ECMWF Newsletter

ecmwf.int/newsletter

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

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PUBLICATION POLICY

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 The *ECMWF Newsletter* is not peer-reviewed.

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

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Front cover image : Photo taken 2 hours before a thunderstorm near Baden-Baden, Germany, in July 2013. Courtesy of Peter Bechtold.

A Year to go!

From 16 to 21 August 2014 the first World Weather Open Science Conference (WWOSC-2014 – The weather: what's the outlook?) will be held in Montréal, Canada. The WMO World Weather Research Programme is a major sponsor of this conference and Alan Thorpe (Director-General ECMWF) together with Michel Béland (President of the WMO Commission for Atmospheric Sciences) are the co-chairs of the International Organising Committee.

As weather science advances, critical questions are arising such as about the possible sources of predictability on weekly, monthly and longer time-scales; seamless prediction; and the effective utilisation of massively-parallel supercomputers. The science is primed for a step forward informed by the realization that there can be predictive power on all space and time-scales arising from currently poorly-understood sources of potential predictability. Consequently the time is right for a major Open Science Conference to examine the rapidly changing scientific and socio-economic drivers of weather science.

This conference will draw the whole research community together to review the frontiers of knowledge and to act as an international stimulus for the science and its future. Hence, WWOSC-2014 will consider the state-of-the-art and the future evolution of weather science and also the related environmental services and how these need to be supported by research. We are particularly excited about bringing together the international community – those starting out in science and those with longer experience – to review progress and set the long-term agenda. There has never been a more important time for weather science, which is poised for great breakthroughs. Society is extremely vulnerable to weather-related impacts and desperately needs that science.

The four key objectives of WWOSC-2014 are to:

- Review the state of knowledge in weather and weather-prediction science. This will create a roadmap for the legacy of THORPEX and enable the strategic plan of the World Weather Research Programme to be updated.
- Explore the many applications of weather prediction to the natural environment. The Earth System Prediction approach for weather and environmental phenomena is seen as an effective way to better address the rapidly changing and increasing socio-economic demands for weather services.
- Encourage a new generation of research scientists who can contribute to new and advanced earth system prediction models.
- Raise the visibility and importance of the strong and vibrant world weather science research activity, in harmony with the needs of operational weather services and their stakeholders in the public and the private sectors.

The overarching theme of WWOSC-2014 is *Seamless Prediction of the Earth System: from minutes to months.* The Conference is structured around two programmes.

- *Science Programme.* This will range from basic research that extends our knowledge of processes and methods to the applied research required to put the prediction system together and assess the impacts of weather and climate events.
- *User, Application & Social Science Programme.* This will range from consideration of the goods and services economy and the role of government to disaster risk reduction/management and the communication of weather information.

We encourage everyone in the weather science and user community to come and participate in WWOSC-2014 in Montréal and to contribute to what promises to be a once in a generation event. For further information please follow: http://wwosc2014.org/.

Alan Thorpe

New items on the ECMWF website

ANDY BRADY

IFS cycle 38r2

IFS cycle 38r2 was implemented on 25 June 2013. It introduces higher vertical resolution in the high-resolution (T1279) forecast and data assimilation of the operational runs at 00 and 12 UTC (HRES) as well as the 06 and 18 UTC cycles of the Boundary Conditions (BC) optional programme. The number of model levels increases from the current 91 levels (L91) to 137 levels (L137).

http://www.ecmwf.int/products/changes/ifs_cycle_38r2/

ORAS4 ocean reanalysis - annual heat transport

Experimental plots for overturning and heat transport, including global and Atlantic and IndoPacific basins, are now available from the ORAS4 ocean reanalysis.

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

Atmospheric composition forecast

Pre-operational near-real-time forecasts are now provided by the EU MACC-II project. This includes forecasts of dust (i.e. aerosol optical depth) and a UV index.

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

Workshop on hyperspectral infrared satellite observations

The ECMWF/EUMETSAT NWP-SAF workshop on efficient representation of hyperspectral infrared satellite observations will be held from 5 to 7 November 2013. This workshop will focus on optimizing dissemination practices to allow data compression with minimal information loss, together with the development of novel data assimilation techniques that can efficiently convey this information to the analysis.

http://www.ecmwf.int/newsevents/meetings/workshops/2013/NWP-SAF_satellite_observations/

NWP course presentations

The four modules of the ECMWF NWP Training Course were held at ECMWF from 15 April to 7 June, covering topics which included numerical methods, parametrization, predictability and data assimilation. A total of 97 presentations given by 60 people are available covering a very wide range of NWP themes.

http://www.ecmwf.int newsevents/training/meteorological_presentations/

Using ECMWF Forecasts (UEF)

The UEF forum for ECMWF forecast users was held from 5 to 7 June, covering a range of topics related to the use of ECMWF's forecasts. The presentations and posters are now available.

http://www.ecmwf.int/newsevents/meetings/forecast_products_user/

ECMWF Annual Report 2012

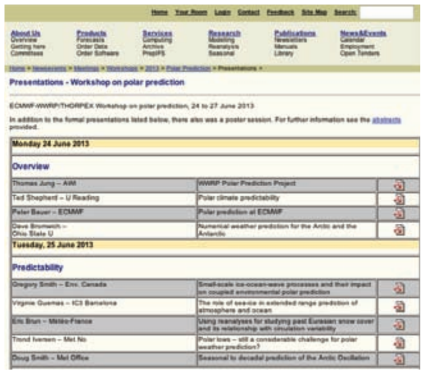
The report presents some of ECMWF's key activities in 2012. These include the provision of good guidance about extreme weather events, the upgrading of the supercomputer and the growth of the meteorological data archive. Also emphasised is the importance of close collaboration with Member and Co-operating States and many partner organisations within Europe.

http://www.ecmwf.int/publications/annual_report/

Workshop on polar prediction

The ECMWF-WWRP/THORPEX workshop on polar prediction was held from 24 to 27 June 2013. Presentations and posters are available.

http://www.ecmwf.int/newsevents/meetings/workshops/2013/Polar_prediction/Presentations/



Training course on satellite data assimilation

The ECMWF/EUMETSAT NWP-SAF training course from 1 to 4 July provided a complete overview of the usage of meteorological satellite observations in operational NWP. It included a series of lectures and practical sessions covering a range of topics - from fundamental theoretical concepts through to detailed practical implementations in modern state-of-the-art data assimilation systems. Presentations are available.

http://www.ecmwf.int/newsevents/training/meteorological_presentations/2013/SAF2013/

Walter Zwieflhofer

ALAN THORPE

At the end of June 2013 Walter Zwieflhofer, Director of Operations, left the Centre after a long and illustrious career at ECMWF. His departure was marked by an event to celebrate Walter's many contributions to key developments at ECMWF. Invited speakers from home and abroad gave presentations to a packed audience about the past, current and future outlook for supercomputing for numerical weather prediction.

In 1979 Walter graduated in computer science from the Technical University of Vienna and joined the Control Data Corporation. He had taken part in the mathematics Olympiad and his many accomplishments include being a ski instructor, scuba diver, bushman, sailor, handyman and more recently a golfer. In 1981 he joined ECMWF and over some years he supported Cyber's NOS/VE operating system; also he was involved in software development, operating system support, computer security and networking. One of his major projects was establishment of the Centre's first Data Handling System.

In 1986 Walter took an extended sabbatical of several months to sail the world's oceans with his wife Martina. After this exciting career break Walter returned to the Centre and in 1992 he became Head of Section with responsibilities which included computer security, internal networks, Regional Meteorological Data Communications Network (RMDCN) and workstation systems. Walter was promoted to the Head of the Computer Division in 1997 with the additional responsibilities for financial management of the computer budget, procurement of supercomputers, and high-availability systems for meteorological applications. Then in 2004 he became the Head of Operations and this post was re-named as the Director of Operations a little later. Consequently Walter was a director at ECMWF for nine years and has worked at the Centre over much of its history.

Walter has been a guiding light for ECMWF as it charted its way through numerous supercomputer and other procurements. Indeed in this respect Walter was kept busy right to the end with the ECMWF contract with Cray for our new supercomputer, which will start operating in 2014, being signed during Walter's last week at ECMWF! Walter also had a key role in the creation of the very successful RMDCN as well as the TIGGE database and EUROSIP collaboration. More recently he was instrumental in the creation of ecCharts to enable forecasters to have an excellent graphical tool with which to view ECMWF weather forecasts.

Contributors to the event celebrating Walter Zwieflhofer's achievements at ECMWF. The photo shows, from left to right, Gerhard Adrian (President, DWD), Alan Thorpe (Director-General, ECMWF), Walter Zwieflhofer (Director of Operations, ECMWF), David Burridge, (former Director-General, ECMWF), Adrian Simmons (ECMWF) and Al Kellie (Director CISL, National Center for Atmospheric Research).

A fitting summary of Walter's contributions to ECMWF comes from David Burridge, a previous Director-General of ECMWF, who said: "*Walter is modern polymath – a successful computer scientist, manager, planner, architect of the fantastic ECMWF operational computer system, an active and effective supporter of meteorological research, sailor, sportsman and a true advocate of the value of craftsmanship at work and at "home". He clearly believes that the Centre's research, computing and operations are of equal importance, all requiring efforts to master – a gift available to all the Centre's staff. Challenging tasks utterly absorb him and his track record at ECMWF is simply astonishing and his contribution to ECMWF's success is enormous.*"

ECMWF will greatly miss Walter's contributions. Everyone at ECMWF wishes Walter and Martina all the best as the next stage in their lives begins.

University of Helsinki meeting on OpenIFS

GLENN CARVER, FILIP VÁŇA, SÁNDOR KERTÉSZ, ERLAND KÄLLÉN (*ECMWF*), VICTORIA SINCLAIR, HEIKKI JÄRVINEN (*UNIVERSITY OF HELSINKI*)

The OpenIFS project at ECMWF is developing a portable, easy-to-use version of the forecast part of the Integrated Forecasting System (IFS) for use at universities and research institutes. A small number of universities have a license to use an early version of OpenIFS and assist in development: the University of Helsinki being one.

Heikki Järvinen and Victoria Sinclair organized an OpenIFS workshop at the University of Helsinki that took place from 4 to 6 June 2013. The workshop aimed to promote OpenIFS to the local and wider communities.

The first day of the workshop was held in the Finnish Meteorological Institute (FMI) and attended by approximately 60 people. It consisted of seminar presentations with two keynote talks by Erland Källén on *'ECMWF research activities'* and *'Experiences in predicting Hurricane Sandy*'. OpenIFS and Metview were also presented along with talks from current and future users of OpenIFS.

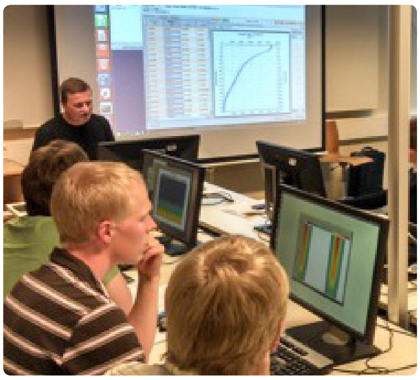
The second and third days were devoted to practical sessions supervised by Glenn Carver, Filip Váňa, Sándor Kertész and Victoria Sinclair using classroom facilities at the University of Helsinki. The course included sessions on:

- How to run OpenIFS.
- Using Metview to visualize OpenIFS simulations of Hurricane Sandy.
- Using Metview with the IFS Single Column Model.

Over 25 people attended the classroom sessions. As only two days were available, it was very much a 'taster' rather than a full tutorial course.

A key feature of the workshop was the use of a Linux 'virtual machine' with OpenIFS and Metview pre-installed on a USB flash drive that contained all the participants needed for the exercises.

Feedback from the workshop participants was very positive - they enjoyed learning about OpenIFS and how to use Metview. Many appreciated the opportunity to discuss issues directly with ECMWF staff and thought hands-on courses the best way to learn how to use OpenIFS and Metview. There is a strong willingness in the burgeoning OpenIFS user community to host a similar meeting every year.



The workshop was a key part of the OpenIFS workshop. Most of the participants came from the University of Helsinki and FMI but also there were some from the University of Stockholm, Hungarian Meteorological Service, Swedish Meteorological and Hydrological Institute and the Royal Meteorological Institute of Belgium.

ECMWF's new departmental structure

From 1 July 2013 ECMWF has a new organisational structure with four Departments:

- **Research Department:** comprises NWP, and connected, research and development of new model cycles.
- **Computing Department:** comprises the 24/7 operation of the computing infrastructure and forecast production.
- **Forecast Department:** comprises the meteorological input to forecast production, forecast evaluation and diagnostics, forecast products and applications, software development, and catalogue and data services.
- **Administration Department:** comprises human resource management; finance; estates and office services;contracts, including legal aspects; communications, including Committee support.

Those wishing to contact User Support or Data Services (in the Forecast Department) or the Calldesk (in the Computing Department) with queries should continue to use their existing contact points in the usual way.

NWP training 2013

SARAH KEELEY

Around 100 people participated in this year's Numerical Weather Prediction training course, which is run by the Research Department. Participants came from Member and Co-operating States as well as Nigeria, South Korea, India and China. Over 135 hours of lecturers and practical sessions were led by 60 scientists from ECMWF.

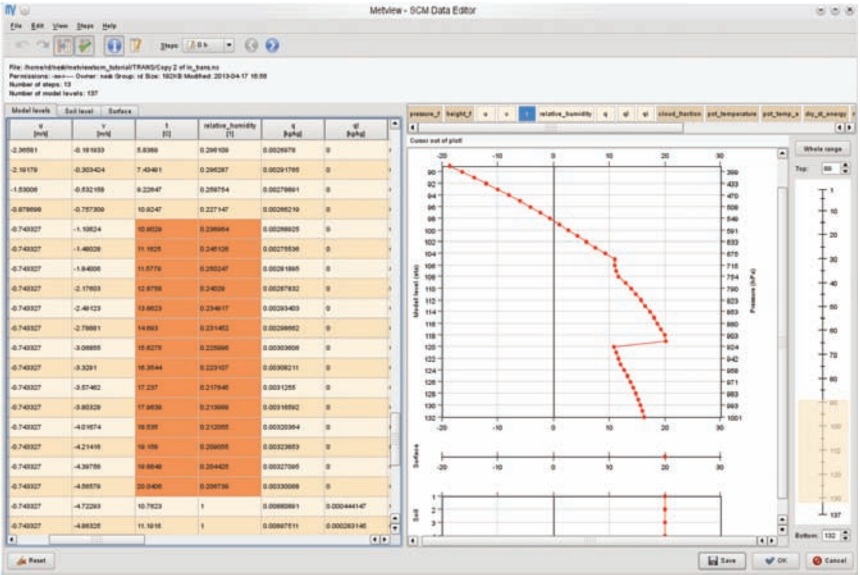
The course is divided into four modules on various aspects of the NWP system.

- *Numerical methods, adiabatic formulation of models and ocean wave forecasting.* The dynamics of the atmosphere and ocean waves, and how to create mathematical models to represent these processes were discussed, along with thinking about future supercomputing requirements for NWP.
- *Parameterization of diabatic and subgrid physical processes.* The atmospheric model's representation of radiative heating and the physical processes in the atmosphere that occur below the resolution of the grid were presented.
- *Predictability, diagnostics and extended-range forecasting.* Other elements of the Earth system that provide predictability to the atmosphere, such as the ocean and sea-ice were discussed along with the theory and design of probabilistic forecasting systems.
- *Data assimilation and the use of satellite data.* Methods to observe and initialise the forecast models were covered.

Presentations given during the most recently-held modules are available for most lectures at: http://www.ecmwf.int/newsevents/training/meteorological_presentations/

Following on from feedback from last year the Physical Aspects Section put a lot of hard work into developing new practical sessions for the module on the parameterization of physical processes. The practical sessions allowed the students to use the Single Column Model (SCM) version of the Integrated Forecasting System (IFS) to investigate the impact of various ingredients of the parameterizations of physical processes. For example, they considered the diurnal cycle of a dry boundary layer over land, a transition between different boundary layer cloud regimes, and the effects of clouds and trace gases on the radiation balance. With the help of the Metview team the SCM has an easy to use interface for running the model and adjusting the input files. Feedback from the students was positive - around 80% said that the practical sessions using the SCM helped deepen their understanding of different elements of the parametrization of physical processes.

We are continuing to develop practical session throughout the courses as well as responding to the detailed feedback we get from each student. If you have any comments about courses you have attended or NWP training you think is missing then please get in touch. Registration for next year's courses will open in the autumn.



Metview interface for editing atmospheric profiles for the Single Column Model. The atmospheric profiles shown in the figure can be altered by dragging the curve into a new shape. Metview was also used to produce a variety of plots to allow students to visualise their results.

Participants attending the module on data assimilation and use of satellite data. 30 people from 13 countries participated in this module. It included data assimilation concepts, algorithms and techniques, land surface analysis, use of satellite data and reanalysis.

Improving polar predictions

PETER BAUER

The Polar Prediction Project (PPP) aims at research into:

• The two-way linkages between polar and lower latitudes and their implications for global prediction.

• The representation of polar key processes in (coupled) models of the atmosphere, land, ocean and cryosphere.

• How to improve data assimilation systems that account for the unique characteristics of polar regions.

• The optimization of polar observing systems and the support of additional observations to enhance modelling and verification.

PPP was recently initiated as part of THORPEX (The Observing System Research and Predictability Experiment) which is a component of the World Weather Research Programme (WWRP).

From 24 to 27 June a joint workshop on polar prediction was organized between ECMWF and WWRP/THORPEX to introduce PPP to the wider community, establish ECMWF's role in polar prediction and provide scientific guidance for future developments.

Participants of the ECMWF - WWRP/THORPEX workshop on polar prediction. The workshop was attended by 50 international experts in numerical weather prediction with an interest in predictability, observations, data assimilation, modelling, verification and diagnostics for polar regions.

About 50 international experts in numerical weather prediction from short to seasonal scales were invited and presentations on predictability, observations, data assimilation, modelling, verification and diagnostics were given. Three working groups compiled recommendations for ECMWF and the international community.

The workshop was followed by a meeting of the planning group of the Year of Polar Prediction (YOPP) that is preparing for an extended period of intense numerical experimentation and observation, including field campaigns, in the mid-2017 to mid-2019 time frame.

YOPP is a key milestone for PPP and ECMWF will contribute by running dedicated research experiments and making available selected global datasets.

The programme for the workshop is posted on:

http://www.ecmwf.int/newsevents/meetings/workshops/2013/Polar_prediction/

Presentations and working group reports will be uploaded soon.

Annual Report 2012

BOB RIDDAWAY

The Annual Report presents some of ECMWF's key activities in 2012. These include the provision of good guidance about extreme weather events, the upgrading of the supercomputer and the growth of the meteorological data archive. Also emphasised is the importance close collaboration with Member and Co-operating States and many partner organisations within Europe.

The report also records some of the key events of 2012 which included:

• Enhancing the EUROSIP multi-model seasonal forecasting project by NCEP (National Centers for Environmental Prediction, USA) becoming an associate partner.

• Updating the ECMWF's Integrated Forecasting System which affected the high-resolution forecasts and analyses, the ensemble of data assimilations and the ensemble forecasts including its monthly extension.

• Providing accurate predictions of Hurricane Sandy - the ECMWF ensemble and high-resolution forecasts gave early indications of the potential for the north-east United States to suffer the impact of Sandy.

• European Flood Awareness System (EFAS) becoming operational with ECMWF being the computational centre of EFAS, working alongside partners from Sweden, Slovakia, the Netherlands and Spain.

