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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 The *ECMWF Newsletter* is not peer-reviewed.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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Cover: In-situ soil moisture measurements in support of the CAROLS airborne campaign in southwestern France – photograph courtesy of Clément Albergel.

Uncertainty

Be it for weather or climate change or even seismological hazards, the way scientists assess and communicate the degree of uncertainty in forecasts is now recognised to be fundamental. The language used is an important part of how the degree of uncertainty is perceived by forecast users; sometimes practitioners can use words like 'error', 'uncertainty' and 'risk' interchangeably whilst the public may think of these as distinctly different things. What is clear is that no forecast is scientifically credible without an estimate of its level of uncertainty.

At ECMWF uncertainty is gauged by producing an ensemble that encompasses 51 individual predictions within the same forecast. By looking at these various evolutions of the state of the atmosphere it is possible to assess the range and likelihood (or risk) of particular weather events occurring. This forecast uncertainty arises from the characteristic uncertainties in the input observations and in the mathematical models that are used. Only after the fact, when we know what has actually happened, is it possible to quantify the error in any given prediction and this allows the estimation of skill.

When communicating forecasts it is critical to ensure the degree of uncertainty is fully reflected. However, if the degree of uncertainty is too large then the forecast may lose its value to users and it can be questioned whether the science is credible. A challenge for meteorologists is that there are certain weather situations that can be predicted rather well with relatively small uncertainty whilst others cannot – how then to persuade the users that both cases are consistent with a high degree of scientific understanding? The concept of forecast reliability is important where over many forecasts we can demonstrate that the frequency that particular events are predicted to occur is close to the frequency that they actually happen. Often commentators on the weather forecast will focus on the skill of a particular forecast and not on the reliability assessed over many forecasts.

When communicating forecasts we aim to be as clear and simple as possible. The same approach should be taken when describing our forecasting system. Consequently, in this edition of the *ECMWF Newsletter*, there is an article that describes the ECMWF Integrated Forecasting System (IFS) and the set of forecasts we produce routinely using terminology that hopefully is clear and simple. No doubt the quest for clarity will continue because effective communication is an enduring task!

Alan Thorpe

New items on the ECMWF website

ANDY BRADY

New ecCharts web service for forecasters

From 15 October 2012, ECMWF is providing a new fully supported web service exclusively for forecasters of organisations designated by National Meteorological Services of ECMWF Member States and licensed subscribers of ECMWF Web Products. ecCharts is a suite of web browser applications that forecasters can use to interactively explore ECMWF forecast products. The functions that ecCharts provides are beyond our standard web charts, in that forecasters can use the service to create bespoke charts on demand and do this themselves as and when they need to, using an easy-to-use web interface. Using ecCharts allows forecasters to explore ECMWF's medium-range forecasts in far greater detail than has previously been possible on the web.

- http://www.ecmwf.int/services/eccharts/

European Flood Awareness System (EFAS)

EFAS is a state-of-the-art flood forecasting system, developed by the Joint Research Centre of the European Commission. It includes several pioneering products, such as probabilistic flood forecasting and novel analysis and communication methods used for interpretation of multiple forecasts. In February 2012, ECMWF was successful in bidding for the contract to provide the facility for operational provision of the Computational Centre. The service moved to operations at ECMWF in October. Our responsibility covers acquiring input data from the collection centres, running of the computational component of EFAS and providing flood forecasts twice daily to the EFAS dissemination centres in Sweden, Slovakia and The Netherlands, which then provide national water authorities with early flood warning information.

- http://www.ecmwf.int/service/efas/

2013 Training Programme

ECMWF has an extensive education and training programme to assist Member States and Co-operating States in the training of scientists in numerical weather forecasting, and in making use of the ECMWF forecast products and computer facilities.

- http://www.ecmwf.int/newsevents/training/2013/

Celebrating twenty years of ensemble prediction

Twenty years ago, on 24 November 1992, the first ensemble forecasts were produced under the operational suite at ECMWF. At that time, the forecasts were produced three times a week, on Friday, Saturday and Sunday, with 33 members with a T63L19 resolution up to 10 days. Today, ensemble forecasts are produced twice a day with 51 members at resolution T639L62 to day 10, and T319L62 from day 10 to 15. A coupled ocean-atmosphere model is used and the forecast is extended to 32 days twice weekly. On 3 December there was an event to celebrate 20 years of ensemble forecasts at ECMWF with an afternoon of talks from people who contributed to our work, either developing the system that went operational, or contributing to the science on which it is based.

- http://www.ecmwf.int/newsevents/calendar/miscellaneous/EPS_symposium.html

High Performance Computing Facility Phase 2

The High Performance Computing Facility Phase 2 system (IBM Power7) is being installed during autumn 2012 and the first cluster (C2A) was made available to users on 8 October 2012. Details of the new system and information on the migration timetable are available.

- http://www.ecmwf.int/services/computing/hpcf/

High Performance Computing Workshop

The workshop on the use of high performance computing in meteorology was held on 1 to 5 October 2012. The emphasis of this workshop was on running meteorological applications at sustained teraflops performance in a production environment. Particular emphasis was placed on the future scalability of NWP codes and the tools and development environments to facilitate this as we move towards petaflop computing. Presentations are available.

- http://www.ecmwf.int/newsevents/meetings/workshops/2012/high_performance_computing_15th/

Invitation to Tender for Procurement of a HPCF

The purpose of this Invitation to Tender is to procure a High Performance Computing Facility (HPCF). ECMWF's existing high performance computing resources were acquired under an agreement that is scheduled to expire at the end of June 2014. The replacement HPCF will run in parallel with the existing HPCF from early 2014 until the end of June 2014. It will then provide a production service to the end of the contract period, June 2018.

- http://www.ecmwf.int/newsevents/itt/2012-210/

Special Projects at ECMWF

Special Projects are "experiments or investigations of a scientific or technical nature, undertaken by one or more Member States, likely to be of interest to the general scientific community". Updates for 2012 and 2013 are now in place.

- http://www.ecmwf.int/about/special_projects/index.html

Application and verification of ECMWF products

Each year, ECMWF Member and Co-operating States are invited to submit reports on the application and verification of ECMWF products in their national services. The reports focus on the use of products in each service; the inclusion of verification of weather parameters is particularly valuable to ECMWF to complement the comprehensive upper-air verification carried out operationally at ECMWF.

- http://www.ecmwf.int/products/greenbook/2012/index.html

The EUROSIP Seasonal Forecasting System User Guide

Research (including under the DEMETER and ENSEMBLES projects) has consistently shown that better and more reliable seasonal forecasts can be created by combining the output from several models, rather than taking just one model. The EUROSIP multi-model seasonal forecasting system consists of a number of independent coupled seasonal forecasting systems integrated into a common framework. From September 2012, the systems include those from ECMWF, UK Met Office, Météo-France and NCEP. Products and documentation are available.

- http://www.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/eurosip/
- http://www.ecmwf.int/products/forecasts/seasonal/documentation/eurosip/

ECMWF Annual Seminar on Seasonal Prediction

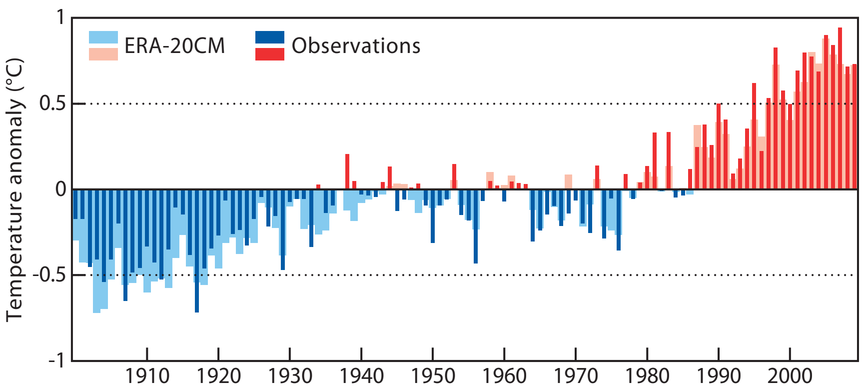
The seminar was held on 3 to 7 September and gave a pedagogical review of the principles behind seasonal predictions. Recent scientific developments in probabilistic, coupled seasonal prediction were reviewed, and the value of seasonal prediction in weather-risk reduction were discussed.

- http://www.ecmwf.int/newsevents/meetings/annual_seminar/2012/

Progress toward ERA-20C

DICK DEE

A key milestone has been achieved in preparations for an ECMWF extended climate reanalysis (ERA-20C) with the completion of an ensemble of atmospheric model integrations for the period 1899–2010 (ERA-20CM). The ensemble was produced using ECMWF's Integrated Forecasting System (IFS) supplied with atmospheric forcing data (e.g. volcanic aerosols and greenhouse gas concentrations) and boundary conditions according to specifications developed for CMIP5, Phase 5 of the international Coupled Model Intercomparison Project. Each of the ten ensemble members makes use of a different but equally plausible estimate of global sea surface temperature and sea-ice evolution taken from the Met Office Hadley Centre's new HadISST2 product. The ensemble approach used in constructing the HadISST2 estimates is intended to represent a key aspect of uncertainty in the observed 20th-century climate.



Comparison of near-surface air temperature anomalies from ERA-20CM with observations. The figure shows globally and annually averaged near-surface air temperature anomalies from the ensemble mean of ERA-20CM compared with independent estimates based on selected station records of high-quality climate observations from the CRUTEM4 dataset produced by the Climatic Research Unit, University of East Anglia, and the Hadley Centre. The comparison is based on 5°×5° grid-cell averages and restricted to locations where CRUTEM4 estimates are available, mainly over land and at some island stations.

The figure shows globally and annually averaged near-surface air temperature anomalies from the ensemble mean of ERA-20CM, compared with independent estimates based on selected station records of high-quality climate observations. The agreement is generally quite good; estimated warming trends differ most during the first three decades of the 20th century. The relative cooling near the surface caused by the 1991 eruption of Pinatubo is clearly visible in both estimates.

As a preliminary step in the development of an extended climate reanalysis spanning the 20th century, it is reassuring to be able to demonstrate that the forecast model alone, when supplied with atmospheric forcing and boundary conditions, can provide useful background information with realistic low-frequency variability of air temperature. The more formidable challenge now at hand is to assimilate historic observations of surface pressure and wind, in order to constrain the model's variability on synoptic scales as well.

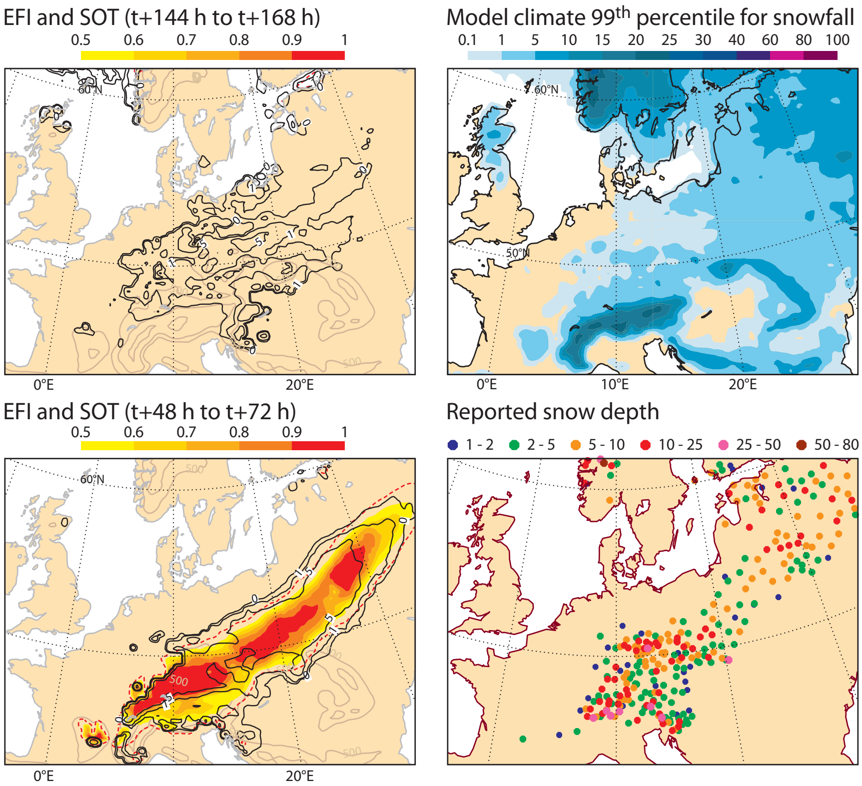
In the coming year, the ERA-20C reanalysis will be completed as an ensemble of data assimilations (EDA) at resolution T159L91, using observations from the historic data collections ISPD (International Surface Pressure Databank) and ICOADS (International Comprehensive Ocean-Atmosphere Data Set). Please watch this space for further news.

Application of the new EFI products to a case of early snowfall in Central Europe

IVAN TSONEVSKY,
DAVID RICHARDSON

The Extreme Forecast Index (EFI) products have been extended to include new parameters and time ranges. The new parameters are 2-metre minimum and maximum temperatures, snowfall and maximum significant wave height. The time ranges were extended from 5 days to cover the whole forecast period up to day 10.

A new index, Shift Of Tails (SOT), has been added to complement the EFI by providing information about how extreme an event might be. Positive values of the SOT indicate that at least 10% of the ensemble members are above the 99th percentile of the model climate (M-climate). The higher the SOT value is, the further this top 10% of the ensemble forecast is beyond the M-climate. For temperature the SOT is also calculated for extreme low values (10% of the ensemble members below the 1st percentile of the model climate). Plots of selected percentiles of the M-climate are shown alongside the new EFI/SOT charts on the web so that users can assess the magnitude of the extremity of an event. The M-climate is also available via MARS.



Examples of new EFI products for the early snowfalls affecting Europe. Shown are the EFI forecasts of snowfall from t+144 h to t+168 h (top left) and from t+48 h to t+72 h (bottom left) valid for 00 UTC on Saturday 27 October to 00 UTC on Sunday 28 October 2012. SOT is plotted with black contours whilst EFI is shaded in yellow to red colours; EFI=0.3 isoline is also plotted with a dashed red line. Also shown are the M-climate 99th percentile (top right) and the observed snow depth (in cm) reported at 06 UTC on Sunday 28 October (bottom right). The interpretation of these products is explained in the text.

A spell of cold weather brought early snowfalls in a large area of Europe from eastern France to Russia at the end of October 2012. As indicated in the figure, the new SOT index gave a signal 7 days in advance that some significant early snowfall might be expected over Central Europe. The EFI is a summary of the whole ensemble forecast distribution, which at this range is not sufficiently far from the M-climate to produce high EFI values (and so does not appear on the plot). However, the SOT indicates a large area (enclosed by the zero contour) with at least a 10% chance of extreme snowfall, exceeding the 99th M-climate percentile. The EFI increases closer to the event and by three days in advance a wide area from the Alps to Russia is covered with high values of both EFI and SOT. High values of the EFI imply high confidence that extreme snowfall may happen, while the higher SOT values indicate where the most exceptional snowfall amounts might be (relative to climate).

More information about the extension of the EFI and the new SOT index can be found via the 'Show guide' button on the web pages for the new extended EFI products.

ECMWF Training Programme 2013

ECMWF has an extensive education and training programme to assist Member States and Co-operating States in the training of scientists in numerical weather forecasting, and in making use of the ECMWF forecast products and computer facilities.

Some training courses consist of modules which can be attended separately. A student may decide to attend the various modules in different years.

Use of Computing Facilities

In this course the use of ECMWF computing and archive facilities is introduced. This course is aimed at both current and potential users of the Centre's facilities.

- http://www.ecmwf.int/newsevents/training/2013/computing/index.html

Use and interpretation of ECMWF Products

This course discusses the ECMWF products in operational weather forecasting available to the Member States. It is mainly aimed at forecasters or people with forecasting experience.

- http://www.ecmwf.int/newsevents/training/2013/use_of_products/index.html

Use and interpretation of ECMWF Products for WMO Member States

A separate course on the use of ECMWF products is organised for participants from WMO National Meteorological and Hydrological Services which are not ECMWF Member States or Co-operating States.

- http://www.ecmwf.int/newsevents/training/2013/wmo_training_course/index.html

Numerical weather prediction

This course targets the various aspects of research on numerical weather prediction at ECMWF. It consists of four modules covering scientific training on numerics, physics, data assimilation and predictability.

- http://www.ecmwf.int/newsevents/training/2013/nwp/index.html

Annual Seminar

A one-week series of lectures dedicated to one specific topic, given in the beginning of September. The subject is different every year. In 2013 it is Numerical Methods.

- http://www.ecmwf.int/newsevents/meetings/annual_seminar/2013/index.html

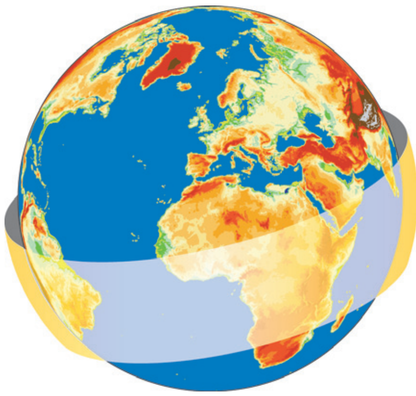
Earth observations from space: a very busy time

STEPHEN ENGLISH, NIELS BORMANN, TONY MCNALLY, JEAN-NOËL THÉPAUT

The last year has been a busy time for new satellite launches. A year ago the first of a new generation of polar orbiting satellites from the USA, called Suomi-NPP (named after the pioneer of satellite meteorology, Verner Suomi) was launched. The most important instruments for NWP were the microwave and infrared sounders, called ATMS and CrIS respectively. CrIS gives us fully operational high spectral resolution infrared soundings in the afternoon orbital plane for the first time, complementing the similar IASI instrument on MetOp-A in the morning plane.

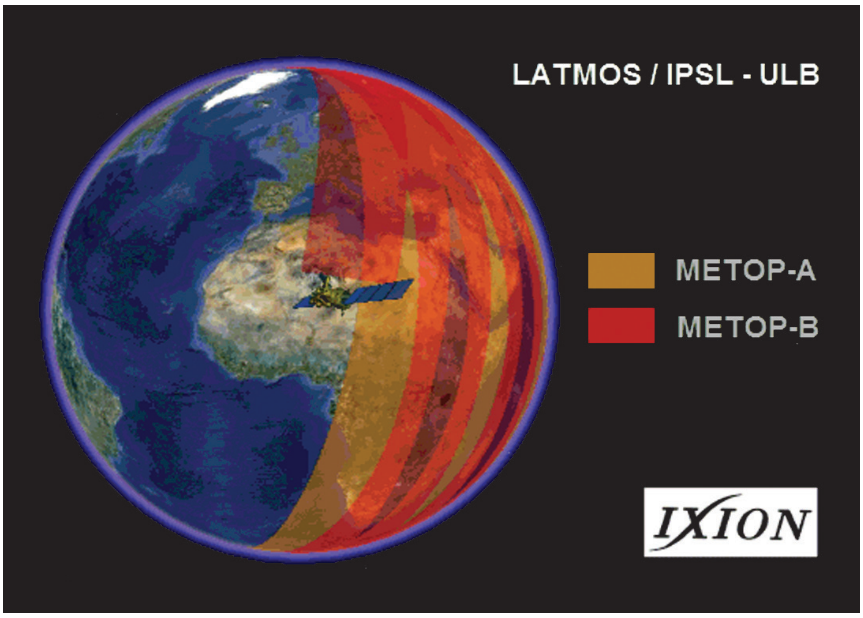
Data from ATMS and CrIS underwent a long and careful post-launch calibration and validation phase organised by NOAA and with input from many centres, including ECMWF. ATMS data has been assimilated in the operational suite since 25 September 2012, and CrIS data is being passively monitored, with operational assimilation expected soon. Suomi-NPP also carries a very advanced visible and infrared imager, VIIRS, and an ozone instrument, OMPS, from which we will be using data products within a year.

