ECMWF Newsletter

Number 142 – Winter 2014/15

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

Copernicus
Europe's eyes on Earth

www.ecmwf.int/publications/newsletter

CONTENTS

PUBLICATION POLICY

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 The *ECMWF Newsletter* is not peer-reviewed.

Editor: Bob Riddaway

Typesetting and Graphics: Anabel Bowen with the assistance of Simon Witter.

Any queries about the content or distribution of the *ECMWF Newsletter* should be sent to Georg.Lentze@ecmwf.int
Guidance about submitting an article is available at www.ecmwf.int/en/about/news-centre/media-resources

CONTACTING ECMWF

Shinfield Park, Reading, Berkshire RG2 9AX, UK

Fax:		+44 118 986 9450
Telephone:	National	0118 949 9000
	International	+44 118 949 9000
ECMWF website		www.ecmwf.int

A Decade of Newsletters

Bob Riddaway has been the editor of the *ECMWF Newsletter* for ten years. As this is his last issue as editor before leaving the Centre, I have invited him to reflect on the highlights and themes that have been covered in the newsletter during his period as editor.

Alan Thorpe

When I retired from the UK Met Office I applied for a part-time job at ECMWF, which included being editor of the newsletter. I was offered the job, but the then Head of Research, Philippe Bougeault, was concerned that I might only want to stay for a few years. I assured him that would not be the case. However, I never imagined that I would stay for ten years.

My first issue of the newsletter, in spring 2005, included two topics that have become increasingly important: reanalysis and monitoring of the global Earth-system. Developments in these areas have underpinned the recent agreement for ECMWF to operate the Copernicus Atmosphere Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S). The same issue of the newsletter covered topics that continue to play a key role in developments at ECMWF: use of satellite data and ensemble-based predictions.

Later issues of the newsletter have included many articles about the effective use of satellite data such as GPS radio occultation measurements, and microwave and cloud-affected infrared radiances. Also the development of the data assimilation system has been recorded and in spring 2008 there was an article celebrating ten years of operational production of 4DVAR analyses. Later issues covered important developments such as the introduction of the Ensemble of Data Assimilations.

The many operational upgrades of the Integrated Forecasting System (IFS) have been described. For example, the impact of increasing the resolution, both in the horizontal and the vertical, of the high-resolution forecast (HRES) has been a constant theme. In addition, the improvements in parametrization, especially of cloud, precipitation and convection, have improved the quality of the forecasts. Developments in the ensemble forecast (ENS), both for the medium-range and longer timescales, have also been covered and the winter 2012/13 edition had many contributions celebrating 20 years of ensemble prediction at ECMWF.

As well as the scientific developments, the newsletter has covered the improvements in technology that underpin the Centre's activities. These include the enhancements to the High-Performance Computing Facility (HPCF) and the implementation of the next-generation Regional Meteorological Data Communication Network (RMDCN). Also improvements in Metview have been described, along with ways of presenting NWP output in a way that enhances its value to users (e.g. the Extreme Forecast Index).

In recent times, the newsletter has put more emphasis on describing how ECMWF output has given good indications of the likelihood of extreme weather events. Also there has been increased coverage of ECMWF's contributions to a variety of EU-funded projects and the benefits of working in partnership with other international organisations. Of course there are many other interesting topics that have been covered, but there is not space to mention all of them.

Finally I would like to thank everyone who has contributed to the newsletter. During my period as editor I have always had positive responses to any suggested changes, and this has added enormously to the enjoyment of the job. I now look forward to receiving the newsletter and keeping abreast of the scientific and technical developments that make ECMWF the world-leading NWP centre.

Bob Riddaway

ECMWF Copernicus Services – Open for Business

ERIK ANDERSSON, MARIA-CHRISTINA ANDERSEN, SYLVIA BAYLIS, HILDA CARR, NYALL FARRELL, VINCENT-HENRI PEUCH, JEAN-NOËL THÉPAUT

ECMWF will operate the Copernicus Atmosphere Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S) on behalf of the European Commission until the end of 2020. ECMWF has now started its first phase of recruitment to build up the Copernicus team, and in addition, has published Prior Information Notices in the Official Journal of the European Union (OJEU) for several Copernicus procurements.

Procurement

In 2015, ECMWF will be carrying out 20 to 25 procurements for organisations to work with it on the Copernicus Services. ECMWF is setting up a procurement portal where suppliers can register their interest in participating in any tenders and submit their tenders online. For the CAMS service the length of contracts will be mostly three years, but for C3S the contract length will vary depending on the development work required and the length of the pre-operational phase. Up-to-date information is provided via the ECMWF website at http://www.ecmwf.int/en/about/suppliers.

Recruitment

ECMWF's involvement in the Copernicus Programme will generate many new and exciting job opportunities to work at ECMWF. This will lead to the creation of a new department to manage and run the Copernicus Services and also strengthen key functions in existing departments. Some functions are to be operated jointly for CAMS and C3S, thus generating economies of scale and realising synergies between the two services. A wide variety of roles will be advertised, including scientists, analysts, legal officers, administrators, procurement specialists and IT professionals. Recruiting and training these new staff in order to cover the whole range of functions needed to manage and operate CAMS and C3S at ECMWF is an important target for the year ahead.

Phase 1 of the recruitment is underway (at the time of writing), and is expected to be completed by March 2015. The recruitment process for Phase 2 is expected to start in February 2015, and positions will be advertised on the jobs pages of the ECMWF website: http://www.ecmwf.int/en/about/jobs. Candidates will have easy access to the on-line application portal to apply for these roles.

Atmospheric Monitoring Service

The key driving principle for CAMS implementation is to ensure continuity of service for users while transitioning from the current (pre-operational) MACC-III precursor project to CAMS. In July 2015, CAMS will enter its next phase as all activities will be entirely funded by Copernicus and no longer by Horizon 2020 R&D funding. This step will be marked by the release of the first version of the CAMS website, which will replace the current MACC-III one at http://www.copernicus-atmosphere.eu.

Climate Change Service

The goal of C3S is to provide reliable information about the current state of the climate and its past evolution, and the likely projections in the coming decades for various scenarios of greenhouse gas emissions and other climate change contributors. Activities in 2015 focus on user consultation and user engagement for the development of the two-year C3S proof-of-concept stage, while setting up and implementing prototype elements and activating some functionalities of the climate data store (CDS) and sectoral information system (SIS).

Copernicus is the European Union's flagship Earth-observation programme. The programme ensures operational monitoring of the atmosphere, oceans, and continental surfaces, and will provide reliable, validated information services for a range of environmental and security applications.

Additional clustering time-periods available for dissemination and in MARS

LAURA FERRANTI

The ECMWF clustering is one of a range of products that summarise the large amount of information in the ensemble forecast (ENS). The clustering gives an overview of the range of different large-scale (synoptic) flow patterns over the North Atlantic and Europe that may occur during the forecast.

Cluster products have been produced operationally since 1992. A revised clustering was introduced in November 2010 to extend the products to different forecast ranges and to provide a framework for the flow-dependent evaluation of forecast performance. For more details on flow-dependent verification see *Ferranti, Corti & Janousek* (2014, *Q. J. R. Meteorol. Soc.*, DOI:10.1002/qj.2411).

The clustering algorithm takes the 51 forecasts (50 perturbed plus 1 control) and groups together those that show a similar evolution of the 500 hPa geopotential pattern over the North Atlantic and Europe (75°N–30°N, 20°W–40°E). For two ENS members to join the same cluster they must show a similar synoptic development at 500 hPa throughout a given time window. Clustering in this way, rather than on individual forecast days, retains the temporal continuity and synoptic consistency of the flow pattern. The clustering is made independently for four time windows: 72–96, 120–168, 192–240 and 264–360 hour forecast ranges.

When the current clustering was introduced in November 2010, only the cluster products for the 120–168 hour window were made available in dissemination and in MARS (to minimize disruption for users in transition from the previous cluster products). However, cluster products for all four time windows were made available on the ECMWF website:

http://www.ecmwf.int/en/forecasts/charts/medium/cluster-scenario

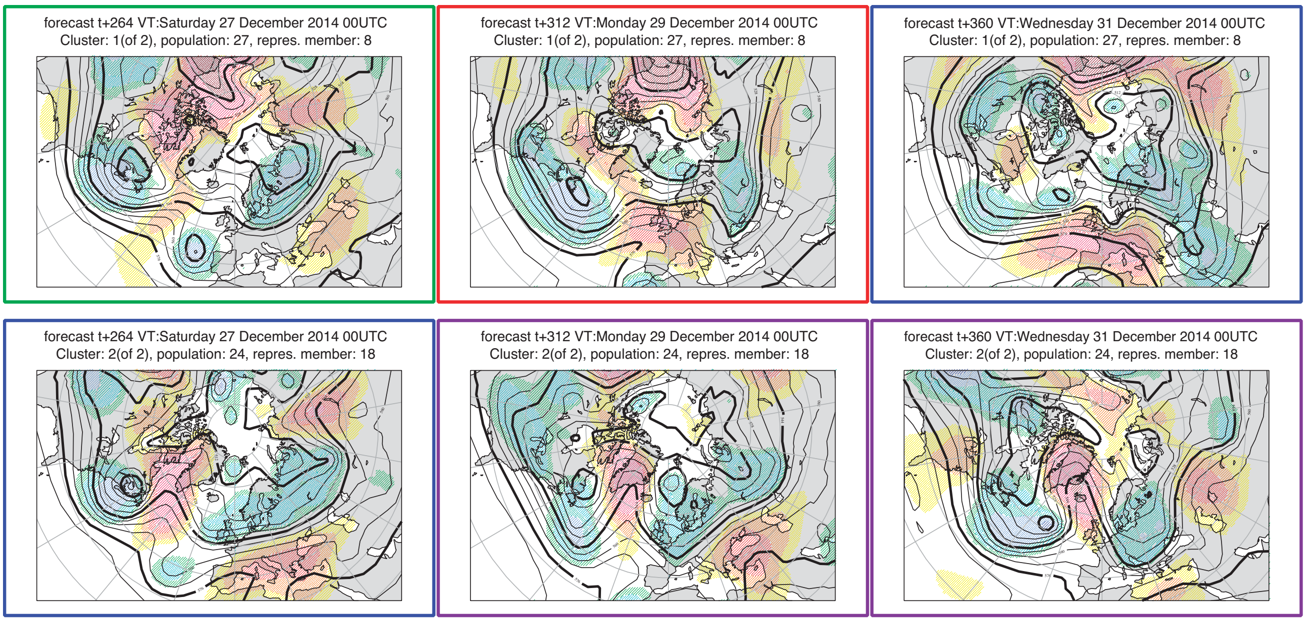
We have had positive feedback from users on the usefulness of the cluster products, and several requests for the dissemination of the clustering products for the three additional time windows. Therefore, on 8 December 2014 we started to disseminate and archive the clustering products for all four time periods. This is illustrated by the figure that shows two clusters for the 264–360 hour time window based on the ENS from 00 UTC on 16 December 2014.

Further information about the recent change can be found on the following web page:

http://www.ecmwf.int/en/forecasts/documentation-and-support/changes-ecmwf-model/cy40r1-summary/cycle-40r1-update-cluster

For more details on the clustering methodology used at ECMWF, see the article in *ECMWF Newsletter No. 127* (Spring 2011, 6–11) available from our website:

http://old.ecmwf.int/publications/newsletters/



Two clusters for the forecast from 16 December 2014. The forecast charts of 500 hPa geopotential and the geopotential anomaly (red: positive, blue: negative) show two clusters for the 264–360 hour time window. The two rows show the ENS members that best represent the two cluster centroids. There are two contrasting scenarios, almost equi-probable, for New Year's Eve (right-hand panels). The first scenario indicates a reinforced westerly flow across the Atlantic and Europe while the second indicates strong northerly flow with advection of cold air from the Arctic regions. The geopotential field is scaled by 100 and the anomaly field is based on a 29-year reanalysis climate.

Forecast performance 2014

THOMAS HAIDEN,
MARTIN JANOUSEK,
DAVID RICHARDSON

ECMWF maintains a comprehensive range of verification statistics to evaluate the skill of the forecasts. Each year, a summary of verification results is presented to ECMWF's Technical Advisory Committee (TAC). Their views about this year's performance of the operational forecasting system are given in the box.

The overall performance of the operational forecasts is summarised using a set of headline scores endorsed by the TAC, which highlight different aspects of forecast skill. Upper-air performance of the high-resolution forecast (HRES) in the extra-tropics is monitored through the anomaly correlation of 500 hPa geopotential. The most recent upgrade to the Integrated Forecasting System (IFS Cycle 40r1) in November 2013 led to a further increase in HRES skill relative to ERA-Interim, which is used as a reference to mitigate the effect of variations in atmospheric predictability.

In the case of the ensemble forecast (ENS) a 'dressed' ERA-Interim forecast, obtained by constructing a Gaussian probability distribution based on forecast errors, is used as a benchmark probability forecast. This is illustrated in the first figure, which shows that the relative skill of ENS for 850 hPa temperature (the second upper-air headline score) has substantially increased in recent years, most notably at shorter lead times. Due to improving reliability of the ENS, the relative skill has become more uniform across the day-3 to day-10 forecast range, reaching values between 25 and 30% in 2014. Forecasts from other centres, which are available from the TIGGE archive, also serve as a benchmark and show that ECMWF continues to maintain its lead over the other centres. The headline scores for precipitation also indicate an improvement of the HRES and ENS compared to the benchmark systems.

The two supplementary headline scores that address forecast skill for severe weather are the HRES tropical cyclone position error at forecast day 3 and the Extreme Forecast Index (EFI) skill of 10-metre wind speed at day 4. The tropical cyclone position error has slightly increased compared to the previous year but remains at a lowa level compared to the last 10 years. The EFI skill of 10-metre wind speed has reached its highest value so far. Also, the EFI skill of 24-hour precipitation has further increased in 2014 and reached its highest value so far.

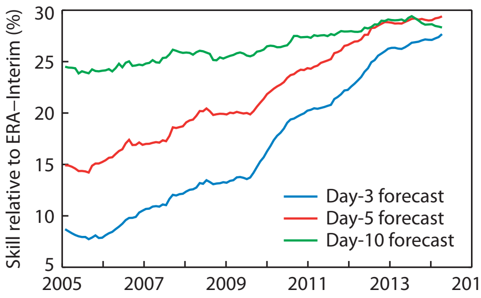
Using ERA-Interim as a reference allows direct comparison of the evolution of HRES skill for upper-air and surface parameters. The second figure shows that forecasts of mean sea level pressure and 500 hPa geopotential have improved the most, such that their skill at day 5 now exceeds that of ERA-Interim by about 20%. For 2-metre temperature and 10-metre wind speed, the lead over ERA-Interim is about one-half of that for upper-air fields. Total cloud cover forecast skill stagnated until about 2011 but is now increasing as well, due to various improvements made to the cloud parametrization.

The increase in cloudiness forecast skill is consistent with improvements in shortwave radiation fluxes seen in verification against satellite data.

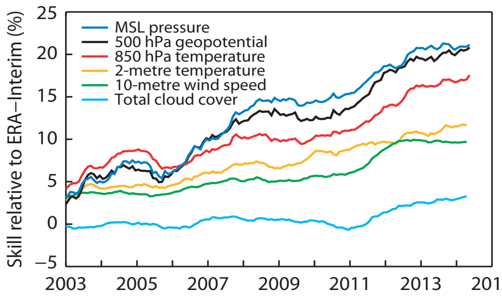
The complete set of annual results is available in *ECMWF Tech. Memo. No. 742* on 'Evaluation of ECMWF forecasts, including 2013-2014 upgrades', downloadable from http://www.ecmwf.int/en/research/publications. This document presents recent verification statistics and evaluations of ECMWF forecasts (including weather, waves and severe weather events) along with information about changes to the data assimilation/forecasting and post-processing system. Also the performance of the monthly and seasonal forecasting systems is assessed.

