, Morocco requested a 768 kbps connection to the RMDCN and a 128 kbps ISDN Backup in October 2009. The installation was finalized in April 2010.

EUMETSAT is currently investigating upgrades of its mission critical connection currently limited to 2 Mbps.

New connections

Until September 2009, part of the IMTN (Improved Main Telecommunication Network) was using a Frame Relay network provided by BT (British Telecom) to interconnect USA, Australia, UK and Japan. As this service has been terminated by BT, the countries not yet connected to the RMDCN decided to apply for membership. Hence, USA and Australia are now connected on the RMDCN:

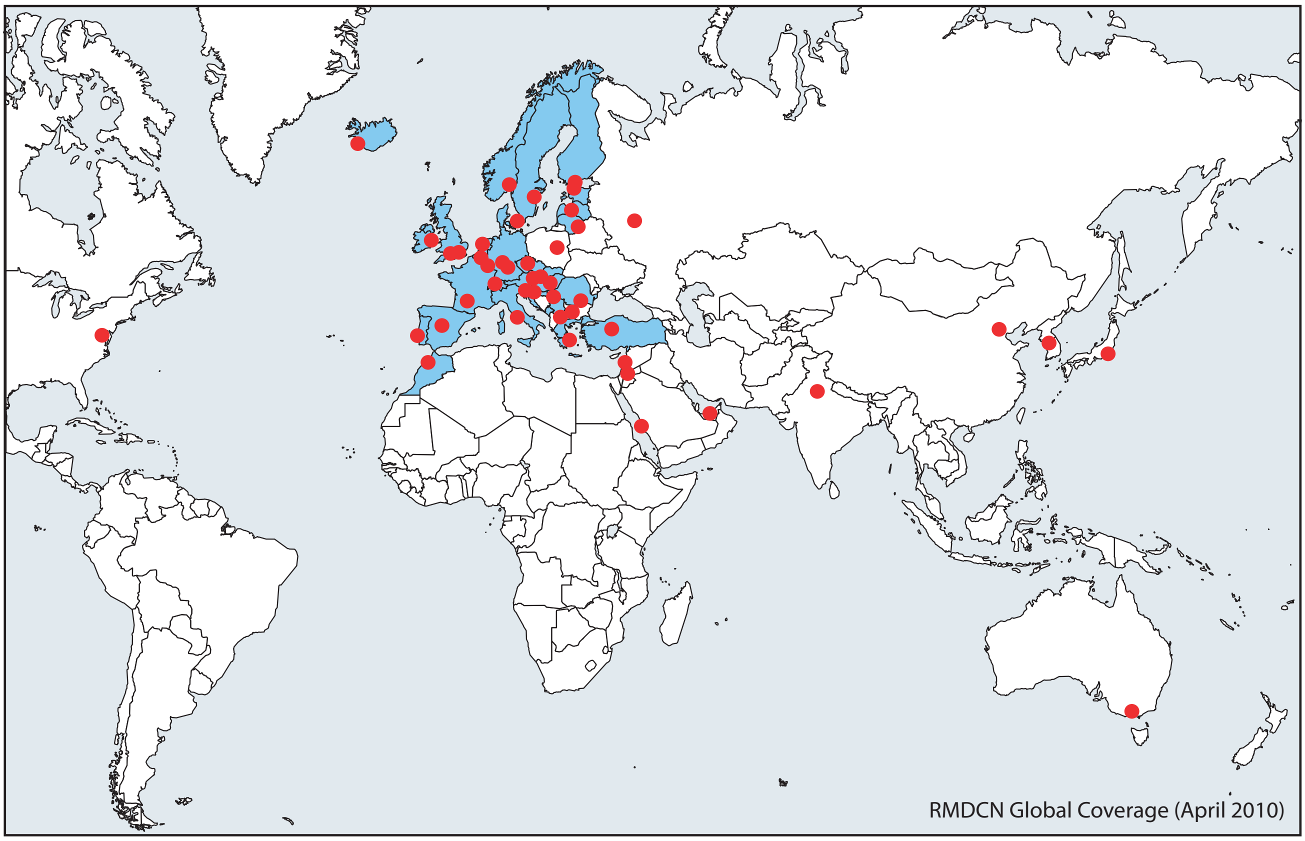

Figure 2 RMDCN global coverage in April 2010.