At around the same time, in October 2011, a new mission to study in detail tropical humidity and clouds, called Megha-tropiques, was launched as a collaboration between the Indian and French space agencies. Megha-tropiques carries two interesting microwave instruments, one for imagery and the other for humidity sounding. Unlike most satellites Megha-tropiques is not in a polar orbit, but orbits at a lower inclination, giving 3 to 5 passes each day for the tropics, but with no data in the extra-tropics. This will enable sampling of the diurnal cycle throughout the microwave spectrum (i.e. in close to all weather conditions) for the first time.



Area covered by the Megha-tropiques orbit in one day. Megha-tropiques is an Indo-French joint satellite mission for studying the water cycle and energy exchanges in the tropics, with emphasis on understanding the life cycle of convective systems and their role in the energy and moisture budgets. The orbit is at 867 km with an inclination of 20° to the equator.

Unfortunately satellites also come to the end of their lives, and in April 2012 communication with the veteran satellite ENVISAT was lost. We were



Orbits of MetOp-A and MetOp-B. MetOp-B was launched on 28 September 2012. It is intended that MetOp-B will replace the ageing MetOp-A as prime operational satellite in polar orbit, after the six-month commissioning phase. Temperature and humidity soundings, wind at the ocean surface, and soil moisture provided by MetOp-B will be essential inputs to NWP models.

using many instruments from ENVISAT for ozone and for ocean surface analysis, and its loss led to additional effort to make use of some alternatives to fill the large gap left by ENVISAT.

May 2012 saw the launch of the GCOM-W1 satellite, a Japanese satellite carrying the second generation of Advanced Microwave Scanning Radiometers. Since its predecessor on the Aqua satellite stopped working after being used operationally for many years we have been looking forward to the GCOM-W1 launch.

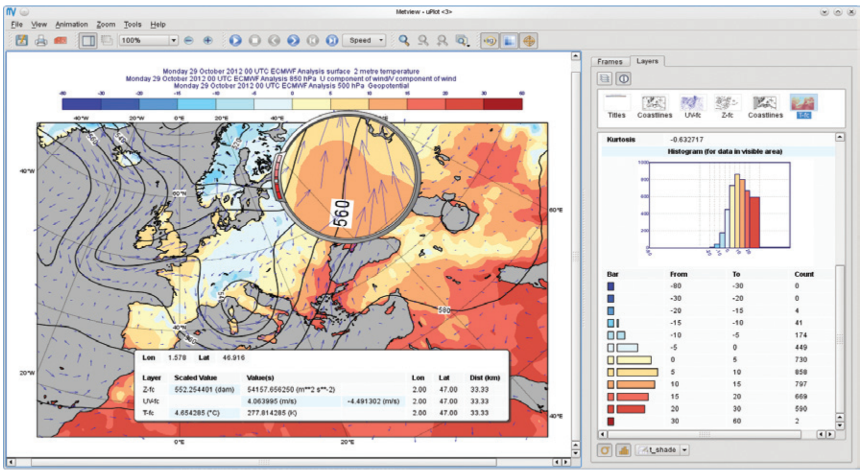
In June 2012 the 10th Meteosat satellite was launched, this being the third satellite to carry the SEVIRI instrument. It will be important, like its predecessors, for the winds derived from tracking features in a sequence of images and also for the assimilation of the radiance observations.

This remarkable year of satellite launches culminated in September 2012 with the launch of the MetOp-B satellite. This carries the same suite of instruments as MetOp-A and will fly in an orbit separated from MetOp-A by only around 50 minutes. It carries state of the art microwave and infrared sounders, as well as a scatterometer, an imager, a GPS radio occulatation sounder and an ozone instrument. We expect to receive the first data from MetOp-B from the microwave instruments and if all goes well this data could be used operationally within a few months. The GPS radio occultation sensor is important as well because recent studies have shown that we would benefit from additional GPSRO observations, at a time when the so called 'COSMIC' system is giving far fewer observations than a few years ago, due to its age.

Metview 4.3 released under Open Source Licence

STEPHAN SIEMEN, IAIN RUSSELL

Metview has been for 20 years ECMWF's integrated software system for accessing, processing and visualising its data in operations and research. Metview is the result of a co-operation between ECMWF and INPE/CPTEC (Brazil). Its latest version, 4.3, has now been released under the Open Source Apache License 2.0. This will remove any past licence restrictions and open up Metview's extensive functionality to the wider user community to help realise the full potential of ECMWF data.



Metview's interactive display window. The screenshot shows plots and statistics for model fields of 2-metre temperature, 850 hPa wind and 500 hPa geopotential.

The latest generation of Metview includes enhanced functionality for interactive inspection and batch processing of data from an increased variety of sources. Metview is extensively used in batch to generate visual products from ECMWF forecasts for its Member States and customers on its web page. Many also use Metview locally to process ECMWF data.

Metview is used for day-to-day tasks in operations to monitor the model's input and output data. For this a large number of data and visual products are generated. The powerful interactive user interface enables analysts to quickly investigate special cases.

Its high-level interface lets researchers quickly prototype products from new data types developed at ECMWF. Users can then let Metview generate a script which can be run in batch. Metview developments are tightly synchronised with other developments at ECMWF; upcoming changes in its forecast system and archive, and new technical developments are anticipated well in advance by Metview.

More information and the download page can be found under:

- https://software.ecmwf.int/metview/

ECMWF forecasts help aid workers

JANE STANDLEY
WFP Emergency Preparedness and Response Branch, Rome, Italy

The World Food Programme (WFP) is using forecasts from ECMWF to boost its preparedness planning and operational capacity in the Yida area of South Sudan. WFP and its partners in Yida are feeding a recent large influx of 63,000 refugees from neighbouring Sudan.

After a successful pilot project, ECMWF forecasts are being used by the Early Warning Team of the WFP's

WFP Early Warning Team. Armin Wilhelm, Marion Cezard, Alessandra Piccolo and Emily Niebuhr.

Air strip in Yida Camp, South Sudan, on a rainy day. Picture courtesy of George Fominyen.

Emergency Preparedness and Response Branch which is based in Rome. Forecasts have been of value when, for example, heavy rain cuts off Yida and an air drop of food supplies has been required. In general, having the forecasts means that informed decisions can be taken about the risk of disruption and thereby avoid damage to WFP's life-saving food supplies.

ECMWF has helped the Early Warning Team develop their meteorological expertise. For example, Alessandra Piccolo (Early Warning Team's Natural Hazards Focal Point) visited ECMWF and met members of the EFAS Application Project Team and Meteorological Operations Section to learn about how to intepret the Centre's products. Also ECMWF staff have helped validate forecasts prepared by the Early Warning Team.

Other UN agencies also benefited from the forecasts provided by the Early Warning Team. UNOPS (United Nations Office for Project Services) helps the UN and its partners run peace-building, humanitarian and development operations for people in need. It is rehabilitating the airstrip at Yida and the forecasts have provided a good basis for making important decisions affecting the work programme. In addition, the UNHCR (UN High Commissioner for Refugees) has used the forecasts to avoid vehicles being bogged down by heavy rain and to determine what should be put on flights containing humanitarian relief.

The staff at ECMWF have always been extremely helpful in many ways and we feel we can always ask them for support. Hopefully our collaboration will continue and develop further in the future as the Early Warning Team looks to extend the weather forecasting service to other emergency areas beyond Yida.

For more information about how weather forecasters are helping aid workers go to:

- http://www.wfp.org/stories/weather-forecaster-helps-aid-workers-plan-ahead.

Training courses: reaching out to the international community

ANNA GHELLI

The annual training course on the '*Use and interpretation of ECMWF products for WMO Members*' took place the second week of October. The classroom was full for the whole week with students coming from 18 countries.

The week was a tremendous opportunity for forecasters to learn more about the Centre's products and to network with others from small to medium size Meteorological Services. The enthusiasm and participation in the activities was commendable. We started the week with a team building game whose aim was to understand the usefulness of probability forecast in decision-making followed by lectures and laboratories. The students used a forum to discuss ECMWF products, and the same products were then used to analyse case studies during the practical sessions.

Students attending the course on '*Use and interpretation of ECMWF product for WMO Members*'. Students and lecturers accounted for 14% of the countries in the world (193 Members of the United Nations), and 12 out of 54 African countries were represented. WMO provided travel support for several of the participants.

Two seminars, broadcast over the web, were arranged as part of the event. They described how long-range weather forecasts could be applied to drought forecasting and an early warning system for malaria. Both the students participating in the course and the remote audience appreciated being able to attend these seminars.

The 2013 training course programme is now available at the following link:

- www.ecmwf.int/newsevents/training/2013/index.html

Looking forward to meeting you at one of our training courses!

High Performance Computing in Meteorology

PETER TOWERS

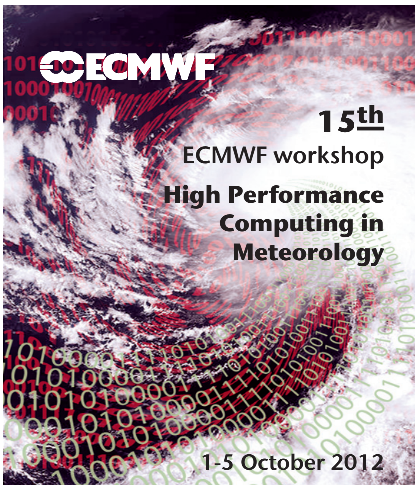
Every second year ECMWF hosts a workshop on the use of high performance computing in meteorology. The 15th workshop in this series took place from 1 to 5 October 2012 and was attended by over 100 participants from Meteorological Services, research institutions and computer vendors, coming from 18 countries. The emphasis of this workshop was on running meteorological applications at sustained teraflops performance in a production environment, and in particular on the future scalability of NWP codes and the tools and development environments to facilitate this.

At the workshop there were 52 presentations covering a wide range of topics including:

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

- Tools to exploit the power of supercomputers.

The keynote talk was given by Dr James Hack who directs the National Center for Computational Science at the Oak Ridge National Laboratory in the USA. He discussed their preparations for the transition to heterogeneous architectures and expressed the view that high performance computing is at an inflection point as we move from multi to many core processors. Several other talks discussed progress that is being made to adapt meteorological applications to take advantage of both General Purpose Graphics Units and the new Xeon Phi which is based on the Many Integrated Core (MIC) architecture. This is a trend that will have an increasing impact on high performance computing as Exascale systems are developed.



Presentations from this workshop can be found at the following web location:

- www.ecmwf.int/newsevents/meetings/workshops/2012/high_performance_computing_15th/Presentations/

ECMWF forecasts of 'Superstorm Sandy'

TIM HEWSON

On 29 and 30 October 2012 'Superstorm Sandy' brought havoc to the highly populated north-eastern US, causing over 100 fatalities, and considerable damage to property and infrastructure. This was in addition to the trail of destruction, and a death toll of 69, attributable to Sandy's earlier track across the Caribbean. Initial estimates put total financial losses at over 50 billion dollars, placing Sandy second only to Katrina (2005) in a list of the most costly Atlantic hurricanes. This storm was a genuine 'multi-hazard' event, with major impacts seen from wind gusts, from high seas, from a tidal surge and related inundation, from heavy rain and even from heavy snow.

A tropical depression was first recognised in the Caribbean at 15 UTC on 22 October, and became the named tropical storm 'Sandy' 6 hours later. There followed some alternating phases of intensification and weakening, as the feature tended to accelerate towards the north (see Figure 1, lower right panel). 'Cat 2' was the highest level reached on the Saffir-Simpson hurricane intensity scale. Sandy eventually turned towards the left (west) early on the 29th, was declared post-tropical late on the same day, and very soon after made landfall near to Atlantic City in the USA state of New Jersey (in this article we denote time of landfall, 00 UTC on 30 October, as 'D'). Post-tropical Sandy decayed quite rapidly inland.

Forecasts from the ECMWF IFS (Integrated Forecasting System) provided considerable assistance to US forecasters responsible for predicting the track, the intensity and the impacts. Over the northern hemisphere as a whole routine statistics show this to have been a period of unusually accurate high-resolution forecasts (HRES). For times when a tropical cyclone is moving into the extra-tropics this is somewhat atypical: forecast error growth in such scenarios can sometimes be very large. The IFS forecasts are illustrated in Figures 1 and 2.

Figure 1 shows all available ECMWF HRES forecasts verifying at landfall time. Evidently a major cyclone was predicted to be close to the US east coast in every forecast onwards from about 00 UTC on the 23rd (7 days before landfall, labelled 'D-7' on Figure 1). As the event approached these forecasts generally became more and more accurate, with forecast intensity also verifying well – note that in many the central pressure is below 950 hPa (thick red contour), compared with 946 hPa observed at landfall.

Some forecast products based on the ensemble (ENS) are represented in Figure 2. Before the storm has formed it is helpful to use 'time-window strike probability' maps to identify risk – as on the upper right inset, which denotes forecasts from 12 UTC on the 21st ('D-8.5'). Even this far in advance, before the HRES had shown anything noteworthy, the ENS was flagging up a region centred on New York as being at risk (~25% probability), from a system yet to form!

Once a cyclone has formed one can use track and plume diagrams to follow its predicted evolution more precisely. Figure 2 includes two forecast products specifically for Sandy: the main panel shows tracks in the ENS and the HRES, whilst the lower inset shows the central pressure evolution along those forecast tracks (red dots are verifying data). These are all forecasts from 12 UTC on the 23rd ('D-6.5', which is 15 hours after Sandy was named). The products show the ENS providing strong support for the HRES, the vast majority of members showing landfall, along the coasts of the north-eastern USA or south-eastern Canada, many at about the right time. Only a handful of members show a 'right turn' in the track, and miss land. Moreover most members show substantial deepening, and minimum pressure values, of the right order, at about the time of landfall.

The lower inset of Figure 2 illustrates also one less satisfactory aspect of the forecast, which is the lack of early deepening (in the Caribbean). In this regard note that tropical cyclone

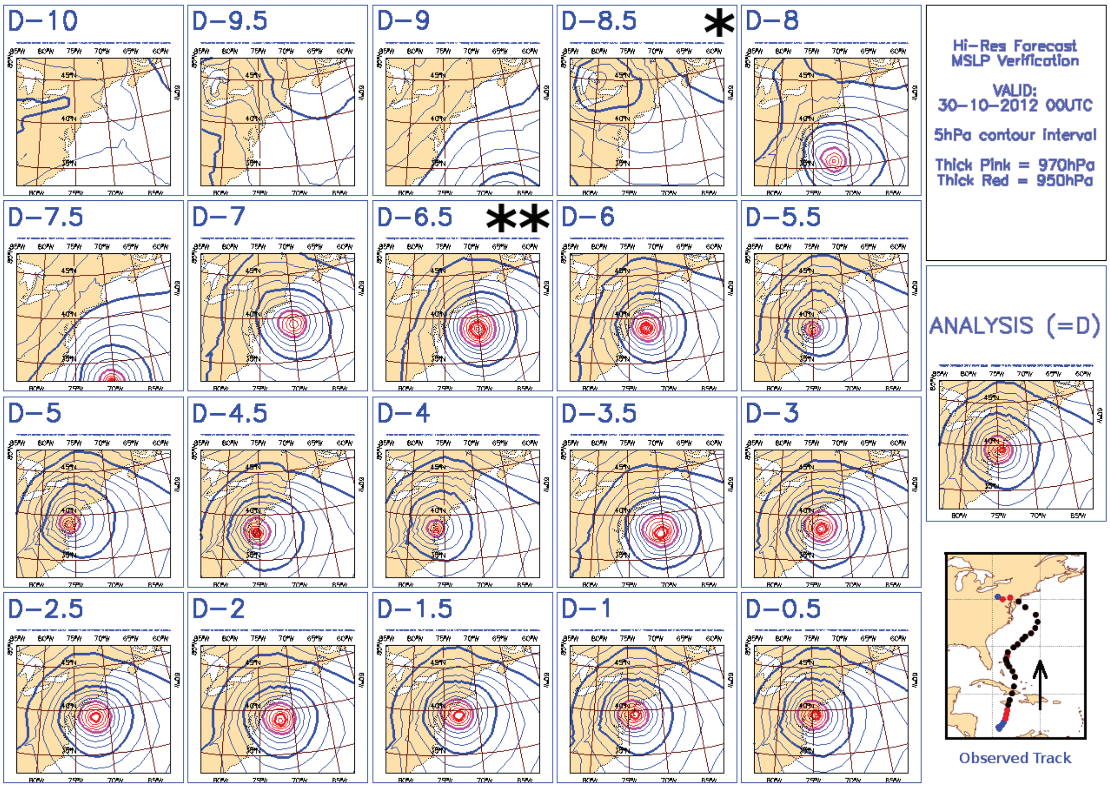


Figure 1 Lower right panel shows the observed track of Sandy (00 UTC on 23 October to 18 UTC on 30 October 2012) with spots at 6-hour intervals (black denotes hurricane, other colours denote lesser intensity). Remaining panels show HRES mean sea level pressure, all verifying at 00 UTC on 30 October, the time of landfall ('D'). The in-frame labels denote lead time (e.g. 'D-5.5' means the forecast with a data time 5.5 days before 00 UTC on 30 October, i.e. from 12 UTC on 24 October). The rightmost panel shows the analysis for comparison. Symbols * and ** denote forecast data times that are portrayed in Figure 2.

