ECMWF Newsletter

Number 139 – Spring 2014

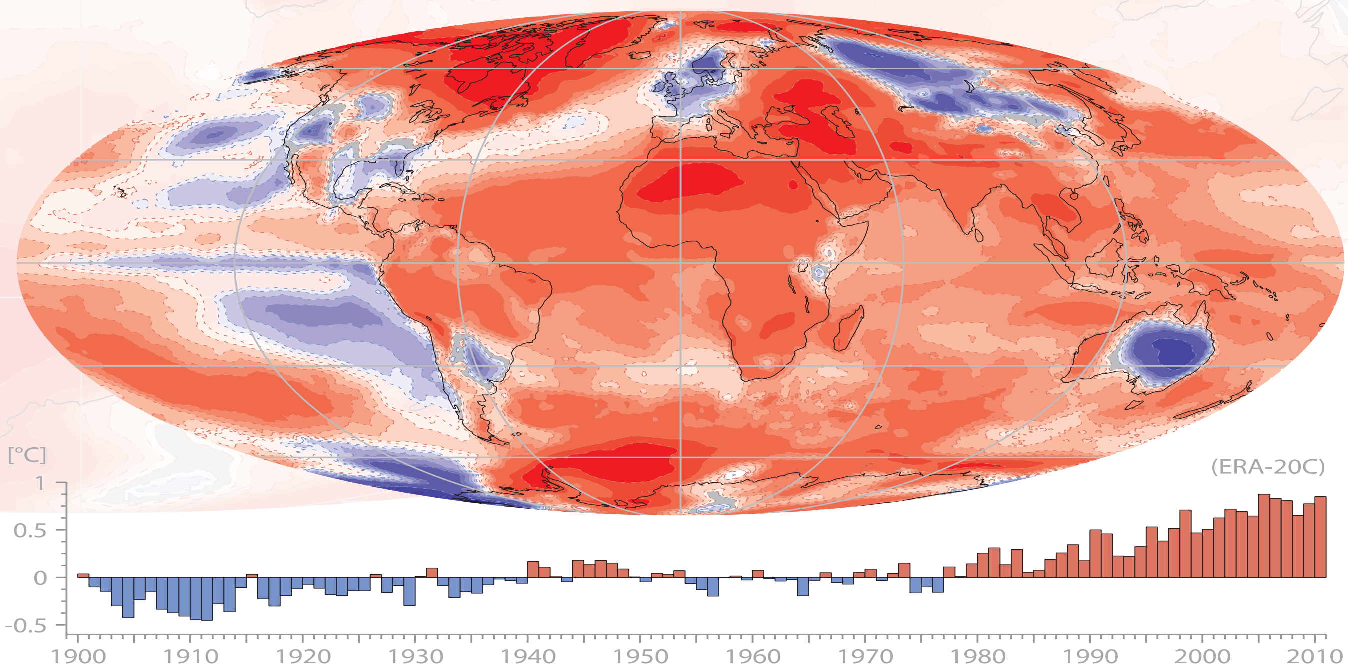
European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen terme

Climate reanalysis

Windstorms in northwest Europe

Evaluation of extreme wind forecasts

Flow-dependent verification



www.ecmwf.int/publications/newsletter


Use of Satellite Observations in Numerical Weather Prediction
8 - 12 September 2014
ANNUAL SEMINAR
2014
Focus
Characterisation of the quality and capability of satellite observations including an assessment of their uncertainty and their current and future ability to improve weather forecasts
Progress towards more complete use of existing observations in areas such as cloud-affected data, atmospheric sounding over sea ice and some land surfaces, and fuller use of high spectral, spatial and temporal resolution satellite observations
New and future observations such as doppler wind lidar, and future observations needed to fully realise the potential of enhanced NWP capability across a broad range of weather-related applications
Invited speakers
Thomas Auligne, UCAR
Wiliam Bell, Met Office
Brett Candy, Met Office
Andrew Collard, NOAA/NCEP/EMC
John Derber, NOAA/NCEP/EMC
Hendrik Elbern, University of Cologne
John Eyre, Met Office
Mary Forsythe, Met Office
Mitch Goldberg, NOAA, NASA/GSFC
Johnny A. Johannessen, NERSC
Fatima Karbou, Météo-France
Masahiro Kazumori, JMA
Dieter Klaes, EUMETSAT
Andrew Lorenc, Met Office
Jean-Francois Mahfouf, Météo-France
Ben Ruston, NRL
Jérôme Vidot, Météo-France
Qifeng Lu, CMA
ECMWF Speakers
Saleh Abdalla
Niels Bormann
Dick Dee
Giovanna De Chiara
Stephen English
Alan Geer
Sean Healy
Marta Janiskova
Tony McNally
Marco Matricardi
Michael Rennie
ECMWF
Artist's view of EarthCARE courtesy of ESA
email: rd-seminar@ecmwf.int
http://www.ecmwf.int/en/learning/workshops-and-seminars

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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.

Editor: Bob Riddaway

Typesetting and Graphics: Anabel Bowen with the assistance of Corinne O'Sullivan.

Any queries about the content or distribution of the *ECMWF Newsletter* should be sent to Bob.Riddaway@ecmwf.int
Guidance about submitting an article is available at www.ecmwf.int/publications/newsletter/guidance.pdf

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Front cover image: 2012 global temperature relative to the 20th century average produced as part of ERA-CLIM.

Telling our story

The Centre recently updated its external website (www.ecmwf.int) and the odds are that you are reading this latest edition of our newsletter from this rejuvenated platform. This new website aspires to present information clearly with a clean and modern look and feel. Of course one's reaction to any website is a very personal matter so it is likely that the new look will not be to everyone's taste. However, we do hope that the clarity and accessibility of the information is improved. It will take some time to complete the transition of content from the old website to the new and for this purpose we will keep the old site open until April 2015.

We have a very strong story to tell in terms of the reliability and accuracy of our numerical weather predictions and the associated underpinning science; we have therefore not allowed the visual appearance to be unduly complicated or flashy such that it detracts from this strong content. Providing clear and simple language to describe science and predictions is a challenge and we are taking the opportunity presented by this new website to refresh our explanations. One of our key objectives is also to ensure that information is kept up to date, which is essential for a centre like ECMWF that is providing operational weather predictions to its Member States.

Whilst we are keen to develop and improve our interaction with all of you via digital channels, many ECMWF scientists and technical experts also engage in face-to-face dialogue, and tell the story about their latest work at conferences and workshops at the Centre and across the world. This August will see the first ever World Weather Open Science Conference – WWOSC2014 – taking place in Montreal, Canada, from 16 to 21 August 2014 and it is inspiring that more than 1,100 abstracts were submitted from an enthusiastic international community of experts. These abstracts, from over 70 countries, deal with a broad spectrum of issues related to weather science and prediction. Over 100 of the abstracts target specific user applications within a variety of weather-sensitive sectors.

Montreal in late August will be the place to be and the conference is not only a landmark event but will also have a number of novel features. For example, a set of white papers are being drafted, and these will be discussed at the conference. The final versions will be published to help set the agenda in research and practice in meteorology over the coming years. There is also a focus on early career scientists, enabling the next generation to be involved in setting the future agenda. Some open discussions, sometimes called Townhall sessions, are being planned to address key issues in our field such as the 'future of the weather enterprise'. Many organisations will be represented from across the research community and the public and private sectors, and ECMWF is one of those.

Whether it's in cyberspace or face to face at events, we want to hear from you, so that we can enhance the way we work together.

Alan Thorpe

Interview with a departing graduate trainee

JUAN DOMINGUEZ
interviewed by
STEPHAN SIEMEN

When you arrived at ECMWF as a graduate trainee, what were your expectations?

When I arrived at the Centre after spending a year working at the Spanish Meteorological Service (AEMET) I had two main expectations: to learn about how ECMWF works and to try to make a contribution to developments at AEMET or ECMWF.

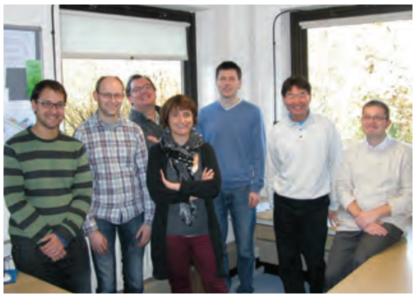
First, having a computer science background, I had a lot to learn about meteorological topics: the numerical weather forecast, forecast products, product visualisation and ECMWF as an organisation. These learning expectations have been fulfilled.

Secondly, as a graduate trainee from the AEMET, I was expecting to have an active role as a contact between ECMWF and AEMET. I have collaborated in a few issues triggered from AEMET's users, but I spent less time on these activities than I had expected.

During the last two years, you worked first in the MetVis Section and then in the Development Section – how did you find the experience of working on a variety of projects?

It was very enjoyable and I only experienced difficulties on a few occasions. At AEMET I developed a web application for the analysis of homogeneity of wind time series. That was the first time I worked in data visualisation and I liked it, so having the opportunity of going deeper into the subject when coming here seemed a stroke of good luck.

One of my first contributions when joining the MetVis Section was to develop a translator from ecCharts products into Metview icons and macros. It was a great learning activity as I acquired a good knowledge of both the range of products available from ecCharts and Metview macro language. In addition, I became familiar with various aspects of Magics++, mostly as a user but also as developer.

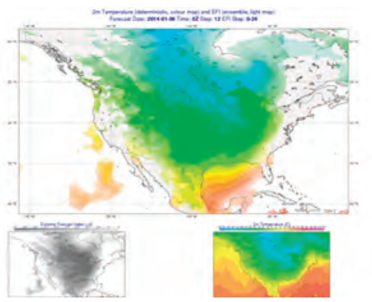


Juan with Metview/Magics developers. The photo was taken at the celebrations to mark Metview's 20th anniversary. Juan is on the left.

Sometimes, due to the frequent swap between activities, I felt I was progressing slowly and not reaching the results as quickly as I would like. However, I appreciate the freedom I was given to work with various packages and programming languages on a variety of activities.

What in particular did you learn?

What has been a surprise is that I have learnt quite a lot about computer science topics. Specifically, I learnt about the development of software (SW) packages for Unix-like systems, where I have limited experience. I previously worked for a global IT company where a 'traditional' SW development methodology was followed and the source codes were closed. That was quite different from how the open source projects are managed at ECWMF, where an agile SW development methodology is followed and use is made of a distributed source code management tool, such as git.



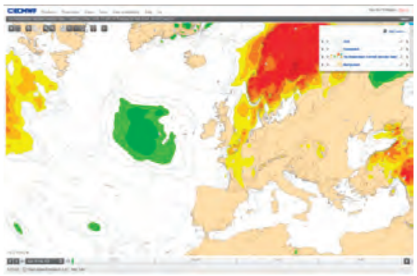
Juan investigated new ways of visualising forecasts. Here he displays the recent cold spell in the USA by combining two fields, 2-metre temperature and Extreme Forecast Index, into a single colour map layer using Metview.

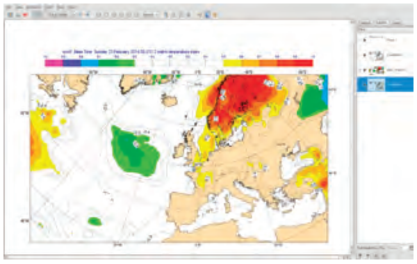
Another unexpected source of learning has been the 'Friends of Python' informal meetings organised by colleagues who volunteered to share their knowledge of the Python programming language. Before I came to ECMWF, I thought there was very little left for me to know about Python but, after attending these meetings, I discovered that this was far from the truth.

What experiences will you take with you back to AEMET?

The most important experience has been becoming a member of the teams that develop Magics++ and Metview packages. I have had a close view of how the teams organised their workload, managed requests from users, chose programming languages, tools and methodologies, and prepared a long-term plan. In the future, I will become one of these Member States' users who suggest a new improvement or report issues, so knowing the people and processes at the Centre will be of value.

From a technical point of view, I will take back a very good knowledge of SW packages developed at the Centre (e.g. Magics++, Metview, grib_api and ecFlow) and the development tools (e.g. Perforce, git, JIRA and Confluence).





Juan worked on synchronisation of styles between ecCharts and Metview. This example shows how the styles for the Extreme Forecast Index for 2-metre temperature are similar in ecCharts and Metview.

I hope that I will have the opportunity to make use of these in future.

What did you find was best about your stay at ECMWF?

It is difficult to mention only one thing. I enjoyed having a lot of freedom to attend a wide range of seminars and workshops, although some were not directly related to what I was doing. I wonder if there is any other organisation in the world where it is possible to get such a great insight into 'state of the art' meteorology.

Another thing that I really liked about the Centre are the conversations during coffee breaks. Sharing a table with talented people from diverse origins almost guarantees interesting discussions about work and other topics.

How did you find life in Reading?

Gradually I found it easier and more rewarding being in Reading. When I arrived, my daughter was only a few months old and I left her with my partner in Spain. I used to travel every other weekend and occasionally I spent the night at Gatwick airport to take the first morning flight to Malaga. Luckily the following summer, my partner was granted a year's leave from teaching and she came to live in Reading. We found that living here with a baby was easier than expected. My impression is that the UK is a family-friendly country and we discovered that Reading is ideally located for day trips around Southern England; there are plenty of places to visit and activities to do in the area. Now that my family has returned to Spain, my travelling to Malaga has restarted and I often feel as if I do not fully belong to either Malaga or Reading.

Anyway, considering the whole year my family spent here, living in Reading has been a great experience.

What message would you send to future trainees at ECMWF?

I would send the same message I was given by a former graduate trainee, José Luis Casado, when I was offered this post: try to attend all the training courses, seminars and workshops organised at the Centre. As I mentioned before, the freedom that I have as trainee to manage my time and to participate in ground-breaking activities at the Centre make a perfect combination.

Another message I would like to send is that the Centre provides a good work environment. I found people are friendly and enthusiastic, and they have the very healthy habit of openly expressing their opinions.

If I were asked to summarise my impressions about ECMWF using just two words, they would be these: enthusiasm and excellence.

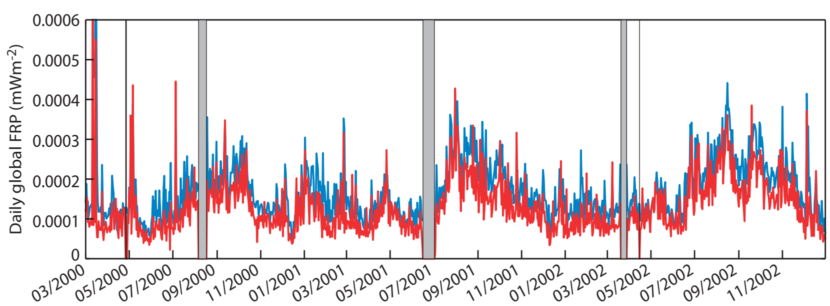
Enhancing the biomass-burning emissions database: release of a new version of GFAS

SAMUEL REMY, JOHANNES W. KAISER, RONAN PAUGAM (King's College, London), **MIHA RAZINGER**

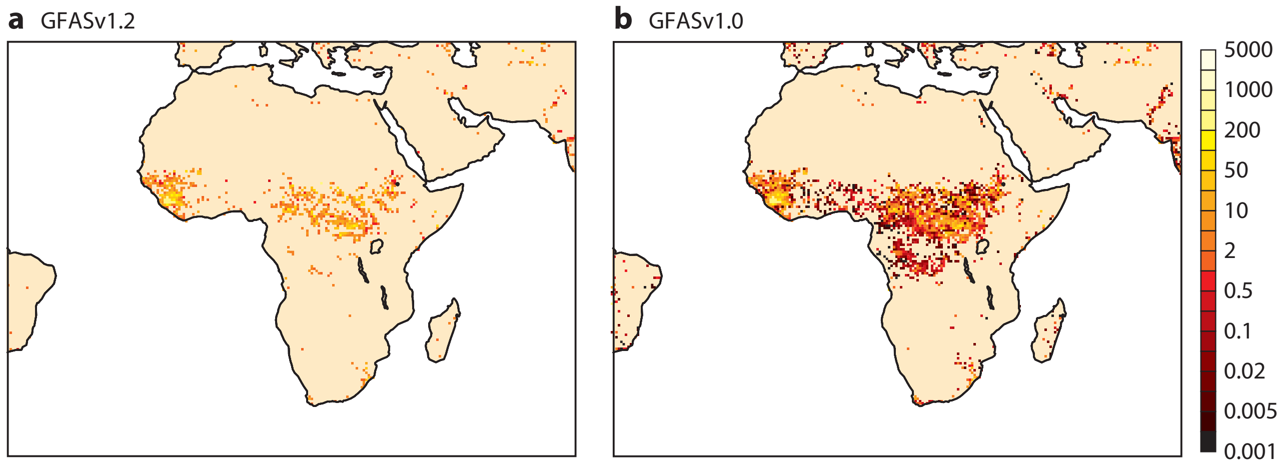
Vegetation fires are a frequent occurrence in all vegetated environments. They are ignited naturally (i.e. by lightning) or by anthropogenic activity. Depending on the vegetation cover, fires emit various aerosols, reactive gases and greenhouse gases. They are in particular a major source of carbonaceous aerosols, of carbon monoxide (CO) and an important source of nitrogen oxides (NO_x) and carbon dioxide (CO_2). As such, biomass- burning emissions play an important role in chemical composition and air quality forecasts. Since fires occur mostly in locations where in-situ observations are not available and are characterized by large temporal and spatial variability, assessing their size and intensity requires the use of remote-sensed observations.

The Global Fire Assimilation System (GFAS) provides biomass-burning emissions of aerosols, reactive gases and greenhouse gases for the near-real-time global forecasts of atmospheric composition which are produced as part of MACC-II (Monitoring Atmospheric Composition and Climate - Interim Implementation). It assimilates observations of Fire Radiative Power (FRP) from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on-board NASA's polar-orbiting satellites, Aqua and Terra, to produce a daily global analysis of FRP. The assimilation step uses these observations in a Kalman filter with a persistence model to build an analysis of daily FRP. Using conversion factors that depend on land cover type, the FRP analysis is translated into a global estimate of daily dry matter burnt. The last step is to apply emission factors to compute a global analysis of biomass-burning emissions for 41 species.

GFASv1.0 provides a 0.5° daily analysis of biomass-burning emissions



Daily global FRP from GFAS. Shown are GFAS daily global FRP, using non-corrected daily FRP observations from Terra in red and corrected daily FRP from Terra in blue for March 2000 to December 2002. The grey areas indicate that the MODIS/Terra observations were not available; persistence was used to fill the gaps. The corrected observations are larger, as Aqua FRP is generally larger than Terra FRP because the overpass time of Aqua is closer to the diurnal peak of fire activity than the overpass time of Terra.



Fire Radiative Power (FRP) analysis for 19 March 2014. These results are provided by (a) GFASv1.2 and (b) GFASv1.0 in mW/m^2. The FRP from GFASv1.2 is interpolated onto the 0.5° grid of GFASv1.0. A large number of very small fires which are artifacts of the assimilation system of GFAS are present in the FRP analysis of GFASv1.0. These are now removed from the analysis of GFASv1.2, with a minimum impact on the global FRP budget for that day, which is only 0.3% smaller with GFASv1.2.

using the Active Fire Product from MODIS (MOD14). Another version, GFASv1.1, includes MODIS geolocation observations (MOD03) to refine the resolution of the analysis to 0.1°. A new version of GFAS, version 1.2, has been released. GFASv1.2 has the following features.

- Computation of plume injection heights using a Plume Rise Model (PRM).
- If FRP observations are available from only one MODIS sensor, these observations are corrected. The same technique could be used to include new FRP observations from other sensors or satellites.
- In the FRP analysis, only the values above MODIS's detection threshold are kept.

Also there is improved quality control applied to the raw MODIS observations from the Terra and Aqua satellites, and the northward shifting by one grid cell of the FRP analysis and biomass-burning emissions in GFASv1.0 and v1.1 has been corrected in GFASv1.2.

Smoke plumes usually reach several hundred metres in altitude, and for large fires such as the Eastmain fire that occurred in Quebec in July 2013 (see http://www.atmosphere.copernicus.eu/news/canada_smoke/) they can reach the tropopause. The associated emissions of smoke constituents can occur at altitude of up to a few thousand metres. As the wind direction varies with altitude, especially in the boundary layer, information about the height at which most of the smoke constituents are emitted for a given fire will improve the quality of the plume forecasts.

The Plume Rise Model (PRM), developed by Ronan Paugam at King's College London based on earlier work by *Freitas et al.* (2007, *Atmos. Chem. Phys.*, **7**, 3385–3398), uses satellite observations together with atmospheric profiles to estimate the area and the temperature of each active fire. Entrainment and detrainment profiles of the smoke plume are computed for each fire by a convection scheme using the Eddy-Diffusivity/Mass Flux parametrization of *Pergaud et al.* (2009, *Bound.-Layer Meteorol.*, **132**, 83–106) with the fire area and temperature information as surface boundary conditions and atmospheric profiles from the IFS providing the atmospheric thermal stratification. From the detrainment profiles, information about the minimum and the maximum height of injection are derived, as well as the height at which injection is at a maximum. These are then assimilated the same way as FRP observations.

The Terra and Aqua satellites have been run by NASA since 1999 and 2002 respectively, and contingency plans need to be made so that GFAS can rely on only one MODIS sensor in case of future satellite failure. Also, as the overpass times of the two satellites are different, and since most fires follow a pronounced diurnal cycle depending on the vegetation and fire types, FRP observations from Terra and Aqua are in general rather different. Consequently, a combination of linear and non-linear regression applied to learning datasets provided by an adaptive regionalization algorithm has been developed so that, if FRP observations are available from only one MODIS sensor, the output of GFAS is globally comparable to that when running with observations from both Aqua and Terra. In future, this algorithm could also be used to include FRP observations from the polar-orbiting Suomi-NPP and Sentinel-3 satellites in GFAS. This algorithm has been applied to FRP observations from Terra for March 2000 to December 2002, when Aqua observations were not yet available. This allowed an extension of the GFAS database of biomass-burning emissions, which now ranges from 1 March 2000 to the current time.

The assimilation algorithm of GFASv1.0 and v1.1 produced a large number of grid cells with FRP values much smaller than the detection threshold of the MODIS instrument. These represent around 80% of all positive FRP grid cells, but usually contributed to less than 1% of global FRP budget. These very small values are removed in GFASv1.2.

Taken together, all these new features bring a notable improvement in the quality of GFAS output. Experimental studies with the global MACC-II system using GFASv1.2 biomass-burning aerosols and associated injection heights showed an improvement in the accuracy of these emissions.

Presentation of maps for the new website

SYLVIE LAMY-THÉPAUT,
CIHAN SAHIN

For many years the ECMWF website has provided a catalogue of graphical products. Most of these products are updated daily and remain available for several days. They are offered for various time steps, geographical areas and parameters as defined in ECMWF's catalogue of real-time products.

In the context of the ECMWF website redesign, the web chart facility has been revised. The goal was not only to modernise the look, but also to improve the software infrastructure to take advantage of the developments made in ecCharts. This would provide more powerful navigation and discovery facilities, and at a later stage more user interaction such as zoom, pan and click.