• Celebrating twenty years of ensemble prediction at ECMWF with an event consisting of a series of presentations from people who helped ECMWF provide the best global, medium-range and monthly probabilistic forecasts.

• Expanding ECMWF by the Republic of Slovenia becoming the 20th Member State with full voting rights at the Council, a portion of the Centre's supercomputer and data archive resources, and access to all ECMWF products and tools.

• Signing of a contract for the provision of the next generation of the Regional Meteorological Data Communication Network (RMDCN) which will provide a highly-available and resilient data communication network for the dissemination of ECMWF products.

Annual Report 2012 can be accessed from:

http://www.ecmwf.int/publications/annual_report/2012/pdf/Annual-report-2012.pdf

Contract for a new High-Performance Computing Facility at ECMWF

MIKE HAWKINS, ISABELLA WEGER

Producing ECMWF's weather forecasts and improving the skill of its weather predictions, in line with the requirements of the ECMWF Strategy, demands that world-leading NWP research is supported by a state-of-the-art High-Performance Computing Facility (HPCF) with regular upgrades.

The performance requirements for ECMWF's HPCF for the coming years continue to be driven by implementation of the planned scientific developments of ECMWF's Integrated Forecasting System. Consequently, a sustained computational performance of about 250 Teraflops is required in 2014, followed by a further performance increase in 2016. This is in line with the historical growth and continues the rate of HPCF upgrades that has been essential for delivering improvements of one forecast day per decade.

After an extensive procurement process for a new HPCF (see the information in the box), a contract between ECMWF and Cray UK Ltd was signed on 24 June 2013. Cray will provide a multi-petaflops supercomputing infrastructure at ECMWF designed for operational resiliency featuring two Cray XC30 systems and a multi-petabyte Cray Sonexion storage system.

The Cray X30 system will replace ECMWF's current IBM POWER7 system in mid-2014, when the service contract with IBM expires. In order to allow for the necessary migration and testing and the transfer or the operational workload to the new system, a parallel run of the existing and replacement HPCF is required. A small test and training system will be installed in autumn 2013 to facilitate the migration of applications to the new architecture.

Signing the contract between ECMWF and Cray UK Ltd. The contract was signed by Ulla Thiel (Vice-President of Cray Europe) and Alan Thorpe (Director-General of ECMWF) on 24 June 2013. Members of the ECMWF and Cray teams involved in contract negotiations are standing behind the two signatories.

The first cluster of the new Cray system will be installed in late 2013 with the second to follow in the first quarter of 2014. Access for ECMWF and Member States users is expected in early 2014. From July 2014 onwards, ECMWF's operational and research workload will solely be supported by the Cray system.

The new system will help improve ECMWF's forecasting capabilities by providing high performance computing to support increased resolution and model enhancements, the development of ensemble-based data assimilation methods in conjunction with the ensemble forecasts, better representation of physical processes and further increased use of satellite data.

HPCF procurement process

In June 2012, the Council endorsed the work carried out by its advisory committees in scrutinising the scientific basis, technical options and funding possibilities for the procurement of the HPCF for the period of mid-2014 to mid-2018.

The following procurement process for the HPCF was followed.

- ECMWF issued an invitation to tender for the acquisition of the next HPCF on 16 October 2012.
- Following receipt of the tenders in January 2013 ECMWF's tender evaluation board concluded its evaluation in May.
- At its 79th session on 19-20 June 2013, the ECMWF Council authorised the Director-General to enter into a service contract with Cray UK Ltd to replace the HPCF from mid-2014 onwards.
- The contract between ECMWF and Cray UK Ltd was signed on 24 June 2013.

New model cycle 38r2

PETER BAUER, ERIK ANDERSSON, DAVID RICHARDSON

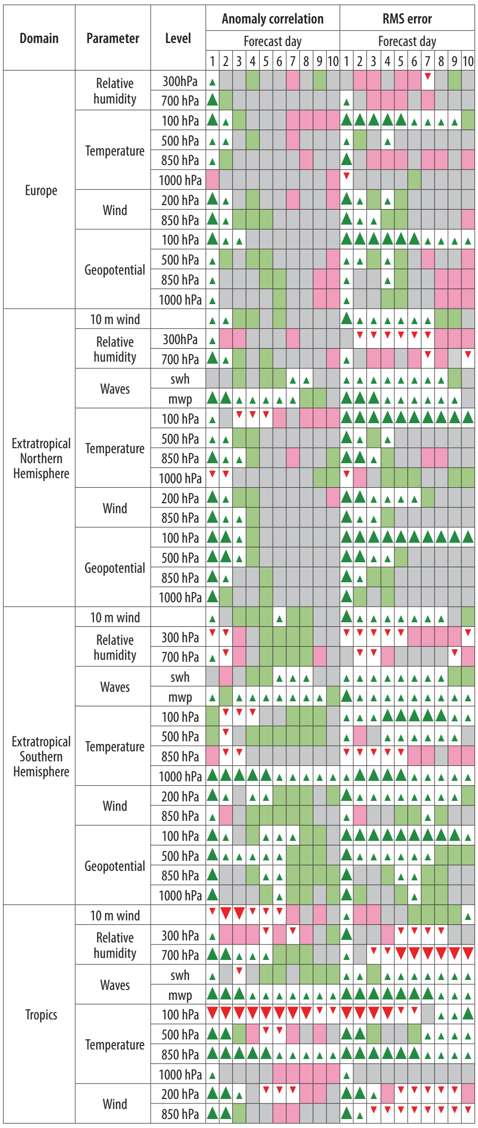
On 25 June 2013, a new model cycle of the Integrated Forecasting System (IFS) was implemented. Cy38r2 contains the long-anticipated upgrade of the vertical resolution from 91 to 137 levels (with the top level remaining at 0.01 hPa). This change has affected the high-resolution forecast model (HRES), the main assimilation (4DVAR), the ensemble of data assimilations (EDA) and the Boundary-Conditions (BC) optional programme.

A number of other changes were introduced with Cy38r2 to enhance performance and prepare for future upgrades, namely:

- Revision of background error variances at 137 levels based on IFS Cy38r1.
- Adaptation of EDA calibration and filtering for 137 levels.
- Deactivation of the model error cycling in the stratosphere.
- Modification of surface drag parametrization and test parcel entrainet in boundary layer and shallow convection.
- Adjustment of non-orographic gravity wave drag to be consistent with the seasonal forecast System 4.
- Oxygen absorption correction in the radiation scheme.
- Revision of Sea-ice/SST quality control over the Caspian Sea and the correction of the glacier mask over Iceland.

Cy38r2 increases the vertical resolution of the model throughout the troposphere and stratosphere. It enables a better representation of physical processes: clouds, inversions and vertically propagating gravity waves, for example. The forecast impacts in terms of objective verification scores against analyses are summarised in the scorecard.

Tropospheric upper-air scores are overall slightly positive in the northern hemisphere and mainly neutral for Europe and the southern hemisphere. The performance in the tropics is mixed, with some negative results compared to observations but neutral against analyses. In the extra-tropics the main negative impacts are for the upper-tropospheric relative humidity (300 hPa). The main positive impacts are for geopotential in the lower stratosphere, and to a lesser extent also in the troposphere.



Symbol legend: for a given forecast step...

- Cy38r2 better than Cy38r1 – statistically highly significant
- Cy38r2 better than Cy38r1 – statistically significant
- Cy38r2 better than Cy38r1 – not statistically significant
- Little difference between Cy38r2 and Cy38r1
- Cy38r2 worse than Cy38r1 – not statistically significant
- Cy38r2 worse than Cy38r1 – statistically significant
- Cy38r2 worse than Cy38r1 – statistically highly significant

Summary Scorecard for Cy38r2. Scorecard for Cy38r2 versus Cy38r1 verified by the respective analyses at 00 and 12 UTC for 1 January 2012 to 24 June 2013. Verification is also carried out against observations, but this is not shown. Thanks go to Martin Janousek for providing the figure.

For precipitation and temperature the overall conclusion is a slight improvement in the extra-tropics and a slight degradation in the tropics. The scores for 10-metre wind show neutral to slightly positive impact in both extra-tropics and tropics. There is an overall slight reduction of wind speed, most notable in Europe at 12 UTC. No significant differences have been found between the synoptic performance of the pre-operational e-suite and the operational forecast.

Tropical cyclone tracks and intensity have been compared for all tropical cyclones available in the research and pre-operational e-suites. There is a slight improvement for the position errors from day-3 onwards, although this is not statistically significant. The impact is neutral for tropical cyclone intensity.

Later this year (cycle 39r1), the vertical resolution of the ensemble forecast (ENS) will also be enhanced. It is planned that the ENS will then use the 91 level configuration that was operational for HRES, BC and EDA before Cy38r2 and that is used also for SEAS (seasonal forecasting System 4). This will reduce the diversity of vertical resolution configurations at ECMWF and thus enhance consistency between the components of the IFS. The ENS model top will thereby be raised to 0.01 hPa (from the current 5 hPa), providing the possibility to explore more of the medium- to long-range predictability of large-scale weather changes exerted by the stratosphere.

RMDCN - Next Generation

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

The Regional Meteorological Data Communication Network (RMDCN) was established in the late 1990s with two primary purposes.

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

The RMDCN is currently undergoing modernisation in order to meet the future requirements of ECMWF's Member States and the wider meteorological community. A procurement exercise carried out 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 item provides an update on progress towards migrating to the next generation of the RMDCN (RMDCN-NG). Further information on the project can be found in the news item and article in *ECMWF Newsletters No. 131* and *No. 134*.

In order to facilitate the migration to the new service, a Pilot Network comprising six sites (Austria, Belgium, Bulgaria, Japan, Sweden and ECMWF) was installed and formally accepted on 1 July 2013, following a 35 day period of Pilot Network Reliability Acceptance Tests. This pilot phase of the project proved to be very valuable, with both Interoute and the ECMWF team learning some useful lessons. It will stand the migration project in good stead when, over the next six months or so, many more sites will be connected.

At the same time as deploying and testing the Pilot Network, ECMWF has been collating the orders from all user sites who wish to migrate their connection to the RMDCN-NG. In addition ECMWF has received orders from a small number of National Meteorological Centres who are not currently connected to the RMDCN but wish to be connected to the future RMDCN-NG.

The 49 sites who submitted their orders by the contractual deadline of 1 July 2013 form the so-called 'Initial Deployment'. This allows to ring-fence the migration and not be side-tracked by additional sites wishing to join during this period. The new network equipment will be ordered, installed and tested during the second half of 2013, and then all sites will be formally migrated during a one-month period from early January to early February 2014.

Once the formal migration has been successfully completed, it will be possible to connect those sites who submitted orders after the deadline of 1 July 2013. It is expected that more than 50 sites will be connected to the RMDCN-NG in a year's time.

Floods in Central Europe in June 2013

FLORIAN PAPPENBERGER, FREDRIK WETTERHALL, CLÉMENT ALBERGEL, LORENZO ALFIERI, GIANPAOLO BALSAMO, KONRAD BOGNER, THOMAS HAIDEN, TIM HEWSON, LINUS MAGNUSSON, PATRICIA DE ROSNAY, JOAQUÍN MUÑOZ-SABATER, IVAN TSONEVSKY

Several days of heavy rain combined with saturated soil at the end of May and beginning of June 2013, led to extreme flooding in vast areas alongside the major rivers of Central Europe.

ECMWF's ensemble forecast gave an early indication of heavy precipitation and the high-resolution forecast captured the spatial distribution very well. Also satellite observations indicated that there were extremely wet soil conditions. However, since high soil moisture and extreme precipitation do not necessarily lead to flooding, a flood forecasting system is required. The European Flood Awareness System (EFAS) provides real-time information of ongoing and forecast floods up to 10 days in advance (see the box). It is an important additional tool for mitigating the impacts of floods in Europe.

Precipitation forecasts and soil moisture

A quasi-stationary low pressure system brought moist, warm air from the east and northeast into Central Europe causing massive amounts of rain in Southern Germany and Western Austria between the end of May and the beginning of June. Orographic enhancement of precipitation along the northern side of the Alps played an important role. Some stations in this area reported 72-hour totals exceeding 200 mm. The extreme nature of this event, and the related floods, seem to owe themselves to particular aspects of the synoptic setup – usually, northerly flow impinging on the Alps is relatively cool, and can therefore not hold that much water vapour; instead in this instance the northerly flow had very moist, almost sub-tropical characteristics.

The ECMWF high-resolution forecast (HRES) captured the spatial extent and location of the rainfall maximum but underestimated amounts in the area of heaviest upslope precipitation. HRES predicted a maximum of 150 mm/72 hours and ECMWF ensemble forecast (ENS) an individual member maximum of 173 mm/72 hours. ECMWF's 'anomalous weather' products, based on the ensemble forecast, gave a strong signal of unusually heavy precipitation in the affected region. Note that these products are designed to take account of model biases, such as those attributable to under-resolving high orography.

As shown in the first figure, the EFI (Extreme Forecast Index) forecast from 30 May, which was approximately one day before the start of the event, reached values close to 1, signifying that a rare event was very likely to occur between 12 and 84 hours ahead. In addition, the Shift of Tails (SOT) index, which complements the EFI by providing a measure of the potential for a truly exceptional event, also reached a remarkably high value (>5). The predictions from ENS from earlier times (27 to 29 May) were fairly consistent with this. Further back the signals were less clear-cut, but even 10 days in advance the ENS had highlighted an elevated risk of very wet weather across the affected region.

Another key factor in determining whether flooding is likely to take place is how saturated the soils are. Land Data Assimilation Systems provide the best estimate of soil moisture conditions by optimally combining information from models and different types of observations. For soil moisture, relevant observations include conventional screen-level reports and satellite data from SMOS (Soil Moisture and Ocean Salinity) and ASCAT (Advanced Scatterometer) on the MetOp series. As part of EUMETSAT's Satellite Application Facility on Support to Operational Hydrology and Water Management (H-SAF), ECMWF has been producing the root zone soil moisture product (H14/SM-DAS-2). It is based on assimilation of ASCAT surface soil moisture in the ECMWF Land Data Assimilation System. Although satellite data provides information of the first few cm of soil, it contributes to improve the estimation of the soil water in the root zone.

The second figure illustrates the difference in SM-DAS-2 soil moisture saturation between 2013 and 2012 over Europe for 20 May to 3 June, before the flooded area reached its maximum. It shows that there were extremely wet root zone soil moisture conditions in Western Europe, with up to 40% difference compared to the previous year in areas of Germany, Czech Republic and Hungary.

European Flood Awareness System (EFAS)

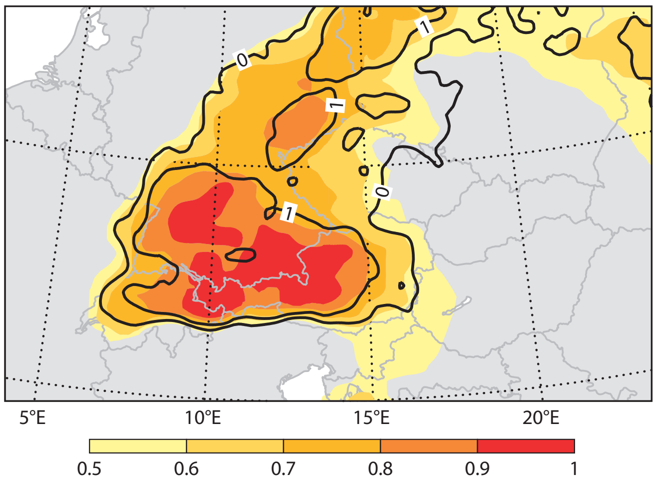
The computations and web services of the European Flood Awareness System (EFAS) are executed and hosted by ECMWF. The EFAS medium-range flood forecasting system has been developed by the Joint Research Centre (JRC) of the European Commission since 2002. It became operational at ECMWF in 2012.

Since January 2012 EFAS is maintained and further developed as operational component of the COPERNICUS Emergency Management System on the European Earth monitoring programme (COPERNICUS) and its initial operations and in support to the European Emergency Response Centre (ERC) of the European Community Humanitarian Office - see: http://ec.europa.eu/echo/about/index_en.htm

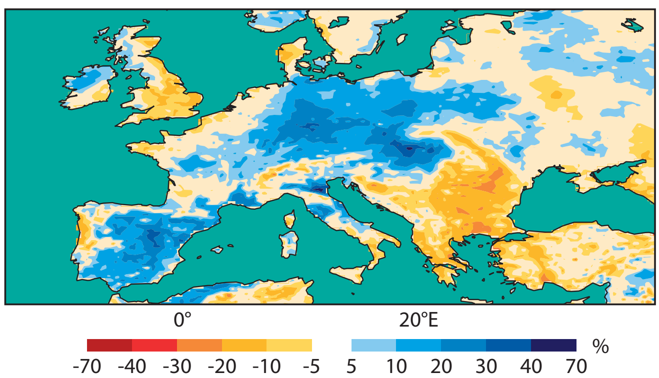
EFAS forecasts are used by national services responsible for flood forecasting in their territory as additional information and by the ERC as basis for daily planning of activities.

The system has provided the ERC with unique overviews on the flood situation across Europe and provided important information and warnings for this event. For more details go to the JRC and HEPEX (Hydrologic Ensemble Prediction Experiment) websites at: http://ec.europa.eu/dgs/jrc/ and http://www.hepex.org/

EFAS is operated by a consortium where ECMWF is the computational centre. For details, visit: http://www.efas.eu/



1: Forecast indicating that a rare event was very likely to occur between 12 and 84 hours ahead. Extreme Forecast Index (EFI) and Shift of Tails (SOT) from 12 UTC on 30 May 2013, valid from 00 UTC on 31 May to 00 UTC on 3 June (T+12 to T+84 h). EFI values above 0.5 are shaded. Black contours represent SOT (0, 1, 5) and significantly the closed contour in southern Germany denotes 5.



2: Difference in soil moisture saturation between 2013 and 2012 over Europe. EUMETSAT H-SAF root zone (0–1 m) soil moisture difference, 2013 minus 2012, for 20 May to 3 June based on ASCAT data assimilation in the ECMWF Land Data Assimilation System.

Flood forecasts

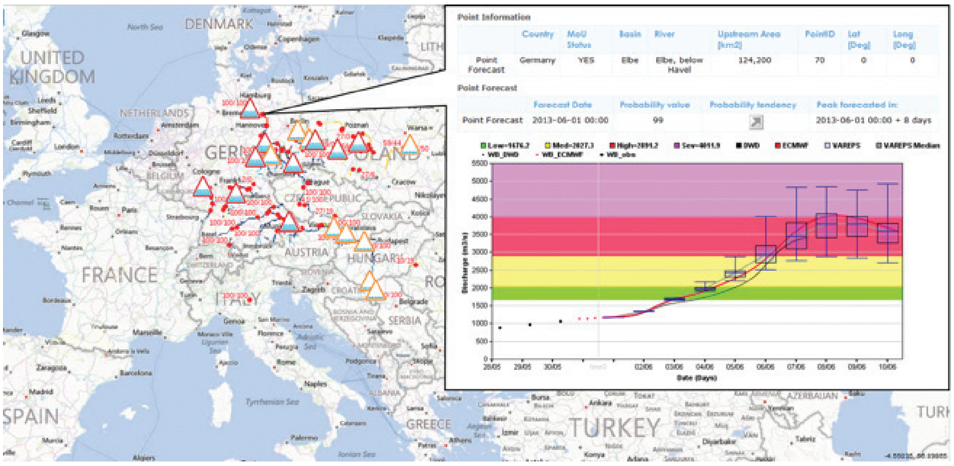
EFAS streamflow forecasts are based on the use of numerical weather predictions in a distributed hydrological model (Lisflood). The early detection of extreme river discharges is performed by comparing forecast hydrographs with model-consistent flood thresholds derived through statistical analysis of reconstructed discharge time series. Key components of the alert detection are the use of a multi-model ensemble approach and the concept of persistence of the flood signal over consecutive forecasts.