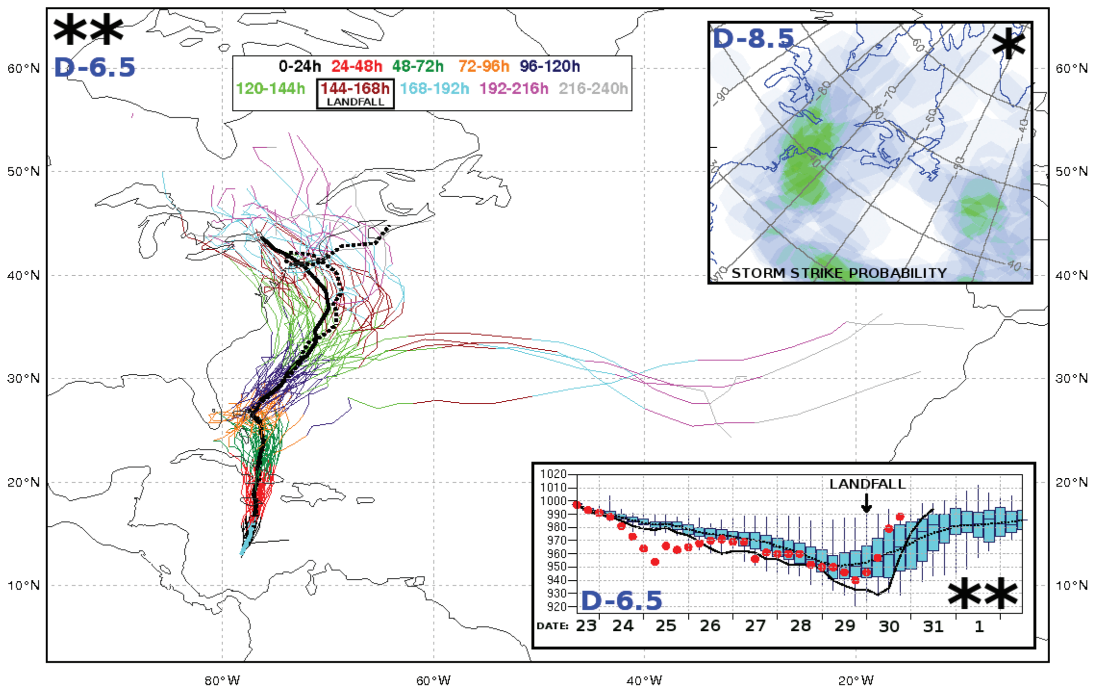


Figure 2 Forecast products for Sandy ('Landfall' labels were added a posteriori). Main panel shows Sandy's track (from ECMWF's new tropical cyclone tracker) for the ENS from 12 UTC on 23 October 2012, with colour denoting time window (legend at top). Also shown are the control forecast (dotted black) and HRES (solid black). Lower right inset shows Sandy's central pressure (hPa) in the same forecasts: boxes denote the ENS inter-quartile range and whiskers the extreme members; also shown are the HRES (thick black) and ensemble mean (dotted black) forecasts with the red dots indicating the verifying pressure. Top right inset shows (from ECMWF's extra-tropical cyclone tracker) the probability that the centre of a substantial cyclonic windstorm will pass within about 300 km in the 24 h time window centred on 00 UTC on 30 October 2012, as represented in the ENS from 12 UTC on 21st October 2012 (white = 0%, bright green = 25%).

intensity forecasting (over tropical waters) is a recognised problem area in all models. Intensity forecasts for extra-tropical cyclones are much more reliable, and it is possible that as Sandy moved north its increasing interactions with extra-tropical weather systems helped to deliver a much better intensity forecast. This was probably aided by the large size of Sandy later in its lifetime, which should have made its prediction less vulnerable to resolution-related problems. Further work is however needed to establish why the predictability of certain cases, such as Sandy, proves to be well above average.

In this brief article we have focussed on the track and intensity of Sandy, as correctly forecasting these aspects tends to be a pre-requisite for correct impact forecasts. Preliminary assessments of direct model forecasts of sensible weather, such as wind, rainfall and snowfall, suggests that these aspects were also well handled, though there will be further work on this in the upcoming months.

Describing ECMWF's forecasts and forecasting system

ECMWF DIRECTORATE

The terminology we use for our forecasts and forecasting system has evolved over time, taking account of scientific and technical advances, but there is now a need to simplify and improve its consistency. So for example, the medium-range weather forecast at ECMWF is variously referred to as the 'deterministic forecast', 'operational forecast' and 'EPS'. Consequently, the ECMWF Directorate has decided to introduce new terminology with the goals of simplification, minimising confusion and promoting clarity of communication.

The name of the ECMWF forecasting system is the 'IFS', short for the 'Integrated Forecasting System'. The term IFS ought to be the only name used for *the system* used at ECMWF – a consequence of this is that we will drop other system labels such as the 'EPS' and 'seasonal system'. Another word we need to be careful with is 'operational' to make sure, for example, that it is not used as a label for just one component of the forecasts we disseminate.

The term 'medium-range' is, of course, fundamental to ECMWF given our name. Following guidelines from the WMO, we have been using the definition of lead times from 3 to 10 days to define medium-range. WMO refer to the range from 10 to 30 days as extended-range (although at ECMWF we often use instead the word monthly), and from 30 days to 2 years as long-range. WMO have designated ECMWF as a Global Producing Centre of long-range forecasts – one of 12 around the world.

New definitions

We will describe our medium-range forecast as comprising two component forecasts – the high-resolution and the ensemble forecasts.

The ECMWF global medium-range forecast comprises a high-resolution forecast (HRES) and an ensemble of lower-resolution forecasts (ENS).

This means we will be replacing the term 'deterministic forecast' with 'high-resolution forecast' with the following definition. The HRES is a single prediction that uses observations, prior information about the Earth-system, and ECMWF's highest-resolution model. On average over many forecasts, the HRES is ECMWF's most accurate prediction of future weather up to about 10 days ahead.

The ENS is an ensemble of lower-resolution forecasts; it provides an estimate of the reliability of a single forecast. Reliability is estimated using an ensemble of predictions, and can be expressed as probabilities of forecast weather actually occurring. The ensemble also gives an estimate of the likelihood of significant weather developments by providing other scenarios that might occur. For any particular medium-range forecast it is impossible to know in advance which specific member of the ENS, or indeed the HRES, will be closest to what actually happens.

Twice a week, the ENS is extended up to 32 days using an ensemble of lower resolution forecasts. ECMWF also produces long-range forecasts (seasonal or SEAS) using an ensemble of low-resolution forecasts coupled to an ocean model.

With this new terminology we wish to encourage users of ECMWF forecast products to regard both the HRES and ENS as an inseparable pair. The HRES and ENS forecasts should, wherever possible, be used together to provide the most detailed description of future weather and of the associated uncertainties; this is the theme of the recently revised User Guide (http://www.ecmwf.int/products/forecasts/guide/) which is discussed in *ECMWF Newsletter No. 128* (8–12). The new terminology is clear that HRES and ENS are forecasts from one and the same forecasting system, the IFS.

The presentation of forecast products on the web will be reviewed and over time corresponding HRES and ENS products will be developed and shown jointly. Enhanced technical infrastructure providing fast, on-demand access to large volumes of ENS data will be developed, building on the success of ecCharts.

ECMWF forecasts and the ECMWF Integrated Forecasting System

The following text will be used on the website and elsewhere as a description of the forecasting system and the forecasts.

a Key characteristics in 2012 of the operational configurations of the ECMWF IFS

	Forecast/Analysis	Number of members	Horizontal resolution	Vertical levels and pressure at model top (hPa)	Perturbation models	IFS cycle
HRES	Forecast 0–10 days	1	T1279/16 km	91/0.01	No	Latest
ENS	Forecast 0–10 days	51	T639/32 km	62/0.5	Yes (in analysis and model physics)	Latest
	Forecast 10–32 days		T319/64 km			
4DVAR	Analysis	1	T1279/16 km (T255 inner loops)	91/0.01	No	Latest
EDA	Analysis	11	T399/50 km (T159 inner loops)	91/0.01	Yes (in observations and model physics)	Latest
SEAS	Forecast 0–13 months	51	T255/80 km	91/0.01	Yes (in analysis and model physics)	2011 version
ERA	Analysis	1	T255/80 km	60/0.1	No	2006 version
BC	Forecast 0–90 hours, hourly output	1	T1279/16 km	91/0.01	No	Latest

b Key characteristics in 2012 of the ENS and SEAS re-forecasts

	Forecast/Analysis	Number of members	Horizontal resolution	Vertical levels	Top of the Atmosphere	Perturbation models	IFS cycle	Number of years
ENS	Forecast 0–10 days	5 run once a week	32 km	62	0.5 hPa	Yes (in analysis and model physics)	Latest	Most recent 20
	Forecast 10–32 days		64 km					
SEAS	Forecast 0–13 months	15 run once a month	80 km	91	0.01 hPa	Yes (in analysis and model physics)	2011 version	30 (1981–2010)

c Key characteristics in 2012 of the ocean component models of the ECMWF IFS

	Forecast/Analysis	Number of members	Horizontal resolution	Vertical levels	Model cycle
NEMO	Forecast 0–13 months	51	1°	42	Latest
ORA-ORTA	Analysis	5	1°	42	Latest

d Key characteristics in 2012 of the ocean-wave component

	Forecast/Analysis	Domain	Number of members	Horizontal resolution	Number of directions	Number of frequencies
LAM WAM	Analysis + forecast 0–5 days	Limited: 5°N-90°N, 98°W-54°E	1	11 km	36	36
WAM HRES	Analysis and forecast 0–10 days	Global	1	28 km	36	36
WAM ENS	Forecast 0–10 days	Global	51	55 km	24	30
	Forecast 10–32 days				12	25
WAM SEAS	Forecast 0–13 months	Global	51	111 km	12	25

Table 1 The ECMWF Integrated Forecasting System (IFS).

ECMWF produces a suite of operational forecasts for various lead times:

- *Medium-range forecast*: comprises the high-resolution and the ensemble forecasts of weather, at the space and time-scales represented by the relevant model, up to 10 and 15 days ahead, respectively, and the associated uncertainty.
- *Extended-range (monthly) forecast*: comprises ensembles of individual forecasts and post-processed products of average conditions (e.g. weekly averages) up to 1 month ahead, and the associated uncertainty.
- *Long-range forecast*: comprises ensembles of individual forecasts and post-processed products of average conditions (e.g. monthly averages) up to 13 months ahead, and the associated uncertainty.

In addition re-forecasts are calculated operationally using the current system configuration but applied to the weather over past decades:

- *Re-forecasts*: comprise forecasts run for past decades necessary to estimate the model climate and the level of skill and to generate some of the operational products.

These forecasts are produced using the ECMWF Integrated Forecasting System (IFS). The IFS comprises various components. These are described below and their key characteristics are summarised in Table 1.

There are five component models of the IFS.

- *Atmospheric model* with various configurations suited to the space scale and time range of the required forecasts. The current configurations for HRES, ENS and Boundary Conditions (BC) are given in Table 1a.
- *Ocean wave model* is a version of the WAM model which has been further developed in house. It is coupled to the atmospheric model or run as a standalone model in the Limited-Area Wave (LAW) configuration.
- *Ocean model* is a version of the NEMO (Nucleus for European Modelling of the Ocean) model.
- *Process models* are used to describe, for example, land-surface processes, surface ocean waves, and sea-ice.
- *Perturbation models* are used to simulate the effect of uncertainties in the observations, initial conditions, surface boundary conditions, and modelled processes. These produce perturbations for use in ensemble forecasts.

In addition, there are five components for analysing the state of the atmosphere and oceans.

- *4DVAR (4-Dimensional Variational analysis)* provides a detailed estimate of the current state of the atmosphere computed utilising as optimally as possible observations and prior information about the Earth-system using ECMWF's highest resolution model.
- *EDA (Ensemble of Data Assimilations)* provides an ensemble of estimates of the current state of the atmosphere and its uncertainty. The EDA estimate of the analysis uncertainty can be used as an approximation of the 4DVAR uncertainty. The current configuration of EDA is given in Table 1a.
- *ORTA (Ocean Real-Time Analysis)* provides an estimate of the ocean initial state and its uncertainty. The current configuration of ORTA is given in Table 1c.
- *ERA (ECMWF Reanalysis)* provides consistent estimates of the state of the atmosphere generated using a fixed, lower-resolution version of 4DVAR for the past decades. The latest ERA product, ERA-Interim, covers the period since 1979 and is continued in real time to support climate monitoring. ERA-Interim is also used to define the atmospheric initial conditions of the re-forecasts.
- *ORA (Ocean Reanalysis)* is the equivalent of ERA for the oceans.

What next?

It is envisaged that the new terminology will be consistently used in the Web2013 project (*ECMWF Newsletter No 131*, 2–4) which will provide a redesigned ECMWF website and more accessible information about the forecasting system, and the ECMWF products and services. In the meantime, on the current web pages, the page describing the forecasting system (http://www.ecmwf.int/about/forecasts.html) and the dissemination manual will be updated and replaced. The new terminology will also be used for the autumn sessions of the Council and the Committees. We encourage everyone to start using the new terminology!

Discussion about the ECMWF Newsletter and communicating science

ANGELES HERNANDEZ, BOB RIDDAWAY

The following is a record of Bob Riddaway, the Editor of the *ECMWF Newsletter*, being interviewed by Angeles Hernandez from the Satellite Data Section.

Background

Angeles Hernandez (AH) How did your interest in meteorology start? Are you one of these people that bought a barometer with their first savings when they were a ten-year old?

Bob Riddaway (BR) When I was fifteen years old, my geography teacher had a friend who worked for British Antarctic Survey, and he came into the school to give a talk about being in Antarctica. He showed us some slides of Antarctica, and I thought, "This is just wonderful!". At the end, I asked my geography teacher "Please Sir, who goes to Antarctica?" And he said, "Meteorologists do." I thought, "Right, I'm going to become a meteorologist". So I wrote to the Met Office asking what I needed to study and I was told to gain a degree

ECMWF Newsletter

The purpose of the *ECMWF Newsletter* 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.

To satisfy this purpose the *Newsletter* will be published four times a year and will include:

- Features about new developments and systems at ECMWF, collaboration in international projects, case studies of important meteorological events, and uses of ECMWF products.
- News items about:
  - Changes to operational systems and progress with projects and other ongoing activities.
  - New activities, including recent initiatives and decisions of Council and new European Union or EUMETSAT supported projects.
- Information about publications, changes to the web site, and plans for ECMWF workshops and the education programme for the coming year.

It is assumed that the readers of the *Newsletter* have a professional interest in the activities of ECMWF, but may have little detailed knowledge of some of these activities.

Guidance for authors is available at:

- http://www.ecmwf.int/publications/newsletters/Guidance_authors.pdf

in maths or physics. This was a complete change because history was my great interest at that time. A few years later I went to Edinburgh University to do a degree in physics with a view to becoming a meteorologist.

AH For how long have you been the editor of the Newsletter? What attracted you to it?

BR I've been the editor of the *Newsletter* since I retired from the UK Met Office over six years ago. In the early 1980s I worked at ECMWF as education officer within the Research Department on secondment from the Met Office, and I enjoyed it very much. So I was delighted when I had the opportunity of returning to the Centre. Also it was during my previous period at the Centre that I got involved in editing so returning was a kind of "coming home".

Role of the Editor

AH What is your role as editor of the *Newsletter*?

BR Essentially, my role is to help the authors make the contents of their articles more appropriate for the intended audience. Initially I act as a scientific editor to try to make sure that what is written is scientifically correct and can be understood by the readers of the *Newsletter*. There is the tendency, especially for people involved in research, to be too technical and write articles almost as if they were for scientific journals. For a journal, readers of a specific article tend to be experts in the subject, but the *Newsletter* is aimed at a broader readership. This means that the scientific content needs to be made more accessible. I don't mean simplified, but things need to be explained a bit more.

As editor I also look at the structure of the article and, if necessary, I make suggestions about how to improve the English. I was once told that for any article submitted for publication the editor should immediately send it back to the author with a note saying, "Reduce by one third and resubmit". Articles can often be improved by them being shorter and more concise.

AH Are there other ways in which *Newsletter* articles differ from those found in scientific journals?

BR In a journal, typically you introduce the topic, then provide the research evidence, and finally move to the conclusions. In a *Newsletter* article, as with a magazine, the reader should get most of the information from the introduction so as to know why it is worth reading that article. The introduction is almost like a summary of the article, not just the background. Then, as you get into the article, you get into more detail.

AH Do authors volunteer to write articles for the *Newsletter* or do you volunteer them?

BR After ECMWF's Scientific Advisory Committee has met, Erland Källén, Director of Research, suggests topics that are going to be of interest in the following year. Also I contact others in management positions within the Centre to get ideas. I then prepare a publication plan for the whole year. But what helps me most is that, instead of me contacting people and asking "Would you like to write an article?", I can say "Erland has suggested that you might write an article" – that makes a difference.

AH I guess it is not easy to follow that plan closely.

BR It's good to have a plan, but it needs to be flexible. Some people who say they are going to do something don't do it, or can't do it when they said they would, but other people come along and say they would like to write an article. Anyway the plan ensures that authors know when an article is expected, so it doesn't come as a surprise – although they often miss the deadline!

AH What do you enjoy the most, when you edit articles?

BR I find it very satisfying helping someone improve their article so that it is in a form that can be more easily read by

Bob Riddaway

Bob Riddaway's career in meteorology started in Edinburgh University, where he did first a BSc physics and followed by a PhD in meteorology. He then joined the UK Met Office to do research, but after spending 18 months working as a forecaster he decided that direct involvement in operational meteorology was more to his liking.

He held a wide range of posts in the UK Met Office concerned with managing and developing the forecasting process. Also he had a very enjoyable six years as Principal of the Met Office College. During that period he became involved in a variety of education and training activities under the auspices of WMO and this has continued to the present time.

His introduction to editing occurred when he was on a three-year secondment to ECMWF. As the education officer, he edited workshop and seminar proceedings. On his return to the UK Met Office, he became editor of the *Meteorological Magazine*, a house journal. He was also the first editor of the *Meteorological Applications,* a journal published by the Royal Meteorological Society – a position that he held for seven years.

On retirement from the UK Met Office he became editor of the *ECMWF Newsletter*. This part-time post still leaves time for a variety of other meteorological activities, both on a national and international basis.

the sort of audience that we are aiming at. What I've found, both with the *Meteorological Applications* journal and with the *Newsletter*, is that authors are very pleased when you help them.

AH Is there something that you like or dislike particularly in an article? Do you have any pet hates?

BR I suppose the most difficult situation to deal with is when the article is too technical, and the authors haven't really thought about "Who am I writing this for?". The author has put lots of effort into preparing something that is scientifically correct, but it's just not aimed at the right audience, and that often requires a lot of work. Problems also occur when there are too many figures, as they easily get displaced from the relevant text. The best is when I get an article which is superbly written, interesting, at the right level, and has an appropriate number figures – that makes my life easy. But if that happened all the time I would not be needed.

AH Regarding the language, what kind of things do you suggest – for instance, simpler sentences?

BR I try to improve the readability of articles. That means getting the structure right, ensuring scientific/technical terms are explained and avoiding complex sentences. If a sentence has to be read twice, there is something wrong – often breaking up long sentences or paragraphs is a great help.

AH About the English, are there any typical mistakes?

BR Sometimes a rule of grammar is correctly applied but in the wrong place. Perhaps the most common one is the use of *forecasted* as the past tense of *forecast*. Often I have to remove the final *ed* from *forecasted*, as *forecast* is both the present and the past tense. Also some people tend to put many adjectives before a noun, which is unusual in English, and the text doesn't flow. I find that what people have most difficulties with are the little words such as *at*, *in* and *on*.

Role of the Newsletter and how it could develop

AH What is the role of the *Newsletter*?

BR It is basically to inform the broad meteorological community about what goes on at ECMWF. There are lots of very exciting developments, and I think that an organisation like ECMWF has responsibility to tell people about what they are doing and why they are doing it. The aim is that anyone with a meteorological background should be able to understand what is in the articles, without being an expert in the subject. When you are a forecaster, occasionally you have a short period without much to do, waiting for the next run of the models. I'd like to think that at times like that, a forecaster somewhere in Europe will pick a copy of the *Newsletter* and spend some time reading something of interest. I don't know whether this really happens, but I'd like to think that it does.

Also I hope that the *Newsletter* helps people working at the Centre, along with their partners in universities, research institutes and meteorological services, keep up-to-date with developments, especially those outside their own specialist areas.

AH Do you collaborate with others, apart from article authors?

BR I collaborate very closely with Rob Hine, the Centre's talented graphics designer. He prepares the figures for publication and does the typesetting so that the material is presented in a logical and attractive way. It is amazing what he can do, and how good articles look after he has prepared them for publication. He tries different things from time to time: different fonts, different colours, etc., so that the *Newsletter*'s appearance doesn't become stale. I work very closely with Rob, and it is an enjoyable partnership.

AH How would you like to see the *Newsletter* changing in the future?

BR Firstly I'd like to have more news items. I feel there is an enormous amount going on within ECMWF, but people are often too busy doing their jobs to think about preparing a news item. That's a pity, but over the years the *Newsletter* has increased the amount of news that is covered.

