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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 The *ECMWF Newsletter* is not peer-reviewed.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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Weather forecasts in 2030

It is astonishing when looking back over the past 37 years since ECMWF was founded in 1975 to see the progress in the science and practice of numerical weather prediction (NWP). In 1975 global NWP models were in their infancy and weather forecast skill was limited to about three days ahead at most. A key reason why ECMWF was established was to enable global NWP to advance more rapidly by creating a European collective effort. By any stretch of the imagination this period has been one of huge progress in this enterprise and today we routinely expect weather forecasts to have skill into the second week ahead. Scientific developments, enhanced observational coverage and increased computational capability have all played a critical role.

What does the future hold and what could we expect weather forecasts to be like in, say, 2030? It is notoriously difficult to foresee the scientific and technological future not least because advances in technology over the next 18 years, if the recent past is anything to go by, are essentially unimaginable. But perhaps other current trends are more straightforward to extrapolate. The implied horizontal mesh size of the ECMWF global forecast model (today 16 km for the high-resolution model) has been reducing at a reasonably steady exponential rate for several decades. The objective skill measures of the NWP forecasts show that skill has been increasing at about a constant rate of a lead time increase (for a useful forecast) of one day per decade. It may be dangerous to extrapolate these two trends forward but if we do then by 2030 skill should have extended by about two days further into the future and horizontal mesh sizes may be in the region of a few kilometres.

Another natural question to ask is what will the global models of the future be able to predict? It is interesting to remind ourselves that since 1992 ECMWF has not only been predicting the weather but also the ocean waves. Of course there is an intimate connection between the near-surface winds and the waves but also the need for mariners to have good forecasts of waves was then and is today substantial. More recently, because of extending our forecasts to the monthly and seasonal time-scales, the ECMWF forecasting model now includes a model of the global oceans coupled to the atmospheric model.

Also ECMWF has been developing two other areas where related aspects of the natural environment are able to be predicted using our forecasting systems and data. The first is in the MACC project to predict atmospheric composition including greenhouse gases, aerosols, fires and air quality. The second is ECMWF's first Third Party Activity- the European Flood Awareness System - where the assessment and prediction of catchment-scale hydrology is being explored. These are scientifically, technically and also from a user viewpoint very exciting initiatives. One can speculate that the NWP system of the future may be closer to being a numerical environmental prediction system. These developments are happening because the science is advancing in these areas but also because new observations of these properties are available from satellites and elsewhere. Of course, the science needed is multi-disciplinary with physics, chemistry and biology all playing an increasing and important role. Techniques like data assimilation that had their origins in meteorology can and are being extended into many other branches of environmental science.

There are many uncertainties about the future, but the opportunities to advance the science of NWP and improve forecast skill are there for ECMWF to grasp in its goal to continue to be the acknowledged world-leader in global medium-range prediction.

Alan Thorpe

New items on the ECMWF website

ANDY BRADY

Project to develop a new ECMWF web site

ECMWF has started a project (Web2013) to redesign its external website. The project officially started on 1 February 2012 and is expected to be complete after two years. For more details, see the article in this edition of the ECMWF Newsletter. Input is welcome from anyone who would like to be involved.

- http://www.ecmwf.int/web2013/

ORAS4 seasonal forecast ocean reanalysis products

The web pages for the ocean products have been updated to display the new OCEAN-S4 operational ocean analysis system. These new products are created from the ocean reanalysis stream (ORAS4) - an historical reconstruction of the world ocean spanning the period 1958 to present. In the near future, OCEAN-S4 will be updated to also include products from the real-time ocean analysis. The ORAS4 atlas displays monthly, seasonal, and yearly averages of selected variables, from 1958 to present conditions, updated on monthly, seasonal and yearly basis respectively. The graphical products include longitude-latitude maps, zonal and meridional sections, as well as Hovmöller diagrams (longitude-time, latitude-time) of both anomalies and full fields.

- http://www.ecmwf.int/products/forecasts/d/charts/oras4/

First MACC-II General Assembly

From 27 February until 2 March 2012, ECMWF hosted the final General Assembly of the Monitoring Atmospheric Composition and Climate (MACC) project combined with the first General Assembly of its follow-on project, MACC-II. The aim of the meeting was to review and present the achievements of MACC as well as the plans for the coming year for MACC-II.

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

ECMWF 2012 Annual Seminar - Seasonal Prediction

The seminar will give a pedagogical review of the principles behind seasonal predictions. Recent scientific developments in probabilistic, coupled seasonal prediction will also be reviewed, and the value of seasonal prediction in weather-risk reduction will be discussed. The seminar will be held from 4 to 7 September 2012.

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

Workshop on ocean waves

In the last decade the quality of wind and wave forecasts has steadily improved. Nevertheless, it is now recognised that the modelling interface between the atmosphere and the waves should also include the upper ocean component. For waves, different scales are inherently present and so a truly global operational system should be able to tackle these different scales. These issues are considered at a workshop on ocean waves held from 25 to 27 June 2012.

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

Workshop on parametrization of clouds and precipitation across model resolutions

This workshop will discuss latest advances in understanding some of the key issues in parametrizing cloud and precipitation processes. Its aim is to provide advice on the direction of future cloud scheme developments, with a particular emphasis on NWP as resolution increases from the 'large-scale' towards the 'convective-scale'. The workshop will be held from 5 to 8 November 2012.

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

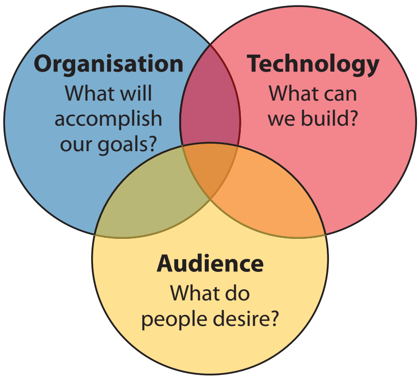
Development of a new ECMWF website

ANDY BRADY

The ECMWF www.ecmwf.int website, in its current form was created in 2002 and now, ten years later, it will be significantly re-developed. ECMWF recognises that our website is an important resource providing many types of information to a wide and growing range of people. Its importance has increased significantly over the years as people have come to rely on the Web as the best way to get the information they need quickly and easily. Going forward, our website must continue to provide services to our Member State users while also meeting the needs of various research communities and serving as the public face of the Centre. As ECMWF and weather forecasts develop, our website will need also to evolve to support our mission.

Why are you re-developing your website?

At the beginning of this project many



Three stakes in a website. The emphasis is on assessing business needs, user/customer needs and technical capability

people have ideas about what is good and bad about our website but there are a few key issues that we will be addressing:

- The design is dated - it looks like a website from 2002.
- There is a lot of good information but the way it is organised makes it hard to find.
- The website does not sufficiently meet the needs of certain communities of users.
- The website does not sufficiently support the long-term strategy of ECMWF.
- Some parts of the website can be unduly affected by high user loads.
- The site was not designed to be highly available.
- It is not easy to publish or maintain content on the website.

Also, as the technology that underpins the Web has matured, there are now opportunities that we can exploit to develop the higher level of functionality expected by our users.

What approach will you take?

The process of creating websites has matured considerably since 2002, shifting from what was a business/technical oriented approach to a more holistic approach including as a fundamental component the on-going representation of user requirements. In developing a website in 2012, the three components one considers are:

- Business needs
- User/customer needs
- Technical capability

Following current best practice, we will produce a website via multiple iterations of the following six steps:

1. Identify, define, refine who are our website users
2. Review how ECMWF's strategy relates to the website
3. Identify what content is required and also what content is redundant
4. Identify what content we have available
5. Develop/refine the website
6. Test, review and validate the website

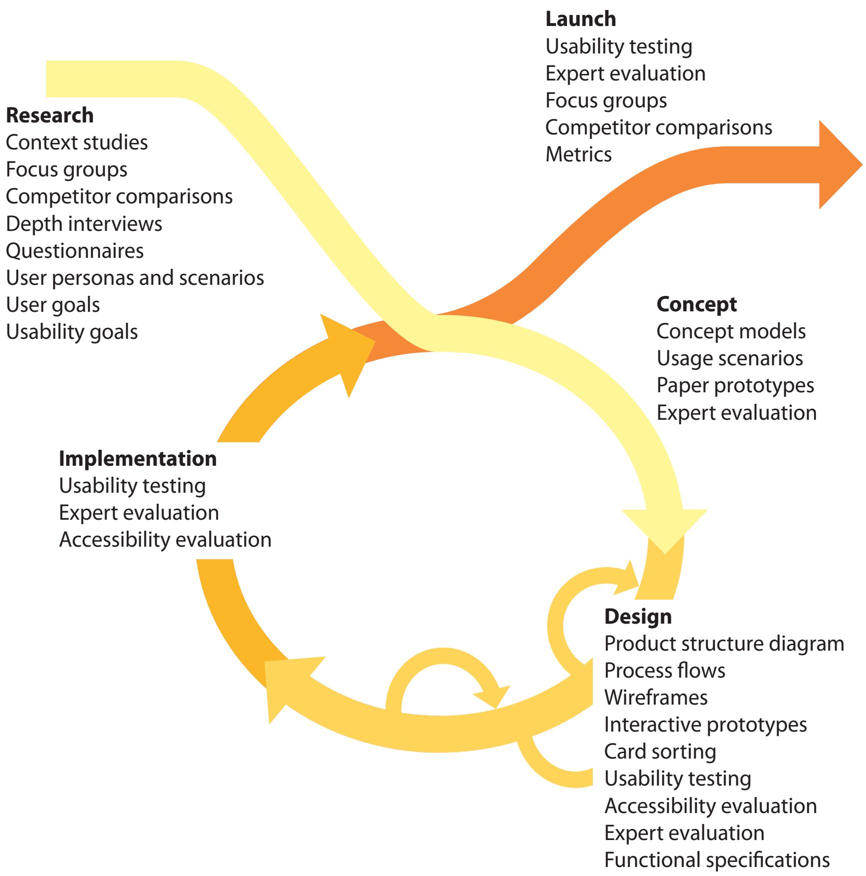
Taking this approach will lead us to a website that is much more responsive to the needs of more of our users. Also, the provision of a website is not a one-off process: consideration of the processes and tools that will be used to maintain the content will be a significant component in the development. If we can get good content in easily and quickly, the website will be better.

When will the new website be available?

The project runs for two years from February 2012 to February 2014 but we are planning to release our first preview website as early as possible, probably around August 2012. This first preview will not be the final product, be completely designed or contain everything required but it should give a first indication of our new website. As the project progresses further we will continuously update and change this preview, possibly even substantial changes if users that review it identify significant design or structural issues. By January 2013 the website will be classified as beta-release which means we will be confident that it won't undergo any further significant changes. We will then continue to refine it and add content and services and will classify the website as in full production (replacing the existing website) towards the end of 2013 or very early in 2014.

Can I be involved?

Yes. Until the end of May 2012 we are working with a content strategy consultant to identify a set of users who are representative of all our users.



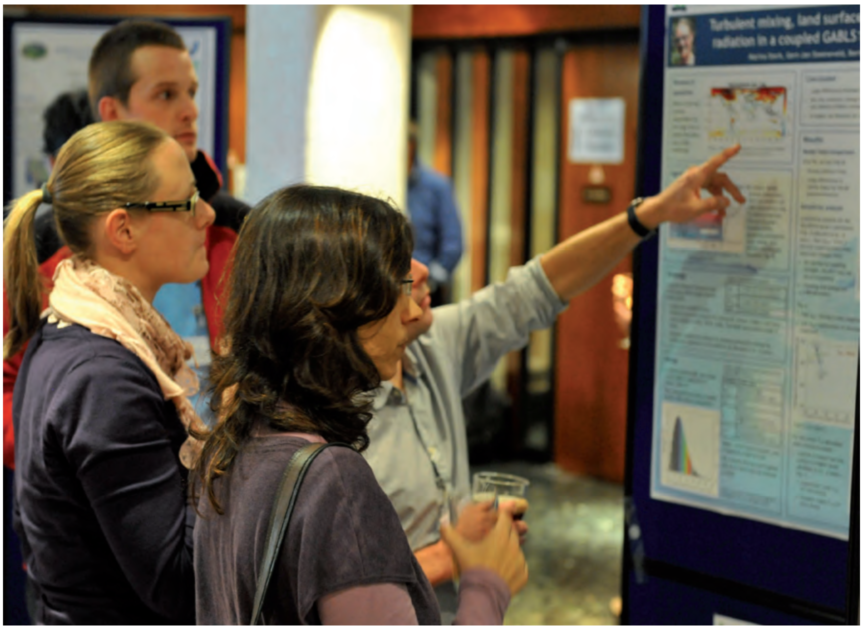
Iterative process for creating a new website. This involves research, concept, design, implementation and launch.

Working with these users we will generate a set of user personas that describe in general terms the scope of use of our website. We will publish these personas publicly so you will be able give feedback on them. After analysing our strategy we will create a content model which we can use to create a very basic prototype website. The aim is to make this documentation publicly accessible and we would welcome feedback on it.

Where can I get more information?
Our project website is publicly available via:

- http://www.ecmwf.int/web2013/

We will be publishing all of our project products here including our user personas and pointers to our prototype websites as soon as we are able to release them.



You can help us. Information about the development of the website will be made publicly accessible and we would welcome feedback about any aspect.

Migration of the MARS system to a Linux cluster

BAUDOUIN RAOULT,
MANUEL FUENTES,
TIAGO QUINTINO

The Meteorological Archive and Retrieve System (MARS) is ECMWF's main managed archive of meteorological data.

MARS holds all ECMWF's operational model outputs as well as all the observations used by its analysis. From a user's point of view, access to the archive is homogeneous for all tools and applications provided by ECMWF. Batch scripts and interactive tools like Metview, all use the same naming convention to describe the data. This makes data sharing very efficient, as most users experience a uniform way to access the archived data.

Over the years, great care has been taken to keep the archive consistent and complete, allowing users to request old and new data in the same fashion, in a consistent format. As a consequence, the archive is widely used (with more than 5,000 registered users) and well established as a very valuable tool for research in the Member and Co-operating States, and by the Space Agencies and other collaborators around the world. Considerable effort is put on ensuring the integrity of the data in the archive, so that users can trust its contents. Data is self-described, which enables its correctness to be checked at various stages.

Over the years, the amount of data stored in and retrieved from MARS has been growing proportionally to the size of the High-Performance Computer. Nowadays, the archive holds 18 petabytes of data (about 7×10^{10} fields) and 20 terabytes of data (60 million fields) are archived daily, while 13 terabytes of data (25 million fields) are retrieved.

The first MARS system was written in PL/1 and was running on an IBM/MVS mainframe. In 1997, MARS was rewritten in C++ and deployed on an IBM/AIX Unix server. As the load continued to increase, the service was split in two: a server for operational data and a server for research data. Later, as the exponential growth continued, the service was split further until there were six MARS servers, each managing part of the archive: operational data, research data, project-related data, Member

Oracle SL8500 tape libraries. ECMWF archive is stored in three Oracle SL8500 tape libraries which currently hold approximately 20,000 cartridges with them varying between 1 and 5 Terabytes.

State data, TIGGE data and e-suite data. This split allowed us to allocate different resources (disk, memory, ...) to each part depending on their expected usage, for example giving large disk cache to the server holding the very popular reanalysis dataset.

As the resource requirements continued to grow there were no obvious ways to split the service further. The MARS servers managing the operational data and the research data were large AIX servers (IBM Power-6 servers, each with 8 3.5 GHz cores and 64 gigabytes of memory), and to expand them would be very costly. It was therefore decided to migrate the archive services to a modern Linux cluster: this will allow a cost-effective capacity scaling of the service in the future, as this would be achieved by simply adding new nodes to the cluster. This work is now complete.

The restructuring posed the following challenges.

- The system would have to be migrated from the AIX system (32-bit big-endian) to a Linux system (64-bit little-endian), and the code therefore had to be thoroughly tested in the new environment.
- The MARS server would have to be restructured so it could be distributed over a series of many nodes in the cluster.
- As the number of computer nodes would grow significantly, the code would have to be made resilient to the loss of one or more nodes, whether these outages are planned (operating system upgrades) or unplanned (system crashes).
- The quality of service is currently ensured using a series of queues and priorities. They would have to be preserved in the new compute environment.
- Monitoring a distributed system is difficult, as logging information is scattered over several machines and needs to be consolidated in a single place.

To solve these problems two MARS servers are deployed as follows.

- A 'core' machine that processes users' requests (queuing, priorities, limits, permissions), manages the metadata (e.g. the archive catalogue) and centralises the monitoring.
- A series of 'mover' machines that move data between disks, tapes and user machines.

As the load will increase with time, more movers will be added to the cluster. If a core node crashed, it can be redeployed on a standby node. If a mover node crashes, its work will be taken over by another node.

There are still six MARS services, as this partitioning has helped us to manage the resources efficiently. The core machines of each MARS service are now federated using peer-to-peer synchronisation techniques, in order to continuously exchange information about the requests each of them are processing or hold in queues. This allows a better usage of shared resources, such as tape drives.

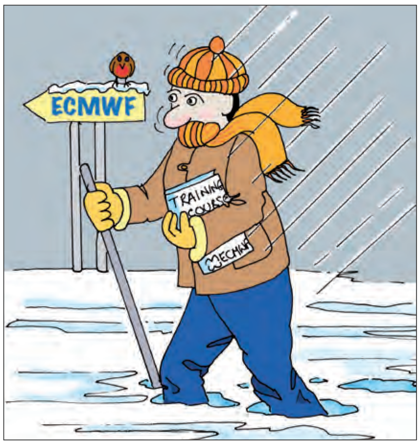
As of 17 of April 2012, all MARS services have been migrated to a cluster of 15 Linux machines, running Red Hat Enterprise 5.7, with either 12 or 6 cores Xeon processors (12 for the MARS cores, 6 for the MARS movers) and 48 gigabytes of memory. The performance of the new system is very good, and will allow us to cater for increasing demand on the archive.

Training courses: a success story

ANNA GHELLI

Two back-to-back training courses on the '*Use and interpretation of ECMWF products*' were run during the last week in January and first week in February. The courses are always well attended and this year we had 47 enthusiastic participants, mostly forecasters coming from meteorological services of Member and Co-operating States, who travelled to Reading, braving the polar weather conditions, to join the courses.

The courses offered a mixture of classroom lectures and practical sessions during which the participants used a wide range of ECMWF products to study a selection of case studies. During the afternoon activities, the participants attempted a forecast for their dream location. They used ecCharts which is a web application that allows forecasters to explore ECMWF meteograms and forecast



charts (for more information go to:

- http://www.ecmwf.int/eccharts/index.html).

Over the years, the hours spent on practical sessions during the course have increased to accommodate the higher demand for the development of expertise in utilising ECMWF products. The case studies offered in the last edition of the courses included severe wind and floods events, prolonged drought conditions and inconsistent behaviour of forecasts. At the end of the week, the participants presented their findings.

The feedback we had from the courses was extremely positive, with a third of the students stating in their self-assessment that they had learned a lot (5 on a scale from 1 to 5).

This is what some of the students had to say about the courses:

"I wanted to say that I had a great time at ECMWF and I've learnt a lot. Thanks for the course and I hope to meet again some time in the future."

"Thank you for a good course and great arrangement. I am looking forward to exploring the new products and put to practice the things I have learned."

"This week was very inspiring and I hope I can bring that inspiration, you gave me, into my profession."

The courses will be running again in 2013. Watch this space!