Over the last week of May, EFAS forecasts showed a rapidly increasing probability of exceeding flood warning thresholds for wide areas in Central Europe including Germany, Poland, Austria, and Slovakia. Between 28 and 31 May, 14 EFAS flood warnings of different levels (namely, flood alerts and watches) were issued for some of the major rivers (e.g. Elbe, Danube, Rhine and Odra) with varying lead times before the beginning of the extreme streamflow conditions. Cities such as Wittenberge, in Germany, were severely affected by the rising waters of the Elbe, where the record high of 2002's 'flood of the century' was surpassed by more than half a metre on 9 June 2013. The third figure shows the EFAS active alerts and watches as of 3 June 2013 and multi-model streamflow prediction for the Elbe River at Wittenberge, Germany based on the model run from 00 UTC on 1 June 2013.

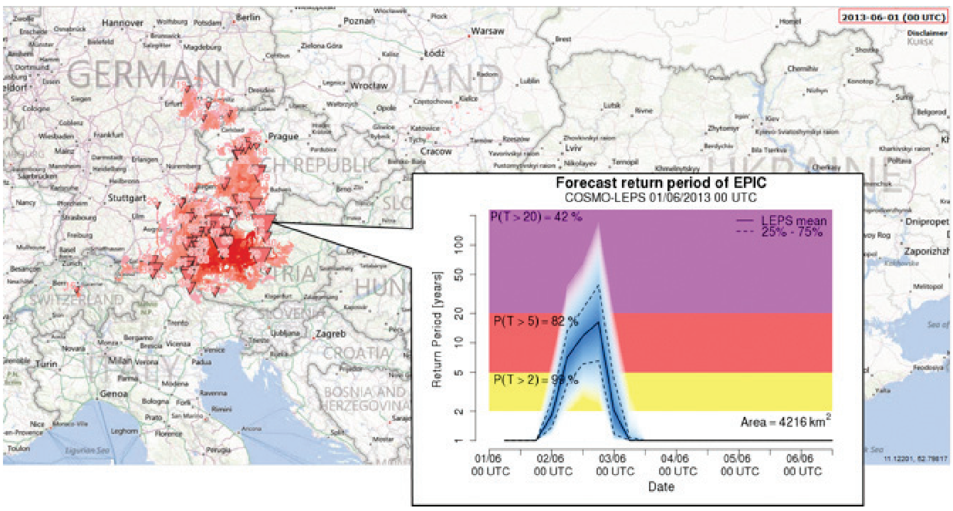
EFAS also provides a flash flood warning based on the European Precipitation Index (EPIC). The EPIC picked up the extreme character of the upcoming precipitation event over a large area centred along the Austrian-German border, indicating high probability of flash flooding in a number of alpine catchments. An EFAS watch for extreme precipitation and possible flash flooding was issued for this area on 1 June, with 30-36 hours lead time on the event peak – see the fourth figure. This area was indeed severely affected by extreme weather on 1 and 2 June. The city of Passau, in southern Germany, was hit particularly severely, with water levels reaching their highest recorded value in the past 500 years.

What next?

The event was the first real test for the operational EFAS system which is specifically designed to provide early warnings for large-scale flood events. The preliminary analysis shows that overall it did perform well in most of the affected areas, even though the severity of the events was somewhat underestimated. A more in-depth analysis of the event and how it was forecast is currently ongoing.



3: EFAS active alerts and watches and a multi-model streamflow prediction. The map shows the EFAS active alerts (red) and watches (orange) as of 3 June 2013. Also shown is the multi-model streamflow prediction for the Elbe River at Wittenberge, Germany (model run of 00 UTC on 1 June 2013); the coloured shadings indicate the low, medium, high and severe risk of flooding.



4: EFAS watch for extreme precipitation and possible flash flooding. The map shows the EFAS forecasts of the European Precipitation Index (EPIC) from 1 June 2013. Also shown is the forecast return period of EPIC for Passau based on COSMO-LEPS; the coloured shading indicates return periods of > 2 years, > 5 years and > 20 years.

Using ECMWF's Forecasts: a forum to discuss the use of ECMWF data and products

ANNA GHELLI

'Using ECMWF's Forecasts' is a forum for exchanging ideas and experiences on the use of ECMWF data and products. It is an opportunity for participants to provide feedback to ECMWF on forecast performance and the range of products, and for ECMWF to update them on recent developments of the forecasting system. The theme of this year's meeting, which focused on applications and impact of weather information, was *'Integrated use of ECMWF forecast products in decision making and risk management'* with three thematic areas:

- Weather and financial/energy applications.
- Weather forecasting.
- Weather and societal impact.

In June 2013 an international audience of 90 people gathered at ECMWF for the annual workshop when ECMWF meets users of its numerical weather predictions, who over the years have increased in number and now encompass National Meteorological Services, commercial businesses, universities, international organisations and international projects. This year's meeting had a strong focus on the impact of weather information in decision-making and applications.

Participants arriving at the meeting registration desk. 90 people from Europe and the USA attended the meeting. They had a wide range of interests including commercial applications, weather and forecasting, and humanitarian operations.

Invited speakers introduced and set the scene for each thematic area. Networking and exchange of ideas among participants and with ECMWF staff were encouraged during a very popular poster session which accounted for 22 posters on a variety of ECMWF data and product applications, and in the group activities. The presentations and posters are available at:
http://www.ecmwf.int/newsevents/meetings/forecast_products_user/

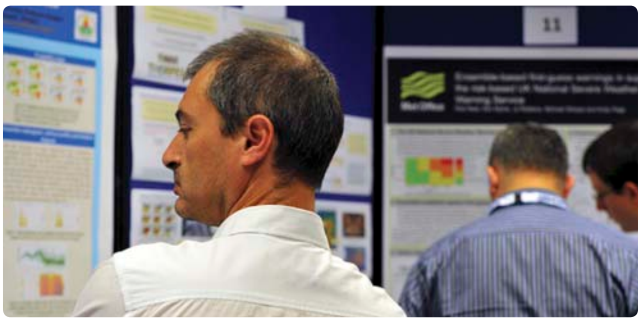
In the following a summary of the key points highlighted by the invited speakers is given for each thematic area.

Weather and financial/energy applications

The theme dedicated to *'Weather and financial/energy applications'* explored the use of ECMWF weather information and uncertainty estimates in managing risk and pricing in sectors such as insurance, agriculture, energy and commodity trading. Contributions on weather impact on energy production, consumption and management of related risks were presented.

Judith A. Curry (Climate Forecast Application Network and Georgia Institute of Technology) informed the audience about the operational forecasting system for the energy sector that had been developed based on ECMWF's analysis and forecasting system. She stressed the influences of weather information on energy demand and supply, and on the resilience of the energy sector. In this context, she highlighted that ECMWF weather forecasting system is particularly appreciated as it allows for an internally-consistent post-processing across time scales as well as an assessment of forecast confidence by making use of ensemble predictions.

Curry illustrated the benefits of extended-range forecasts in the energy sector to stabilize energy costs and supplies. She described how trading prices of gas futures can be affected by reduced gas production due to, for example, offshore platforms being evacuated in expectation of a severe weather event. But the needs of the energy sector do not stop at extended-range forecasts. Curry said that there is also interest in early warnings up to seven days in advance to be able to mitigate risk – for instance by implementing a pre-hazard strategic stockpiling whereby in the event of severe weather generators are disconnected from the grid but continue to deliver power to a local circuit. Moreover, operators are able to mobilize emergency crews to deal with the aftermath of an extreme event.



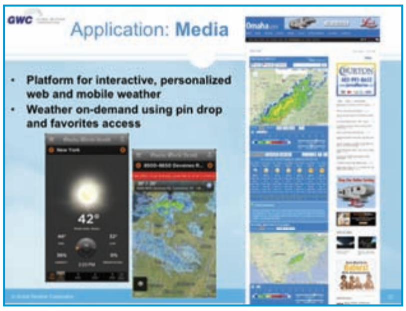
The poster session. The 22 posters on display offered the participants and opportunity to explore a variety of applications of ECMWF data and products. They also encouraged participants to network and exchange ideas.

Weather forecasting

The *'Weather forecasting'* theme focused on weather and marine forecasting practices in the operational environment with emphasis on the use of ECMWF's data and products to shape decisions and assess risks of high impact weather events. Some of the presentations in this session described novel ways of communicating weather information to decision makers, including use of new technologies to extend the reach of warnings. Also the importance of post-processing as a way to add value to NWP output data was highlighted.

William B. Gail (Global Weather Corporation) described the post-processing technology (DICast – Dynamic Integrated foreCast) developed at the National Center for Atmospheric Research (NCAR); this is used to compute forecasts at specific locations. The technique employs a three-step process using a number of NWP models and observations as input. He reported that recent inclusion of ECMWF's high-resolution and ensemble forecasts (HRES and ENS) in the DICast system had improved significantly the skill of their post-processed forecasts.

Gail emphasized that the market for weather apps is rapidly evolving in step with technology; customers demand high-quality weather information delivered for their location which can be displayed on mobile devices. He showed an example of these applications developed for a group of end-users which encompassed a pin drop facility, whereby a location can be easily selected with a dynamic overlay (i.e. to be able to visualize more variables for hourly to daily summaries) and weather alerts.



Weather forecasting and technology. Commercial enterprises mentioned that the market for weather apps is rapidly evolving in synchronism with technology and customers demand high-quality weather information delivered for their location and displayed on mobile devices (Courtesy of William B. Gail).

Nicole Girardot (Météo-France) told the audience that Météo-France uses ECMWF forecasts in operations for a wide range of activities and forecast ranges. Moreover she stressed that weather warnings provided by a National Meteorological Service (NMS) very much rely on the NWP data, post-processing and human expertise. She reminded the participants that at present forecasters are still facing difficulties linked to the vast amount of information that has to be assimilated in a short time, the availability of heterogeneous tools as opposed to a single solution, and the lack of precise methods to communicate uncertainty. The latter is a long journey started many years ago and its progress relies on the ability of NMSs and other meteorological organisations to provide adequate training for their users about uncertainty and probability forecasts.

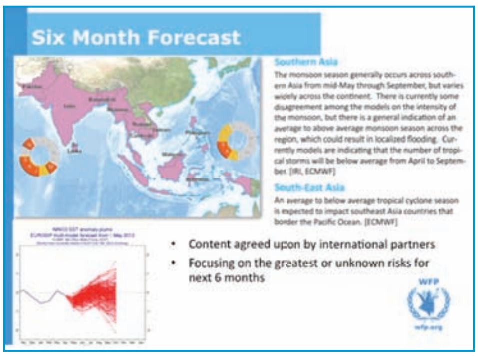
It was interesting to see in a number of oral presentations and posters that severe events, which had always be defined as absolute thresholds for specific meteorological variables, are now increasingly referred to as thresholds for the parameter distributions.

Weather and societal impacts

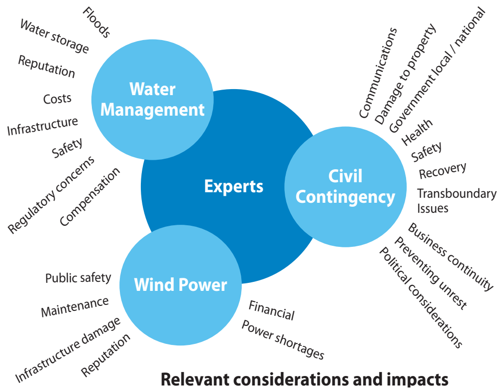
In the session on 'Weather and societal impacts' the contributions described applications that helped mitigate or reduce risks associated with high-impact weather events. Emily Niebuhr (World Food Programme) presented the use of ECMWF's meteorological data for humanitarian relief operations. These work on the assumption that saving time usually leads to saving lives; therefore timely intervention and prevention of high impact events is a crucial element. The large amount of weather information needs to be summarized and integrated in complex systems that take into account human activities, health, conflicts and infrastructure.

Niebuhr suggested, supported by other speakers during the meeting, that a framework would be needed to digest the vast quantity of weather information available to support humanitarian relief, as most humanitarian organisations do not have the resources and ability to do it. There was no conclusion on what this framework should look like, but it was clear that more training is essential to ensure that the information provided can be understood and used in an appropriate manner.

Niebuhr highlighted that, even though local NMSs in the intervention areas are the first contact for humanitarian organisations, it is not always possible to obtain the necessary local weather information to build a complete picture. Therefore, to plan the logistics for the intervention, indices such as the Extreme Forecast Index, which describes the departure from the local climate, are very useful as they provide local knowledge.



Weather and societal impacts. Humanitarian operations work on the assumption that saving time usually leads to saving lives, therefore timely intervention and prevention of high-impact events is a crucial element (Courtesy of Emily Niebuhr and WFP GIS team).



Discovering the needs of different users of weather data. The *'Decision making in action'* group activity started with a role-playing game aimed at discovering the needs of different users of weather data. The forecasters ('Expert') interacted with diverse customers represented by the categories of water management, wind power and civil contingency. Risks and weather impact was specific to each type of customer (Courtesy of Liz Stephens and Steven Ramsdale).

Exchanging ideas and experiences

Group activities provided an opportunity to exchange ideas and experiences about using ECMWF products and services. There were three group activities:

- *'Decision making in action'* focused on users needs in decision making processes.
- *'Product delivery'* discussed future developments in ECMWF products delivery and services.
- *'Calibration'* explored the concepts of data post-processing.

The *'Decision making in action'* group offered an opportunity for participants to explore how different users of NWP products expect to integrate weather information into their decision-making processes. The group analysed how the diverse needs could be addressed by providing bespoke products rather than 'selling' the one-fits-all approach. It was recognized that there is a huge appetite for information on extreme weather but communicating forecasts is not enough; the end-user is interested in clear and concise forecasts that include the impact of weather for their circumstances. Clearly customer consultations, training and support are key elements to bridge the gap between forecasters or meteorologists and weather data users. Terminology and jargon need to be understood by all parties to be able to obtain the largest benefits from weather forecasts. Moreover, sensitivities and vulnerabilities of the various users must be explicit to allow the development of new weather products.

Communication of uncertainty was touched upon at various stages of the group discussion, and it was clear that education and training for all the users of weather information are essential and more should be done in this direction. The participants expressed appreciation for the education and training provided by ECMWF on its NWP products and software.

Members of the *'Product delivery'* group commented on their experiences with ECMWF products and expressed their requirements for future development of ECMWF services. The graphical products available on the website and via the interactive web interface ecCharts are appreciated. The group expressed the need to increase the number of products available on ecCharts (e.g. soundings and cross sections) and make interactive features available for the plots on the web (e.g. zooming, panning, overlays and feature hovering). There was a definite interest in having maps delivery via Web Map services. Modalities of data delivery and cloud services to facilitate expensive data processing were discussed as well as data availability on the commercial catalogue. The group highlighted the need for earlier delivery of the 00 UTC run of the ensemble, which would encourage the use of ensemble forecasts in the daily routines at weather services. Options on how to achieve this are currently under investigation as part of a two-year project at ECMWF on product delivery.

Finally, during the *'Calibration'* working group, post-processing of raw model output was discussed. There is evidence that calibration improves forecast skill; it is therefore encouraged at least for those variables that are commonly used. While spatial calibration is less common, point calibration is more widely used and it relies on the availability of timeseries of hindcasts for specified locations. Therefore, easy access to timeseries of specific variables for a number of selected locations was desirable for future developments. The group highlighted the importance of calibration for extreme event forecasts with the caveat that care must be taken in selecting the appropriate method for post-processing.

Feedback

The general feedback to the meeting was very positive. Participants appreciated having a theme to focus on and the opportunity of exchanging experiences with people with different business backgrounds. The poster session was very well received, even though it was suggested that in future meetings the time allocated to it could be longer. Having the opportunity to discuss issues with ECMWF staff as well as time to share experiences, whether in the group activities or in coffee breaks, was commended by many participants.

I would like to thank all the participants for making *'Using ECMWF's Forecasts'* an enjoyable and successful meeting. Also my thanks go to ECMWF staff who contributed to the success of the meeting, particularly Erik Andersson, Konrad Bogner, Karen Clarke, Alfred Hofstadler, Florian Pappenberger, David Richardson, Cihan Sahin, Stephan Siemens, Ivan Tsonevsky, Fabio Venuti, Fredrik Wetterhall and Ervin Zsoter.

Breakthrough in forecasting equilibrium and non-equilibrium convection

PETER BECHTOLD, NOUREDDINE SEMANE, PHILIPPE LOPEZ, JEAN-PIERRE CHABOUREAU, ANTON BELJAARS, NIELS BORMANN

A new diagnostic convective closure has been developed. Important improvements in global NWP forecasts have been obtained with the new convective closure. In particular, there is not only a better representation of the diurnal cycle of convection, but also a better depiction of its spatial distribution.

A comparison of low-resolution seasonal integrations and high-resolution short-range forecasts against satellite and radar data shows that with the new convective closure it is possible to realistically represent non-equilibrium convection. Other investigations, which involve comparisons with a cloud resolving model (CRM) for the Sahel region and with satellite data, confirm the good performance of the new scheme.

The new convective closure is dependent on an extended convective available potential energy (CAPE). It has been derived under a quasi-equilibrium assumption for the free troposphere subject to boundary-layer forcing. The simple closure involves adjustment time-scales for the free troposphere and the land and ocean boundary-layers.

Equilibrium and non-equilibrium convection

Equilibrium convection is generally interpreted as indicating that the convection is in equilibrium with the forcing due to the mean advection and processes other than convection. In other words, the convection can react on time scales short enough for the residual tendency between the forcing and the convective stabilization to be small. This is generally referred to as quasi-equilibrium. Numerous theoretical and experimental studies have confirmed the validity of quasi-equilibrium for synoptic disturbances and for time-scales of the order of one day. Today most global numerical weather prediction (NWP) and climate models employ a convection parametrization based on the quasi-equilibrium assumption – see Box A.

In contrast to equilibrium convection, the forcing of non-equilibrium convection varies typically on time scales of a few hours. Non-equilibrium convection under rapidly-varying forcing typically occurs when either the upper-tropospheric forcing is strong and the convection is inhibited by a capping inversion, or the upper-level forcing is weak and the precipitating convection is driven along its trajectory by rapidly-varying and strong surface heat fluxes. The large-scale flow, in turn, readjusts to the convective heat source by a process called geostrophic adjustment that operates via inertia-gravity waves on time-scales of a few hours. Forecasting non-equilibrium convection is challenging for models, and this is particularly true for surface forced convection where the mid- to upper-tropospheric vertical motions are the response to and not the driver of deep convection.

A

Convection parametrization

Most convection parametrization schemes are based on the concept that vertical mass transport occurs in convective plumes which exchange mass with their environment. In these schemes the rate of horizontal mass exchange has to be specified, and the mass flux at cloud base is determined from the assumption of convective quasi-equilibrium. In spite of employing a similar basic convective framework, the models can produce substantially different large-scale tropical wave spectra and intra-seasonal variability such as the Madden-Julian oscillation. However, *Bechtold et al*. (2008) and *Jung et al.* (2010) demonstrated with ECMWF's Integrated Forecasting System (IFS) that the basic mass flux framework under the quasi-equilibrium assumption provides a realistic reproduction of the observed middle-latitude synoptic variability, as well as the tropical wave spectra and intra-seasonal variability.