The second thing I'd like is to get more articles from users of the Centre's products in its Member States and Co-operating States, and from the wider meteorological community. At present most articles in the *Newsletter* come from the Centre's Research Department, but I'm very keen to have more articles about operational aspects that are of direct interest to forecasters and other users of the Centre's products.

Communicating science

AH I'd like to move to the subject of scientists communicating with a broader audience. Do you think scientists have the responsibility to explain what they do to a broader audience?

BR Of course communicating with other scientists involved in research and development through peer-reviewed literature is very important. But also I think that any scientific work that is publicly funded brings with it an obligation to seek opportunities to explain what is being done and why to the wider community. For meteorologists this is particularly worthwhile as people are interested in what we do.

AH What do you think scientists could do to communicate to a broader audience, for instance to attract young people to science?

BR The Centre's website is a key way of communicating with a broader audience. There is a web project going on at the Centre which will eventually make it easier for people to find the information they want. Also it is important that information is made available in a timely and attractive way at the right level.

Another way to communicate with the broader community is looking for opportunities to explain to young people what it is that we are doing. So I think it is good that some people take the opportunity to go into their local schools or participate in other public events and talk about the weather or about science. Hopefully talking about the pleasure and the satisfaction from a career in science helps inspire another generation to follow the same path that we have taken.

AH What do you think about scientists as communicators?

Are scientists skilled communicators?

BR For effective communication with both your peers and a broader audience the key is the same – think about the needs of the audience and how you are going to get your message across. In general it is best to keep things simple and avoid over-estimating the knowledge of the audience. There may be 5% of the audience who wish you had gone into more detail or in more depth about something, but you are not aiming your presentation at those people, you need to consider the other 95%.

AH Are there any other pitfalls to avoid, something one should be aware of, when speaking or writing?

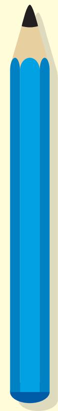
BR When speaking, no matter how much you practise your presentation beforehand, when you do it for real it takes longer. It is one of life's mysteries. So when you prepare a presentation, don't prepare it so that it exactly fits the time you've been allocated, because it will take longer. Also, think beforehand "If I'm running out of time, what am I going to do – what bit am I going to miss?".

Getting the visual material right is also important. Sometimes the slides are too complex or contain too many words, so following visual design principles is worthwhile. Indeed presenters often try to fit in too many slides.

AH Thank you very much, Bob, for this interview. A final question: did you ever go to Antarctica?

BR No, I haven't been to Antarctica, but every so often I see adverts in newspapers about trips to Antarctica – I must go there one day!

Effective writing



Any written material should be clear and concise and at a level appropriate or the readers. Here are some tips that might help.

- Avoid complex sentences and the use of unnecessary words or phrases.
- Vary sentence length and structure.
- Avoid long paragraphs covering more that one topic.
- Avoid a long string of adjectives in front of a noun.
- Use active rather than passive verbs.
- Avoid jargon, clichés and the overuse of particular words.
- Explain abbreviations and acronyms
- Use section headings to help guide the reader.

Effective presentations

The first step is to consider the objective of the presentation. This should be based on the characteristics of the audience. Asking the following questions might be helpful:

- What does the audience already know about the subject?
- What does the audience expect to get out of the presentation, and what do I want the audience to get out of it?
- How will they benefit from the presentation?

Also it is important to ensure the presentation material is effective. Adhering to six visual design principles will help make the material visually appealing and support effective communication.

- ***Simplify***. Eliminate words or graphics that do not support understanding.
- ***Contrast***. Use contrast to focus attention on the important things.
- ***Repetition***. Be consistent with repetition of style, colour and layout.
- ***Alignment***. Align headings, text and graphics.
- ***Proximity***. Ensure that things that go together are placed together.
- ***Images***. Use high quality images and minimal clip-art.

Global, non-hydrostatic, convection-permitting, medium-range forecasts: progress and challenges

NILS P. WEDI, MATS HAMRUD, GEORGE MOZDZYNSKI, GEIR AUSTAD, SINISA CURIC, JEAN BIDLOT

Numerical weather prediction (NWP) requires an answer in real time: after observations have been gathered, transmitted, received, processed and analysed there is a window of approximately one hour to run ECMWF's medium-range global forecast such that it can be delivered to the Member States in time for them to provide services to their customers. Moreover, forecasts are not based only on single realizations when assessing the fidelity of severe weather predictions. Ensembles of simulations and assimilations are run every day using the same dynamical model, suitably perturbed, to spread as much as possible across the range of uncertainty in the initial conditions, due to model and observation errors, and more fundamentally due to the error growth of the truncated solutions of the governing non-linear equations.

While computational efficiency remains one of the most pressing needs of NWP, there is an open question about how to make the most efficient use of the affordable computer power that will be available over the next decades, while seeking the most accurate forecast possible. Fundamental to the latter is the development of a high-resolution assimilation, forecast and ensemble system that is highly scalable (i.e. can exploit massively parallel computers). Such a system would be able to resolve and describe organized cloud systems with deep moist convection in the atmosphere and small-scale orographic, land-cover and land-use features as well as waves and eddies in the ocean. All of these are important aspects of increasing the skill and fidelity of severe weather predictions in a changing climate. Equally, the randomness of probabilistic Earth-system models must be built around a meaningful and accurate prediction of the mean circulation so as not to render the assessment of uncertainty useless.

At the same time there are significant scientific challenges associated with further resolution increases: how to change the governing equations because the hydrostatic assumption is no longer satisfactory for the scales resolved and how to best represent sub-gridscale processes? The problems associated with both aspects and their interconnection have already been described in an earlier newsletter article (*Wedi & Malardel*, 2010). ECMWF plans to implement a global horizontal resolution of approximately 10 km by 2015 for its assimilation and high-resolution forecasts, and approximately 20 km for the ensemble forecasts, which is in line with its steady progress in resolution increases over the past thirty years. The scales resolved at these resolutions are still hydrostatic and the efficiency of the current hydrostatic, semi-Lagrangian, semi-implicit solution procedure using the spectral transform method is likely to remain a relevant benchmark.

In this article we describe a breakthrough in the acceleration of the spectral transform technique, the fast Legendre transform, and subsequently ECMWF's first ever global, convection-permitting, non-hydrostatic weather forecasts at up to T7999 or equivalently ~2.5 km horizontal gridlength. Several examples illustrate the great potential of ECMWF's new ultra-high resolution capabilities.

Fast Legendre Transform

The spectral transform method involves discrete spherical harmonic transformations between:

- Physical (gridpoint) space, where the (semi-Lagrangian) advection and the physical parametrizations are computed.
- Spectral (spherical harmonic) space, where the Helmholtz equation arising from the semi-implicit time-stepping scheme can be solved easily and horizontal gradients are computed accurately, particularly the Laplacian operator (second-order spatial derivative) that is so fundamental to the propagation of atmospheric waves.

A spherical harmonic transformation is a Fourier transformation in longitude and a Legendre transformation in latitude. The Fourier transform is computed numerically very efficiently by using the Fast Fourier Transform (FFT). However, due to the relative cost increase of the Legendre transforms compared to the gridpoint computations, spectral transform models were believed to become prohibitively expensive at very high resolution. However, to address this issue a Fast Legendre Transform (FLT) has now been successfully implemented into Cycle 38r1 of ECMWF's Integrated Forecasting System and is the default option for horizontal resolutions beyond the current operational resolution (T1279). More detailed information about the FLT is given in Box A.

The success of the FLTs is best summarised in Figure 1 which shows the wall-clock time computational cost (in milliseconds scaled by N^2, where N denotes the truncation limit) of the spectral transforms during a one-hour T7999 simulation with 40 vertical levels with and without the fast transforms. The computational cost of the transforms at T7999 resolution is more than halved using the FLTs.

Figure 1 also shows results for a one-hour T3999 simulation with 40 vertical levels, indicating a much lower cost increase from T3999 to T7999 when the FLTs are used. Note that the number of spectral transforms performed in the T7999 simulations is twice as large because a time-step of 1 minute was used compared to 2 minutes in the T3999 simulations. All simulations used the non-hydrostatic high-resolution model. It is also worth noting that the saving is per simulated hour and therefore is also substantial at T3999.

A particular concern is the computational efficiency of the non-hydrostatic model formulation in part due to its increased use of spectral transforms. Additional runs using the hydrostatic version of the model confirm that the cost of the non-hydrostatic T7999 simulation with FLTs is reduced to a level below the cost of an equivalent hydrostatic T7999 simulation without FLTs. Notably, the hydrostatic model requires two prognostic three-dimensional variables less and does not need the use of an iterative scheme for stability, thus more than halving the number of transforms required compared to the corresponding non-hydrostatic simulation. The results suggest that the concern about the disproportionally growing computational cost of the Legendre transforms with increasing resolution has been mitigated. At T2047 (or equivalently ~10 km horizontal grid length), T3999 (~5 km) and T7999 (~2.5 km) the spectral transform computations take approximately 17%, 20% and 25% of the total elapsed model simulation time.

The cost and latency of the parallel communications of the spectral transforms and the communications within the spectral computations remain a concern. Spectral-to-gridpoint transformations require data-rich global communications at every timestep that may become too expensive on future massively parallel computers. This aspect is being investigated as part of the Collaborative Research into Exascale Systemware, Tools and Applications (CRESTA) project and preliminary results suggest a way forward through the use of modern computer language concepts (e.g. PGAS) to overlap computations and communications. Moreover, there is some evidence that further reductions in the wall-clock time computational cost of the spectral transforms may be achieved by use of GPU (graphics processor unit) and vector technology.

Fast Legendre Transform (FLT) — A

Legendre transforms involve many sums of products between associated Legendre polynomials at given (Gaussian) latitudes and corresponding spectral coefficients of the particular field (such as temperature or vorticity at a given vertical level).

The FLT algorithm is based on the fundamental idea that for a given zonal wavenumber all the values of the associated Legendre polynomials at all the Gaussian latitudes of the model grid have similarities that may be exploited in such a way that one does not have to compute all the sums. Rather, FLTs pre-compute a compressed (approximate) representation of the matrices involved in the original sums and then apply a compressed (reduced) representation instead of the full representation at every time-step of the model simulation. The cost increase involved in the additional pre-computation step is negligible (typically less than 0.1% of the total elapsed time of a 10-day forecast).

ECMWF's first ultra-high resolution, convection-permitting, global weather forecasts

With the FLTs in place, using ECMWF's recently installed IBM Power 7 computer produced the first 10-day forecasts at T3999 (~5 km grid interval) with the operational 91 vertical levels. At this resolution each prognostic variable has approximately 21 million points per vertical level, and with 14,336 compute threads (i.e. independent and in parallel executed program instructions) about 23 forecast days per (wall-clock) day were achieved. In addition, the world's first global T7999 12-hour forecast (~2.5 km grid interval with about 80 million points per vertical level) has been successfully completed. Using 12,800 compute threads, not surprisingly, the speed was only 2.7 forecast days per day, so just ahead of real time. The T7999 simulation was restricted to only 40 vertical levels due to the large memory requirements and the compute threads were physically spread over more than half of the total IBM Power 7 cluster.

To put these numbers in perspective, we would require about one million compute threads to achieve the operational requirement of 240 forecast days per day at T7999 resolution (and more with a corresponding increase in the number of vertical levels) and it remains an open question whether the relative cost of communications for such a computer will scale accordingly. Nevertheless, "that's one small step...". The ability to run such ultra-high resolution simulations and the evaluation of their results will greatly impact on our understanding of the multi-scale interactions, from convective to global scales, while feeding back into future weather and climate model developments.

The first integration of a global, non-hydrostatic, convection-permitting simulation at ECMWF, where non-

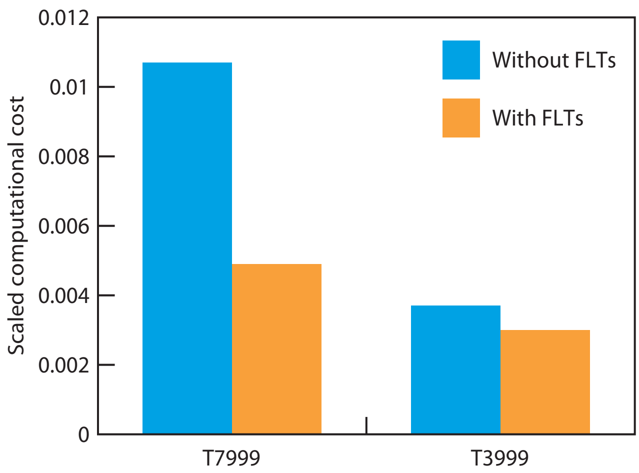


Figure 1 Wall-clock time computational cost (in milliseconds scaled by N^2, where N denotes the truncation limit) of all the spectral transforms during a one-hour simulation with $N=7999$ and $N=3999$ respectively, and with 40 vertical levels. A comparison is made between otherwise equivalent non-hydrostatic high-resolution simulations with (red) and without (blue) fast Legendre transforms (FLTs). The latter use the standard matrix-matrix multiply routine (DGEMM) instead. Since the number of spectral transforms performed in the T7999 simulations is twice as large, because a time-step of 1 minute was used compared to 2 minutes in the T3999 simulations, the T3999 values have been scaled accordingly.

hydrostatic effects start to be resolved, has been made possible not least because of the successful collaboration between Météo-France and ECMWF. Naturally, the handling of these ultra-high resolution datasets is challenging and specialised software had to be written to handle the latest satellite-derived surface datasets to be used as initial and boundary data in the T3999 and T7999 forecasts. ECMWF's newly developed interpolation software ecRegrid has been used for creating and processing the climatological ultra-high resolution surface datasets. Here we would also like to thank Manuel Fuentes, Fernando Ii and Iain Russell for their help with archiving and plotting this data.

Error growth and kinetic energy spectra

An important point to make is that these resolutions are well beyond the spatial resolution of the globally-available observations, and our simulations indicate a faster (root mean square) error growth over the first 24 to 48 hours with substantial kinetic energy in the smaller scales cascading upwards, in particular over the first 12 hours. This effect is best illustrated with the T7999 simulation initialised from the T1279 (~16 km) analysis (suitably interpolated from low-to-high resolution) yet forced with the underlying climatological topographic and land-cover information representative of 2.5 km resolution.

Figure 2 shows the global horizontal kinetic energy spectra at 500 hPa for the first 12 hours of the T7999 simulation, where a relative maximum can be clearly identified at the smaller scales not represented by the analysis. But as time progresses the 'energy gap' is filled quickly, consistent with experience from limited-area model studies forced by global models, where the observed -5/3 energy spectrum

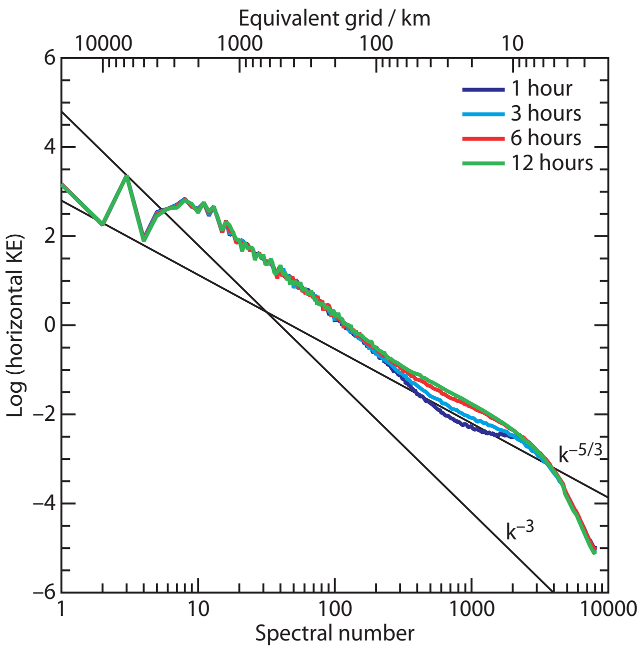


Figure 2 Global horizontal kinetic energy spectra at 500 hPa height for the first 12 hours of the T7999 (~2.5 km grid length) simulation against the total wavenumber (with the largest number corresponding to the truncation limit of the spherical harmonics series expansion, i.e. 7999).

is established very quickly (*Skamarock*, 2004). Notably, we find approximately equal contributions from divergent and rotational motions (not shown) to the well resolved part of the global -5/3 kinetic energy spectrum starting from about wavenumber 300 (~70 km).

The results concerning the kinetic energy spectrum are of significant theoretical importance (*Lindborg*, 2007). On the one hand this result provides bounds of validity to quasi-geostrophic theory, the fundamental explanation of the dynamic evolution of large-scale atmospheric flow, since the horizontal divergence spectrum is far from negligible as would be the case for geostrophic flow. On the other hand, the equipartition of divergent and rotational contributions over a wide range of wavenumbers (300 to 3,000), which is established within the first 6 to 12 hours of simulation and then maintained, rules out the dominance of divergent motions as the main reason for the shallower tilt of mesoscale energy spectra.

As pointed out by *Skamarock* (2004), the rapid adjustment of the model in the (uninitialized) mesoscale range may indicate that these ultra-high resolution forecasts provide added value in deterministically predicting mesoscale structures when forced with realistic external forcings (i.e. orography and land-cover) and perhaps also by removing problematic parametrizations (i.e. deep convection). Indeed it is not known if the initial rapid error growth due to the small time and length scales resolved by the model may diminish the predictive skill of the ultra-high resolution forecasts or not. However, the T3999 10-day forecasts beyond the initial period of 24 to 48 hours indicate a similar large-scale (root-mean-square) error evolution compared to the T1279 control forecasts. This suggests that the influence is not overwhelming and rather stresses (a) the important challenge for data assimilation in providing accurate initial conditions at these ultra-high resolutions and (b) substantial future opportunities for ensemble data assimilation and ensemble forecasting.

Simulation of severe weather events

Improved realism can already be demonstrated with two examples of severe weather events. The first example evaluates the impact of ultra-high resolution on the predicted wave-height when the storm Xaver (also named Berit) hit the Faroe Islands on 25 November 2011. Figure 3 shows the 24-hour T1279 forecast coupled to the (operational) 0.25° wave model and the 24-hour T3999 forecast coupled to the higher resolution 0.1° wave model, both compared to buoy observations. The added value of the finer resolution is seen in the much more realistic prediction of monster waves approaching, as not only surfers but anybody at sea or on the shore will appreciate the difference, whether to expect a 10 or 15 metre swell!