- USA, with a 1.5 Mbps mission critical connection, was connected in September 2009.
- Australia, with a 2 Mbps mission critical connection, was connected in October 2009.

Consequently, Japan upgraded its connection to 3 Mbps in September 2009. China also ordered an upgrade of its connection to 3 Mbps IP bandwidth.

In July 2009 ECMWF received formal requests from two countries outside RA IV, Canada and South Korea, to join the RMDCN. Both requests were supported by the United Kingdom. South Korea then ordered the installation of a 2 Mbps IP bandwidth mission critical connection. This was completed on 7 December 2009. Canada has not yet decided which type of connection it would like to establish.

Future developments

From April 2010 there are now 48 sites connected to the RMDCN. These are 44 National Meteorological Centres (NMCs), 1 NMC disaster recovery site, EUMETSAT (HQ and EUMETCast uplink site) and ECMWF. The current configuration is detailed in Tables 1 and 2. And the current geographical coverage of the RMDCN can be seen in Figure 2.

In the near future, new countries should join the RMDCN. South Africa has been investigating a connection to the RMDCN for quite some time. After extensive discussions with ECWMF and the UK Met Office, South Africa has now started the process of requesting membership to the RMDCN and is discussing the details of the Accession Agreement with OBS. Preliminary discussions have also started with Brazil.

Lastly, the DMVPN project, which investigated the use of Dynamic Multipoint Virtual Private Network connections over the Internet for providing a backup of the RMDCN connections, was a success. It provides a good, scalable and secure alternative backup method for the RMDCN. The RMDCN Operations Committee agreed to continue the project and start a large scale operational pilot open to all members of the RMDCN. The service went operational on 1 February 2010 with ECMWF and Sweden (acting as the DMVPN backup hub). Various NMCs (Bulgaria, Norway, Romania and Italy) have already shown an interest and it is expected that the first connections for this service will soon be established.

Since the migration to MPLS (Multi Protocol Label Switching) completed in June 2007, the RMDCN has changed a lot. With many more countries, implementation of more resilient solutions and higher bandwidths the RMDCN is larger and has an even more important role in supporting ECMWF activities as well as the meteorological community, both in Europe and elsewhere. There is no doubt that in the coming months and years the RMDCN will continue to evolve and be able to support successfully the coming changes in the WMO Information System.

ECMWF Calendar 2010

September 6–9	Seminar on 'Predictability in the European and Atlantic regions from days to years'
September 9–10	TAC Subgroup on 'Green Computing'
September 20–21	TAC Subgroup on 'Verification measures'
September 23–24	TAC Subgroup to 'Review the BC Project'
October 4–6	Scientific Advisory Committee (*39th Session*)
October 6–8	Technical Advisory Committee (*42nd Session*)
October 11–15	Training Course – Use and interpretation of ECMWF products for WMO Members
October 11–13	Finance Committee (*85th Session*)
October 14	Advisory Committee of Co-operating States (*16th Session*)
October 18–19	Policy Advisory Committee (*30th Session*)
October 19–20	Working Group on 'Long-term building and refurbishment requirements'
October 18–27	NWP Training Course – Predictability, diagnostics and extended-range forecasting (originally scheduled for 19–28 April)
November 1–5	14th Workshop on 'Use of High Performance Computing in Meteorology'
November 8–10	Workshop on 'Non-hydrostatic modelling'
December 7–8	Council (*74th Session*)

ECMWF publications (see http://www.ecmwf.int/publications/)

Technical Memoranda

625 Orr, A., P. Bechtold, J. Scinocca, M. Ern & M. Janisková: Improved middle atmosphere climate and forecasts in the ECMWF model through a non-orographic gravity wave drag parametrization. *April 2010*

624 Muñoz Sabater, J., P. de Rosnay & G. Balsamo: Sensitivity of L-Band NWP forward modelling to soil roughness. *April 2010*

623 Jung, T., G. Balsamo, P. Bechtold, A. Beljaars, M. Köhler, M. Miller, J.-J. Morcrette, A. Orr, M. Rodwell & A. Tompkins: The ECMWF model climate: Recent progress through improved physical parametrizations. *April 2010*