Diurnal cycle of convection

The diurnal cycle of convection is probably the most prominent manifestation of non-equilibrium convection driven by the boundary-layer. Numerous observational studies and those based on cloud resolving models (CRMs) have been devoted to the diurnal cycle of convection over land. The phase of the diurnal cycle can vary strongly on regional scales, though the general picture is that of a morning shallow convective phase, followed by a gradual onset of deeper convection, with rain rates peaking in the late afternoon to early evening. It has been found that the phase and intensity of precipitation mainly depends on the surface fluxes and lower to mid-tropospheric stability and moisture, but boundary-layer processes such as convergence, gravity waves and cold pools also play a role in the onset and propagation of deep convection. In addition, it has been shown that CRMs with resolutions of order 2.5 km or higher, as also used by many of our Member States for their regional short-range forecasts, are able to reproduce the observed diurnal cycle (*Langhans et al.*, 2012) though the high-resolution forecasts are sensitive to the formulation of the horizontal turbulent mixing.

The same success in reproducing the observed diurnal cycle can generally not be reported for large-scale models. Indeed, numerous global and regional model studies point to systematic errors in the diurnal cycle of precipitation when a convection parametrization scheme is employed, namely a too early onset of deep convection with a diurnal cycle of precipitation that is roughly in phase with the surface fluxes. These problems have also persisted in the IFS over the last decades. The diurnal cycle of non-precipitating shallow convection, however, can be realistically represented with a quasi-equilibrium closure for the boundary-layer and a prognostic cloud scheme, as demonstrated with the IFS by *Ahlgrimm & Forbes* (2012).

Various approaches have been taken to improve the representation of convection driven by surface fluxes focusing on the entrainment rates, the convective triggering and particularly the convective closure. New closure formulations include the convective inhibition (CIN), lifting by cold pools, environmental moisture, and also prognostic formulations with convective memory. However, so far none of the above methods have proved to be general and robust enough to replace, at least in the global NWP context, the standard equilibrium closures for the CAPE.

It is pleasing that it has been possible to develop a convective closure that extends the current CAPE closure in the IFS and, as outlined below, realistically represents both synoptically and boundary-layer forced convection.

CAPE and convective closure

The CAPE (J kg^{-1}) is defined as the vertical integral, from the cloud base to the cloud top, of the acceleration a moist air parcel experiences due to the density deficit with respect to its dry environment. The World Meteorological Organization's definition of CAPE assumes that the cloudy parcel does not mix with the environment. With this definition typical values of CAPE, as available from the ECMWF archive, are on the order of 1000 J kg^{-1}. However, in the context of convection parametrization, we use the more representative CAPE of an entraining parcel which has typical values of order 100 J kg^{-1}.

CAPE is produced in the free troposphere by:

- Cooling through mean large-scale advection and cooling from radiation, both affecting the large-scale environment.
- Surface heat and moisture fluxes, affecting the height of the cloud base and the properties of the rising parcel (updraught).

In the case of weak large-scale forcing the CAPE varies essentially with the surface fluxes. Therefore, a convection scheme that determines the convective intensity from the assumption that convection consumes all CAPE over a convective time-scale (typically of order 1 hour) tends to produce a diurnal cycle of precipitation that follows the surface fluxes. Over land this obviously does not correspond to the observations. The IFS also uses such a closure which in the following is referred to as CTL.

The NEW closure that has been developed uses an effective CAPE that recognizes that not all the boundary-layer heating is available to be converted into deep precipitating motions, but only a fraction, while the main part during the morning and noon is balanced by dry and shallow non-precipitating convection. The effective CAPE, which accounts for the imbalance between shallow near-surface heating and deep convective motions, can be computed by assuming different adjustment time-scales for the free troposphere and the boundary-layer. Over land the boundary-layer time-scale is set to the convective turnover time scale (defined as the ratio between cloud depth and mean updraught speed), while over water it is set to the advective time-scale (ratio of cloud base height to mean wind speed in the boundary-layer).

Convective closure aims to determine through scaling the actual mean mass flux and precipitation of a population of convective up- and downdraughts. While simple parcel theory (CAPE) is obviously not sufficient to determine the ensemble mean properties of convection in non-equilibrium surface forced convection, the NEW closure effectively corrects for these deficiencies.

Climatology of the diurnal cycle of precipitation

The diurnal cycle of convection in the IFS is first evaluated from an ensemble of one-year integrations and compared against a ten-year precipitation climatology from the Tropical Rainfall Measurement Mission (TRMM) for June, July and August. The simulations are forced by analysed sea surface temperatures, and use spectral truncation T159 (gridlength 125 km) with 91 vertical levels, and a time step of 1 hour. Precipitation data from both the simulations and the observations are composited in hourly bins, and the diurnal amplitude and phase are computed from the first harmonic of a Fourier series.

The diurnal amplitude (mm day^{-1}) of the precipitation in the tropical belt from the TRMM radiometer is displayed in Figure1a. Maximum amplitudes reach around 10 mm day^{-1} over tropical land.

Amplitudes from the model integrations using the CTL and NEW closures are displayed in Figures 1b and 1c. Overall, the spatial distribution of the amplitudes is reasonably reproduced in both simulations, but the amplitudes reach higher values than the TRMM-based observations, particularly over northern Amazonia. However, the simulated total rainfall over Amazonia appears realistic when compared to the Global Precipitation Climatology Project 2.2 dataset (not shown).

The corresponding phase of the diurnal cycle (LST) is displayed in Figure 2. As already discussed in earlier studies, maximum precipitation in the TRMM radar data (Figure 2a) occurs over tropical land roughly in the late afternoon to early evening, though strong regional variations are present. In particular, convective rainfall over Amazonia may peak as early as local noon due to the high relative humidity and low stability in the lower troposphere. In contrast, maximum precipitation over the tropical oceans occurs during the early morning. The CTL closure (Figure 2b) provides a reasonable reproduction of the diurnal phase over water, but the convective precipitation over land generally peaks around local noon.

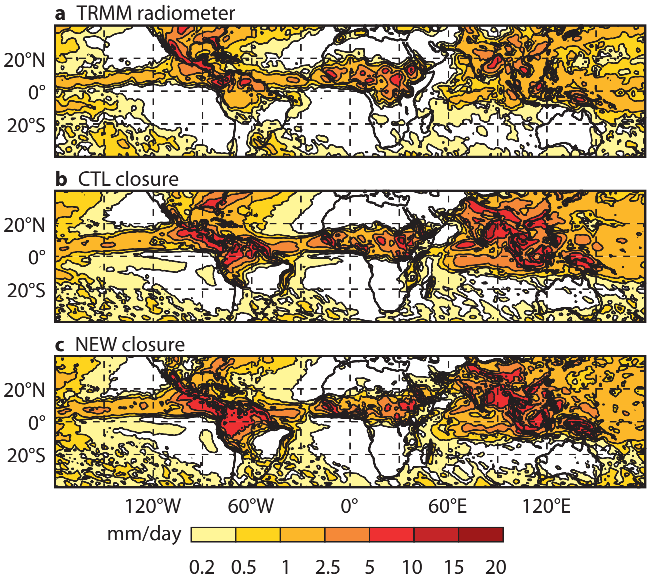


Figure 1 Diurnal amplitude (mm day^{-1}) of the precipitation in the tropical band as obtained (a) from a 10-year climatology of TRMM radiometer data for June, July and August (courtesy Yukari Takayabu and colleagues), and from an ensemble of annual IFS integrations with (b) the CTL and (c) NEW closures at T159 (gridlength 125 km).

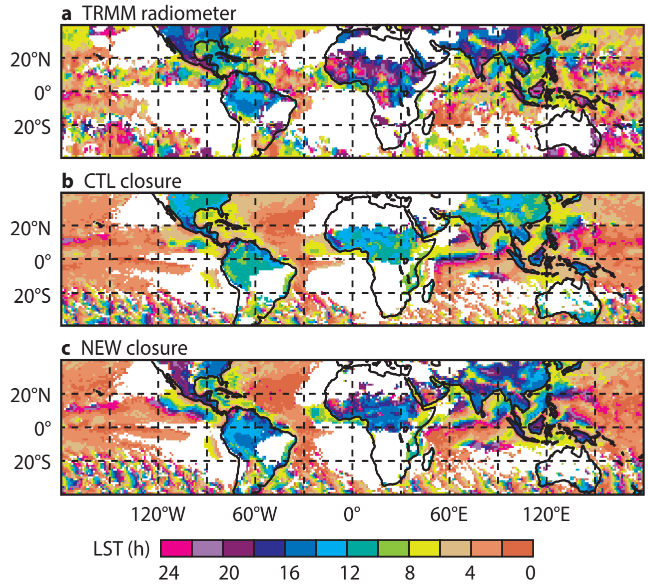


Figure 2 Same as Figure 1, but for the diurnal phase (LST) of the precipitation. Also, TRMM radar data has been used instead of the radiometer data.

However, as shown in Figure 2c, a marked improvement is obtained with the NEW closure that shifts the diurnal cycle over land by 4–5 hours compared to CTL, and also improves the diurnal cycle in coastal regions (e.g. off the Central American and West African coasts, as well as off the Indian subcontinent and over the Maritime Continent). Experimentation shows that the improvements over coastal regions are primarily due to a better representation of the convection generated over land and advected over sea, along with the associated subsiding motions, but the modified adjustment over sea also contributes.

High-resolution forecasts of the diurnal cycle of precipitation

In addition to seasonal integrations, higher resolution daily 3-day forecasts have been performed for June, July and August 2011 and 2012 at T511 (gridlength 40 km) with 137 vertical levels and a time step of 900 s. The forecasts were initialised from ECMWF's operational analyses at T1279 (gridlength 16 km) with 91 levels. The forecasts are compared to the NCEP Stage IV composites obtained from the combination of radar and rain gauge data (NEXRAD, hereafter) over the continental United States during summer 2011 and 2012, and German radar composites from the Deutsche Wetterdienst for summer 2011. All forecast days have been used to compute the diurnal composites that are three times 90 days for each summer season.

The amplitude and phase of the diurnal cycle of precipitation averaged over the summers 2011 and 2012 are depicted in Figure 3 and Figure 4 for the continental United States. Numerous previous studies have already described the diurnal cycle over this region. In summary, as is also evident from the NEXRAD data (Figure 3a and Figure 4a), the diurnal cycle over the continental United States is characterized by three distinctive regions.

- Rocky Mountain area, where convective activity peaks during the late afternoon.
- Central Planes with predominantly night-time convection from propagating mesoscale convective systems triggered over the Rocky Mountains.
- Eastern United States and coastal regions with predominantly late afternoon convection and a particularly strong diurnal amplitude over the Florida peninsula.

The CTL forecasts have quite a reasonable representation of the spatial variations in the amplitude (Figure 3b), but underestimate the amplitude east of the mountain ridge and somewhat overestimate the amplitude in the coastal regions. The results with the NEW forecasts (Figure 3c) are rather similar though slightly improve on the CTL. However, concerning the phase, the NEW forecasts (Figure 4c) substantially delay the diurnal cycle by 4–5 hours compared to CTL (Figure 4b) so that the results more closely match the observations. But over the Eastern United States the diurnal cycle in NEW still precedes the observed cycle by up to 2 hours.

To give an overview of the diurnal cycle in the high-resolution short-range forecasts, the area-averaged diurnal rainfall composites are depicted in Figure 5 for the Eastern United States and Germany and also for the central Sahel region, which has TRMM climatological data for comparison. The area-averaged representation for all three locations shows that NEW has quite a good fit to the daytime and evening diurnal cycle of precipitation, shifting it by up to 6 hours compared to CTL. The late

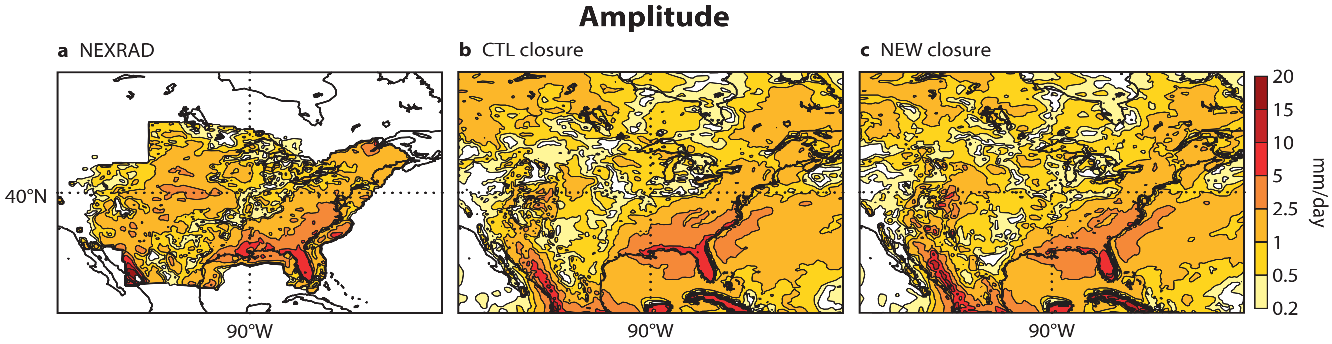


Figure 3 Amplitude (mm day^{-1}) of the precipitation averaged over June, July and August 2011 and 2012 for the continental United States from (a) NEXRAD, and from daily 72-hour forecasts with (b) CTL and (c) NEW closures at truncation T511 (gridlength 40 km).

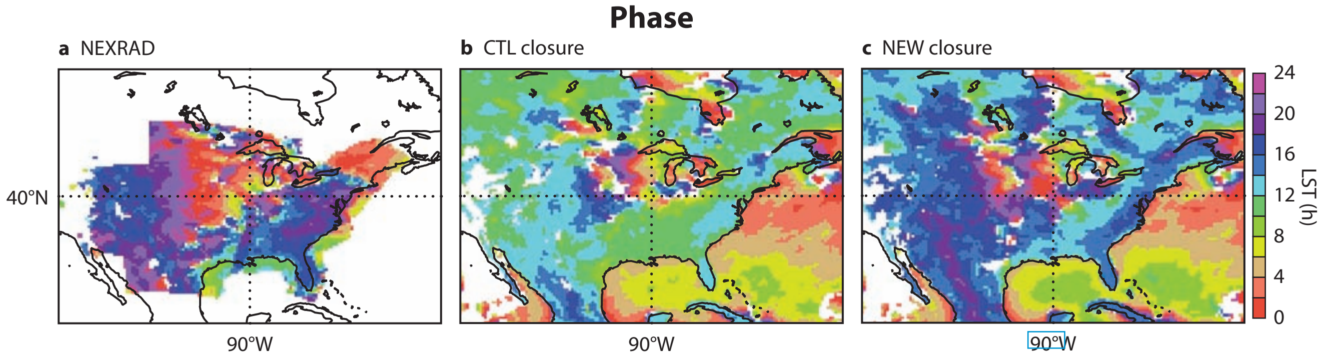


Figure 4 Same as for Figure 3, but for the diurnal phase of the precipitation (LST).

night precipitation, however, remains underestimated in both NEW and CTL in spite of having the convection parametrization coupled to a prognostic cloud scheme. This precipitation deficit might be due to the missing representation of convective system dynamics including spreading surface cold pools and predominantly upper-level mesoscale lifting during the night.

Over the Sahel (Figure 5c), NEW realistically increases the precipitation with respect to CTL. A correct phase representation of the diurnal cycle is particularly important in this region where the convective heating is a key driver of the meridional pressure gradient and the large-scale dynamics.

Heating and moistening profiles

The convective heating and its dynamical response are investigated over the central Sahel region using CRM data from the Meso-NH limited area model (*Lafore et al.*, 1998) that has been run during 10–25 June 2012 at 2.5 km grid-spacing daily for 24-hours over a domain that is roughly 2,200 km by 1,700 km. The CRM uses the same ECMWF T1279 analyses as initial conditions as are used for CTL and NEW. In addition, the CRM open boundaries are updated every 6 hours from the ECMWF analyses.

The heating and moistening rates (K day^{-1}) shown as shaded in Figure 6 are the total heating less the radiation (traditionally called the apparent heat source Q1-Qrad) and the total moistening (traditionally called the apparent moisture source –Q2).

One recognizes for both CTL and NEW (Figures 6a & 6c) a distinctive phase with deep boundary-layer heating from 6:30 to 12 LST, followed by boundary-layer cooling and more elevated dry and shallow convective heating lasting until 17 LST. Boundary-layer moistening (Figures 6b & 6d) lasts until about 9 LST. It is followed by strong drying of the lower boundary-layer, and dry and shallow convective moistening of the lower troposphere extending to or exceeding the 600 hPa level at 15–16 LST.

During the strong growth phase of the boundary-layer from 10–17 LST, corresponding to a continuous growth of CAPE, the heating in the upper part of the boundary-layer is in balance with the cooling due to adiabatic motions, but the upper-troposphere is not in equilibrium. Indeed, the evolution of the upper-tropospheric heating profiles differs strongly between CTL and NEW. Whereas in CTL the mid- to upper-tropospheric heating of 5–10 K day^{-1} from precipitating deep convection occurs around 13 LST, and therefore during the growth of the boundary-layer, the strong deep convective heating in NEW occurs when the lower- to middle-troposphere has reached its maximum total heat content.

The dynamic response to deep convective heating is a couplet of upper-tropospheric cooling and lower-tropospheric warming, which through the quasi-geostrophic adjustment process becomes effective a few hours after the convective heating. This dynamic cooling/heating couplet is particularly important for the formation

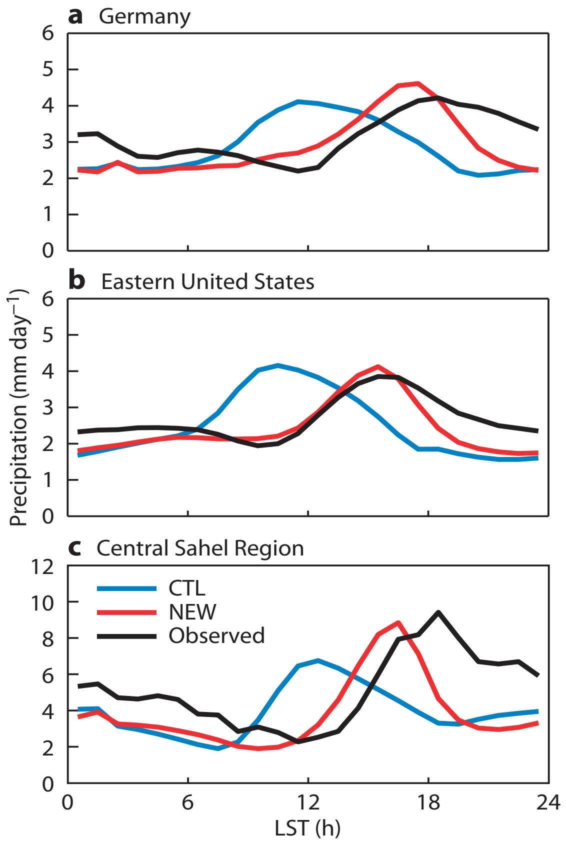


Figure 5 Diurnal composites of area-averaged total precipitation (mm day^{-1}) from CTL and NEW against observations for (a) Germany [48°–52°N, 7°–14°E] using DWD radar, (b) eastern United States [30°–45°N, 100°–80°W] using NEXRAD, and (c) central Sahel region [5°–20°N, 10°–30°E] using TRMM climatological radiometer data. The observations are for June, July and August 2011 for (a) and June, July and August 2011 and 2012 for (b) and (c).