The second example picks up on the often publicised shortcoming of operational forecast models at the time failing to predict the true intensity of 'Lothar' on 26 December 1999 with record wind speeds observed in France, Germany and Switzerland. A particular aspect of this storm was its rapid development and progression from

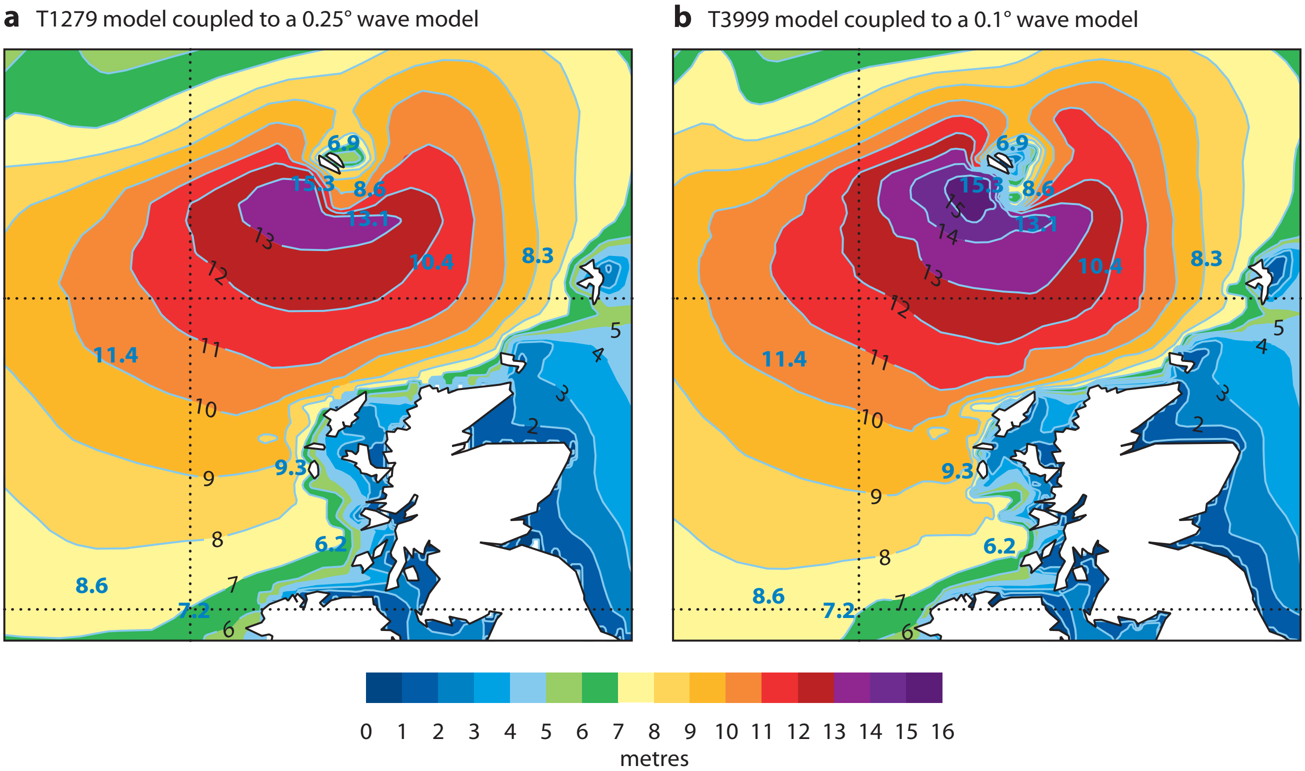


Figure 3 24-hour forecast for significant wave height for 00 UTC on 25 November 2011: (a) T1279 model coupled to a 0.25° global wave model (operational configuration) and (b) T3999 model coupled to a 0.1° global wave model. The blue numbers are the corresponding two-hourly averaged significant wave height observations (data from the UK Met Office, UK WaveNet Programme, Irish Marine Institute, and Faroese Office of Public Works).

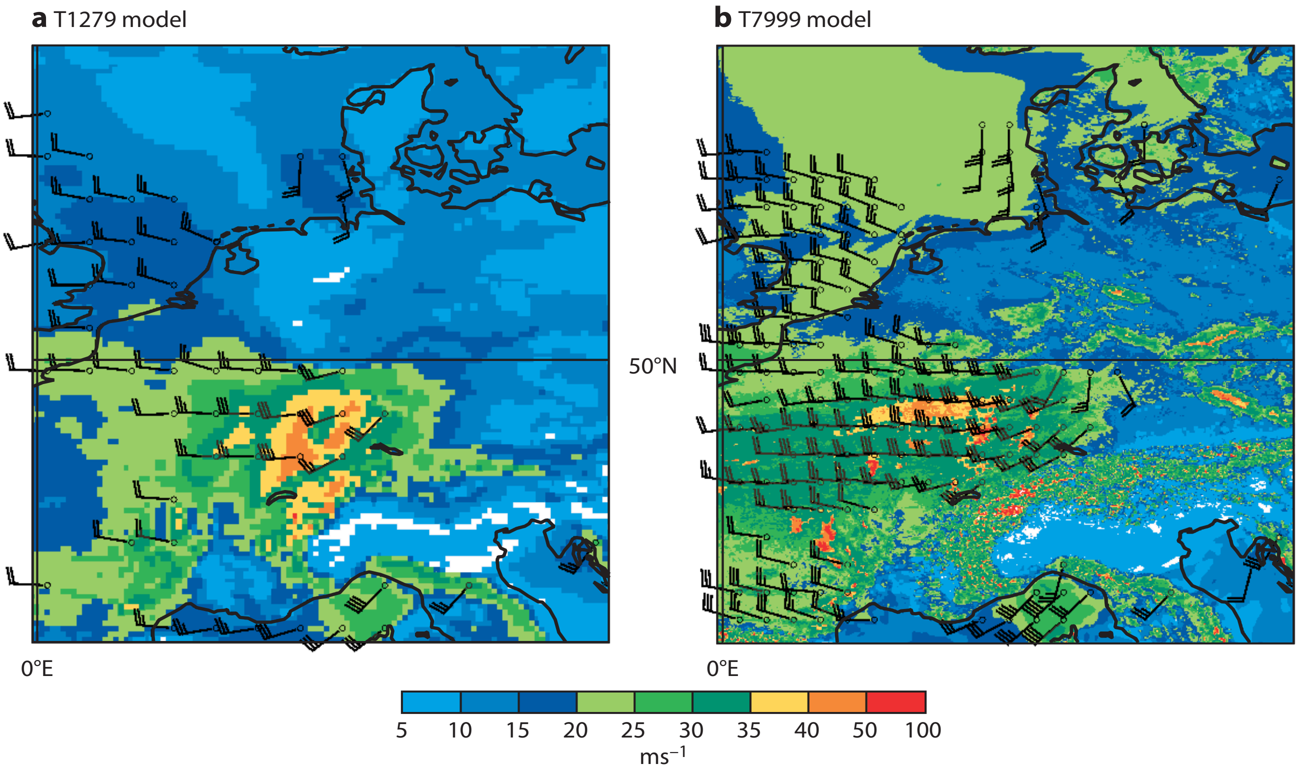


Figure 4 11-hour forecast of wind gusts and 10-metre surface winds for the Christmas storm 'Lothar' on 26 December 1999 from: (a) T1279 (~16 km) model and (b) T7999 (~2.5 km) model. During the storm some of the highest wind speeds ever recorded in Europe were observed (69 ms^{-1} on Jungfraujoch, Switzerland; 75 ms^{-1} on Hohentwiel, Singen, Germany). The trail of 'destruction' is clearly marked by the wind gust data. Note that the lower mountain ranges now prominently feature in the wind gust data for T7999.

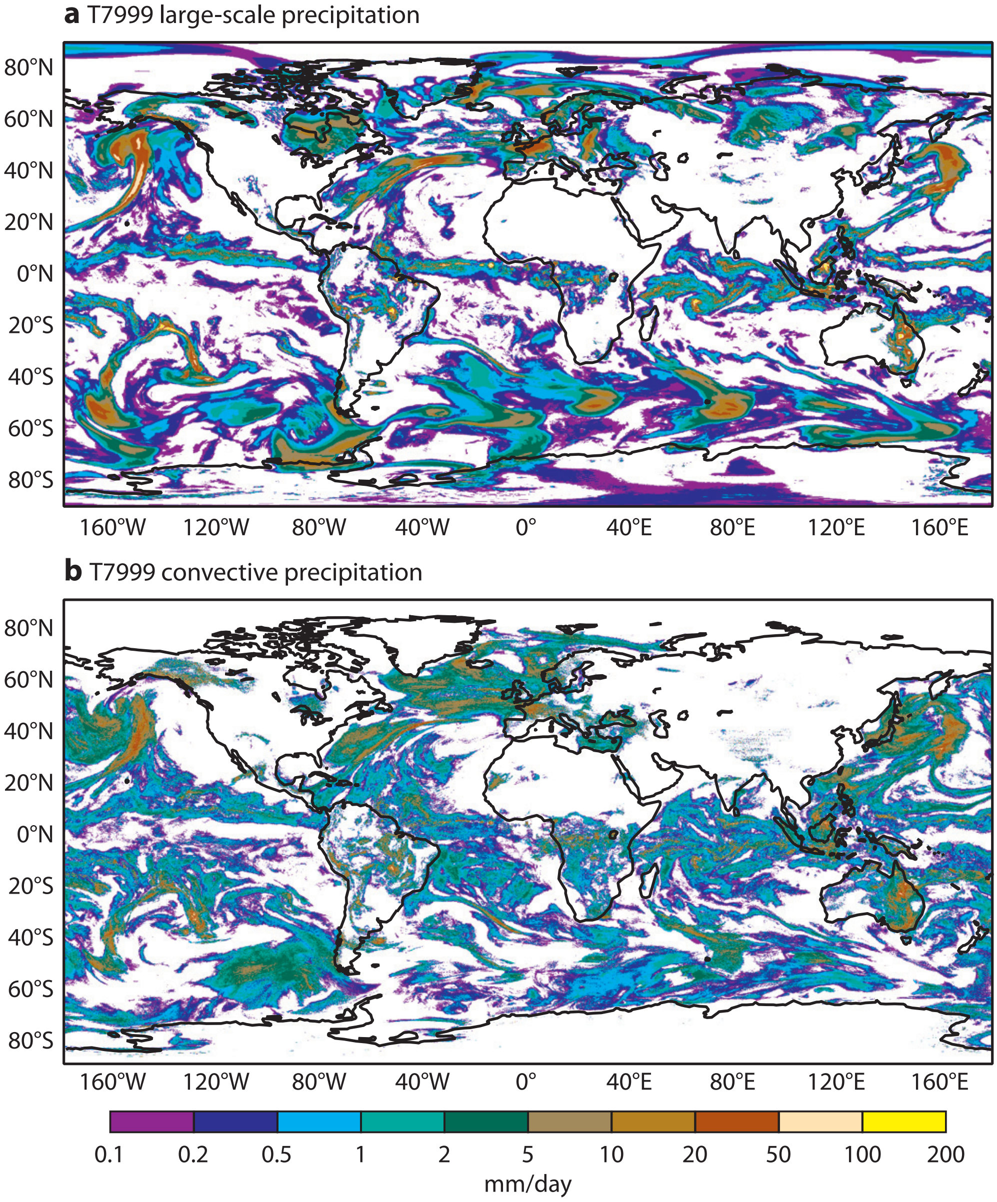


Figure 5 Global (a) large-scale precipitation and (b) convective precipitation for the T7999 (~2.5 km) simulation with an explicit representation of deep convection after 9 hours. Note that in this simulation convective precipitation originates only from the still parametrized shallow convection. The parameter 'large-scale precipitation' is not so large-scale anymore at this resolution as it includes all the explicitly resolved motions including deep convective systems.

the Atlantic across France to Germany making it difficult to capture with high-resolution limited-area models forced by low-resolution global boundary conditions. In this case the large-scale conditions triggered a meso-scale development of hurricane strength within just a few hours. Even as late as the evening before the storm affected large parts of Europe, one would not have easily spotted it on the satellite picture.

Figure 4 shows the expected wind gusts and surface winds predicted (just) 11 hours in advance by the T1279 (~16 km) forecast compared with the T7999 (~2.5 km) forecast, neither of which was available at the time. While both forecasts much improve on the predicted level of excessive wind speeds compared to the actual forecasts available at the time, it is the ultra-high resolution that matches much closer the reality of extraordinary high wind speeds, especially for the Alps and for the lower mountain ranges throughout Western Europe.

Explicit representation of convection

A big step forward in the development of global models is the transition from a parametrized (where sub-gridscale effects are expressed in terms of grid-scale parameters) to an explicit representation of convective processes. This is a big and problematic transition because, with increasing resolution, the model explicitly resolves large thunderstorm cells, towering nimbostratus and cumulonimbus clouds, as well as cloud clusters and fronts with embedded deep convection, yet part of their early development (i.e. starting from a little cumulus cloud) is not. The T7999 simulations are also the first global high-resolution forecasts from ECMWF with an explicit representation of deep convection

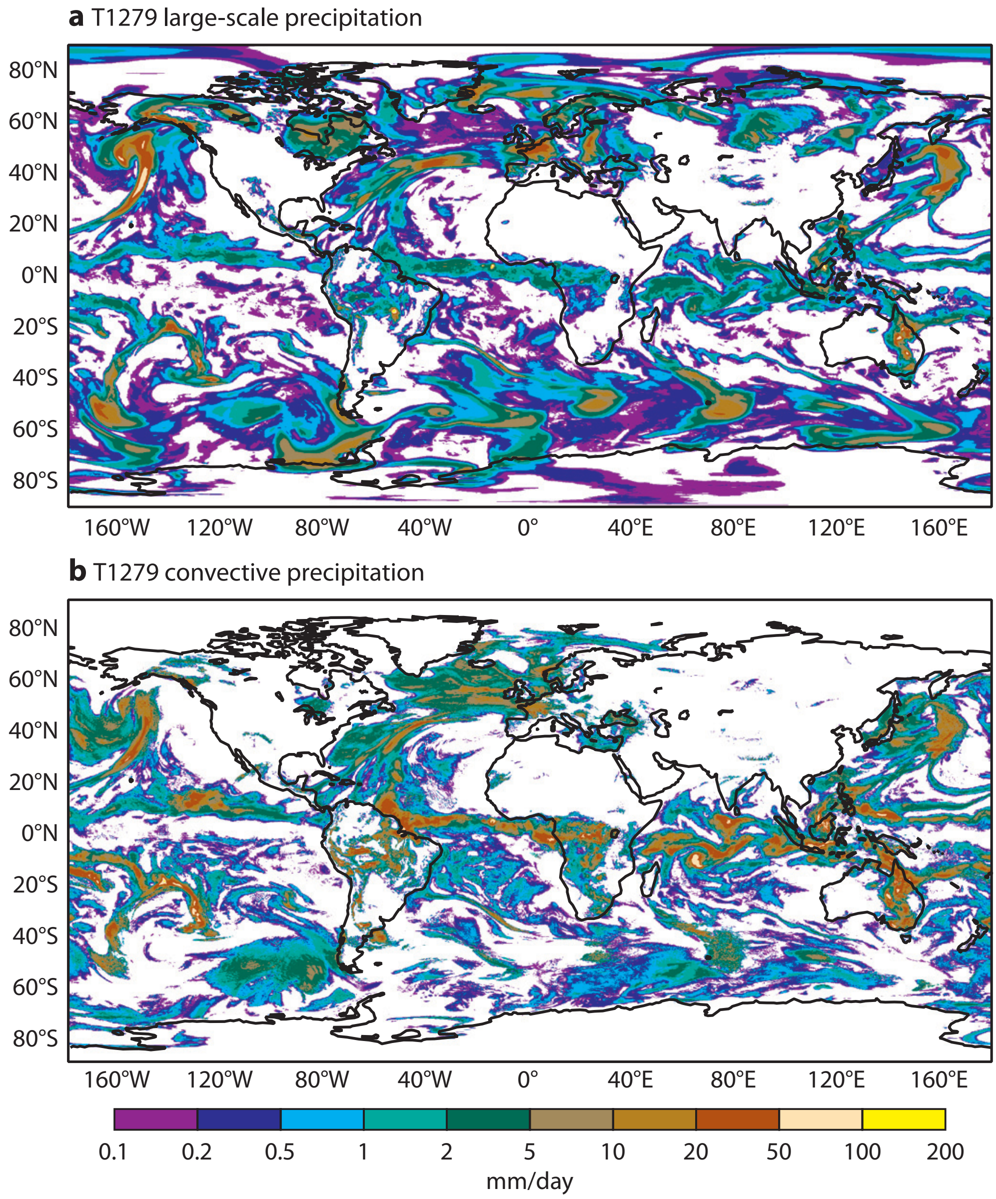


Figure 6 Same as Figure 5 but for the T1279 (~16 km). In this case both deep and shallow convection are parametrized.

(i.e. with the deep convection parametrization switched off). Detailed studies of the data will hopefully provide us with much insight on this transition region.

Here a preview is given of the large-scale and convective precipitation from the T7999 model (Figure 5) compared with equivalent simulations using parametrized deep convection at the operational resolution of T1279 (Figure 6). At ultra-high horizontal resolutions the cloud microphysics and the vertical and horizontal transport of hydrometeors become very important and a more different picture may have perhaps been expected (*Wedi & Malardel*, 2010). However, it is reassuring that the large-scale precipitation is quite similar in the T1279 and T7999 simulations, with parametrized shallow convection still covering large parts of the globe in both, and with only few systematic (but positive) reductions in convective precipitation over some areas in the T7999 simulation. This comparison provides further evidence of the fundamentally deterministic predictability at larger scales albeit explicit representation of the smallest scales.

What next?

Much work will be required to turn the glimpse of ultra-high resolution capabilities into an operational reality over the next 20 years, but undoubtedly, considerable opportunities for research lie ahead and ECMWF is now in a good position to explore these.

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ECMWF soil moisture validation activities

CLEMENT ALBERGEL, PATRICIA DE ROSNAY, GIANPAOLO BALSAMO, JOAQUIN MUÑOZ-SABATER, SOUHAIL BOUSSETTA, LARS ISAKSEN

The importance of soil moisture in the global climate system has recently been underlined by the Global Climate Observing System (GCOS) Programme endorsing soil moisture as an Essential Climate Variable. It is a crucial variable for weather and climate predictions and plays a key role in hydrological processes. A good representation of soil moisture conditions can help to improve (a) the forecasting of precipitation, droughts and floods, and (b) the making of climate projections and predictions.

In situ measurements of soil moisture are an indispensable source of information for evaluating soil moisture analyses and forecasts. At ECMWF they are used to evaluate the operational soil moisture analysis and the interim reanalysis (ERA-Interim). They also support of the development of new land-surface parametrizations and analysis systems.

In this article we describe the soil moisture validation strategy adopted at ECMWF and present a selection of validation results.

Soil moisture validation strategy

Soil moisture is usually defined as the amount of water present in the unsaturated part of the soil (i.e. between the soil surface and the ground water level) and is generally expressed as the volumetric fraction of water in a given soil depth (m^3 water per m^3 soil). While in the 1990s records of in situ soil moisture measurements were available for only a few regions and often for only short periods, huge efforts were made in recent decades to make available such observations in contrasting biomes (i.e. major ecological communities, extending over a large area and usually characterized by a dominant vegetation) and climate conditions. The establishment of the International Soil Moisture Network (ISMN, http://www.ipf.tuwien.ac.at/insitu/), a new data hosting centre where globally-available ground-based soil moisture measurements are collected, harmonized and made available to users, is a clear indication of the importance attached to making such data available to the scientific community.

ECMWF has collected data from several networks across the world to establish a comprehensive database of in situ soil moisture measurements – some of these networks are illustrated in Figure 1. The database is used to evaluate various soil moisture products from ECMWF's Integrated Forecasting System (IFS).

Figure 2 gives an overview of the SMOSMANIA network in southwestern France, which is extensively used at ECMWF for validation purposes. It is a unique data set; for the first time, automatic measurements of soil moisture have been integrated in an operational meteorological network (i.e. the RADOME network of Météo-France). At those sites, four soil moisture probes were installed at each station at depths of 5, 10, 20 and 30 cm. The probes used the dielectric permittivity properties of the soil to estimate the volumetric soil moisture content – this is a common way to measure soil moisture. Site-specific calibration curves were developed using in-situ gravimetric soil samples to convert the signal from the probe into volumetric soil moisture content. As calibrations have to be performed for each soil type (i.e. for all stations) and for each depth, 48 calibrations curves were obtained for the SMOSMANIA network. The calibration was performed both in situ and in a laboratory (monitoring of a given sample in various controlled conditions).