The following are other sources of information about verification and forecasting system changes.

- Verification pages on the ECMWF web server are regularly updated. They are accessible at: http://www.ecmwf.int/en/forecasts/tools-and-guidance/quality-our-forecasts
- Interactive plots showing inter-comparisons of global model forecast skill can be found on the WMO Lead Centre for Deterministic Forecast Verification (WMO-LCDNV) web page at: http://apps.ecmwf.int/wmolcdnv/
- All IFS cycle changes since 1985 are described at: http://www.ecmwf.int/en/forecasts/documentation-and-support/changes-ecmwf-model



Probabilistic skill of the ENS relative to the dressed ERA-Interim forecast. Results for temperature at 850 hPa in the northern hemisphere extra-tropics show that the relative skill has substantially increased in recent years. Shown are 12-month running average values, based on the Continuous Ranked Probability Score (CRPS).



Skill of the HRES relative to ERA-Interim. The results for the northern hemisphere extra-tropics at day 5 show that the skill of various upper-air and surface parameters has increased at different rates. The computation of skill is based on the standard deviation of the forecast error.

Assessment of ECMWF's Technical Advisory Committee, 9–10 October 2014

With regard to its overall view of the ECMWF operational forecasting system, the Committee:

a) congratulated ECMWF on maintaining its world leading position in medium-range forecasting and encouraged ECMWF to maintain this lead;

b) noted with satisfaction the continuous improvement compared to benchmark systems of headline scores for HRES and ENS as well as other scores (500 hPa, CRPSS, MSLP, wind at 850 hPa);

c) acknowledged the quality, timeliness and accuracy of the up-to-one-week-ahead forecast by ECMWF of such high impact weather events as the severe flood event which hit western Europe in February 2014 or the disastrous flood event in the Balkans in spring 2014; noting the improvements still required, such as the developments that were demonstrated for the freezing rainfall event in Slovenia in February 2014;

d) noted in particular that in a number of cases of mid-latitude severe events, a significant forecast signal is present up to two weeks in advance, and encouraged the Centre to continue to develop skill for this range which is important for contingency planning; noted the continuing improvement in the monthly forecasts, for example the better prediction of MJO events;

e) noted the difficulty of the seasonal forecasting system to predict the anomalous circulation over Europe in the past winter, and the tendency to predict too early and too strong the El Nino development in 2014;

f) welcomed ECMWF efforts to analyse forecast performance with regard to weather regimes and improve the understanding of the sources of predictability;

g) welcomed the significant advances made by ECMWF in the verification of surface weather, including for severe events, and ECMWF efforts to use more surface stations in the forecast verification in order to improve the monitoring of skill for significant weather parameters (e.g. wind gusts, cloud cover, precipitation); encouraged Member States to provide these observations to ECMWF for verification purposes;

h) noted that biases still affect 2 metre-temperature forecasts, either negatively in the evening and night time across several European regions or positively in other regions; noted the occurrence of very large errors (both positive and negative) in specific meteorological situations;

i) noted the persistence of some over-prediction of small precipitation totals and under-prediction of large totals although a steady long term improvement can be observed, and welcomed the planned improvements scheduled for the next model cycle;

j) noted the improvement in cloud forecasts in recent years, for both the tropics and extra-tropics;

k) noted with satisfaction the operational implementation of cycle 40r1 and welcomed in particular:
- the coupling with the ocean model in ENS from the start of the forecast,
- the introduction of new satellite data, such as atmospheric motion vectors from NOAA-19 AVHRR and updated GOES,
- the upgrade of the ENS from L62 to L91;

l) noted with interest the ongoing action of ECMWF to make use of FY-3 (now in operational use), Metop-C, MSG-4, Aeolus and other satellite data in the data assimilation system;

m) encouraged ECMWF to pursue the upgrade of the resolution to an equivalent 8–10 km-mesh size for HRES and 4DVAR and 16–20 km for ENS, noting that this is moving towards the convection-permitting scale and subject to HPC capacity to maintain timeliness of delivery;

n) welcomed the extension of track-related products for tropical cyclones from 5 to 10 days;

o) welcomed and encouraged the continuing development and delivery of products to meet Member State needs, including via the new website;

p) encouraged ECMWF to continue its efforts to make the 00 UTC ENS available earlier, without compromising analysis and forecast quality;

q) encouraged ECMWF to explore the potential for calibration of gridded fields and to intensify co-operation with Member States on this topic.

Membership of the Scientific Advisory Committee

ERLAND KÄLLÉN

The Scientific Advisory Committee (SAC) is one of the Council's six advisory committees. The SAC and the Finance Committee are mentioned in the Convention of ECMWF; the other four committees have been established by the ECMWF Council.The 12 members of the SAC are appointed in their personal capacity for a period of four years. They can be re-appointed once for a second four-year term. The SAC meets once a year to provide opinions and recommendations on the Centre's research plans and review progress over the previous year.

The current SAC members are: Dr Jan Barkmeijer (KNMI, The Netherlands), Prof Dr Wilco Hazeleger (KNMI &

Prof Eigil Kaas. The Council has appointed Prof Eigil Kaas, Copenhagen University, as a member of the Scientific Advisory Council for a four-year period.

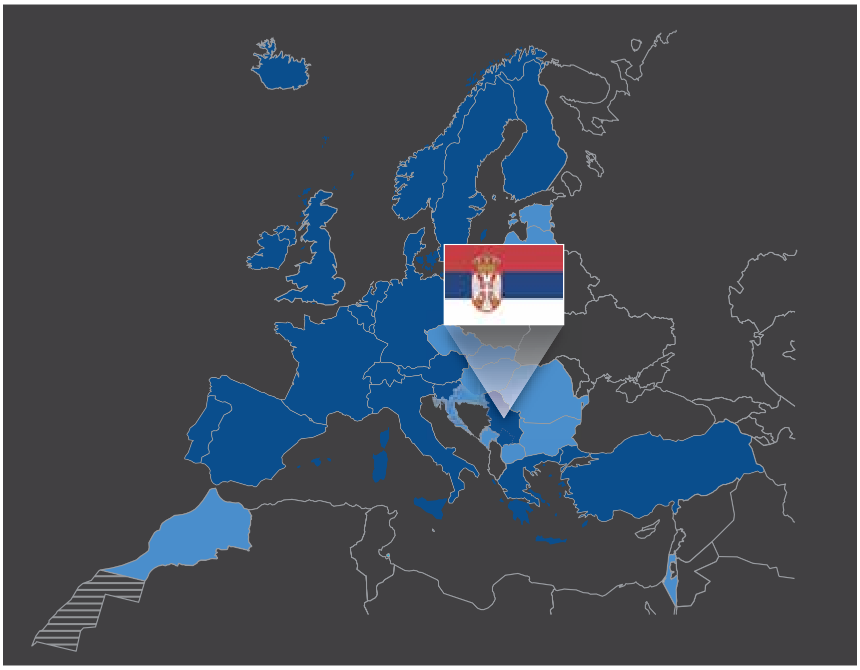
Netherlands eScienceCenter, The Netherlands), Dr Alain Joly (Météo-France), Prof Sarah Jones (DWD, Germany), Prof Eigil Kaas (University of Copenhagen, Denmark), Prof Jón Egill Kristjánsson (University of Oslo, Norway), Prof Piero Lionello (University of Salento, Lecce, Italy), Prof Alan O'Neill (University of Reading, UK), Prof Dr Johannes Orphal (Karlsruhe Institute of Technology, Germany), Dr Roger Saunders (Met Office, UK), Prof Sonia Seneviratne (ETH, Zurich, Switzerland), Dr Robert Vautard (LSCE, Paris, France).

At its meeting in December 2014, the Council re-appointed Dr Roger Saunders, Prof Dr Wilco Hazeleger and Dr Johannes Orphal for a second four-year period. At the same time it appointed Prof Eigil Kaas as a new member of the SAC.

Prof Eigil Kaas is professor of meteorology at Copenhagen University and has an abiding interest in NWP. He has spent most of his career at the Danish Meteorological Institute as a scientist and head of the Climate Research Division and then as head of the NWP Scientific Division; he took up the professorship at Copenhagen University in 2006. Eigil has worked in the areas of climate modelling, numerical methods and large-scale atmospheric dynamics. He developed a mass conserving version of the semi-Lagrangian scheme, which his students have tested in several prediction models around the world. He will bring expertise to the SAC that is closely linked to the dynamical core of the IFS. Developments in this area will be central to the scalability effort and vital for the future numerical efficiency of the model. Eigil will provide independent advice and guidance in this critical area of research.

Serbia becomes ECMWF's 21st Member State

BOB RIDDAWAY



On 1 January 2015 Serbia officially joined the other 20 Member States of ECMWF after having been a Co-operating State since 2003. The Centre's Director-General, Prof Alan Thorpe, welcomed Serbia's accession to full membership, saying that it marks a new chapter in the collaboration between ECMWF and Serbia. He emphasised that each Member State brings its own experience and expertise to ECMWF's collective knowledge, and he looked forward to even closer collaboration with the Serbian Administration in the fields of weather and climate to ensure the safety of life and property.

Prof Dr Jugoslav Nikolic, Acting Director of the Republic Hydrometeorological Service of Serbia (RHMSS), issued a statement saying that the Government of the Republic of Serbia recognized the significance of the accession to ECMWF for the further growth and development of RHMSS. He indicated that full membership in ECMWF is of vital importance, as it enables Serbia to contribute to the key issues related to the development of ECMWF, which is in direct correlation with the strategic plans for the development of the meteorological profession and science in Serbia. In particular, participating in the work and development of ECMWF will provide support to the operational activities of RHMSS and give strong encouragement to the research and development activities in the field of the numerical modelling of the atmosphere for the needs of the numerical weather and climate forecasting.

Prof Dr Jugoslav Nikolic added that full membership will improve the production of different weather forecasts and warnings in Serbia, and enable a broader scope and higher quality of research in the field of meteorology, including climatology, with a special focus on medium-range weather forecasts, seasonal forecasts and climate projections. In conclusion, he stated that strengthening of cooperation with ECMWF through the use of numerical modelling products, participation in staff training programmes, and usage of available computer and software resources has a strategic importance for the realization of the long-term and medium-term goals related to the development of meteorological and hydrological activity in the Republic of Serbia.

Flow-dependent background error covariances in 4DVAR

MASSIMO BONAVITA

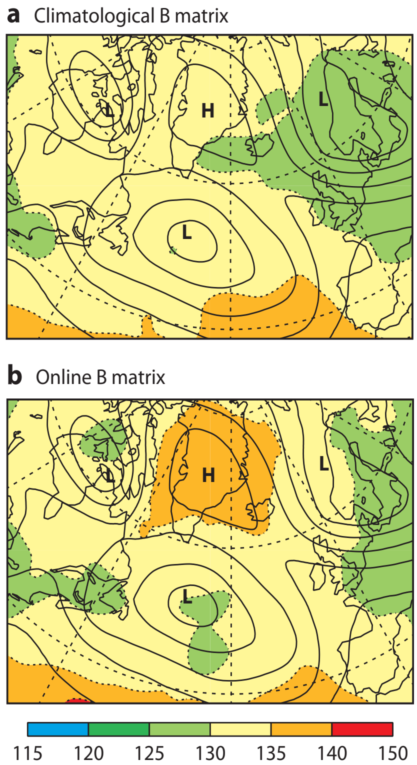
The trend towards using flow-dependent, ensemble-based estimates of background errors and error covariances has been one of the main themes of atmospheric data assimilation research and development in recent years. This is mainly because the background contains the information from previous observations which is then propagated and evolved by the forecast model up to the current analysis time. To a large extent, the skill of an assimilation system is determined by the accuracy of the statistical description of errors in the background and the observations.

The main weakness of standard four-dimensional variational data assimilation (4DVAR) is that it relies on almost static background errors. Since background errors and covariances tend to be highly spatially and temporally variable, especially in the proximity of active weather systems, a long-standing objective of research at ECMWF has been to provide accurate, flow-dependent background errors and error covariance estimates to the 4DVAR analysis. This goal had been partially achieved with the incremental introduction of background error estimates from the ECMWF Ensemble of Data Assimilations (EDA) as described by Isaksen et al. (*ECMWF Newsletter No. 123*), Bonavita et al. (*ECMWF Newsletter No. 129*) and Bonavita (*ECMWF Newsletter No. 135*). These changes have been implemented in Cycles 37r2, 38r1 and 38r2 of the Integrated Forecasting System (IFS).

A major limitation of the changes made over the past four years resided in the fact that only the background errors (i.e. the diagonal components of the background error covariance matrix B) were estimated online from the EDA. The covariance part of the B matrix (i.e. the off-diagonal elements) was based on a static estimate computed from a climatologically representative sample of EDA forecasts.The statistical estimation of a full covariance matrix requires a much larger sample, and consequently an EDA with a much larger number of members than what is needed for merely estimating its diagonal components. For this reason, starting with IFS Cycle 40r1 (November 2013), the operational EDA size has been increased from 10 to 25 members and a slowly-evolving estimate of error covariances based on a twelve-day moving window of the most recent EDA background forecasts has been adopted.

Qualitatively, the impact of the recent change can be seen in the figure which shows the background error correlation length scales for vorticity at 500 hPa from the climatological and online B matrices. While the former, which is computed from a composite of summer/winter EDA samples, captures the spatial distribution of the 'climatological' weather patterns in the area and the distribution of the observing system, the online B matrix is able to add structures that are relevant to the prevailing flow regime. This means that the error correlation length scales tend to become shorter in low-pressure areas and larger in high-pressure areas. The quantitative impact on analysis and forecast skill of using online error covariance estimates in 4DVAR is significantly positive and has been documented by Bonavita et al. (*ECMWF Tech. Memo No. 743*).

One potential drawback of the described online approach to error covariance estimation is that the lagged EDA forecasts will tend to introduce a systematic phase shift in the location of the diagnosed correlation structures. This can be significant for fast-moving meteorological systems. For this reason a revised computation of the error covariances will be introduced in IFS Cycle 41r1 (March 2015), based on a method that combines a climatological B matrix with information from only the latest EDA forecast cycle. As described in *ECMWF Tech. Memo. No. 743*, this hybrid approach has been shown to produce more realistic error-of-the-day covariance structures and further improve the forecast skill scores with respect to the online algorithm based on lagged EDA forecasts. Currently, the relative weights given to the flow-dependent and climatological components in the computation of the B matrix are 30% and 70%. Planned future increases in the size of the operational EDA will allow a larger weight to be given to the flow-dependent component in the hybrid estimate.



Comparison of the length scales from the climatological and online B matrices. Shown are the length scales of the 500 hPa vorticity background error correlation (shaded; legend in km) from (a) the climatological B matrix and (b) the online B matrix, valid at 21 UTC on 1 June 2012. 500 hPa geopotential background forecast valid at the same time is superimposed (solid line, units: 102 m^2/s^2) on the length scales. These panels show that with the online B matrix the correlation length scales tend to become shorter in low-pressure areas and larger in high-pressure areas by adding structures that are relevant to the prevailing flow regime.