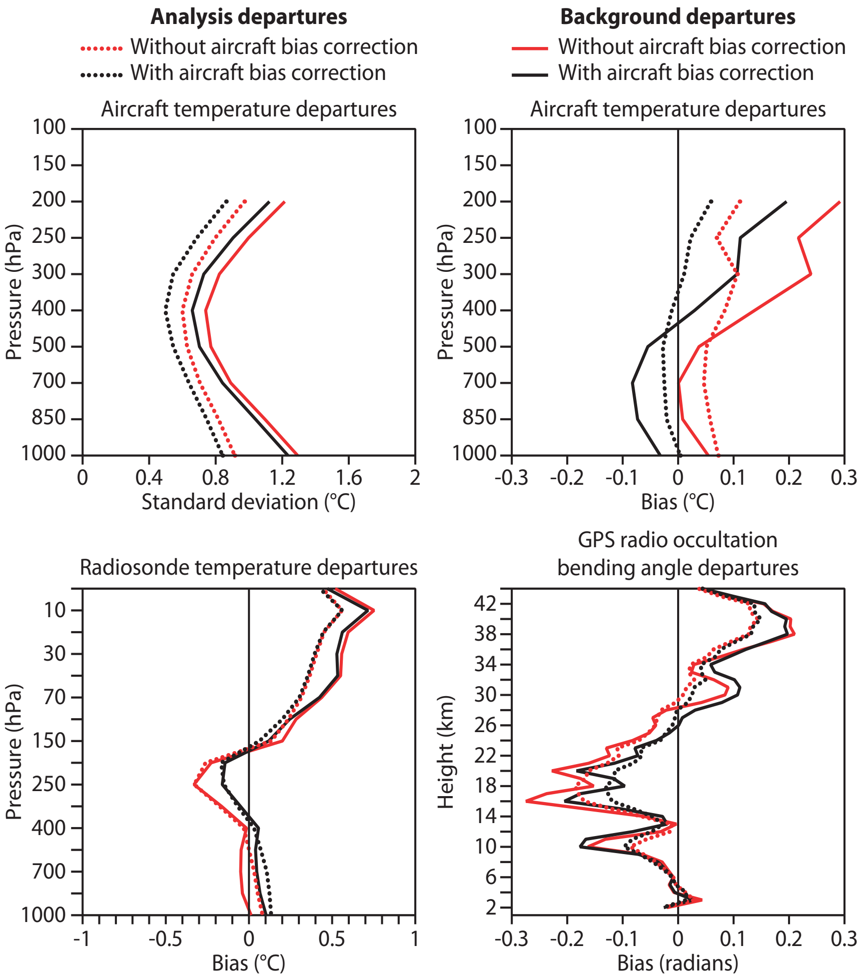
Bias correction of aircraft data implemented in November 2011

LARS ISAKSEN,
DRASKO VASILJEVIC, DICK DEE,
SEAN HEALY

Aircraft measurements of temperature and wind are very valuable for the analysis due to the large amount of data and their high accuracy, and because they provide profile information from ascents and descents near airports. But it has been clear for some time that the temperature measurements are biased, often by 0.5°C compared with radiosonde measurements. This has a considerable impact on temperature analyses, especially over Europe and North America at the tropopause level, where the aircraft data volumes are large and dominate the analysis. Investigations have shown that the bias characteristics depend on whether the aircraft is ascending, descending or cruising at a constant level. It has been shown that the bias characteristics also vary from aircraft to aircraft, even for the same aircraft type.

An automated method is required to bias-correct the measurements from the more than 5,000 different aircraft reporting. The variational bias correction method, extensively used for satellite bias correction, has been extended in the IFS (Integrated Forecasting System) to enable the bias correction of aircraft temperatures. Each aircraft is bias-corrected individually. One predictor corrects the bias at cruise level, and two additional predictors apply corrections that are functions of the positive/negative vertical aircraft velocity (dp/dt), so it effectively accounts for descent/ascent conditions. Indeed, additional investigations have clearly shown that one constant predictor is not sufficient to correct for both cruise level and ascent/descent temperature biases.

When aircraft data is bias corrected in this way the fit of the analysis and short-range forecast (i.e. background) to the data improves considerably. Not surprisingly the bias is reduced, but it is very encouraging to see that also the random error (standard deviation) is reduced, as shown in the first and second panels of the figure. But the most important result is the reduced bias for radiosonde temperatures compared to the analyses and short-range forecasts, as shown in the third panel of the figure. Radiosonde temperatures are known to be very accurate with low biases in the troposphere. The large volume of aircraft data, compared to the amount of radiosonde data, cause the analyses and short-range forecasts to mainly rely on the aircraft data. Before the bias correction of aircraft data this introduced a spurious bias in the analysis. It is also very encouraging that the analysis and short-range forecast improves the fit to GPS radio occultation data, as shown in the fourth panel in the figure. The GPS radio occultations provide accurate bias free temperature information, primarily in the upper troposphere and lower stratosphere.



Average departure statistics for the extra-tropical northern hemisphere. Red curves are from standard 4D-Var without aircraft bias correction and black curves with bias correction applied. Top left and top right: aircraft departure standard deviations and biases for temperature. Bottom left: radiosonde departure temperature biases. Bottom right : GPS radio occultation bending angle departure biases. Full lines represent background departures and dotted lines the analysis departures.

RMDCN - Next Generation

TONY BAKKER, AHMED BENALLEGUE, REMY GIRAUD, OLIVER GORWITS, ALAN RADFORD

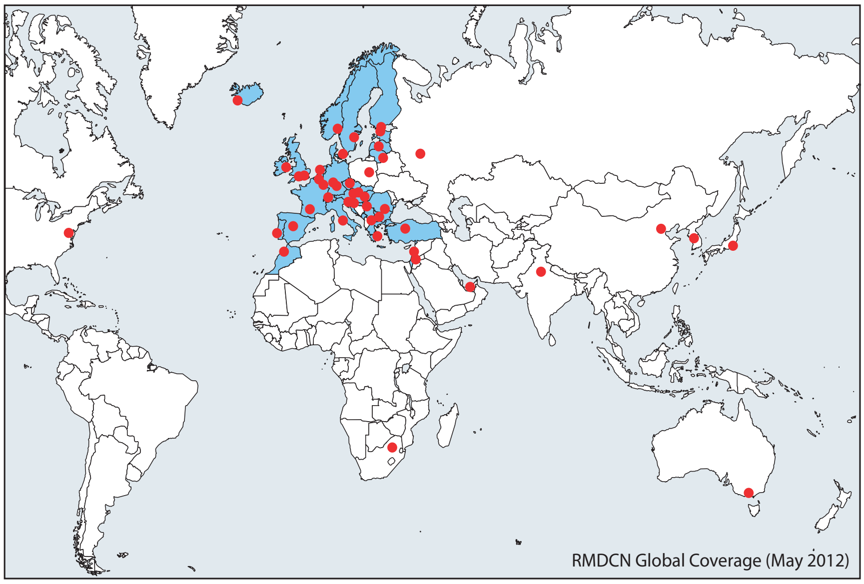
The requirements on the Regional Meteorological Data Communication Network (RMDCN) are changing rapidly, including increased volumes of ECMWF's product dissemination and the evolution of the Global Telecommunication System (GTS) towards the new WMO Information System (WIS). So, after 12 years of operational service, it has been decided to move to the next generation of the network (RMDCN-NG).

The RMDCN was established in the late 1990s with two primary purposes.

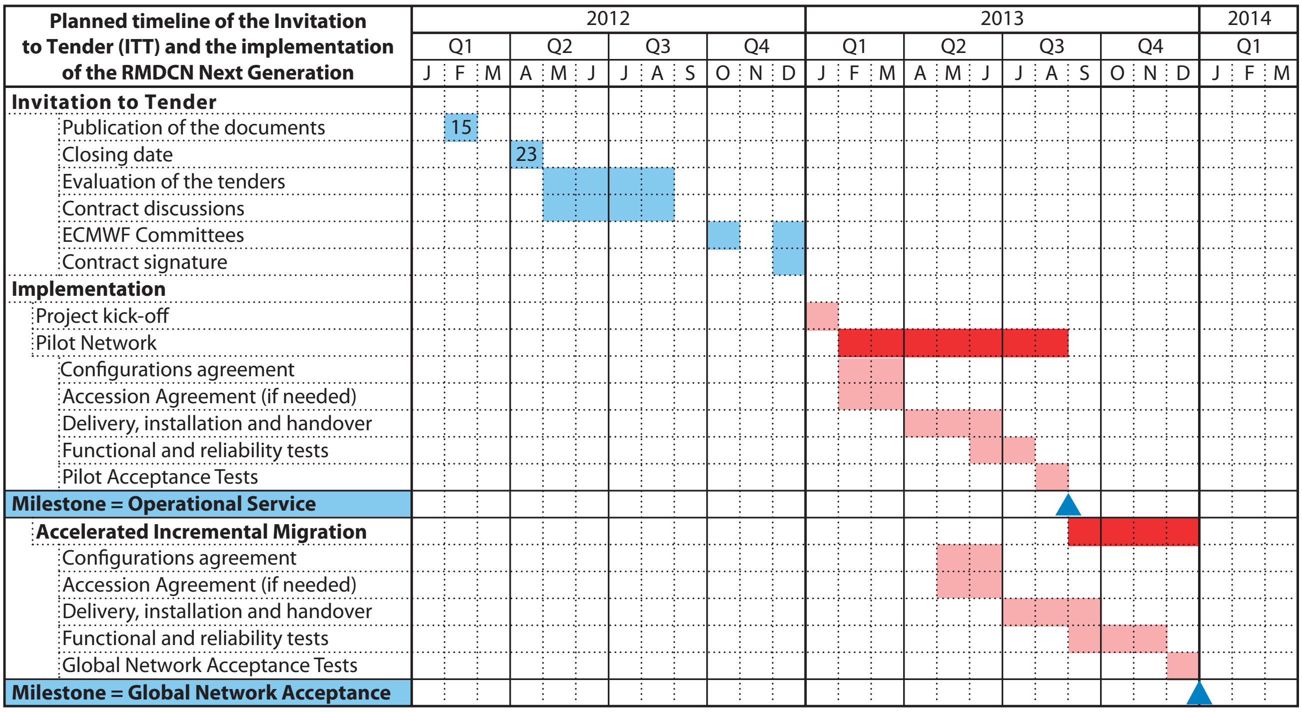
- To provide the means of disseminating ECMWF products to its Member States and Co-operating States.
- To provide the GTS of the World Meteorological Organization (WMO) in the region of Europe and the Middle East (WMO Regional Association VI).

ECMWF has been, and continues to be, responsible for the procurement, implementation and operation of the network for all connected countries. Following a competitive procurement the RMDCN began operational service in 2000, using a Frame Relay solution, with 31 participating sites in Europe and the Middle East.

Since its implementation the network has evolved both technically (the Frame Relay solution was replaced by



The global coverage of the current RMDCN. There are 49 sites (45 National Meteorological Centres, ECMWF, two EUMETSAT sites and one disaster recovery site in the Netherlands) connected to the network. The shaded countries indicate ECMWF Member States and Co-operating States.



Planned timeline of the ITT and the implementation of RMDCN-NG. The blue and red squares represent activities during the ITT and implementation phases respectively. The blue triangles indicate the major milestones of Operational Service Commencement and Global Network Acceptance.

Multiprotocol Label Switching (MPLS) in 2007) and geographically, with many sites outside Europe now being connected.

The definition of requirements for RMDCN-NG was carried out during 2011 and in December 2011 the ECMWF Council authorised the publication of an Invitation to Tender (ITT) for the replacement of the RMDCN. The ITT was published on 15 February and on 6 March a presentation was given to all interested tenderers. The closing date for receiving tenders was 23 April. There is then a period of several months during which we evaluate the tenders, both technically and contractually.

The ECMWF Council will be asked to authorize the conclusion of a contract with the envisaged supplier at its session in December 2012. Migration to the new network is scheduled to take place in 2013.

Introduction to the science of weather and weather forecasting

SARAH KEELEY

An introductory meteorology course has been given at ECMWF this spring. It aims to provide an understanding of basic meteorology and an appreciation of the forecasting process for members of staff with little or no meteorological knowledge. The material is presented in a descriptive way; no previous knowledge of physics or mathematics above a basic school level is required. Around 40 staff members have taken part.

The course consists of seminars followed by discussion groups, with guided reading and extra material identified to help participants understand the basic concepts. Each week the course participants have recommended reading from the book: '*Understand the Weather - Teach Yourself*' by Peter Inness (Teaching Fellow, Department of Meteorology, University of Reading). The extra material is a mixture of online material including: training software provided by MetEd; YouTube clips and web pages.

The seminars have be given fortnightly by Erland Källén, Director of Research, and are informal, with interactions between the participants and Erland being encouraged. Seminars have covered the following topics:

Erland Källén delivering a seminar on 'Weather charts and NWP'. This seminar was one of six that formed part of a basis course on the science behind numerical weather prediction for ECMWF staff.

- The atmosphere - structure and composition
- Atmospheric circulation
- Vertical motion and clouds
- Weather charts and NWP
- Predictability - ensembles
- Climate change

Key ideas that have been presented include: atmospheric motion and how the rotation of the Earth is vital for balancing atmospheric winds; and the chaotic nature of the atmosphere and why it is challenging to extend the time limits of prediction.

In the weeks between the seminars the discussion groups are led by ECMWF scientists. These provided an opportunity for participants to ask further questions, discuss things that may not be clear or consider the seminar contents in more detail.

Preliminary feedback suggests that participants have increased their understanding of meteorology and enjoyed the seminars and discussion groups. As a result they now have a greater grasp of the science behind the Centre's meteorological activities.

Monitoring and forecasting the 2010/11 drought in the Horn of Africa

EMANUEL DUTRA, LINUS MAGNUSSON, FREDRIK WETTERHALL, HANNAH L. CLOKE*, GIANPAOLO BALSAMO, SOUHAIL BOUSSETTA, FLORIAN PAPPENBERGER

The 2010/11 drought in the Horn of Africa affected approximately 12 million people, and might have been the worst in the last 60 years. It resulted from a precipitation deficit in the October–December 2010 and March–May 2011 rainy seasons; both were captured by the ERA-Interim reanalysis. Soil moisture anomalies of ERA-Interim also identified the onset of the drought condition early in October 2010 with a persistent drought still present in September 2011. The precipitation deficit in October–December 2010 was associated with a strong La Niña event, which was predicted by the ECMWF seasonal forecasts from June 2010 onwards, as well as a dry precipitation anomaly in the region. The March–May 2011 anomaly was only captured by the forecasts starting in March 2011.

Monitoring drought

ERA-Interim precipitation compares reasonably well with several global precipitation datasets based on a variety of sources (satellite and gauges). This agreement is especially consistent for the October–December rainy season, while during March–May the ERA-Interim has some difficulties in capturing the inter-annual variability of precipitation in the region. However, during 2010/11 both rainy seasons were correctly represented by ERA-Interim with anomalous dry conditions (Figure 1). The rainfall anomaly early in October-December 2010 led to the depletion of soil moisture. This anomaly was persistent throughout 2011 due to the consecutive dry season in March–May, and only recovered to normal conditions later in September 2011 (Figure 2). ERA-Interim soil moisture intra-seasonal to inter-annual variability can be affected by the soil moisture analysis that is based on near-surface air temperature and relative humidity (ECMWF Newsletter No. 127). Therefore, its use as a monitoring tool should be carefully evaluated.

An evaluation of the Normalized Difference Vegetation Index (NDVI) satellite estimates, which is independent from ERA-Interim, showed temporal consistency between the soil moisture anomalies and NDVI anomalies (Figure 2). These results are encouraging since they link remote sensing of vegetation characteristics with soil moisture. The reduction of NDVI, or vegetation activity, was also enhanced by a warm near-surface temperature anomaly during October–December 2010 and March–May 2011. Ultimately these conditions caused a failure in crops and livestock production and, since the region is mainly dependent on traditional rainfed agriculture, there was a famine. These results indicate that ERA-Interim precipitation could be used for drought monitoring purposes in the region, and complemented with soil moisture due to its temporal integration of precipitation (forcing) and evaporation (demand) anomalies.

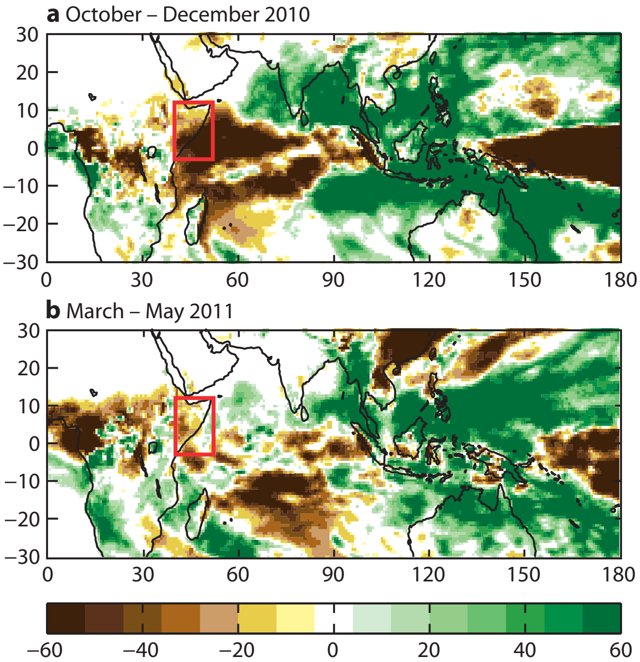


Figure 1 Spatial patterns of ERA-Interim precipitation anomalies (mm month-1) during (a) October–December 2010 and (b) March–May 2011 for the 1979–2011 mean ERA-Interim climate. The box indicates the Horn of Africa area.

Seasonal forecasts

The biannual migration of the Intertropical Convergence Zone (ITCZ) across East Africa is the main driver of the precipitation seasonality in the region. This results in two rainy seasons (October–December and March–May). El Niño conditions (warm sea surface temperatures in the Pacific Ocean) tend to generate an equatorial Indian Ocean sea surface temperature pattern referred to as the positive phase of the Indian Ocean Dipole. In this phase, there is a warming of the western Indian Ocean that intensifies and shifts the ITCZ, leading to wetter conditions. Therefore, the Horn of Africa precipitation during the October–December season is indirectly influenced by El Niño (or La Niña – colder sea surface temperatures in the Pacific Ocean) conditions that cause a warming (cooling during La Niña) in the western

* Hannah L. Cloke is affiliated to King's College London as well as ECMWF.

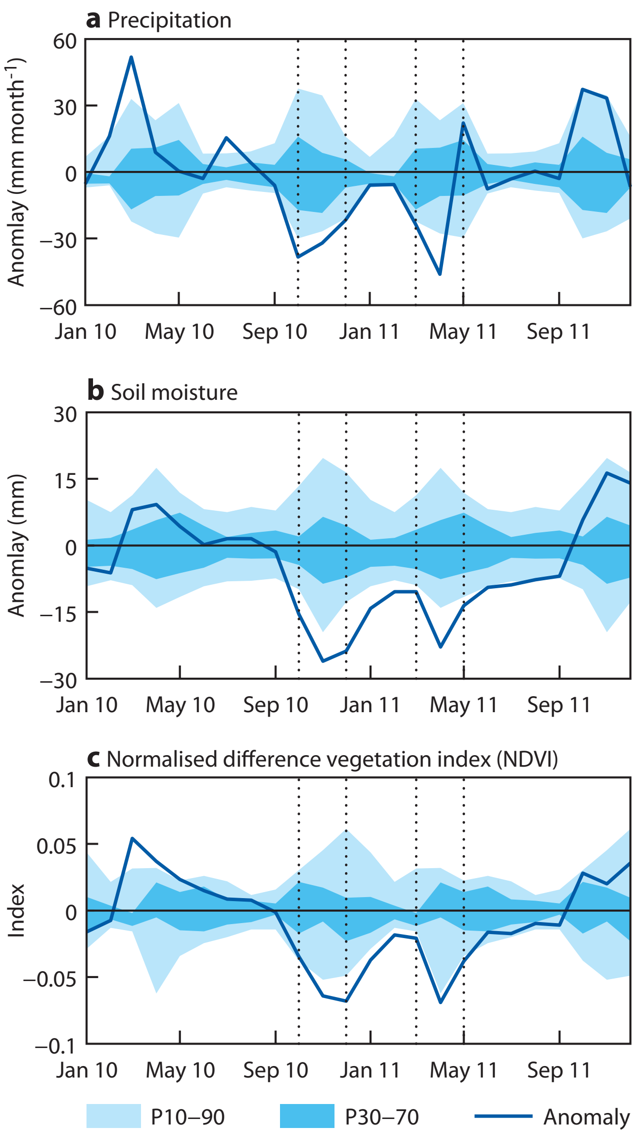


Figure 2 Time series of anomalies of (a) ERA-Interim precipitation, (b) ERA-Interim soil moisture and (c) Normalized Difference Vegetation Index (NDVI) from MODIS satellite data for 2010/11. The results are based on spatial averages over the Horn of Africa region (see box in Figure 1) of the anomalies (solid blue), and the climatological distribution between percentiles 10 to 90 (light blue) and percentiles 30 to 70 (dark blue). The vertical dashed lines indicate the October–December 2010 and March–May 2011 seasons.