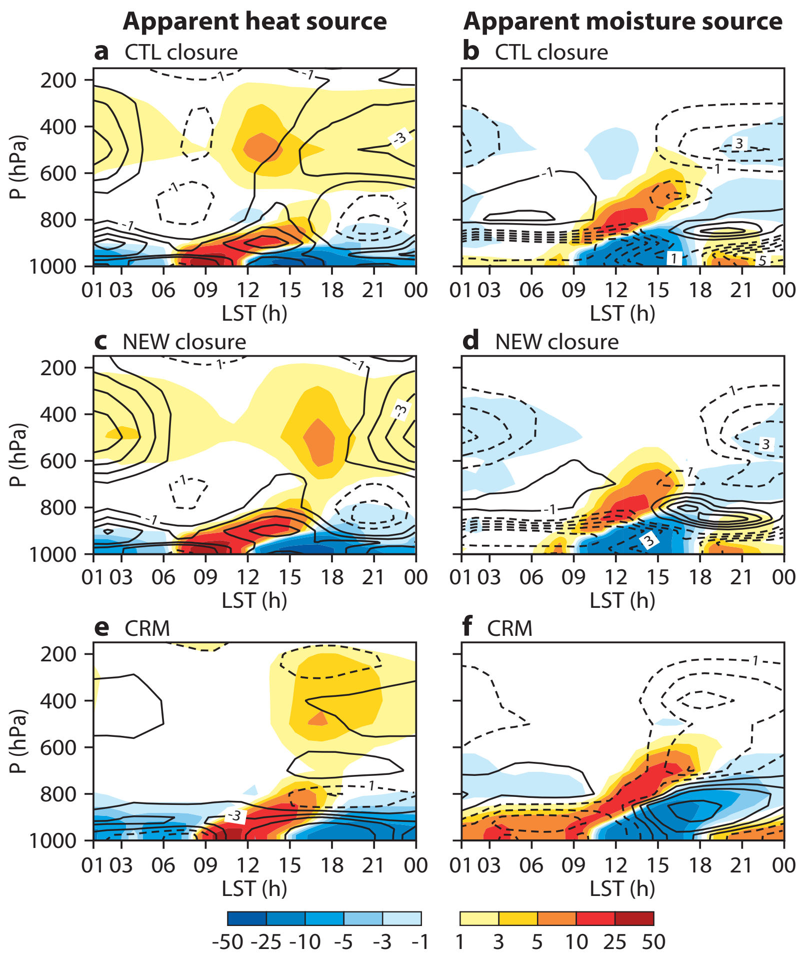


Figure 6 Diurnal composites of heating rate (left panels) and moistening rate (right panels)) over the central Sahel for CTL (top panels), NEW (middle panels), and from the CRM (bottom panels) during 10–25 June 2012. Total heating rate minus radiation (Q1-Qrad) and total moistening rate (-Q2) are shaded. Solid contour lines denote cooling and drying rates due to adiabatic motions and dashed contour lines (interval 1 K day^{-1}) denote adiabatic heating and moistening.

of mesocale stratiform rain during night. The upper-tropospheric response in NEW is clearly delayed, and is stronger than in CTL, attaining values of -4 K day^{-1}. Nevertheless, NEW still underestimates the night-time precipitation with respect to the observations (Figure 5).

A comparison of the heating and moistening profiles with CRM data (Figures 6e & 6f) reveals that NEW produces a realistic diurnal cycle in phase and amplitude, including the shallow and congestus heating phase, though the latter is less pronounced in the CRM. The heating profiles (Figures 6c & 6e) are also in fair agreement with the observed cloud evolution during days with late afternoon convection *(Zhang & Klein, 2010)*. The moistening rates (Figures 6d & 6f) are also in good agreement during daytime. However, larger differences in the heating profiles between the CRM and the IFS exist in the early morning hours which can be partly attributed to boundary-layer spin-up processes in the CRM.

Overall, we think that the structure and evolution of the convective heating and its dynamical response using NEW compares fairly well with the results from the CRM, given the limited domain size of the CRM and its sensitivity to the parametrization of horizontal mixing.

Comparison with satellite data

A global picture of the improvement in the heating structure of NEW compared to CTL is presented in Figure 7 using July 2012 as an illustration. This shows a reduction in root-mean-square (rms) error of the brightness temperatures (BTs) when evaluating the short-range (first-guess) forecasts during the 12-hour assimilation window against the clear-sky BTs from AMSU-A microwave sounders on board sun-synchronous NOAA satellites. The satellites have different twice-daily overpass times, and the results are shown for two channels, sensitive to temperature over broad atmospheric layers around 500–1000 hPa and 250–600 hPa. Clearly, NEW provides an improvement over CTL over most land regions with persistent active convection, and in particular in the middle to upper-troposphere where the convective heating is strongest. The improvement of order 0.1 K is primarily a result of a reduction in the bias for the day-time overpasses. It is small in absolute values, but it is statistically significant, and has to be compared to the absolute rms error of the 12-hour forecasts that does not exceed 0.3 K. The areas of reduction in the short-range forecast errors are consistent with the improvements in the diurnal cycle seen in the long integrations (Figure 2).

The improvements in the diurnal cycle in NEW can also be easily identified on infrared satellite imagery. As an illustrative example, Figure 8 shows the observed 10.8 µm infrared satellite images over Europe at 12 and 18 UTC on 1 July 2012 from Meteosat 9 and the synthetic forecast images from the CTL and NEW short-range forecasts at T1279 (gridlength 16 km).

The satellite images show synoptically-forced convection over western and central Europe, and surface-forced convection over the Balkans and the Atlas Mountains, a situation that is frequently observed during summer. Indeed, CTL overestimates the convection over Eastern Europe and the Balkans at 12 UTC and underestimates the convection in these areas and the Atlas Mountains at 18 UTC. In contrast, NEW clearly better reproduces the daytime convective evolution and also better represents the localisation and structure of convection. Due to the higher CAPE values in NEW, the convection is more coarse-grained with higher local convective rain intensities during late afternoon. A separate comparison of NEW with CRM data revealed that the higher daytime convective rain intensities in NEW are more realistic than the more large-spread, but weaker rain events in CTL.

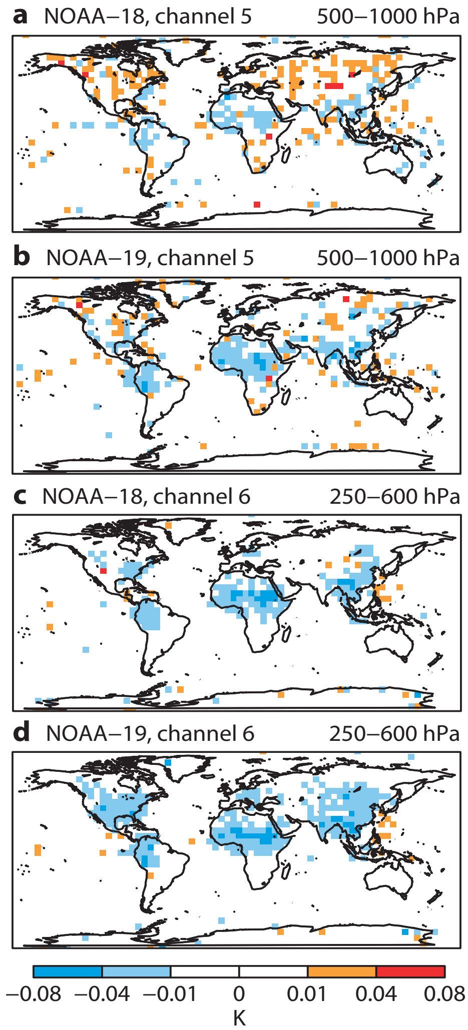


Figure 7 Root mean square error differences in clear-sky brightness temperatures for July 2012 between NEW and CTL during the 12-hour window of the 4D-Var analysis, when evaluated against AMSU-A microwave sounding channels onboard NOAA sun-synchronous satellites. The channels are representative for different atmospheric layers: (a) and (b) NOAA-18 and 19 channel 5 for the 500–1000 hPa layer, and (c) and (d) NOAA-18 and 19 channel 6 for the 250–600 hPa layer. The twice daily overpass times are 03 LST and 15 LST for NOAA-18, and 01:30 LST and 13:30 LST for NOAA-19.

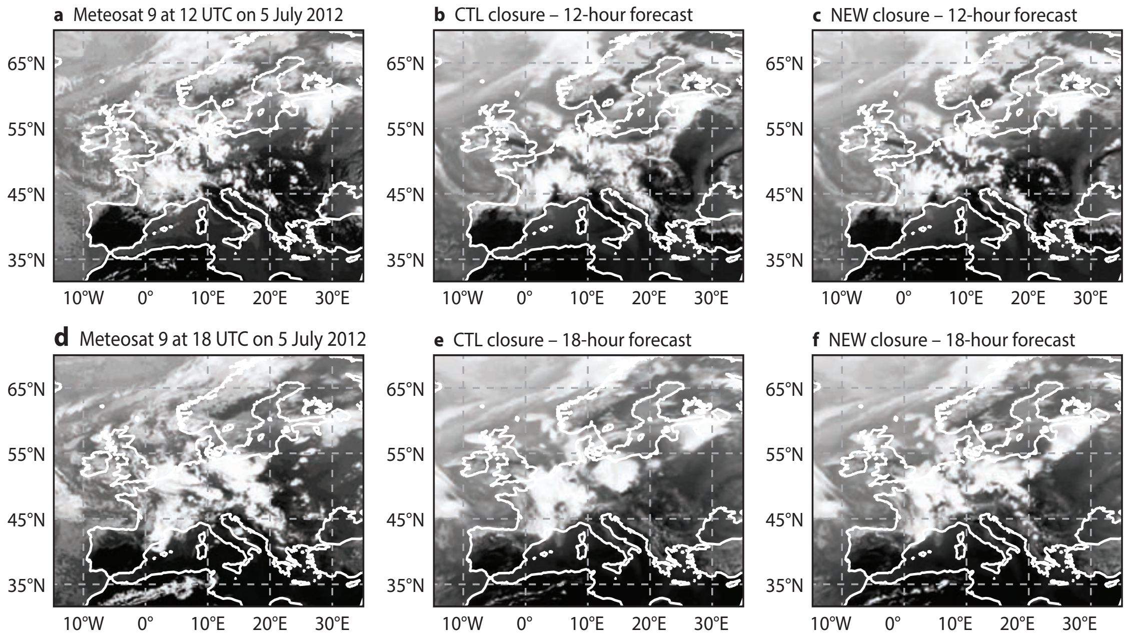


Figure 8 (a) Infrared 10.8 μm satellite image from Meteosat 9, channel 9 over Europe on at 12 UTC on 5 July 2012 along with the 12-hour forecasts from (b) CTL and (c) NEW closures at truncation T1279 (gridlength 16 km). (d) As (a) but for 18 UTC on 5 July 2012. (e), (f) As (b), (c) but for 18-hour forecasts. All images are at resolution 0.2°.

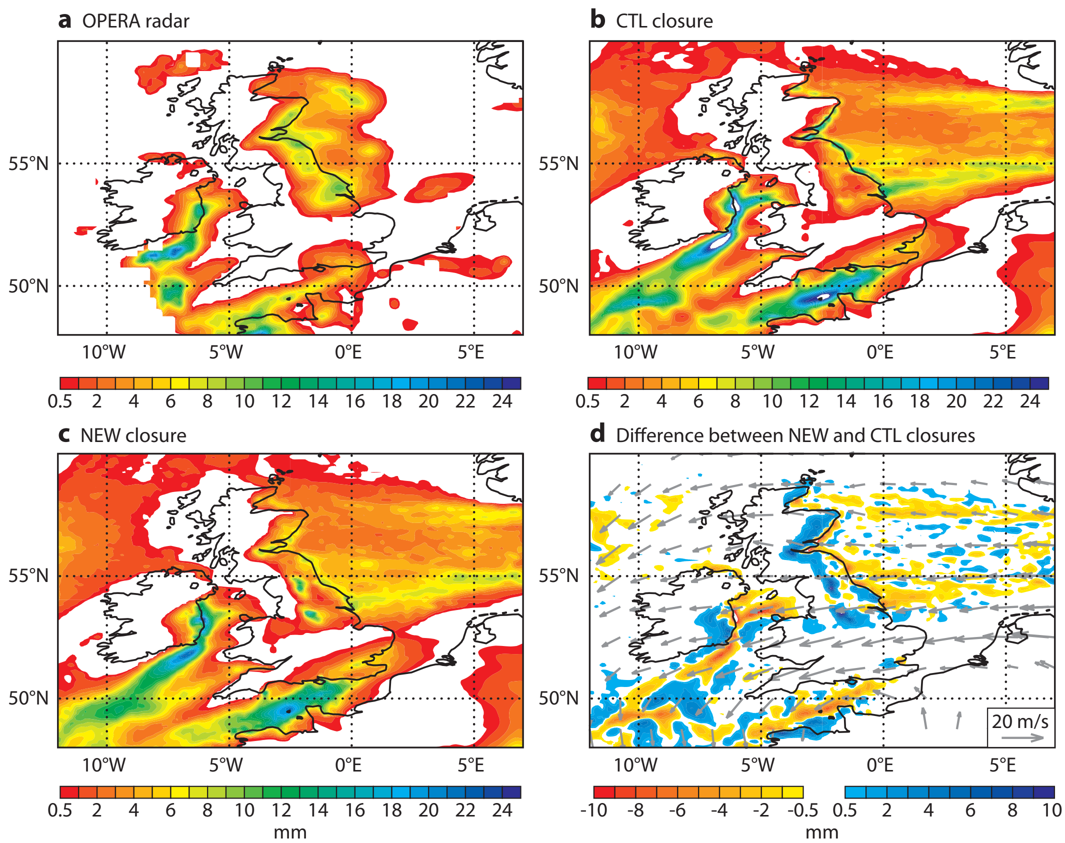


Figure 9 24-hour precipitation accumulations (mm) for 1 December 2010 over the British Isles and near European mainland from (a) radar observations on a 0.25° grid, and 24-hour forecasts with (b) CTL and (c) NEW at truncation T1279 (gridlength 16 km). (d) The difference between NEW and CTL closures. The advection is represented in (d) by the mean 500–850 hPa wind.

Convection over the oceans and wintry showers

So far, there has been little discussion on the effect of NEW over the oceans. In these areas, the overall synoptic impact can be described as largely neutral, including the medium-range forecasts of tropical cyclones and the representation of the Madden-Julian oscillation in seasonal integrations. However, there is a positive impact on the representation of convection and the diurnal cycle in near-coastal areas. Of particular concern in NWP is, for example, the inland advection of wintry showers forming over the relatively warm sea. This is illustrated by considering the 24-hour precipitation accumulations over the British Isles and the near European mainland on 1 December 2010 as observed from ground-based radar (Figure 9a) along with the 24-hour forecasts for CTL (Figure 9b) and NEW (Figure 9c) at T1279.

Nearly all precipitation accumulated as snow on the ground, reached up to 20 cm and was predominantly of the convective type. Clearly, NEW reduces the unrealistically strong snowfall along the coast by up to 50% compared to CTL and more realistically moves the convective snowfall inland, bringing up an extra of 10 cm snow (Figure 9d). This is possible even with a diagnostic formulation of convection as the moist unstable air is advected inland, and the simulated convection is formulated so that it is allowed to depart from elevated layers. The main difference between NEW and CTL is the slower convective adjustment, avoiding a too strong large-scale response leading to coastal convergence.

Benefits and challenges

Important improvements in global NWP have been obtained with a new convective closure, which is dependent on the convective available potential energy CAPE and assumes a quasi-equilibrium for the free troposphere subject to boundary-layer forcing. With this formulation only at the end of the lower tropospheric heating and moistening cycle is the entire CAPE available for conversion into deep convective motions. Consequences for NWP are not only a better phase representation of convection, but also better forecasts of its spatial distribution and local intensity.However, the representation of the night-time precipitation that is related to a mesoscale lifting/subsidence couplet in the upper-troposphere remains a challenge in convection forecasting. With parametrized convection the night-time precipitation is underestimated. Future improvements in this bias might be achieved by a tighter coupling between the microphysics in the convection and the resolved microphysics, or a more prognostic formulation of convection.

Finally, concerning future higher-resolution upgrades of the IFS, from the current T1279 (16 km) operational resolution to the envisaged T3999 (5 km) resolution in 2020, we think that the new convective closure will enable a smooth transition from parametrized to resolved deep convection in both the forecasts and the data assimilation as there is no longer a substantial discrepancy in the phase and location between parametrized and resolved convection.

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Winds of change in the use of Atmospheric Motion Vectors in the ECMWF system

KIRSTI SALONEN, NIELS BORMANN

The use of Atmospheric Motion Vectors (AMVs) in the ECMWF system is undergoing an extensive revision. The aim is to ensure effective and realistic use of AMVs in data assimilation in order to improve their impact on model analyses and forecasts. The main amendment will be the introduction of situation-dependent observation errors. This is done to ensure that the errors assigned in the data assimilation better account for height assignment errors of the observations. The use of situation-dependent observation errors also enables notable simplifications to the AMV quality control. The modifications give significant positive impact on model analyses and forecasts especially at low levels, and they are planned to be implemented to the ECMWF Integrated Forecasting System (IFS) cycle 39r1 later this year.

Information about AMVs currently used in the ECMWF analysis is given in Box A.

Situation-dependant observation errors

Errors in the AMVs originate mainly from two sources: errors in the height assignment and errors in the wind vector tracking. The impact of errors in height assignment is highly situation dependent. It can be very significant in regions where wind shear is strong but on the other hand it is less relevant in areas where there is not much variation in wind speed with height. *Forsythe & Saunders* (2008) have introduced an approach to estimate situation-dependent observation errors for AMVs and this method has been investigated in the ECMWF system.

Height assignment errors

The error in the height assignment is thought to be the dominant source of error for AMVs. These errors can originate from several sources. Each height assignment method has built-in assumptions which will affect the accuracy of the assigned height depending on the atmospheric conditions. Identification of the representative pixels in the target box to be used in the height assignment is important. In addition, errors in the NWP temperature and humidity profiles applied in the height assignment methods contribute to the height error. Also problems may arise because the AMV observation and the model counterpart do not represent the same phenomena. For example, high-level AMVs are assigned to an estimate of the cloud top, yet it is unclear whether this is the appropriate height or whether the cloud motions are more representative of the wind at a level within the cloud.

A

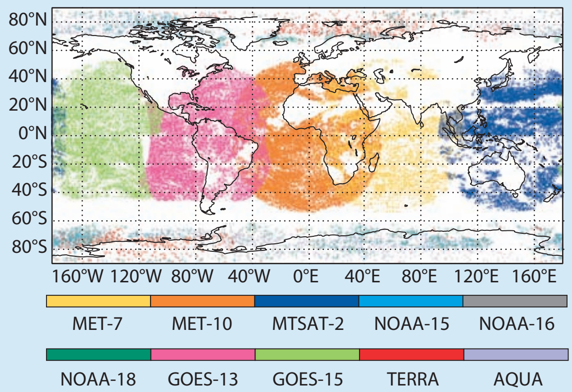
AMVs used in the ECMWF analysis

AMVs are wind observations derived by tracking clouds in the infrared (IR), water vapour (WV), or visible (VIS) channel, or clear-sky features in the WV channel. It is assumed that the tracked features act as passive tracers of the atmospheric flow. AMVs are interpreted as single-level wind observations assigned to a representative pressure level provided by the AMV producers.