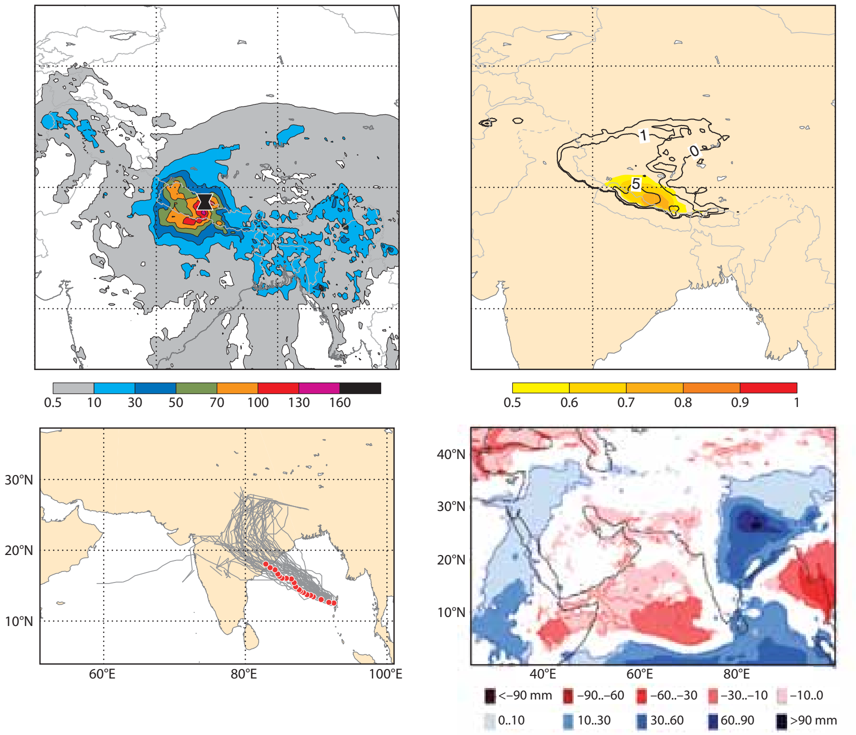
Forecasts for a fatal blizzard in Nepal in October 2014

LINUS MAGNUSSON,
TIM HEWSON

On 14 October 2014 a blizzard hit the Annapurna massif in north-central Nepal. The snowfall had a devastating impact, killing more than 40 people, mainly trekkers trapped on popular hiking routes (at altitudes around 4,000 to 5,000 m). Part of the area is believed to have received 1.8 metres of snow (source: Wikipedia article '2014 Nepal snowstorm disaster'), but unfortunately we are missing official observations of precipitation for the event. Instead, the top-left panel of the figure shows the short-range precipitation forecast (accumulated for 14 October). The position of Annapurna is marked with an hourglass symbol. The precipitation amount in the region is in excess of 130 mm, which broadly agrees with the reported snowfall.To put this into perspective, in the (model-based) climatology for this region, the threshold for an unusual 24-hour total (1 in 100 chance) at this time of year is only about 20 mm.

The intense precipitation was caused by the remains of tropical cyclone Hudhud. The cyclone formed on 8 October close to the Andaman Islands in the Bay of Bengal. The bottom-left panel shows the cyclone tracks from the ensemble forecast from 00 UTC on 8 October. After making landfall on the Indian eastcoast most of the ensemble members predicted a turn to the north towards the Himalayas. The actual track until landfall (from the Best Track database) overlaid shows that this forecast verified well.

The top-right panel shows the Extreme Forecast Index (EFI, shaded) and Shift of Tails (SOT, contours) for snowfall on 14 October from the same forecast as above (6–7 days in advance). The SOT index complements EFI by providing information about the extreme tail of the ensemble distribution compared to the model climate distribution. Considering the long lead time, the signals in both EFI and SOT are unusually strong for extreme snowfall on the Nepalese mountains. The SOT reaches values above 5 for the Annapurna region. The strong signal for snowfall is closely linked to the track of Hudhud.



Forecasts associated with the blizzard in Nepal in October 2014. Top-left: 24-hour accumulated precipitation for 14 October from the last forecast before the snowfall event (Annapurna marked by hourglass symbol). Top-right: EFI (shading) and SOT (black contours: 0, 1, 5, 10, 15) for snowfall for 14 October from 00 UTC on 8 October. Bottom-left: Tropical cyclone tracks from the ensemble forecast from 00 UTC on 8 October (reported track until landfall in red circles). Bottom-right: Weekly precipitation anomaly for 13–19 October from the monthly forecast starting on 6 October. The interpretation of these charts is given in the main text.

Finally, the bottom-right panel shows the weekly anomaly of precipitation in the forecast from 6 October, two days before the genesis of Hudhud. The forecast is valid for the week of 13–19 October. The forecast has a strong anomaly for wetter than normal conditions along the track of the cyclone, especially over Nepal.

Whilst determining the precise causes of the snowfall may warrant further investigation, it is clear that the track of Hudhud favoured a strong northward flux of moisture into a very-high-altitude region. At the same time an eastward-moving upper-level subtropical trough is believed to have provided assistance to snow-generation (from this moisture) through dynamically-driven uplift. It also seems that this event is not without precedent; another with very similar synoptic-scale characteristics, and a similar death toll, occurred near mount Everest (about 300 km away) on 11–12 November 1985 (thanks to Lance Bosart of the University of Albany-SUNY, USA, for this insight).

To summarize, the forecasts gave a strong indication of extreme snowfall in the Annapurna region more than a week in advance. This extreme event was caused by tropical cyclone Hudhud. Its track was consistently well predicted, even in forecasts initialised during its early stages, and this led to the high predictability of the snowfall event.

New blog for software developers

DANIEL VARELA SANTOALLA

As a way to increase communication between the developers of ECMWF software packages and the wider user community we have started a new blog in our software.ecmwf.int Confluence website that is publicly accessible to everyone. The blog can be found at:

https://software.ecmwf.int/developersblog.

Posts on this blog will include information about new releases, roadmaps, important technical changes, tutorials, general announcements and any other matters that could be of interest to our user community. The packages covered will be all those externally released and supported by ECMWF, including but not limited to grib_api, Magics, Metview, ecFlow and Emoslib.

At the current time we are planning to use this channel in addition to all the existing mailing lists where we normally announce our software releases. User registration is not required to access the blog, but registered users benefit from additional features like the ability to subscribe for updates, to 'like' the blog posts and to share the content with other users.

We would recommend that anyone interested in ECMWF's software packages subscribes for blog updates in one of two ways: (a) in a blog click 'Watch' on the top-right of the page and check the option 'Watch for new blog posts in this space' or (b) create a custom RSS feed via the 'Feed Builder' option in the 'Help' menu of Confluence.

Please contact software.support@ecmwf.int if you have any questions or suggestions about our new blog for software developers.

Recognition of ECMWF's role in THORPEX

CHANTAL DUNIKOWSKI

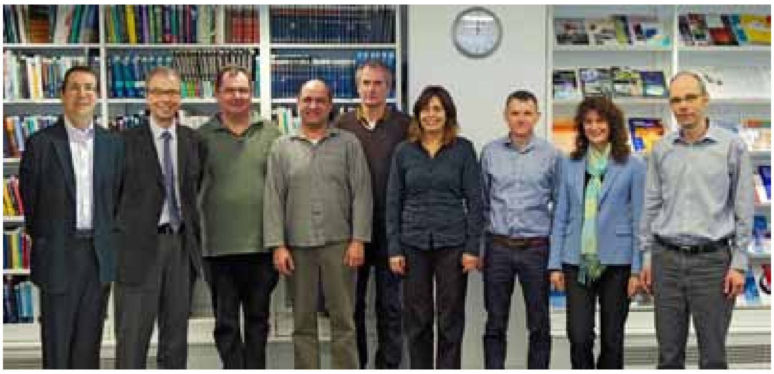
THORPEX was a ten-year research programme that started in 2005 and, whilst this year marks its official completion, many legacy activities continue such as TIGGE (THORPEX Interactive Grand Global Ensemble) and follow-on research programmes.

Officially adopted at the 14th World Meteorological Congress in 2003, THORPEX was designed as an international research and development programme to accelerate improvements in the accuracy of one-day to two-week high impact weather forecasts for the benefit of society, the economy and the environment.

In November 2014, THORPEX held its closing Symposium in Geneva. Alan Thorpe, one of the main instigators of the programme and co-author of the THORPEX International Science Plan, was invited to talk about the original vision of the programme and present the THORPEX development timeline. A previous Director-General at ECMWF, David Burridge, was head of the THORPEX International Office for much of the programme and he also presented his perspective on the achievements.

International collaboration among academic institutions, operational forecast centres and users of forecast products were key components of the THORPEX programme, making it the perfect environment for ECMWF to get involved in a variety of ways from the very beginning.

After ten years of collaboration, WMO presented *Certificates of Appreciation* to nine people currently working at ECMWF for their contributions to THORPEX – the recipients are shown in the photo.



Recipients of the Certificates of Appreciation. David Richardson, Alan Thorpe, Baudouin Raoult, Manuel Fuentes, Peter Bauer, Carla Cardinali, Mark Rodwell, Florence Rabier and Martin Leutbecher (left to right).

"With the end of THORPEX, DAOS (Data Assimilation and Observing Systems)has become part of the WMO WWRP (World Weather Research Programme) and I have been appointed co-Chair of DAOS in WWRP. DAOS has been very productive in organising conferences, symposiums and regular annual meetings. We have produced several peer review papers and contributed to many observation field campaigns with the goal of improving the numerical weather forecast from a few to 15 days."
Carla Cardinali

"I have been involved in the Predictability and Dynamical Processes (PDP) Working Group of THORPEX. This working group has facilitated international collaboration in the (increasingly important) area of probabilistic forecasting. I am now participating in the successor to the PDP – the Predictability, Dynamics and Ensemble Forecasting (PDEF) Working Group. This group should have an even stronger focus on probabilistic forecasting."
Mark Rodwell

Update on migration to BUFR for radiosonde, surface and aircraft observations at ECMWF

BRUCE INGLEBY, ENRICO FUCILE, TOMAS KRAL, DRASKO VASILJEVIC, LARS ISAKSEN, MOHAMED DAHOUI

In November 2014 some observations stopped being exchanged on the Global Telecommunication System (GTS) in traditional alphanumeric codes (TAC):

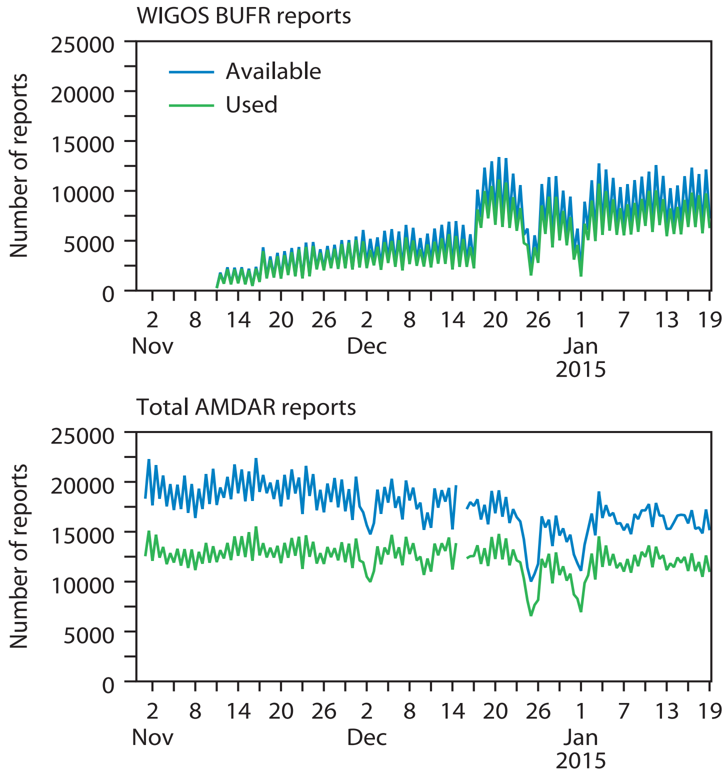
- SYNOP (surface) reports from the UK, Ireland and the Netherlands.
- SHIP TEMP reports from about half the ships making radiosonde ascents.

An article in *ECMWF Newsletter No. 140* described the background to the change and summarised the BUFR (binary code) coverage at that time (the coverage since then has improved and is now about 70% for land stations, both surface and radiosonde).

On 11 November 2014 in its operational forecasting system ECMWF started actively assimilating BUFR reports to replace the TAC reports mentioned above and reports from 16 other radiosonde stations – this is about 2–3% of the total number of reports for both land surface and radiosonde. The BUFR radiosonde reports can contain up to about 5,000 levels, but ECMWF thins these to about 350 before assimilation. Those BUFR reports not currently being assimilated are monitored and will gradually be added to the operational assimilation once their quality is assessed to be the same or better than the corresponding TAC.

Checking the availability and quality of the new reports is a continuous activity requiring a considerable amount of resources and collaboration with data providers, WMO and other NWP Centres to address problems and hence improve the quality of the data. To foster international collaboration, ECMWF has made available a wiki space to summarise the current status, discuss problems and find effective solutions: https://software.ecmwf.int/wiki/display/TCBUF/.

For land stations the positions in the BUFR reports are checked against those in the WMO station list and are reset to the station list positions if the difference is more than 0.1° in latitude/longitude. The BUFR usage described above is for the global ECMWF atmospheric analysis; further work is needed before the BUFR data can be assimilated in the surface, reanalysis and atmospheric composition analysis systems. At other global NWP centres it seems that more are currently using BUFR surface data than BUFR radiosonde data.



Numbers of WIGOS BUFR and total AMDAR temperature reports at ECMWF. The top panel shows the number of WIGOS BUFR reports increasing and the bottom panel shows that the total number of used AMDAR reports was relatively constant. There was an unrelated dip in the numbers of reports around Christmas and New Year because of fewer flights on those days. Shown are the number of reports available and the number used after duplicate checks and thinning. Note that (a) at ECMWF 'ACARS' reports, primarily from North American airlines, are categorised separately and are not included in the numbers and (b) there are also daily and weekly cycles in the numbers of reports and the WIGOS data contains fewer duplicates than the old formats.

Globally many BUFR radiosonde reports are currently converted from alphanumeric TEMP and are not making use of some of the important improvements provided by the new BUFR format (such as higher precision and the position and time coordinates for each point of the ascent). Moreover, some of the converted profiles are sent in four parts as different messages: this is forbidden by the new regulations and not supported by GTS headers, making it particularly difficult to merge this data into a single profile for assimilation purposes.

In November/December 2014 there was a phased migration (airline by airline) of European AMDAR (automated aircraft) data to the 'WIGOS' BUFR template. This was rather simpler than the surface/radiosonde migration discussed above and the figure shows the total number of used AMDAR reports stayed approximately constant during the migration.

Sharing knowledge about climate data

BAUDOUIN RAOULT, IRYNA ROZUM, DICK DEE

CHARMe is a two-year EU European project aimed at sharing knowledge about climate data. Different users need different kinds of supporting information, termed 'commentary' metadata, in order to understand climate data. The new CHARMe system gives users and producers of climate data a simple way of judging whether a dataset is fit for the user's purpose. It lets users view or create annotations that describe how climate data has been used and what has been learned. This information can include:

- Citations that reference a particular dataset.
- Results of assessments – reanalysis and quantitative error assessments.
- Provenance – processing algorithms and chain data source.
- External events that may affect the data – volcanic eruptions, El Niño and sensor failure.
- Supplementary dataset quality information – maturity, discontinuity, and updates.

The CHARMe system comprises a central CHARMe node storing CHARMe commentary metadata, CHARMe tools (CHARMe maps and the Significant Event Viewer) and a CHARMe plug-in to link datasets and CHARMe tools to the central CHARMe node. ECMWF developed the Significant Event Viewer and used the CHARMe plug-in to link reanalysis datasets to the commentary annotations.

The Significant Event Viewer is a web-based graphical tool for associating time series of climate variables with relevant events. The tool will help a user to study possible causes of variability, shifts and drifts apparent in the time series, and, in particular, to distinguish between natural and spurious variability in the data. It will also allow the user to become more familiar with the variety of observations used in a climate reanalysis and to understand their impact. Categories of external events that can be visualised in the latest version include:

- Natural events (e.g. hurricanes, volcanic eruptions, El-Niño occurrence).
- System events (e.g. how the data was obtained, satellite or instrument failure, operational changes to satellite orbit calculations).