The old website had a hierarchical navigation approach that leads a user to a map or a family of maps after a series of clicks. This approach works well if users know where to find a product or a family of products, but it can create confusion if that is not the case. To tackle this challenge, the new catalogue introduces faceted navigation with improved search functionalities. This technique allows a user to access very quickly well-known categories of plots such as medium-range forecasts, but at the same time the user is made aware of complementary maps that in the past were sometimes more difficult to discover. Using a faceted display enables easy access to all charts on one page and allows the grouping of charts based on the categories provided in the facets (each product belongs to at least one category in the facets) as shown in Snapshot 1. The implementation of the faceted approach is based on Apache Solr, which provides a scalable and reliable set of search features.

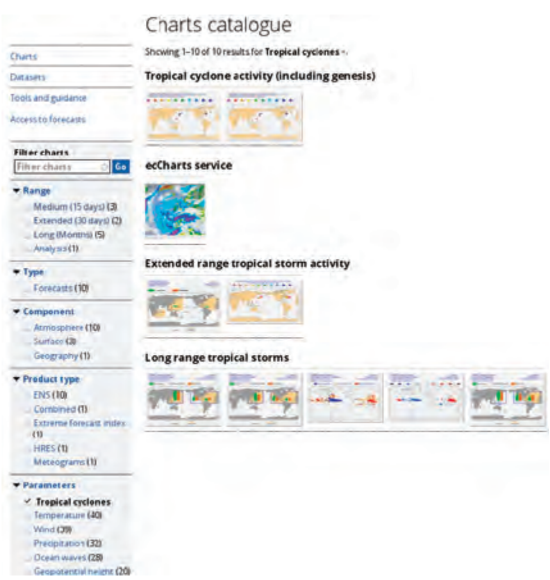
As with any other information, charts are now discoverable through the website search. General search results are grouped into different themes (e.g. Site, Charts, Datasets, FAQ). Once the 'Charts' theme is selected, the 'Chart' facets appear on the left-hand side to fine tune the search results. Snapshot 2 shows the result of such a search.

Once a chart is selected from a catalogue or search, it is displayed in a 'Chart' page (see Snapshot 3). A parameter bar is displayed to switch between the possible values for the chart (e.g. area, forecast base time, parameter) and provides a link to download a PDF version of what has been selected.

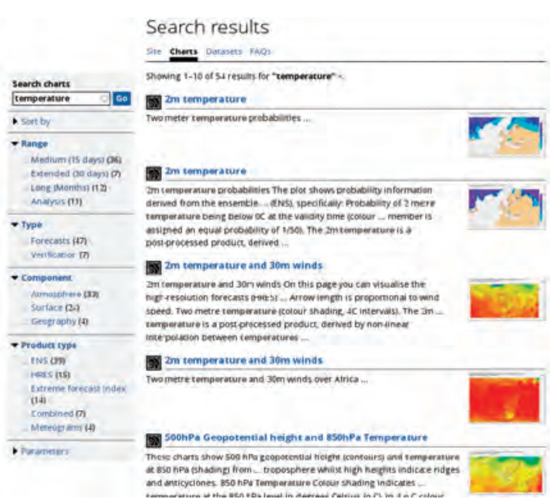
For medium-range charts, it is possible to animate and navigate between forecast times by using buttons and arrow keys provided by the time navigator, specifically implemented for these pages. Related products are listed on the left-hand side for quick and easy access.

The ENS meteogram (formerly known as the EPSgram) is one of the most popular products based on the ensemble forecast. The user interface presented in Snapshot 4 has been enhanced to provide easy access to all meteograms. Five types are currently provided: 10-day, 15-day, 10-day wavegram (as on the old website), 15-day with climate and 10-day plumes (these are new additions). Users can search for a pre-defined location or provide any latitude, longitude and title of their choice. The meteogram user interface displays meta data on the right-hand side of the web page, such as the height of the requested location and the coordinates and height of the grid point from the ensemble and high-resolution forecasts used to create the display.

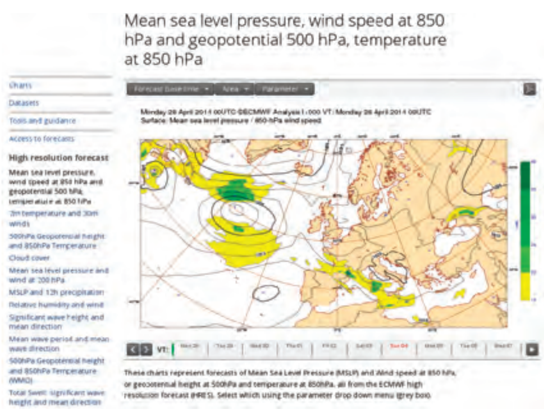
The left-hand side of the meteogram page displays the 'Recently viewed' meteograms to provide easy access to what has been generated by the



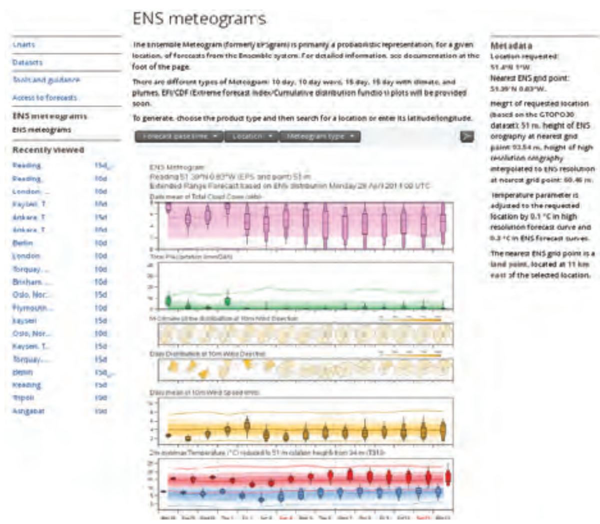
Snapshot 1. The 'Charts' catalogue displaying 'tropical cyclones' products.



Snapshot 2. 'Search' results with the 'Charts' theme selected.



Snapshot 3. The 'Chart' page.



Snapshot 4. The meteogram user interface.

user in the past. Note that, as this list is stored in the user's browser, restarting the browser or using a different browser will reset the list.

The main groups of charts have been migrated to the new website, and the migration of remaining products will continue in the next few months.

Some popular functionalities on the old website such as the 'Your room' facility will also be redesigned and implemented. In addition, there will be the introduction of interactive charts features such as zoom, pan and click. Further enhancements to the meteogram interface are also in the list of up-coming developments.

During the finalisation of the new website, the old website will remain accessible by users for a year to prevent service disruptions. As this is a radical change to our website, we are keen to receive any feedback that could help us improve the user experience.

Start of the ERA-CLIM2 project

DICK DEE, REBECCA CALNAN

The kick-off meeting for the ERA-CLIM2 project took place at ECMWF on 24 and 25 February 2014. This new EU Framework Programme 7 project is a three-year continuation of the ERA-CLIM project that ended in December 2013. The total cost of ERA-CLIM2 will be €15 million, with €7 million to be contributed by the EU, including €2.5 million for ECMWF. The project involves 16 partner institutions, many of which participated in ERA-CLIM.

ERA-CLIM2 is regarded by the European Commission as an important precursor for the Copernicus Climate Change Service to be implemented in the near future. The overall goal for ERA-CLIM2 is to develop new climate reanalysis products with consistent descriptions of the atmosphere, ocean, land-surface, cryosphere, and the carbon cycle. This will be accomplished within five categories of work:

- Production of coupled atmosphere-ocean reanalyses.
- Development of data assimilation methods for coupled models.
- Preparation of input observations for reanalysis, including data rescue.
- Uncertainty assessments on observations and reanalysis products.
- Improving access and dissemination of climate data.

ECMWF will be responsible for reanalysis productions and data services, in addition to project management and coordination.

More than 30 external participants, including the EU project officer, and many from ECMWF attended the kick-off meeting. Its main purpose was for all project partners to get to know each other, bring everyone to a common understanding about the project's goals and work plan, and discuss the first practical steps for working together during the next three years. We also discussed the outcomes of ERA-CLIM, including lessons learned, and the ways that ERA-CLIM2 can contribute to the Copernicus Climate Change Service.

It was a very successful meeting and a good start. All involved are highly motivated and confident that we will have an exciting and successful project. In the end it was agreed that we are in a unique moment in the development of climate services in Europe, and that, with this project, we have a great opportunity to make a real and lasting impact.

More information about ECMWF's reanalysis activities can be found in the article starting on page 15 of this edition of the *ECMWF Newsletter*.

ERA-CLIM2 project partners

- ECMWF, international, located in UK
- Met Office, United Kingdom
- EUMETSAT, international, located in Germany
- Universität Bern, Switzerland
- Universität Wien, Austria
- Fundação da Faculdade de Ciências da Universidade de Lisboa, Portugal
- All-Russian Research Institute of Hydrometeorological Information, Russia
- Mercator Océan, France
- Météo-France, France
- Deutscher Wetterdienst, Germany
- Centre Européan de Recherche et de Formation Avancée en Calcul Scientifique, France
- Centro Euro-Mediterraneo Sui Cambiamenti Climatici SCaRL, Italy
- Ilmatieteen Laitos, Finland
- The University of Reading, United Kingdom
- Institut National de Recherche en Informatique et en Automatique, France
- Université de Versailles Saint-Quentin-en-Yvelines, France

TIGGE-LAM improves regional ensemble forecasts

RICHARD MLADEK, TIZIANA PACAGNELLA
(ARPA-SIM, Italy)

The World Weather Research Programme has launched a new tool to improve regional ensemble forecasts of high-impact weather and so strengthen early warning and disaster prevention.

TIGGE-LAM is an extension of the THORPEX Interactive Grand Global Ensemble (TIGGE) archive to include weather forecasts from limited-area model (LAM) ensembles. Data from five European ensemble systems is now available in a standard format through a single web portal hosted by ECMWF; data from five more ensemble systems will be added in the near future. These forecasts are produced on grids between 12 and 2 km resolution and provide detailed information for the short range, up to a few days ahead.

TIGGE-LAM complements the larger-scale information provided by the global data in the established TIGGE archive. It will enable users to compare models and improve the methodologies for the generation and application of regional ensemble forecasts. It will also provide valuable feedback to global ensemble developments as the resolution of these systems is planned to increase significantly in the coming years. All contributions have been coordinated at ECMWF.

The TIGGE-LAM archive has been developed as part of the EU-funded GEOWOW project to improve Earth observation data discovery, accessibility and exploitability. It is part of the weather contribution to the GEO System-of-Systems (GEOSS) and is accessible through the GEO Common Infrastructure (GCI).

TIGGE-LAM was launched at a conference at WMO headquarters on 19 March. Speaking at the event, David Richardson, Head of Evaluation at ECMWF, said: "Although originally proposed in 2007, the TIGGE-LAM project only recently came to fruition thanks to GEOWOW. For the first time, we can easily access all of these ensembles and study their performance to improve our understanding. Having data from five European ensemble systems is a great start, and another five providers will join the scheme shortly."

The TIGGE-LAM data portal is available at: http://apps.ecmwf.int/datasets/data/tigge_lam/

More information about the TIGGE-LAM project is available at: http://tigge.ecmwf.int/lam

TIGGE-LAM Dataset	Institution
Available data	
ALADIN-LAEF	ZAMG, Austria
COSMO-DE-EPS	DWD, Germany
COSMO-LEPS	ARPA-ER SIMC, Italy (for COSMO)
HUNEPS	OMSZ, Hungary
MOGREPS-UK	Met Office, UK
Soon to be available	
PEARP	Météo-France, France
SRNWP-PEPS	DWD, Germany
AEMET-SREPS	AEMET, Spain
DMI-HIRLAM	DMI, Denmark
GLAMEPS	DMI, Denmark (for HIRLAM & ALADIN)

THORPEX and TIGGE

THORPEX (The Observing System Research and Predictability Experiment) is a ten-year international research programme that was established in 2005 to accelerate improvements in the accuracy and utility of high-impact weather forecasts up to two weeks ahead. THORPEX is part of the World Weather Research Programme and is a key research component of WMO's disaster risk reduction programme.

In the TIGGE (THORPEX Interactive Grand Global Ensemble) project, ten of the leading global weather forecast centres are providing regular global ensemble predictions to support research, particularly addressing predictability, dynamical processes and the development of probabilistic forecasting methods. TIGGE has become a focal point for a range of research projects, including research on ensemble forecasting, predictability and the development of products to improve the prediction of severe weather.

Scalability programme at ECMWF

PETER BAUER

A Scalability Programme has been initiated at ECMWF with the aim of coordinating developments towards a more scalable Integrated Forecasting System (IFS) including data processing, archiving and overall workflow. The Programme will provide accurate, efficient and scalable algorithms and code structures to cater for a variety of potential future high-performance computer (HPC) architectures. ECMWF is not alone with this concern and worldwide efforts are targeted towards improving the scalability of operational large-scale software applications.

The Programme will initially last five years. It will coordinate resources from across the Centre to define the future forecasting system for all scales. As it is essential to ensure these resources are available, the projects that form parts of the Scalability Programme will be run under the formal project management methodology known as PRINCE2. This encompasses the management, control and organisation of projects and enables their successful delivery within time, cost and quality constraints.

What is scalability?

Scalability refers to running a computer code like ECMWF's NWP model faster if more processors are used.

Today tens of thousands of processors are employed, but in the future millions will be required. This is because the realism of simulations will be enhanced by running with continuously increasing resolution, larger ensembles of simulations, more observations, more complex physics and chemistry, and by coupling with ocean, waves and sea-ice in the future.

Processor speed is likely to decrease and total energy consumption must be limited. Efficiency gains can only be obtained from more of the same or a combination of traditional and low-energy processors specialised at performing many floating point operations locally without much need for data communication.

Various parts of the code, like data assimilation and forecasts, have been tested on different configurations at ECMWF and on external machines, and it is clear that this problem needs to be addressed across all our applications, albeit in different ways. Therefore, there is a need to face the challenge of future technologies and their implications for the scientific and numerical algorithms that are used, as well as the efficiency of code infrastructure across the entire operational forecasting system. Similar challenges arise for data pre- and post-processing as well as data archiving.

Collaboration is crucial for the Programme's success. In addition to collaboration with Member States, ECMWF will work in partnership with various consortia and other organisations such as HIRLAM, ALADIN, COSMO, NEMO, NEMO-VAR, HPC centres and hardware companies. Vendors will have an important role in the design process and providing advice and access to the latest computing architectures. The collaboration with HPC centres will allow ECMWF to run its development codes on emerging novel computer hardware so that informed decisions can be made about their efficiency.

As a first step a workshop was held at ECMWF on 14 and 15 April. Its purpose was to define objectives for external collaboration by:

- Identifying common areas of fundamental research towards exa-scale scalability of numerical algorithms, software infrastructures and code adaptation.
- Exploring the potential for common/shared code components.
- Defining future benchmarking strategies.
- Facilitating intercomparison projects of different model components on selected architectures.

The workshop was co-funded by CliMathNet, an initiative that aims to break down barriers between researchers in the Mathematical Sciences and those in Climate Sciences. For more information about CliMathNet go to: http://www.climathnet.org/

Participants in the Scalability Workshop. Over 50 external scientists from NWP centres, HPC centres, universities and computer hardware vendors attended the workshop that was held at ECMWF on 14 and 15 April 2014.

Metview's interface to 3D interactive graphics

SÁNDOR KERTÉSZ

Metview is ECMWF's meteorological workstation software for accessing, manipulating and visualising meteorological data, incorporating both an interactive and a batch mode. Metview has been long renowned for its vast range of 1D and 2D visualisation techniques. In order to further extend its capabilities and offer cutting-edge interactive 3D graphics, in the latest version (4.4.6.) it was interfaced to an external tool called VAPOR.

VAPOR (Visualization and Analysis Platform for Ocean, Atmosphere, and Solar Researchers) is an open source software system providing an interactive 3D visualisation environment that runs on most UNIX, Windows and Mac systems equipped with modern 3D graphics cards. Its development is led by NCAR (USA) and has a large worldwide user community covering a wide range of scientific disciplines.

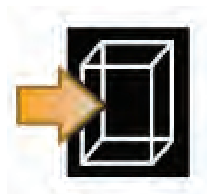
VAPOR has its own internal data model and any gridded data to be visualised has first to be converted into this format. In spite of VAPOR being equipped with various data conversion tools, GRIB, which is the major gridded format at ECMWF and its Member States, is not yet supported. To overcome this difficulty the VAPOR Prepare icon was developed in Metview. This icon, using the powerful data processing capabilities of Metview, allows conversion of pressure and model level GRIB data into the VAPOR format. It is also able to compute the orographic height of all levels needed for the accurate 3D representation of this data.

Besides data processing, the VAPOR Prepare icon also has a visualisation role: by using its 'visualise' action VAPOR can be started up, loading and rendering the converted dataset. At this point users enter the VAPOR world and can select from various 3D techniques such as volume rendering, isosurface visualisation, cross sections and vector field rendering using different flow visualisation methods.

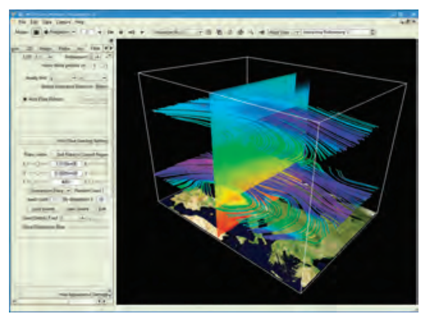
Experience so far has showed that it is worth combining the capabilities of Metview and VAPOR. Metview's highly customised plotting and in-depth data analysis facilities allow selection of the features to be studied in VAPOR; then, after converting the data, VAPOR lets users gain insight into the 3D structure of the meteorological fields. In this way the 2D and 3D world complement each other.

We would like to thank John Clyne from NCAR for his cooperation and assistance with setting up the Metview/VAPOR interface.

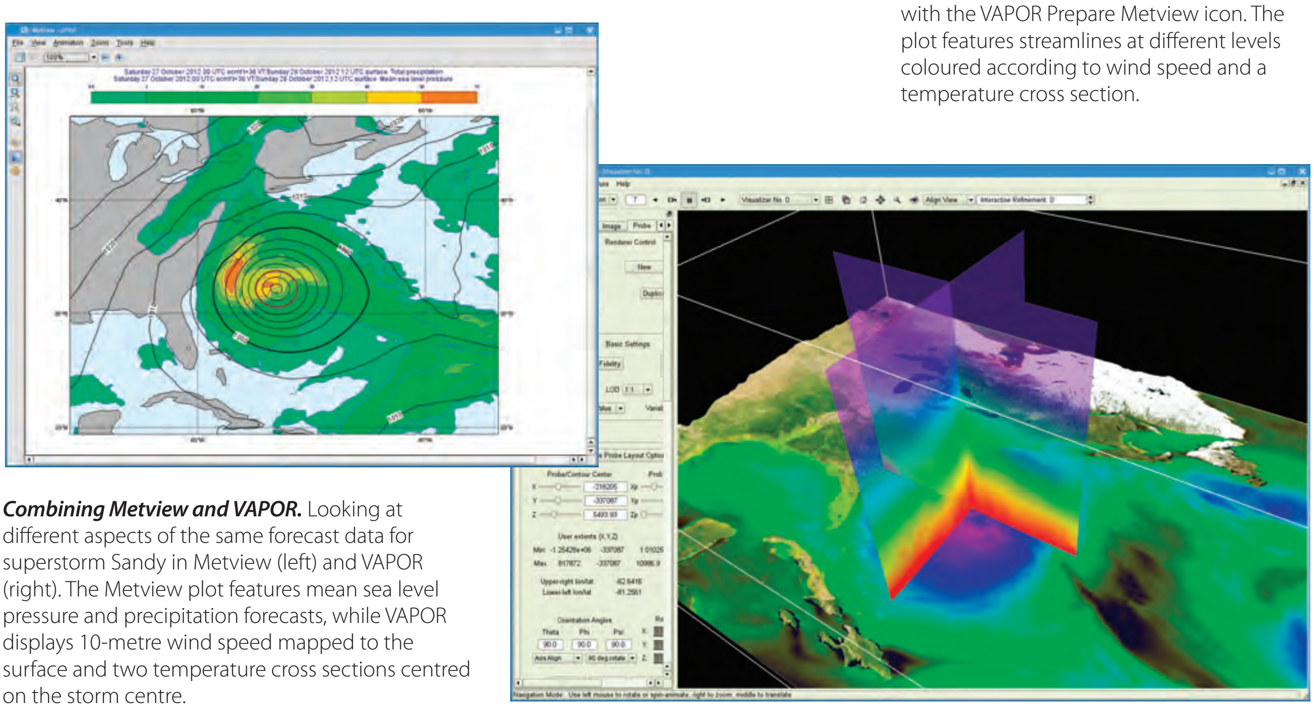
More information about Metview and VAPOR is available at:
http://software.ecmwf.int/metview
https://www.vapor.ucar.edu/



The VAPOR Prepare icon. This new Metview icon helps users convert GRIB data into the VAPOR format and also allows visualisation with VAPOR.



VAPOR Visualisation. Screenshot of VAPOR displaying ECMWF forecast data converted with the VAPOR Prepare Metview icon. The plot features streamlines at different levels coloured according to wind speed and a temperature cross section.



Combining Metview and VAPOR. Looking at different aspects of the same forecast data for superstorm Sandy in Metview (left) and VAPOR (right). The Metview plot features mean sea level pressure and precipitation forecasts, while VAPOR displays 10-metre wind speed mapped to the surface and two temperature cross sections centred on the storm centre.

Migrating the RMDCN

TONY BAKKER, AHMED BENALLEGUE, OLIVER GORWITS, ALAN RADFORD

The Regional Meteorological Data Communication Network (RMDCN) has recently undergone modernisation in order to meet the future requirements of ECMWF's Member States and the wider meteorological community. A procurement exercise in 2012 identified that these requirements could be met most cost-effectively by migrating to a new state-of-the-art network operated by a new service provider – Interoute Communications Limited. This article follows on from a previous one published in *ECMWF Newsletter No. 134* and describes the migration of the RMDCN from the previous service provider, Orange Business Services (OBS), to Interoute.

Background

The RMDCN provides a network infrastructure for the connections between ECMWF and its Member States and Co-operating States. In addition it has most of the connections for WMO Regional Association VI (RA VI) that are part of the WMO's Global Telecommunication System (GTS). The RMDCN is used for dissemination of ECMWF's forecast products and exchange of meteorological data (e.g. observation and radar data, between the connected sites). ECMWF manages the RMDCN and monitors the network on behalf of the connected user sites following an agreement with WMO.

Signing the contract on 11 December 2012. Alan Thorpe, ECMWF's Director-General, signing the contract with Lee Myall, UK Regional Director at Interoute Communications Limited, for the provision of the Next Generation of the RMDCN.

Since the RMDCN started operational service in March 2000 (with 31 participating sites) the demand for membership has grown. Supporting a further limited expansion of the RMDCN while keeping the number of user sites to a manageable level, the ECMWF Council agreed in 2008 to consider the following four categories of countries as potential future members of the RMDCN:

- ECMWF Member States and Co-operating States.
- RA VI countries not currently connected to the RMDCN.
- Countries operating Main Telecommunications Network (MTN) centres, including future Global Information System Centres (GISCs) of the WMO Information System (WIS).
- Countries outside RA VI connected to an RA VI country as part of the GTS, upon request by the RA VI country concerned.

Further details may be found on the ECMWF website at http://www.ecmwf.int/services/computing/rmdcn/.