In recent years the land-surface modelling and analysis systems at ECMWF have been extensively revised. An improved soil hydrology, new snow scheme, multi-year satellite-based vegetation climatology and new bare-ground evaporation have been included in the IFS. Also a new soil moisture analysis scheme, based on a point-wise Extended Kalman Filter (EKF) for the global land surface, was developed and implemented. *ECMWF Newsletter No. 127* (12–16, 17–22 and 23–27) described in more detail all these recent upgrades of land-surface processes and analysis

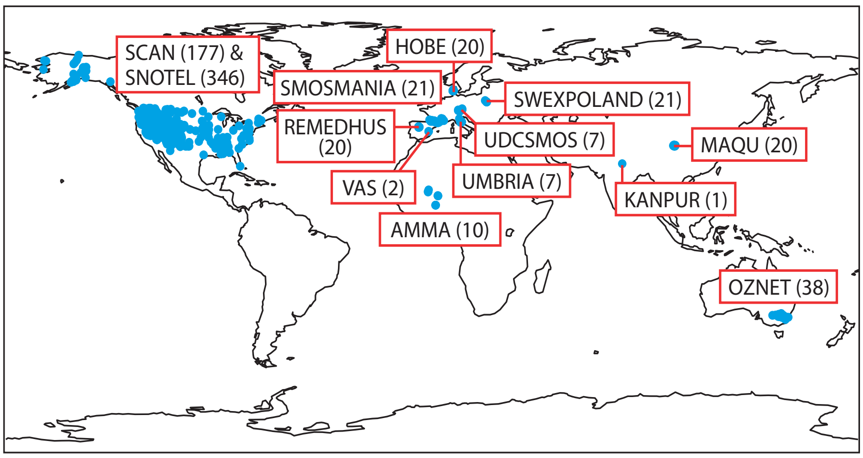

Figure 1 Location of some in-situ soil moisture stations used at ECMWF for validation activities.

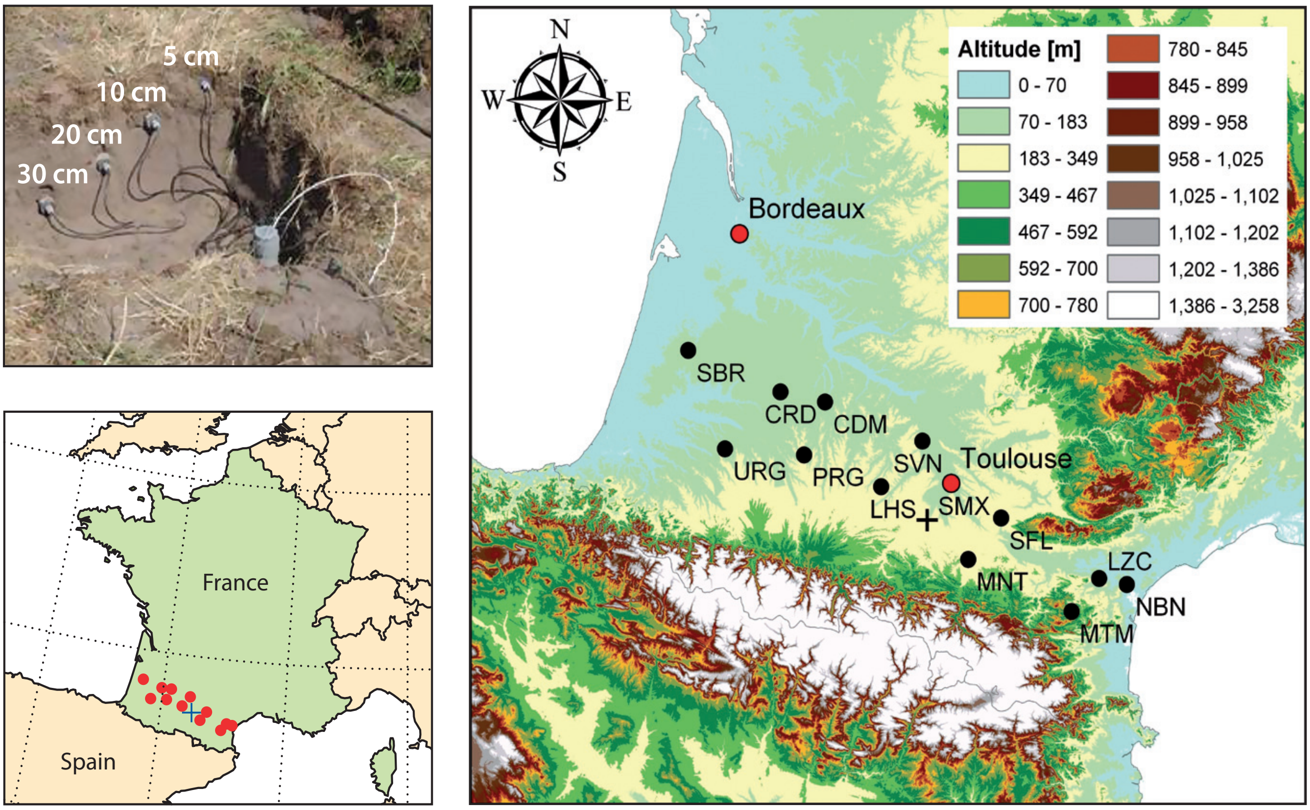

Figure 2 Illustration of the SMOSMANIA network (from Météo-France). In-situ soil moisture measurements from this network were used to evaluate various ECMWF's soil moisture analyses. The digital elevation model (90 m) is from the Consortium for Spatial Information (CGIAR-CSI), http://srtm.csi.cgiar.org. The SMOSMANIA network used ThetaProbe ML2X of Delta-T Devices.

affecting soil moisture. As with any updates, it is important to validate their impact.

The in situ data has been used to evaluate soil moisture from ECMWF's operational analysis, ERA-Interim and research experiments (*Albergel et al.*, 2012a,b). While the IFS is updated regularly to improve the analysis and modelling systems, ERA-Interim is produced using a fixed version. In addition, in-situ measurements have been used to evaluate the impact of two specific modifications: the new bare-ground evaporation and the new EKF soil moisture analysis. Table 1 provides more details about the experiments that are being evaluated.

The main metrics used for comparing in situ soil moisture data with model fields are the temporal correlation, bias (in situ minus ECMWF data) and root-mean-square difference (RMSD). Box A presents the validation methodology in detail. The rationale for using the root-mean-square difference instead of root-mean-square error is to emphasise that in situ data may contain errors (instrumental and representativeness) so they are not considered as 'true' soil moisture.

Soil moisture data set	Type	Period	Spatial resolution (as from Jan. 2007)	Land Surface Model IFS cycle***
ECMWF operational analysis	Analysis	Jan. 2007 to May 2012	*Before 26 Jan. 2010:* 23 km (T799) *From 27 Jan. 2010:* 16 km (T1279)	Cy31r2 to Cy37r3
ERA-Interim	Reanalysis	Jan. 2007 to Dec. 2012	80 km (T255)	Cy31r1
BEVAP-NEW	Surface-only simulations*	Jan. 2007 to Dec. 2010	80 km (T255)	Cy36r4
BEVAP-OLD	Surface-only simulations*	Jan. 2007 to Dec. 2010	80 km (T255)	Cy36r4 (old bare-ground evaporation)
OI **EKF** **EKF+ASCAT**	Research experiments**	Dec. 2008 to Nov. 2009	80 km (T255)	Cy36r1

Table 1 List of various soil moisture analyses used in this study.

* ERA-Interim near-surface meteorology is used as forcing term; more information in *Balsamo et al.* (2012).
** More information in *de Rosnay et al.* (2011). *** More information at http://www.ecmwf.int/research/ifsdocs/

Metrics used for the validation of soil moisture analyses

A

As in situ observations of soil moisture are frequently associated with soil temperature measurements, observations were flagged for temperatures lower than 4°C to avoid frozen conditions.

Comparison of soil moisture time series between in situ observations and ECMWF's soil moisture analysis are based on data at 00 UTC. At each station the correlation (R), bias (in situ minus ECMWF data) and root-mean-square difference ($RMSD$) are computed between observations and soil moisture analyses. Additionally, the ratio between analysed and in situ standard deviations (SDV) and the centred normalized root-mean-square difference between the analysis and in situ patterns (E) are computed.

$$SDV = \sigma_{analyse} / \sigma_{in\ situ}$$

$$E^2 = (RMSD^2 - Bias^2) / \sigma^2_{in\ situ}$$

The SDV gives the relative amplitude whilst E quantifies errors in the pattern variations. Note that E does not include any information on biases since the means of the fields are subtracted before computing second order errors.

R, SDV and E are complementary but not independent as they are related by:

$$E^2 = SDV^2 + 1 - 2 \cdot SDV \cdot R$$

Taylor diagrams, like those found in Figure 4, represent these three statistics using two-dimensional plots.

The normalized standard deviation (SDV) is displayed as a radial distance and the correlation with in situ data (R) as an angle in the polar plot.

In situ data are represented by a point located on the horizontal axis at R = 1 and SDV = 1. The distance to this point represents the centred normalized root-mean-square difference (E) between the analysis and in situ patterns.

The p-value, a measure of the correlation significance, is also calculated. It indicates the significance of the test. Only cases with p-values below 0.05 are considered.

Usually, soil moisture time series show a strong seasonal pattern that could artificially increase the agreement between satellite and in situ observations in terms of R. Therefore, to avoid seasonal effects, monthly anomaly time series are also be calculated. The difference from the mean is calculated for a sliding window of five weeks (if there are at least five measurements in this period), and the difference is scaled to the standard deviation. For each soil moisture estimate at day (i), a period F is defined, with $F = [i - 17, i + 17]$ (corresponding to a five-week window). If at least five measurements are available in this period, the average soil moisture value and the standard deviation are calculated. R is computed for both volumetric and anomaly time series.

The ECMWF Land Surface Model (LSM) is a multi-layer model where the soil is discretized in four layers with depths of 0.07, 0.28, 0.72 and 2.89 m (from top to bottom). In-situ measurements at corresponding depths are used to evaluate the output from the LSM. For example, observations at a depth of 5 cm are used to evaluate the first layer (0–7 cm).

Evaluation of the operational analysis and ERA-Interim

During 2008–2010, averaged statistical scores for the correlation, bias and root-mean-square difference (RMSD) are given below for the operational analysis and ERA-Interim (first layer of soil) when compared to in situ soil moisture from 117 stations across the world under different biome and climate conditions (Europe, USA, West Africa, Australia).

	Operational analysis	ERA-Interim
Correlation	0.70	0.63
Bias (m^3m^{-3})	-0.081	-0.079
RMSD (m^3m^{-3})	0.113	0.121

In general, both products captured well the temporal dynamics of the observed soil moisture, though the operational analysis has slightly better scores than ERA-Interim.

Figure 3 illustrates the soil moisture from ECMWF's operational analysis and ERA-Interim, compared to in situ data from two SMOSMANIA stations (Sabres and Lahas) from southwestern France for the period 2007–2010. Until October 2007 the operational and ERA-Interim results are similar, but after the implementation of the H-TESSEL land-surface scheme in operations in November 2007 was a shift in the soil moisture range (e.g. a shift down for Sabres and up for Lahas station). It is clear that, because of the use of H-TESSEL, the operational soil moisture analysis has a larger variability than ERA-Interim which uses the original TESSEL model. Overall the H-TESSEL implementation leads to a larger dynamical range and is in better agreement with the in situ observations.

To assess the ability of ECMWF analyses to capture the short-term soil moisture variability, anomaly time-series were derived and the correlations were computed. For this group of stations, correlations of the anomaly time-series range from 0.29 to 0.61 with an average of 0.51 for the operational analysis and from 0.27 to 0.62 with an average of 0.49 for ERA-Interim. Correlations of volumetric time series are larger than those for the monthly anomaly time-series. This is largely explained by the seasonal variations being suppressed in the monthly anomalies.

Figure 4 shows two Taylor diagrams (see Box A for further detail) illustrating the statistics from the comparison between soil moisture from ECMWF and in situ data for the 12 stations from the SMOSMANIA network during 2008–2010 (the diagram on the left is for the first layer of soil, 0–7 cm and the one on the right is for the first two layers, 0–28 cm). These results show a very high level of correlation between ECMWF soil moisture and in situ data: most values are between 0.70 and 0.90 (as indicated by the angle in the Taylor diagrams). Also, they show that the variability of

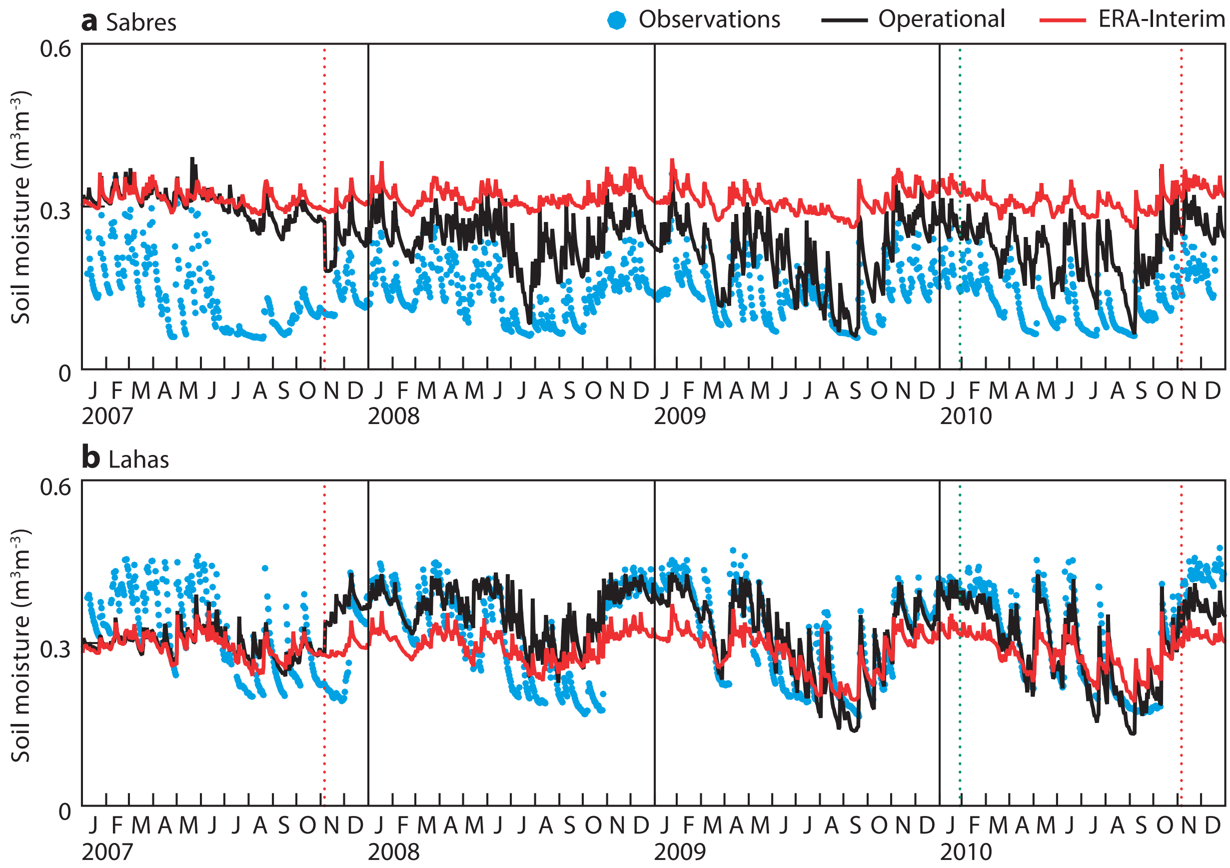

Figure 3 Soil moisture time series for the first layer of soil (0–7 cm) for 2007–2010 for two stations of the SMOSMANIA network: (a) Sabres and (b) Lahas. Results are shown for in situ observations, the ECMWF's operational analysis and ERA-Interim. Dashed vertical lines indicate major changes in the operational system affecting soil moisture: in November 2007 the implementation of H-TESSEL, in January 2010 a change in the spatial resolution from 23 km (T799) to 16 km (T1279) and in November 2010 the implementation of the EKF soil moisture analysis and bare-ground evaporation parametrization.

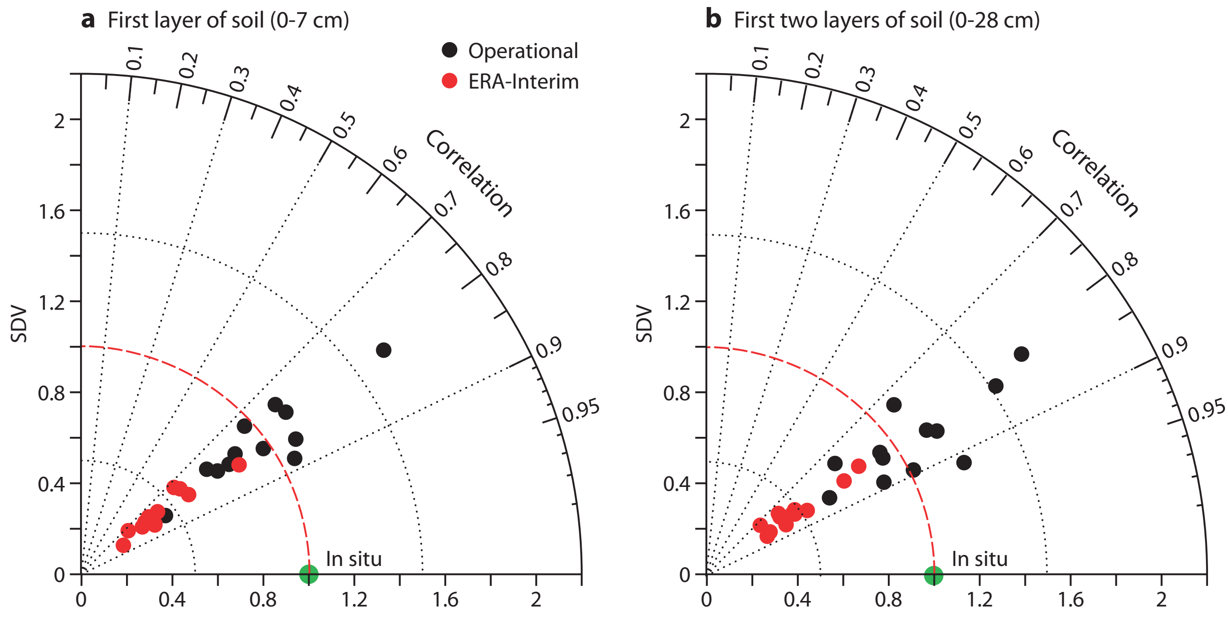

Figure 4 Taylor diagrams illustrating the statistics from the comparison between ECMWF's operational analysis and ERA-Interim reanalysis against in situ observations for (a) first layer of soil (0–7 cm) and (b) first two layers of soil (0–28 cm) and in situ observations from the SMOSMANIA network for 2008–2010. Symbols indicate at each station the correlation (angle), normalized SDV (radial distance to the origin point), and normalized centred root-mean-square error (distance to the green point marked "In situ") between the ECMWF analysis and in situ data. The red, dashed line indicates an SDV value of 1.

ERA-Interim (red dots), which is gauged by the normalised standard deviation (SDV), is smaller than that of the operational analysis (black dots) compared to in situ data (as indicated by the radial distance in the Taylor diagrams). Also the ERA-Interim analysis has SDV values that are systematically lower than 1 (i.e. the red dashed line). This indicates that the variability of the in situ data is higher than for ERA-Interim. Although, both the operational analysis and ERA-Interim show good skills in capturing the variability of surface soil moisture, they tend to overestimate soil moisture, particularly for dry land. This is consistent with the statistical scores presented above.