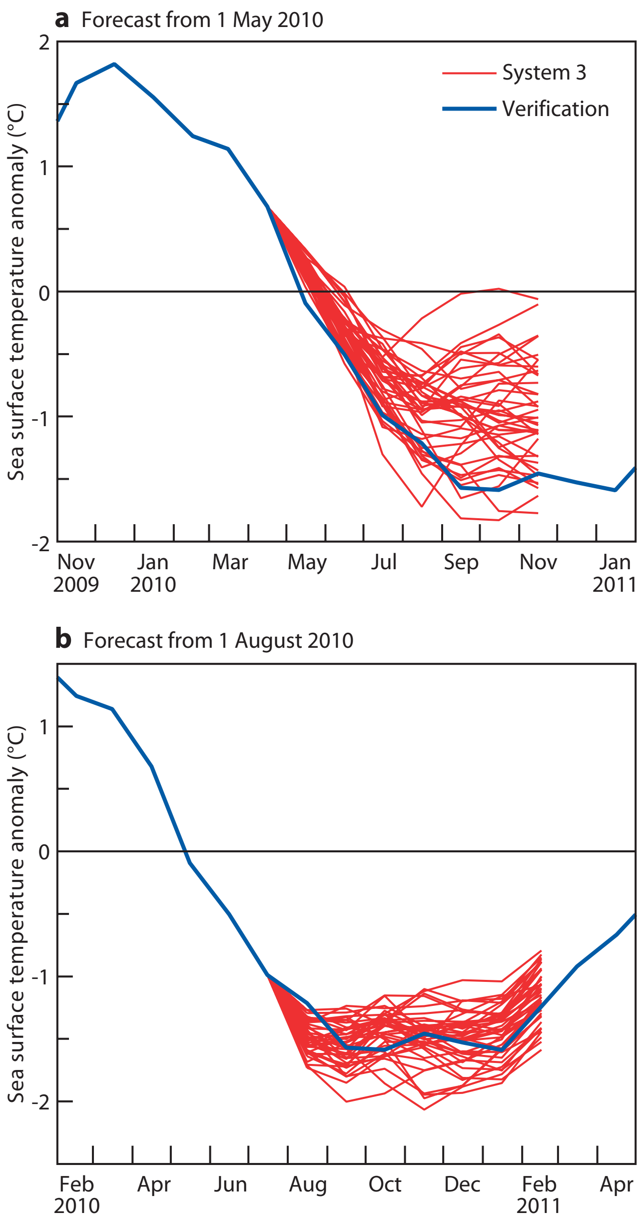


Figure 3 ECMWF seasonal forecasts of sea surface temperature anomaly issued in (a) May 2010 and (b) August 2010 for NINO3.4 (5°S–5°N, 170°W–120°W; the area with a large variability on El Niño time scales) using System 3 and verification of the forecasts.

Indian Ocean. On the other hand, there is no strong relationship with any large-scale climate anomaly and precipitation in the Horn of Africa during the March–May season.

The ECMWF seasonal forecasts generally have a good skill in forecasting El Niño/La Niña conditions, and this was the case in 2010. The forecasts starting in May 2010 pointed to a La Niña situation four months in advance and were consistent during the following forecast months (Figure 3). Results using the z-score (a way of standardizing data by removing the mean and dividing by the standard deviation) show that the October–December 2010 dry anomaly (i.e. negative z-score) was consistently predicted by the seasonal forecasts from July 2010 onwards (Figure 4a). The forecasts valid for March–May 2011 pointed to normal conditions, except for the forecasts starting in March 2011(Figure 4b). These results are consistent with the overall evaluation of the ECMWF forecasts of precipitation using retrospective forecasts for the period 1981–2005 showing that there is:

- Skilful forecasts up to four months in advance for the October–December season.
- Low predictability for the March–May season, where only the forecasts starting in March have skill.

This information can guide users when interpreting the seasonal forecasts for the region, and presents an example of an application of ERA-Interim and seasonal forecasts for drought monitoring and forecasting. This methodology can be adapted and refined for other regions, taking into account the local specificities, other data sources (e.g. in-situ observations – monitoring) and the user's needs.

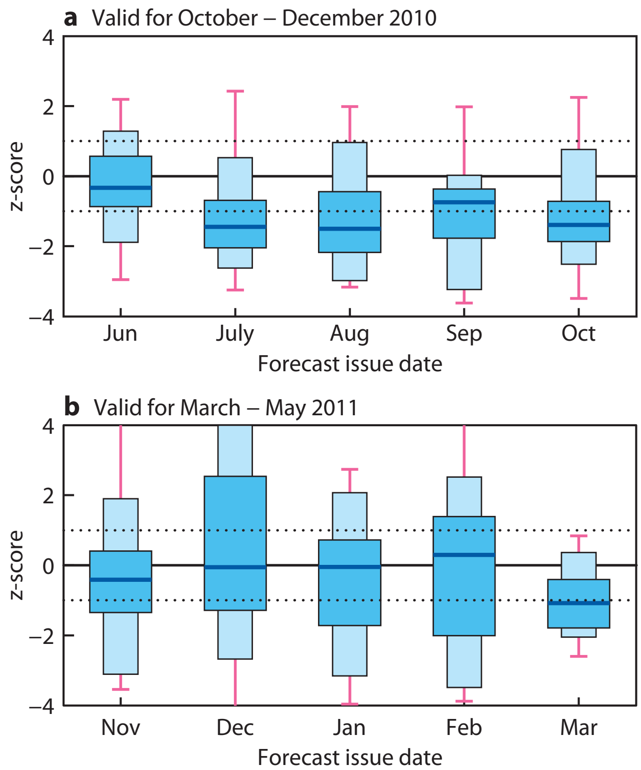


Figure 4 Distribution of z-scores for seasonal forecasts of precipitation valid for (a) October–December 2010 and (b) March–May 2011 for various initial forecast dates (horizontal axis) averaged over the Horn of Africa region (see box in Figure 1). The box plots extend from the minimum to percentiles 10, 30, 50 (blue line), 70, 90 and maximum.

Concluding remarks

ECMWF products, such as the ERA-Interim and the operational medium- to long-range weather forecasts, can provide useful and reliable information to national and international organizations. Consequently they can support early warnings and mitigation strategies in the region (in the absence of more reliable ground truth) that suffers from the lack of in-situ networks and infrastructures. The region and its population are highly vulnerable to future droughts, thus global monitoring and forecasting of droughts are going to become increasingly important in the future.

The results outlined here are part of an ongoing effort in a EU-funded FP7 project, DEWFORA (http://www.dewfora.net), aimed at developing a framework for the provision of early warning and response to mitigate the impact of droughts in Africa.

Characteristics of occasional poor medium-range forecasts for Europe

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A feature of medium-range weather prediction is the occasional strong dip in forecast skill. Such events are often referred to as 'drop outs' or 'busts'. Although frequencies have decreased, even a single bust is inconvenient for users of ECMWF products, and it can have a significant impact on seasonal-mean scores.

The ECMWF Working Group on Diagnostics has carried out a study aimed at understanding the nature of forecast busts over Europe, and exploring possibilities of further reducing their frequency or severity.

This article outlines what has been found out about the general characteristics of European busts. It is established that a large proportion of these busts are associated with increased forecast uncertainty, particularly associated with blocking onset. Much of this uncertainty, particularly in spring, appears to arise from sensitivities to initial conditions over the United States and, in agreement with *Grazzini & Isaksen* (2002), mesoscale convective systems (MCSs) over the USA play a key role.

A companion article in this edition of the *ECMWF Newsletter* shows how the bust of 10 April 2011 corresponds to the general characterisation found here. It then examines this case in more detail with a view to identifying key factors that could help reduce the frequency or severity of forecast busts.

Background

European busts are defined here as occasions on which both the following conditions apply to the day-6 forecast of 500 hPa geopotential height (Z500) for Europe.

- Mean root-mean-squared-error (RMSE) is greater than 60 m.
- Spatial anomaly correlation coefficient (ACC) is less than 40%.

These two conditions ensure that a bust is associated with errors of a sufficient magnitude and also involve a pattern or phase discrepancy.

Figure 1 depicts a bust in the spring of 2011. It shows the time series of ACC for day-6 forecasts of Z500 over Europe from several of the world's forecast centres during spring 2011. In general, scores fluctuate around the 80% level, but around 10 April a bust occurs. On this particular occasion all centres suffered, with the UK Met. Office (UKMO) recovering earliest.

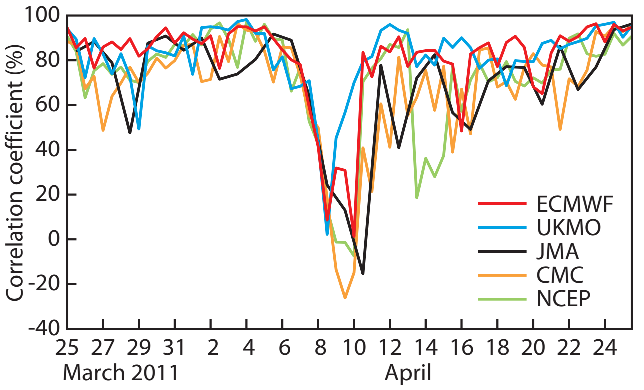

Figure 1 Time series of the spatial anomaly correlation for day-6 forecasts of Z500 over Europe from some of the world's leading NWP centres (within the 'TIGGE' programme): UK Met Office (UKMO), Japan Meteorological Agency (JMA), Canadian Meteorological Centre and National Centers for Environmental Prediction (NCEP), The dates correspond to the start of the forecast.

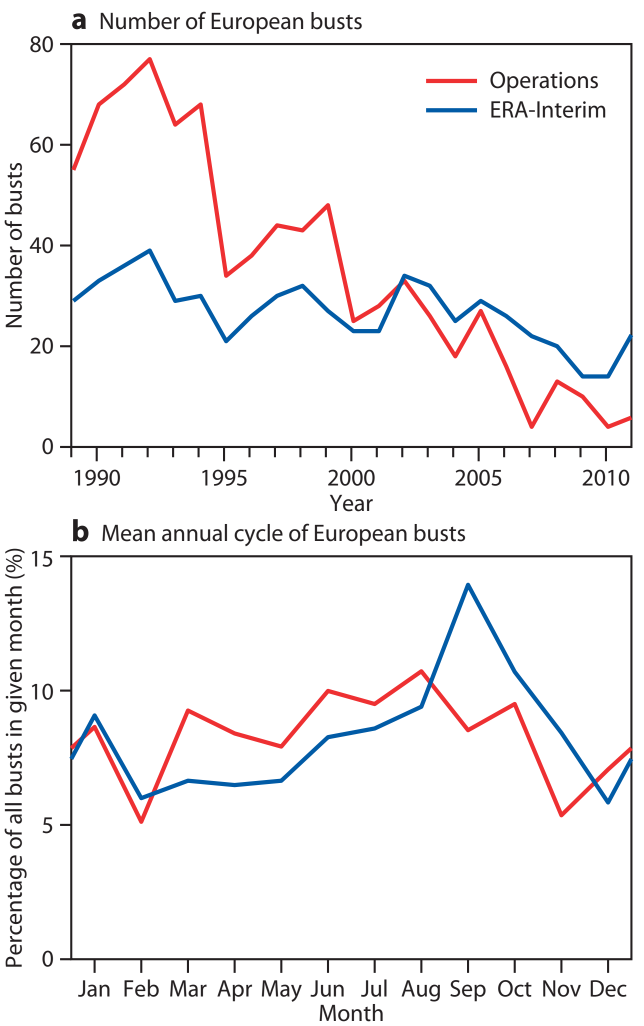

Figure 2 European busts at day 6 from the operational forecast and ERA-Interim reanalysis project for 1989 to 2011. (a) Time series of annual totals. (b) Mean annual cycle. Results are based on forecasts started at 12 UTC since operational forecasts were not made at 00 UTC before 2001. Since operational annual totals have decreased, the operational mean-annual cycle will emphasise the early part of the record.

Over the years, significant progress has been made in reducing the frequency of busts. Figure 2a shows that annual totals for the ECMWF operational forecast have decreased from around 70 per year in 1990 to around 5 in 2011. But even this low level of busts causes problems for users of NWP products. Note that, as indicated by Figure 2b, busts occur throughout the annual cycle, not just in spring.

It would be most beneficial to understand busts in recent cycles of the ECMWF Integrated Forecasting System (IFS), but this means that there are very few busts to investigate. The approach taken here is to first use forecasts made within the 'ERA-Interim' reanalysis project. Figure 2a shows that bust frequency for the ERA-Interim forecast only decreases slightly over the last 22 years – owing to the use of a fixed IFS cycle (which was operational in 2006; note that the curves should not necessarily intersect in 2006 because the resolutions were different). Using all 22 years' worth of data from this stable forecasting system allows us to characterise the busts. Later we check whether these characterisations are still valid for more recent IFS cycles.

Conditions when a bust occurs

To characterise the scenario most clearly associated with busts, a 'bust composite' is made using all 584 dates for which the ERA-Interim forecast had a European bust during the period 1 January 1989 to 24 June 2010. This period was before implementation of a significant change to the initialisation of the Ensemble Prediction System – this is discussed later.

Figure 3 shows the Z500 mean verifying analysis for the bust composite. Bold colours indicate mean values that are statistically different from zero at the 5% level. Despite only defining busts by their gross scores, it appears that there is a particular verifying analysis associated with many busts – it includes a high-pressure 'block' over northern Europe and a low centre over the Mediterranean; this might be part of a larger wave-train that stretches across the Atlantic.

Initial conditions of the forecast preceding a bust

We can use the same bust composite to search for the key features in the initial conditions of these poor forecasts. Figure 4a shows that the statistically significant features in the Z500 mean initial conditions are not over Europe, but include a 'Rockies trough' embedded in an apparent Rossby wave covering the USA, and a northern 'Canada High'. Over northern Europe, there is a weak and statistically insignificant low centre in the composite initial conditions. This might indicate that busts are often associated with a particular difficulty in developing the northern European block 6 days later.

Previous studies and internal reports have linked busts to MCSs over the USA, particularly around the Great Lakes region. Figure 4b shows the convective available potential energy (CAPE) in the composite-mean initial conditions (throughout this article 'analysed CAPE' is actually a 6-hour forecast, since this is what is archived). While each grid-point is not individually statistically significant at the 5% level, there is a coherent region of increased convective instability over the USA that stretches north to the Great Lakes and beyond. The question arises as to whether a situation of convective instability ahead of a trough over the Rockies leads to increased forecast error and uncertainty in more recent IFS cycles.

Forecast error and uncertainty

The trough/CAPE regime was identified above from deterministic forecasts from the ERA-Interim IFS cycle. To quantify forecast error and uncertainty associated with this regime in more recent IFS cycles, we now turn to the Ensemble Prediction System (EPS). Since there was a major change to the initialisation of the EPS on 24 June 2010 (with the involvement of the 'ensemble of data assimilations'; EDA) and subsequent changes on 9 November 2010 (that affected our representation of uncertainty estimates), we focus on the period from 10 November 2010 to 20 March 2012. Note that this period is also designed to be independent of the dates used to generate the bust composite, thereby ensuring statistical rigor. We wish to identify dates in this new period when the trough/CAPE regime occurs in the forecast initial conditions. To do this we project the 00 and 12 UTC operational Z500 analyses (actually analysis anomalies from climatology) onto the patterns within the highlighted regions shown in Figure 4, and select dates for which the trough has a projection coefficient greater than 3 and the CAPE has a projection coefficient greater than 1. This means that, if a Z500 analysis anomaly had exactly the same spatial pattern as that shown in the 'Rockies trough' box in Figure 4a, it would need to have three times the magnitude. The CAPE threshold was set lower because Figure 4b indicates small-scale uncertainties in the pattern. Using this approach, 84 date/times are selected – including, incidentally, the major busts of 10 April and 10 May 2011. Note that results are not sensitive to the precise choices of these thresholds.

Figures 5a and 5c show ensemble 'spread' and ensemble-mean RMSE averaged over the 84 incidences of the trough/CAPE regime. (Here, spread is actually the ensemble standard deviation, scaled so that long-term means of spread and RMSE would be equal in a reliable system.) Figures 5b and 5d show corresponding 'background' spread and error, respectively, for days when at least one of these projection thresholds was not exceeded.

The results in Figure 5 show that error is indeed enhanced (by around 30% over Western Europe) in trough/CAPE situations. Spread is also increased, particularly around Iceland, but more data or better techniques may be required to assess whether this increase is sufficient to match the increased error.

The dates used to generate the trough/CAPE composite tend to be concentrated in northern spring– suggesting a different cause for the autumn busts seen in Figure 2b. Note that the 'Canada High' does not appear to be so crucial for increasing error or spread. Hence it would appear that for recent IFS cycles, the same trough/CAPE situation over North America is a highly unstable situation as far as day-6 forecasts for Europe are concerned. One can perhaps think of this situation as being close to a bifurcation point on Lorenz's 'butterfly diagram'.

The trough/CAPE situation also leads to a very similar mean flow anomaly at day 6 to that seen in the bust composite in Figure 3 – including the Northern Europe high. However, a similar pattern is also seen at day 1, and would appear to be associated with the simple extension of the Rossby wave that incorporates the Rockies trough.

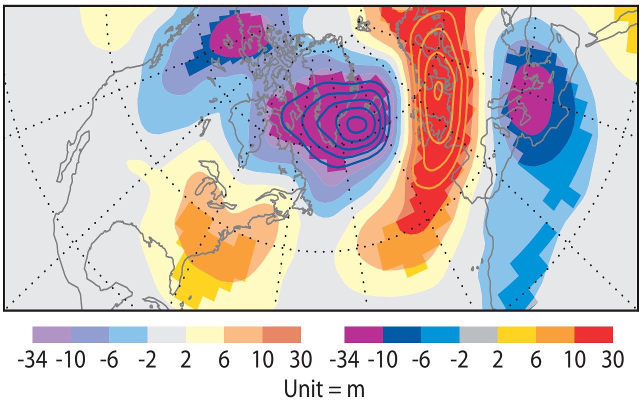

Figure 3 The composite mean Z500 verifying analysis anomaly averaged over 584 European bust events produced by the ERA-Interim forecast system from 1 January 1989 to 24 June 2010. Anomalies are relative to the ERA-Interim climatology for 1989–2008. Statistical significance at the 5% level is indicated through the use of bold colours.

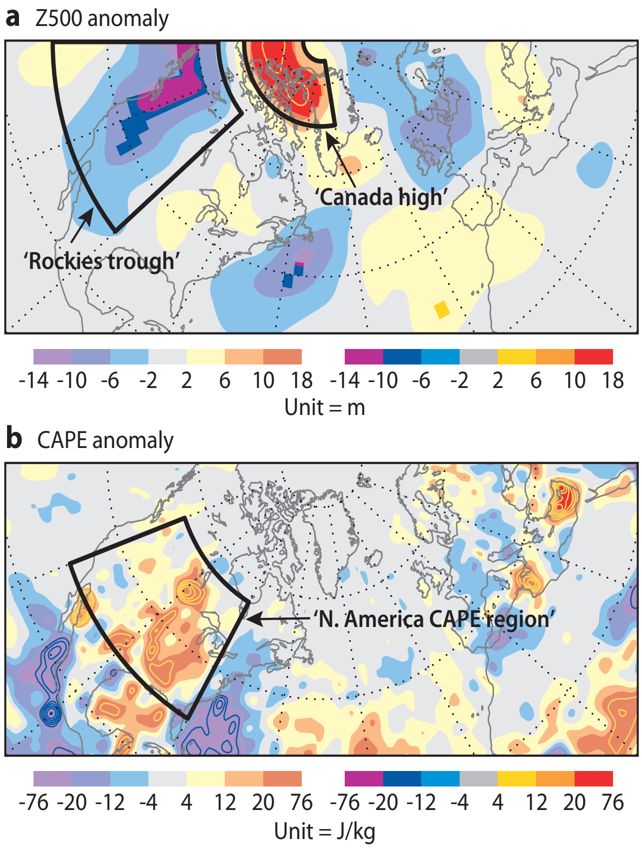

Figure 4 The composite mean initial condition anomalies of (a) Z500 and (b) CAPE leading to the same busts used in Figure 3. Anomalies are relative to the ERA-Interim climatology for 1989–2008. Statistical significance at the 5% level is indicated through the use of bold colours.