AMVs are obtained both from geostationary and polar-orbiting satellites, and they constitute an important source of tropospheric wind information for global and regional data assimilation systems. Currently AMVs from the following satellites are actively used in the ECMWF analysis.

- Five geostationary satellites: Meteosat-7, Meteosat-10, GOES-13, GOES-15 and MTSAT-2.
- Five polar-orbiting satellites: Aqua, Terra and NOAA-15,-16,-18.

In addition AMVs from five other satellites (FY-2D, FY-2E, MetOp-A, MetOp-B, NOAA-19) are operationally monitored. New AMV data sets are routinely being investigated, the latest being AMVs from MetOp-B, and the hourly wind product from the GOES satellites.



The figure illustrates the 12-hour sample coverage for active AMVs.

In order to estimate the wind error due to error in height assignment an estimate of the height error is required. One option would be to use estimates of height errors provided by the AMV producers but these are not yet operationally available. Thus, currently the height errors are estimated based on model best-fit pressure statistics for the ECMWF system. The best-fit pressure is defined as the height where the vector difference between the observed and the model background wind is the smallest. Typical values for the height errors are of the order of 70 to 110 hPa. Comparison of best-fit pressure statistics for the ECMWF and Met Office systems has shown that the statistics are very similar for both systems (*Salonen et al.*, 2012). This result increases confidence that the concept of best-fit pressure is useful in estimating the magnitude of the height errors.

In the ECMWF system, the height errors are defined for all satellites, channels and height assignment methods and are regularly updated when changes in the AMV processing take place. The height error is converted to a wind error following the *Forsythe & Saunders* (2008) approach. In the ECMWF implementation it is assumed that there are no clouds or water vapour features suitable for AMV tracking above the height of the model tropopause.

Tracking errors

Tracking errors originate also from several sources. In some cases the cross-correlation fails to locate the correct tracer in the search area. For example, the shape and orientation of the dominant feature affects the tracking accuracy. Also, if there are several features moving with different speed and directions in the target window, the result may be a compromise between the different motions (e.g. in case of multi-layer clouds). For AMVs from polar satellites the parallax error can also be significant.

For the ECMWF system tracking errors are estimated from observation minus model background statistics by selecting cases where the wind error due to error in the height assignment is small. Also the tracking errors have been studied separately for all satellites, channels and height assignment methods. As the differences are relatively small, we currently distinguish only between geostationary and polar orbiting satellites. The defined tracking errors vary from 2 ms^{-1} to 3.2 ms^{-1} depending on height and satellite.

Final observation error

The final observation error for each AMV combines the tracking error and the error due to error in height assignment, resulting in a highly situation-dependent observation error. Figure 1 displays the observation minus model background field (upper panel) and the corresponding assumed observation errors (lower panel) for the zonal component of cloudy water vapour AMVs for levels 100–400 hPa at 12 UTC on 1 June 2012. Comparison of the panels indicate that at locations where there are significant differences between the observed and the model wind speed, the situation-dependent observation errors reach higher values. Thus, the behaviour of the observation errors is consistent with expectations. On average the situation-dependent observation errors are of the same magnitude or slightly larger than the current observation errors in the operational system.

The new observation errors imply that AMVs will receive less weight in the analysis in areas of strong wind shear, whereas they will receive more weight in areas where there is less variation of wind with height.

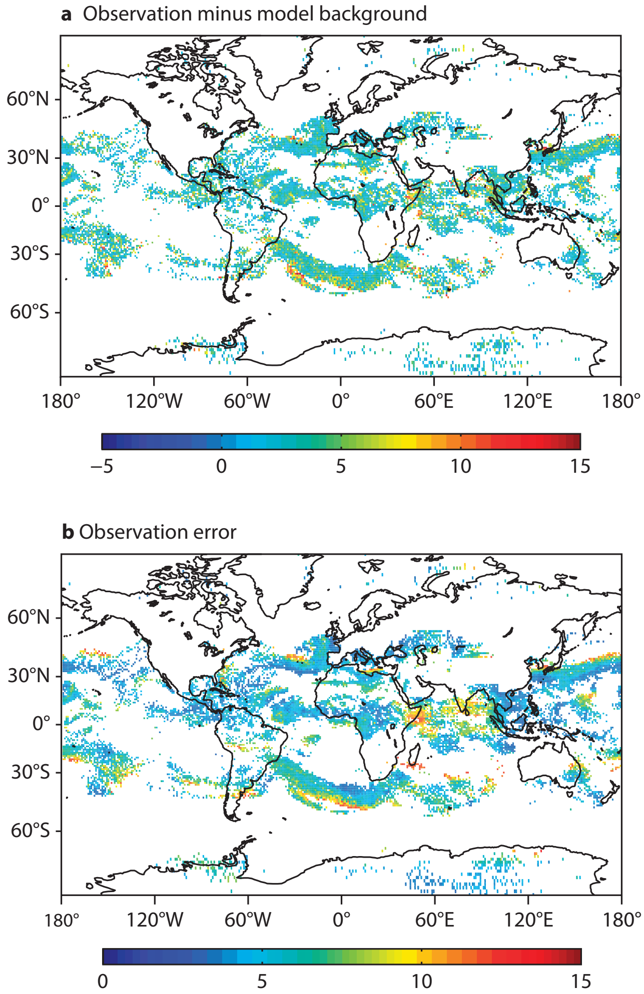


Figure 1 (a) Mean observation minus model background difference and (b) mean observation error for the zonal component of cloudy water vapour AMVs for levels 100–400 hPa at 12 UTC on 1 June 2012.

Revised quality control

Before an observation is accepted to be used in the model analysis it goes through several quality control steps. One of these is the model first-guess check where observations are compared with their model counterparts. If an observation deviates from the model first-guess field more than a pre-defined limit it is rejected.

Original checks

Traditionally the first-guess check has been very strict for AMVs in the ECMWF system. The rejection limits applied for AMVs are over three times tighter compared to the limits used for conventional wind observations, and the limits have also some geographical dependencies. In addition, in the current operational system the first-guess check is asymmetric: it is tighter for AMVs that under-report wind speed when compared to the model first-guess field. This feature has been implemented primarily to avoid that AMVs slow down the extra-tropical jets.

Figure 2 illustrates how the first-guess check operates. A scatter plot of observed wind speed versus first-guess wind speed is shown in the top left panel for Meteosat-10 cloudy water vapour AMVs at 100–400 hPa levels. The upper-right panel shows the scatter plot of AMVs which have been accepted by the first-guess check used in the current operational system. Outliers have been removed effectively and also the impact of the asymmetric check is clearly seen.

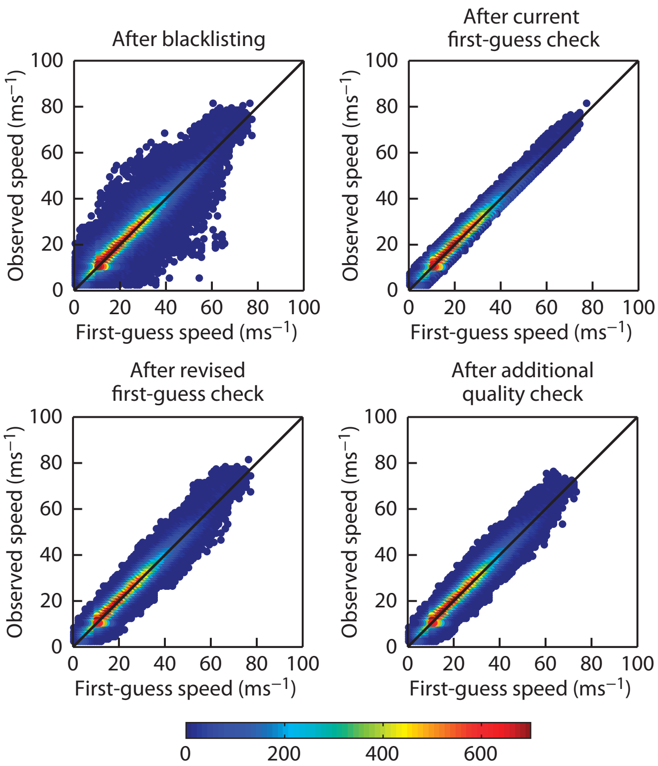


Figure 2 Demonstration of the operation of the model first-guess check. The upper-left panel shows Meteosat-10 cloudy water vapour AMVs at 100–400 hPa heights after blacklisting. The upper-right panel displays the AMVs after applying the current operational first-guess check, and the lower-left panel after the revised first-guess check. The lower-right panel shows AMVs after applying the additional quality criterion to limit the magnitude of the observation error due to height error to be smaller than four times the tracking error.

Revised checks

Introduction of the situation-dependent observation errors gives the opportunity to re-evaluate the first-guess check for AMVs. The situation-dependent observation errors allow a reduction in the weight given to observations in areas where wind shear is strong and the error in the height assignment can have a drastic impact, such as the regions with extra-tropical jets.

Several experiments have been conducted to investigate removing the asymmetric part of the AMV first-guess check, and the other ad hoc geographical adjustments to the rejection limits. In addition, variations of the rejection limits have been tested to allow more AMV observations to pass the first-guess check than in the current operational system. Results of the experiments reveal that with the situation-dependent observation errors it is possible to (a) use a symmetric first-guess check for AMVs similar to that used for conventional wind observations and (b) remove the geographical dependencies in the rejection limits for AMVs. However, rather tight rejection limits need to be retained, as relaxing the rejection limits results in degraded forecast quality.

The lower-left panel of Figure 2 illustrates how the revised first-guess check operates. Also the revised first-guess check effectively removes outliers but the spread in the scatter plot is symmetric and notably wider compared to the operational first-guess check.

New quality control criterion

Furthermore, a new quality control criterion has been investigated. The criterion limits the magnitude of the observation error due to error in height assignment to be smaller than *n* times the tracking error. The new quality control criterion is motivated by the fact that the height assignment errors are likely to be more correlated spatially, and such correlations are currently neglected in assimilations.

Experimentation with the criterion with varying values for *n* indicates that it is an effective tool to detect and reject suspect observations. However, a too tight criterion results in rejecting too many good quality observations and leads to negative forecast impact. In the configuration to be implemented operationally *n* is set to 4. The value has been chosen after trial and error based on a set of model experiments. This allows AMVs with an observation error up to 8–13 ms^{-1} to enter the analysis, depending on the height of the AMV.

The effect of using the new quality control criterion is illustrated in the lower-right panel of Figure 2. The criterion rejects on average 1% of the AMVs on top of the revised first-guess check.

Impact on model analysis and forecasts

The impact of using the situation-dependent AMV observation errors and the revised quality control described above has been investigated for two 3-month periods. The winter period covers 1 January to 31 March 2012, and the summer period 1 June to 31 August 2012. IFS cycle 38r2 at a T511 resolution, 137 levels, and 12-hour 4D-Var has been used in the experiments. All operationally assimilated conventional and satellite observations are used. In the control experiments AMVs are treated as in the current operational system, and in the test experiments the revised system is used.

Figure 3 shows the relative change in the number of used AMVs compared to the control experiment for the northern hemisphere extra-tropics (left panel), tropics (middle panel), and southern hemisphere extra-tropics (right panel). Also shown is the number of AMVs used in the control experiments. Both the winter and summer periods behave similarly and in Figure 3 the periods are combined. The results show that:

- Below 850 hPa the number of AMVs used in the control and test experiments is almost the same.
- In the extra-tropics at higher levels the number of used AMVs is increased in the revised system by 5 to 15% depending on height and hemisphere.
- In the tropics some increase in the number of used AMVs is seen between 850 hPa and 500 hPa but at higher levels the number of used AMVs is almost the same for the control and test experiments.

Overall in the revised system the number used AMVs increased by about 4% compared to the current operational system.

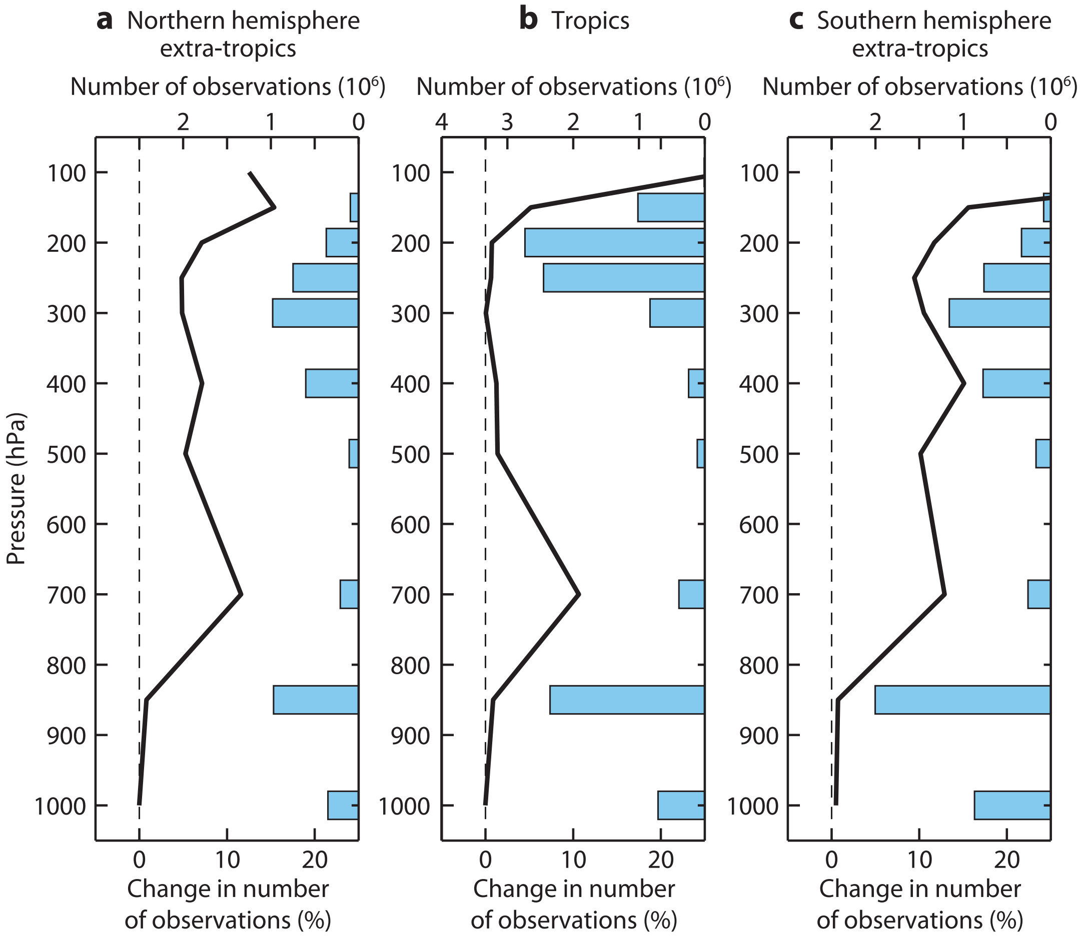


Figure 3 The relative change (percentage: black solid line) in the number of used AMVs compared to the control experiment for (a) northern hemisphere extra-tropics, (b) tropics and (c) southern hemisphere extra-tropics. The pale blue bars indicate the number of AMVs used in the control experiments. The periods are 1 January to 31 March 2012 and 1 June to 31 August 2012.

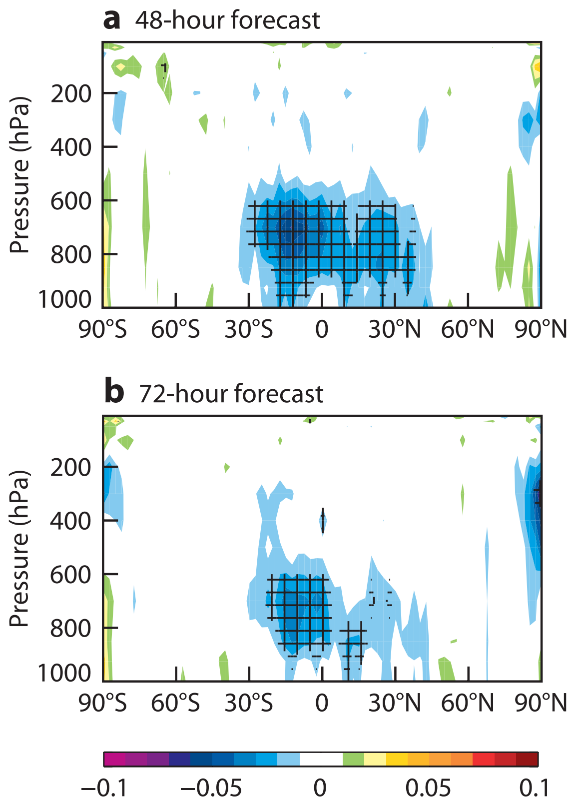


Figure 4 Zonal plot of the normalised difference (test experiment minus control) of the root-mean-square errorfor (a) 48-hour and (b) 72-hour wind forecasts. Verification is done against each experiment's own analysis. The period is 1 June to 31 August 2012.

Differences in the mean wind analysis between the control and test experiments are mainly seen in the tropics and the magnitude is typically less than 0.5 ms^{-1}. This is a positive result, as it supports that the asymmetric part of the first-guess check can be safely removed without slowing down the extra-tropical jets.

The revised assimilation of AMVs leads to a significant positive forecast impact below 500 hPa especially in the tropics but also at higher latitudes. Figure 4 shows zonal plots of the normalised difference in the root-mean-square error for 48- and 72-hour wind forecasts for the summer period. The difference is calculated as test experiment minus the control experiment (i.e. blue shades indicate positive impact and green and red shades negative impact). The verification has been applied against each experiment's own analysis. The results are similar for the winter period. Verification against observations also shows positive impact especially over the northern hemisphere extra-tropics.

Overall the use of the situation-dependent observation errors and the revised first-guess check clearly improves the use of AMVs in the ECMWF system with a positive impact on the model forecasts.

Concluding remarks and future plans

Situation-dependent observation errors together with a revised quality control for AMVs will be introduced in IFS cycle 39r1. Experimentation with the revised system shows that it is possible to get significant positive impact on forecasts from an existing observation type by refining the way it is exploited. Also the number of used AMVs will slightly increase compared to the current operational usage. The most important change is that the uncertainties in the AMV height assignment are taken into account in the observation errors, leading to more realistic use of the observations.

Work on further improving the use of AMVs continues. One area is the height allocation and interpretation of AMVs. For instance, as a part of our study regarding height assignment errors, we found indications of height assignment biases that varied, for instance, with level and between satellites. These could be investigated further and possibly corrected.

The traditional interpretation of AMVs is a single-level point estimate of wind at the pressure level assigned to the AMV during the derivation. A recent study by *Hernandez-Carrascal & Bormann* (2012) has investigated alternative ways of interpreting AMVs using a simulated framework. Simulated AMVs were considered, for example, as an average wind over the cloud layer. Also, other studies have suggested some benefit from interpreting AMVs as layer averages. Work is ongoing to further investigate these aspects in the data assimilation context.