Both the Significant Event Viewer and the plug-in will be available for free use on the ECMWF Web Applications Server (http://apps.ecmwf.int/) in early 2015.

On 10 and 11 December 2014 ECMWF hosted a meeting where the CHARMe project launched its system for sharing information about climate datasets. Partners reviewed the project's progress over the past year and held a symposium entitled 'Climate data informatics – sharing our collective expertise'. The symposium gathered scientists working on related projects such as CORE-CLIMAX, QA4ECV, CLIPC and ERA-CLIM. As the project draws to a close, the partners looked ahead to how the CHARMe system can help data providers, scientists, Copernicus services, and consultants to select relevant information. Many data providers, including ECMWF, have already implemented the CHARMe icon on their databases and a project is under way in the USA to connect scientists to the network.

CHARMe is coordinated by the University of Reading and has nine partners from both industry and public institutions: Science and Technology Facilities Council, University of Reading, Royal Netherlands Meteorological Institute (KNMI), Deutscher Wetterdienst, Airbus Defence & Space, Terra Spatium SA, CGI, UK Met Office, and ECMWF. The two-year project started in January 2013.

Some examples of what CHARMe will and will not enable

Users will be able to:

- Find all documents that have been written about a dataset.
- Find factors that might affect the quality of a dataset.
- Find datasets that are related to another one.

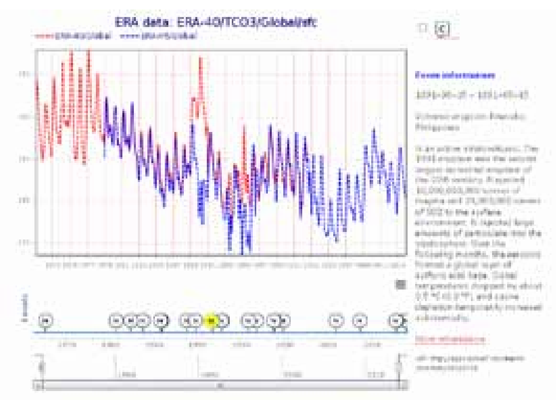
Data providers will be able to:

- Find out who is using their datasets and what is being said about them.
- Subscribe to new user comments and reply to them.

CHARMe will not:

- Identify the best dataset for a specific parameter.
- Provide a "quality stamp" for datasets.
- Provide access to actual data – it only enables discovery.

Significant Event Viewer form. Although the Significant Event Viewer focuses on reanalysis datasets, it is designed to be general enough to be extended to other datasets and user needs.



Total Column Ozone plot and a timeline of significant events produced by the Significant Event Viewer. The plot of Total Column Ozone is based on reanalysis data from ERA-40 and ERA-Interim. Event information on the right corresponds to the selected event highlighted in yellow. The icon 'C' in the upper right corner will launch a CHARMe plug-in linked to the selected significant event.

Calibration of ECMWF forecasts

DAVID RICHARDSON, STEPHAN HEMRI, KONRAD BOGNER, TILMANN GNEITING, THOMAS HAIDEN, FLORIAN PAPPENBERGER, MICHAEL SCHEUERER

ECMWF has studied the benefits of calibrating the ECMWF medium-range forecasts, based on statistical post-processing, to improve probabilistic predictions of four near-surface weather parameters. The motivation was the expert review of calibration methods carried out for ECMWF by Prof Tilmann Gneiting, who has recently been appointed as one of the inaugural ECMWF Fellows. The study was carried out in collaboration with Prof Gneiting and members of his Group on Computational Statistics at the Heidelberg Institute for Theoretical Studies (HITS).

The aim of the study was to demonstrate the benefits of using state-of-the-art calibration for the ECMWF forecasts, including an objective approach to combine the various components of ECMWF's forecast. It was found that calibration can provide substantial additional skill compared to the raw ECMWF forecasts.

Data and method

Calibration was carried out for four surface parameters.

- *T2M*: 2-metre temperature
- *PPT24*: 24-hour accumulated precipitation
- *V10*: near-surface wind speed
- *TCC*: total cloud cover

Synoptic observations (SYNOP) from a large number of stations across the globe were used for verification. SYNOP stations with suspicious data or significant missing data were excluded from the study. With these stations removed, around 4,000 stations for T2M and V10 and 3,000 stations for PPT24 and TCC were used in the study. Observations were used for 12 UTC only.

The ECMWF forecast was considered as a 52-member ensemble comprising the high-resolution forecast (HRES), the ensemble control (CTRL), and the ensemble forecast (ENS) consisting of 50 perturbed members. Operational forecasts were used from 12 UTC for the period 1 January 2002 to 20 March 2014.

The performance of the forecasts was measured using the continuous ranked probability score (CRPS). The CRPS is negatively oriented – lower scores indicate better forecasts, with a lower limit of zero for perfect forecasts. CRPS is a widely used measure of performance for probabilistic forecasts, and the ECMWF headline scores for the ensemble probabilistic forecasts of 850 hPa temperature and precipitation use the CRPS.

The aim of the calibration is to generate a probabilistic forecast with lower CRPS than the raw forecasts. A reduction in the CRPS indicates that the calibrated forecasts provide more skill value than the raw ensemble for the individual stations. During preliminary work a number of calibration methods were tested. For each parameter it was found that the best results were obtained using

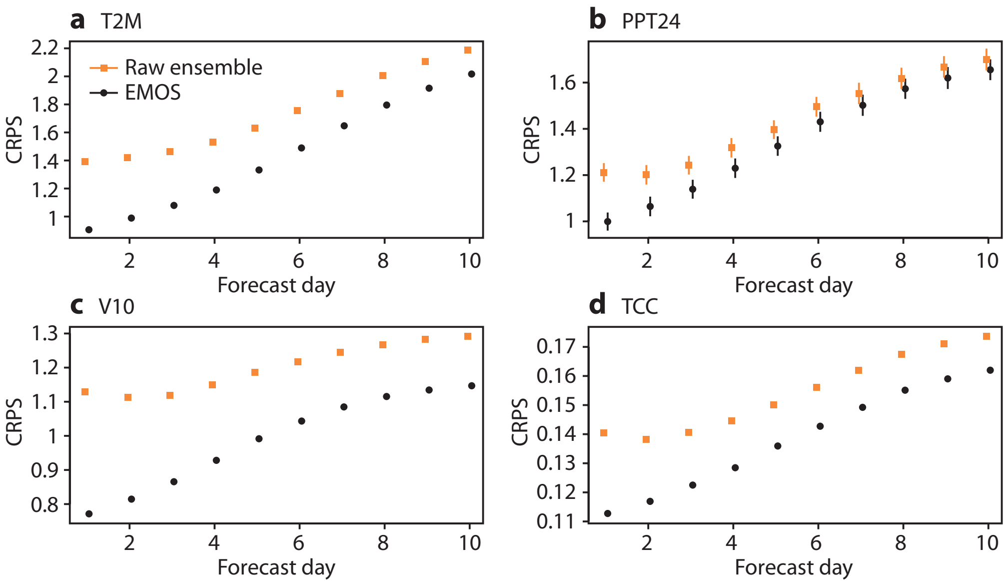


Figure 1 Mean CRPS for raw ensemble and calibrated ensemble for forecast lead times of one to ten days over whole verification period for European stations for (a) T2M, (b) PPT24, (c) V10 and (d) TCC. The vertical bars correspond to 90% confidence intervals for the expected average CRPS over all stations in the European subset (these bars are only large enough to show in panel b).

AFFILIATIONS
David Richardson, **Konrad Bogner**, **Thomas Haiden**, **Florian Pappenberger**: ECMWF, Reading, UK
Stephan Hemri, **Tilmann Gneiting**: Heidelberg Institute for Theoretical Studies, Germany
Michael Scheuerer: University of Heidelberg, Germany; now at NOAA/ESRL, Boulder, USA

the method known as ensemble model output statistics (EMOS). This is a technique that converts a raw ensemble of discrete forecasts into a continuous probability distribution – see Box A.

Overall impact of calibration

We first compare the mean CRPS values over the entire verification period for each of the calibrated parameters. Figure 1 shows the results averaged over European stations: the benefit of the EMOS calibration can be seen throughout the 10-day forecast range. For T2M the calibration brings a lead-time gain of around two days; for example the CRPS of the calibrated T2M forecast at day 6 is approximately the same as that of the 4-day raw forecast. The same lead-time gain is obtained for the TCC forecasts while the improvement for V10 is even larger. PPT24 shows the smallest benefit from the calibration, although there is still a one day gain or more in CRPS at all forecast lead times.

To put these results into some context, the overall increase in performance of the ECMWF forecasting system due to (a) model developments and (b) improved availability and use of data is typically one day per decade. In other words, the calibration brings similar gains in skill for forecasts at specific locations as is achieved for the basic atmospheric fields with 10–20 years of development of the Integrated Forecasting System (IFS). As we show in a later section, as the IFS has improved so has the skill of the calibrated forecasts. This shows that the modelling improvements and the calibration are complementary, both contributing to the overall skill of the final point forecasts.

Geographical variation of results

We now investigate how the effect of the calibration varies between stations. It should be noted that the selection of the best calibration method (i.e. EMOS) and training period was made based on results from the European stations, and may not be optimal for other regions.

Figure 2 shows the percentage change in CRPS at all evaluated stations for forecast days 5 and 10 for T2M. CRPS is improved significantly for almost all stations at lead times up to five days. Beyond day 5, there is an increasing number of stations for which CRPS cannot be improved significantly by calibration. Nevertheless, even for the 10-day forecasts the majority of stations show a performance improvement. There are only four out of over 4,000 stations at which CRPS deteriorates.

As for temperature, calibration significantly improves the CRPS of PPT24 for the vast majority of stations. With increasing forecast lead time, there is a growing number of stations, especially in North Africa, on the Arabian Peninsula and in central Asia, where there is no significant difference in CRPS between the raw ensemble

Calibration using ensemble model output statistics (EMOS)

A

Calibration using EMOS converts a raw ensemble of discrete forecasts into a continuous probability distribution. The most appropriate distribution will be different for the different forecast parameters.

Temperature (T2M)

For T2M we use a normal density distribution with mean *m* and variance σ^2. In the original EMOS the mean of the forecast distribution is given by

$$m = a_1 f_{\mathrm{HRES}} + a_2 f_{\mathrm{CTRL}} + a_3 f_{\overline{\mathrm{ENS}}}$$

where the parameters a_1, a_2 and a_3 can be interpreted as the relative weights given to the HRES, CTRL and the set of ENS members. In the present study a variant of this approach is used to account for the seasonal cycle of T2M: the departures of the observed temperatures from the climatological mean are related to those of the forecasts. A regression model using a combination of sine and cosine functions is applied to both observations and forecasts over the training period.

The variance of the forecast distribution is

$$\sigma^2 = b_0 + b_1 s^2$$

where s^2 is computed as the standard deviation across all 52 members of the ECMWF forecast.

The five parameters a_1, a_2, a_3, b_0 and b_1 are estimated from a set of training data, separately for each observation station.

Precipitation (PPT24), wind speed (V10) and total cloud cover (TCC)

Different distributions are appropriate for the other surface variables used in the study. For PPT24 we used a left-censored (cut-off at zero) generalised extreme value (GEV) distribution, while for V10, the most appropriate choice was found to be a left-truncated (at zero) normal distribution applied to the square-root transformed variables. For more details see *Hemri et al.* (2014). A mixed approach was found to be best for total cloud cover: the model needs to be able to allocate probabilities for zero cloud or totally cloudy as well as a continuous range in between.

Model fitting

For each of the forecast variables the parameters of the relevant forecast distribution are estimated by minimising the CRPS over a training period *T*. The training period for each verification day consists of the *n* days preceding the initialisation date of the forecast. A number of different lengths of the training period were considered, using data for a subset of European stations. The best results were obtained for a training period of 720 days (2 years) for T2M, 365 days (1 year) for V10, and 1816 days (5 years) for PPT24 and TCC. In principle, longer training periods should give the most robust parameter estimates. However, the long training periods will almost all include model upgrades and sometimes changes to the ensemble configuration. Such changes may have an adverse effect on the parameter estimates.

and the calibrated forecast. However, there are no stations at which calibration deteriorates the CRPS.

For V10, calibration improves the skill in terms of CRPS compared to the raw ensemble at almost all stations for all lead times. Even for the later steps, including day 10, there are very few stations at which CRPS is not significantly reduced by calibration, and there are none where this increases (i.e. worsens) the CRPS. This confirms the European results on the global scale – that the largest and most consistent impact of the calibration is achieved for the 10 m wind speed.

For TCC, calibration leads to better skill in terms of CRPS compared to the raw ensemble for the vast majority of stations. However, there are a few stations for which there is a deterioration in the forecast skill; further analysis has shown that this is probably due to problems in the numerical optimization procedure used in the calibration process. This problem should be resolvable. Generally the relative improvement in skill by calibration decreases with increasing lead time, but it remains significant even at a forecast range of 10 days.

Trend in CRPS over time

The performance of the raw ensemble has changed significantly between the beginning and end of the 10-year verification period used in the study. The skill of the calibrated ensemble will also have changed as a result. In this section, we investigate whether the benefits of calibration decrease as the skill of the raw ensemble improves. Figure 3 shows how the percentage change in CRPS between the calibrated forecasts and the raw ensemble (over all European stations) has changed over time for T2M for the 5-day forecast. The plot shows selected quantiles of these differences: the median change is shown together with the 5%, 25%, 75% and 95% values; a temporal smoothing is applied to reduce the sampling variability. The distribution is not symmetrical about the median value – there are occasions where the calibration can result in very large improvements compared to the average change. However, there is no clear trend in these results: the benefits of calibration in terms of the percentage reduction in CRPS are about the same in 2014 as they were in 2004. This also applies for the 10-day forecast.

The results for PPT24 also show no strong overall trend. Both V10 and TCC show larger variations over time than T2M and PPT24, particularly for the lower quantiles. For example, calibration of V10 resulted in reduction of CRPS by up to 60% in 2008–2010, while maximum benefits are now closer to 35%. However, the median improvement has remained more constant over the years at around 10–15%. For TCC, there has been some increase over the years in the maximum benefit that the calibration can achieve.

For PPT24 and TCC there are some periods that show some increase in the number of cases where the calibration degrades the forecasts. This could be related to changes in the model. Some operational upgrades have introduced substantial changes to the model physics. It could be that the calibration using previous operational forecasts is no longer sufficient for the new model cycle, at least for some aspects of the forecast. However, further investigation (and a longer period of verification) would be needed to confirm this. Nevertheless, it is worth noting that the operational reforecasts (which always use the current model cycle) are designed explicitly to account for such model changes.