At the end of 2013 the number of RMDCN members stood at 51 and included National Meteorological Centres in countries such as Japan, China, India, United Arab Emirates, South Korea, Australia, USA, Canada and South Africa, as well as two EUMETSAT sites, the Swiss National Supercomputing Centre (CSCS) and one disaster recovery site in the Netherlands.

The need for change

The network has evolved technically as well as geographically. A major change occurred in 2006 when the RMDCN was migrated from the Frame Relay architecture to a more modern one based on Multiprotocol Label Switching (MPLS). This provided several advantages, including improved availability levels, any-to-any connectivity and the provision of Class of Service (CoS) to allow traffic prioritization. Throughout its lifetime the RMDCN has also seen a steady increase in the speed of the connection of the sites, with the bandwidth of the ECMWF Member States Basic Package configuration typically doubling around every three years.

As the resolution of ECMWF's operational models continues to increase, so does the size of files that must be sent to its Member States. One of ECMWF's objectives is to provide the network infrastructure for the dissemination of products so it is vital to periodically verify that the RMDCN is fit for purpose and provides value for money. Therefore, in October 2010 the Technical Advisory Committee (TAC) supported a plan presented by ECMWF to initiate a procurement process for the next generation of the network and established a TAC Subgroup on the RMDCN to assist with the definition of requirements and to review the outcome of the procurement.

As described above, the membership of the RMDCN now extends beyond ECMWF Member States and Co-operating States. Indeed the WMO intends to use the RMDCN as part of the core network for the new Weather Information Service (WIS), so the involvement of WMO was sought throughout the procurement process.

Following an invitation to tender (ITT) published in February 2012, the evaluation of tenders clearly showed that the offer from Interoute Communications Limited provided significantly better overall value for money, even when taking into account the cost of migration to a new provider. A nine-year contract (with a break point after six years) was finally signed by the ECMWF Director-General and Interoute on 11 December 2012.

Migration Project

Migration of an operational network of this size is not a straightforward exercise so following signature of the contract a project was established under the overall direction of Interoute; this is standard practice for activities of this nature. However, ECMWF also initiated its own project to ensure that the activity proceeded according to the desired timescales of the RMDCN community, and within the agreed cost envelope. Regular (usually weekly) meetings took place between the project teams of ECMWF and Interoute.

Pilot Phase

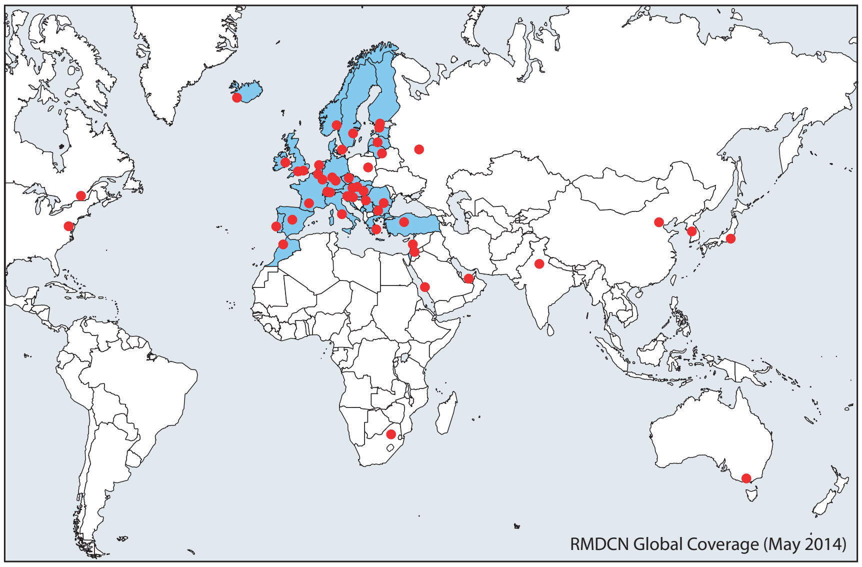
The first phase of the project, which lasted until the end of June 2013, was to deploy, test and accept a Pilot Network. In cooperation with Interoute, we selected six sites considered to be representative for the whole community (ECMWF Member States, RA VI sites and sites outside Europe). The sites participating in the Pilot Network were: Austria, Belgium, Sweden, Bulgaria, Japan and ECMWF.

One of the main purposes of establishing a Pilot Network was to get used to the working processes of our new network provider and to expose and correct any problem areas. In this regard the Pilot phase of the project was certainly a success. The testing period was not all smooth sailing; in particular, several issues were found with the router configurations. However, working closely with the Interoute technical staff we finally managed to end up with a fully functioning Pilot Network by 30 June – a key milestone in the contract and project plan. In July a 'lessons learned' meeting was held with Interoute, where we were all very open about what could have gone better and agreed on what to improve before the main rollout.

Initial Deployment Phase

At the beginning of July, immediately following acceptance of the Pilot Network, orders for a total of 41 further sites were submitted to Interoute for the main phase of the project called the Initial Deployment. The second key milestone was to formally accept the 'Global' Network by 20 December 2013, which meant starting the Global Network Reliability Acceptance Test (GNRAT) one month earlier on 20 November (see article in ECMWF Newsletter No.134 for more details of the testing process). When we were negotiating the contract in autumn 2012 we recognised that there was a reasonable chance that not all of the Initial Deployment sites would have been connected and tested by 20 November, so we agreed that a minimum of 70% of the sites should take part in the GNRAT. In the event, exactly 29 sites (70.7%) were ready by the deadline so the test went ahead and the Interoute network was formally accepted by the milestone date of 20 December 2013.

Meanwhile Interoute worked hard to ensure that the remaining 12 sites, which were not able to participate in the GNRAT, were connected and handed over as soon as possible. This occurred from 20 November 2013 to 7 April 2014.



The global coverage of the current RMDCN. There are 51 sites (48 National Meteorological Centres, ECMWF, EUMETSAT and one disaster recovery site in the Netherlands) connected to the network. The shaded countries indicate ECMWF Member States and Co-operating States.

Migration Phase

At the point of accepting the new network (20 December) most sites had live connections to both the OBS and Interoute networks. However, the OBS network was still carrying the operational traffic. Therefore the final phase was to 'properly' migrate the sites, i.e. move all operational traffic across to the new network. Because the primary consideration was to ensure that connectivity was maintained between all sites at all times, it had been decided at an early stage that a 'big-bang' approach – i.e. an instantaneous switch-over from the old network to the new – would be far too risky. Instead there would be a designated period of one month, from 6 January to 6 February 2014, during which all sites were switched over. During this period, ECMWF acted as a gateway between the old OBS network and the new Interoute network, thus enabling all RMDCN sites to continue to inter-communicate during the migration, whether they were on the OBS network or had already migrated to Interoute.

By the end of the migration period only 2 of the 47 sites (6 Pilot plus 41 Initial Deployment) had not been handed over by Interoute. Connection to the Turkish Met Service was delayed because changes had to be made to the cable ducting into the building and was finally migrated on 4 March. The NOAA site (Washington DC) was delayed due to contractual issues in their data centre in New York and was finally migrated on 1 May 2014.

OBS Disconnection Phase

Despite the fact that by early February most operational traffic had been transferred on to the Interoute network, the sites were also still connected to the OBS network. We chose to wait until the migration period had finished before giving the formal 90-days' notice of disconnection to OBS, because we considered the price of dual payments for three months to be good value for mitigating the risk of a delay occurring during the migration phase.

What next?

Now that the migration to the new network has finished, we move on to a 'business-as-usual' footing, with the door open for new members to join the RMDCN. As the requirements for the RMDCN continue to grow, whether due to higher data volumes, increasing bandwidths or a continuing demand for membership from the wider WMO community, we will be in an excellent position to meet those requirements readily and cost-effectively. Already waiting in the wings are a handful of other sites (outside Europe), most of them future Global Information System Centres (GISCs) in WIS (WMO's next generation of the GTS). It is expected that more than 50 sites will be connected to the RMDCN by the end of 2014.

Top class training

SARAH KEELEY

The Numerical Weather Prediction training courses have finished for another year. This time we had over 130 participants from 25 different countries. They came from our Member and Co-operating States and other national meteorological services and universities such as those in South Korea, China, Brazil and Australia.

This year saw the start of two new courses: the 'Advanced numerical methods for Earth-System modelling' and the shorter 'Data Assimilation' course. The advanced numerical methods course covered numerical techniques and modelling advances for future massively parallel computer architectures. The feedback about the course structure and topics has been very positive, including comments such as: "Top class training course, one of the best I have been on."

There have been some other changes to the courses this year. We have created online training web pages for course participants that include learning outcomes for the lectures and forums as well as general information for the participants and copies of the lecture materials. We have also run poster sessions as part of each course. This has been a great opportunity for ECMWF staff and course participants to discuss the research work of those attending the course.

Registration for next year's courses will open in the autumn and we look forward to meeting many of you in the coming year. Courses are free to attend for participants working or studying in our Member and Co-operating States.

Please get in touch if you have any ideas or thoughts about the training courses that are offered by ECMWF.

Global partnership for enhanced resilience to flood risk

FLORIAN PAPPENBERGER,
G. ROBERT BRAKENRIDGE (Dartmouth Flood Observatory),
TOM DE GROEVE,
JUTTA THIELEN-DEL POZO (JRC)

In March the Global Flood Partnership was launched at the 4th meeting of the Global Flood Working Group hosted by ECMWF. The initiative is led by the European Commission's Joint Research Centre (JRC) and the Dartmouth Flood Observatory (University of Colorado); it is a unique international forum aimed at developing a global flood observation and modelling infrastructure for managing and forecasting flood risk at a global scale. ECMWF will play a role in forecasting by making use of experience it gained in running the European Flood Awareness System.

The partnership aims to provide operational and globally applicable flood monitoring and, at a later stage, forecasting tools and services, as well as short- and long-term flood risk assessment tools, which will be complementary to national capabilities. This will be achieved by bringing together the scientific community, satellite and weather service providers, national flood and emergency management authorities, humanitarian organisations and donors.

In Europe, the World Bank has estimated that hydro-meteorological information and early warning systems save hundreds of lives and avoid between 0.46 and 2.7 billion euros of disaster losses per year (these figures are for 2012). While early warning systems are well established in the European Member States and are complemented by continental-scale systems, many regions around the world do not have access to this kind of information. The potential for savings in losses and damages through early warning systems in developing and less-developed countries is estimated to be between 3 and 26 billion euros per year.

The Partnership establishes strong links with core international stakeholders such as the World Bank's Global Facility for Disaster Risk Reduction, the United Nations (UN) World Food Program, the UN Office for Coordination of Humanitarian Affairs and UN Office for Disaster Risk Reduction. It also brings together national flood authorities as well as meteorological authorities (e.g. WMO, ECMWF and UK Met Office), space agencies (ESA and NASA), rapid flood mapping services (e.g. UNOSAT and Copernicus) and regional operational response centres (including the Emergency Response Coordination Centre of DG ECHO).

Background to the Global Flood Partnership

Key personnel from the international scientific community have met over the past four years to discuss global flood forecasting and monitoring systems within the framework of the Global Flood Working Group. During this period, the working group extended their dialogue to include international response organisations as well as meteorological authorities and other public and private stakeholders in flood management.

Drawing upon the December 2012 recommendations of the JRC-organised meeting of the Senior Officials of the Carnegie Group countries, the United Nations and the World Bank, the Global Flood Working Group concluded in their annual meeting (Washington DC, March 2013) that the dialogue must be turned into action, and to start building global flood forecasting and monitoring systems. This led to the concept of the Global Flood Partnership.

International initiatives such as the Flood Initiative (UNESCO, WMO, UN-ISDR), the Hydrological Ensemble Prediction Experiment (HEPEX), the Committee on Earth Observation Satellites (CEOS) Flood Pilot and the OECD Global Science Forum are represented in the Partnership, as are other public and private stakeholders in flood management, including reinsurance and the commercial space industry.

Copernicus Climate Change Service Workshop

JEAN-NOËL THÉPAUT, DICK DEE

ECMWF organised a workshop to discuss the possible scope and content of the Copernicus Climate Change Service (CCCS) being implemented by the European Union (EU). The rationale for the workshop was to bring climate experts together to provide input to the community for responding to the EC 'Call for Expressions of Interest' in operating the CCCS.

The workshop took place at ECMWF on 17 and 18 February 2014, gathering representatives from 43 organisations in 19 countries, including the USA. The programme was articulated around the four main building blocks of the CCCS as proposed by the European Commission: Climate Data Store, Sectoral Information System, Evaluation and Quality Control, and Outreach and Dissemination. The workshop included keynote presentations followed by working group discussions focusing on each of the building blocks.

The workshop participants put forward the following comments and recommendations on the scope and content of the future CCCS.

- Defining the interface between the CCCS and the various relevant national activities will require a lot of attention. At the national level, discussion of climate change impacts is rather broad and extends beyond just the meteorological domain. National initiatives that aim to build a common architecture for climate information portals in various domains should be factored in the definition of the CCCS. The CCCS should also harness new capacities developed in existing European initiatives and projects (e.g. EU's 7th Framework Programme).
- Although long-term research is beyond the scope of the CCCS, there should be a strong development component within the CCCS.
- Trusted local information providers should be included in the service. A layered structure is required, where the main task of the CCCS is to provide shared climate data products and processing services. The CCCS will be in a position to supply common, overarching and authoritative messages. However, final dissemination of climate information should be handled via national services. The issue of trust is important: the same message is often trusted more when delivered locally.
- A flexible approach is needed to address the diverse requirements of the entire European community. Each country is different and may require different solutions. The CCCS should promote best practice, as a networking activity, to the national level. It should develop a shared knowledge base with the aim to support and improve national services, and to help establish new ones.
- While national meteorological services carry out many activities related to climate services, it is important that the capabilities of other types of institutes and services should also be exploited by the CCCS (e.g. ECV, Essential Climate Variable) product generation by ESA CCI (Climate Change Initiative) or by the EUMETSAT Climate SAF, and climate services by other environmental agencies.
- The CCCS should be inclusive and engage with a broad user community, understanding that EU policies on adaptation and mitigation, DG Climate Action and national policy makers are primary users. It will need to call on a wide range of expertise in various domains. The meteorological services have developed a technical infrastructure that naturally provides them with a leading role in this endeavour. The implementation of the Copernicus Atmospheric Service illustrates well how very diverse communities can be involved in building a shared operational service.
- Among all Copernicus services, climate represents the crosscutting theme. The implementation of the CCCS should therefore build on elements of the other services. The required links and dependencies among the various services should be made explicit in the implementation plan.

Specific recommendations that addressed the four building blocks of the CCCS are now summarised.

Climate Data Store (CDS)

- The CDS should be designed as a distributed system, providing improved access to existing databases via a one-stop shop, generating and maintaining a documented European catalogue. The CCCS should identify gaps in the currently existing climate information datasets and ensure that the CDS will fill these gaps.
- The scope of the CDS should be global, with a higher resolution focus on Europe and possibly regions of particular interest to European users. Clear selection criteria with appropriate metrics should be established to include climate information in the CDS.

Building blocks of the CCCS	Illustrative activities
Climate Data Store	Data store infrastructure, climate reanalysis (global, regional), seasonal forecasting, climate projections, climate observations, and ECV products other than reanalysis
Sectoral Information System	Customised product development, technical infrastructure, data acquisition and monitoring, and user support and outreach
Evaluation and Quality Control	Engagement (workshops, surveys, reports etc.), liaison with Horizon2020, evaluation of CCCS products and services, and support for advisory groups
Outreach and Dissemination	Website development and maintenance, publicity, liaison with public authorities, and events (conferences, summer schools etc.)

Building blocks of the CCCS. The table gives an indication of the types of activities that might be involved in the four building blocks.

- The content of the CDS should include in-situ and satellite-based climate data records, ECV datasets, reanalyses (global and regional), seasonal forecast products, multi-model projections, aggregate climate indices. Datasets should be fully traceable, documented and include associated uncertainties. Data mining and visualization tools should be provided to explore these datasets, based as much as possible on open source software.
- The CDS should provide some production capacity and clear mechanisms should be established for continual improvement of the CDS content, based on user requirements (e.g. provided by GCOS: Global Climate Observing System).
- CDS products should comply with the EU free and open data access and any data restrictions should be handled in a transparent way.

Sectoral Information System (SIS)

- SIS should produce geographically and sector-specific tailored datasets, and progressively develop relevant climate impact indicators. This will require engagement with end users and European policy needs, and interaction with other disciplines and networks at a very early stage in the definition phase. SIS should be designed to progressively include a socio-economic and adaptation dimension.
- The formulation and specification of sector-specific climate products will require iterations between providers and users. This iterative process will necessitate a phase of prototyping and case studies. The SIS should not only be designed as a production system but also as a function, fully interactive with sector-specific communities of practice. The definition of the interface between the SIS and the Evaluation and Quality Control function is therefore essential.
- Full traceability and uncertainty assessment should apply to sector-specific indicators and impact datasets. This will require a definition of 'climate compliance' and associated validation chains as GCOS does not apply to tailored climate information.

Participants at the Copernicus Climate Change Service Workshop. The workshop was held on 17 and 18 February 2014 and included representatives from 43 organisations in 19 countries.

Evaluation and Quality Control (EQC)

- The EQC function should define the reference for quality of climate services and promote best practices. These best practices do not apply only to data or variables but also to processes, impact indicators, etc. EQC is therefore essential in linking the CDS and the SIS.
- There should be both internal (monitoring and evaluation of the datasets, quality assurance on traceability, documentation and uncertainty estimation) and external (independent assessment of the Service and evaluation of the processes) components of the EQC. The external EQC function may draw on wide international (outside Europe) evaluation expertise.
- EQC should foster CCCS development to ensure continual improvement and fitness-for-purpose of climate information products. In particular, it should assess the quality of service relative to user requirements, identify and map existing gaps in capabilities, and accordingly promote research (e.g. via the Horizon 2020 programme) to address shortcomings.

Outreach and Dissemination (OD)

- OD will be the vehicle to identify and target users, and to support national outreach efforts.
- OD should create a feedback loop from downstream users of the core services and upstream data providers. This should lead to innovation in the infrastructure for dissemination, in order to complement and advance rather than replace existing data and information portals.
- The CCCS should organise and engage with 'communities of practice' for specific sectors to map existing applications and quality requirements, and to help develop suitable information services for these sectors.
- The OD platform should ensure that the CCCS supports capacity building and training in European countries that have less advanced capabilities in climate services. Homogenisation of capabilities will ultimately benefit all.
- Several levels of dissemination and outreach to the global community should be provided for global climate assessments for policy makers in the European Commission, the EU institutions, the media and general public amongst others. The OD platform should be dimensioned to address these different levels.

The workshop was successful in bringing the community together, assessing and endorsing the structure of the CCCS foreseen by the European Commission and developing a path towards further definition of the content and elements of the CCCS.

Climate reanalysis

DICK DEE INTERVIEWED BY BOB RIDDAWAY

Dick Dee *is the Head of the Reanalysis Section at ECMWF. He is responsible for leading a group of scientists producing state-of-the art global climate datasets. This has involved coordinating two international research projects: ERA-CLIM and ERA-CLIM2.*

The ERA-CLIM2 project has recently started – what is its purpose?

This exciting new project extends and expands the work begun in the ERA-CLIM project that ended in December 2013. The aim is to produce physically consistent reanalyses of the global atmosphere, ocean, land-surface, cryosphere and the carbon cycle – see Box A for more information about what is involved in reanalysis. The project is at the heart of a concerted effort in Europe to build the information infrastructure needed to support climate monitoring, climate research and climate services, based on the best available science and observations.

The ERA-CLIM2 project will rely on ECMWF's expertise in modelling and data assimilation to develop a first coupled ocean-atmosphere reanalysis spanning the 20th century. It includes activities aimed at improving the available observational record (e.g. through data rescue and reprocessing), the assimilating model (primarily by coupling the atmosphere with the ocean) and the data assimilation techniques (e.g. related to data assimilation in coupled models). The project will also develop improved data services in order to prepare for the need to support new classes of users, including providers of climate services and European policy makers.

Who is involved in ERA-CLIM2 and how is it funded?

The project will be conducted by ECMWF together with sixteen other institutions in Europe and Russia: two international organisations, four national meteorological services, five academic institutions and five national research centres. At ECMWF, four scientists in the Reanalysis Section and one in the Forecast Department will be working on ERA-CLIM2. The project as a whole will require 88 person-years of effort and significant computing and data handling. The overall cost is €15 million, approximately half of it funded by the EU within the 7th Framework Programme (FP7) for Research and Technological Development.

The main strategic objectives of FP7 are to strengthen the scientific and technological base of European industry, encourage its international competitiveness, and promote research that supports EU policy development. Specifically, ERA-CLIM2 is one of several current FP7 projects aimed at improving the EU's capacities in the area of climate change adaptation and mitigation.

Earlier you mentioned the ERA-CLIM project – would you tell me more about its purpose and who was involved?

ERA-CLIM was a very successful project conducted by ECMWF together with eight other institutes in Europe, Russia and Chile. The goal was to improve the available observational record for the 20th century, and to develop the observational input and technical infrastructure needed to produce a climate reanalysis going back 100 years or more. A large portion of the project was dedicated to data rescue, with a focus on early upper-air observations in sparsely observed regions critical for climate (e.g. in the tropics and at high latitudes). This has already resulted in a huge increase in the digitised instrumental record

What is reanalysis?

A

Reanalysis is a method for producing a comprehensive and physically consistent numerical description of the climate as it has evolved in the recent past. The aim is to extract maximum information from the relevant instrumental record by using the best available models to assimilate different types of observations, e.g. from weather stations, ships, balloons, aircraft and a large variety of satellites. The use of models in a reanalysis ensures that all observations are interpreted in a consistent manner and that spatial and temporal gaps in the data are filled based on physical and dynamical constraints. The use of observations from multiple sources makes it possible to reduce uncertainties, to detect bad observations and, in some cases, even to correct them. The reanalysis generates time series of gridded estimates for many different variables, including some that are not directly observed such as stratospheric winds, radiative fluxes, root-zone soil moisture, etc. To maintain the best possible temporal consistency in these time series it is imperative that the models and data assimilation methods used in a reanalysis production remain unchanged throughout.

A global reanalysis typically spans multiple decades at sub-daily frequency and moderate spatial resolution determined by available computational resources. Reanalysis products are very widely used in research and education, as indicated by numerous citations in the scientific literature. The encyclopaedic nature of a reanalysis enables many applications that are difficult or impossible to achieve with observations alone. For example, one can calculate climatologies and probability distributions for many variables, study the statistics of extreme weather events in different locations, and compute diagnostics of the global energy budget and the hydrological cycle. Modern reanalysis productions are often continued in near-real time using observations as received by operational forecasting centres. This makes it possible to use reanalysis for monitoring climate change, and to support a variety of applications and climate services that require timely information about the current state of the climate.

for the early 20th century, more than doubling the total number of pre-1957 weather observations from kites and early radiosondes ready for reanalysis (see Figure 1). ERA-CLIM also kick-started an important international activity in satellite data rescue by investigating the availability of data records from pre-operational satellites and their potential use in future climate reanalyses. The project produced the first comprehensive inventory of early satellite data for reanalysis, including priorities for data rescue and information about next steps (see Table 1 for an excerpt of the inventory).

ERA-CLIM provided substantial support to the UK Met Office Hadley Centre for developing improved global estimates of sea-surface temperature and sea-ice concentration during the 20th century. The Met Office also developed important new data collections with high-quality sub-surface and surface ocean observations for reanalysis.