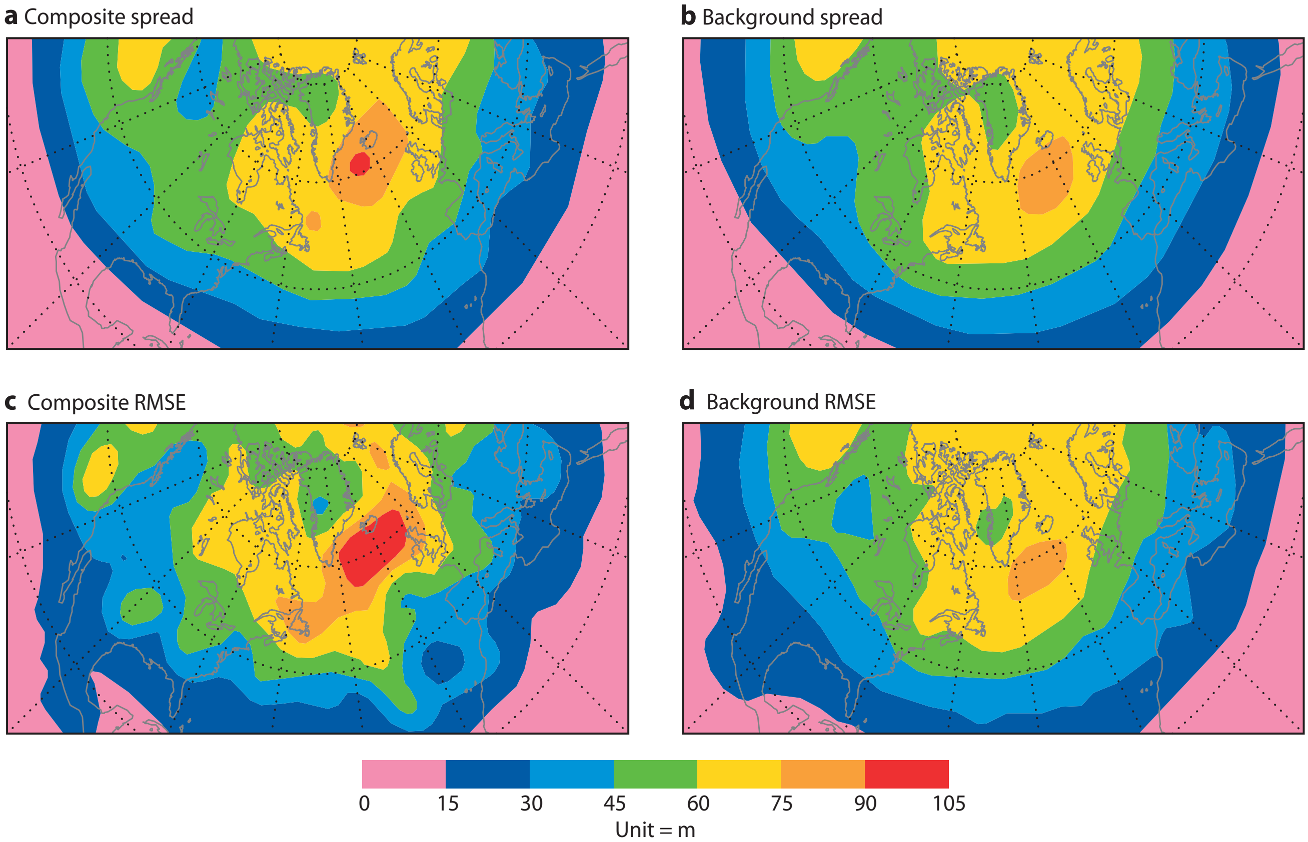

Figure 5 Spread and error results for Z500 at day 6 from the EPS. (a) Ensemble spread for the trough/CAPE composite. (b) Background spread. (c) Ensemble-mean RMSE for the trough/CAPE composite. (d) Background RMSE. Results are based on all 00 and 12 UTC forecasts from 10 November 2010 to 20 March 2012. To ensure a fair comparison, spread and error, for each month of the year, are given the same weight in the background composite as they are given in the trough/CAPE composite.

Mesoscale convective systems over the USA

The above results indicate that a trough/CAPE situation can lead to forecast busts over Europe. Such trough/CAPE situations also lead to MCS events over the USA, so one would expect correlations between busts and MCS events. It is clearly possible, however, that the MCS events play a more active role in the forecast busts. As an attempt to quantify one aspect of this role, the Potential Vorticity (PV) budget on the 330 K isentropic surface (approximately at 250 hPa) is calculated. The aim is to assess whether the time-evolution of the trough (and the Rossby-wave feature in which it is embedded) is consistent with simple adiabatic advection, or whether diabatic/frictional effects are essential.

Since we calculate this budget for the operational deterministic analysis, we are not constrained by the issue of the EPS initialisation and so can extend the period of investigation back to the end of the period used to construct the bust composite. Figure 6a shows, contoured, the anomalous PV calculated using all 95 trough/CAPE events from 25 June 2010 to 20 March 2012. The trough over the Rockies is clearly evident as a positive PV anomaly. The ridge over the eastern USA is also evident. Shading in Figure 6a shows the anomalous local time-tendency of PV. The ridge is strengthening to its northeast while little tendency is evident on the leading (eastern) edge of the trough.

Shading in Figure 6b shows the anomalous adiabatic advection of PV. Since the advection anomalies lie east of PV anomalies of the same sign, this advection clearly acts to propagate the Rossby wave eastward, and accounts for much of the local time-tendencies found in Figure 6a. Nevertheless there are non-negligible differences, and these must be attributed to the combined effects of anomalous diabatic and frictional processes.

The diabatic plus frictional PV tendency (i.e. the difference between Figures 6a and 6b) is shown in Figure 6c. This term is seen to oppose the adiabatic advection term, and thus slows-down the eastward propagation of the wave and, indeed, virtually halts the eastward propagation of the leading edge of the trough. Since the budget is based on analyses, this term is likely to be reasonably consistent with the observations and, to some extent at least, model-independent. The term includes diabatic advection, diabatic changes in stratification, diabatic tilting, surface friction and turbulent mixing. A major component of this term may well be the 'destruction' of PV above the maximum in convective heating (associated with stratification changes). This would explain the negative values seen over central North America in Figure 6c. On the other hand, frictional effects on southerly flow along the eastern flanks of the Rockies would be more likely to lead to positive vorticity forcing, and so are probably of secondary importance.

Based on the results given in Figure 6, it seems likely that MCSs do play an active role in the evolution of the trough – they slow it down.

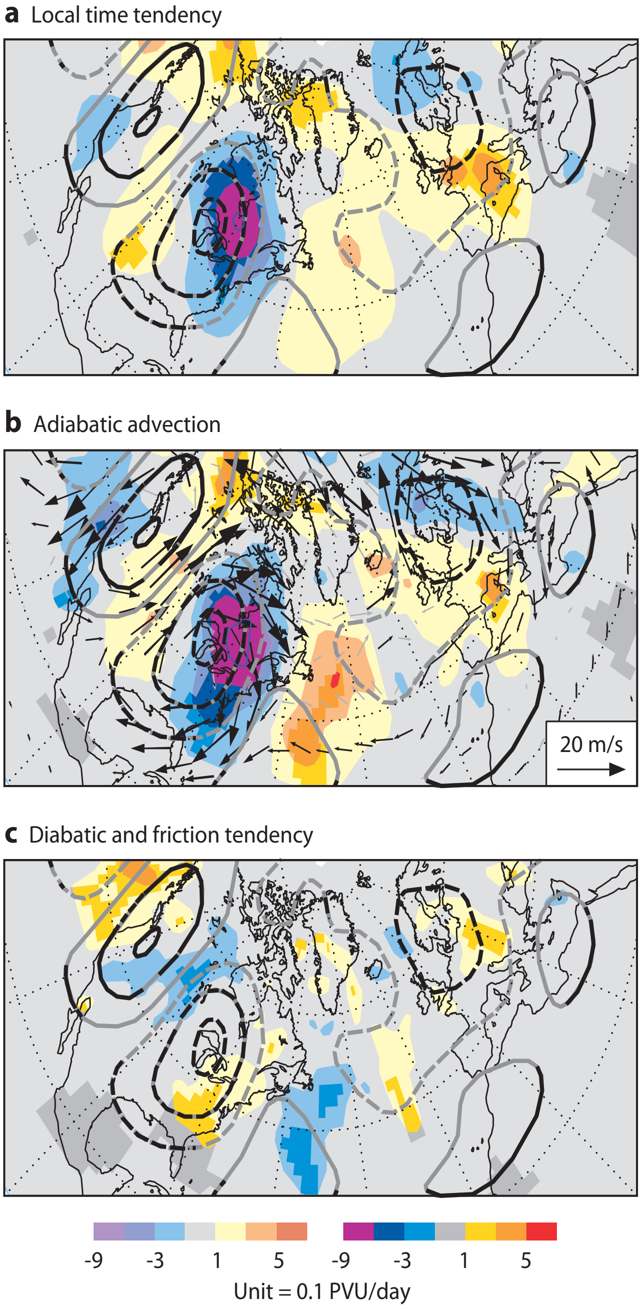

Figure 6 Mean PV anomaly (contoured) and anomalous PV budget terms (shaded) for the trough/CAPE composite on the 330 K isentropic surface in operational analyses from 25 June 2010 to 20 March 2012. (a) The local time-tendency calculated as the central difference of analyses displaced by ±6 hours. (b) The adiabatic advection of PV calculated using IFS spectral transforms, together with anomalous horizontal winds. (c) The diabatic plus frictional PV tendency, deduced as the difference (a) minus (b). All components were calculated using the full set of spectral coefficients in the analysis and a filter on total wavenumbers greater than 10 has been applied to the fields. PV anomalies are contoured with interval 0.4 PVU, and with contours smaller or equal to -0.2 PVU dashed. Statistical significance at the 5% level is indicated through the use of bold colours and black vectors and contours. Anomalies are relative to a climatology made using the same days of the year, from the preceding three years.

General characteristics of busts

It has been shown that busts tend to occur when there is a high over northern Europe, and are often associated with a trough in the initial conditions over the Rockies. To the east of the trough there is warm, moist, southerly flow and high convective available potential energy (CAPE). Using independent data, it has been confirmed that this flow regime tends to occur in northern spring, and does lead to increased medium-range errors over Europe and, to a lesser extent, increased ensemble spread. Hence the trough/CAPE regime can be thought of as being a 'bifurcation point' (i.e. close to the body of Lorenz's butterfly) as far as European medium-range forecasts are concerned. Using Potential Vorticity budgets, it has also been shown that the MCSs – that accompany the high CAPE – act to slow-down the eastward propagation of the trough, thereby perpetuating the trough/CAPE regime. The representation of convection in the model could, therefore, affect the analysis and the forecast evolution of the trough (and the Rossby-wave it is embedded in, which also includes the north European high). Baroclinic instabilities over the North Atlantic are likely to magnify the errors that eventually develop over Europe.

The difficulty with predicting the north European high is well supported by dynamical studies of flow mechanisms in connection with blocking situations. For example, *Mauritsen & Källén* (2004) demonstrated that ECMWF ensemble spread systematically increases a few days ahead of the onset of a European block – thus indicating a bifurcation point with increased sensitivity to the initial conditions. Since the Rockies trough is an integral component of the negative Pacific-North-American (PNA) pattern, the present findings are also consistent with the results of *Corti & Palmer* (1997) who demonstrated that the amplitude of the PNA pattern over North America influences the onset of European blocking.

Case studies

Although the dominant flow regime that gives rise to European busts was obtained by constructing large composites, it is not feasible, from a technical and computational resources point of view, to apply analysis and forecast experiments to a large set of bust and 'no-bust' cases. Hence an assessment has been made of how well the busts of spring 2011 (primarily the 10 April bust) fit the general characterisation described above. The results of this investigation are described in the companion article '*A case study of occasional poor medium-range forecasts for Europe*' in this edition of the *ECMWF Newsletter*.

FURTHER READING

Corti, S. & **T.N. Palmer**, 1997: Sensitivity analysis of atmospheric low-frequency variability. *Q. J. R. Meteorol. Soc.*, **123**, 2425–2447.

Grazzini, F. & **L. Isaksen**, 2002: North America Increments – a problem in 2002. *ECMWF Tech. Memo. 674.*

Mauritsen, T. & **E. Källén**, 2004: Blocking prediction in an ensemble forecasting system. *Tellus A*, **56**, 218–228.

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A case study of occasional poor medium-range forecasts for Europe

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In the companion to this article ('*Characteristics of occasional poor medium-range forecasts for Europe*'), it was demonstrated that poor medium-range forecasts for Europe often occur when there is a high over northern Europe. During spring, the initial conditions for these poor forecasts tend to involve warm, moist, southerly flow and high convective available potential energy (CAPE) ahead of a trough over the Rockies. In these situations, the forecast is more sensitivity to the initial conditions – as demonstrated by increased ensemble spread. Hence it is likely that general improvements in the analyses used to initiate our forecasts will result in a reduced frequency of these forecast 'busts'. Using Potential Vorticity budgets, it was also shown that mesoscale convective systems (MCSs) – that accompany the high CAPE – act to slow-down the eastward propagation of the trough, thereby perpetuating the trough/CAPE regime.

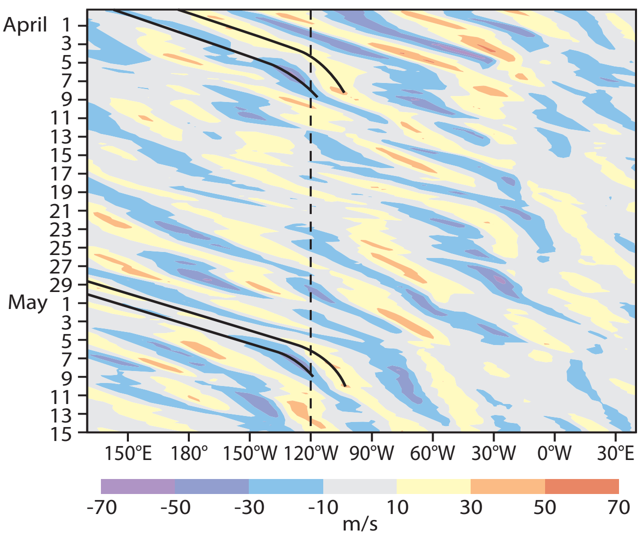

Figure 1 Meridional wind anomaly on the 330 K isentropic surface, averaged over 35°N – 50°N, and plotted as a function of longitude and time. The dashed line indicates the location of the Rockies. The solid lines highlight waves approaching the Rockies from the west. Data are the operational analyses at 00, 06, 12 and 18 UTC from 1 April to 15 May 2011.

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Here, we complement the general characterisation of forecast 'busts' with a more detailed investigation of specific case studies. The aim is to identify key factors that could help reduce the frequency or severity of these forecast busts. For computational and technical reasons, sensitivity studies can generally only be made for a few cases. Here attention focuses primarily on just one poor forecast – that of 10 April 2011 (see Figure 1 of the companion paper).

An important issue arises if only poor forecasts are considered – namely the fact that any change to the system is more likely to improve the poor score than degrade it. The effect is an example of 'regression toward the mean'. In the present context, it is uncertainties associated with chaos (when small modifications are made to the model, observations etc.) that tend to improve the bad score, and so this spurious improvement effect is termed here 'chaotic improvement'. Because of this effect, it is the sensitivity studies that do not improve the scores that are most valuable – they allow us to focus other experiments and diagnostic tools on establishing whether the changes that did improve the scores did so for 'real reasons' or simply due to chaotic improvement.

Correspondence between case study work and general characterisation

Before discussing our sensitivity and diagnostic results, we first look to see how well the bust of 10 April 2011 fits the general characterisation.

Forecast initial conditions preceding the bust

Figure 1 shows meridional wind on the 330 K isentropic surface (approximately at 250 hPa), averaged over the latitude band 35°N – 50°N, from 6-hourly operational analyses, as a function of longitude and time for April and the first half of May 2011. Diagonal stripes, in the left half of this figure, are indicative of (Rossby) waves travelling east across the Pacific. The dashed line indicates the approximate location of the Rockies. It can be seen that on two occasions these waves slow down as a trough crosses over the Rockies (meridional wind negative to the west and positive to the east, of the dashed line). These two events correspond exactly to the two European busts for forecasts starting between 8–10 April and 9–11 May. In this sense it would appear that these two busts fit well the general characterisation. In addition, they highlight the pre-cursor role of waves crossing the Pacific (although there is clearly no one-to-one relationship with the busts).

Figures 2a and 2b show the full fields and anomalies from ERA-Interim of 500 hPa geopotential height (Z500), CAPE and 850 hPa wind at this time. The similarities between

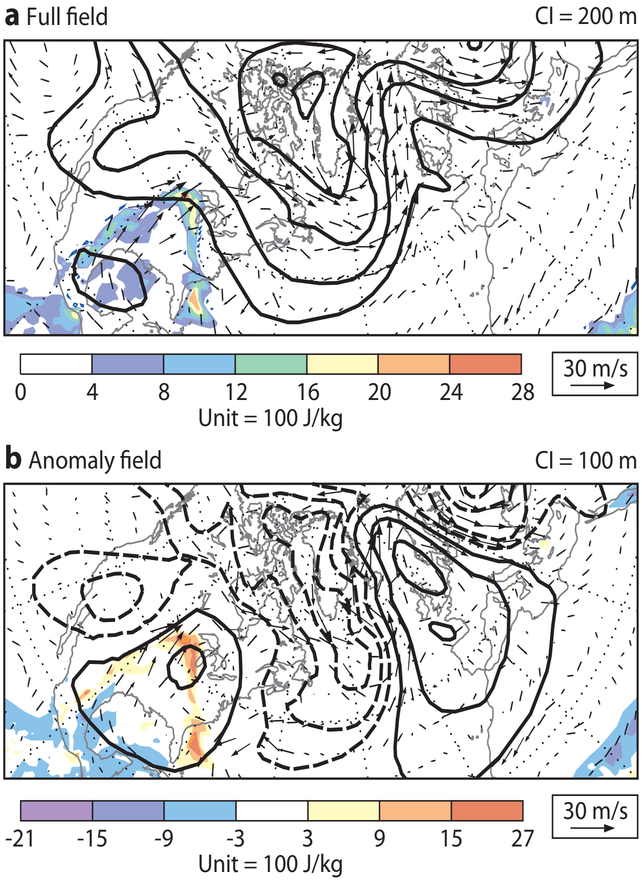

Figure 2 Operational analyses of Z500 (contours), CAPE (shading) and 500 hPa wind (vectors) at 00 UTC on 10 April 2011: (a) full fields and (b) anomalies from ERA-Interim climatology 1989–2008.

Figure 2b and the composite initial conditions (Figures 4a and 4b in the companion article) are striking. One sees the upper-level trough over the Rockies. Ahead of the trough low-level southerlies advect heat and moisture from the Southern USA and Gulf of Mexico – providing the environmental conditions (CAPE) for the development of storms.

Forecast uncertainty

The 10 April case is also associated with increased forecast uncertainty. Figure 3 shows, for the first 12 days of April 2011, the Z500 European spatial anomaly correlation coefficient (ACC) for the operational high-resolution forecasts made by ECMWF and the UK Met. Office, along with those for each member of the ECMWF Ensemble Prediction System (EPS). The increased spread in ensemble scores near 10 April is consistent with increased forecast uncertainty. Note that the ECMWF high-resolution forecast score lies well within the spread of the EPS and there is even an ensemble member score matching that of the UK Met. Office deterministic forecast which, for this case, recovered earliest from the bust. Since both deterministic forecasts lie within the ensemble spread, it would be difficult to conclude anything from this single bust case about the underlying relative performance of the two systems. Nevertheless, a comparison of the two systems has proved useful to gauge the relative importance of initial conditions relative to the forecast model; these results might apply more generally.

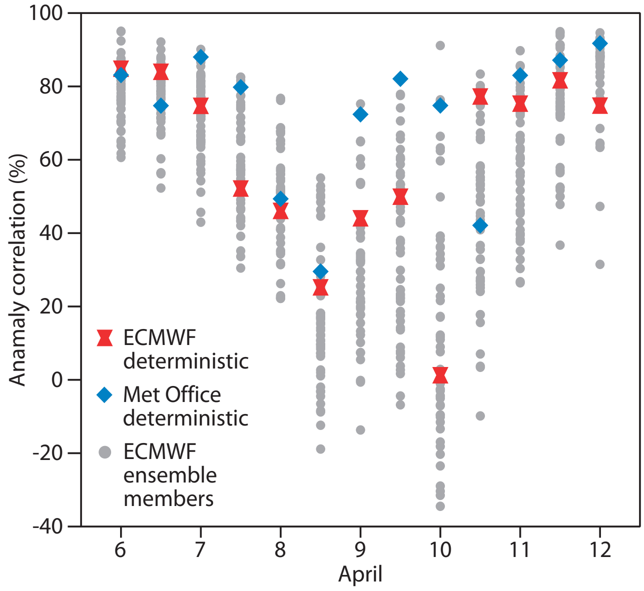

Figure 3 ACC of Z500 forecasts at day 6 for Europe initiated between 6 and 12 April 2011. Grey: for each ensemble member of the ECMWF ensemble prediction system. Red: the ECMWF deterministic forecast. Blue: the UK Met. Office deterministic forecast system. Each centre's forecasts are verified against their own operational analyses.

The importance of the initial conditions

Figure 4a shows the Z500 error at day 6 for the ECMWF operational forecast initiated at 00 UTC on 10 April 2011. The largest errors associated with this European bust occur over the eastern North Atlantic and into Europe (somewhat consistent with the trough/CAPE composite results in Figure 5 of the companion paper). The corresponding errors for the UK Met. Office operational forecast, Figure 4d, are generally smaller – consistent with the UK Met. Office recovering more quickly from the bust. Notice, however, that scores for each forecast are sensitive to the precise region chosen. For example, on this occasion, the ECMWF score for Europe is sensitive to how much of the strong positive height error is included in the north-western corner of the domain (between Scandinavia and Greenland).