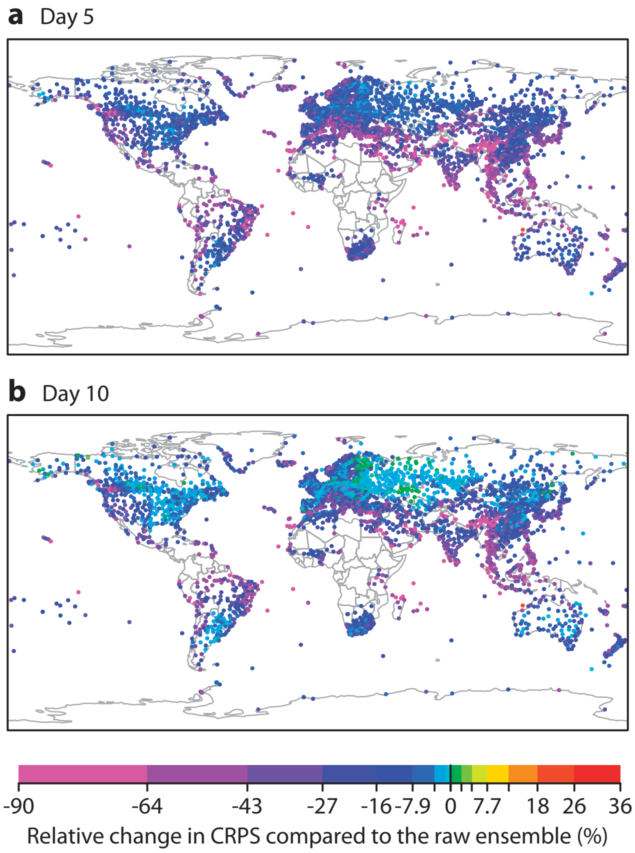


Figure 2 Relative change (%) in CRPS by EMOS compared to the raw ensemble at all stations for T2M for (a) day 5 and (b) day 10.

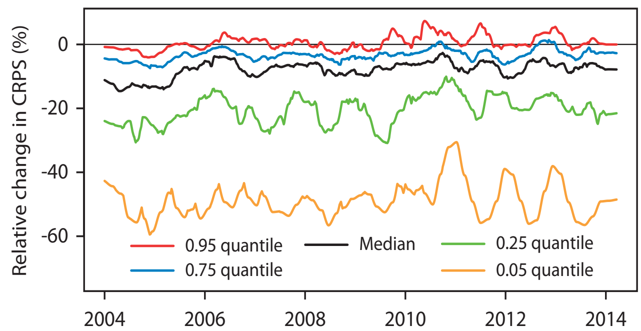


Figure 3 Change in CRPS by calibration compared to the raw ensemble against date for 5-day T2M forecasts. The lines correspond to a continuous smoothed box-plot showing the 0.05, 0.25, 0.5, 0.75, and 0.95 quantiles of the CRPS difference between the calibrated and the raw forecast among the European stations.

Weighting of HRES and CTRL

The calibration treats the HRES, CTRL and ENS members together as a 52-member ensemble. All 50 perturbed members are considered equally (all have the same weight), but the HRES and CTRL are allowed different weights. The preliminary tests, using a sample of European stations, assessed different basic configurations, for example excluding either the HRES or CTRL, or even excluding the ENS altogether and just using the HRES. Including the HRES together with the ENS was shown to give the best results, significantly improving the CRPS.

Overall, the HRES has a very high weight for the first few days. This decreases with increasing lead time, but even at day 10 the HRES is weighted significantly more than an individual ENS member. The CTRL has a much lower weight than the HRES, especially at shorter lead times. Although there is some variation between stations and parameters, the weight of the CTRL generally increases with forecast lead time and the CTRL has higher weight than an ENS member (greater than 1/51) for most forecast steps. If the HRES is not included in the calibration then the weight increases for the CTRL. This behaviour is illustrated by Figure 4, which shows the weights for T2M for two of the European stations: Vienna (representative of central Europe with modest terrain effects) and Skopje (in south-east Europe with more complex terrain).

The results for TCC are somewhat different from the other parameters. The HRES has lower weight and in particular the control forecast has decreasing weight as the forecast range increases (becoming less than 1/51 towards the end of the forecast). This would be consistent with TCC being the least predictable of the parameters being considered, and therefore having the most need for the full ensemble distribution.

Use of reforecasts

The results in the previous sections used the traditional approach of training the calibration on a sliding window of previous operational forecasts. This has the drawback that it does not account for changes to the IFS: a calibration applied to a new model cycle based on results from a previous cycle may be inconsistent and could degrade the performance. Although the results show that overall the benefits outweigh these disadvantages, some potential adverse effects were noted.

ECMWF runs a set of ensemble reforecasts as part of the operational suite of products. Once a week, 5-member ensembles are re-run for the equivalent date in each of the last 20 years using the current version of the IFS. These 'reforecasts' are used to calibrate the monthly forecast products as well as to generate the Extreme Forecast Index (EFI).We can use these reforecasts to calibrate the medium-range ensemble and compare the results with those using past data shown in the previous sections, which we will refer to as the sliding window approach. However, since there is no reforecast data set for the HRES, we exclude the HRES from the sliding window results in this comparison.

Figure 5 shows initial results for T2M forecasts during winter 2013/14 at the European stations. The evolution of CRPS with forecast lead time from one to ten days is shown for

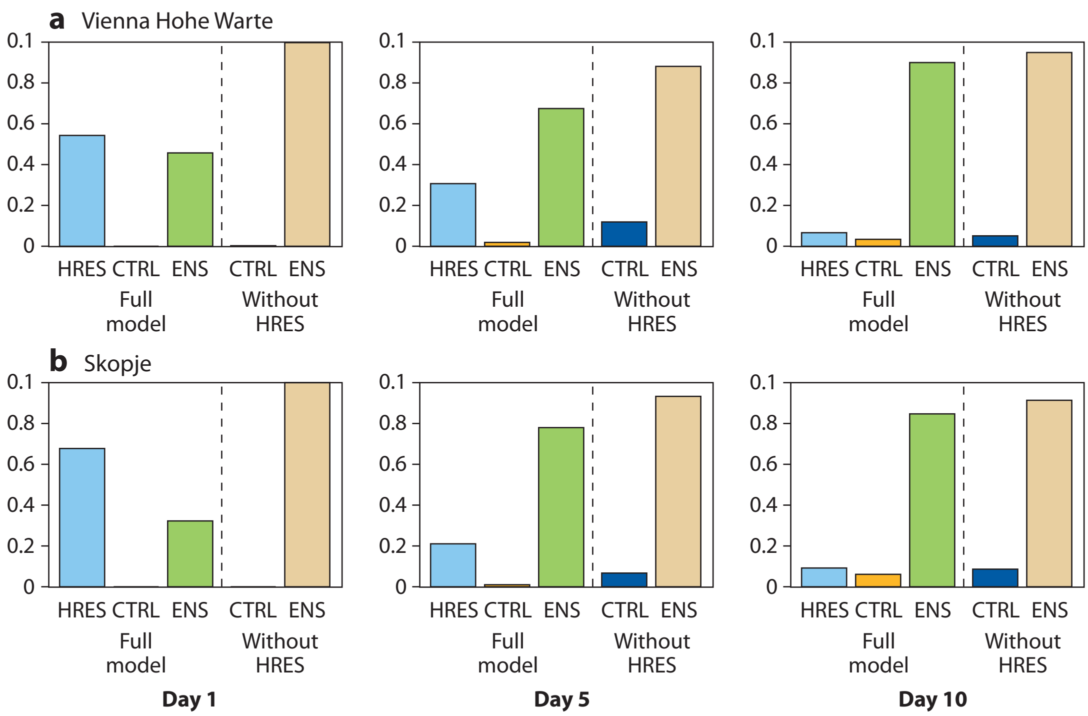


Figure 4 The left-hand side of each panel (labelled 'Full model') shows the weights assigned to HRES, CTRL, and ENS, respectively by EMOS for T2M at (a) Vienna Hohe Warte and (b) Skopje. The right-hand side of each panel (labelled 'Without HRES') shows the weights for CTRL and ENS when the HRES is not included in the calibration.

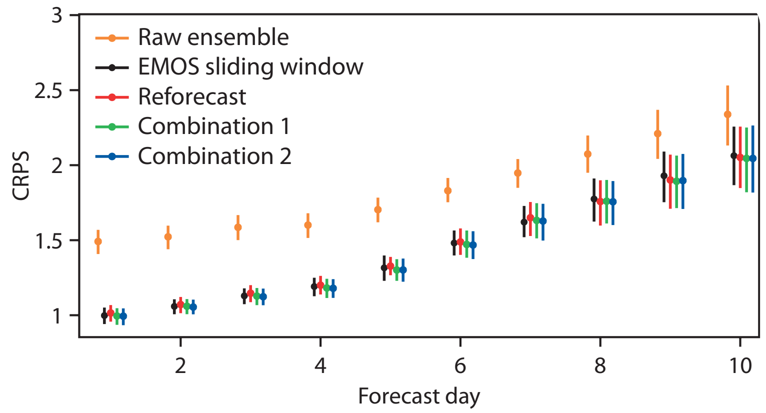


Figure 5 Mean CRPS over all considered stations for winter 2013/2014 for T2M for the raw ensemble, the EMOS sliding window approach, the reforecast approach and two versions of a combination of reforecast and sliding window forecasts. The vertical bars correspond to 90% confidence intervals for the expected average CRPS over all stations in the European subset.

the raw ensemble and the different calibration methods. The vertical lines show the 90% confidence intervals. Both the sliding window approach and the reforecasts give very similar results, with no significant difference between the two methods at any forecast step. The benefit of combining the sliding window and reforecast methods was also investigated. The results are shown for two slightly different combination methods: both show some potential, but no overall significant extra benefit.

One major difference between the reforecast data and the operational forecasts is the ensemble size. An important aspect of the EMOS calibration method is the need to estimate the ensemble spread and only 5 members is not sufficient to give a good estimate of this. A new reforecast configuration using 11-member ensembles (and running twice a week) will be introduced soon. This has the potential to substantially improve the reforecast approach to the calibration.

Summary and outlook

A study was carried out to assess the benefits of calibrating the ECMWF medium-range forecasts to improve probabilistic predictions of four near-surface weather parameters. The main conclusions from the study are summarised below.

- Overall, state-of-the art methods of calibration provided substantial additional skill compared to the raw ECMWF forecasts. The reduction in CRPS for point forecasts is typically equivalent, and complementary, to 10–20 years of model system development.
- The skill of the calibrated forecasts has increased over time at a similar rate to the raw ensembles: in relative terms, the benefit of calibration is the same now as it was 10 years ago, suggesting that model development and calibration improve different aspects of the forecast error. It is expected that similar relative benefits will be obtained by calibration for the foreseeable future.
- Treating the complete set of ECMWF forecasts (HRES, CTRL and ENS members) as one forecasting system, with appropriate weight to each component, provides the greatest benefit.
- Although it was not primarily designed for such calibration, the current reforecast data gives equivalent results to the alternative and more traditional approach of using a sliding window training period using previous operational forecasts.

A number of relevant aspects were not addressed in the present study, which focused on individual locations and on overall performance as measured by the CRPS. Important areas for further study include the spatial and temporal structure of calibrated products and the impact of calibration on the forecasting of extreme events. The enhanced reforecast dataset to be introduced in 2015 will allow ECMWF to begin investigating these topics. ECMWF will explore the potential for calibration of gridded fields (against analyses). This work will allow the development of 'seamless' forecast products that cover all time-ranges from the medium-range to seasonal.

Resources for this work were made available through the externally-funded EFAS and GEOWOW projects.

FURTHER READING

Gneiting, **T**, 2014: Calibration of medium-range weather forecasts. *ECMWF Tech. Memo. No. 719*. http://old.ecmwf.int/publications/library/do/references/show?id=91014

Hemri, **S.**, **M. Scheuerer**, **F. Pappenberger**, **K. Bogner** & **T. Haiden**, 2014: Trends in natural calibration of raw ensemble weather forecasts. Submitted to *Geophys. Res. Lett.*

Assimilation of cloud radar and lidar observations towards EarthCARE

MARTA JANISKOVÁ, PETER BAUER

Active satellite instruments provide a three-dimensional characterization of clouds and thus promise new information about the vertical structure of clouds for the benefit of numerical weather prediction (NWP). Observations from CloudSat and CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) are already available and new missions, such as EarthCARE (Earth Clouds, Aerosol and Radiation Explorer), will be launched in the near future (Box A). Whether information on clouds extracted from such data can be beneficial for NWP analyses and forecasts has been studied at ECMWF.

Assimilation experiments for cloud radar and lidar observations have been performed at ECMWF using a two-step technique which combines one-dimensional (1D-Var) with four-dimensional variational (4D-Var) data assimilation. The principle of 1D-Var is similar to that of 4D-Var, but only single column model data is used and the time dimension is not included. 1D-Var searches for the optimal model state that fits as closely as possible assimilated observations and the first-guess model data taken from the short-range NWP forecast valid at the time of assimilation. The 1D-Var retrieved model states are then used in a certain form (either as vertically-integrated quantities or vertical profiles themselves) as pseudo-observations to be included in the 4D-Var system together with other regularly assimilated observations.

In this two-step approach (see Box B for more details), 1D-Var assimilation on its own can already provide very useful information about the potential of assimilating new observational data. This was, for instance, demonstrated in preparation for the assimilation of cloud and rain-affected microwave radiometer observations.

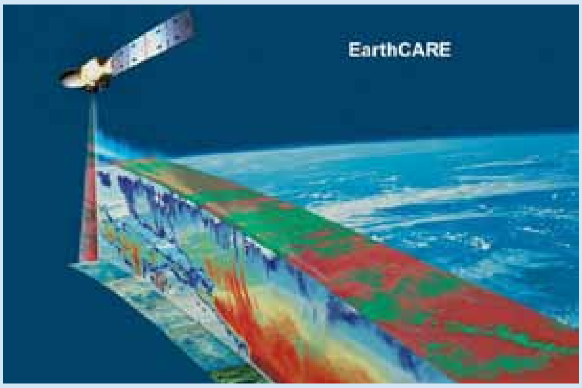
From CloudSat and CALIPSO to EarthCARE

A

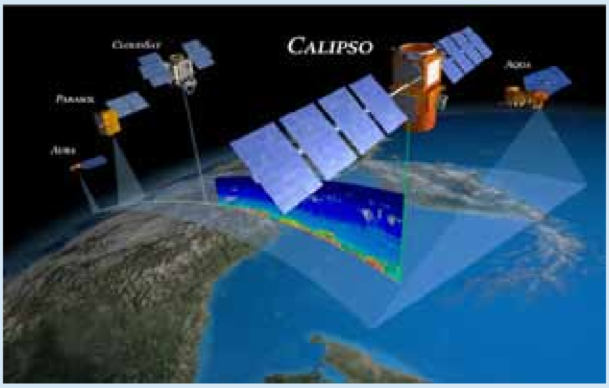
The objective of the joint ESA-JAXA EarthCARE mission is to make global observations of clouds, aerosols and radiation. Cloud and aerosol processes play a crucial role in the global energy budget and their accurate representation in models is one of the top priorities in climate change prediction. The satellite will carry two active instruments, namely a high-resolution atmospheric lidar (ATLID) and a Doppler radar (cloud-profiling radar, CPR), and two passive instruments, a scanning multispectral imager (MSI) and a broadband radiometer (BBR).

For EarthCARE, vertical profiles of aerosol and thin cloud properties will be derived from lidar observations while profiles of thicker clouds and precipitations will be obtained from the radar. A multispectral imager will provide cloud and aerosol information in the direction perpendicular to the lidar and radar measurements, and a broadband radiometer will measure the outgoing reflected solar radiation and the emitted thermal radiation from Earth. The great asset of the EarthCARE mission is that the combination of these observations will permit cloud and aerosol properties to be quantitatively linked to radiation. EarthCARE is planned for launch in early 2018 with a three-year nominal lifetime.

The enormous benefit of combined lidar and radar observations from space has been demonstrated by the US CloudSat and CALIPSO missions, which are part of the so-called A-train with its core satellite Aqua launched in 2002. The A-train comprises several satellites that fly in a sequence to provide quasi-collocated observations of the atmosphere. Among these are the CloudSat 94 GHz cloud-profiling radar (CPR) and the CALIPSO 532 and 1064 nm lidar that are hosted on different platforms separated by 15 seconds. Both were launched in 2006 and are still functional today. Other cloud-related observations can be derived from A-train instruments such as AMSR2 (microwave imager onboard GCOM-W1) and MODIS (visible/infrared imager onboard Aqua).