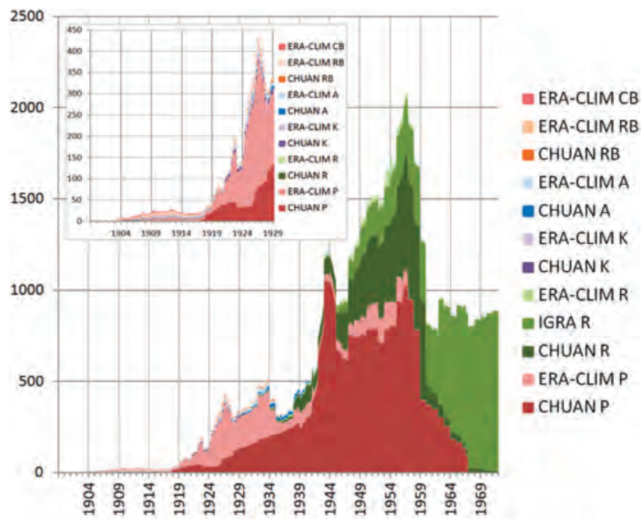


Figure 1 Number of upper-air records recovered in ERA-CLIM for various observing platforms, compared with those available in the existing data collections CHUAN (Comprehensive Historical Upper-Air Network) and IGRA (Integrated Global Radiosonde Archive). CB: captive balloon, RB: registering balloon, A: aircraft, K: kite, R: radiosonde, P: pilot balloon. Reproduced from *Stickler et al.* (2014, *Bull. Am. Meteorol. Soc.*, in press).

Instru-ment	Characteristics	Immediate concern	Recom-mendation
NEMS	Microwave spectrometer, with two water vapour channels near 22 GHz (5 mm) and three channels near 59 GHz (10 mm), spatial resolution 180 km at nadir	Nadir-viewing only, data on microfiche	**Reject for now**
SCAMS	Microwave spectrometer, with one water vapour channel near 22 GHz (5 mm), three channels near 59 GHz (10 mm), one window channel, spatial resolution 150 km at nadir	Data recovery in process by NSSDC	**Consider for assimilation**
SSM/T	Microwave temperature sounders precursors to AMSU-A and AMSU-B but with bigger fields-of-view. Met Office preparing homogenized data for ERA-CLIM.	RT forward model needed for SSM/T	**Assimilate**
SMMR	Microwave radiometer, ten channels: dual-polarization measurements at 6.63, 10.69, 18.0, 21.0, and 37.0 GHz, spatial resolution 150 km at nadir	Raw radiance data not found	**Keep looking for data**
SSH	Discrete filter radiometer, six channels in the 15 micron CO_2 band, one window channel, eight water vapour channels in the 22–30 micron band, one channel in the 10 micron ozone band	Data lost forever?	**Keep looking for data**
HIRS on Nimbus-6	Discrete filter radiometer, seven channels in the 15 micron CO_2 band, two window channels, two water vapour channels, five channels in the 4.3 micron band, spatial resolution 25 km at nadir	Data recovery in process by NSSDC. Digital version of the SRF not found	**Assimilate**
SCR	Radiometer observing through a pressurized optical cell, six channels in the 15 micron CO_2 band, spatial resolution 112–160 km at nadir (Nimbus-5: eight channels in the 15 micron CO_2 band, three window channels, one water vapour channel at 18.6 microns, spatial resolution 30 km at nadir)	RT coefficients challenging	**Validate**
PMR	Radiometer observing through a pressurized optical cell	RT coefficients challenging	**Assimilate**
HRIR	Visible and infrared imager, 8 km spatial resolution at nadir, 3.5–4 micron channel (and also 0.7–1.3 for Nimbus-3)	Digital version of SRF not found	**Validate**
MRIR	Infrared imager, five channels including a water vapour channel in the 6.7 micron band	Digital version of SRF not found	**Validate**
THIR	Infrared imager, one window channel and one water vapour channel in the 6.7 micron band	Only JPEG images available, raw radiance data lost forever?	**Keep looking for data**
IRIS	Michelson interferometer, covering 5–20 microns with 5 cm^{-1} normalized apodized spectral resolution (Nimbus-4: 6.25–25 microns, 2.8 cm^{-1} resolution), nadir spatial resolution 144 km	Short time period, calibration biases	**Validate**
SIRS	Grating spectrometer, covering 11–15 microns (Nimbus-4: 11–36 microns), nadir spatial resolution 220 km	Narrow swath (up to 12 degrees only from nadir)	**Consider for assimilation**
AVHRR	Imager on polar orbiters, atmospheric motion vector (wind) retrievals at the poles. EUMETSAT and CIMSS working on reprocessing.	Reprocessing not complete yet	**Assimilate**
SeaSat	First scatterometer ever. Suspicious end-of-life.	Very short dataset (97 days)	**Validate**
NSCAT	Scatterometer from U.S.	Short dataset (9 months)	**Assimilate**

Table 1 Selection of early satellite instruments with potential impact on reanalysis, with recommendations for future use.

Did ECMWF's technical infrastructure need to be developed for ERA-CLIM and what were the main outputs from the project?

A great deal of work had to be done to prepare the Integrated Forecasting System (IFS) for a century-long reanalysis. The IFS forecast model was supplied with boundary conditions and radiative forcing data appropriate for a climate simulation (*ECMWF Newsletter No. 133*, page 3), and vast numbers of input observations were organised, checked for quality, archived, and prepared for reanalysis. Various modifications had to be made to the data assimilation scheme in order to optimize performance, both in terms of computational efficiency and scientific quality. We described some of the technical challenges associated with running such a major reanalysis production on the ECMWF computing and data handling systems in an earlier newsletter article (*ECMWF Newsletter No. 134*, page 6).

In the end we were able to complete ERA-20C, ECMWF's first global atmospheric reanalysis of the 20th century within a reasonable amount of time. ERA-20C is based on surface observations only (surface pressure and marine winds) and provides 3-hourly atmospheric data for the period 1900-2010 at 125 km horizontal resolution and on 91 vertical levels. We also produced the corresponding set of model simulations for the same period (ERA-20CM); this will be useful for assessing the impact of the observations on quality and temporal consistency of the reanalysis. Finally we generated a higher-resolution (25 km) land-surface model integration (ERA-20CL) using the meteorology from ERA-20C. Taken together, the ERA-20C/M/L reanalysis products constitute a major new dataset for climate research (see Figures 2 and 3). The combined set, with hundreds of terabytes of data, is currently being prepared for public release via the internet (see Table 2).

Another important contribution to the technical infrastructure at ECMWF that came from ERA-CLIM is the Observation Feedback Archive, designed to provide better access to the input observations used in reanalysis – see Box B for more information.

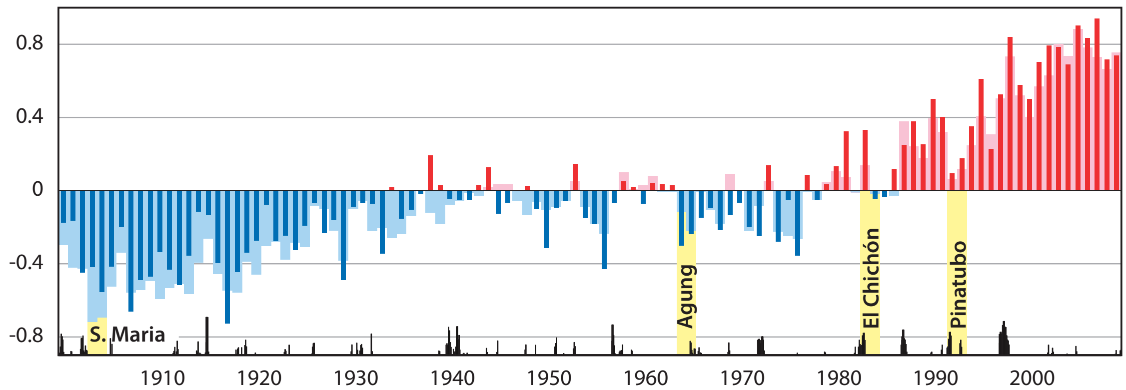


Figure 2 Verification of ERA-20CM annual-mean 2-metre temperature anomalies (K) (light shading) against independent estimates from station observations based on CRUTEM4 version 2.0.0 (dark shading). Yellow bars mark major volcanic events; timing and strength of El Niño events is indicated along the horizontal axis. The CRUTEM4 dataset is produced at the Met Office Hadley Centre (available at www.metoffice.gov.uk/hadobs). Anomalies are computed relative to 1961–1990 averages, and the comparison is for area-weighted averages taken over all grid boxes for which CRUTEM4 has values. Reproduced from *Hersbach et al*. (2013, *ERA Report Series No. 16*, ECMWF, UK).

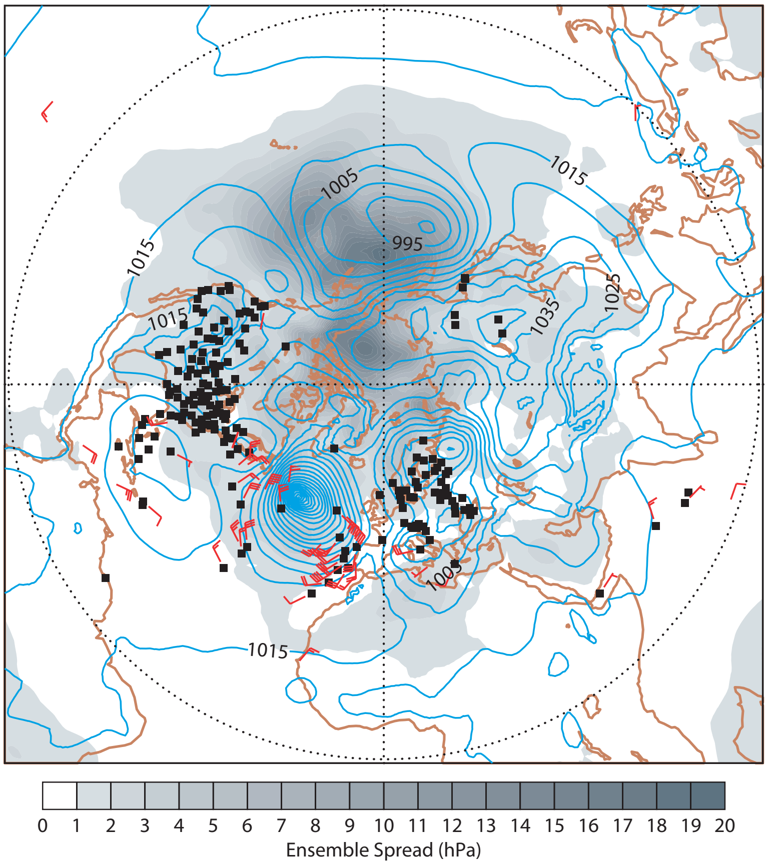
Improving access to observations

B

A major outcome of ERA-CLIM is the Observation Feedback Archive (OFA). Its function is to provide direct access to all input observations used in a reanalysis, together with 'quality feedback'. This is information generated by reanalysis pertaining to the quality of the observations, such as quality control indicators, bias estimates, estimates of observation uncertainty, and reanalysis fit to observations. The OFA also provides identifiers and other information that enables users to trace each individual observation to its source, and ultimately to retrieve additional metadata relevant to the quality of the observation. Examples of such metadata include images of logbooks or journals used to record early weather observations, documentation of the instruments used, or of changes in the environmental conditions for the instrument location.

The thinking behind the OFA is that users of reanalysis products need better tools for answering questions about the assimilated observations. The information content of a reanalysed field or parameter strongly depends on the types of observations used, where they are located and how well they are represented in the final product. This is especially relevant for climate reanalyses that extend far back in time. For the ERA-CLIM and ERA-CLIM2 projects we therefore adopted a strict data policy requiring all observations used in reanalysis to be made available to users, without exception.

The OFA will provide a dynamic, user-friendly interface for selecting, visualising, and retrieving observations from the ECMWF archive. The facility is still in an early stage of development and will be greatly expanded and improved in coming years. Please visit apps.ecmwf.int/datasets/ to try out the current version.

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TERRIFIC STORMS AT SEA

Steamships from All Quarters Report Extremely Rough Voyages.

ALL MORE OR LESS BATTERED

Vessels Sighted in Distress and Abandoned — Blinding Snow and Waves Like Mountains.

All the steamers that came in yesterday were coated with ice from the tops of the masts down to the water line, and all had passed through storms of blinding snow and mountainous waves. The British steamer Ethelgonda, from Bristol and Swansea, which left the latter port on Jan. 19, ran into a gale of hurricane force, and seas swept her decks repeatedly. So fierce was the wind that the boat drifted before the gales and was barely able to keep steerage way. She anchored outside the bar late Sunday afternoon. The cable parted and she lost her anchor, together with 100 fathoms of chain. Then the great snowstorm drove her 150 miles off the shore. She succeeded in getting back late on Tuesday night.

The French liner La Bretagne, from Havre, came in a little before noon yesterday, with 58 cabin and 225 steerage passengers. She left Havre on Feb. 4, and two days later she encountered a fierce gale, which soon raised tremendous seas. This lasted until Feb. 12, and during this time the vessel had to be slowed down. The following day heavy head seas were encountered, but the steamship proved herself a stanch craft in heavy weather. She had hard work in breaking the ice while getting into her slip.

Figure 3 The map shows the ERA-20C reanalysis of surface pressure (hPa) at 12 UTC on 3 February 1899 in the northern hemisphere (blue contours), with locations of all surface observations used (black dots: surface pressure; red vanes: 10-metre winds). Also shown are error estimates for the reanalysis (grey shading). Note the very deep low-pressure system in the North Atlantic and the large uncertainties in the active but poorly observed North Pacific. An extract from The New York Times published on 16 February 1899 describing the severity of the weather in the North Atlantic is also shown.

Reanalysis provides a wide range of data, but how will this data support the provision of climate services?

Climate services encompass a wide range of activities that deal with generating, processing and delivering information about past, present and future climate and its effect on society and the environment. Applications include monitoring and seasonal prediction of droughts, policy development in agriculture, water use, health and urban planning, climate-related risk assessments for the reinsurance industry, optimal design of sustainable energy projects, and much more. Reanalysis already supports many of these activities by providing consistent estimates of a large set of climate variables, with the possibility of updating these estimates close to real time. Global reanalyses of the atmosphere, ocean and land surface are used to calibrate the coupled models needed for seasonal prediction, and, more generally, to validate and improve climate models. Production of high-resolution reanalyses for limited domains (e.g. Europe, or the Arctic) requires boundary conditions and other background information from global reanalyses.

Indeed, a central place for reanalysis in the information chain for climate services is foreseen in current plans of the European Commission for the establishment of an operational Copernicus Climate Change Service. To prepare for this, we have already started to transfer some of the reanalysis activities at ECMWF from research to operations, ultimately to combine monitoring, evaluation and dissemination of near-real-time reanalysis and forecast products. We are also working hard to replace the current ERA-Interim reanalysis, which is based on a 2006 version of the IFS, with a new atmospheric reanalysis of the satellite-dominated modern observing period.

ERA-20C	Global atmospheric reanalysis from 1900–2010, 3-hourly data at 125 km spatial resolution and 91 vertical levels.
ERA-20CM	Global atmospheric model simulations from 1900–2010, monthly data at 125 km spatial resolution and 91 vertical levels.
ERA-20CL	Global land-surface reanalysis from 1900–2010, 3-hourly data at 25 km spatial resolution.

Table 2 Summary of ERA-20C/M/L family of reanalysis products.

As well as supporting climate services, should reanalysis data be used to estimate trends and low-frequency variability?

The short answer is yes, but with great care. Early generations of reanalyses, and some recent ones as well, have produced spurious shifts and other artefacts in the data that can be attributed to a number of causes. Some of these are technical in nature; for example, improper use of satellite observations, transitions between multiple production streams, or various mistakes that can occur in a complex reanalysis production. A much more difficult issue to deal with is the presence of biases in the assimilating model. This inevitably leads to residual biases in the reanalysis, which change over time depending on the quality and quantity of the assimilated observations. Since major changes in the observing system tend to occur on timescales relevant for climate, the impact of model biases can deteriorate the representation of climate signals and trends in a reanalysis. In short, the 'climate quality' of a reanalysis depends on the accuracy of the assimilating model as well as on the observational coverage. Of course, any other method for estimating trends from observations suffers from the same fundamental difficulty – which is, in fact, that neither models nor observations are perfect.

Nevertheless, between producing ERA-40 and ERA-Interim a great deal of progress was made at ECMWF in addressing many of the technical issues just mentioned. The ERA-Interim reanalysis uses a more sophisticated data assimilation method, based on a 4DVAR analysis that generates automatic bias adjustments for satellite observations. Technical facilities for observation handling, monitoring and diagnostics, have greatly improved as well. All of these factors have led to a much better representation of trends and low-frequency variability in ERA-Interim, as has been demonstrated for near-surface temperature and humidity by comparisons with independent estimates obtained from in-situ observations (see Figure 4).

The range of reanalysis activities you have described is very impressive. How do you know whether reanalysis products are being used by climate scientists and the EU is getting value for money from its investment in reanalysis?

The impact of reanalysis on climate science and applications is indicated by the large body of scientific work that makes use of reanalysis products. Journal articles describing global atmospheric reanalyses are consistently among the highest-cited in geosciences, with (according to Google Scholar at the time of this writing) 1,856 citations of *Dee et al.*, 2011 (on the ERA-Interim reanalysis) and 4,627 of *Uppala et al.*, 2005 (on the earlier ERA-40 reanalysis). As reported in the literature, reanalysis products are used for studies in a broad range of subjects in atmospheric science, oceanography, climate science, and in many application areas such as energy, health and the environment.

International awareness of the ERA-CLIM and ERA-CLIM2 projects has grown as well, with numerous users in the scientific community inquiring about availability and characterization of future data products. The full impact of

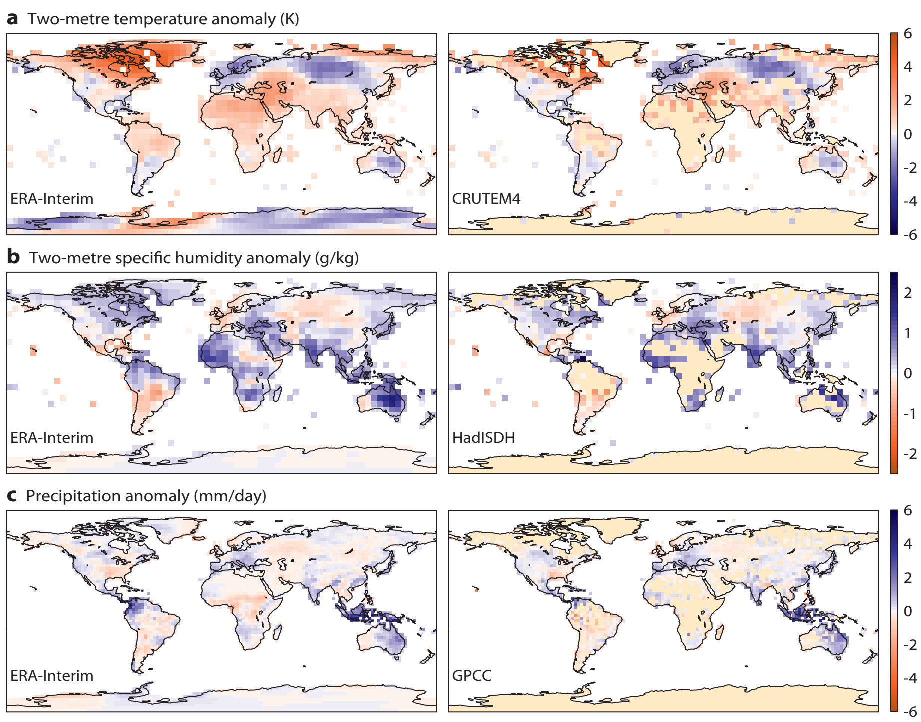

Figure 4 Anomalies for 2010 relative to 1981–2010 in (a) surface air temperature (K), (b) surface specific humidity (g/kg), and (c) precipitation rate (mm/day) from ERA-Interim (left) and from three climate datasets: CRUTEM4 (a, right), HadISDH (b, right) and GPCC Full Data Reanalysis Version 6 (c, right). ERA-Interim values for a particular variable are averaged over the 5° or 2.5° grid boxes of the dataset with which comparison is made, and are plotted for grid boxes that are at least 10% land or where there are otherwise data values for comparison. Values from CRUTEM4, HadISDH and GPCC are plotted only for grid boxes with a complete monthly data record for 2010. For GPCC it is also required that there be at least one station per grid box. 2010 was a relatively warm and moist El Niño year. This figure is taken from *Dee et al.* (2014, *Bull. Am. Meteorol. Soc.*, in press).

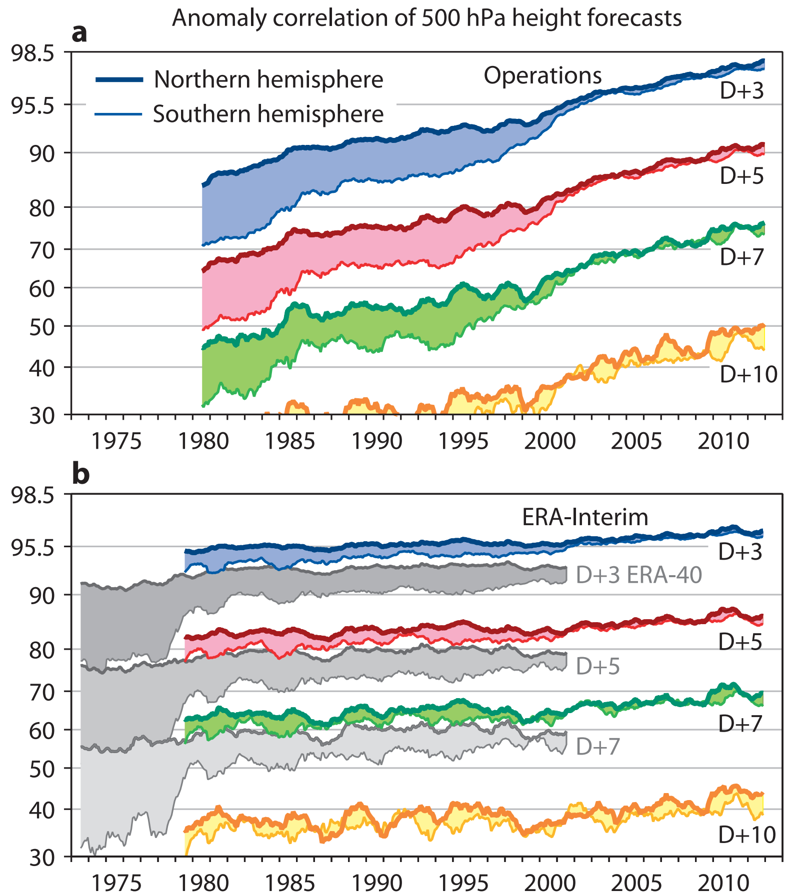

Figure 5 Twelve-month running mean anomaly correlations (%) of 3-day, 5-day, 7-day and 10-day 12 UTC forecasts of 500 hPa height for the extratropical northern and southern hemispheres from (a) ECMWF operations from January 1980 to May 2013 and (b) ERA-Interim from 6 January 1979 to April 2013 and ERA-40 from January 1973 to December 2001. The shading shows the difference in scores between the two hemispheres at the forecast ranges indicated. This figure is taken from *Dee et al*. (2014, *Bull. Am. Meteorol. Soc.*, in press).

these projects on climate science will not be realized until the first major reanalysis datasets for the 20th century are published, later in 2014. The EU will get excellent value for money from these projects, because the existing reanalysis capability at ECMWF is state-of-the-art and has been largely paid for by its Member States.