When the UK Met. Office forecast is initiated from the ECMWF analysis (Figure 4c), it appears to reproduce the larger ECMWF operational errors. Similarly, when the ECMWF forecast is initiated with the UK Met. Office analysis (Figure 4b), it reproduces the smaller UK Met. Office operational errors. The correspondence between error and initial conditions would appear to indicate that the initial conditions are more important than the model used to make the forecast in this particular case. This tends to reinforce the interpretation of the composite results.

Identifying the salient errors in the initial conditions

Although the above results suggest the importance of the initial conditions for the 10 April bust, we have not yet made a link to the trough/CAPE situation over the USA. As a first approach to identifying the key aspects of the initial conditions, we continue the comparison between the UK Met. Office and ECMWF.

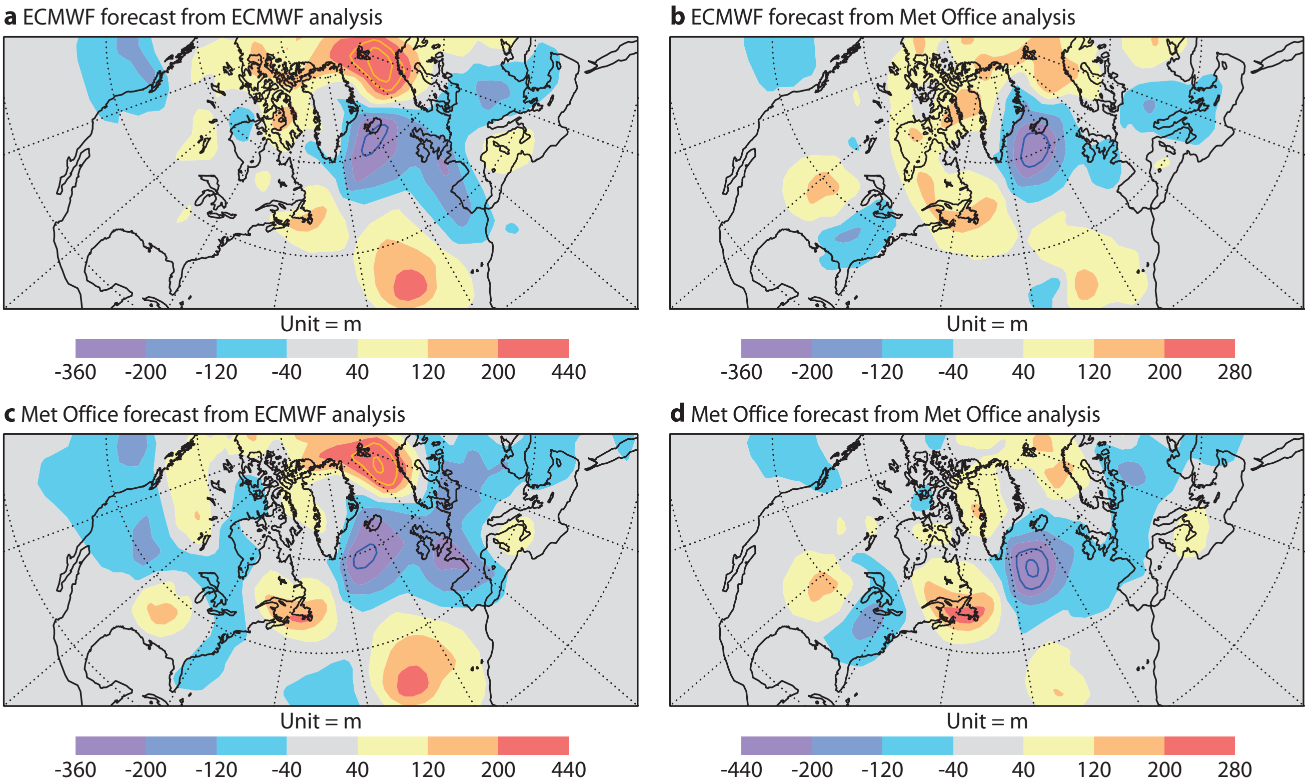

Figure 4 Errors in day-6 forecasts of Z500 from initial conditions at 00 UTC on 10 April 2011. (a) ECMWF forecast started from ECMWF analysis. (b) ECMWF forecast started from UK Met. Office analysis. (c) UK Met. Office forecast started from ECMWF analysis. (d) UK Met. Office forecast started from UK Met. Office analysis. Verification data is ECMWF analysis at 00 UTC on 16 April 2011.

Figure 5a shows the difference in operational analyses (UK Met. Office minus ECMWF) at 00 UTC on 10 April 2011. Although there are differences over the USA, there are actually differences everywhere, and these reflect random and systematic aspects. However, it is those differences that project onto fast growing modes that will play the most important role in the error differences that develop by day 6. Figure 5b shows the difference in operational forecasts at day 1 (the contour interval is double that of Figure 5a). The differences over the USA have developed to show a strengthened Rockies trough and downstream ridge in the UK Met. Office forecast. However, differences in other regions remain. In order to better isolate the salient aspects, we now focus on just one forecast system, the ECMWF Integrated Forecasting System (IFS).

If forecast errors are not dominated by model problems, then it is useful to trace these errors back to shorter lead-times in order to highlight the salient errors in the initial conditions. Figure 6a shows the Z500 day-2 error in the ECMWF operational forecast from 00 UTC on 10 April 2011, and this more clearly highlights North America as a key region.

It becomes difficult to trace errors back to even shorter lead-times, as uncertainties in the verifying analysis begin to affect the calculation of forecast error. Instead, one can look at the 50 ensemble members of the EPS. Each ensemble member is started from a slightly perturbed set of initial conditions. Results show a strong correspondence between the initial condition perturbation of a given member and its eventual error over Europe. For example, the two ensemble members that had the smallest root-mean-square error (RMSE) over Europe at day-6 shared essentially the same initial perturbations. Furthermore, another two ensemble members shared the negative of these initial perturbations, and they produced the worst and sixth-worst European scores at day-6.

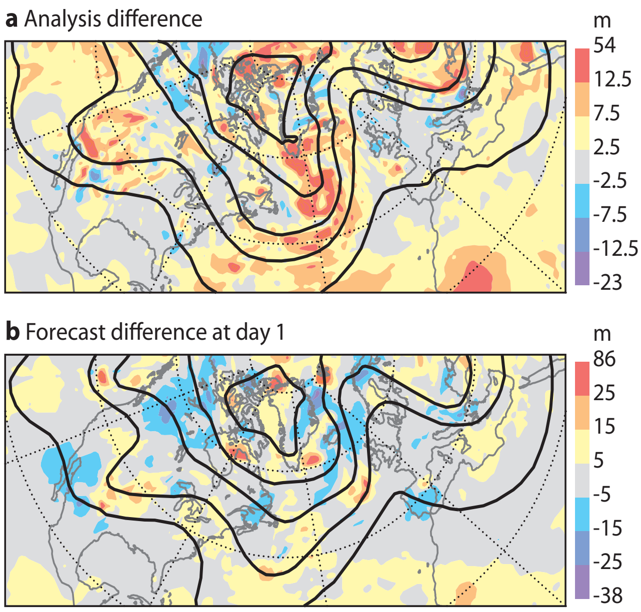

Figure 5 Difference in Z500 between operational forecasts (UK Met. Office minus ECMWF) at (a) day 0 (i.e. the analysis difference) and (b) day 1. Contours show the full field for the UK Met. Office at the same lead-times with interval 200 m.

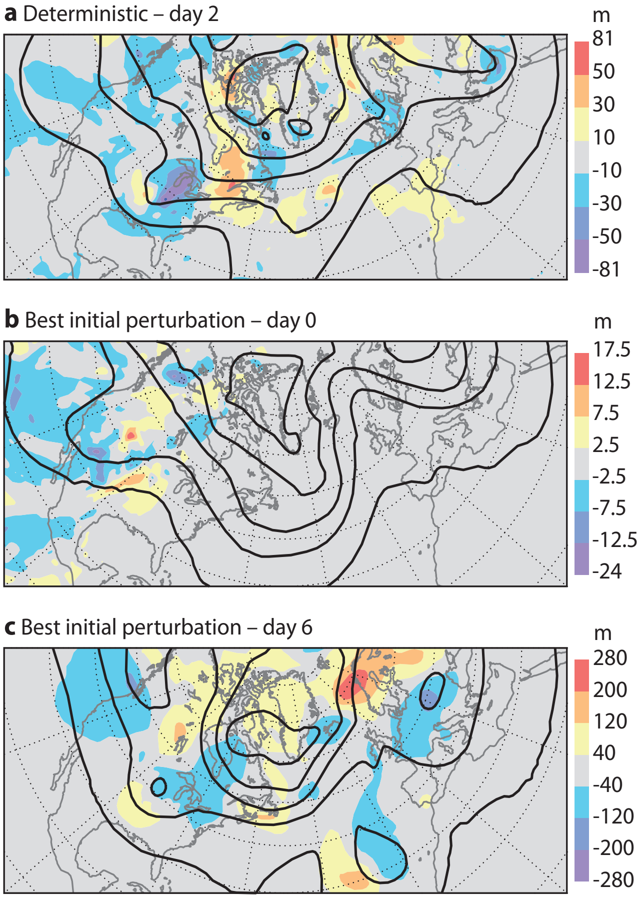

Figure 6 Z500 forecast error (shaded) for ECMWF forecasts initiated at 00 UTC on 10 April 2011. (a) Operational forecast at day 2. (b) and (c) Forecasts with initial condition perturbation equivalent to that of the 'best' operational EPS member, but confined to the region [180°W–90°W, 0°N–90°N] at day 0 and day 6. In all panels, the full forecast field is contoured with contour interval 200 m.

We have further isolated the key initial condition perturbations of the best ensemble member by progressively confining the perturbations to ever smaller domains. Figure 6b shows the result of this process. The key perturbations have been confined to the North American/eastern North Pacific region. They highlight a strengthening (of order 5 – 10%) of the Rockies trough and the downstream ridge (and presumably increased CAPE). This is consistent with the comparison with the UK Met. Office. Indeed, over North America the difference at day 1 between the forecast initiated with this perturbation and the control is almost identical to that shown in Figure 5b. At day 6, errors for the perturbed forecast (Figure 6c) are, indeed, reduced over the eastern Atlantic and western Europe compared to the control (Figure 4a).

Summary of the correspondence between the case study and the general characterisation

For the bust of 10 April 2011, there appears to be a strong similarity with the general characterisation of spring busts discussed in the companion article. A wave packet crossing the Pacific slows-down when a trough is over the Rockies and a ridge is over the eastern USA. We have shown that small perturbations to this trough/ridge structure lead to large differences in day-6 errors (and ensemble spread) over the eastern North Atlantic and into Europe. In this case, the best initial perturbation strengthens the trough and ridge. By identifying a key perturbation structure, we have been able to go further, for this particular case, than the general characterisation. However, there is no reason to assume that the sign of the best perturbation is the same for all busts. Indeed, it is unclear from this one case how common the best perturbation structure is to all busts.

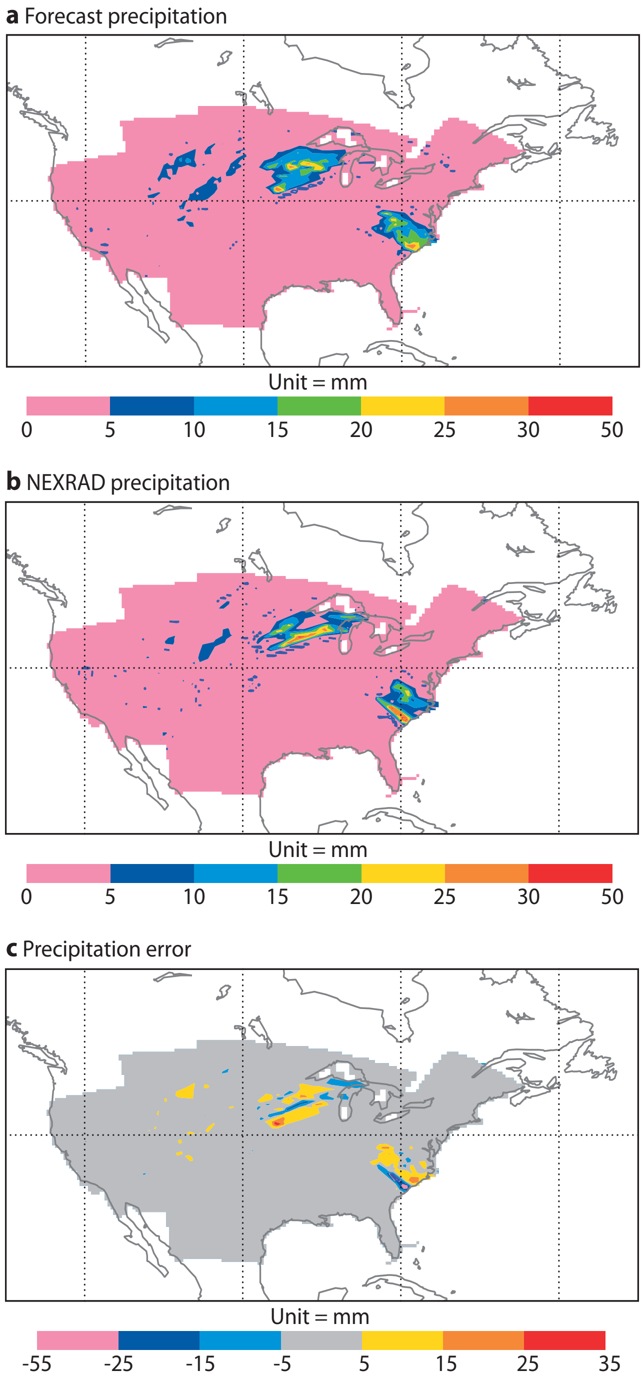

Figure 7 Accumulated precipitation over the 12-hour period from 21 UTC on 9 April 2011 to 09 UTC on 10 April 2011. (a) Precipitation from the first-guess forecast started at 18 UTC on 9 April 2011. (b) Precipitation as retrieved from NEXRAD radar data. (c) Precipitation error: (a) minus (b).

Mesoscale convective systems in the data assimilation system and forecast model

The composite results demonstrated that MCSs (associated with increased CAPE) are active components in the propagation of the trough. Hence it is worth understanding how these systems are represented in the forecast model and corrected by the data assimilation. Several cases have been considered – both for MCSs that occur during busts and for those that occur during 'no-bust' conditions. Conclusions are similar in all cases but, for consistency we continue to focus on the 00 UTC 10 April 2011 analysis and forecast.

MSC events in the first-guess forecast

Figure 7a shows 'first-guess' precipitation accumulated over the 12-hour data assimilation window that was used to make the analysis. The area plotted has been limited to that reliably 'observed' by NEXRAD ground-based radar – shown in Figure 7b. By eye, the first-guess and observed fields display good correspondence – both showing two MCSs over the USA: one to the west of the Great Lakes (up to 30 mm and, incidentally, associated with numerous tornado reports) and the other near the east coast of the USA (up to 50 mm). However, there are considerable differences between the first-guess and the observations (Figure 7c) of over 25 mm – associated with location and intensity errors.

One of the strongest MCS events during spring 2011 was on 24 April and centred over Cleveland, Ohio (up to 100 mm). In this case, the first-guess forecast managed to predict the location reasonably well, but the intensity was underestimated (even at large scales) by as much as 60 mm.

Grazzini & Isaksen (2002) highlighted a tendency for the model at that time to erroneously resolve the fluxes associated with convection and thus produce 'large-scale' precipitation. Our investigations have revealed that the precipitation is now largely associated with parametrized convection – which is thought to be a significant improvement since present model resolution is still too course to resolve real convective fluxes.

Use and impact of observations in the correction of MCS errors

In order for the data assimilation to correct MCS errors (or any other errors) in the first-guess forecast, it requires relevant observations. To compare the first-guess field with the observations, the first guess is interpolated to the observation locations. The data assimilation system then acts to draw the analysis away from the first-guess and closer (in general) to the observations in a way that is consistent with estimated observation and model errors. The difference between the final analysis and the first-guess is known as the 'analysis increment'. Figure 8 shows analysis increments for two representative observation types during the production of the 00 UTC analysis on 10 April 2011.

Aircraft data (Figure 8a – known as AIREP data) are particularly important for the upper-tropospheric analysis over the USA (lower-down, flights converge at airports and

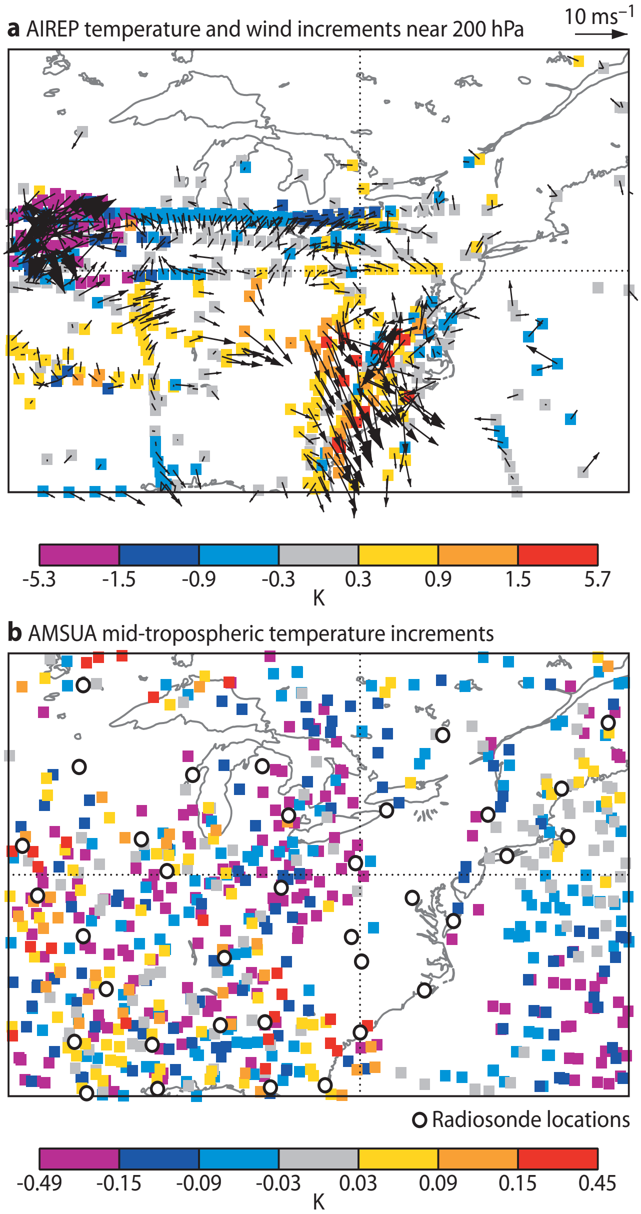

Figure 8 Analysis increments of temperatures and winds (interpolated to observation locations) during the production of the operational analysis at 00 UTC on 10 April 2011. (a) Aircraft observations near 200 hPa (185–215 hPa). (b) AMSUA microwave channel 5 (which measures mid-tropospheric temperatures). The radiosonde network is also indicated.

the horizontal data coverage becomes poorer). Although other observation types will have an influence on these increments, it is likely that the AIREP data plays a major role in correcting upper-tropospheric winds and temperatures in the region of the MCS over the east coast of the USA. However, there was no AIREP data assimilated in the region of the other MCS, to the west of Lake Michigan. Comparison with AIREP data on the same day of the week, seven days later, suggests that flights were avoiding the extreme weather associated with the MCS.

If signficant cloud is present, then satellite observations are also difficult to assimilate. The coloured squares in Figure 8b show the analysis increments for the AMSUA microwave channel 5, which measures mid-tropospheric temperatures.

While AMSUA data is generally very powerful within the data assimilation system, ‘holes’ can be seen over the MCS regions where cloud has led to the rejection of data. Similar holes occur for the AIRS infrared channel 156 and the AMSUA microwave channel 7, both of which measure upper-tropospheric temperatures.

The black circles in Figure 8b show the radiosonde network. While thought to be quite accurate, these data tend to be too sparse to resolve features of the scale of MCSs. Other data can be rejected if the difference with the first-guess is too large. In addition, we are only able to use some satellite observations over the ocean.

These results indicate that, for the variety of reasons discussed above, there are fewer in-situ observations available to the data assimilation within MCSs. Similar conclusions can be drawn from the other MCS events investigated.

Note that, since the busts of spring 2011, the assimilation of NEXRAD precipitation rates has been implemented in the IFS. Results show that the analysis does draw towards to these observations within MCS events, but the actual impact of the radar data on the forecast (relative to the impacts of other surface observations) remains to be quantified.