EarthCARE (courtesy of ESA).



A-train including CloudSAT and CALIPSO (courtesy of NASA).

Between 2005 and 2009, the 1D+4D-Var technique was used operationally for the assimilation of rain-affected passive microwave observations at ECMWF (*Bauer et al.*, 2006; *Lopez & Bauer*, 2007). Experimentally, it was also applied in first assimilation attempts with space-borne cloud radar observations (*Janisková et al.*, 2012). More recently, this experimentation has been extended to the combination of cloud radar and lidar observations (*Janisková*, 2014).

In this study, pseudo-observations of temperature and specific humidity retrieved from 1D-Var were assimilated in the ECMWF 4D-Var system to assess the impact of radar and lidar observations on the analyses and subsequent forecasts. The results from these experiments have shown that 1D-Var analyses fit both assimilated and independent observations better than the first guess, suggesting that the assimilation is able to produce a more realistic state of atmosphere and clouds when radar and lidar observations are available. However, it was found that the impact of cloud radar reflectivity observations is larger than that of lidar backscatter data since the lidar mostly constrains the cloud top while radar observations provide information on the entire cloud column. The 1D+4D-Var assimilation experiments have indicated a positive impact of the new observations also on the subsequent forecasts. Selected results from this encouraging study are presented here, demonstrating the great potential of this new data.

1D-Var assimilation of cloud radar and lidar observations

A number of 1D-Var experiments have been performed using observations of cloud radar reflectivity from CloudSat and cloud lidar backscatter from CALIPSO, either separately or in combination. Observations have been averaged over model grid-boxes. Observation error definition, quality control and bias corrections have been applied as described in Box B. The performance of 1D-Var has been verified against independent observations which were not assimilated, such as MODIS cloud optical depth retrievals (at reference wavelength of 550 nm) or radar reflectivity and lidar backscatter when these were not assimilated.

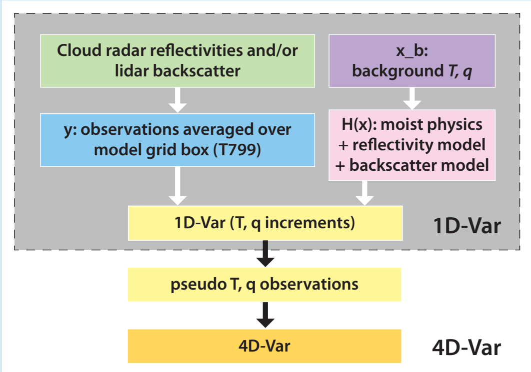
Here results are presented for a single satellite track from 23:50 UTC on 23 January to 00:26 UTC on 24 January 2007 crossing the Pacific Ocean from 62°N to 62°S, and for multiple tracks recorded over a 12-hour period from 21:00 UTC on 23 January to 09:00 UTC on 24 January 2007 corresponding to the full length of the 4D-Var assimilation window. The single track covers a variety of meteorological situations (e.g. tropical convection and an extratropical cyclone in the northern hemisphere) while the multiple-track experiment represents global cloud variability.

A comparison was made between the simulated radar reflectivity using first-guess and 1D-Var analysis profiles with CloudSat radar observations over the Pacific Ocean. The 1D-Var analysis (Figure 1c) is closer than the model first guess (Figure 1b) to the observations (Figure 1a) for most of the profiles. However, one can notice that convective clouds between 8°N and 8°S are only weakly

Description of the 1D+4D-Var approach

B

The diagram illustrates the work flow of the 1D+4D-Var assimilation method. In the first step, a 1D-Var retrieval is used to assimilate radar reflectivity from the CloudSat 94 GHz radar and/or 532 nm lidar backscatter from CALIPSO in order to adjust temperature and humidity profiles obtained from model short-range forecasts. To provide model equivalent to the observations, the observation operator *H* employs the physical parametrization schemes for moist processes (convection scheme and cloud scheme simulating large-scale condensation and precipitation processes – *Janisková & Lopez*, 2013) and a fast cloud radar reflectivity and lidar backscatter (*Di Michele et al.*, 2014a,b) simulator.



For a proper handling of observations in the context of an assimilation system, the definition of observation errors, an appropriate quality control methodology and a bias correction scheme are essential (*Di Michele et al.*, 2014a,b). Particularly for highly variable cloud observations observed by instruments with a narrow field of view, a suitable representativity error definition is important. This representativity error needs to be state dependent and uses a statistical approach based on probability distributions (*Stiller*, 2010).

The bias correction scheme uses temperature and altitude as predictors, and it includes dependence on geographical location and on seasons to account for the cloud variability associated with different weather regimes and cloud types.

The second step of the 1D+4D-Var approach performs the 4D-Var assimilation of specific humidity (*q*) and temperature (*T*) profiles retrieved from 1D-Var. In 4D-Var these retrievals are treated like radiosonde or dropsonde observations of the same quantities. However, they have their own error definition and quality control, but are not bias corrected. This second step allows the study of the impact of the new observations on global analysis and subsequent forecast. The observation errors for *T* and *q* retrievals (pseudo-observations) correspond to the 1D-Var retrieval errors which depend on the background error assumed for the 1D-Var control variables, the observation errors (either for reflectivity or for backscatter) and the accuracy of the observation operator used in the 1D-Var. As in *Bauer et al.* (2006), *Lopez & Bauer* (2007) or *Janisková et al.* (2012) the retrieval errors are calculated from the 1D-Var analysis error covariance matrix.

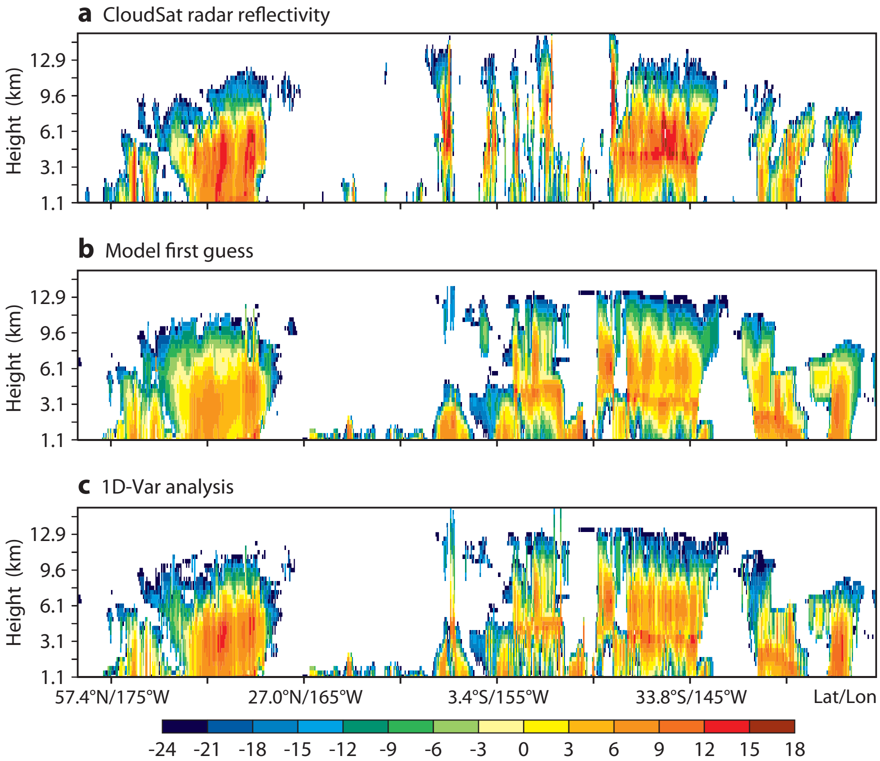


Figure 1 Cross-section of radar reflectivity (in dBZ) on 24 January 2007 over the Pacific Ocean: (a) CloudSat observations from 94 GHz radar, (b) model first guess and (c) 1D-Var analysis.

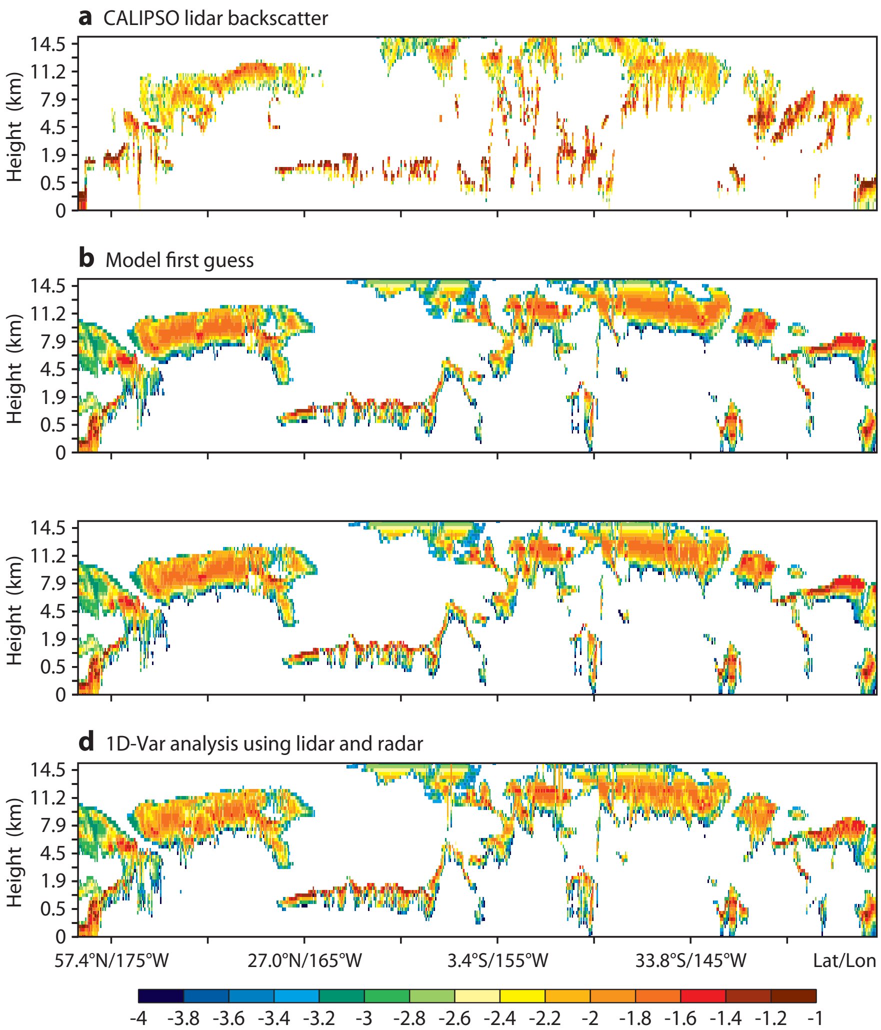


Figure 2 Cross-section of lidar cloud backscatter (in km^{-1} sr^{-1} using logarithmic scale) for the same situation as in Figure 1: (a) CALIPSO observations, (b) model first guess, (c) 1D-Var analysis using cloud lidar backscatter alone, and (d) the 1D-Var analysis using a combination of cloud lidar backscatter and radar reflectivity.

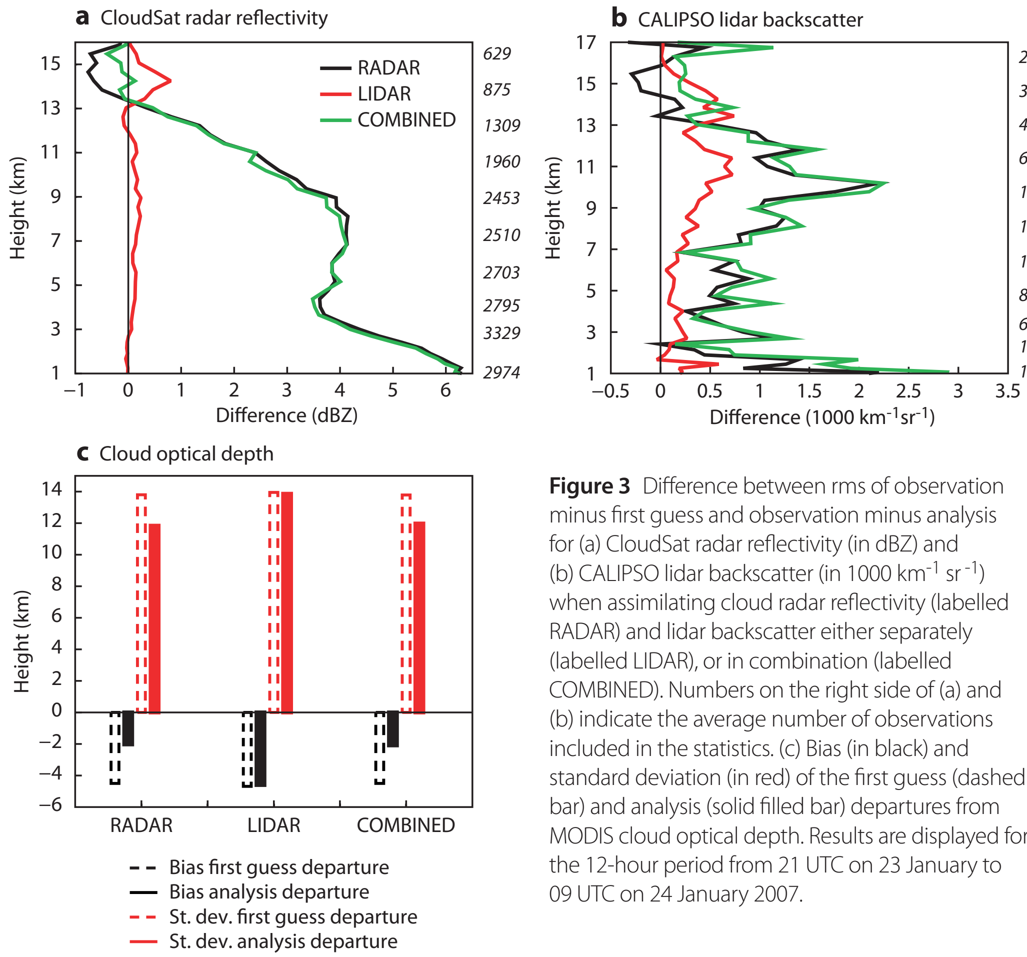


Figure 3 Difference between rms of observation minus first guess and observation minus analysis for (a) CloudSat radar reflectivity (in dBZ) and (b) CALIPSO lidar backscatter (in 1000 km^{-1} sr^{-1}) when assimilating cloud radar reflectivity (labelled RADAR) and lidar backscatter either separately (labelled LIDAR), or in combination (labelled COMBINED). Numbers on the right side of (a) and (b) indicate the average number of observations included in the statistics. (c) Bias (in black) and standard deviation (in red) of the first guess (dashed bar) and analysis (solid filled bar) departures from MODIS cloud optical depth. Results are displayed for the 12-hour period from 21 UTC on 23 January to 09 UTC on 24 January 2007.

modified and remain close to the first guess. This is due to large representativity errors assigned to the observations in areas of convection since the observations only sample a small sub-set of cloud variability.

Results from the 1D-Var assimilation of CALIPSO lidar observations (Figure 2c) for the same track indicate that the analysis fit to observations (Figure 2a) is only marginally better than that of the first guess (Figure 2b). This is partly related to the small observed field of view, which again produces large representativity errors reducing the weight given to these observations in the analysis. When a combination of cloud radar reflectivity and lidar backscatter data is used in 1D-Var (Figure 2d) the analysis also has a better fit with cloud lidar backscatter observations, indicating that the lidar data alone provides a weaker constraint on the analysis than the combined observations.