What scientific and technical expertise does ECMWF bring to its long involvement in reanalysis activities?

Producing a reanalysis is a complex technical feat involving multiple disciplines, with lots of opportunity for error. ECMWF's core business is, of course, numerical weather prediction for the medium range (days to weeks ahead). Tools and systems developed for this purpose include state-of-the-art forecast models, data processing systems that handle millions of weather observations daily, and the world's largest archive of meteorological data. Together these provide the basic technical infrastructure needed for production and dissemination of high-quality reanalysis products. The most important ingredient that the Centre provides, however, is its highly collaborative work environment, created over many years by motivated scientists and developers who enjoy working together. The benefit to reanalysis of this collaborative spirit cannot be underestimated.

Clearly the meteorological community as a whole benefits from reanalysis activities, but how does ECMWF benefit?

Reanalysis has always been closely connected with the development of the operational forecasting system at ECMWF. A reanalysis of observations collected for the First Global Experiment of the Global Atmospheric Research Programme (FGGE) started only months after the first operational forecast was issued in August 1979, with the aim to improve the use of observations for initializing the forecasts. This was the beginning of a strong and lasting feedback loop between improvements in the global observing system, advances in data assimilation, and development of better forecast models through reanalysis. Successive reanalyses produced at ECMWF have improved along with the forecasts (e.g. due to model improvements, introduction of 4DVAR). Conversely, many new developments especially in data assimilation benefit from reanalysis activities (e.g. the use of humidity observations, treatment of biases in observations).

Today, many of the Centre's probabilistic forecast products, such as those based on the Extreme Forecast Index (EFI), would not be possible without reanalysis.

Similarly, the skill of seasonal forecasts depends on the quality of the reanalyses that are used to correct systematic errors in the coupled models used to produce the forecasts. And, of course, the familiar measure of forecast skill based on anomaly correlations requires climatologies derived from reanalyses.

Can you give me a specific example of how ECMWF has used reanalysis data?

The ability to update a reanalysis (and associated forecasts) in near-real time provides a powerful way to assess changes in performance of ECMWF's IFS. Since reanalyses are produced with a fixed configuration of the IFS, it can be very useful to compare the evolution over time of medium-range forecast skill with that of reforecasts produced with the reanalysis system. This is illustrated in Figure 5 for anomaly correlations of 500 hPa geopotential height forecasts averaged over the hemispheres, obtained from operations and from reanalyses (ERA-40 prior to 2002, and ERA-Interim from 1979 to 2013).

The figure shows, for example, the effects of atmospheric predictability (common to all curves), the role of an improving observing system (visible in the reanalyses), including better satellite data (convergence of hemispheric scores for ERA-Interim), and of improvements in satellite data assimilation (convergence of hemispheric scores for operations). Comparing the slopes in the top and bottom panels suggests that, on average, at most 15% of medium-range forecast skill improvement achieved during the last three decades can be directly attributed to the evolution of the observing system – the lion's share is due to advances in modelling and data assimilation. The figure does not show, of course, that the research and development conducted at ECMWF that led to those advances benefited greatly from the improved observations – a perfect example of the feedback loop mentioned earlier.

So far the discussion has focused on atmospheric reanalyses. Are there different types of reanalysis produced by ECMWF and other organisations?

Apart from the global atmospheric reanalyses that many are familiar with, ECMWF also produces separate reanalyses of the ocean and (more recently) of the land surface. Both depend on estimates of meteorological forcing obtained from atmospheric reanalyses. A relatively short (from 2003) reanalysis of global atmospheric composition was produced within the framework of the MACC (Monitoring Atmospheric Composition and Climate) project, using a version of the IFS that includes chemically reactive gases, aerosols and greenhouse gases. The ERA-CLIM2 project mentioned earlier will take the first steps toward consolidating these separate reanalyses into a single, consistent reanalysis of the coupled Earth system.

Other types of reanalyses are being developed, both at ECMWF and elsewhere, to support a variety of applications in climate science and environmental modelling. These include extended climate reanalyses such as ERA-20C that span a century or more, which tend to assimilate only a select subset of observations in order to maintain some degree of uniformity in the observational input over the period in question. On the other side of the spectrum, regional reanalyses produced at increased spatial resolution can potentially provide additional benefit from high-resolution observations. In all cases, the goal is to make the best possible use of the available instrumental record.

Now a final question. What do you find particularly rewarding about being involved in reanalysis activities?

I really enjoy the collaborations we have both here at ECMWF and elsewhere. The European projects we are involved in have connected us with many interesting people, not least those who are dedicated to the painstaking but heroic task of preserving historic climate observations. These people, while not very visible, are highly motivated to do their part in advancing climate science. The other rewarding aspect of working on reanalysis is the enormous amount of goodwill and support from users who are well aware of its value for their work. Finally, I am excited about our role in climate services development – it is an opportunity to have a real and positive impact on the well-being of society.

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Windstorms in northwest Europe in late 2013

TIM HEWSON, LINUS MAGNUSSON, OYVIND BREIVIK, FERNANDO PRATES, IVAN TSONEVSKY, HANS (J.W.) DE VRIES

The winter period of 2013/14 has been very active in terms of windstorms affecting northwest Europe. This article provides a short summary of two such storms, from 28 October (Christian) and 5 December (Xaver), and the handling thereof by the ECMWF IFS (Integrated Forecasting System). It is shown that for both storms IFS output provided an indication of high winds 5 to 6 days in advance. This is important because a key component of ECMWF's strategy is to provide Member States' National Meteorological Services with reliable forecasts of severe weather across the medium range.

Figure 1 shows a model-based estimate of areas where the 5-year return period of 24-hour maximum wind gust was exceeded for Christian and for Xaver. Here we have used ERA-Interim forecasts as a proxy for observations, with red squares denoting those grid points where maximum wind gust in the short-range (0–24 hour) forecast from ERA-Interim exceeded the 5-year return period value. Return period values were first estimated by fitting the generalised extreme value distribution to a 20-year block of annual maximum wind gust (again using 0–24 hour ERA-Interim forecasts). The results in Figure 1 suggest that in some locations these were indeed very rare events.

Whilst the representation of extreme gusts in windstorms in ERA-Interim suffers from resolution limitations, this issue can to some extent be circumvented by comparing model climate with model forecast, as we have done here. Indeed similar results are seen in real observations exceeding the 5-year event for Christian over Germany and the Netherlands, as computed by the 'European Climate Assessment and Dataset' (ECA&D).

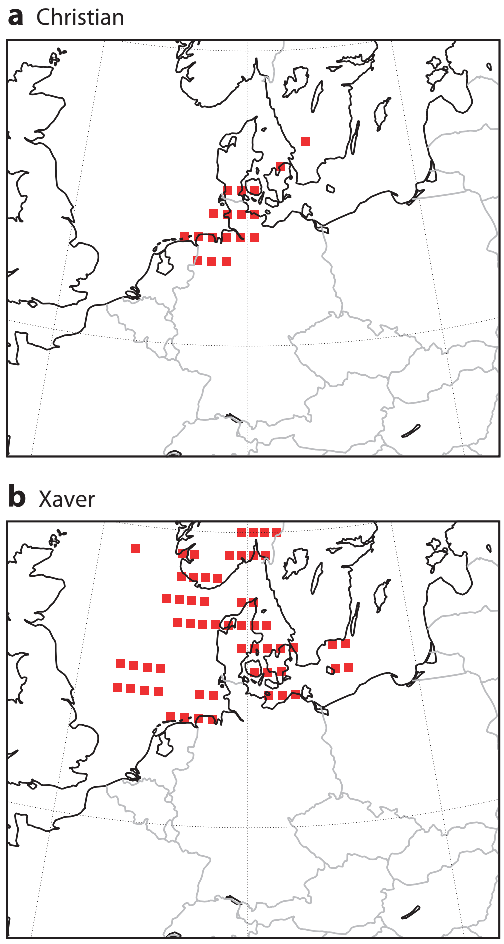

Figure 1 Areas exceeding the 5-year return period of 24-hour maximum wind gust for windstorms (a) Christian and (b) Xaver as diagnosed using the ERA-Interim reanalysis as a proxy for observations.

28 October (Christian)

On 28 October a small but vicious windstorm hit northwest Europe, killing 19 people (8 in Germany, 5 in UK, 3 in the Netherlands, 2 in Denmark and 1 in France) and causing extensive disruption. The highest ever wind gust for Denmark was measured at Kegnäs on Als (53 ms^{-1}). The storm was named Christian by the Institute of Meteorology at Berlin's Free University, though other institutions have used alternative names including St Jude and Simone.

The cyclone first appeared, as a cold front wave, south of Nova Scotia late on 25 October. It then transferred rapidly east-northeast and deepened, with the centre moving into southern Sweden late on the afternoon of the 28^{th}. According to the Met Office surface synoptic charts the 6-hour period of most rapid deepening was 06 to 12 UTC on the 28^{th} (fall of 9 hPa), between eastern England and the eastern North Sea. It was during this period, and the subsequent few hours, that the strongest surface gusts were recorded, south of the track.

Figure 2e shows observed maximum wind gusts during the 28^{th} (24-hour period). The band of very strong gusts started in Brittany in France and followed the English Channel and southern England, up through the southern North Sea and on towards Denmark, but with exceptional values reserved for northern parts of The Netherlands, northernmost Germany and southern Denmark. Strong wind gusts were also experienced along the Baltic Sea coasts. The surface pressure field around the storm at 12 UTC on 28^{th} can be seen on Figure 2d (this is actually a 12-hour forecast, but is quite accurate).

AFFILIATIONS

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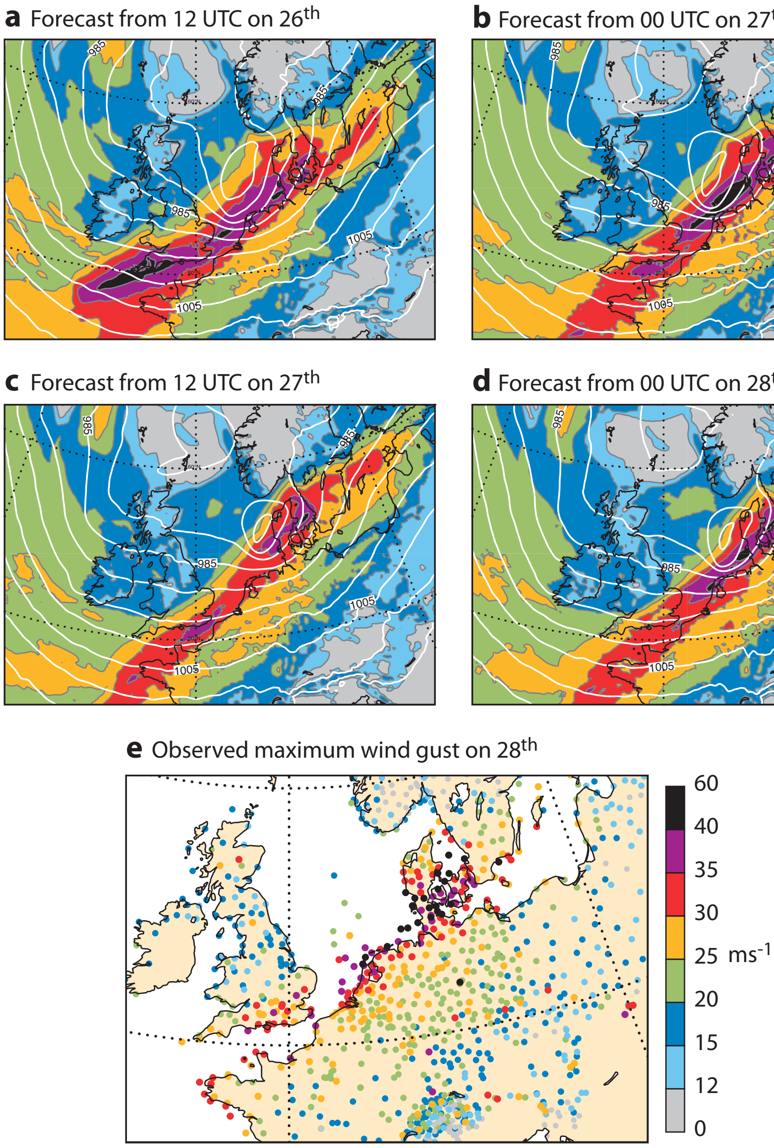

Figure 2 Forecasts of 24-hour maximum wind gust between 00 and 24 UTC on 28 October (shading) with the mean-sea-level pressure for 12 UTC on the 28th (contours) from HRES from data times (a) 12 UTC on 26 October, (b) 00 UTC on 27 October, (c) 12 UTC on 27 October and (d) 00 UTC on 28 October 2013. Panel (e) shows verifying data from observations.

High-resolution forecast

Figures 2a to 2d show the 24-hour maximum wind gust for the 28th from the high-resolution forecasts (HRESs) starting at 48, 36, 24 and 12 hours before 12 UTC on the 28th. HRES from 00 UTC on the 28th (Figure 2d) and 00 UTC on the 27th (Figure 2b) both agree well with observations. However, the forecast from in-between, from 12 UTC on the 27th (Figure 2c), is less good, showing less strong gusts in general, notably over the far north of the Netherlands. Meanwhile, forecasts from data times before 00 UTC on the 27th, whilst capturing peak intensity quite well, tended to develop the storm too soon, and as a result placed the strongest winds too far to the southwest, and often over the sea. The forecast from 12 UTC on the 26th (Figure 2a) is one such example – note the peak over and southwest of southwest England.

Preliminary investigations of observational data suggest that the most extreme winds associated with this windstorm were probably attributable to a 'sting jet' (after *Browning*, 2004). This is a very rare phenomenon comprising a pulsing stream of strong winds that can descend rapidly from within the cyclone's cloud head region. When this stream of strong winds hits the surface, very strong gusts can arise for short periods, with inland locations being especially vulnerable to major impacts. In numerical experiments it has been shown that high spatial resolution is necessary to predict this phenomenon. Thus this case provided a stern test for the ECMWF IFS.

Only a small subset of rapidly-deepening extratropical cyclones exhibits the sting jet phenomenon. This is an ongoing area of research but evidence to date suggests that in order for a cyclone to possess a sting jet, the cyclone's cloud head region must, as a minimum, be unstable to slantwise convection, and should contain warm air from a relatively low-latitude source. Conventional observations have also been shown to exhibit hallmarks of the sting jet in past cases; these include evaporating cloud filaments emanating from the tip of the cloud head (in imagery), and surface observations that show gusts that peak downwind of the gaps between these filaments. It is on the basis of observational evidence of this type that we think Christian was probably a sting jet storm.

The sting jet phase likely terminated over eastern Denmark. Note how wind gust strength in Figure 2e is generally maintained across the landmasses of Denmark, but dies away much more rapidly inland over southern Sweden. This behaviour over Sweden is more typical of strong winds in the 'cold conveyor belt' (CCB) zone of a cyclone, which tend to follow and overlap any sting jet phase. In this CCB phase the forced descent of high momentum air is lacking, so unless there is an alternative mechanism for bringing the high momentum air downwards, such as convective overturning, gusts tend to not be as strong.

Ensemble forecast

At lead times of 7–10 days, the ensemble forecasts (ENSs) generally provided cyclonic solutions for northwest Europe, but with the more extreme cyclones mostly located west of the UK. Figure 3 encapsulates the ENS handling at shorter leads, showing the Extreme Forecast Index (EFI) and shift of tails (SOT) for 24-hour maximum wind gusts for (a) 5–6, (b) 3–4 and (c) 1–2 day forecasts, all valid on 28 October, as well as 24-hour maximum wind gust CDFs (cumulative distribution functions) for Leeuwarden in the north of the Netherlands. By 5–6 days before the event, the EFI (indicating, broadly, the likelihood of high gusts) and SOT (signifying how extreme the gusts might be) were pointing to the potential for a major windstorm (Figure 3a). Closer to the event the signal increased (Figures 3b and 3c). The most noteworthy feature of these plots is perhaps the fact that the SOT reaches a value of 5 over Denmark in the 1–2 day forecast. For *very extreme* events the EFI saturates, as it is unaffected by changes in forecasts beyond the maximum of the model climate. The SOT on the other hand can be more useful here, as it is designed to focus on the domain beyond the model climate maximum, telling the forecaster how extreme an extreme event might really be (*Zsótér*, 2006).

The wind gust CDFs for Leeuwarden (Figure 3d) confirm that many forecast outcomes, at different lead times, lay above the maximum of the model climate (shown here for lead time 24–48 hours). Also one can see 'jumpiness' in the

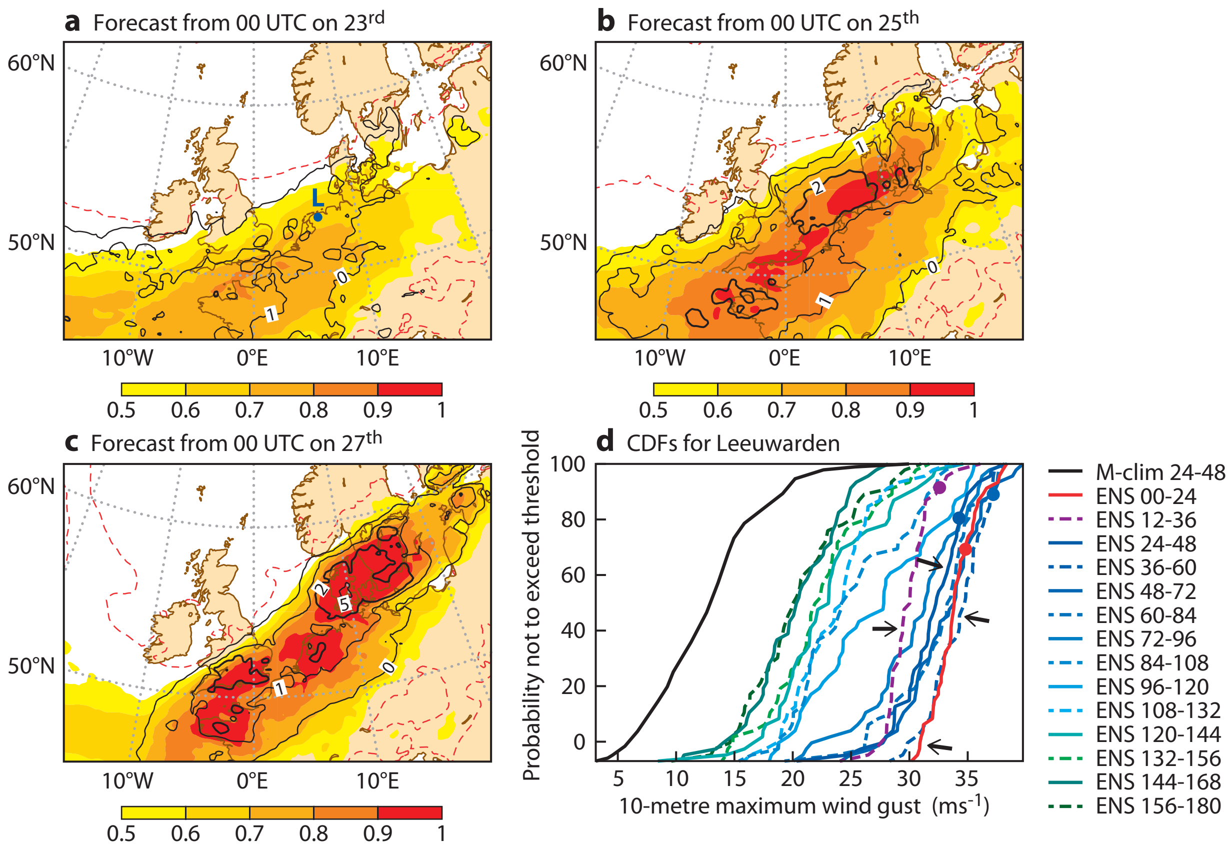

Figure 3 Maximum gust forecasts from ENS represented as the EFI (shading as on legend, and red contours = 0.3) and SOT (black contours = 0, 1, 2, 5) for 00 to 24 UTC on 28 October 2013 from data times (a) 00 UTC on the 23rd, (b) 00 UTC on the 25th and (c) 00 UTC on the 27th. Panel (d) shows, for the same 24-hour period, maximum wind gust CDFs for Leeuwarden in the Netherlands (location 'L' marked on panel (a)) from 14 ENS runs (see legend), with spots denoting the corresponding HRES from the last four runs (colours as on legend). Arrows highlight CDFs referred to in the text. M-clim (black line) is the 20-year model climate distribution based on 500 realisations.

ENS probabilities at short leads, that roughly mirrors HRES behaviour discussed above (for the Leeuwarden grid point, the corresponding HRES values are shown with spots on Figure 3d). Following the last four forecast sets, highlighted with arrows, one sees a steady reduction in maximum gusts (a movement of the CDFs to the left, dashed blue to solid blue to purple) until the very last forecast (red) which jumps back to stronger values.

To explain the changes depicted in Figure 3d in spatial, synoptic terms, one can reference ECMWF extratropical cyclone products (see *Hewson*, 2009), as illustrated in 'dalmatian chart' format in Figure 4. These charts show the positions of all synoptic-scale cyclonic features from all IFS runs. Forecasts from 12 UTC on the 26th (a, b) commonly showed intense solutions, as denoted by bright colours, but also highlighted uncertainty. In the runs from 00 UTC on the 27th (c, d) uncertainty seems to have increased, at least for 12 UTC on the 28th (d), when the storm turned out to be near to its peak. The 'maximum 1 km wind' represented ranges from 55–60 knots (dark green, equivalent to an ordinary winter cyclone) to 80–85 knots (light magenta, equivalent to a once in a lifetime event!). The positions of these cyclones also varied, the weaker cyclones having progressed further east, commensurate with less interaction with upper levels; this is a common feature of dalmatian charts in potentially cyclogenetic situations.

For the forecasts from 12 UTC on the 27th (e, f) the spatial range of the outcomes had narrowed, and intensities had weakened, to lie generally between 60 and 70 knots. The short-range forecast then jumped back, to show outcomes of mostly 70–75 knots (h). This final change seems to relate, in turn, to the analysis at 00 UTC on 28th (g) being on the edge of the range of the previous 12-hour forecast (e) – i.e. the surface cyclone being a little slower and therefore perhaps interacting a little more favourably with upper-level forcing.

One can thus see how finely balanced the situation was and, if this is added to the related difficulties of modelling mesoscale structures (e.g. the sting jet), it starts to become apparent why we may occasionally see unwanted jumps in ECMWF forecasts in such situations. Intertwined with all this is the issue of initial condition uncertainty, which other studies have shown is the major factor leading to jumpy forecasts.

5 December (Xaver)

On 5 December a large and violent cyclonic storm hit the North Sea region and several adjacent countries. Problems were caused both by high wind speeds and a related storm surge. The surge reached 6 metres on the Elbe in Hamburg for example, and along the east coast of England and in the south of the Netherlands it was the highest for 60 years. In the cold air outbreak following the storm a blizzard hit Sweden. The storm system was name Xaver by Berlin's Free University; other names assigned elsewhere include Bodil, Sven and St. Nicholas.