The four-dimensional variational data assimilation system (4D-Var) optimally fits a model trajectory through all the available observations and this means that observations outside an MCS can correct the first-guess within the MCS. Above, we interpolated to individual observation locations to highlight the reduced availability of in-situ data but, to assess the aggregate impact of all observations, we now look at the model fields.

Figure 9c shows these analysis increments for temperatures and winds at 500 hPa. The question we would like to answer is whether the magnitudes of the increments in the MCS regions are consistent with the first-guess precipitation errors shown in Figure 6c.

We can decompose the evolution of the first-guess forecast into the contributions from the dynamics and each of the physical processes. Within the MCS events, there is strong convective heating due to latent heat release (Figure 9b). The precipitation data suggest that this heating is in error by at least 50%. However, much of the convective heating is balanced by dynamical cooling associated with ascent (Figure 9a), and so it is not appropriate to compare the magnitude of the increment with that of the convective heating error.

Other processes (not shown) involving clouds, radiation and vertical diffusion are also important but smaller in magnitude. The sum of the impacts of the dynamics, physical processes and the analysis increment represents the analysed evolution of the flow (Figure 9d). It is the magnitude of this evolution that is most appropriate to compare with the increments in the MCS regions. Comparison of Figure 8d with Figure 8c (which is plotted with a much smaller contour) suggests that the increments are typically about ⅓ those of the evolution. This ratio is probably too small when we consider the magnitudes of the precipitation errors. Similar results apply to the mid-tropospheric specific humidity budget.

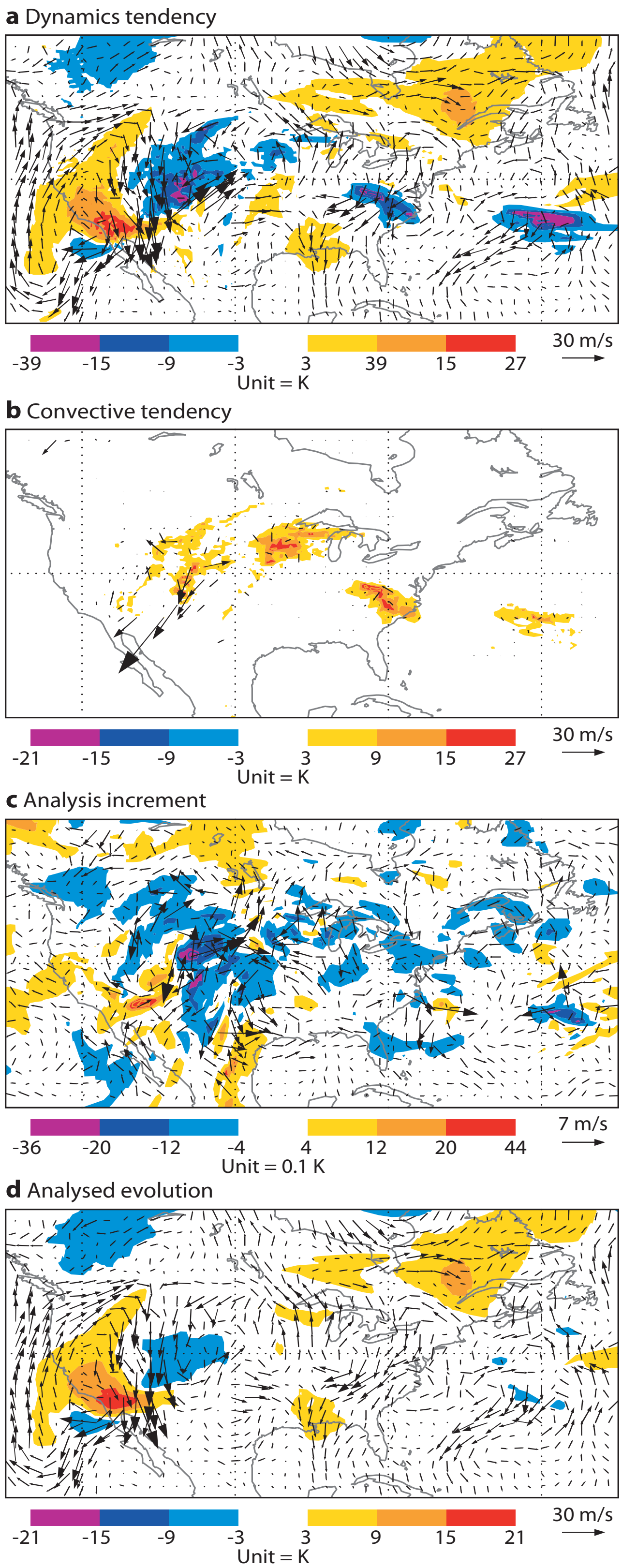

Figure 9 Diagnostics of 500 hPa temperature (shaded) and horizontal wind (vectors). (a) Dynamics tendencies integrated over the first 12 hours of the first-guess forecast started at 18 UTC on 9 April 2011. (b) Similar integrated tendencies from the convection scheme. (c) The analysis increment valid at the end of the 12-hour period. (d) The analysed evolution of the flow (the difference between the analysis at the start and end of the 12-hour period). See individual panels for contour intervals and reference vectors.

Summary of the investigation into mesoscale convective systems

Mesoscale convective systems are generally well predicted by the first-guess forecast, but precipitation accumulations can be in error by over 50% and locations can be offset. It is unclear at present whether these errors are adequately represented in the ensemble data assimilation system, and this could be a future area for research. The MCS events reduce the quantity of observational data available to the assimilation system. While 4D-Var does still produce analysis increments in these regions, the magnitudes of these increments in the mid-troposphere may be somewhat too small. Hence MCS events may act to degrade the analysis in addition to playing an active role in the evolution and chaos of the flow.

Sensitivity studies

The final part of the investigation into busts was to assess the sensitivity of busts to types of observations, flow-dependent background errors and other factors.

Sensitivity to types of observations

Here we diagnose the 'usefulness' of the observations when they are assimilated. To do this, a technique is used that quantifies the contribution to (global) 24-hour forecast error associated with each individual observation type (the so-called 'forecast error contribution', FEC). FECs were averaged over one week (6 April 2011 to 13 April 2011 – approximately 50% of this period is within the bust, and 50% outside the bust event). Hence the effect of chaotic improvement should be small. With the exception of PILOT data, mean FECs over the USA and north eastern Pacific were found to be negative – i.e. using the observations is reducing forecast error.

The mean forecast error contribution for AIREP data above 400 hPa is shown in Figure 10a. Over the USA – where the data density is high and thus the mean contribution is well quantified – these aircraft data are seen to decrease 24-hour forecast error. On the other hand, PILOT data over the USA (Figure 10b) often increases the 24-hour forecast error. For the USA, PILOT data are actually re-labelled radiosonde observations that provide additional information at 'significant levels', such as temperature inversions, and might be expected to be particularly difficult to reconcile with the first-guess forecast. In general PILOT data show weaker mean westerlies over North America than the other observation types. These results suggest that the impact of PILOT data should be the first candidate for further investigation.

An 'observation system experiment' was performed whereby PILOT data was denied (globally above 400 hPa) from the data assimilation system run at operational resolution from 1 April 2011. However, no reduction in the 10 April bust was found in the full non-linear forecast. Hence, while PILOT data could have a detrimental impact on our analyses in general, it does not appear to have a specific impact on the analysis that leads to the bust.

Sensitivity to flow-dependant background errors

When producing the analysis, the 4D-Var assimilation system requires knowledge of likely errors in observations and the background model. By altering the error covariances, the extent to which the analysis is drawn away from the background and towards the observations can be changed. In general, these error covariances are probably near optimal – as judged by average forecast performance. However, since it is possible that a poor trough/CAPE analysis is being perpetuated through the background (by systematic errors in the model for example), a sensitivity study was conducted whereby background error covariances were trebled for a few days leading up to the busts on 10 April and 10 May.

Although the effect of chaotic improvement cannot be discounted, Figure 11 shows that the Z500 European ACC

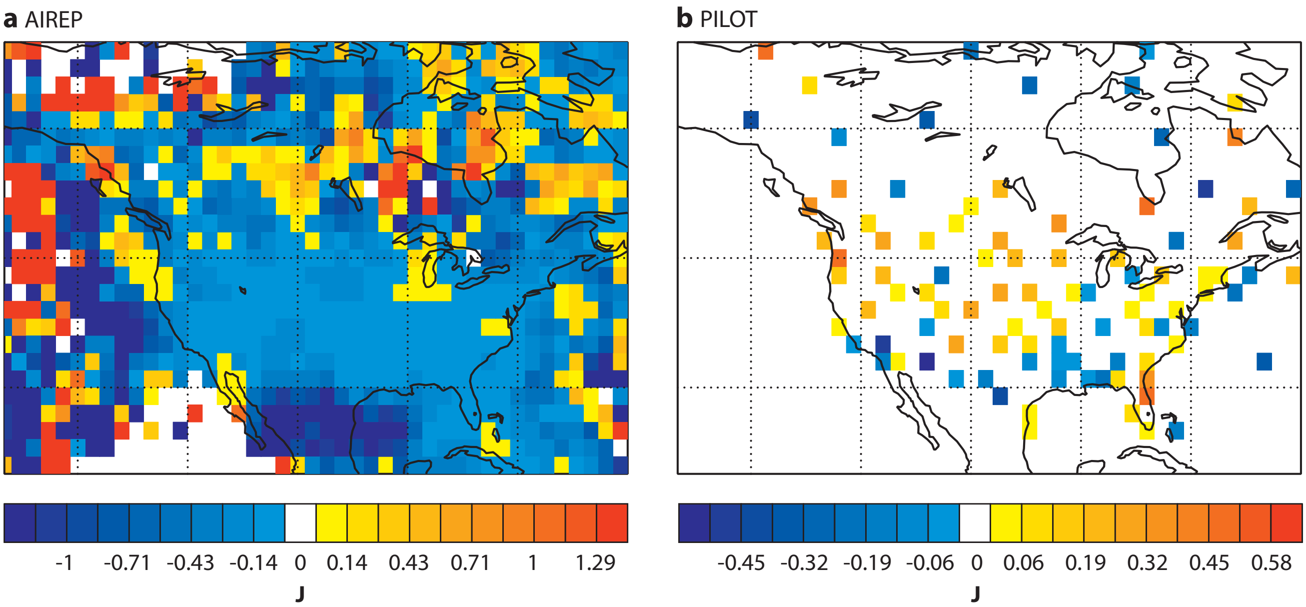

Figure 10 Contribution to 24-hour forecast error above 400 hPa, averaged over the week 21 UTC on 6 April 2011 to 21 UTC on 13 April 2011 from (a) AIREP and (b) PILOT data types.

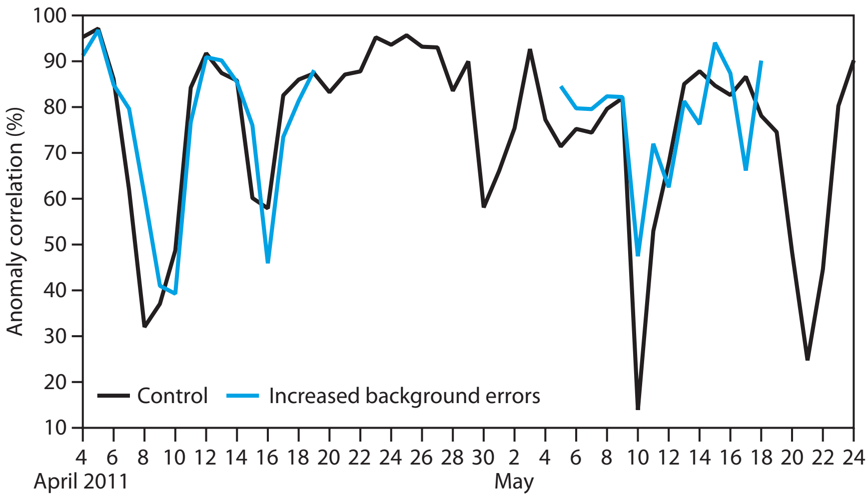

Figure 11 ACC for day-6 forecasts of Z500 for Europe for T511 forecasts initiated from T511 analyses generated with control, and trebled, background error covariances. A 12-hour data assimilation window was used.

at day 6 is moderately improved around the times of both busts – especially for the 10 May case. Since 18 May 2011, the Ensemble of Data Assimilations (EDA) has been used to incorporate flow-dependence into the background errors. Although the use of the EDA (in its default configuration) did not improve the 10 April bust either, further investigation of the EDA-generated background errors in these trough/CAPE situations over the USA would be beneficial.

Sensitivity to other factors

The previous result suggests that, if the observations are given more weight, this improves the forecast (particularly for the second bust case around 10 May). However, the complexity of this situation, and the extreme sensitivity to the initial conditions is illustrated by a somewhat contrary result. The denial of all data over land within a single assimilation cycle led to a markedly reduced bust on the 10 April (by more than a factor 2 in European ACC and RMSE at both day 5 and day 6). Figure 12 shows the change in initial conditions when the data over the land was denied. It shows a strengthened trough (somewhat consistent with the best ensemble member, Figure 6b) although it does not strengthen the ridge. Further investigation will ascertain if this is a case of chaotic improvement or otherwise.

We have also considered the possibility of sensitivities to the formulation of the model's dynamical core. The IFS and the UK Met. Office's Unified Model (UM) differ substantially in several aspects of their dynamical cores. The IFS version used operationally at ECMWF is a spectral model that solves the hydrostatic primitive equations, whereas the UM is a latitude-longitude grid-point model that solves the non-hydrostatic, deep atmosphere equations. Moreover, there are differences in the numerics associated with the vertical discretisation and the time marching scheme as well as in the coupling to the physical parametrizations. Hence an extensive series of experiments eliminating some of the differences in the dynamics between the UM and the IFS was conducted. The spring busts were found to be insensitive to any of these changes except that the April 10 bust was less severe with a change to the 'implicitness' of the vertical diffusion scheme in the boundary layer. Again, this one example could be associated with chaotic improvement. Based on these results, it is concluded that the dynamical core formulation is unlikely to be the key factor for the occurrence of the forecast busts.

Based on coincidences with the 10 April bust case, other work has investigated possible links to the El-Niño-Southern-Oscillation, the Madden-Julian Oscillation, and to Rossby wave forcing by the Tibetan Plateau. While all of these features undoubtably contribute to forecast error in general, no strong correlation was found with the incidences of European bust forecasts over the last decade or more. It has also been noticed that the Rockies trough leads to strong winds over the Sierra Madre mountains of Mexico, and the generation of gravity waves. Improved diagnostic techniques, and their application to other flow regimes, would be required to quantify the impact of these waves on the busts.

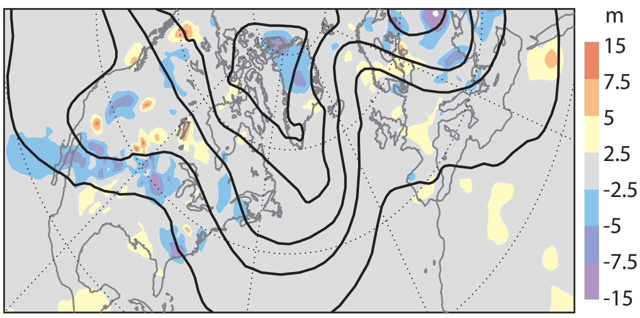

Figure 12 Z500 analysis at 00 UTC on 10 April 2011 when observations over land are denied from the data assimilation system for a single analysis cycle. Shaded: difference from control analysis. Contoured: full field with contour interval 200 m.

Future directions

Poor medium-range forecasts for Europe, as defined in the companion article, are an order of magnitude rarer now than they were 20 years ago. Nevertheless, even a single 'bust' is not good for our users, and has a significant impact on our seasonal-mean scores.

If past trends also predict future improvements, then general development of the IFS, with no focus on forecast busts per se, may continue to reduce bust frequency. However, if we wish to specifically target the bust issue then the above results can help inform decisions about future work.

The results suggest that the initial conditions in trough/CAPE situations need to be more accurate to reduce bust frequency or severity in our forecasts.

- The primary reasons for first-guess errors in the trough need to be identified. Are they associated with Tibetan wave forcing errors (passed through several assimilation cycles as the waves propagate across the Pacific) , or do the available observations over the Pacific and baroclinic instability in the Pacific storm-track obliterate this effect? Are there systematic errors in (Rossby) wave speeds or magnitudes over the Pacific?
- Do we have accurate enough, and abundant enough, observations to constrain circulation structures over the USA like those of the best ensemble member perturbation? (Note that the magnitude of the best ensemble member perturbation is similar to the standard deviation of Z500 errors from radiosonde observations over the USA.) Special focus could be placed on observations that are particularly important for the analysis over the USA– aircraft data for example. The role of PILOT data (for the USA, this is radiosonde observations at significant levels) on analyses in general could be investigated further. The analysis experiment that denied all data over land will be refined and extended to larger samples.
- There is an indication that background errors, which are optimal for general forecast performance, might not be optimal in this particular trough/CAPE flow regime. The IFS now uses the standard deviation of EDA first-guess forecasts to estimate the flow-dependence of background errors. Figure 13 shows this standard deviation in 12-hour forecasts started from 12 UTC on 9 April. Enhanced uncertainties do occur in the central USA region highlighted by the best ensemble member (Figure 6b), although they are weaker. Note, however, the lack of significant uncertainty in the region of the MCS to the west of the Great Lakes. One reason for this may be because sub-gridscale uncertainty associated with the triggering of convection is not represented by the stochastic scaling of tendencies at present. Investigation of more cases of trough/CAPE situations will confirm whether the new EDA-generated background errors adequately represent local uncertainty in these convective situations.

The roles played by convection suggest that further investigation of MCSs would be beneficial.

- Can we improve the (deterministic) prediction of convection in the first-guess forecast? The representation of MCS convection has already improved a lot over the last decade. Further improvements in predicting the location and intensity of convection in the first guess forecast (let-alone at longer lead-times) will continue to be a challenge. Future increases in computing power will present new opportunities as we start to resolve the convection within MCS events.
- Can we improve the data assimilation in MCSs – present in the observations and/or first-guess? Do we have the necessary observations to constrain the convection? How representative are observations of model grid-box-mean values in these convective situations? How is the MCS represented at each iteration within the data assimilation? How well does the linear physics represent such extreme precipitation events? How can we reduce data rejection and improve the impact, throughout the troposphere, of non-rejected data?

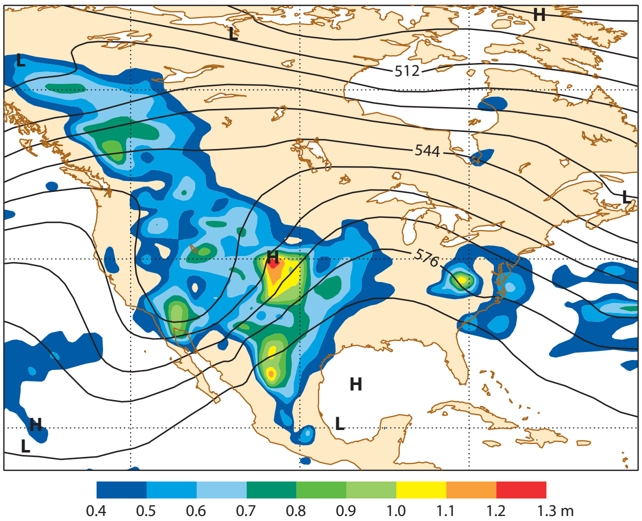

Figure 13 Standard deviation of Z500 for the EDA 12-hour forecasts from 12 UTC on 9 April 2011.

For flow situations where forecast error is substantially different from its mean value, as in the case of the trough/CAPE regime, it is important to assess whether EPS spread in the medium-range adequately reflects the change in likely error.

- Can we develop diagnostics that better assess the flow-dependent spread-error relationship in the face of short datasets (due to frequent system updates) and the annual cycle in predictability?

This study has highlighted reasons for, primarily springtime, European forecast busts.

- Can autumn busts be explained by a similar trough/CAPE situation that arises over the North Atlantic when a tropical cyclone transitions into the extratropics and happens to encounter an upper-level trough (*Jones et al.*, 2003)?

The conclusion of this study is that more accurate initial states around the Rocky mountains, and improvements in the assimilation and forecasting of mesoscale convective systems over North America, will be necessary to decrease the frequency of European medium-range forecast busts, particularly in spring. Indeed, it is also likely that much of the strong reduction in the frequency of these busts over the past decades must be attributed to improvements in these two aspects. However, due to the chaotic nature of the atmosphere, with flow states whose evolution is highly sensitive to the accuracy of the initial state, we may never be able to completely eliminate busts in the future.