The 1D-Var assimilation performance shows that the analyses also produce a better fit to independent observations. Again, the impact of lidar backscatter data is smaller than that of cloud radar reflectivity. This is shown by comparing the root-mean-square (rms) error differences between the first-guess and analysis departures for both CloudSat radar reflectivity (Figure 3a) and CALIPSO lidar backscatter (Figure 3b) for the full 12-hour period. A comparison of the first-guess and analysis departures for independent MODIS cloud optical depth data is shown in Figure 3c, indicating that the analyses get closer to these observations for all assimilated experiments with the smallest improvement when assimilating cloud lidar backscatter alone.

Analysis increments for temperature and specific humidity have been evaluated because they can provide information about the impact of the assimilated observations on the variables that control the 1D-Var system. Generally, increments from lidar data assimilation occur at higher altitudes than those from radar assimilation and point at the complementarity of both instruments. At altitudes where both radar and lidar observations are available the increments are consistent. Both temperature and specific humidity are modified by the assimilation of cloud radar reflectivity and/or lidar backscatter data since the analysis not only modifies cloud condensates but also the related thermodynamic state. Therefore both profiles obtained from the 1D-Var retrievals need to be included in the 4D-Var system as pseudo-observations. This is an extension of the formerly operational 1D+4D-Var rain assimilation where only pseudo-observations of total column water vapour were used (*Bauer et al.*, 2006).

Impact of 1D+4D-Var assimilation on analyses and subsequent forecasts

Several 1D+4D-Var experiments have been run over a single assimilation cycle of 12 hours by assimilating pseudo-observations of temperature and specific humidity retrieved with 1D-Var. These pseudo-observations have been added to the full system of regularly assimilated observations at ECMWF. From the resulting 4D-Var analyses, 10-day forecasts have been run to study the impact of these observations on subsequent forecasts.

Verification of the assimilation runs has been carried out against other assimilated observation types used in 4D-Var. The results indicate (not shown here) that, when compared against conventional observations (such as TEMP radiosonde, PILOT or AIREP observations), there is some reduction in bias of the analysis departures while standard deviations are systematically larger when CloudSat and CALIPSO data is assimilated. This indicates that the new cloud-related observations introduce variability into the system which is associated with the observations constraining the small-scale features. The small but systematic bias reduction obtained from combined lidar-radar data assimilation suggests an additional improvement of the mean model state. No significant changes were found in the statistics of satellite data departures. Achieving significant improvements with new observations over a domain well covered by a large amount of other measurements is always a big challenge. Therefore a small but beneficial impact is encouraging since it indicates an area of potential for the future role of cloud observations in NWP.

The impact on the subsequent forecasts has also been assessed. The evaluation has been performed for temperature, specific humidity and wind by considering differences in rms forecast errors between experiments and a reference run (without new observations) computed with

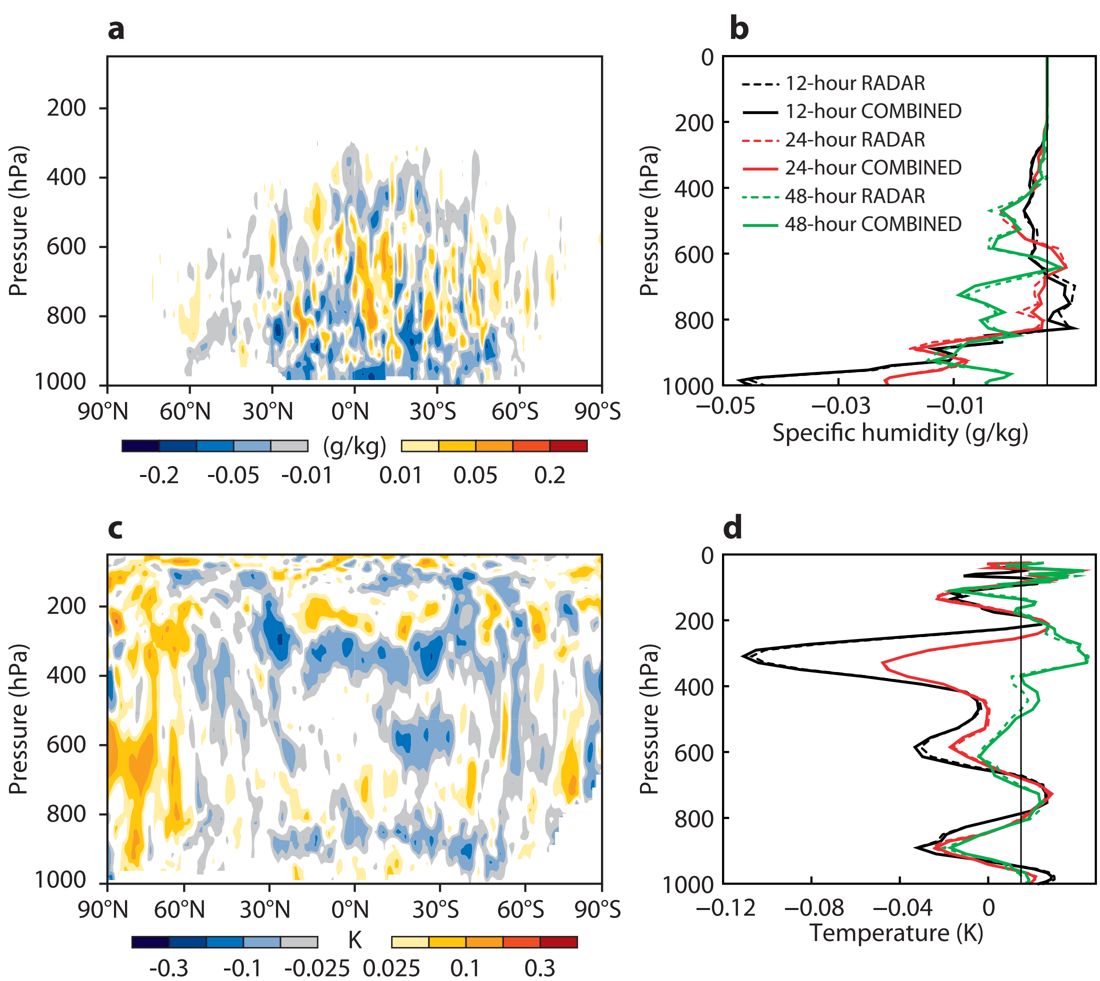


Figure 4 (a) Zonal mean of rms error difference for 24-hour forecasts of specific humidity from experiments with cloud radar reflectivity alone (reduction/increase of rms errors for the experimental run is shown with blue/red shadings). (b) The rms error difference presented as global values for 12-, 24- and 48-hour forecasts of specific humidity from experiments with cloud radar reflectivity alone (labelled RADAR) or in combination with lidar backscatter (labelled COMBINED). (c), (d) As (a), (b) but for temperature. Shown are the differences between the rms error of forecasts starting from the analysis created by 4D-Var assimilation of pseudo-observations and the rms error of forecasts starting from the reference analysis (i.e. without the pseudo-observations). The rms errors are computed with respect to the operational analysis.

respect to the operational analysis. Zonal means of the rms-error differences for temperature and specific humidity are shown in Figures 4a and 4c for 24-hour forecasts. Generally, errors are reduced when cloud data is assimilated. Even though this positive impact decreases quickly with time, it is still noticeable for 48-hour forecasts (Figures 4b and 4d). Assimilating data related to moist variables tends to produce little impact in the medium range because moist physical processes act on short time scales and the model effectively diffuses the initial state information.

Summary and perspectives

The studies described here have demonstrated the potential offered by the assimilation of cloud observations from space-borne radar and lidar instruments. Information retrieved from these observations combined with spaceborne Doppler-lidar observations could further enhance analysis quality in the tropics indicated by wind lidar observations (*ECMWF Newsletter No.137*, *Horányi et al.*, 2013). Although the feasibility of assimilating cloud radar and lidar observations has been proven but is by no means easy to accomplish. The first and foremost condition is to have a good short-range forecast of clouds which provides the first guess. The experiments suggest that the model physics used in the Integrated Forecasting System (IFS) represents clouds well enough to be able to exploit observations with spatial and physical detailed cloud information. However, there are a number of other requirements that need to be fulfilled in order to succeed. One of them is the availability of sufficiently accurate observation operators, i.e. models that enable the comparison of equivalent model fields with observations. Another requirement is the linearity and regularity of the observation operator used in the variational assimilation which is based on the strong assumption that the analysis is performed in a quasi-linear framework. Without the proper handling of threshold processes, the linearized model required for variational data assimilation can produce erroneous results as demonstrated by Janisková & Lopez (2013). In addition, for the safe handling of observations, an appropriate quality control strategy and a bias correction scheme are required. This is particularly difficult for cloud observations due to the very large dynamic range of the observations as a function of cloud states. An important aspect is that the observation error definition needs to account for the spatial representativity of radar and lidar observations with their rather narrow horizontal field-of-view.

The first results from cloud radar and lidar assimilation have been encouraging. To achieve the full benefit from these observations in an operational context, a substantial amount of work is still required.

- More experiments and statistical evaluations of the model simulations of reflectivity and backscatter need to be performed for a wider range of situations to refine data quality control and error definition.
- The 1D+4D-Var assimilation method also needs to calculate 1D-Var retrieval errors that serve as observation errors in the second stage when retrieved temperature and humidity profiles are assimilated in 4D-Var. Their computation from the 1D-Var analysis covariance matrix is expensive for profiling observations and only affordable in non-operational applications. Therefore, for any future operational implementation, the direct 4D-Var assimilation of cloud related observations will be considered.
- The observational data handling in the described experiments employed an off-line route. The next stage of these developments will therefore aim at integrating data flow and pre-processing in the path used for all operationally assimilated data. Implementing these changes means that experiments for long data assimilation periods can be performed in preparation for the future operational assimilation of cloud radar and lidar data. The completion of this step will mark the readiness level for the eagerly expected availability of EarthCARE observations.

FURTHER READING

Bauer, **P.**, **P. Lopez**, **D. Salmond**, **A. Benedetti**, **S. Saarinen** & **M. Bonazzola**, 2006: Implementation of 1D + 4D-Var assimilation of precipitation-affected microwave radiances at ECMWF. II: 4D-Var. *Q. J. R. Meteorol. Soc.*, **132**, 2307–2332.

Di Michele, **S.**, **E. Martins** & **M. Janisková**, 2014a: Observation operator and observation processing for cloud radar. *WP-1100 Report for the ESA project Support-to-Science-Element STSE Study – EarthCARE Assimilation, 4000102816/11/NL/CT*; ECMWF, Reading, UK, 59 pp.

Di Michele, **S.**, **E. Martins** & **M. Janisková**, 2014b: Observation operator and observation processing for cloud lidar. *WP-1200 Report for the ESA project Support-to-Science-Element STSE Study – EarthCARE Assimilation, 4000102816/11/NL/CT*, ECMWF, Reading, UK, 40 pp.

Horányi, **A.**, **M. Rennie** & **L. Isaksen**, 2013: The expected NWP impact of Aeolus wind observations. *ECMWF Newsletter No.* **137**, 23–29.

Janisková, **M.**, **P. Lopez** & **P. Bauer**, 2012: Experimental 1D+4D-Var assimilation of CloudSat observations. *Q. J. R. Meteorol. Soc.*, **138**, 1196–1220.

Janisková, **M.** & **P. Lopez**, 2013: Linearized physics for data assimilation at ECMWF. In *Data Assimilation for Atmospheric, Ocean and Hydrological Applications (Vol II)*, S.K. Park and L. Xu (Eds), Springer-Verlag Berline Heidelberg: 251–286.

Janisková, **M.**, 2014: Assimilation experiments for radar and lidar. *WP-3200 Report for the project STSE Study – EarthCARE Assimilation, 4000102816/11/NL/CT,* ECMWF, Reading, UK, 56 pp.

Lopez, **P.** & **P. Bauer**, 2007: "1D+4D-Var" assimilation of NCEP Stage IV Radar and gauge hourly precipitation data at ECMWF. *Mon. Weather Rev.*, **135**, 2506–2524.

Stiller, **O.**, 2010: A flow-dependent estimate for the sampling error. *J. Geophys. Res.*,**115** D22, 10.1029/2010JD013934.

The direct assimilation of principal components of IASI spectra

MARCO MATRICARDI

The assimilation of high-resolution radiances measured by the Infrared Atmospheric Sounding Interferometer (IASI) has produced a significant positive impact on forecast quality (*Collard & McNally*, 2009). The operational use of IASI radiances at ECMWF is currently restricted to a selection of temperature sounding channels in the long-wave and short-wave regions of the spectrum and to a small number of ozone and humidity sounding channels. In principle, to exploit the full information content of IASI, the number of channels used in the assimilation could be increased to cover the full spectrum.

Currently, NWP users have to assimilate less than the full IASI spectrum because of the high computational cost, but it is also known that the independent information on the atmosphere contained in an IASI spectrum is significantly less than the total number of channels. There is thus a need to find a more efficient way of communicating the measured information to the analysis system than simply increasing the number of channels. Similarly, satellite agencies are seeking a more efficient means of near-real-time data dissemination for instruments such as IASI because the traditional practice of transmitting full spectral data at full spatial resolution is likely to become prohibitively expensive in the future (as instruments are flown on multiple polar and geostationary platforms).

Principal Component Analysis (PCA) is a classic statistical method for the efficient encapsulation of information from voluminous data (*Joliffe*, 2002). As such, it has been proposed as a solution to the problems associated with the assimilation and dissemination of high spectral resolution data although, while noting that the two issues are quite similar, the requirements are quite separate. There are strong indications that data providers will start to disseminate principal component (PC) scores (i.e. the values of the PCs associated to each observation) to improve efficiency. It is thus timely and opportune to investigate the feasibility of directly assimilating PC scores into NWP models.

In this article we document the development and the functionality of a global four-dimensional variational assimilation system (4D-Var) based on the direct use of PC data. The primary aim is to develop an efficient use of the entire measured IASI spectrum that could not be achieved by traditional radiance assimilation.

A brief review of Principal Component Analysis

PCA is a method that allows the reduction of the dimensionality of a dataset by exploiting the interrelations between all the variables contained in the dataset. This is achieved by replacing the original set of correlated variables with a smaller number of uncorrelated variables called principal components. Because the new derived variables retain most of the information contained in the original data, PCA provides a tuneable mechanism to efficiently represent the information in the data.

In our case, the original variables are n radiances of the IASI spectrum. A number of PCs, which is less than n, can often represent most of the variation in the data. This means that we can replace the n radiances with the first m PCs (referred to as reducing the 'dimension' of the data). In many applications the choice of the number of dimensions is based on the total variation accounted for by the m leading PCs and it will in general depend on specific characteristics of the data. The truncated PC scores may be regarded as an efficient encapsulation of the original set of observations that may be used for storage, transmission or indeed assimilation.

In addition to reducing the dimension of the observed data, the value of m can also be tuned to achieve noise filtering of the observations, using PCA to separate variations of the atmospheric signal from variations of the random instrument noise. Of course great care must be taken if the PC scores are truncated for this specific purpose. Small-scale and small-amplitude atmospheric features can be important sources of rapid growth of forecast error. However, such features might not be strongly correlated across the measured spectrum and could potentially be confused with noise. Consequently, a truncation that is too severe should be avoided because it could potentially remove atmospheric features.

The IASI long-wave channels and derived PC scores

To demonstrate PC-score assimilation it is assumed that we have access to the full IASI measured spectrum and that we are only investigating the suitability of PCA as a mechanism for efficiently presenting this information to an assimilation system. As such we are deliberately separating this from the potential application of PCA to the logistical issue of compressed data dissemination.