Overestimation of soil moisture by ECMWF compared to in-situ observations might be caused by shortcomings in the models representation of soil textures, and by the difficulty of representing the heterogeneity of soil moisture. The spatial variability of in situ soil moisture is very high and differences in soil properties could imply differences in its mean and variance.

Support for the new land-surface parametrization

In situ soil moisture data from 122 stations across the United States from SCAN (Soil Climate Analysis Network) were used to evaluate the impact of a new bare-ground evaporation formulation described by *Balsamo et al.* (2011) and *Albergel et al.* (2012b). This model upgrade produces more realistic soil moisture values when compared to in situ data, particularly over bare-ground areas.

Two experiments were run.

- *BEVAP-NEW*: Used the new bare-ground evaporation formulation.
- *BEVAP-OLD*: Used the old bare-ground evaporation formulation and acted as the control.

More information about these experiments is given in Table 1.

Considering the field sites with a fraction of bare ground greater than 0.2 (according to the model), the RMSD of soil moisture is shown to decrease from 0.118 m^3m^{-3} to 0.087 m^3m^{-3} when using the new bare-ground evaporation in research experiments, and from 0.110 m^3m^{-3} (in 2010) to 0.088 m^3m^{-3} (in 2011) in operations. The new scheme also improves correlations.

Figure 5a illustrates the results from BEVAP-NEW and BEVAP-OLD as well as the in situ observations for one site located in Utah (USA) with a bare-ground fraction of 0.7. Minimum values of BEVAP-OLD soil moisture are limited by the dominant wilting point for vegetation types; however ground data indicate much drier conditions, as is clearly observed from May to September 2010. The new bare-ground evaporation allows the model to go below this minimum value so BEVAP-NEW soil moisture is in much better agreement with the observations than that of BEVAP-OLD. Along with the decrease in RMSD, the correlation is

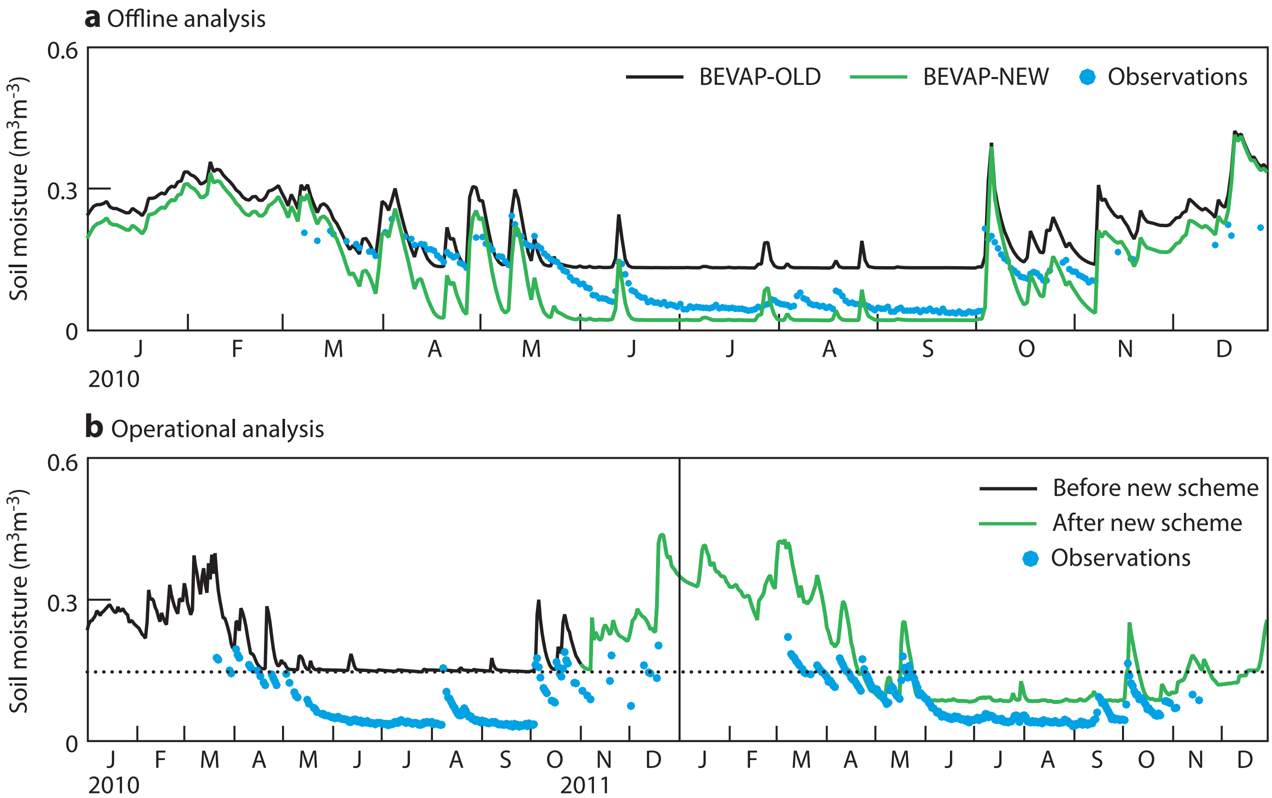

Figure 5 Surface soil moisture time series for two sites in Utah from the SCAN network. (a) Offline analysis at a site in Utah over 2010 for one-surface only simulation without the new bare-ground evaporation formulation (BEVAP-OLD) and with the new formulation of bare-ground evaporation (BEVAP-NEW; also shown are in situ observations. (b) The operational soil moisture analysis for another site in Utah during 2010–2011. The black line becomes green when the new bare-ground evaporation formulation is implemented in November 2010. Also shown are the in situ observations of surface soil moisture. The horizontal dotted line represents the model's minimum soil moisture limit before the implementation of the new bare-ground evaporation (permanent wilting point).

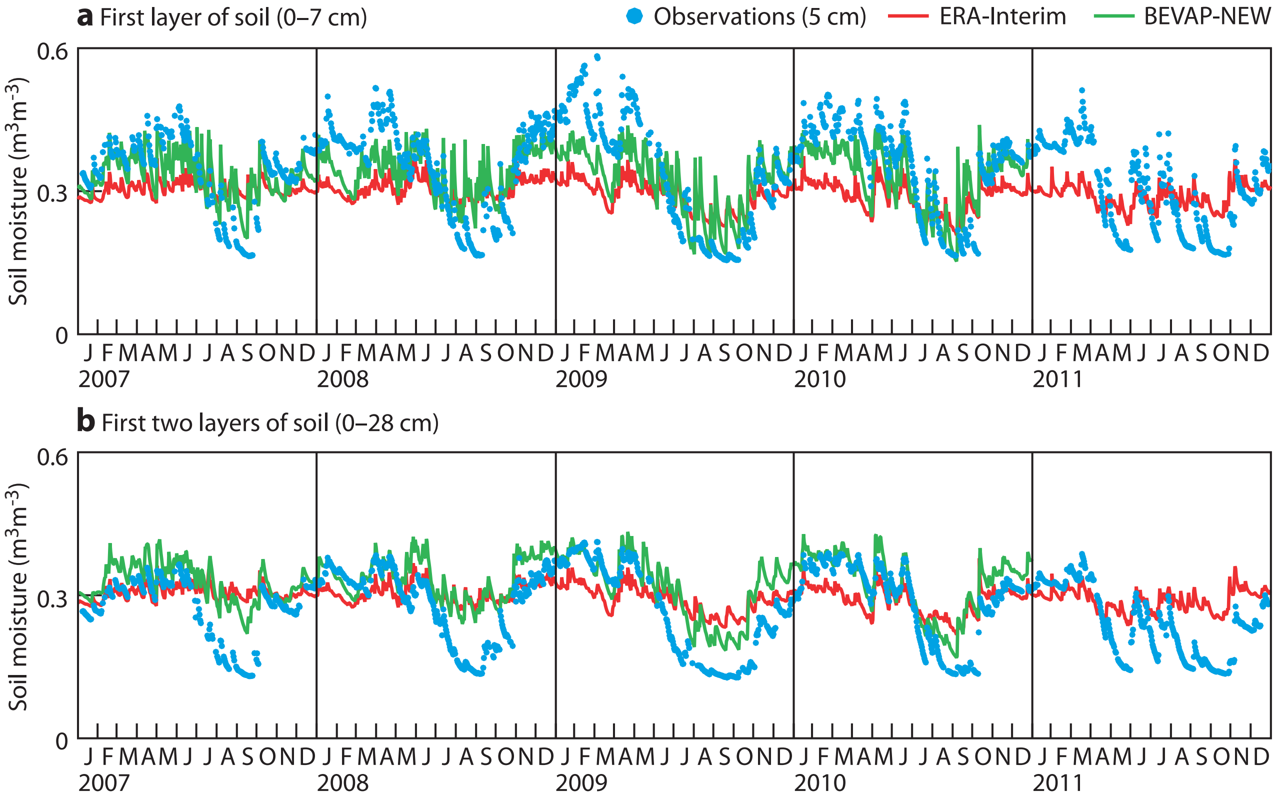

Figure 6 Illustration of soil moisture time series for (a) first layer of soil (0–7 cm) and (b) first two layers of soil (0–28 cm) from in situ data, ERA-Interim and BEVAP-NEW for the Montaut station belonging to the SMOSMANIA network in southwestern France.

increased from 0.63 to 0.65. Also BEVAP-NEW has a more realistic decrease in soil moisture after precipitation events due to its higher water holding capacity; this explains the slightly better correlations.

Figure 5b shows the operational analysis over 2010–2011. It is in much better agreement with the observations after the implementation of the new bare-ground evaporation in November 2010; this is particularly clear for the period from May to September. Considering the short-term variability, this is similar in both experiments with the average correlations for the monthly anomaly time series being 0.54 for BEVAP-OLD and 0.55 for BEVAP-NEW.

Support for the new soil moisture analysis: Extended Kalman Filter

de Rosnay et al. (2011) investigated the impact of the new EKF analysis compared to the previous Optimal Interpolation (OI) scheme. It was found that the new scheme slightly improved both soil moisture and screen-level parameters (analyses and forecasts) when verified against independent observations (e.g. correlation of 0.80 between the OI analysis and in situ data from the SMOSMANIA network from December 2008 to November 2009, but 0.84 when using the EKF). Also the EKF analysis has a stronger impact on the soil moisture of the second layer of soil.

Soil moisture data set	SMOSMANIA (France)				SCAN (USA)			
	First layer, first two layers: 12 stations in each				First layer: 153 stations, first three layers: 137 stations			
	ERA-Interim		BEVAP-NEW		ERA-Interim		BEVAP-NEW	
	First layer	First two layers	First layer	First two layers	First layer	First three layers	First layer	First three layers
Correlation	0.75	0.81	0.79	0.85	0.57	0.61	0.64	0.70
Bias (m^3m^{-3})	0.040	0.045	0.058	0.060	0.054	0.024	0.056	0.048
RMSD (m^3m^{-3})	0.099	0.086	0.091	0/080	0.111	0.093	0.124	0.104

Table 2 Results of the comparisons between in situ observations and soil moisture analyses from ERA-Interim and BEVAP-NEW for 2007–2010. Mean correlation, bias and root-mean-square difference (RMSD) are given for two networks and for two layers: first layer covering 0–7 cm versus observations at 5 cm for both networks and first two layers covering 0–28 cm versus averaged observations at 5, 10, 20, 30 cm for SMOSMANIA and first three layers covering 0–100 cm versus averaged observations at 5, 20 and 50 cm for SCAN.

The EKF scheme makes it possible to combine screen-level parameters and satellite data to analyse soil moisture. While EKF assimilations using remotely-sensed soil moisture from ASCAT show a neutral impact on both soil moisture and screen-level parameters, recent improvements in the ASCAT soil moisture products are expected to enhance its impact on the soil moisture analysis.

ERA-Interim and surface-only simulations

ECMWF recently developed a system to run surface-only simulations; it permits the updating of the land-surface component of the ERA-Interim reanalysis (Balsamo et al., 2012). With this approach, the ERA-Interim near-surface meteorology is used as a forcing term to constrain various LSMs used in the IFS. For example, BEVAP-NEW is one of these surface-only simulations – it uses the LSM in IFS cycle 36r4 forced by ERA-Interim near-surface atmospheric fields.

Now consider two soil moisture networks (SMOSMANIA in France and SCAN in the USA) and two soil moisture analyses from ECMWF (ERA-Interim and BEVAP-NEW). In this case various comparisons are performed.

- The first layer of ECMWF soil moisture (0–7 cm) is compared to observations at a depth of 5 cm.
- ECMWF soil moisture integrated over the two first layers (0–28 cm) is compared to averaged observations (5, 10, 20 and 30 cm) from the SMOSMANIA network.
- ECMWF soil moisture integrated over the first three layers (0–100 cm) is compared to averaged observations (5, 20 and 50 cm) from the SCAN network.

As an illustration, Figure 6 shows the comparison of ERA-Interim and BEVAP-NEW with the Montaut station belonging to the SMOSMANIA network for the first layer of soil (top panel) and the integrated first two layers (bottom panel). Detailed statistical scores are given in Table 2. Correlations and RMSD are slightly better when considering the first two layers (0–28 cm). Similar results were found with stations of the SMOSMANIA network in southwestern France and from the SCAN network over the USA (but with slightly lower scores for SCAN).

Latest operational soil moisture evaluation

Finally, the first layer of ECMWF's operational soil moisture analysis is evaluated in the USA (SCAN and SNOTEL networks) over the most recent period, January 2011 to April 2012. For this period, no significant model and analysis changes affected the soil moisture. An averaged correlation value of 0.70 is found for both networks. These results, plus those given in the following table, underline the good quality of the ECMWF's operational soil moisture analysis.

	SCAN	SNOTEL
Number of stations	149	257
Correlation	0.70	0.70
Bias (m^3m^{-3})	0.071	0.100
RMSD (m^3m^{-3})	0.123	0.141

Summary

A database of in situ soil moisture observations from several networks across the world, under different biome and climate conditions, was used to evaluate various ECMWF soil moisture analyses. They were shown to capture well the temporal dynamics of observed soil moisture, both in term of annual cycle and short-term variability.

All the recent updates in the land-surface modelling and analysis systems are shown to contribute to improved representation of soil moisture.

It has been shown in this article how the in situ soil moisture database gathered at ECMWF makes it possible to validate the soil moisture analysis, and how it also can be used to evaluate the impact of modifications of the land-surface parametrization and the analysis system.

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Forecast sensitivity to observation error variance

CARLA CARDINALI, SEAN HEALY

An overview of the latest developed diagnostic tool for observation usage and impact is presented. The tool consists on calculating the sensitivity of the short-range forecast error with respect to the assigned observation error variances by using the adjoint version of the assimilation and forecast model. This sensitivity is compared with the influence of the same observations in the assimilation process and their related contribution to the forecast error is also assessed. The results indicate that a reduction of the error variances for all observation types, except radiosondes and polar atmospheric motion vectors, would potentially reduce the 24-hour forecast error. In particular, a sensitivity experiment with reduced error variance for radio occultation observations shows, on average, a smaller mean 24- and 48-hour forecast difference with respect to aircraft and radiosonde measurements.

Background

The ECMWF four-dimensional variational system (4D-Var) handles a large variety of both space and surface-based meteorological observations (more than 30 million a day) and combines the observations with the prior (or background) information on the atmospheric state. Being able to assess the contribution of each observation to the analysis is amongst one of the most challenging diagnostics in data assimilation and numerical weather prediction. Methods have been developed to measure the observational influence in data assimilation schemes (see *Cardinali et al.*, 2004 and the references therein). The two key parameters are the Degree of Freedom for Signal (DFS), which quantifies how many atmospheric state elements are determined by the observations, and the Observation Influence (OI) which is the DFS divided by the number of observations (*OI*=0 indicates that background information dominates whereas *OI*=1 indicates that the observations totally dominate).

These techniques show how the influence is partitioned between the observation and the background or pseudo-observation during the assimilation procedure. They therefore provide an indication of the robustness of the fit between model and observations, and indicate the necessity for some refinement of the assigned accuracies in the assimilation system.

For the forecast, adjoint-based techniques are able to characterize the forecast impact of every measurement (see *Cardinali*, 2009 and the references therein). The technique computes the variation of the forecast error due to the assimilated data – this is known as the Forecast Error Contribution (FEC). In particular, the forecast error is measured by a scalar function of the model parameters, namely wind, temperature, humidity and surface pressure that are more or less directly related to the observable quantities. In general, the adjoint methodology can be used to estimate the sensitivity of a forecast not only to observations but also to any parameter used in the assimilation system. In particular, the sensitivity with respect the observation error variance offers guidance to variances tuning beneficial to short-range forecast (*Daescu & Langland*, 2012 and reference therein). This is quantified by FSR (Forecast Sensitivity to the observation error covariance matrix R) in such a way that positive (negative) values indicate that for a specific type of observation a decrease (increase) in the corresponding observation error variance will be of benefit.

Assessment of the ECMWF system performance

Analysis and forecast experiments using the ECMWF 4D-Var system have been performed for June 2011 to assess the impact of observations on the analysis and forecast. Figure 1a shows the DFS of all the assimilated observations.

- Microwave radiances from AMSU-A together with infrared radiances from IASI are the most informative data type, each providing 21% of the total observational information for the analysis; infrared radiances from AIRS follow with 16%.
- The information content of AIREPs (aircraft) at 9% is the largest amongst conventional observations, followed at about 4% by TEMPs (radiosondes) and in situ surface pressure SYNOP observations.
- Noticeable is the 7% contribution of GPS radio occultation (GPS-RO) data which is fourth in the satellite ranking.

The 24-hour forecast error contribution (FEC) of all the observing system components is shown in Figure 1b.

- The largest contribution in decreasing the forecast error is provided by AMSU-A radiances (~21%); data from IASI, AIRS, GPS-RO and AIREPs provide 10% of the forecast error reduction followed by TEMPs and SYNOPs (5%). All the other observation types each contribute up to 3%.
- Atmospheric Motion Vectors (AMVs) from all the various platforms (MODIS, Meteosat and GOES) make a useful contribution to the 24-hour error reduction (6%).

Comparing Figure 1a with Figure 1b is clear that the impact of the observations (by observation type) on the analysis (DFS) is quite similar to their impact on the forecast as measured by the forecast error (FEC) reduction. For some observation types the DFS is larger than the FEC (e.g. IASI and AIRS). This impact loss can predominantly depend on either the observation quality or biases in the model that will prevent the analysis changes affecting the short-range forecast thereby increasing the 24-hour forecast error.