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New microwave and infrared data from the S-NPP satellite

NIELS BORMANN, TONY MCNALLY

With the launch of the Suomi National Polar Partnership (S-NPP) satellite in October 2011 the USA made its first step into a new era of operational meteorological polar-orbiting satellites. The satellite carries a suite of new instruments, including a microwave radiometer, a hyperspectral infrared interferometer, and an ozone instrument; together these instruments are primarily aimed at providing temperature, humidity and ozone soundings. S-NNP is the successor of the extremely successful NOAA-series of satellites whose ATOVS data has been providing essential input to operational NWP systems for many years. Calibration and validation of the radiance data from S-NPP in the ECMWF system shows that the data is generally of good quality, and assimilation of the data leads to some improvements in forecast skill.

To assist the reader, Box A gives the full name of instruments referred to in this article.

A

Instruments onboard the S-NPP satellite

- ATMS: Advanced Technology Microwave Sounder
- CrIS: Cross-track Infrared SounderOMPS: Ozone Mapping Profiler Suite

Instruments onboard other satellites

- AMSU-A: Advanced Microwave Sounding Unit-A (onboard NOAA-15–19, MetOp, and Aqua)
- AMSU-B: Advanced Microwave Sounding Unit-B (onboard NOAA-15 – 17)
- MHS: Microwave Humidity Sounder (onboard NOAA-18 – 19 and MetOp)
- HIRS: High-resolution Infrared Sounder (onboard NOAA and MetOp satellites)
- ATOVS: Advanced TIROS Operational Vertical Sounder: suite of AMSU-A, AMSU-B/MHS, HIRS instruments
- AIRS: Atmospheric Infrared Sounder (onboard Aqua)
- IASI: Infrared Atmospheric Sounding Interferometer (onboard MetOp)

ATMS

The Advanced Technology Microwave Sounder (ATMS) on S-NPP provides temperature and humidity sounding capabilities in the microwave part of the Earth's spectrum. ATMS continues the heritage of AMSU-A and MHS (similar to AMSU-B) which have been flown on the NOAA platforms as well as on the European MetOp satellites. The temperature sounder AMSU-A in particular has been established as one of the leading satellite instruments contributing to today's forecast skill. Microwave data is less affected than infrared data by the presence of clouds, therefore providing important information in these areas. Further ATMS-like instruments are planned for follow-on missions for S-NPP, and a successful exploitation of ATMS data for NWP is hence of paramount importance to maintain or improve forecast quality. Also, while currently five AMSU-A instruments are being assimilated, these are 4–15 years old and have a design lifetime of three years, so failure or instrument degradation of some of these instruments can be expected in the near future.

The temperature sounding channels of ATMS are similar to those of AMSU-A, but with important differences in the detailed channel specifications: ATMS samples the atmosphere more densely than AMSU-A and with a smaller footprint, but each individual ATMS measurement is less accurate than that of AMSU-A. By design, only a spatially-averaged version of the data achieves similar accuracies to the ones we are used to with AMSU-A. This aspect is very important for NWP, as errors in short-term forecasts from today's NWP systems are rather small (of the order of 0.1 K for tropospheric channels), such that the accuracy requirements for temperature-sounding radiances are rather high. In the following, we therefore consider only spatially-averaged ATMS data, obtained by averaging nine adjacent footprints. After averaging, the instrument noise for the tropospheric channels is expected to be around 0.15 K.

To assess the general quality of the ATMS data, we first compare brightness temperature observations unaffected by cloud to short-term forecast equivalents. Given the accuracy of the short-term forecast, this is a very stringent test, benefitting from the wealth of other observations assimilated in the ECMWF system. It allows significant instrument anomalies to be detected easily. Such comparisons are an integral part of the international calibration/validation of the data.

Comparisons against short-term forecasts show that the ATMS data achieves an overall accuracy that is similar to or better than that of AMSU-A and MHS (Figure 1), and the instrument is well within specification. For the tropospheric channels (ATMS 6–9), ATMS performs clearly better than all the AMSU-A instruments currently assimilated; this is particularly good as some of these channels have already failed for the AMSU-A instruments currently in orbit. Another attractive feature of ATMS is that the scan biases vary very smoothly with scan position, even out to the outermost scan positions, for which AMSU-A tends to show complicated biases that make assimilation more difficult (Figure 2). Combined with the wider swath from ATMS, this means a significant gain in the number of observations that are considered for assimilation.

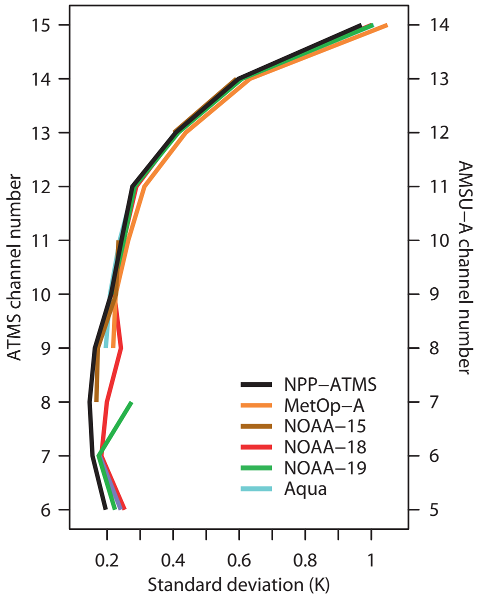

Figure 1 Performance of the ATMS instrument in comparison to AMSU-A: Standard deviations of first-guess departures for ATMS in comparison to AMSU-A instruments carried on Aqua and the NOAA satellites, and MHS on MetOp-A, all of which are currently assimilated in the ECMWF system.

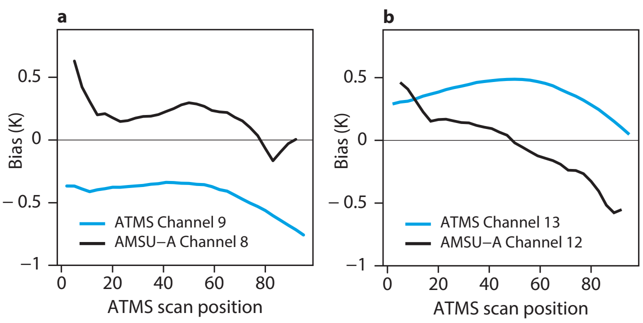

Figure 2 Comparison of scan biases for ATMS and AMSU-A: Mean differences between observed and simulated brightness temperatures as a function of scan position for (a) ATMS channels 9 and the equivalent channel 8 from AMSU-A onboard NOAA-18 and (b) ATMS channel 13 and the equivalent channel 12 from AMSU-A onboard NOAA-18.

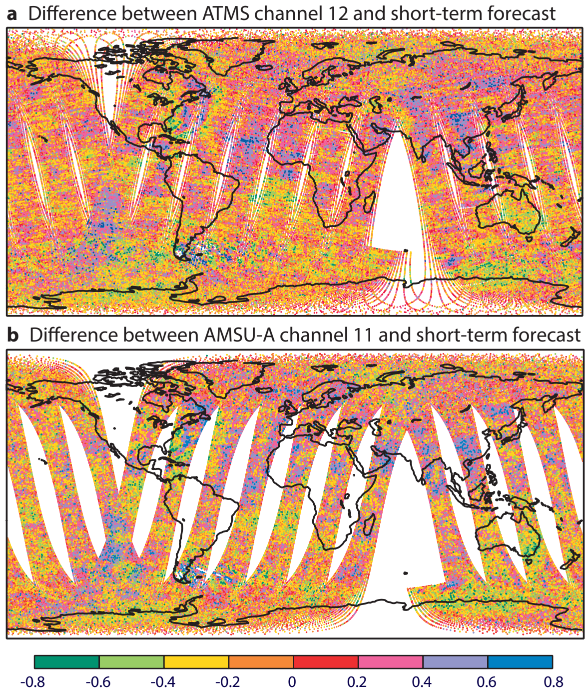

Figure 3 Cross-track striping feature in ATMS data: (a) Map of differences between observations and short-term forecast equivalents for ATMS channel 12 for the 6-hour period around 00 UTC on 2 July 2012. (b) As (a), but for the equivalent channel 11 from AMSU-A onboard NOAA-19.

Closer inspection, however, reveals a small anomaly in the data which is not present for AMSU-A. Maps of differences between observations and short-term forecasts show a scanline-dependent striping (Figure 3). While the effect is very small, such signatures are clearly not visible for AMSU-A data. Further investigations by the calibration/validation team indicate that this feature is likely due so-called 1/f-noise of an amplifier used in the instrument. The instrument nevertheless still performs within specification, but it is unlikely that this error can be corrected through advanced processing of the data. For the assimilation of the data this means that a proportion of the error in the observations is correlated spatially and between channels. Such error correlations are usually neglected in the assimilation, and this feature of ATMS means that the data should not receive quite as much weight in the analysis as AMSU-A. However, given the excellent performance of the instrument otherwise, this was not considered a show-stopper.

Added to the suite of operationally assimilated observations, ATMS shows a neutral to positive forecast impact in the ECMWF system, with particularly positive impact for the short-range over the southern hemisphere (Figure 4). This is an excellent result, given that the system already assimilates data from five AMSU-A and three MHS instruments, with some of these in orbits very similar to that of S-NPP. It highlights that benefits are still to be gained with additional observations, and that ATMS is clearly a capable complement to today's global observing system.

ATMS data has been assimilated operationally in the ECMWF system since 25 September 2012.

CrIS

The Cross-track Infrared Sounder (CrIS) is a Fourier transform spectrometer that measures atmospheric infrared radiation in 1,305 spectral channels. These cover three wavelength regions: long-wave (9.14–15.38 microns), mid-wave (5.71–8.26 microns) and short-wave infrared (3.92–4.64 microns). CrIS provides information on atmospheric temperature, humidity and chemical composition. On the ground a typical CrIS pixel has a diameter of 14 km, and 30 Earth views consisting of a 3×3 array of CrIS pixels make up a single scan line across the 2,200 km swath. The CrIS is the contribution of the USA to operational hyper-spectral infrared sounding with the European contribution being the IASI instrument onboard the MetOp satellites.

As with ATMS, the quality of the CrIS observations has been evaluated by comparison with radiances computed from the ECMWF short-range forecast. Statistics for CrIS evaluated over a one month period are shown in Figure 5 where, for comparison purposes, the equivalent statistics for IASI are also displayed. It can instantly be seen that departure standard deviations are significantly lower for CrIS (typically a factor of two compared to IASI) indicating that the observations have a very low radiometric noise. Of course the comparison is not a fair one as IASI measures radiation with a much finer spectral resolution (8,463 spectral intervals compared to the 1,305 of CrIS), but the results do confirm that the CrIS radiance observations are of extremely high quality.

Assimilation experiments have been run where CrIS data is used in a very similar manner to IASI and AIRS data. Initially a very modest set of just 65 channels has been actively assimilated – taking into account that S-NPP sits in an almost identical orbital plane to the Aqua satellite and that 165 channels are already assimilated from AIRS. With observation errors set to the same values currently used for IASI (arguably conservative given the much lower noise levels) the impact of CrIS was rather neutral with some very slight positive impact. However, any attempts to increase the weight given to the CrIS radiances in the analysis by reducing observation errors closer to levels consistent with the departure statistics produces significantly worse results. Similarly, attempts to increase the number of channels assimilated results in degraded analyses and forecasts.

Research continues to understand the factors that are currently limiting the impact of CrIS. The most likely candidate is the presence of inter-channel error correlations that are not currently modelled in the ECMWF analysis. While the noise levels in the data are very low, certain processing of the observed spectra by the data provider correlates the error in one channel with its neighbours (through a process known as apodisation). Also, as noise levels in the observations are so low, correlated contributions from other sources (such as radiative transfer model error and errors of representativeness) become more significant in the overall radiance error. Experiments where these correlations are estimated and explicitly taken into account are in progress.

Interaction with space agencies

The experience with S-NPP highlights again the fruitful role that ECMWF plays during the calibration and validation phase for new satellite data. The feedback provided is not only important for the instruments under evaluation, but also helps to shape future satellite missions. We will continue our strong links with satellite agencies which are vital in this respect.

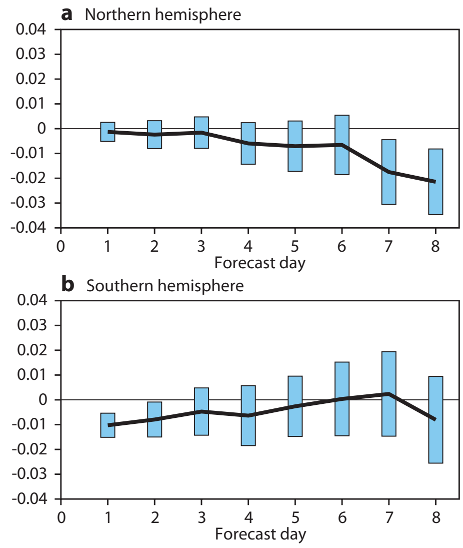

Figure 4 Positive impact from adding ATMS data to the assimilation: Normalised differences in the root-mean-square error (RMSE) of the 500 hPa geopotential for (a) the northern and (b) the southern hemispheres as a function of forecast range from a total of 102 cases from December 2011 to February 2012 and July to August 2012. Error bars indicate 95% confidence intervals.

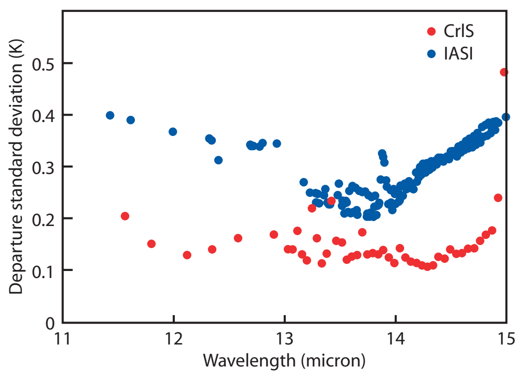

Figure 5 Performance of the CrIS compared to IASI: Standard deviations of radiance departures for CrIS and IASI for the long-wave region of the infrared spectrum. Statistics are evaluated over one month (August 2012).

Cold spell prediction beyond a week: extreme snowfall events in February 2012 in Italy

FEDERICO GRAZZINI

Recent winters will be remembered in Italy for the return of substantial snowfall episodes after there being very few in the 1990s. The winters of 2004, 2005, 2010, 2012 and 2013 are characterized by abundant snowfalls, not only in the mountains but also at low levels (e.g. reaching the Po valley and other lowland areas of northern and central Italy). These events are often associated with blocking patterns. A growing number of studies show that the frequency of blocking patterns is increasing over land in the northern hemisphere in response to diminishing Artic sea ice. More blocking patterns and larger waves lead to an increased probability of cold surges over large parts of northern continents (*Liu et al.*, 2012).

In Italy, and in particular in Emilia-Romagna, February 2012 can be considered a good example of what has occurred in recent winters, especially in terms of extreme variability. Therefore it is worthwhile studying in detail the weather of that month. The beginning of the 2011/12 winter was very dry and warm until the end of January when a large retrogressive wave (Figure 1) brought very cold air from Eurasia into the Mediterranean. This situation, which persisted for about 15 days, transformed the winter weather; it marked an abrupt swing from warm towards very cold conditions. We recorded up to 1 m of snow in some lowland areas (see the photos in Figure 2) and up to 3 m in the mountains of Romagna, falling mainly in two very heavy precipitation events. Towards the end of February the cold weather rapidly turned first towards normal conditions, and then became even warmer and drier. March was one of the warmest and driest months ever recorded in spring with +4°C temperature anomaly in Emilia-Romagna with respect to the 1991–2010 climate.

This brief introduction highlights the importance of having an early prediction of sudden changes in weather in an emerging scenario of enhanced variability and an increase in extreme events. In this article we will give a brief overview of the ECMWF forecasts of the onset, evolution and demise of the February 2012 cold spell used by ARPA-SIMC (Agenzia Regionale per la Protezione dell'Ambiente – Servizio Idro-Meteo-Clima), the Regional Weather Service of Emilia-Romagna. Particular emphasis will be given to the value of the forecasts for the planning and handling of an unprecedented weather situation (*Nanni*, 2012).

AFFILATION

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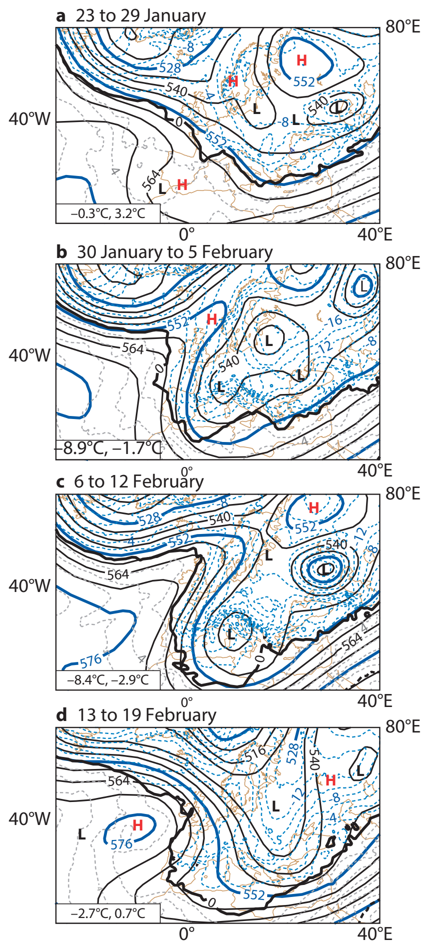

Figure 1 Observed weekly mean 500 hPa geopotential height (solid black lines) and 850 hPa temperature (blue dashed contours every 4°C) for (a) 23 to 29 January, (b) 30 January to 5 February, (c) 6 to 12 February and (d) 13 to 19 February 2012. The boxes in the bottom-left corner indicate the weekly mean 850 hPa and 2-metre temperatures computed for the Emilia-Romagna region. Note the strong temperature drop that occurred at the beginning of February due to the retrogressive extension toward Europe of a large trough.

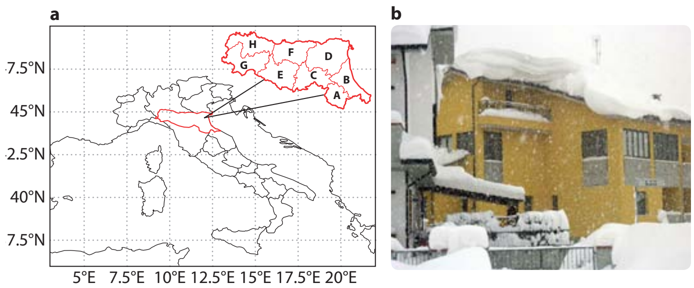

Figure 2 (a) The Emilia-Romagna region and its subdivision into eight warning regions. (b) Picture taken in S. Carlo (about 100 m above sea level) near Cesena (warning area A) during the second big snowfall event in February 2012. The snow depth is about 1 metre.

Long-range indications

In mid-January we observed a rapid transition of the hemispheric circulation, from zonal toward a more meridional flow characterized by larger Rossby waves with low wavenumbers (3–4). It is interesting to examine to what extent the ECMWF monthly forecasts captured this transition.

Figure 3 shows the observed 500 hPa geopotential anomaly for the calendar week 30 January to 5 February along with the ECMWF ensemble-mean forecasts for the same period from 5 January (days 26–32), 12 January (days 19–25), 19 January (days 12–18) and 26 January (days 5–11). The transition to more meridional flow was apparent in the monthly forecast a few weeks in advance (i.e. from 19 January) with a correct positioning of a strong ridge over the Norwegian Sea and Scandinavia The forecast from 19 January was also somewhat successful in maintaining the negative geopotential anomaly for the following week (6–12 February, week 3 of forecast) as shown in Figure 4.