The cyclone first developed around 00 UTC on the 4th as a warm front wave/diminutive wave, northeast of

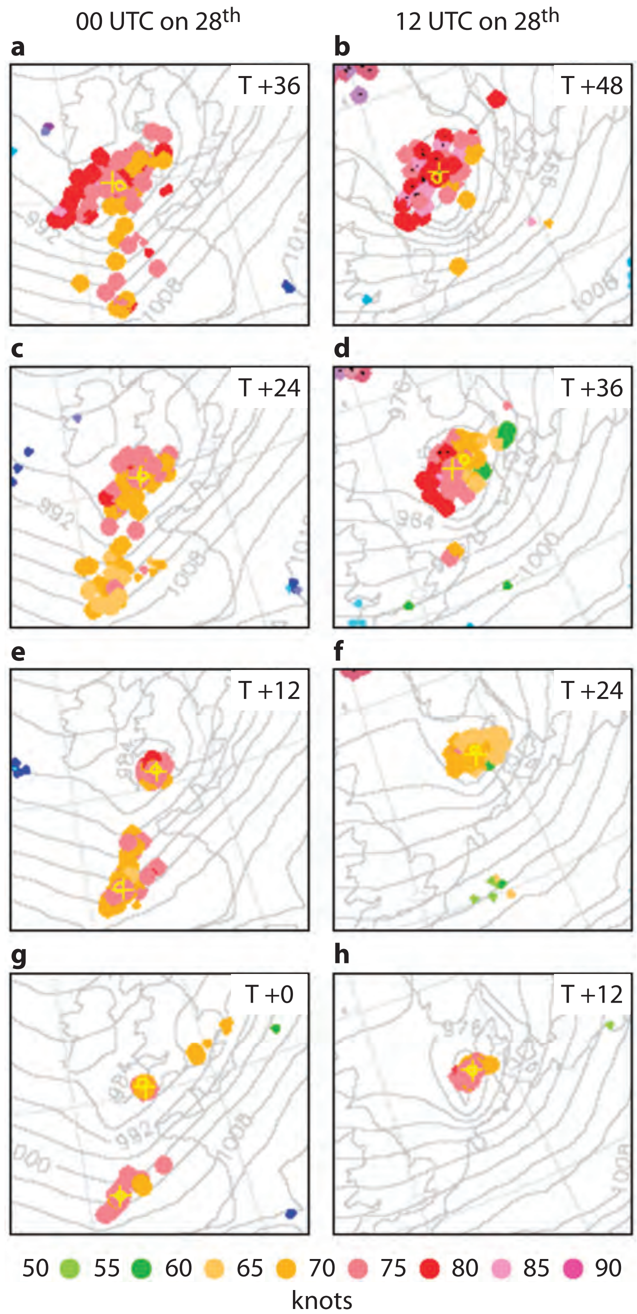

Figure 4 'Dalmatian max wind attribute' charts from the ECMWF extratropical cyclone tracking system, for two validity times: 00 UTC on 28 October (left side) and 12 UTC on 28 October 2013 (right side) from forecasts with data times of (a, b) 12 UTC on the 26th, (c, d) 00 UTC on the 27th, (e, f) 12 UTC on the 27th and (g, h) 00 UTC on the 28th. Each spot denotes a cyclonic feature (frontal wave, barotropic low or diminutive frontal wave) identified in one of 52 IFS runs. A small spot means that the feature lies on a front that is thermally weak. Black dots denote barotropic low centres. Colours signify a 'maximum 1 km wind' attribute: this is the maximum of all the grid point mean wind speed values lying within a 300 km radius of the feature point, on a level that is everywhere 1 km above the Earth's surface, in the relevant model run. Legend below is in knots (1 knot ≈ 0.5 ms^{-1}); the limits of a colour's range are the values either side. Contours show mean-sea-level pressure from the control run. Yellow circles/crosses denote respectively control/deterministic run features; these features are plotted last.

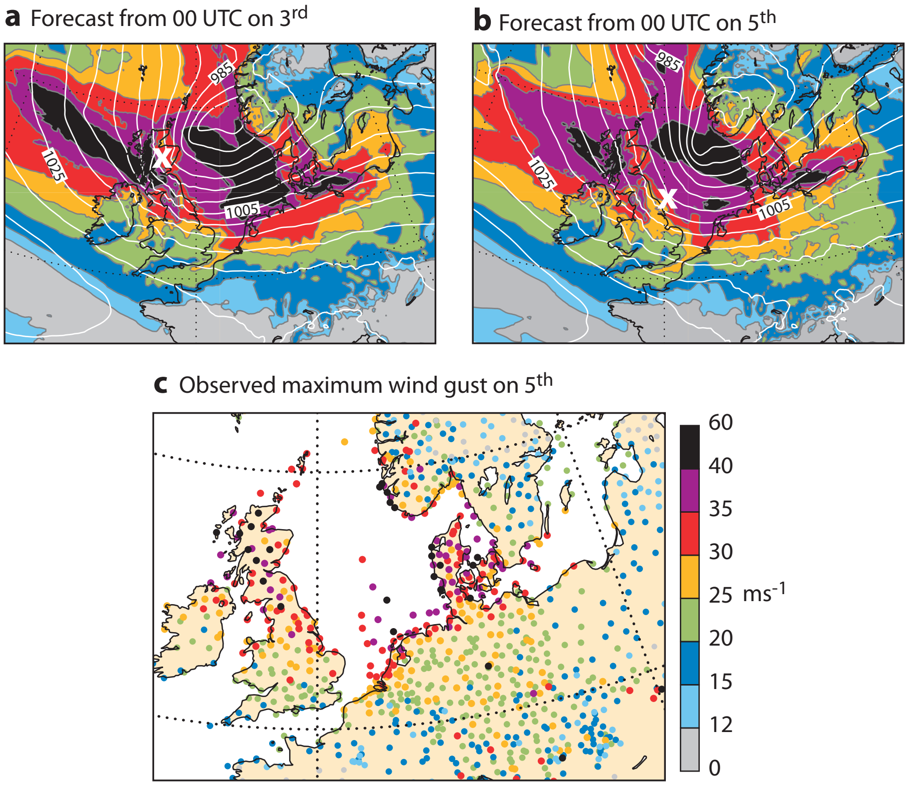

Figure 5 Forecasts, of 24-hour maximum wind gust between 00 and 24 UTC on the 5th (shading) with mean-sea-level pressure for 12 UTC on the 5th (contours) from data times of (a) 00 UTC on 3 December and (b) 00 UTC on 5 December 2013. White crosses denote the remnants of a meso-vortex discussed in the text. Panel (c) shows verifying data from observations.

Newfoundland. In common with many formative North Atlantic windstorms, the cyclone was then situated between converging northerly and southerly airstreams, convergence which in turn gave rise to substantial increases in the strength of both the low-level thermal gradient and the upper-level westerly jet. Subsequently, under the influence of the accelerated jet stream, the cyclone sped northeast, then east along latitude 60°N, deepening explosively and attaining its minimum central pressure of 961 hPa near Oslo around 18 UTC on the 5th. The maximum 6-hour deepening (from Met Office surface charts and ECMWF analyses) was about 13 hPa, north of Scotland, between 00 and 06 UTC on the 5th, whilst the maximum 24-hour deepening was about 44 hPa, which is extreme. The cyclone had a more complex structure than storm Christian, with an intense meso-vortex hanging back to the west of the main low for a time, and this enhanced the strong wind swathe running into western Scotland (see observations and model forecasts of 24-hour maximum gust in Figure 5). The barely discernible remnants of this meso-vortex (at 12 UTC on the 5th) are marked with white crosses in Figures 5a and 5b.

High-resolution and ensemble forecasts

The main band of very strong gusts extended from the northern North Sea, around the coasts of southwest Norway and on into Denmark and the coastal fringes of the Netherlands, Germany and Sweden (Figure 5c). HRES in the lead up to this event generally captured the maximum wind gusts well (two examples are shown on Figure 5), albeit with an over-estimation inland over northern Germany, and with some timing errors (cyclone progress is too slow in the 60-hour forecast of surface pressure in Figure 5a).

The cause of the very strong winds appears to have been CCB flow around the southern flank of the cyclone. On imagery sequences, unlike for Christian, there was no signature of a sting jet. Indeed the cloud head, which should be the source region for any sting jet, was barely present, being very ragged and ill-defined. Note also how wind gust strength dies away downstream of coastlines for the Xaver case, both in observations and model output (e.g. compare the west coast of Jutland with other parts of Denmark in Figure 5). This relates to the CCB being the synoptic scale cause of the gusts, and not the sting jet, as discussed above for storm Christian. Meanwhile the wind gust CDFs for Torsminde (Figure 6d) show a signal for extreme winds that grows and then stabilises. This all contrasts with the more jumpy forecasts for storm Christian. CCB windstorms tend to cover larger areas and be more predictable than sting jet windstorms.

At longer lead times of 7 and 8 days (not shown) some ENS runs had produced vigorous cyclones in about the right location, though few if any of these were sufficiently extreme. As with Christian, the EFI and SOT products from the ENS provided an indication for the event from

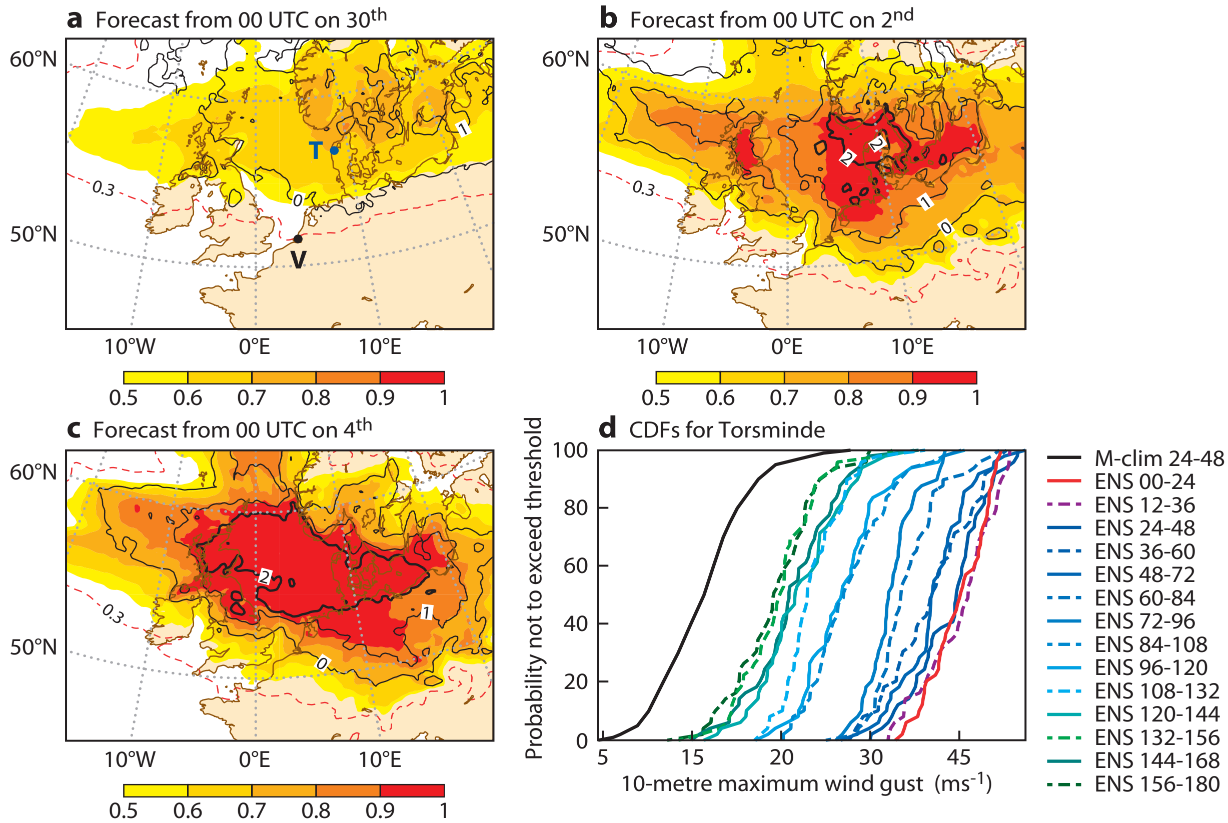

Figure 6 Maximum gust forecasts from ENS represented as the EFI (shading as on legend, and red contours = 0.3) and SOT (black contours = 0, 1, 2, 5) for 00 to 24 UTC on 5 December 2013 from data times (a) 00 UTC on 30 November, (b) 00 UTC on 2 December and (c) 00 UTC on 4 December 2013. Panel (d) shows, for the same 24-hour period, maximum wind gust CDFs for Torsminde in northwest Denmark (location 'T' marked on panel (a) from 14 ENS runs (see legend). M-clim (black line) is the model climate, as in Figure 3.

about 5–6 days in advance, and this signal strengthened in later forecasts (Figures 6a, 6b and 6c). The area with large values of EFI (>0.9 say) and SOT (>2 say) was greater than for Christian, though the maximum SOT was not as high (compare Figures 3c and 6c). These differences are consistent with the larger size of Xaver compared to Christian, and the different causes of the strong winds (CCB versus sting jet).

Ensemble storm surge forecast

The most significant impacts to have occurred in connection with Xaver were arguably related to the associated storm surge. Record surges were set up by the windstorm along the east coast of Britain, the coasts of the Netherlands and in the German Bight.

The atmosphere influences the sea surface elevation in two distinct, but related, ways:

- There is the inverse barometric effect where, as a rule-of-thumb, a 1 hPa reduction in surface pressure leads to a 1 cm increase in water level.
- Due to the Earth's rotation, winds will push water away at right angles, and to the right of the airflow direction, through what is known as Ekman transport.

In turn, a pulse of piled-up water will travel forwards as a Kelvin wave, with the coast to its right, as a consequence of the Coriolis effect. The North Sea is prone to such storm surges when the wind is blowing from the north or northwest. By piling up water along the east coast of Scotland, a pulse (the aforementioned Kelvin wave) is set off which travels southward before turning northward in the direction of Denmark.

Although storm surge forecasting is not performed by ECMWF, the 10-metre wind fields and surface pressure fields from our ensemble forecasts are put to use by KNMI and Rijkswaterstaat, who are jointly responsible for issuing ensemble storm surge forecasts for Dutch waters. The barotropic WAQUA/DCSM98 (Dutch Continental Shelf Model), which covers the northwest European Continental Shelf, including the North Sea, is run at 8 km resolution. A 51-member ensemble is integrated to 240 hours twice daily. The destructive potential of a storm surge depends on whether it coincides with the astronomical tide or not, and the Dutch system includes all the major tidal constituents (see *de Vries*, 2009).

Figure 7 shows the ensemble storm surge forecast for Vlissingen (location marked on Figure 6a), based on a data time of 00 UTC on 2 December. Box-and-whisker symbols denote water levels in the 51 ensemble members. Evidently the peak of the storm surge coincided quite closely with the fortnightly spring tide which will occur

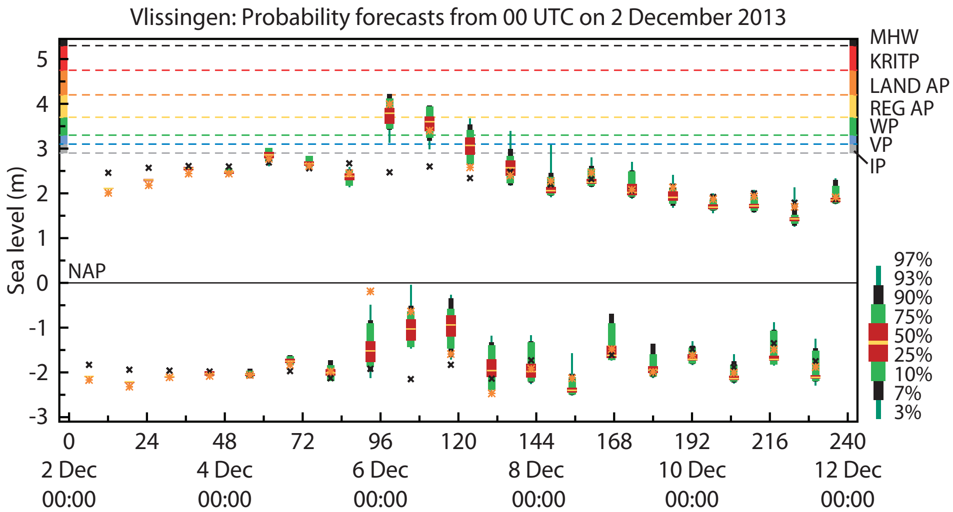

Figure 7 The ensemble storm surge forecast for Vlissingen (location marked on Figure 6a), from 00 UTC on 2 December 2013. Box-plots show water level probabilities for high and low waters as derived from the 51 ENS inputs. Marked with black through to grey dashed lines are various risk levels for the coastal district. The semi-diurnal tide is clearly visible as the box-plots jump between high and low water roughly every six hours. The fortnightly spring-neap tidal cycle is less visible, but reaches its peak on 4 December, 1.5 days before the peak of the storm surge. Orange asterisks are the observed water levels and grey crosses show, as a reference point, the pure astronomical tides.

two or three days after the moon is new or full. There was a new moon on 3 December.

The Dutch forecasting system highlights the value of ensemble forecasts in planning and preparing for events with high destructive potential. The storm surge is but one of the hazards that storms bring to European coasts. Cyclones can also bring high waves (wind wave and swell) and large amounts of rain. The multi-hazard scenario of flooding, waves and surge can be a highly destructive mix for coastal Europe. Forecasting the joint probability of two or even all three of these events is within reach of the present suite of ensemble forecast products.

Importance of case studies

In this study we have evaluated forecasts for the extreme windstorms Christian and Xaver, which both hit northwest Europe in late 2013. For both storms the EFI and SOT provided an indication of extreme wind gusts 5–6 days in advance. However, the finer details regarding timing and strength of Christian were not well forecast even one day before the event. These uncertainties probably relate to the sting jet, a small-scale phenomenon that presents resolution difficulties for models, and to a simultaneous and probably related high sensitivity to subtle differences in synoptic-scale forcing. For the larger storm Xaver, the strongest gusts were instead connected to the cold conveyor belt, and were more consistently and accurately predicted.

To make a robust evaluation of a forecasting system, verification should be aggregated over many cases, not just two. This type of multi-case evaluation has been undertaken in a companion article in this issue of the *ECMWF Newsletter* starting on page 29. However, for such an evaluation, one has to include less extreme cases in order to obtain reliable statistics. Therefore, we need always to complement statistical assessments with case studies, such as those presented here, to obtain a more complete picture of IFS performance for severe weather, and to get pointers to weaker aspects that should be further explored.

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Statistical evaluation of ECMWF extreme wind forecasts

THOMAS HAIDEN, LINUS MAGNUSSON, DAVID RICHARDSON

An article starting on page 22 of this edition of the *ECMWF Newsletter* analyses forecast skill for two major windstorms which hit Europe in 2013. Case studies such as these are an important part of model evaluation as they allow a detailed diagnosis of model errors associated with specific types of severe weather. However, in order to determine to what extent such findings can be generalized, they need to be complemented by verification over a larger number of cases. The increased generality of results comes at a cost, since one has to include cases that are less extreme in order to obtain robust statistics. Nevertheless, the statistical assessment does provide a framework for the quantification of model deficiencies and the monitoring of forecast improvements.

Here we evaluate the skill of the ECMWF forecasting system in predicting high wind events over a large sample. Events can be defined based on absolute thresholds (e.g. gale-force winds) or the degree of severity compared to climatology (e.g. wind speeds above the 99th percentile). While the absolute value may be more relevant with respect to damage, the percentile-based definition is useful for producing spatially or seasonally aggregated scores, since by definition the number of events becomes comparable between different regions and seasons. An additional reason for choosing a percentile threshold is that the actual impact of an event of given absolute intensity in a certain region will depend on how often it occurs in that location, as this will influence the degree to which the natural environment, buildings and infrastructure are adapted to it. In any case, the choice of specific thresholds involves a compromise. A high threshold is more targeted to rare events but at the cost of a small sample, while a low threshold may provide more reliable statistics but fails to distinguish the skill in forecasting extreme weather from the more general skill of the forecast.

By verifying wind speed forecasts against SYNOP observations, we will show that predictions of severe wind events have benefited from improvements in the forecasting system as much as more 'normal' weather as suggested by improvements in standard skill scores.

Verification method

A basic measure of forecast quality is whether the model is able to simulate the events of interest with the correct frequency. This aspect is evaluated using the frequency bias which is the ratio of the number of forecast and observed events. Here the local conditions (e.g. orography and surface characteristics) at the observation station play a role, as the direct model output is representative of the grid scale rather than a specific location. To evaluate the skill of the forecasts we use the symmetric extremal dependence index (SEDI) which was developed by *Ferro & Stephenson* (2011).

In this investigation we verify both the high-resolution forecast (HRES) and ensemble forecast (ENS) including the ensemble control forecast (CTRL). They are based on the same data assimilation and forecast model but at different resolutions (currently T1279, or 16 km, for the HRES and T639, or 32 km, for the ENS and CTRL). Results from the HRES and CTRL are also compared to those based on forecasts from the ERA-Interim reanalysis.

ERA-Interim uses the forecasting system which became operational in September 2006, but at a different resolution (*Dee et al.*, 2011). The horizontal resolution of ERA-Interim is T255, corresponding to a grid spacing of 80 km. It uses 60 levels in the vertical, compared to 137 for HRES, and 91 for CTRL and ENS. One benefit of a 'frozen' forecasting system such as the one used for ERA-Interim is that it provides a benchmark for operational forecasts and allows the effect of atmospheric variability on the scores to be taken into account.

To calculate a reference model climate, we use the reforecast dataset for the ensemble system which has been operationally produced since 2008. It consists of one unperturbed and four perturbed ensemble members and is run once a week for initial dates in the past 20 years (18 years before 2012). The sensitivity of the resulting model climate to choices in the reforecast configuration, and their effect on the Extreme Forecast Index (EFI), are discussed in *Zsótér et al.* (2014). An important property of the reforecasts is that they are always produced with the latest model cycle.

In this study we focus on the verification of wind speed against SYNOP observations in Europe (defined here as 35°–75°N, 12.5°W–42.5°E) where the overall station density is high. For 10-metre wind speed about 1,600 stations were available. A weighting function is used to account for geographical variations in station density (*Rodwell et al.*, 2010). The station climatology is calculated separately for each calendar month based on observations from the 30-year period 1980–2009.

Forecasts can be verified against analyses and observations. A drawback of using analyses in surface verification is that they share some of the systematic errors of the forecasts. On the other hand, conventional observations such as SYNOPs are more or less point measurements and do not represent the same scales as the model. This representativeness mismatch is particularly relevant for severe weather events that are small-scale (e.g. convective precipitation and wind gusts). Another issue is the quality control of observations, which becomes more important as the observations reach more extreme values and sample sizes get smaller. The evaluation presented here uses the simple nearest neighbour method to match forecasts and observations, and employs just a basic quality control. The results should therefore be regarded as a conservative estimate of forecast skill.