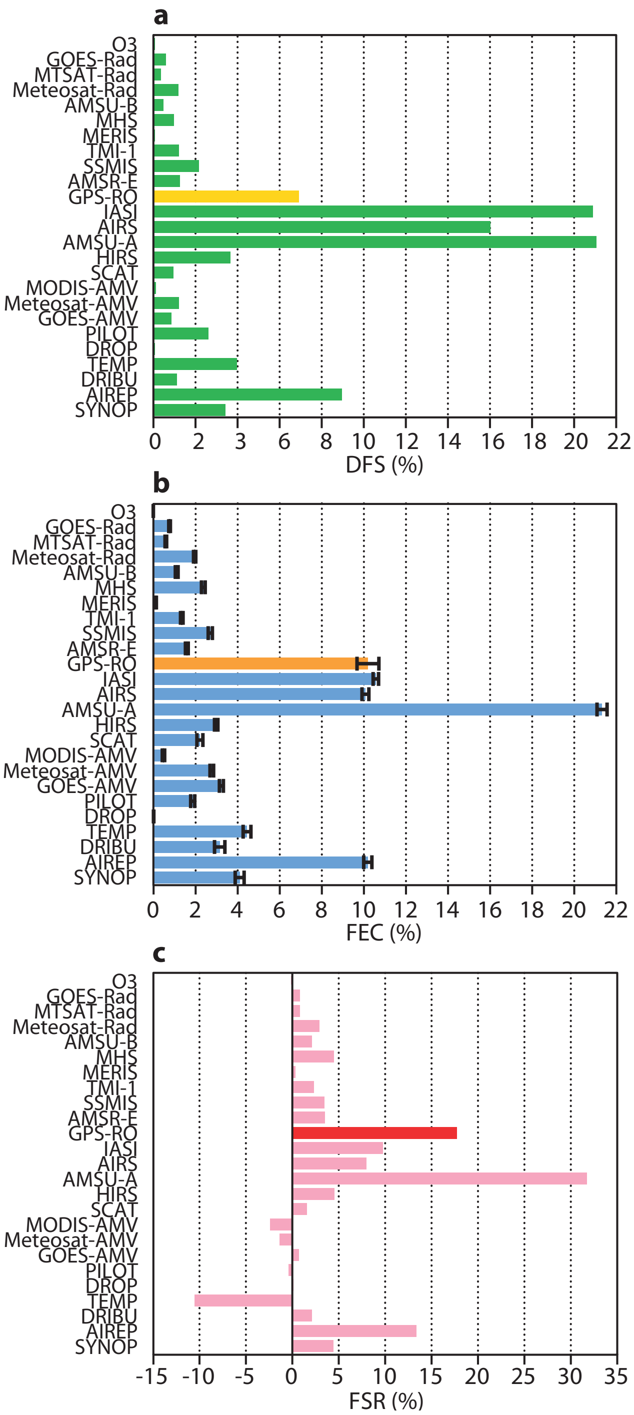

Figure 1 Total amount of (a) DFS, (b) FEC and (c) FSR for all assimilated observation types for June 2011.

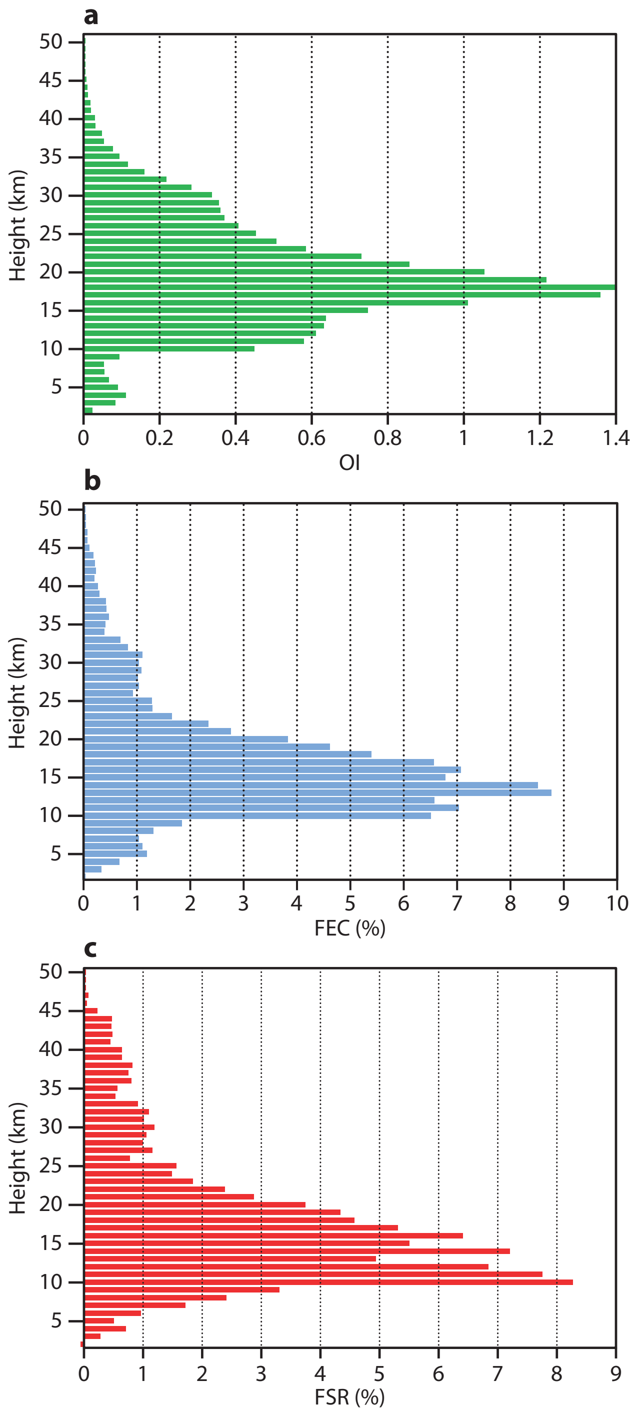

Figure 2 (a) Mean OI, (b) total FEC and (c) FSR for GPS-RO observations as a function of height for June 2011.

In Figure 1c, the sensitivity with respect to the observations error variance (FSR) is shown for the observation types. The positive sensitivities indicate that a reduction in error variance should decrease the 24-hour forecast error whilst a higher error variance should be applied for observations with negative sensitivity. According to Figure 1c, all the variances should be deflated apart for TEMPs and AMVs from MODIS and Meteosat. An alternative interpretation of Figure 1c is that the background error variances are in general too small and increasing their size should be beneficial for the short-range forecast.

GPS-RO case study

In the ECMWF system, the GPS-RO data provides 7% of DFS (Figure 1a) and 10% of FEC (Figure 1b). The GPS-RO measurements mainly provide temperature information in the upper-troposphere and lower/middle stratosphere. The GPS-RO measurements complement the information provided by satellite radiances because they have superior vertical resolution, and they can be assimilated without bias correction in the NWP model.

The assumed GPS-RO observation error standard deviation (i.e. square root of the observation error variance) used in the assimilation of the data at ECMWF varies as a function of the impact height z, which is defined as impact parameter minus the 'radius of curvature', where the radius of curvature is the radius of the best spherical fit to the Earth at the location of the observation. The assumed standard deviation of the bending angle errors, is 20% of the observed value at $z = 0$ km impact height, falling linearly with impact height to 1% at 10 km. Above 10 km, the error is assumed to be 1% of the observed value, until this reaches the lower limit of 3 microradians. Given the high observation accuracy, the mean GPS-RO observation influence in the analysis is also high, contributing half to the DFS with the other half coming from the relatively high number of assimilated observations.

Figure 2a shows the mean Observation Influence (OI) of GPS-RO data with respect to the height. The largest OI is in the troposphere and the low stratosphere where the largest forecast error reduction is also found. The number of measurement per level is the same. These profiles are consistent with earlier studies of information content using 1D-Var (e.g. *Healy & Eyre*, 2000), and reflect the large weight given to the observations between 10–30 km. At these levels the largest forecast error reduction is also observed as indicated in Figure 2b).

Figure 2c shows GPS-RO observations sensitivity to the observation error variance. Generally, a reduction of the variances is suggested for all vertical levels and in particular

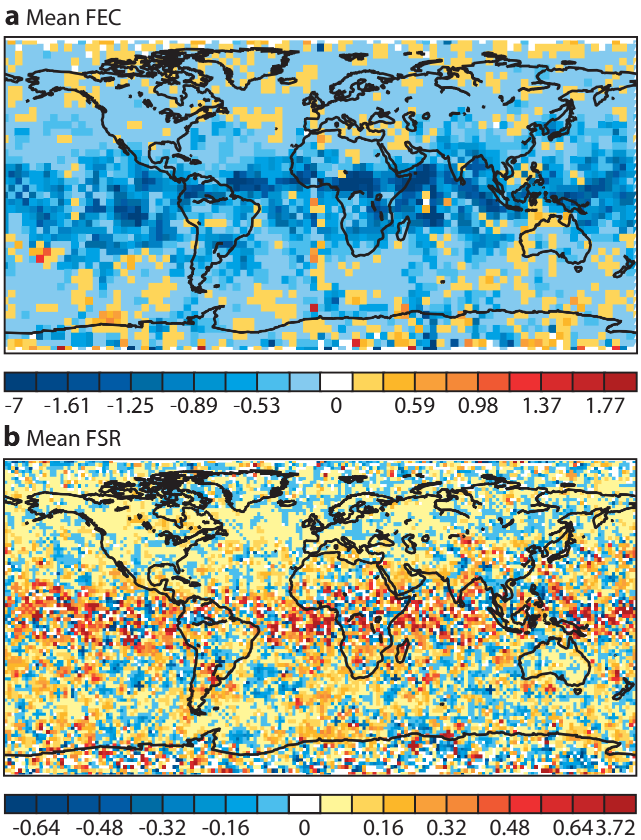

Figure 3 GPS-RO (a) mean FEC and (b) mean FSR from 12 to 30 km for June 2011. For (a) positive (negative) values indicate an increase (decrease) of forecast error. For (b) positive (negative) values indicate that a decrease (increase) of the observation error variances would improve the 24-hour forecast error.

between 10 and 30 km. It is interesting to note that the FSR computation suggests reducing the assumed errors mostly in the layer where the weight given to the GPS-RO is already very large.

Figure 3 shows the geographical distribution of the forecast error reduction due to GPS-RO data (Figure 3a) and the forecast sensitivity to the GPS-RO observation error variance (Figure 3b) averaged between 12 and 20 km for June 2011.

The mean forecast impact of GPS-RO is larger over the tropics than in the extra-tropic (Figure 3a blue contour) but in general, apart from a few areas of degradation close to the poles, the GPS-RO observations decrease the 24-hour forecast error everywhere. As can be seen from Figure 3b, the largest signal for observation error variance reduction is also in the tropics (yellow-red contours).

An analysis sensitivity experiment (*Half-Sigma*) has been performed by reducing the GPS-RO error variance as indicated by the study of the forecast sensitivity to error variance (i.e. between 10 to 30 km the error standard deviation has been halved). In terms of observation fit, the performance of *Half-Sigma* has been compared with that of the control (*CNTR*) experiment which contains the operational assigned variances.

Figure 4 shows the mean forecast differences with respect to radiosonde observations of 24-hour and 48-hour forecasts for *CNTR* and *Half-Sigma* and for the zonal wind component (panel a), meridional wind component (panel b) and temperature (panel c). For *Half-Sigma* there is a mean improvement with respect to the radiosonde fit, especially for the 48-hour forecast at every level. The best improvement occurs in the high troposphere and lower stratosphere and for both wind components. When compared with the aircraft observations a larger mean forecast difference reduction is noticed in *Half-Sigma* than in *CNTR* for the 48-hour forecast for the troposphere for the zonal component of the wind in the tropics (Figure 5a) and the southern hemisphere (Figure 5b).

Outlook

The largest contribution in the analysis as measured by the DFS and in the forecast as measured by FEC is provided by microwave sounder radiances (AMSU-A) followed by the infrared sounder radiances (IASI and AIRS) from the instruments that mainly provide information on temperature and humidity. For microwave satellite humidity information, SSMIS (microwave imager), MHS (microwave sounder) and AMSR-E (microwave imager) instruments are, in decreasing order, contributing to the reduction in forecast error. Of all the conventional observations, AIREPs and TEMPs provide the largest contribution.

The forecast sensitivity to the observation variance suggests that if there is a reduction in the observation error variances for all the observation types, except TEMPs and AMVs, the 24-hour forecast error will decrease. The fifth largest impact either in the analysis or in the forecast is provided by GPS-RO data, with the largest contribution coming from the heights between 12 and 20 km. The forecast sensitivity to the observation error variance suggests that the GPS-RO error variance should be reduced leading to a

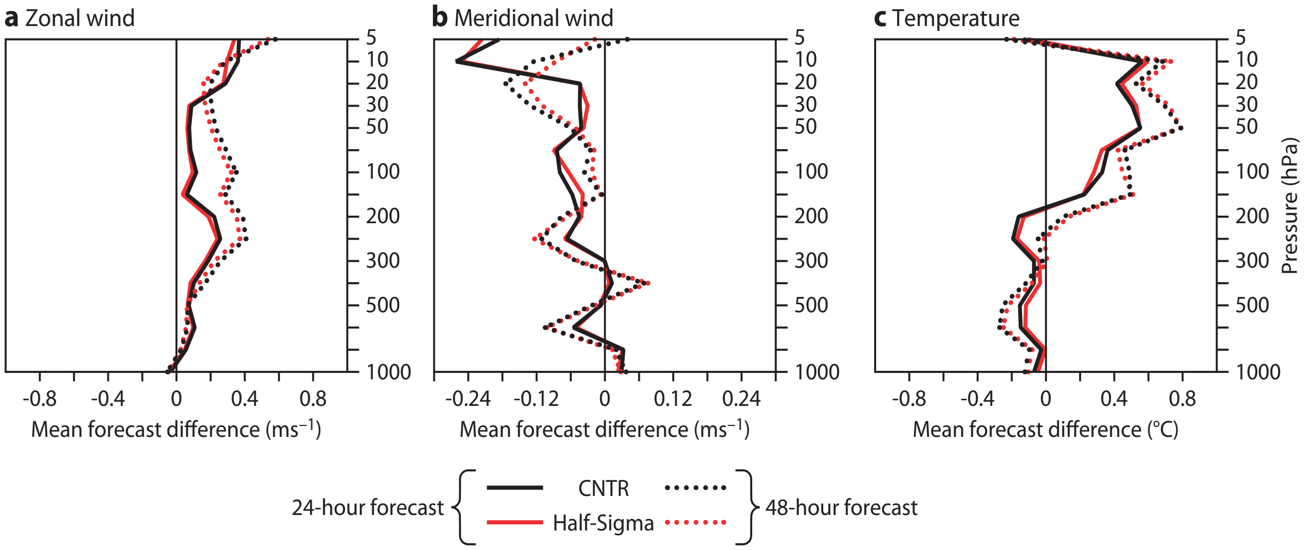

Figure 4 Mean forecast differences with respect to radiosonde observations for (a) zonal wind component, (b) meridional wind component and (c) temperature in the northern hemisphere for 24-hour (solid line) and 48-hour (dotted line) forecasts for CNTR (black) and Half-Sigma (red) for June 2011.

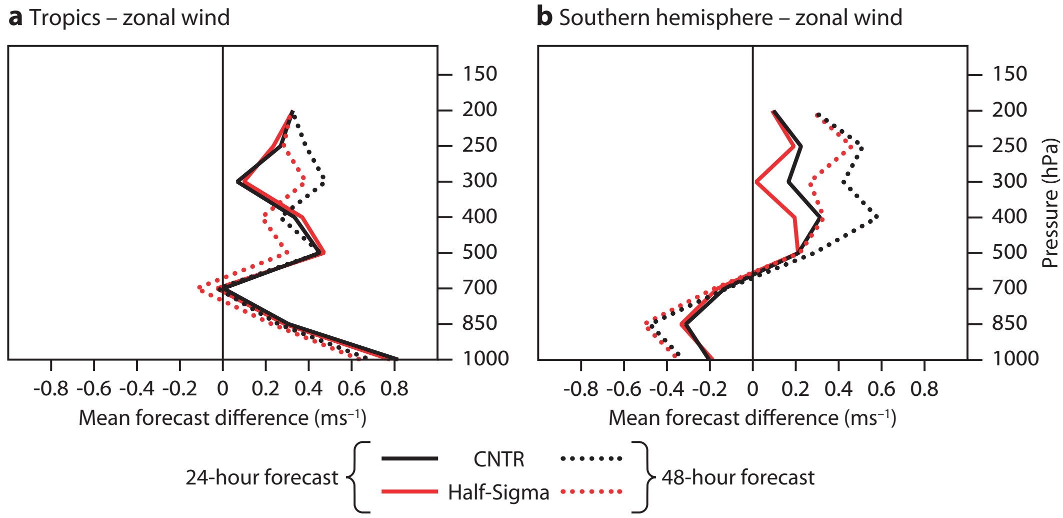

Figure 5 Mean forecast differences with respect to aircraft observations for zonal wind component in (a) the tropics and (b) southern hemisphere for 24-hour (solid line) and 48-hour (dotted line) forecasts for CNTR (black) and Half-Sigma (red) for June 2011.

decrease in the forecast error. Interestingly, the suggested reduced variances are mostly in the layer where the weight given to the GPS-RO is already quite large.

A first attempt to decrease the GPS-RO observation error variances has been made and some improvement in terms of a smaller mean forecast difference with respect to conventional (aircraft and radiosonde) observations has been found. However, a different measure of forecast error reduction due to the revision of the observation error accuracy must be considered. Also more experimentation is needed to fully exploit the benefits and understand the limitations of the FSR tool. A revision of the observation error variances for all the assimilated observations at ECMWF, as indicated by the forecast sensitivity tool, is planned for implementation in 2013.

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684 **Sandu, I., A. Beljaars, P. Bechtold, T. Mauritsen & G. Balsamo**: Why is it so difficult to represent stably stratified conditions in NWP models? August 2012

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677 **Hernandez-Carrascal, A., N. Bormann, R. Borde, H.-J. Lutz, J. Otkin & S. Wanzong**: Atmospheric motion vectors from model simulations. Part I: Methods and characterisation as single-level estimates of wind. *October 2012*

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Feb 4–15	Training Course – Use and interpretation of ECMWF products
Feb 4–8	Use and Interpretation of ECMWF Products
Feb 11–15	Use and interpretation of ECMWF products (repeat course)
Feb 26–Mar 27	Training Course – Use of computing facilities
Feb 26–Mar 1	GRIB API: library and tools
Mar 4–8	Introduction for new users/MARS
Mar 11–12	Magics
Mar 12–15	Metview
Mar 18–22	Use of supercomputing resources
Mar 25–27	Introduction to ecFlow
March 4-6	4th Workshop on the 'Use of GIS/OGC standards in meteorology'
Apr 15–Jun 7	Training Course – Numerical Weather Prediction
Apr 15–19	Numerical methods, adiabatic formulation of models and ocean wave forecasting
Apr 22–May 2	Parametrization of subgrid physical processes
May 8–17	Predictability, diagnostics and extended-range forecasting
Jun 3–12	Data assimilation and use of satellite data
Apr 18–19	Advisory Committee for Data Policy (14th Session)
Apr 23–24	Finance Committee (92nd Session)
Apr 24	Policy Advisory Committee (35th Session)
May 13–14	Security Representatives' meeting
May 14–16	Computer Representatives' meeting
Jun 5–7	Forecast Products Users' meeting
Jun 19–20	Council (79th Session)
Jun 24–27	Workshop on 'Polar prediction'
Jul 1–4	ECMWF/EUMETSAT NWP-SAF satellite data assimilation training course
Sep 2–5	Annual Seminar on 'Numerical methods'
Oct 7–11	Training Course – Use and interpretation of ECMWF products for WMO Members
Oct 14–16	Scientific Advisory Committee (42nd Session)
Oct 17–18	Technical Advisory Committee (45th Session)
Oct 21–22	Finance Committee (93rd Session)
Oct 22–24	Workshop on 'Parameter estimation and inverse modelling'
Oct 25	Advisory Committee of Co-operating States (19th Session)
Oct 28	Policy Advisory Committee (36th Session)
Oct 28–Nov 1	14th Workshop on 'Meteorological operational systems'
Nov 5–7	Workshop on 'Efficient representation of hyperspectral infrared satellite observations for assimilation and dissemination'
Dec 4–5	Council (80th Session)

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Meteorological Applications & Studies