Now consider the impact of the prediction of a transition from zonal to meridional flow on the surface temperature. Figure 5 compares the observed 2-metre temperature anomaly for 6 to 12 February with the forecasts for that period from 12 January (days 26–32), 19 January (days 19–25), 26 January (days 12–18) and 2 February (days 5–11). It shows that there was some weak evidence for the cold temperature anomaly three weeks ahead (i.e. from 19 January) but displaced over northern Europe. A significant shift towards very cold conditions and correct positioning of the cold anomaly could be traced back to the forecast issued on 23 January: this further enhanced the signal for a significant cold anomaly in week 2 (30 January to 5 February) and indicated its persistence into week 3 (6 to 12 February).

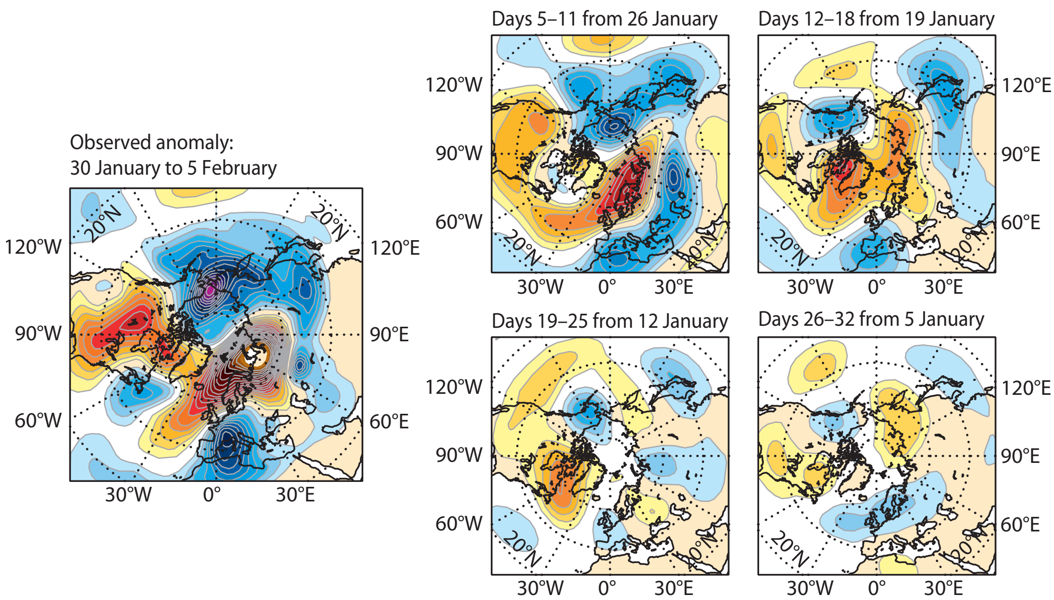

Figure 3 Comparison of the observed 500 hPa geopotential anomaly for 30 January to 5 February with the forecasts valid for the same period from 5 January (days 26–32), 12 January (days 19–25), 19 January (days 12–18) and 26 January (days 5–11).

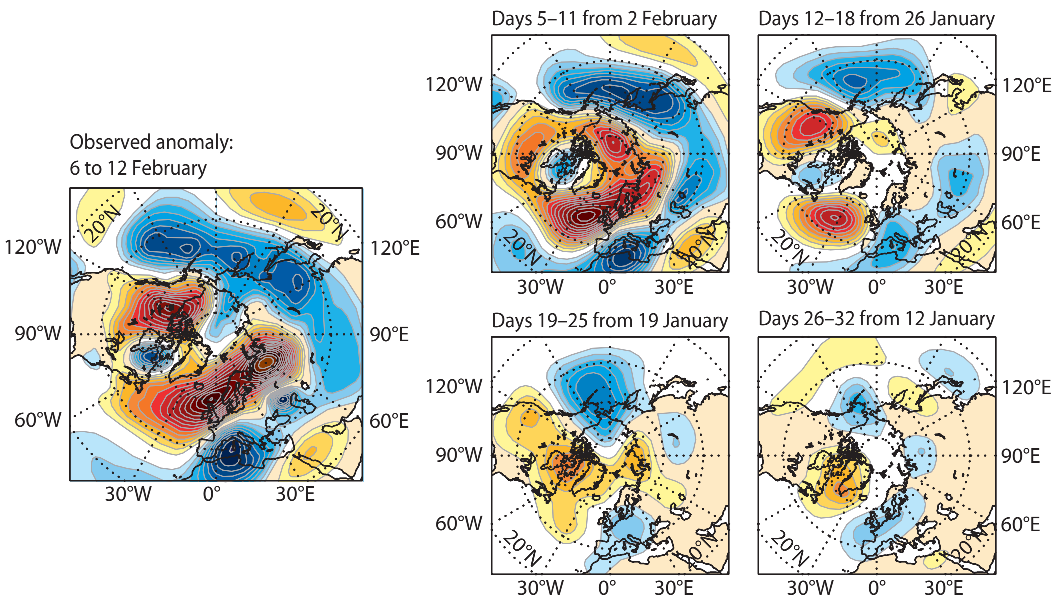

Figure 4. As Figure 3 but for the period 6 to 12 February with forecasts from 12 January (days 26–32), 19 January (days 19–25), 26 January (says 12–18) and 2 February (days 5–11).

Based on the ECMWF monthly forecast from 19 January and the more recent 15-day ensemble forecast (ENS) from 23 January, ARPA-SIMC issued the following long-range outlook valid for the week from 30 January to 5 February 2012.

"In the period under consideration the large-scale atmospheric flow will push toward Italy very cold air masses of continental origin. This type of meteorological situation could bring typically wintry conditions over our region with freezing temperatures and snowfalls even at lower grounds....".

At that time we were formulating our long-range bulletin only once a week, every Monday, based on the previous Thursday run. In this particular case we were not able to use the forecast from 23 January, though subsequently it was found that this gave an even better indication of the severity of the cold spell. Also, based on this experience, in 2013 we revised the scheduling of our long-range outlook by going from one issue per week (on Monday) to twice per week (on Friday and Tuesday).

Medium-range indications

Given the very good indications in the long-range forecasts of a cold spell, in the following days much attention was dedicated to using the medium-range predictions to better quantify the impact of the predicted cold advection. Since 27/28 January, it was clear from the medium-range forecasts that there was an increasing possibility of major snowfall over the Emilia-Romagna region associated with very low temperatures. In the following days the signal intensified leading to the issue of an alert for heavy snowfall on 30 January covering the period 31 January to 2 February. The timing of the event occurred as indicated by the forecast, although the intensity was somewhat underestimated. About 45 cm of dry powdery snow fell in two days (1 and 2 February) in Bologna city and up to 1 m on the Apennines.

This was the first snowfall event. Despite the actions taken in response to the alert issued on 30 January, there were several problems (e.g. school and road closures due to the unusual amount of snow), especially for the southern part of our region.

In places weak to moderate snow kept falling in the next few days making it difficult for clearance operations. Just few days later, on 5 February, the ENS indicated a second, deep and cold cyclonic system approaching from the north-east, bringing more heavy snow between 10 and 12 February. At this stage, with civil protection authorities still in the process of restoring normality, local governments were faced with another major problem – there was a moderate likelihood of having to deal with another extreme event, just 10 days after the previous one, that would have even greater impact in terms of snow accumulation.

In this unusual situation it became a high priority to issue a warning as early as possible to provide the time required (a few days) to move extra rescue workers and specialized snow clearing equipment, such as snow turbines, from neighboring alpine regions. In this context the medium-range forecast acquired great importance for planning the deployment of rescue teams. It is also worth mentioning that the issuing of an early warning was needed due to the high risk of collapse of many snowpacked roofs, especially in rural buildings; with a new fresh snowfall event in the forecast, removing the existing snow from the roofs became a priority (Figure 6). A correct medium-range forecast became, therefore, a key factor for the optimization of the resources and activities.

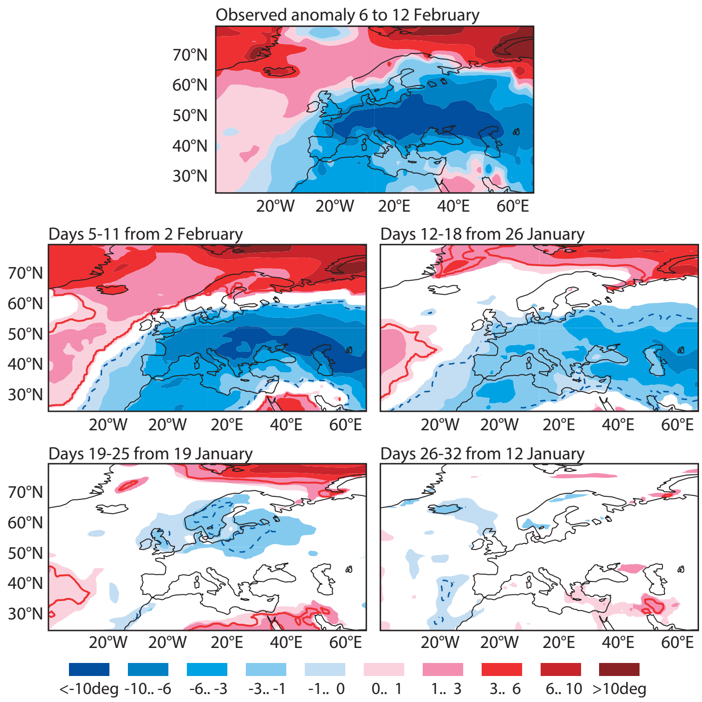

Figure 5 Comparison of the observed 2-metre temperature anomaly for 6 to 12 February with the forecasts for that period from 12 January (days 26–32), 19 January (days19–25), 26 January (days 12–18) and 2 February (days 5–11).

Figure 6 A colleague rushing to clear packed snow because of fear the roof would collapse under the weight of incoming new snow (taken on the 7 February before the second big snowfall).

Our forecasting operations department was requested to provide civil protection warnings at longer lead time than the usual 48 or 24 hours. Being forced to push further ahead with the alerting procedures, we decided to rely more on probabilistic products, both from ECMWF's ENS and COSMO-LEPS (see *Montani et al.*, 2011 for a description of the COSMO- LEPS system). Having noticed the good consistency amongst subsequent probabilistic forecasts and relying mostly on ENS and COSMO- LEPS outputs available on 7 February (see Figure 7), we issued a first alert to the civil protection authorities; this provided a warning, 3 days before the beginning of the event, that in the next 4–5 days exceptional snowfalls were likely to affect the same area already hit a few days earlier. Box A has a translation of the full text sent to the Regional Civil Protection.

The severity and rarity of these two consecutive events made it very challenging to decide whether to issue a second warning for more than 1 m of fresh snow in 48 hours. Should we announce, with an unusual 3-day warning period, something that we have never seen in output from an NWP model for our region? At the end, based on the available forecasts, we decided to issue the warning.

A

The message sent to Regional Civil Protection on 7 February 2012

"A descent of a cold trough from continental Europe toward central Europe and northern Italy, will bring a new deterioration of weather conditions especially between Friday 10/02 and Saturday 11/02. On these two days, the probability of having heavy and widespread snowfall is high for all parts of the region with larger amounts more probable in the south-eastern part of the region. For this area (warning area A) there exists a ***moderate probability*** *that the 48 h total of fresh snowfall could reach up to 1 m adding to the snow that is already on the ground. Temperatures will stay well below zero with a further decrease during the passage of the trough. Winds will be sustained from the north-east."*

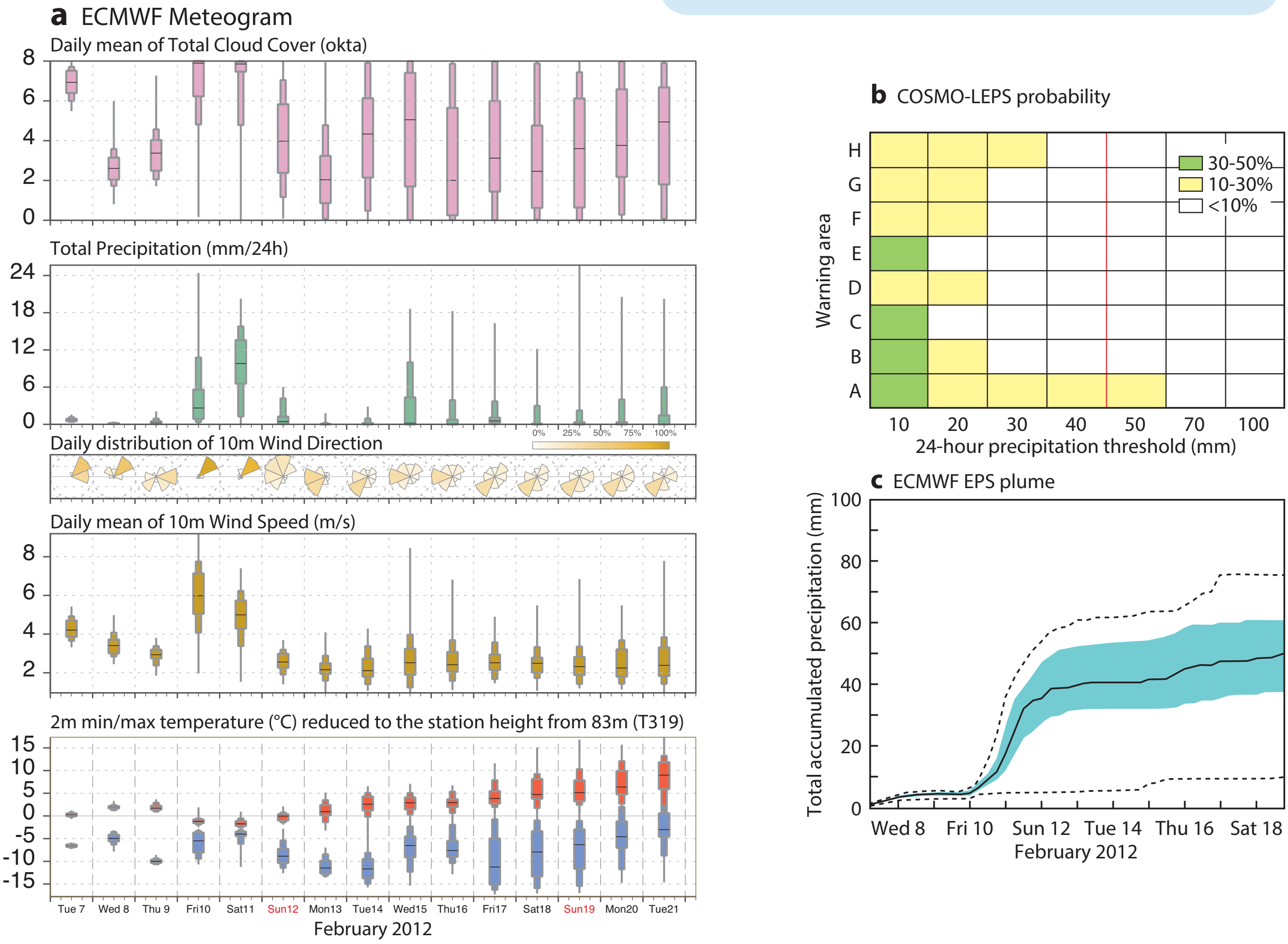

Figure 7 Some probabilistic products from ECMWF-ENS and COSMO-LEPS used as a basis for issuing a warning on 7 February of heavy snowfall in the coming days. (a) ENS 15-days meteogram valid for a location in the southern part of the region. (b) COSMOS-LEPS 5-day forecast, valid for 11 February, showing the probability of exceedence of the 24-hour precipitation thresholds (x-axis) and the warning areas (y-axis). A low probability of a very high threshold of 24-hour precipitation (all falling as snow) were evident for areas A and C (the area mainly affected) in the five-day forecast from COSMO-LEPS. (c) ECMWF EPSplume showing the total accumulated precipitation during the forecast period. Upper dashed line indicates the 90th percentile of the forecast distribution, the blue line corresponds to value greater than 25th percentile and less than 75th percentile and the dashed low line indicates the 10th percentile. The middle black line is the median.

The day after we issued the alert, the meteorological briefing was extraordinarily well attended, not only by civil protection operators but also by high-level decision makers, such as the regional governor and some members of the regional council. They were stunned at hearing of the possibility of a second massive snowfall, possibly bigger than the one that happened only ten days earlier.

The forecasts turned out to be very good both in terms of quantity and timing. From a weather-risk management perspective, the issuing of the warning 3 days before the event was extremely valuable. It gave enough time for the regional and national civil protection authorities to deploy rescue teams in advance in the part of the region that we thought would be the hardest hit. This planning was done on the basis of the very successful combination of low- and high-resolution probabilistic forecasts (ENS and COSMO-LEPS) and ECMWF's high-resolution forecasts (HRES). In particular the combined use of these different kind of systems allowed us to:

- Estimate at longer lead time (6 to 7 days) the probability of occurrence of significant snowfall over our region (mainly from ENS).
- Estimate the probability of snowfall exceeding a specific threshold for sub-areas allowing a better definition of which areas to be warned (mainly from COSMO-LEPS for 4 to 5 days before the event).
- Further specify the expected amount of snowfall over various sub-areas 1 to 2 days in advance from deterministic forecasts (mainly from HRES and COSMO-I7/COSMO-I2 which have horizontal resolutions of 7 and 2.8 km).

Note that, if we had only deterministic forecasts, it would have been impossible to estimate forecast uncertainty, while if we had only ensemble forecasts we would have underestimated the amount of snow. Combining information from probabilistic and deterministic forecasts was very successful and helped the population deal with extreme weather conditions.

Improving forecasts through collaboration

ARPA-SIMC is committed in improving the forecasting of high impact events as well as being able to predict abrupt transitions between weather regimes. This will allow regional resources to be managed more effectively. Regarding this aspect, we are interested in developing methods to exploit the 'residual' predictability beyond one week lead time by fostering collaboration with ECMWF and other Italian research institutions such as the Institute of Atmospheric Sciences and Climate (ISAC-CNR) in Bologna.

In this context it is worth mentioning two projects in which the author and other colleagues of ARPA-SIMC are involved.

- Collaboration with the ECMWF Predictability Division to develop an objective method for tracking Rossby wave trains to be applied at the ECMWF monthly forecasts.
- Involvement in an ECMWF Special Project SPIT-SPIA, in partnership with ISAC-CNR Italy, to investigate a multi-model ensemble approach for producing a monthly forecast.

FURTHER READING

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ECMWF Calendar 2013

Sep 2–6	Annual Seminar on 'Recent developments in numerical methods for atmosphere and ocean modelling'	Oct 28	Policy Advisory Committee (36th Session)
Oct 7–11	Training Course – Use and interpretation of ECMWF products for WMO Members	Nov 4–7	EUMETSAT NWP-SAF Workshop on 'Efficient representation of hyperspectral infrared satellite observations'
Oct 14–16	Scientific Advisory Committee (42nd Session)	Nov 12–13	Security Representatives' Meeting
Oct 17–18	Technical Advisory Committee (45th Session)	Nov 13–15	Computer Representatives' Meeting
Oct 21–22	Finance Committee (93rd Session)	Nov 18–20	14th Workshop on 'Meteorological operational systems'
Oct 22–24	Workshop on 'Parameter estimation and inverse modelling for atmospheric composition'	Dec 4–5	Council (80th Session)
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701 **Bonavita, M:** The role of satellite data in the forecasting of hurOn some aspects of the impact of GPSRO observations in global numerical weather prediction. *May 2013*

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