Verification scores

The verification of severe weather is commonly based on binary events defined as either exceeding a specific absolute value of a physical quantity or exceeding a percentile of the climate distribution of that quantity. Paired with the observation, the forecasts represent four types of outcome (hits, misses, false alarms and correct negatives) forming a 2x2 contingency table.

	Observed	Not observed
Forecast	*a* (hits)	*b* (false alarms)
Not forecast	*c* (misses)	*d* (correct negatives)

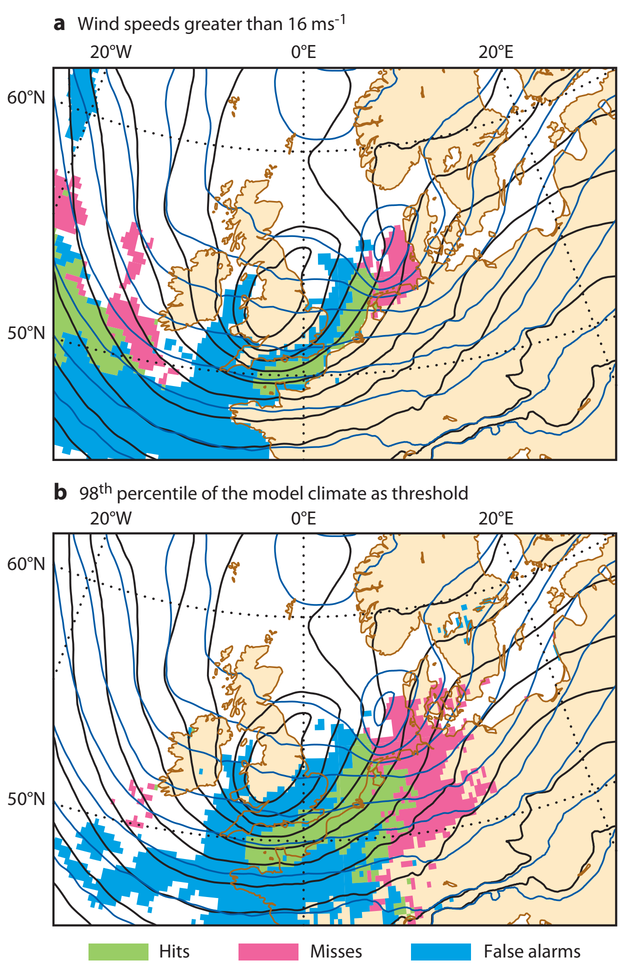

Figure 1 Example of the spatial distribution of hits (green), misses (red) and false alarms (blue) for (a) wind speeds greater than 16 ms^{-1} and (b) use of the 98th percentile of the model climate as a threshold for the three-day forecast valid at 12 UTC on 28 October 2013, verified against the model analysis. Also shown is the mean-sea-level pressure of the forecast (black contours) and the analysis (blue contours).

Figure 1shows hits, misses and false alarms of the three-day forecast for 10-metre wind speed valid at 12 UTC on 28 October 2013 (storm 'Christian', though it also has a variety of other names including 'St Jude' and 'Simone'). The threshold of 16 ms^{-1} approximately corresponds to the 98th percentile of the model climate over the North Sea. This particular forecast underestimated the speed of propagation of the storm system. The timing error leads to false alarms to the west, and misses in the east. Use of the absolute value of 16 ms^{-1}(Figure 1a) leads to a restriction of the event mainly to the sea, while the definition relative to the model climate (Figure 1b) gives signals also over land. Because of this, and because of the need to aggregate over climatologically diverse areas, we use relative thresholds in this study. We specifically focus on the 98th percentile of the climate distribution as a compromise between sample size and rarity of the event.

A common problem of standard scores which are based on a 2x2 contingency table, such as the equitable threat score or the Peirce skill score, is that they degenerate to trivial values (0 or 1) for rare events because the correctly forecast non-events (i.e. correct negatives) dominate the score. Consequently, *Ferro & Stephenson* (2011) introduced the symmetric extremal dependence index (SEDI) to address this problem – see Box A.

The SEDI score has a number of desirable properties such as: no explicit dependence on the base rate (climatological frequency of occurrence), robustness to hedging (the score cannot be improved by making unskilful modifications to the forecast), and symmetry with respect to events and non-events. However, as pointed out in *Ferro & Stephenson* (2011),

Verification scores used in the investigation — A

Frequency Bias (FB)

Referring to the 2x2 contingency table, the frequency bias of an event is defined as the ratio of the number of forecasts and the number of observations.

$$FB = \frac{a+b}{a+c}$$

Values larger (smaller) than 1 indicate the event is over-forecast (under-forecast).

Symmetric Extremal Dependence Index (SEDI)

$$SEDI = \frac{\log F - \log H - \log(1-F) + \log(1-H)}{\log F + \log H + \log(1-F) + \log(1-H)}$$

where *H* and *F* are the hit and false alarm rates given by:

$$H = \frac{a}{a+c} \quad F = \frac{b}{b+d}$$

Potential Economic Value (V)

$$V(r) = \frac{\min(r,B) - Fr + H(1-r) - B}{\min(r,B) - Br}$$

Where *r* is the cost-loss ratio, *B* is the base rate of the event, and *H* and *F* are the hit and false alarm rates defined above.

forecasts still need to be calibrated in order to obtain a fair comparison between different forecasting systems. It means that the results indicate potential rather than actual skill.

The calibration is performed for each threshold independently, over a three-month (i.e. seasonal) verification period. Data from all stations in the verification domain is pooled, which is necessary to get a sufficiently large sample; this is made possible by the use of percentile thresholds. The actual calibration is carried out iteratively by varying the percentile threshold applied to the forecast until the frequency bias (see Box A) gets as close as possible to 1, which means that the number of misses and false alarms become (almost) equal.

A contingency-table based score which measures actual skill is the potential economic value *V* (*Richardson*, 2000). This score is based on a simple cost-loss model, where an event is connected to a loss that could be avoided by taking an action which is associated with a cost – see Box A. A zero value of *V* means there is no benefit in using the forecast rather than climatology as a basis for action, while $V=1$ means that one always makes the correct decision (perfect forecast). For ensemble forecasts *V* is calculated for a set of probability thresholds (e.g. action is taken if 10% of the members predict the event), and the maximum *V* for the ensemble is determined for each cost-loss ratio.

Verification results – systematic errors in the forecast climatology

Before we evaluate the predictability of extreme events we investigate systematic errors in the forecast climatological distribution of such events. By climatology we refer to the full probability density function (PDF) for each point (observation station or model grid point) in a given month. The PDF will mainly be evaluated in its cumulative form (CDF), where the phrasing '98th percentile' refers to a value which is not exceeded 98% of the time. Hence, evaluating daily data, values above the 98th percentile will on average occur once in 50 days at each grid point. Figure 2 shows the 98th percentile for 10-metre wind speed of the model climate (shaded) and the observed climatology at individual stations (circles). Plots such as this help to highlight differences between modelled and observed climatologies.

Over the Alps the model gives very low values of the 98th percentile. Observed values show a much large variation in this region than those generated by the model. There are stations with more than 15 ms^{-1} as observed for the 98th percentile, while the model climatology gives values less than 6 ms^{-1}. The stations with high extreme winds are typically mountain stations, whereas nearby stations that have a wind-speed climatology similar to the model are usually located in valleys. Along the coasts the model underestimates the 98th percentile at many stations, for example along the North Sea coast. Here the climatology is sensitive to the land-sea mask in the model. It is another example of a representativeness mismatch between the model and observation scales. Nevertheless, in the evaluation performed here we have included both mountain and coastal stations.

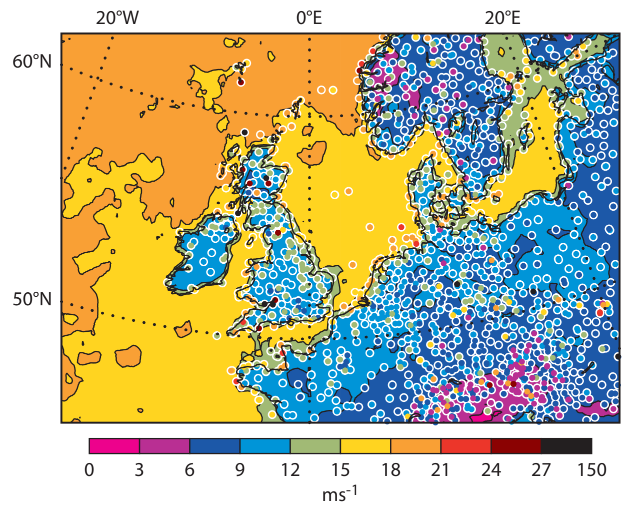

Figure 2 Value of the 98th percentile for 10-metre wind speed in October for the model climate (shaded) and observed climatology (circles).

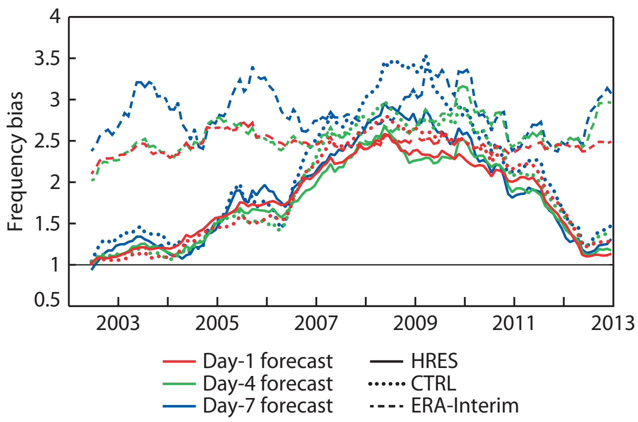

Figure 3 Time series for 2002–2013 (one-year running mean) of frequency bias for the 98th percentile over Europe for HRES, CTRL, and ERA-Interim for day-1, day-4 and day-7 forecasts.

While Figure 2 refers to the most recent model configuration, Figure 3 shows the longer-term evolution of frequency bias for the 98th percentile of 10-metre wind speed in the operational forecast. All data is valid for 12 UTC. The figure includes results for HRES, CTRL and ERA-Interim for one-day, four-day and seven-day forecasts. In the absence of model drift the frequency bias should be approximately constant with forecast range and, optimally, it should also be close to 1. The reasons for a frequency bias could be representativeness (model resolution) and/or model errors. As already discussed, large representativeness errors may occur in the presence of steep orography for wind speed, but also surface characteristics (e.g. closeness to sea and surface roughness) around the station play a significant role. ERA-Interim is using the same forecasting system throughout this period; hence its variability with respect to the frequency bias mainly reflects atmospheric variability.

As shown in Figure 3, in terms of the frequency bias for the 98th percentile, HRES, CTRL, and ERA-Interim over-forecast the extreme winds. The frequency bias was similar for all three forecasts around 2007, when HRES and CTRL used the same model physics as ERA-Interim. In June 2011, the roughness length was modified, targeting the positive wind bias; this led to a marked improvement of the frequency bias in HRES and CTRL. For both forecasts the frequency bias is similar for different lead times, indicating no severe model drift with regard to wind speed.

Verification results – prediction of extreme events

We now consider the ability of the forecasting system to predict extreme events and how the forecast skill has varied with time.

Figure 4a shows the SEDI score for four-day forecasts as a function of the evaluated percentile for HRES, CTRL and ERA-Interim. As described above, SEDI is designed to not explicitly depend on the base rate. Therefore a change in SEDI for higher percentiles reflects an actual change in the ability of the forecasting system in predicting such events. In general SEDI decreases for more extreme events, and it does so more rapidly for percentiles above the 95th. As expected, HRES generally scores higher than CTRL and ERA-Interim but the differences do not seem to increase for more extreme events.

As can be seen in Figure 4b, the skill of the forecasts decreases with increasing lead time. The loss in skill from day 1 to day 4 for the 98th percentile is about the same as the loss in skill from the 80th to the 98th percentile on day 4. Nevertheless, positive skill for the 98th percentile is present even at day 10 in all three forecasts.

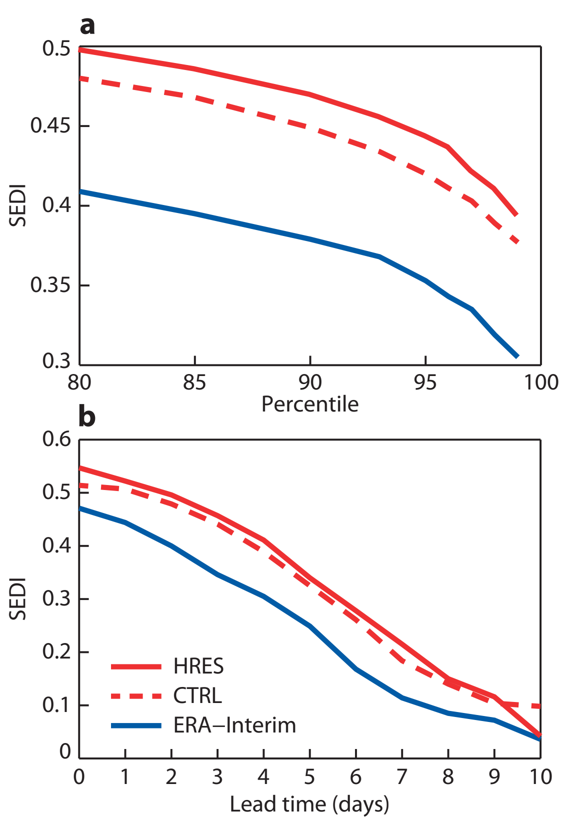

Figure 4 SEDI score over the one-year period July 2011 to June 2012 as (a) a function of percentile for the four-day forecast and (b) as a function of forecast lead time for the 98th percentile.

The results displayed in Figure 4 indicate that the skill is higher for HRES than for CTRL, showing the benefit of the higher resolution. As expected, the difference between HRES and ERA-Interim is much larger, indicating the importance of both increased resolution and model changes for the prediction of severe wind events.

Figure 5 illustrates to what extent forecast skill has improved over time. It shows time series from 2002 to 2013 of the difference in SEDI between HRES and ERA-Interim for three percentiles (50th, 80th and 98th). These three percentiles represent the change in skill for the median, one-in-five-day events, and one-in-fifty-day events. A positive value indicates that HRES is better than ERA-Interim. In general the scores are better for HRES than ERA-Interim for all years (because of the higher resolution), and the operational forecasts improve over time compared to ERA-Interim due to increasing resolution and model improvements.

Any trends in the difference between HRES and ERA-Interim are superimposed on considerable inter-annual variability which increases with lead time and percentile. A general conclusion from these plots, although the results are noisy,

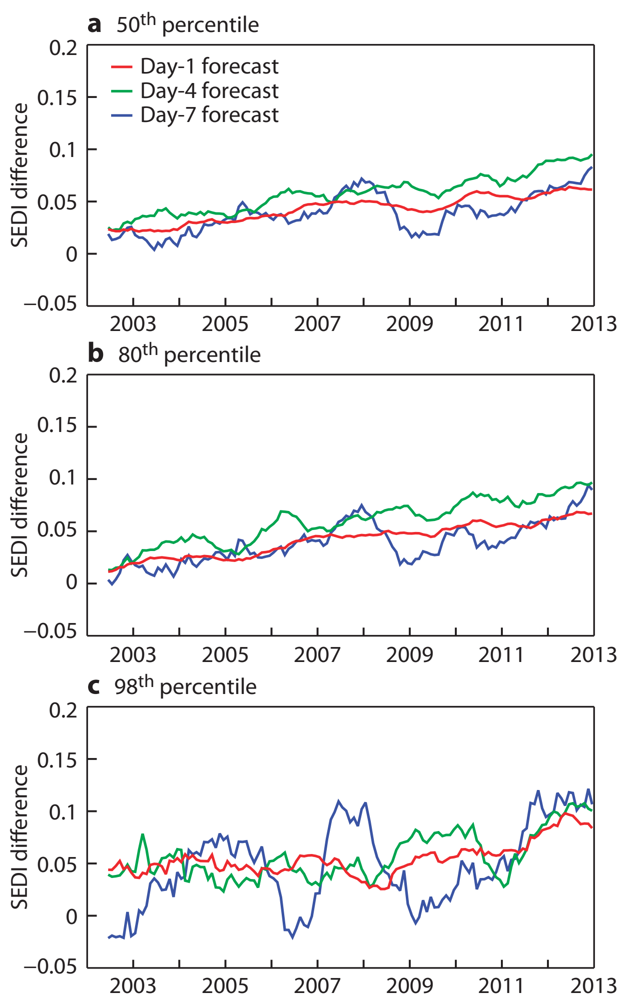

Figure 5 Time series from 2002 to 2013 of the difference in SEDI between HRES and ERA-Interim for 10-metre wind speeds above (a) 50th, (b) 80th and (c) 98th percentiles for day-1, day-4 and day-7 forecasts.

is that over the past ten years SEDI has improved by about the same amount for the 50th, 80th and 98th percentiles. This is an important result since it suggests that (a) forecasts of extremes benefit from the general model improvement and (b) one may not need to specifically verify extremes when evaluating model changes.

Figure 5 also shows that for the 50th and 80th percentiles the difference in skill between HRES and ERA-Interim is slightly higher at day 4 than at days 1 and 7. This can be explained by the constraining effect of the analysis on the forecast at short lead times and the asymptotic approach towards the model climatology at longer lead times.

A user-oriented measure of severe wind forecast skill is the potential economic value; this is shown in Figure 6 for the 98th percentile. The benefit to the user critically depends on their specific cost-loss ratio. At forecast day 1 the users with cost-loss ratios up to about 0.2 can benefit from the forecast. With increasing lead time this range diminishes. As for SEDI, the skill of HRES exceeds CTRL and ERA-Interim. Due to the additional degree of freedom provided by the choice of probability threshold, the ensemble forecast has considerably higher skill than HRES for users in a certain cost-loss range. This is most apparent in the intermediate forecast range at day 4.

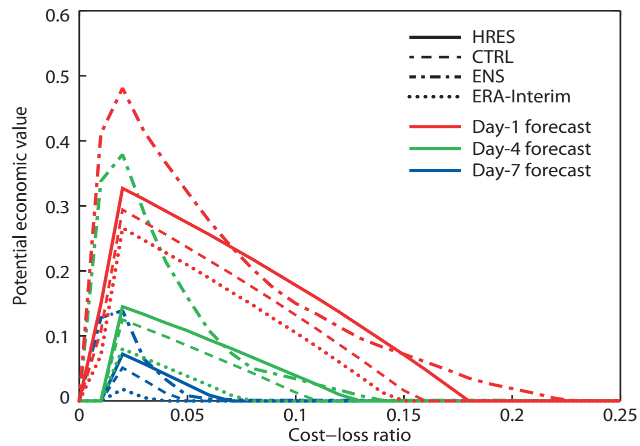

Figure 6 Potential economic value of forecasts of 10-metre wind speed exceeding the 98th percentile for day-1, day-4 and day-7 forecasts for July 2011 to June 2012.

Summary and outlook

We have evaluated the forecast performance for extreme events of wind speed. However, verification of extreme events is not straightforward as sample sizes are small and scores need to be designed to be applicable to rare events. With respect to the threshold for event definition we focus on the 98th percentile of the climate distribution, as a compromise between sample size and rarity of the event. On average such an event occurs once every 50 days and can therefore not be regarded as extreme. High-impact events such as the storm Christian (see the article by Tim Hewson and others in this edition of the *ECMWF Newsletter*) have return periods of several years.

One aspect of forecast performance is whether a model can produce events with a frequency similar to that observed. Such an evaluation is useful to find systematic model issues and to recognize limitations due to resolution in simulating extreme events. By studying maps of frequency biases for the 98th percentile, potential sources for biases of extreme events can be identified, such as orographic and coastal effects.

We have quantified forecast skill using the recently-developed SEDI score. For a fair comparison of different forecasts, they have to be calibrated before calculation of the score. The calibration adds complexity to the verification and removes part of the systematic error such that the result needs to be interpreted as potential skill.

With respect to the long-term evolution of the SEDI score, we found that SEDI for the 98th percentile has improved over the past ten years by about as much as the 50th and 80th percentiles. This indicates that the prediction of extremes has benefitted from improvements in the forecasting system (data assimilation and model) as much as the forecasts of more 'normal' weather.

Apart from the removal of frequency bias required in the computation of SEDI, no calibration has been performed. We expect that forecast calibration will improve forecast skill. Work is being carried out at ECMWF to explore this topic.

We have focused on scores based on hit and false alarm rates. Future work will include more probabilistic verification. One possibility is to use a modified version of the continuous ranked probability score (CRPS), where a function is applied to give more weight to extreme events.

In this study we used SYNOP observations for verification and employed only the most basic quality control by filtering out obviously unphysical values. In order to be able to extend the evaluation to higher percentiles a more sophisticated quality control is required. Finally, we need to acknowledge that for events with return periods of several years, such as the storm Christian, a robust statistic is difficult to achieve even with a very good quality control process. This is why case studies will remain an important tool in the evaluation of forecasts of extremes.

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Flow-dependent verification of the ECMWF ensemble over the Euro-Atlantic sector

LAURA FERRANTI, SUSANNA CORTI, MARTIN JANOUSEK

Because the atmospheric circulation is chaotic and its evolution is sensitive to the initial state, the skill of numerical weather predictions is flow dependent. This means that it is easier to make skilful predictions starting from some flow configurations than from others. For simplified models, chaos theory can provide the 'intrinsic' predictability level of atmospheric variations, but in operational practice, estimates of predictability are made from forecast ensembles.

ECMWF runs an ensemble of 50 independent forecasts (with perturbed initial conditions and model physics) to estimate forecast uncertainty, such that the spread amongst ensemble members gives an estimate of predictability. On some days, the spread will be small, implying that the atmosphere is very predictable. On other days, the ensemble of forecasts will diverge considerably, indicating that the atmosphere is less predictable. Identifying which circulation patterns lead to more predictable states than others (i.e. forecasting the forecast skill) is relevant for interpreting the forecast.

This study aims to assess the relative skill of medium-range weather forecasts depending on which flow pattern is in place over the North Atlantic when the forecast is initiated. A key aspect in the evaluation of flow-dependent predictability is that a defined flow circulation pattern must occur with sufficient frequency that statistics of ensemble forecast spread can be gathered. For this reason we use the concept of weather regimes to classify a small number of flow patterns. Consequently, the intra-seasonal variability of the North-Atlantic atmospheric circulation is described as transitions between a small number of recurrent and quasi-stationary states called weather regimes.