FURTHER READING

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The European Flood Awareness System (EFAS) at ECMWF: towards operational implementation

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Together with national and regional hydro-meteorological services and small-to-medium sized enterprises, ECMWF is currently establishing the operational services for the European Flood Awareness System (EFAS). ECMWF will be hosting the Computational Centre for EFAS which is envisaged to be fully operational in the second half of 2012. This follows many years of research and development on ensemble-based, probabilistic hydrological prediction, during which ECMWF has been increasingly interacting with national and international institutes that are developing hydrological prediction systems. The close collaboration with the European Commission's in-house science service, the Joint Research Centre, that developed EFAS over the past decade has been particularly fruitful.

This article describes how EFAS started in 2002 as well as the stakeholders and partners. The set-up of the operational phase of EFAS is described along with ECMWF's role. It is demonstrated that the EFAS system is skilful and the advantages for the Member States of ECMWF are highlighted.

Background

The need for a European-wide flood alert system was recognised in 2002 when, following a decade of severe natural disasters including record floods, the European Commission funded several initiatives related to flood risk management acting on the four major phases of the disaster cycle: prevention, preparedness, crisis management and recovery. Regarding prevention there have been several important developments.

- The EU flood directive (http://floods.jrc.ec.europa.eu/eu-floods-directive) requires countries to map those areas at risk of flooding.
- The development of the European Flood Awareness System (EFAS) was initiated to improve preparedness for floods by increasing warning times up to 10 days and by providing catchment-based overviews across Europe.

AFFILIATIONS

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- Crisis management in Europe has been greatly enhanced through the establishment of the European Community Mechanism with its Monitoring and Information Centre (MIC, http://ec.europa.eu/echo/civil_protection/civil/prote/mic.htm).
- The establishment of an EU solidarity fund provides financial support during the recovery phase for those countries exceptionally hit by disasters.

Administratively at the EC level, the operational EFAS has been inserted into the Emergency Management Service of the Global Monitoring of Environment and Security (GMES) programme which enters its GIO (GMES Initial Operations) phase from 2011–2013. The objective of the GMES Emergency Management Service is to support users in the field of crisis management by providing them with information based on space (satellite) data combined with other sources of data. It addresses natural disasters (e.g. floods, forest fires, earthquakes, tsunamis, volcanoes, landslides and storms) and man-made disasters (e.g. industrial, nuclear accidents and terrorism attack), both inside and outside the EU.

EFAS has developed into a unique system that serves two purposes. It provides:

- The European Commission with harmonized overview information about forecast and ongoing floods across Europe (i.e. for the preparation and management of aid during a flood crisis).
- National hydrological services and water authorities with medium-range and catchment-based flood information thereby raising their preparedness for future flood events by complementing information from their local and regional systems.

EFAS has developed in strong collaboration with a variety of organisations. These fall into four broad categories.

- National meteorological services, consortia (e.g. LAM consortia) and NWP centres.
- National hydrological services.
- Private sector.
- European and international organisations.

Box A gives some information about the contributions made by the stakeholders and partners of EFAS.

Initial operations phase of EFAS

This initial operations phase of EFAS (2011–2013) involves four centres:

- EFAS dissemination centre
- EFAS computational centre
- EFAS hydrological data collection centre
- EFAS meteorological data collection centre

The overall coordination of the project and the contract

Stakeholders and partners of EFAS **A**

National meteorological services, consortia (e.g. LAM consortia) and NWP centres

- ECMWF's medium-range weather forecasts are key inputs for EFAS. Currently use is made of forecasts and re-forecasts of surface data from the high-resolution model (with geographical resolution of about 16 km) and Ensemble Prediction System (EPS, with a geographical resolution of about 32 km). With 104 single forecasts a day, the ECMWF products constitute the bulk input of the probabilistic EFAS.
- Deutscher Wetterdienst (DWD, Germany) provides deterministic predictions of surface variables as input to EFAS (COSMO-EU, with a geographical resolution of 7 km, and DWD-GME, with a geographical resolution of 30 km). They are an important part of the combined hydrological ensemble prediction system as they introduce a different meteorological model to the hydrological ensemble system.
- The Limited Area Ensemble Prediction System developed within the international COSMO Consortium (COSMO-LEPS, run at ECMWF by the COSMO members: Germany, Greece, Italy and Switzerland) provide limited-area ensemble predictions of surface variables (with a geographical resolution of about 7 km). They are an important part of the combined hydrological prediction system, in particular over mountainous terrain within the COSMO-LEPS domain. The COSMO-LEPS modelling framework uses a version of the DWD model and drives it with initial conditions from the ECMWF EPS.

National Hydrological Services

- Currently 30 services, which are responsible for more than 80% of all trans-national river basins in Europe, have agreed to receive EFAS information for testing purposes and provide feedback to improve the system.
- 27 water authorities provide hydrological discharge and water level data for EFAS in realtime.

Private sector

- Commercial companies, small and medium-sized enterprises or commercial arms of national institutes have been involved in EFAS. Examples are Atkins Ltd (data collection and database set-up), PCRaster (provider of specialized GIS software) and several consultancies working with JRC to support their developments.

European and international organisations

- WMO hosts the Global Runoff Data Centre (GRDC) which was involved in collection of real-time river discharge for EFAS.
- The Monitoring and Information Centre (MIC) in the European Commission in Brussels is the operational heart of the Community Mechanism for Civil Protection in Europe. The MIC receives EFAS information for improved aid management. Any country affected by a major disaster – inside or outside the EU – can launch a request for assistance through the MIC.
- The European Earth monitoring programme GMES (Global Monitoring for Environment and Security) addresses emergency response for floods in Europe through EFAS.

management of these four centres remain with the European Commission's Joint Research Centre (JRC). This will also continue to provide off-line development and research support for improving the operational services.

The role of the individual centres is described in Box B.

EFAS performance in the past

The performance of EFAS has been assessed using a range of verification metrics, both in a statistical sense based on several years and for selected key events.

Information about hits and false alarms for all EFAS warnings are collected for flood events throughout the year and presented during the EFAS annual meeting to all partners. Figure 1 shows such a statistic for the last four years and illustrates that there have been many more hits than false alarms. Here a 'hit' is counted if EFAS has issued an alert to a partner organisation and somewhere within the catchment flooding has been reported. A 'false alarm' is counted if flooding was predicted but not observed or, if in the days following the warning, EFAS has forecast a decreasing probability for flooding. In some cases, feedback from the partners could not yet be collected or was not provided. Clearly, 2010 was a busy year for the EFAS forecasters with almost twice as many alerts sent out as in previous years. Although this is mostly due to the many floods that took place in 2010, it also reflects that alerts are sent out with lower probabilities in order to achieve longer lead times. Average warning lead times ranged between 6 to 3 days.

A more objective, statistical approach to evaluate the skill of EFAS has been completed for a period of ten years within the framework of the SAFER (Services and Applications For Emergency Response) project. This analysis showed that the skill has been progressively increasing over the past ten years due to improved NWP inputs and higher-resolution observational networks used to calculate the initial conditions (*Pappenberger et al.*, 2010).

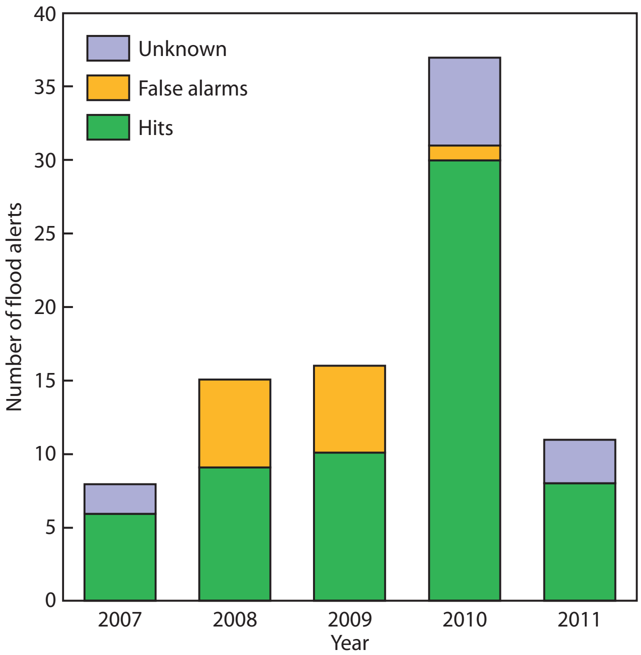

Figure 1 Hits and false alarms from EFAS flood alerts from 2007 to 2011. Note that there are more hits than false alarms and that in 2010 more than twice as many alerts were issued compared with previous years.

The Central European floods in May/June 2010 serves as an example how the different actions at the EU level worked, for the first time, hand in hand to provide improved flood and crisis management. Figure 2 shows the EU actions on the floods. The triangles indicate river basin authorities which received EFAS alerts with at least a 3 day lead-time warning, at some locations up to 6 or 7 days. Clearly, EFAS forecasts picked out the Vistula, Odra, and Danube tributaries as being at risk of flooding affecting Poland, Germany, Czech Republic, Austria, Hungary, Slovakia and Romania.

For the first time, the Monitoring and Information Centre (MIC) received EFAS information on a daily basis and used it to prepare aid actions in advance and so was prepared when Poland (19 May) and Hungary (25 May) requested international assistance through the MIC (indicated by MIC-PL and MIC-HU in Figure 2). Also, although EFAS is primarily designed to provide early flood warnings, EFAS information helped MIC to keep an overview of what was reported in terms of flooding and whether second flood waves were predicted.

Figure 3 gives an example of an EFAS forecast associated with the May/June floods. This shows which rivers were expected to be affected by flooding. Also shown is a hydrograph indicating that the rate of flow reaches a peak on the sixth day. During February 2012 the high amounts of accumulated snow raised fears that suddenly raising temperatures could lead to severe snow melt floods. Public information on the possibility of widespread flooding, such as the one issued by the UN News Centre (http://www.un.org/apps/news/story.asp?NewsID=41310) on the possibility of sudden thaw in the Danube, made both EFAS partners and the MIC look to EFAS for a more detailed assessment of the probability for floods 3 to 10 days in advance.

Roles of the four EFAS centres — B

EFAS dissemination centre

The EFAS dissemination centre will analyse the EFAS results provided by the EFAS computational centre, investigate any on-going floods in Europe and issue early flood warnings to partners of the EFAS network. Furthermore, feedback on flood forecasts and performance of the system will be collected and reviewed at the EFAS annual meetings organised in close collaboration with the JRC. The EFAS dissemination centre is the most visible part of the EFAS chain and is led by the Swedish Meteorological and Hydrological Institute (SMHI) in collaboration with the Slovakian Hydrological and Meteorological Institute (SHMU) and Rijkswaterstaat (RWS, The Netherlands).

EFAS computational centre

The EFAS computational centre will be responsible for the transfer of the EFAS computational tasks from a research and development environment into operations with a guaranteed 24/7 support, together with associated testing and support for further research and development. This role will be performed by ECMWF. – for more details see the section concerning 'Operational EFAS at ECMWF'.

EFAS hydrological data collection centre

The EFAS hydrological data collection centre will manage an existing network of data providers for real-time hydrological observations, set up the data collection system for discharge and water level, implement quality control on the real-time data and provide the data in an agreed format for EFAS, operating with guaranteed 24/7 support. This task will be performed by a consortium based in Andalusia (Spain) formed by ELIMCO SISTEMAS (private company) and the Environmental Information Network of Andalusia (REDIAM) (public sector).

EFAS meteorological data collection

The EFAS meteorological data collection centre will manage an existing network of data providers for real-time and historic meteorological observations, set up the data collection system for surface observations, implement quality control on the real-time and historic data time series and provide the data in an agreed format for EFAS. This part of the is managed by the JRC through exiting framework contracts.

Operational EFAS at ECMWF

The pre-operational version of EFAS has been set-up on a 5×5 km^2 grid and a 6-hour time step for the ECMWF high-resolution and COSMO-LEPS (COSMO Limited Area Ensemble Prediction System) forecasts and a daily time step for the initial conditions and the ECMWF EPS (Ensemble Prediction System) runs. The lead time is set to 10 days for the medium-range forecasts and 5 days for the LEPS forecasts. Temperature forecasts are corrected for height above ground while precipitation is not corrected.

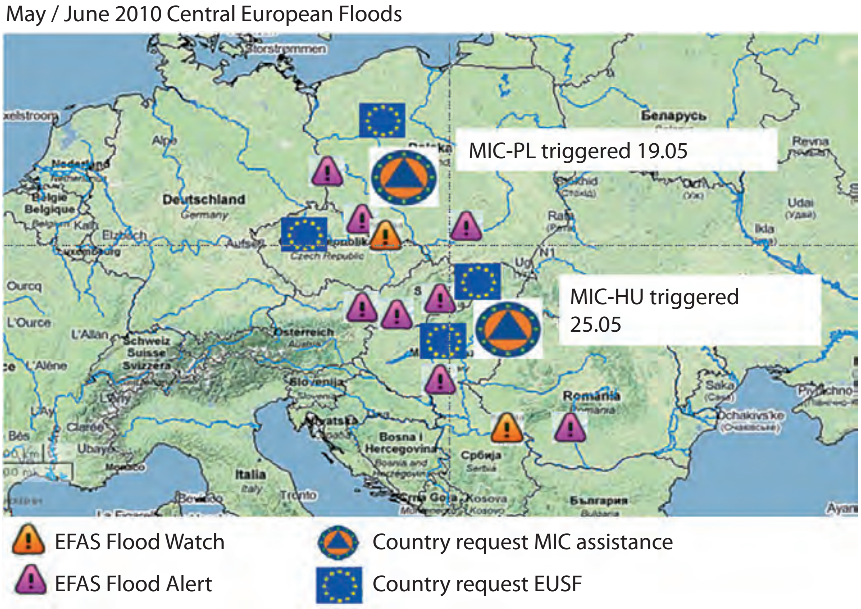

Figure 2 EU actions on the May/June floods in 2010. The triangles refer to flood watches and flood alerts. An 'EFAS Flood Alert' is issued when a probability of exceeding critical flood thresholds are forecast more than 2 days ahead in a river basin which is covered with an existing EFAS Memorandum of Understanding (MoU). An 'EFAS Flood Watch' is issued when a probability of exceeding critical flood thresholds are forecast in a river basin but the forecast event does not satisfy the rules laid out in the MoU (e.g. regarding warning lead time, size of river basin, or location of event). The other symbols indicate where a country requests MIC assistance or support from the European Solidarity Fund.

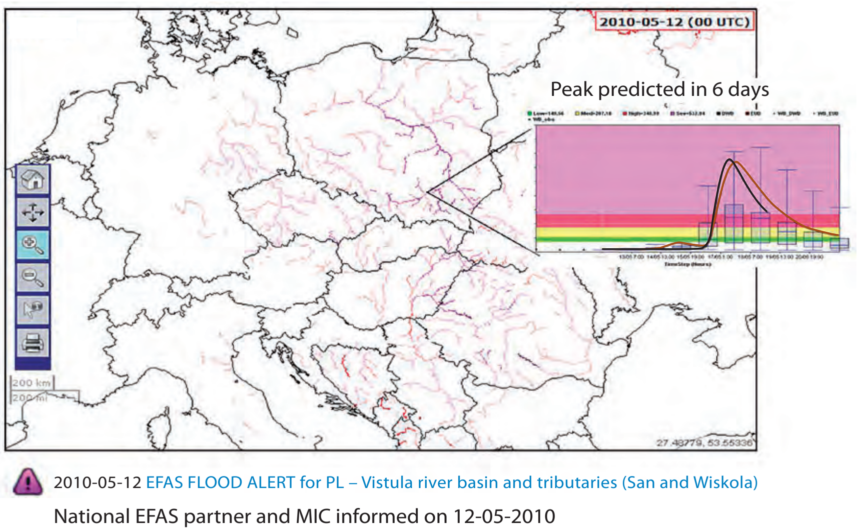

Figure 3 EFAS forecasts from 00 UTC on 12 May 2010. All rivers which maybe affected by flooding are shaded in red and purple. Also shown is a hydrograph, which predicts a peak in 6 days. The box plots on this hydrograph represent EPS forecasts: the black line shows the ECMWF high-resolution forecast and the brown line the DWD forecast. The green area indicates the low flood warning level, the yellow the medium, the red the high and the purple the extreme flood warning level.

From a content point of view, the future operational set-up will be considerably enhanced. The most important changes are as follows.

- All forecasts will be running on a 6-hour time step including all those from the EPS.
- Lead times will be 15 days instead of 10 days and twice a week monthly forecasts will be run.
- Weather forecasts will be pre-processed before being input to the hydrological model (e.g. bias corrections for temperatures and precipitation are going to be performed).
- Skill scores for past performance will be calculated automatically.

Another major feature is the availability of a fully independent test environment. During the research phase the disk space and computing time was limited and therefore testing was restricted to a few months of comparison between old and new set-ups. However, the computational centre at ECMWF now has the capability of running extended tests and comparisons with previous versions.

From a technical point of view, the major task of running EFAS within an operational environment splits into implementing a data acquisition suite, integrating the JRC-EFAS system into a workflow software (SMS or ecFlow) and deploying the web infrastructure (EFAS-IS).

Data acquisition suite

EFAS requires a wide variety of input data. Some meteorological input parameters are produced by the NWP models running at ECMWF; these are ECMWF and COSMO-LEPS ensemble forecasts as well as ECMWF deterministic forecasts. In addition DWD routinely provides the latest regional deterministic forecasts.

EFAS also requires the acquisition of observational data:

- Observations collected by the JRC MARS (Monitoring Agricultural ReSources) project.
- Observations from SYNOP stations acquired via the DWD.
- Discharge observations from European Terrestrial Network for River Discharge.

These observations are used to derive initial conditions for the hydrological forecasts and in the post-processing of the forecast discharge rates.

The NWP forecasts and observations from external providers (JRC and DWD) are acquired by the ECMWF data acquisition suite. Its task is to regularly contact external FTP servers and fetch any new data. The retrieved files are stored on the file system of the LINUX cluster for use by the operational EFAS. The data is also stored permanently in the ECMWF Data Handling System.

Workflow software

ECMWF currently uses SMS (Supervisor Monitor Scheduler) as a workflow software to manage the operational and research work. SMS is an application that enables users to run a large number of programs which may have dependencies on one another. It provides a controlled environment with reasonable tolerance of both hardware and software failures, combined with good restart capabilities. Furthermore it is a very good tool for running different versions of the EFAS suite (e.g. the operational EFAS system at ECMWF and an identical EFAS shadow system at the JRC for development).

Figure 4 shows the experimental set-up of the EFAS suite which is run on the ECMWF LINUX Cluster. The suite is set up using three main families: a make family (‘make’) that installs the EFAS software and initializes the computations, a main family (‘main’) which computes the forecast and a lag family (‘lag’) for archiving and distribution of results. Forecasts in the main family are currently run twice daily at 00 and 12 UTC driven by the ECMWF EPS (‘eue’), ECMWF high-resolution forecast (‘eud’), DWD forecasts (‘dwd’) and COSMO LEPS (‘cos’, 12 UTC only). Forecasts are (where appropriate) directly triggered from other suites running at ECMWF. For example, the EFAS/ECMWF implementation using COSMO forecasts is directly triggered from the COSMO suite running at ECMWF; this allows a more timely delivery of the EFAS forecast. In addition to executing the forecasts, the suite performs large parts of the pre-processing of input data and post-processing of results.

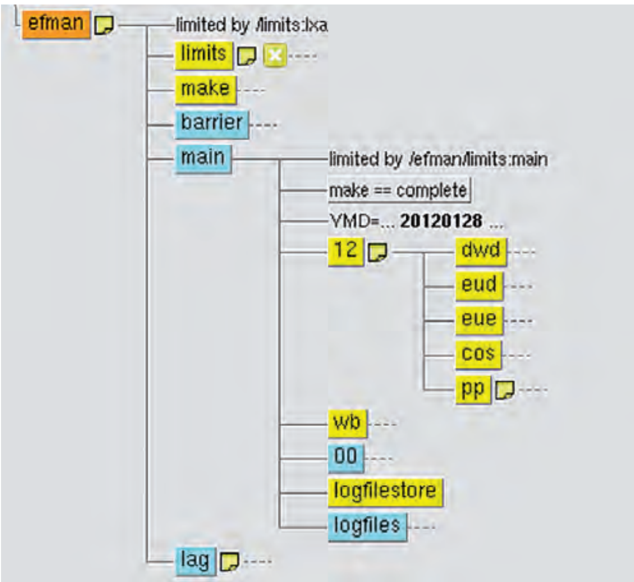

Figure 4 A diagram of the experimental EFAS suite. See the text for information about the components of the EFAS suite.

ecFlow is a new workflow software, also written by ECMWF, which will replace SMS over the next 18 months (see *ECMWF Newsletter No. 129*, 30–32). To a large extent it is backward compatible and will be available freely from ECMWF early in 2012. All EFAS suites will be migrated to use ecFlow in line with the migration of the other operational suites running at ECMWF.