620 Geer, A.J. & P. Bauer: Enhanced use of all-sky microwave observations sensitive to water vapour, cloud and precipitation. *April 2010*

619 Geer, A.J., P. Bauer & P. Lopez: Direct 4D-Var assimilation of all-sky radiances. Part II: Assessment. *April 2010*

618 Bauer, P., A.J. Geer, P. Lopez & D. Salmond: Direct 4D-Var assimilation of all-sky radiances. Part I: Implementation. *April 2010*

617 Matricardi, M.: A principal component based version of the RTTOV fast radiative transfer model. *April 2010*

616 Hamrud, M.: Report from IFS scalability project. *February 2010*

615 Rodwell, M.J., D.S. Richardson & T.D. Hewson: A new equitable score suitable for verifying precipitation in NWP. *February 2010*

ESA Contract Reports

Dragini, R.: Monitoring and assimilation of SCIAMACHY, GOMOS and MIPAS retrievals at ECMWF. January 2010

Index of past newsletter articles

This is a selection of articles published in the *ECMWF Newsletter* series during the last five years. Articles are arranged in date order within each subject category. Articles can be accessed on the ECMWF public website – www.ecmwf.int/publications/newsletter/index.html

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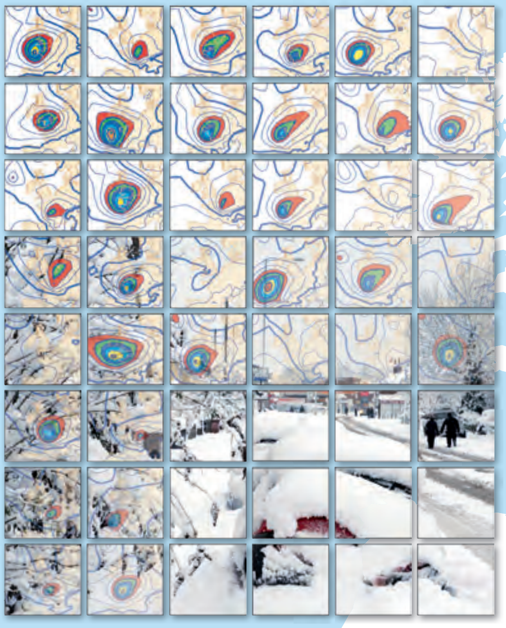
ECMWF

2010 SEMINAR

Predictability in the European and Atlantic regions from days to years



6–9 September

These are some of the topics that will be discussed:

- Dynamical understanding of weather and climate variability over Europe.
- Predictability and actual predictive skill of operational systems from daily to seasonal scales.
- Influence of ocean/land-surface/stratospheric conditions on Europe, including planetary scales.
- Looking ahead – areas of possible/expected progress such as high-resolution modelling, atmospheric composition and decadal time range.

Invited speakers

Myles Allen	(AOPP Oxford)	Hai Lin	(RPN Dorval, QC)
Andrea Buzzi	(ISAC-CNR Bologna)	Olivier Nuissier	(Météo-France Toulouse)
Christophe Cassou	(CNRS-CERFACS Toulouse)	Jan Polcher	(CNRS/IPSL Paris)
Paco Doblas-Reyes	(IC3 Barcelona)	Adam Scaife	(UK Met Office)
Huug van den Dool	(NCEP Camp Springs MD)	Julia Slingo	(UK Met Office)
Lizzie Froude	(ESSC Reading)	Rowan Sutton	(NCAS University of Reading)
Alessandra Giannini	(Columbia University NY)	Takayuki Tokuhiro	(JMA Tokyo)
Renate Hagedorn	(ECMWF)	Joe Tribbia	(NCAR Boulder, CO)
Wilco Hazeleger	(KNMI De Bilt)	Martin Visbeck	(IFM-GEOMAR Kiel)
Brian Hoskins	(University of Reading)	Frédéric Vitart	(ECMWF)
Heiner Körnich	(University of Stockholm)	Pedro Viterbo	(IM Lisboa)
Peter Lemke	(Alfred Wegener Institute Bremerhaven)	Heini Wernli	(ETH Zurich)

For details of the programme see:
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