Weather regimes are generally computed by applying clustering algorithms on a circulation variable (such as the geopotential height at 500 hPa). The study of the

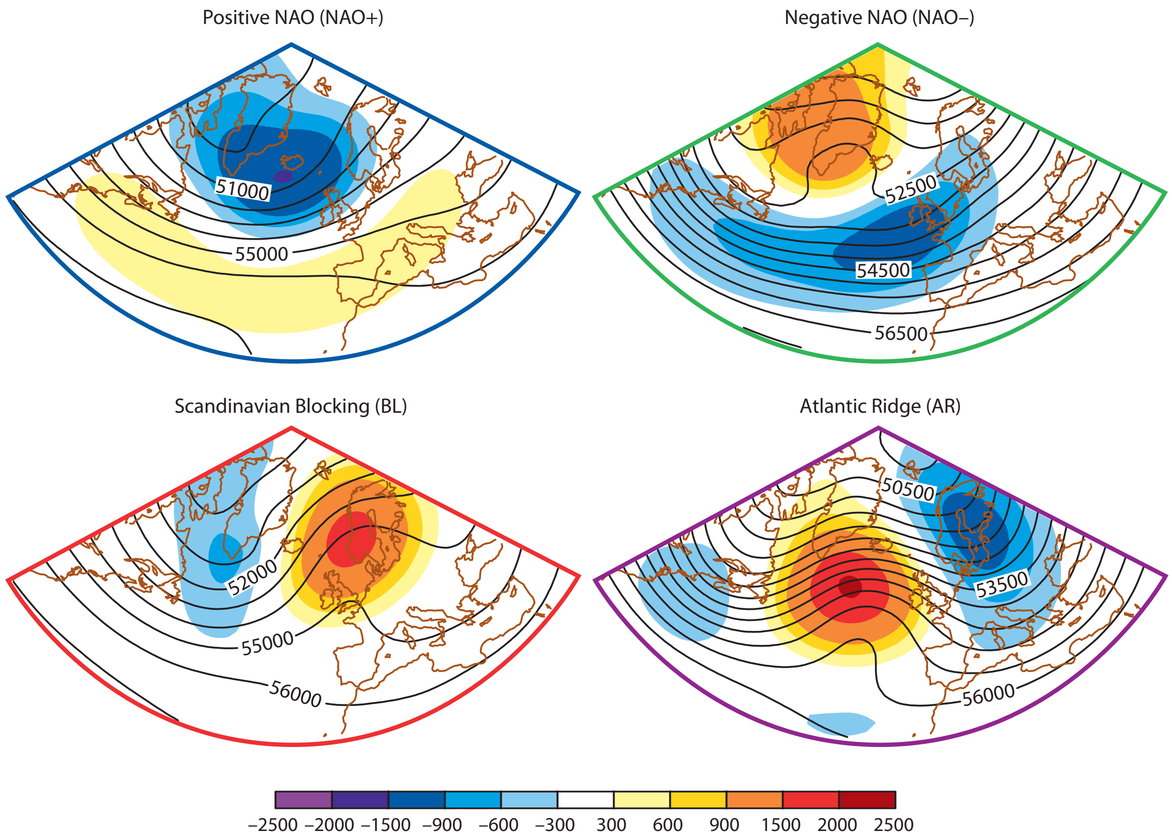

Figure 1 Geographical patterns of the four Euro-Atlantic climatological regimes (both anomalies and full fields) for the October to April cold season. The geopotential anomalies (colour shading) and geopotential (contours) at 500 hPa in units of m^2s^{-2} are derived from ECMWF's reanalysis data.

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frequency of occurrence and/or persistence of weather regimes provides a framework for the analysis of the complex atmospheric dynamics. This description assumes that there are preferred regions in the phase space (the space in which all possible states of a system are represented) where atmospheric trajectories tend to reside for extended periods. This study uses the four Euro-Atlantic climatological regimes (Figure1) that explain a large portion of the low-frequency variability in this geographic area. These regimes are:

- Positive North Atlantic Oscillation (NAO+)
- Negative North Atlantic Oscillation (NAO-)
- Scandinavian Blocking (BL)
- Atlantic Ridge (AR)

See Box A for further information.

Which flow regime leads to less or more skilful predictions?

Changes between the four weather regimes shown in Figure 1 are used to describe the low-frequency component of the atmospheric variability. In this simplified representation, where only four possible flow configurations are considered, we assess which circulation regime leads to more or less accurate predictions over the Euro-Atlantic sector. All forecasts are stratified according to the regime in the initial conditions. For example, all the forecasts initiated with a dominant zonal flow over the Atlantic are grouped in the category of forecast initiated with a NAO+ regime.

The next step is to consider the anomaly correlation of the ensemble means forecast for the four categories as a measure of deterministic skill (Figure 2). Between day 9 and day 13 the forecasts initiated in a Scandinavian Blocking or Atlantic Ridge flow-type show a larger drop in skill than the forecasts initiated in NAO- or NAO+. By day 15, forecasts initiated in a blocking regime have the lowest anomaly correlations. Forecasts initiated in NAO- are the most skilful beyond 10 days.

The Root Mean Square Error (RMSE) of the ensemble mean normalized by the standard deviation of the analysis (not shown) provides equivalent results. Probabilistic scores are also consistent, although the differences in skill levels between the four categories appear to be less significant.

Several studies show that instability processes of the large-scale flow play major roles in the development of blocking anomalies and in the growth of errors during blocking transitions. The fact that in the late medium range, forecasts initiated during a blocking regime are generally less skilful suggests that further progress is needed to understand the processes that maintain the blocking circulation.

Regime transitions

The model's ability to correctly reproduce regime transitions and regime persistence is assessed by stratifying the forecasts according to both their initial conditions and their accuracy at day 10. All ensembles of forecasts, initiated with a given regime, are grouped into the same category within which we distinguish two additional groups: the good and poor

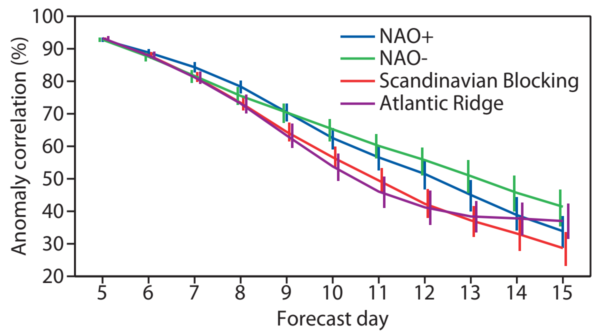

Figure 2 Anomaly correlation of the ensemble for the four forecast categories as a function of forecast range for Europe for five cold seasons (October–March 2007/08 to October–March 2011/12). The bars, based on 1,000 subsamples generated with the bootstrap method, indicate the 95% confidence intervals.

Data and methods

A

The present analysis uses the ECMWF operational ensemble forecast (ENS) (*Leutbecher & Palmer*, 2008) and the ECMWF operational analyses of daily geopotential height at 500 hPa. The data used covers five cold seasons from October 2007 to April 2012. The ENS, based on 51 members (1 unperturbed and 50 starting from slightly perturbed initial conditions), has been designed to simulate initial and, through the application of stochastic physics, model uncertainties. At present, ENS runs with approximately 32-km horizontal resolution up to forecast day 10, and 64 km thereafter. Since the ECMWF forecasting system is regularly upgraded, the evaluation is confined to the five most recent winters. This is a compromise between reducing discontinuities associated with the impact of model changes in the forecast data and retaining a sufficient amount of cases.

The climatological regimes used in this study have been computed by using the 'k-means' clustering algorithm on daily anomalies of 500 hPa geopotential height taken from ECMWF reanalysis over the domain (80°W–40°E, 30°–90°N) for the 29 cold seasons (October to April) 1980–2008. The patterns obtained correspond to the four well-known clusters described by many authors (e.g. Cassou, 2008). There are the two patterns describing the opposite phases of the North Atlantic Oscillation (NAO+, NAO-), the Scandinavian Blocking (BL) and the Atlantic Ridge (AR) (Figure 1). It is interesting to note that the two phases of the NAO together with the AR regimes describe the three preferred North Atlantic jet stream locations (*Woollings et al.*, 2010), namely, NAO-, NAO+ and AR correspond to southern, central and northern jet-states respectively.

The four regimes are used in the ECMWF medium-range clustering products (*Ferranti & Corti*, 2011) to provide additional information about the ENS in terms of large-scale circulation and to allow an objective verification of the regime transitions. A pattern-matching algorithm is used to assign each individual forecast member to the closest climatological weather regime (in terms of the root mean square difference). To account for the seasonal evolution (in the classification), the patterns and amplitudes of the climatological regimes are adjusted month by month.

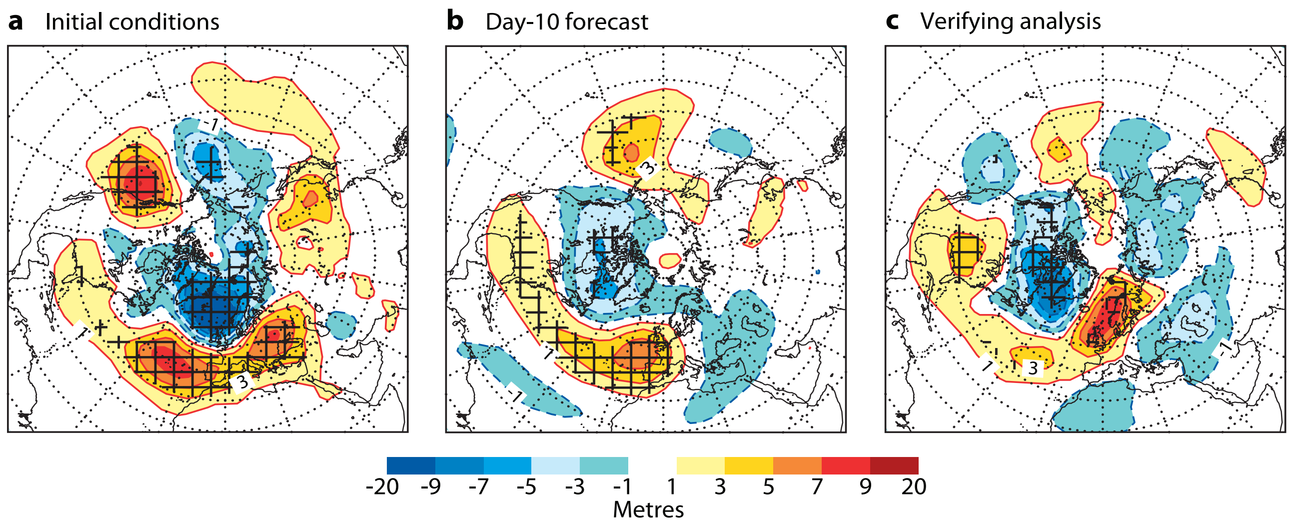

Figure 3 Anomaly composites of 500 hPa geopotential height for the poor forecasts initiated during NAO+ for (a) the initial conditions, (b) the forecasts at day 10 and (c) the corresponding verifying analysis. Hatched shading indicates statistical significance at the 10% level.

forecasts. We define as poor (good) forecasts those with a RMSE of the ensemble mean being in the upper (lower) fifth of the whole RMSE distribution computed over the European domain (12.5°W–42.5°E, 35.0°N–75.0°N) at day 10. For each group and each category we compute composite maps of anomalies of 500 hPa geopotential height.

Figure 3 shows the composites of the anomalies for the poor forecasts initiated in the NAO+ regime: at initial time (Figure 3a) and after 10 days (Figure 3b), with the composites of the verification anomalies (Figure 3c). Over the Euro-Atlantic sector the model composite at day 10 exhibits a similar anomaly pattern to that of the initial conditions, indicating that in both cases the large-scale flow is characterized by enhanced westerlies across the Atlantic. On the other hand, the verifying composite, with a high anomaly over the Scandinavian Peninsula, exhibits the typical blocking circulation pattern. Such a high level of spatial coherence in the observed anomaly patterns of the composites after 10 days and their similarity to the Scandinavian Blocking regime structure is remarkable and indicates that most of the poor forecasts are missing the same observed regime transition. The composite for the poor forecasts clearly suggests that the model failed to make a transition from a strong zonal flow to a blocking pattern, instead favouring the persistence of the zonal circulation.

It is interesting to note that the change from NAO+ (zonal flow) to a blocked flow is one of the preferred observed transitions documented by *Vautard* (1990). Table 1 shows the population of the four climatological regimes (as a percentage) at different time ranges for the good and poor forecasts initiated in NAO+. The numbers in black indicate the forecast values and in red the verification values (if different). Looking at the poor forecasts in Table 1, it can be seen that 40% of the observed cases developed into a blocking type of flow by day 5 and by day 10 those cases increased to 51%. In the forecast the number of transitions to a blocking regime at day 10 are underestimated (42% versus 51%) and the persistence of the prevalent zonal flow is over-estimated (37% versus 21%).

The composite anomalies (Figure 3a) at initial time show a coherent structure over the Pacific sector reminiscent of the negative phase of the Pacific North Atlantic circulation pattern (PNA). This is consistent with analysis from *Corti & Palmer* (1997) which showed that the largest NAO sensitivity to small initial perturbation, and therefore loss of predictability, is associated with a negative phase of the PNA.

The composite anomalies associated with the poor forecasts documented by *Rodwell et al.* (2013) are very similar to the ones represented in Figure 3c. However, the flow conditions preceding the poor forecast events in their study bear no similarity with those depicted in Figure 3a. This inconsistency could be due to us looking at different forecast ranges (10 days versus 6 days) and the poor forecasts in their study occurring in a different season (late spring).

For the good forecasts initiated in NAO+, Table 1 shows that these are characterized by 35% of cases during which the zonal flow persisted, 28% of transitions to blocking

	Day 0	Day 1	Day 5	Day 7	Day 10
Forecasts with large RMSE at day 10 (poor forecasts)					
NAO+	100	81	56, 44	54, 40	37, 21
BL	0	8	28, 40	35, 53	42, 51
NAO-	0	2	0	2	2, 5
AR	0	9	16	9, 5	19, 23
Forecast with small RMSE at day 10 (good forecasts)					
NAO+	100	65	40, 35	28, 33	37, 35
BL	0	24	30, 33	30	28
NAO-	0	2	19, 23	28	23, 21
AR	0	9	11, 9	14, 9	12, 16

Table 1 shows the population in percentage of the four climatological regimes at different time ranges for the good and poor forecasts initiated in NAO+. The numbers in black indicate the forecast values and in red the verification values if they are different.

and 21% of transitions to an NAO- regime. The forecast, for these selected good cases, was able to represent the correct percentage of transitions to blocking as well as to the other flow patterns. As opposed to the poor forecasts, the good forecast composites at the initial condition (not shown) do not present a definite coherent structure over the Pacific area, perhaps suggesting a reduced sensitivity to initial perturbations and in turn an increased predictability.

The composites for the 'poor' and 'good' forecasts initiated in the other three regimes are not shown here for the sake of brevity. However, we can point out that:

- Poor forecasts initiated in NAO- underestimate the transitions to the blocking regime; the good forecasts are mainly dominated by the cases with persistence of NAO-.
- Poor forecasts initiated in blocking are characterized by the model failure to maintain the blocking regime and favouring instead transitions to the AR and zonal regimes. The poor forecasts initiated in blocking show the largest errors compared with the poor forecasts initiated in any other regime.

Overall the main forecast deficiency, in terms of flow regimes, is in reproducing transitions to blocking and in maintaining the blocking circulation.

Relationship between spread and error

It is possible that some of the forecast failures in capturing the flow transitions from one circulation regime to another are a consequence of an intrinsic low predictability of such events. This can be addressed by considering the variations of spread of the ensemble forecasts in different flow configurations. Consequently, we investigate whether there is a relation between flow changes associated with large forecast errors (such as transition to/from a blocking regime) and large uncertainties measured in terms of spread of the ensemble forecast.

By incorporating uncertainties associated with initial conditions and model formulation into the forecast process, an ensemble of forecasts automatically takes account of flow dependence. For an ideal ensemble that accurately accounts for all sources of forecast uncertainty, the verifying truth should be statistically indistinguishable from the members of the forecast ensemble. Consequently, the spread of such an ideal forecast ensemble should provide an estimate of the forecast uncertainty: cases with large (small) ensemble spread should be associated with large (small) forecast uncertainty. The probability of specific weather events could be reliably specified from such ideal uncertainty forecasts, allowing forecasters and other users to determine the associated risk. Operational forecast ensembles are naturally imperfect and they may require statistical post-processing to generate calibrated probability forecasts for users. Nevertheless, it is interesting to look at the raw ensemble data to assess the ability to capture some fraction of the true forecast uncertainty.

We first show that for the operational forecasts covering the cold seasons 2007–2012 the spread is a good indicator of the expected forecast error. Figure 4 shows a scatterplot

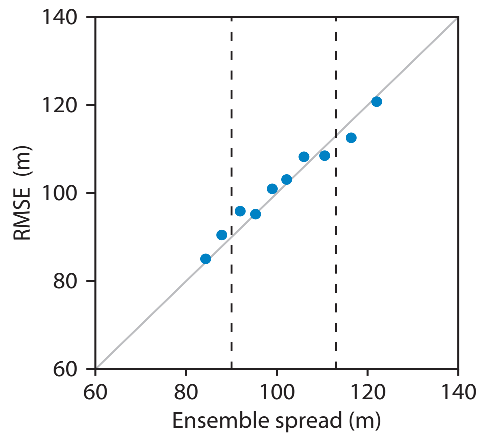

Figure 4 Scatterplot of RMSE versus the spread for day 10 forecasts. The vertical lines in the scatterplot represent the upper and lower fifth values of the ensemble spread distribution.

of RMSE versus ensemble spread at day 10 for all the forecasts. The ensemble spread distribution is binned into ten equally-populated categories, and the RMSE is averaged over each bin. After this bin averaging, properly tuned spread and error measures should then equate (ignoring observation error), and a perfect ensemble forecast should therefore produce points lying along a 45° line. Indeed Figure 4 shows that the ECMWF ensemble exhibits a good spread-error relationship.

Then, by considering the ensemble spread distribution for all the forecasts initiated in each of the four regimes (Figure 5), we evaluate whether the variability in the ensemble spread exhibits any flow dependency. The spread distribution for the forecasts initiated in NAO- has significantly the smallest mean value according to the Kolmogorov Smirnov test ($p<0.001$). This is consistent with the fact that the NAO- is the regime leading to the most skilful predictions at day 10. On the other hand, the spread distributions for the forecasts initiated in the other regimes are not significantly different from each other. It follows that, for the sample considered, the flow dependency of the ensemble spread is evident only for the forecasts initiated in NAO-.

Summary and outlook

In this study weather regimes have been used to describe the low-frequency atmospheric variability in the Europe-Atlantic area, focusing on the prediction of regime transitions in the late medium range (around day 10) in winter. The regimes leading to either more or less skilful forecasts have been identified.

Overall the model performance, measured in terms of anomaly correlation coefficient, is reasonably good (i.e. correlation greater than 0.6): up to day 9 for predictions initiated in Scandinavian Blocking and Atlantic Ridge regimes, and up to day 10.5 for predictions initiated in either phase of the NAO.

The skills of the forecasts initiated in the NAO+ and NAO- regimes are comparable up to days 10–13. Poor forecasts

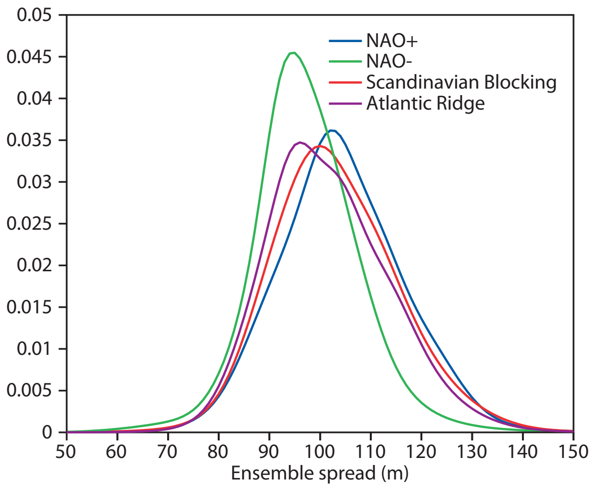

Figure 5 Ensemble spread distribution at day 10 for forecasts initiated in NAO+, NAO-, Scandinavian Blocking and Atlantic Ridge regimes. The NAO- spread distribution is significantly ($p<0.001$) different from the other spread distributions according to the Kolmogorov Smirnov test.

fail to predict transitions from a strong zonal flow to a blocking pattern, favouring instead the persistence of the zonal circulation. The initial conditions leading to such poor forecasts show a coherent structure over the Pacific reminiscent of the negative phase of the PNA.

Blocking is the regime associated with the least accurate forecasts. Poor forecasts tend to underestimate the persistence of blocking, while overestimating the maintenance of and transitions to zonal flow (NAO+). Consistent with several previous studies, our results show that transition to blocking is also difficult to predict. The least skilful forecasts are mainly associated with unpredicted onset of blocking. It is found that the forecasting of blocking onset is particularly difficult when, at initial time, the westerly jet across the Atlantic is in its southern (NAO-) or northern location (Atlantic Ridge). The Atlantic Ridge is the other regime that leads to lower forecast accuracy. Most of the poor forecasts initiated in the Atlantic Ridge regime missed the transitions to blocking and tended instead to persist in the same regime.

Consistent with our results, *Frame et al*. (2011) showed that the ensemble predictions are less skilful when the initial conditions have the jet shifted to the north.

At forecast day 10 the ensemble spread over Europe is a useful indicator of the forecast error. The spread of forecasts initiated in the NAO- regime is significantly smaller than for forecasts initiated in the other regimes. This is consistent with their higher skill.

According to the last five years of forecast data, NAO- is the circulation regime that leads to the most skilful forecasts. Consistent with this, the ensemble spread is generally small for the forecast initiated in NAO- indicating a relatively high level of inherent predictability. Generalizing the present results only on the basis of five cold seasons might be difficult. For example, in Europe, the winter of 2009/2010 was unusually cold and coincided with an exceptionally long occurrence of NAO- events persisting for about two weeks in December 2009 and February 2010. However results from a recent study, looking at a longer dataset from NCEP reforecasts and TIGGE (THORPEX Interactive Grand Global Ensemble) data, provide supporting evidence.

Since this flow-dependent predictability analysis is based on Euro-Atlantic weather regimes, it does not directly provide information on a global scale although to obtain good regime predictions at the medium range a global model is needed. It is also worth noting that there is some level of arbitrariness in considering a specific number of flow patterns. The choice of four weather regimes is a compromise: the aim was to explain the maximum portion of the low-frequency variability in the region whilst using as small a number as possible to increase the representativeness of each regime.

The present study documents the existence of flow dependency in the model's performance in the late medium range. This constitutes the basis for further research into the dynamical and physical processes that initiate regime transitions or favour the maintenance of a specific flow pattern. The ultimate goal is to establish which aspects of the forecasting system should be improved in order to obtain more accurate and reliable predictions at this time range.

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ECMWF Calendar 2014

Sep 8–12	Annual Seminar on 'Use of satellite data'
Oct 6–8	Scientific Advisory Committee (*43rd Session*)
Oct 9–10	Technical Advisory Committee (*46th Session*)
Oct 13–16	EUMETNET STAS and PFAC
Oct 16–17	Finance Committee (*95th Session*)

Oct 20	Policy Advisory Committee (*38th Session*)
Oct 27	Advisory Committee of Co-operating States (*20th Session*)
Oct 27–31	Workshop on 'High performance computing in meteorology'
Nov 3–7	Combined H-SAF and HEPeX workshops on 'Coupled hydrology'
Dec 3–4	Council (*83rd Session*)

ECMWF publications

(see http://www.ecmwf.int/en/research/publications)

Technical Memoranda

722 **Weisheimer**, **A.** & **T.N. Palmer**: On the reliability of seasonal climate forecasts. *April 2014*

720 **Weisheimer**, **A.**, **S. Corti**, **T. Palmer** & **F. Vitart**: Addressing model error through atmospheric stochastic physical parameterisations: Impact on the coupled ECMWF seasonal forecasting system. *February 2014*

719 **Gneiting**, **T.**: Calibration of medium-range weather forecasts. *March 2014*

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