The EFAS Information System (EFAS-IS)

The EFAS-IS (http://efas-is.jrc.ec.europa.eu) is a password protected web-portal where EFAS partners (such as National Hydro-Meteorological Services, the MIC) can browse, in an easy and intuitive way, different aspects of the most recent or past forecasts as spatially distributed information. An example is shown in Figure 5 which displays the reporting points where the maximum discharge is expected within the next 5 days or more. Also indicated are when the maximum discharge is expected and the highest alert level exceeded by a certain forecast.

In addition, maps with different contents (e.g. maps with the flood probability of different meteorological models, precipitation forecasts and combined probability maps) can be activated or overlaid with other shapes such as land use or urban areas to see whether the flooding is forecast to occur in a potentially vulnerable area. Critical points in the river channels (i.e. pixels showing an increased probability of flooding over various forecasts) are linked to time series of flood threshold exceedances in order to provide more detailed information. ECMWF will install the EFAS-IS and fulfil administrator duties, such as insert new users, keep references up to date and follow up the forum discussions.

Benefits of an operational EFAS

The following are some of the key benefits of an operational EFAS for the Member States’ national hydrological services.

- Timely information on possible flood situations across Europe more than 3 days in advance, based on multiple medium-range weather forecasts. This allows the national services to compare their own results against another reference model and complement their systems with information derived from different NWP inputs.
- Consistent and coherent probabilistic meteorological and hydrological predictions, allowing users not only to estimate the most likely scenario but also the probability of occurrence of any event of interest.
- Increased interactions between institutions developing meteorological and hydrological numerical prediction systems.
- Participation in EFAS as an exchange platform for information, methods and data.

The European Commission is going to directly benefit from a consistent, harmonized and timely overview of ongoing and forecast floods across Europe, including access to expert knowledge on floods through the EFAS activity and forecaster team.

Benefits are not restricted to the hydrological community. In fact, an operational EFAS has tangible benefit for the meteorological NWP communities.

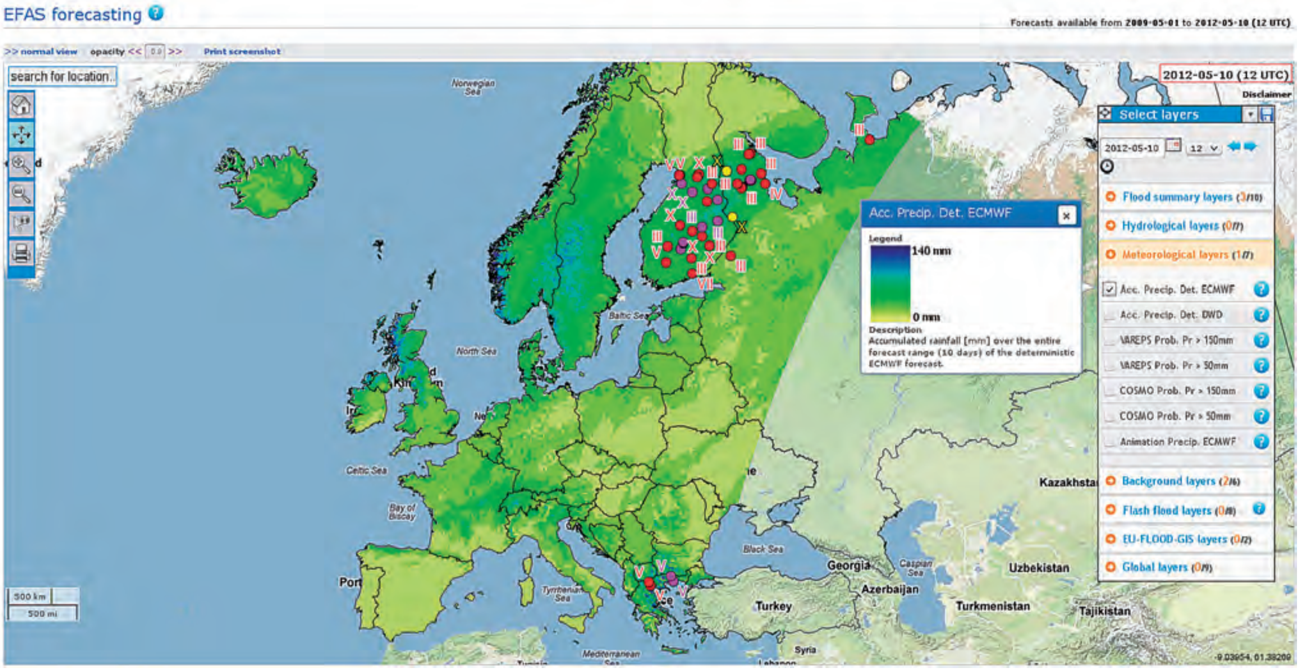

Figure 5 Screenshot (DATE) of EFAS-IS displaying reporting points where the maximum discharge is expected within the next 5 days or more. Roman numerals denote when the maximum discharge is expected. The colours indicate the highest alert level exceeded by a certain forecast (purple being extreme and red being high).

EFAS produces real-time simulations of hydrological processes not just for individual catchments, but across Europe with a resolution of 5 km. Therefore, EFAS simulations can be used for verification of NWP models. This allows the identification of deficiencies in the NWP system, especially in the land surface representation. For example, in the case of ECMWF, certain components of the EFAS hydrological model can be used to improve the land surface model HTESSEL, leading to a better representation of surface fluxes and freshwater flux into the oceans. Along the same lines, some components of HTESSEL could be adopted by the EFAS system. Such synergy would accelerate these developments within ECMWF's core activities.

NWP systems are steadily moving towards higher resolutions (closer to the 5-km resolution of EFAS), making the coupling of meteorological and hydrological modelling components possible, also for operational NWP systems. Furthermore, EFAS fosters increased awareness and use of ECMWF products within the hydrological user community.

EFAS has become a distinctive means for the meteorological centres to verify the skill of their NWP models with regards to hydrologically-relevant surface variables. For example, the collection of river discharge measurements across Europe allows the verification of integrated spatial and temporal surface variables. EFAS predicts extremes in river flows which can be used to verify the quality of ECMWF's forecast data in cases when heavy rainfall leads directly to fluvial flooding. This supports one of ECMWF's main goals of providing early warnings for severe weather.

In summary, EFAS has developed into a unique tool for forecasting floods across Europe that is embedded in a large network of hydrological and meteorological services as well as civil protection agencies. The operational phase of EFAS that is starting soon will not only help to improve the preparedness for floods across Europe and its crisis management, but also be a very useful tool to improve NWP models through European-wide verification of the hydrological response to the meteorological model outputs.

FURTHER READING

Pappenberger, F., J. Thielen & **M. del Medico**, 2011: The impact of weather forecast improvements on large scale hydrology: analysing a decade of forecasts of the European Flood Alert System. *Hydrol. Process.*, **25**, DOI : 10.1002/hyp.7772, 2010.

Cloke, H.L. & **F. Pappenberger**, 2009: Ensemble Flood Forecasting: a review, *J. Hydrol.*, **375**, 613–626.

Cloke, H.L., J. Thielen, F. Pappenberger, S. Nobert, P. Salamon, R. Buizza, G. Bálint, C. Edlund, A. Koistinen, C. de Saint-Aubin, C. Viel & **E. Sprokkereef**, 2009: Progress in the implementation of Hydrological Ensemble Prediction Systems (HEPS) in Europe for operational flood forecasting. *ECMWF Newsletter No 121*, 20–24.

Buizza, R., F. Pappenberger, P. Salamon, J. Thielen & **A. de Roo**, 2009: EPS/EFAS probabilistic flood prediction for Northern Italy: the case of 30 April 2009. *ECMWF Newsletter No 120*, 10–16.

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A new trajectory interface in Metview 4

SÁNDOR KERTÉSZ, SYLVIE LAMY-THÉPAUT, IAIN RUSSELL

The previous versions of the Metview meteorological workstation featured a trajectory computation model. This model has not been developed and maintained for several years therefore a decision was made to develop a new trajectory interface in Metview based on the widely used FLEXTRA trajectory model. This article gives an overview of the new interface and highlights how users can benefit from working with FLEXTRA in Metview 4.

Using FLEXTRA

FLEXTRA is a trajectory model originally developed almost twenty years ago and still being used by a growing scientific community. It can be driven by meteorological input data from a variety of global and regional models including ECMWF analyses and forecasts. FLEXTRA is freely available from its joint home page with FLEXPART (a Lagrangian particle dispersion model) hosted by the Norwegian Institute for Air Research (NILU) at the following address:

- http://transport.nilu.no/flexpart.

From version 4.2 onwards Metview has the new trajectory interface allowing users to prepare input data for FLEXTRA, run FLEXTRA, visualise the generated trajectory data and perform computations on them.

Information about how Metview uses FLEXTRA is given in Box A.

Trajectory computations, results and visualisation

FLEXTRA trajectory computations require gridded input data for a set of atmospheric variables. Users can generate this data in Metview via the FLEXTRA Prepare icon (Figure 1a), which retrieves the required fields from MARS, performs the necessary pre-processing steps and presents the data in the desired format for FLEXTRA. Once the data is in place FLEXTRA trajectory computations can be started by using the FLEXTRA Run icon (Figure 1b). This icon provides a high level interface allowing users to define all the control parameters for a FLEXTRA run. Having finished the computations Metview concatenates the results into a single file, which can be saved, in whole or in part, to disk for a local copy.

The FLEXTRA output format is one of the supported data formats in Metview. FLEXTRA result files are represented as FLEXTRA File icons (Figure 1c) in the Metview desktop, no matter if they were generated via Metview or not. Users can inspect the contents of these files with the FLEXTRA examiner, as illustrated in Figure 2, and an advanced visualisation is also available for them.

The FLEXTRA Visualiser, whose icon can be seen in Figure 1d, provides a high-level interface for selecting a subset of FLEXTRA results to be visualised in the desired plot type. With this icon Metview users can easily generate maps or graphs with symbol plotting and customise the graphical attributes of each trajectory individually as shown in Figures 3 and 4. A rich set of meta-data is displayed in the Layers tab on the right of the Display Window to help users interpret FLEXTRA plots. Figure 3 illustrates this feature.

How FLEXTRA is used in Metview — A

FLEXTRA is not distributed with Metview, but has to be downloaded from the FLEXTRA web site and installed separately. Metview requires version 5.0 of FLEXTRA, which is using GRIB API to handle GRIB2 fields.

The FLEXTRA input data generation and trajectory visualisation do not require the existence of a FLEXTRA executable. However, FLEXTRA itself can be only run if an executable is present. The path to the FLEXTRA executable can be specified for Metview via the `MV_FLEXTRA_EXE` environment variable.

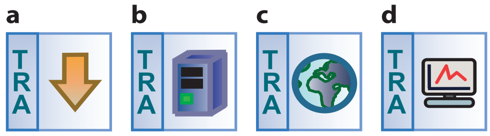

Figure 1 The icons representing (a) FLEXTRA Prepare, (b) FLEXTRA Run, (c) FLEXTRA File and (d) FLEXTRA Visualiser in Metview 4.

Metview Macro

Metview's Macro scripting language offers a powerful framework for incorporating all the functionality provided by the FLEXTRA icons. A particularly useful feature of Macro is that users can access both the meta-data and data of trajectories via the **flextra_group_get ()** and **flextra_tr_get ()** macro functions. These functions allows users to derive new datasets and generate new plots out of FLEXTRA output data.

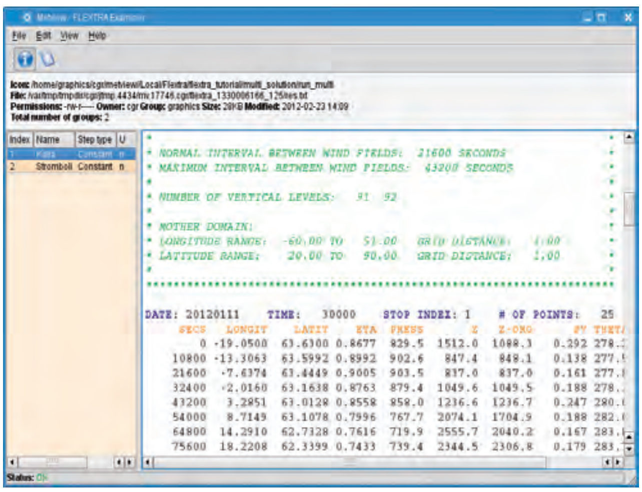

Figure 2 The FLEXTRA examiner in Metview 4 offers an easy way to inspect FLEXTRA trajectory outputs.

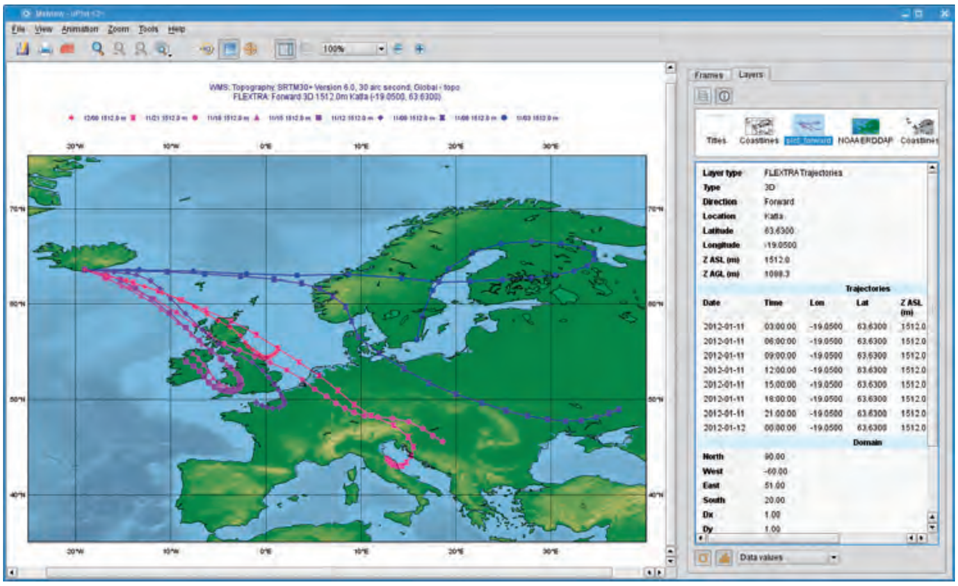

Figure 3 Three-dimensional forward trajectories, released from the same point but at different times, visualised using an automatically-generated colour palette. The sidebar on the right-hand side of the window displays detailed statistics about the visualised data.

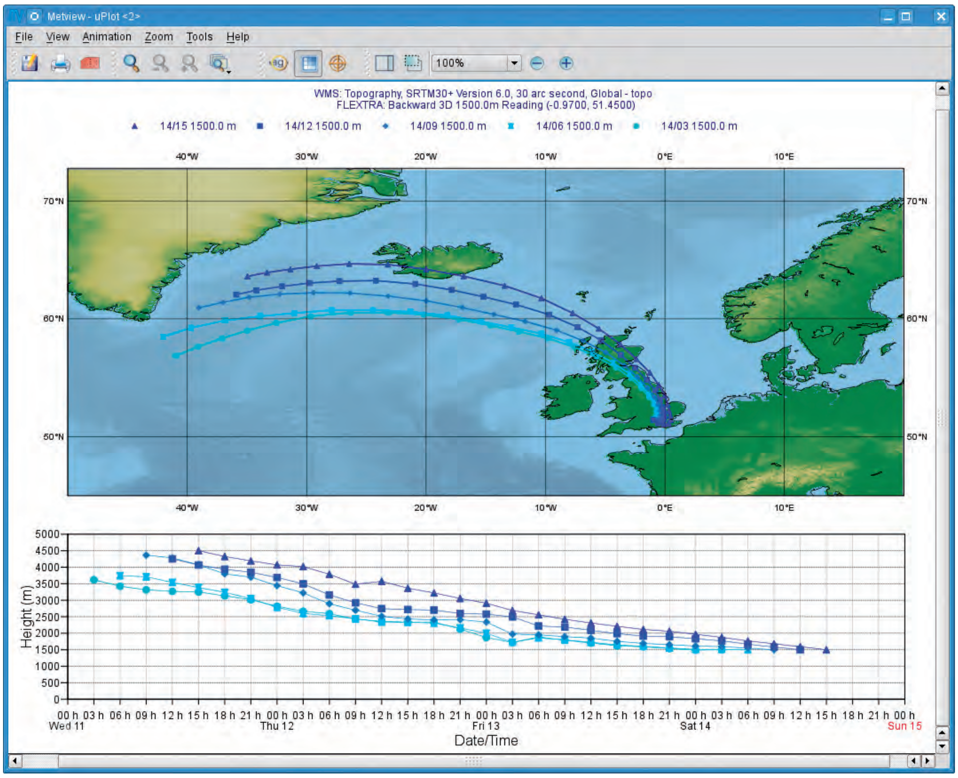

Figure 4 Different graphical representations of a the same three-dimensional backward trajectory group: on a map (top) and on a time-height graph (bottom).

More information

Metview users will find a tutorial that goes into more detail about how to use the FLEXTRA interface on the Metview documentation web page at:

- http://www.ecmwf.int/publications/manuals/metview/documentation.html

User feedback is important for improving Metview, and users are encouraged to send their suggestions by e-mail to metview@ecmwf.int.

ECMWF publications

(see www.ecmwf.int/publications/)

Technical Memoranda

673 **Mogensen, K., S. Keeley & P. Towers**: Coupling of the NEMO and IFS models in a single executable. *April 2012*

672 **McNally, T.**: Observing System Experiments to assess the impact of possible future degradation of the Global Satellite Observing Network. *March 2012*

670 **Geer, A.J., P. Bauer & S.J. English**: Assimilating AMSU-A temperature sounding channels in the presence of cloud and precipitation. *April 2012*

669 **Bengtsson, L., M. Steinheimer, P. Bechtold & J.-F. Geleyn**: A stochastic parameterization for deep convection using cellular automata. *February 2012*

668 **Mogensen, K., M. Alonso Balmaseda & A. Weaver**: The NEMOVAR ocean data assimilation system as implemented in the ECMWF ocean analysis for System 4. *February 2012*

667 **Bormann, N., A. Geer & S. English**: Evaluation of the microwave ocean surface emissivity model FASTEM-5 in the IFS. *February 2012*

666 **Janisková, M. & P. Lopez**: Linearized physics for data assimilation at ECMWF. *January 2012*

665 **Haiden, T., M.J. Rodwell, D.S. Richardson, A. Okagaki, T. Robinson & T. Hewson**: Intercomparison of global model precipitation forecast skill in 2010/11 using the SEEPS score. *January 2012*

664 **Bonavita, M., L. Isaksen & E. Holm**: On the use of EDA background error variances in the ECMWF 4D-Var. *January 2012*

663 **Hagedorn, R., R. Buizza, T.M. Hamill, M. Leutbecher & T.N. Palmer**: Comparing TIGGE multi-model forecasts with reforecast-calibrated ECMWF ensemble forecasts. *January 2012*

655 **Fisher, M., Y. Tremolet, D. Tan & P. Poli**: Weak-constraint and long-window 4D-Var. *December 2011*

Proceedings

ECMWF/WCRP Workshop on Diurnal Cycles and the Stable Boundary Layer, *7–10 November 2011*

ECMWF Seminar on Predictability in the European and Atlantic Regions from Days to Years, *6–9 September 2010*

EUMETSAT/ECMWF Fellowship Programme Research Reports

24 **Geer, A., P. Bauer & S. English**: Assimilating AMSU-A temperature sounding channels in the presence of cloud and precipitation. April 2012 (simultaneously released as Tech. Memo. No. 670)

25 **Lupu, C. & A.P. McNally**: Assimilation of cloud-affected radiances from Meteosat-9 at ECMWF. *March 2012*

ESA Contract Reports

Dragani, R.: Monitoring and Assimilation of SCIAMACHY, MIPAS and GOMOS retrievals at ECMWF. *January 2012*

Abdalla, S., G. De Chiari & H. Hersbach: The technical support for global validation of ERS wind and wave products at ECMWF (July 2008 – July 2011). *December 2011*

ECMWF Calendar 2012

September 3 – 7	Annual Seminar on ‘Seasonal prediction: Science and Applications’
October 1 – 5	15th Workshop on ‘High performance computing in meteorology’
October 8 – 12	Training Course – Use and interpretation of ECMWF products for WMO Members
October 15 – 17	Scientific Advisory Committee (*41st Session*)
October 18 – 19	Technical Advisory Committee (*44th Session*)
October 22 – 23	Finance Committee (*91st Session*)
October 24 – 25	Policy Advisory Committee (*34th Session*)
October 29	Advisory Committee of Co-operating States (*18th Session*)
November 5 – 8	Workshop on ‘Parametrization of clouds and precipitation across model resolution’
December 4 – 5	Council (*78th Session*)

Index of newsletter articles

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

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