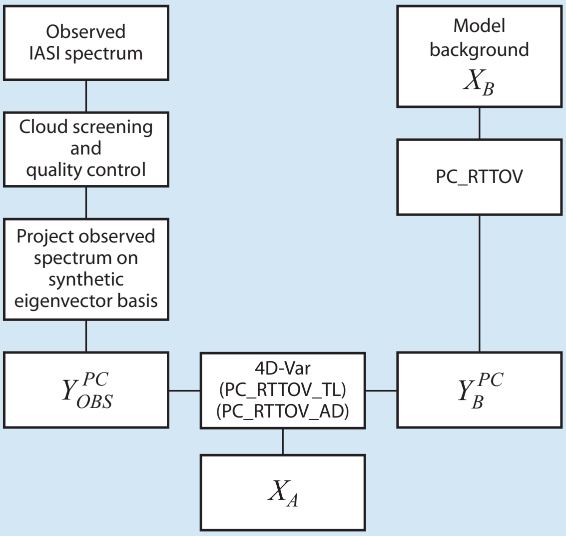
In this article we consider the assimilation of PC scores derived from radiances in the long-wave region of the IASI spectrum. The radiances we have employed are a subset of those used operationally at ECMWF. This subset comprises 165 long-wave channels in IASI band 1 and has been obtained by removing from the operational data the channels located in the water vapour absorption band and in the short-wave region of the spectrum. Excluding radiances with a strong sensitivity to water vapour allows us to run assimilation experiments in more controlled conditions using sounding channels with a primary sensitivity to temperature and the surface.

A detailed description of the PC assimilation methodology can be found in *Matricardi & McNally* (2013) and the methodology is outlined in Box A.

PC assimilation methodology

A

The methodology adopted for the direct 4D-Var assimilation of PC scores is shown schematically in the figure (refer to *Matricardi & McNally*, 2013, *Q. J. R. Meteorol. Soc.*, **140**, 573–582, for more details).



The observed IASI spectra are first screened for the presence of clouds and contaminated spectra are discarded. This must be done before assimilation as the PC training has been performed with only completely clear data and none of the eigenvectors correspond to cloud signals. The clear spectra are then converted into a vector of observed PC scores Y^{PC}_{OBS}.

Each vector of observed PC scores has length *n*, but crucially we assimilate only the first *m* of these, preferentially retaining highest rank PC scores that convey most information about the atmospheric state. The *m* observed PC scores are then provided as input to the 4D-Var. Trajectory estimates of the atmospheric state (*X*) are used as input to the observation operator to compute model equivalents of the *m* PC scores, Y^{PC}_{B} (*X*). The PC score observation operator used in our tests is PC_RTTOV (*Matricardi*, 2010, *Q. J. R. Meteorol. Soc.*, **136**, 1823–1835) which has been available as part of the operational RTTOV observation operator since the release of RTTOV version 10.

During the minimization of the 4D-Var cost function, perturbations of the atmospheric state are mapped into the observation (PC) space by the tangent linear of the observation operator PC_RTTOV_TL. Likewise, gradients of the cost function with respect to the PC scores are evaluated and mapped into gradients with respect to the atmospheric state by the adjoint of the observation operator PC_RTTOV_AD. The atmospheric state X_A that minimizes the above cost function is referred to as the *analysis* and the departures of this from the background atmospheric state X_B are referred to as analysis increments defined at the start of the 4D-Var window.

The 4D-Var cost function involves the specification of the error covariance matrix of PC scores, *R*, which should describe the combined error of the observations (PC scores) and observation operator (PC_RTTOV). An initial estimate of the diagonal elements of R can be obtained by computing the standard deviation of the observed minus background departures. Of course these values are not optimal in that they contain a contribution from the uncertainties in the background state and as such can only be regarded as an upper bound upon the required error. To separate the contribution of the observation error and the background error in the departure statistics we have used the techniques proposed by *Hollingsworth & Lönnberg* (1986, *Tellus*, **38A**, 111–136) and *Desroziers et al.* (2005, *Q. J. R. Meteorol. Soc.*, **131**, 3385–3386) which should give a refined estimate of the observation error (for details see *Bormann & Bauer*, 2010, *Q. J. R. Meteorol. Soc.*, **136**, 1036–1050).

PC-based quality control

Currently, the assimilation of PC scores is restricted to clear-sky conditions utilising a dedicated cloud detection scheme that uses three separate tests applied to uncorrected radiance departures and seeks to identify only fully clear IASI pixels. In conjunction with the new cloud detection scheme, an additional PC-based quality control is used and acts as an extra check for residual cloud contamination.

Because the first principal component (PC1) has similar characteristics to an infrared window channel showing a heightened sensitivity to the surface emission and the presence of clouds, positive observed minus background departures of the observed PC1 score from the clear-sky computed value are an indication that the observation is affected by clouds. Using a visual inspection of AVHRR imagery overlaid with IASI pixels it was found that a threshold of 40 (in dimensionless units) applied to the departure in the long-wave PC1 is sufficient to reject most cases of residual cloud contamination.

Bias correction for PCs

In the ECMWF PC-based assimilation system, biases in the PC observations and systematic errors in the PC-based radiative transfer model and cloud screening are removed using the variational bias correction scheme (VarBC). This is an adaptive correction algorithm used operationally at ECMWF for all satellite data, including IASI radiances (and indeed some in situ observations, such as from aircraft), where the bias is expressed as a linear combination of pre-defined atmospheric predictors. For consistency with radiance observations, but also because PC scores are likely to be influenced by rather similar sources of systematic error, we have applied the same multi-predictor bias correction scheme for the assimilation of the PC scores.

After an initial training phase of typically two to three weeks, it is found that the bias correction for PC scores performs extremely well – it becomes very stable in time and removes almost all systematic differences between the observations and the analysis. An exception to this are the corrections computed for a small number of PC scores that are slower to stabilize and tend to drift slightly over time, most likely because these PCs are affected by the same processes that cause drifts in radiance biases (time varying model error and feedback with quality control). While this slow variation of bias corrections is undesirable and certainly warrants further investigation, previous experience with radiances, confirmed by tests with PC scores, suggests that it is not a significant source of quality degradation in the assimilation.

Set-up of the assimilation experiments

To quantify the performance of the PC-score assimilation system we have designed a basic set of 4D-Var assimilation experiments that consist of a baseline experiment (BASE), a radiance assimilation control experiment (RAD) and a PC-score experiment (PC-SCORE).

- BASE uses all operational observations (satellite and conventional) with the exception of IASI data.
- RAD is identical to BASE, but additionally assimilates 165 IASI radiances.
- PC-SCORE is identical to BASE, but additionally assimilates 20 PC scores derived from the 165 IASI radiances.

Note that in the RAD and PC-SCORE experiments the use of IASI data is restricted to fully clear pixels over the ocean. All experiments have been run using a reduced horizontal resolution version (T511, ~40 km) of cycle 38r2 of ECMWF's Integrated Forecasting System (IFS) with 137 vertical levels for the period from 1 June to 15 September 2012.

For the PC assimilation testing we have retained only the first 20 PC scores because it was found that beyond around that number there was no discernible improvement in performance (as measured by the fit of the analysis to other observations).

Impact on the assimilation

Analysis increments

Figure 1 shows the difference between zonally-averaged root-mean-square temperature analysis increments between RAD and BASE (left) and PC-SCORE and BASE (right) evaluated over the three-month assimilation period. Analysis increments (defined as the change to the initial conditions at the beginning of the 4D-Var analysis window) are a good indication of how much and where the background errors are corrected by the assimilation of observations.

It can be seen in Figure 1 that above 400 hPa the RAD and PC-SCORE display similar patterns of analysis increments. In other areas, for example in the tropics and at high latitudes, PC-SCORE has slightly larger adjustments than RAD. It is likely that the differences can be attributed to the slightly greater weight assigned to the PC scores than to the IASI radiances and to differences in data coverage. However, the most important conclusion is that in these statistics there is no evidence of any anomalous or spurious behavior in the analysis increments produced by the PC-SCORE experiment.

Fit to radiosonde data

When we examine how the assimilation of either PC scores or radiances modifies the fit to radiosonde temperature observations, we see that the assimilation of 20 PC scores produces results that are statistically comparable with those obtained from the assimilation of 165 radiances. This is exemplified in Figure 2, which shows results for the extratropical southern hemisphere (90°S to 20°N) where the fit to radiosonde data is particularly sensitive to changes in the use of satellite observations and thereby provides a reliable measure of quality. Standard deviations averaged over the three-month assimilation period for RAD and PC-SCORE are shown with respect to the BASE (values are explicitly normalised by the BASE to improve visualization) for the analysis (Figure 2a) and background (Figure 2b). Thus, reduced values indicate the extent to which the assimilation of the IASI satellite data (either using radiances or PC scores) improves the fit to radiosonde data compared to the BASE assimilation.

Computational efficiency

The primary objective of developing a PC-score assimilation system is to improve computational efficiency. Performance tests indicate that the 4D-Var minimization requires 25% less computer resources (elapsed CPU time) when 20 PC scores are used compared to the system that assimilates

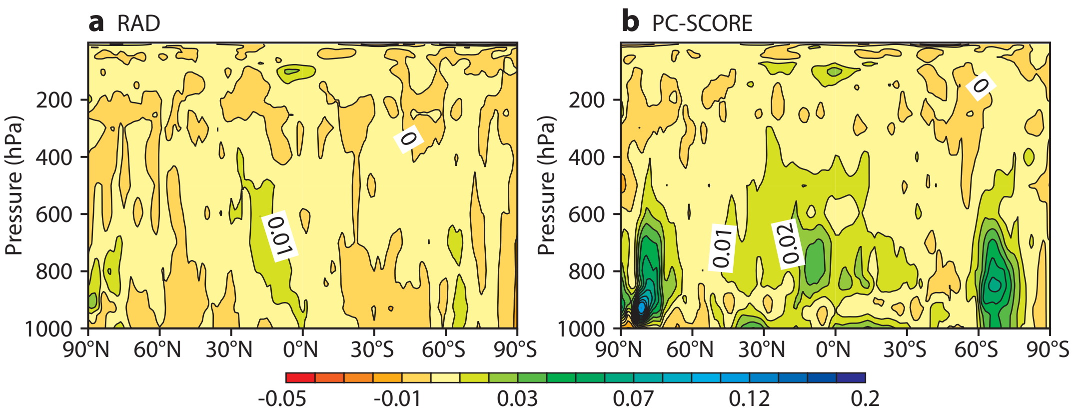


Figure 1 The difference between zonally-averaged root-mean-square temperature analysis increments for (a) RAD and BASE experiments and (b) PC-SCORE and BASE experiments. The results are evaluated over three months of assimilation for June to September 2012.

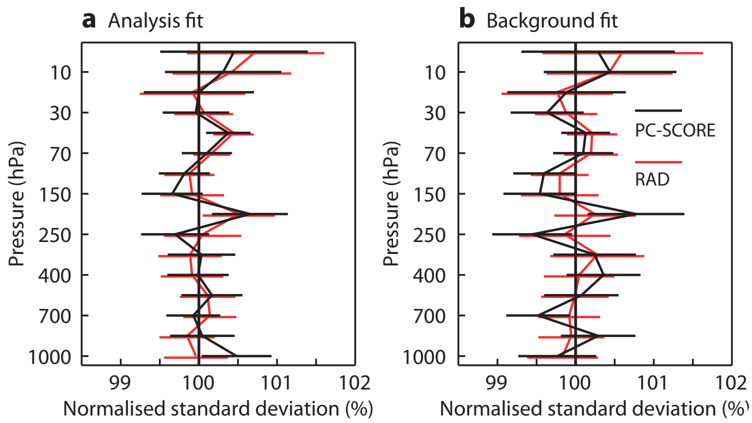


Figure 2 Normalised standard deviation of the fit to radiosonde temperature data of (a) the analysis and (b) background in the southern hemisphere for 15 June to 15 September 2012 are shown for the RAD and PC-SCORE experiments. The error bars indicate the 95% confidence range and thus give an indication of the statistical significance of the results.

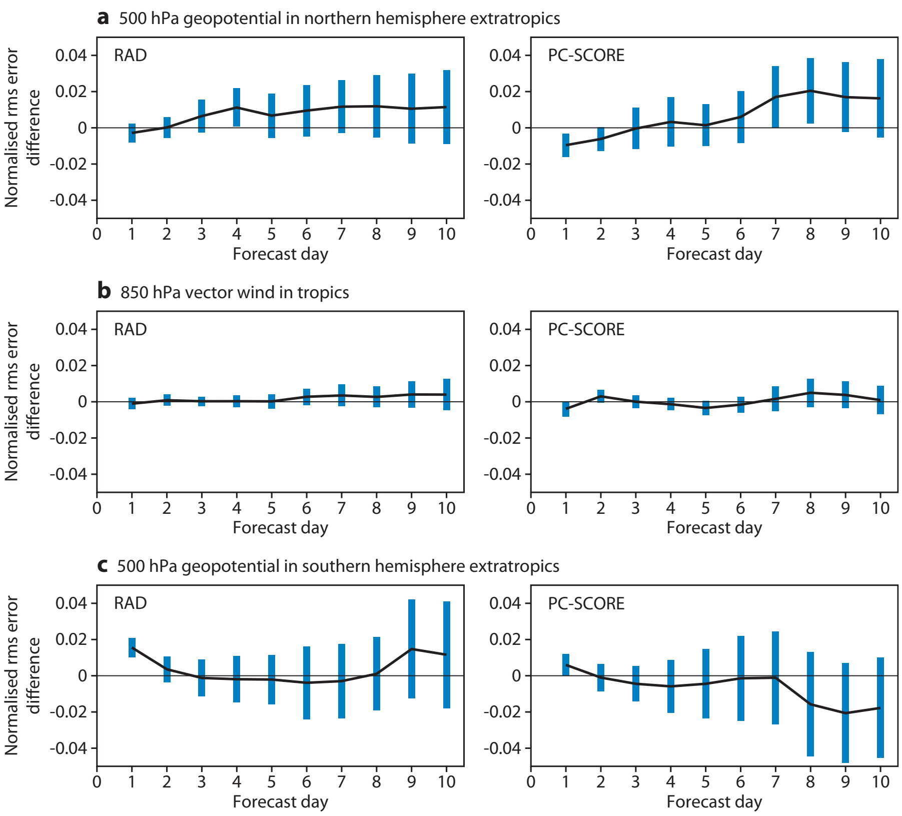


Figure 3 Normalised root-mean-square (rms) error difference for (a) 500 hPa geopotential forecasts in the northern hemisphere extratropics, (b) 850 hPa wind vector forecasts in the tropics and (c) 500 hPa geopotential forecasts in the southern hemisphere extratropics for RAD (left) and PC-SCORE (right) experiments for each forecast day. The forecasts are verified versus the operational analysis for 15 June to 15 September 2012. Error bars indicate the 95% confidence range.

165 radiances. This represents a significant saving inside the time-critical processing path for NWP centres, but could potentially be improved even further by tuning the efficiency of calculations for the radiative transfer model used for the simulation of the PCs (PC_RTTOV).

Impact on forecasts

Forecasts have been run from analyses generated by the BASE, RAD and PC-SCORE assimilation systems and verified using ECMWF operational analyses. Forecast scores for 15 June to 15 September 2012 have been computed as the change in the root-mean-square error compared to the BASE with the differences normalised by the forecast error of BASE. While this normalisation is arguably the best way to illustrate the impact on forecast errors in the medium range, it can result in the amplification of small differences in the shorter range (0 to 72 hours) where errors in the verifying analyses may be important.

To verify the forecast, the geopotential is traditionally used as a representative field because it provides a very good measure of the skill to predict large-scale flows and the general weather type. In the tropics, however, because of the different nature of the atmospheric circulation, the geopotential height (and indeed temperature) is not suitable to describe the predictive skill of the forecasting system and it is better to verify the wind vector.

Here we present results in terms of 500 hPa geopotential height for the extratropical northern and southern hemispheres (Figures 3a and 3c) and the 850 hPa wind vector in the tropics (Figure 3b). Results for the RAD experiment are plotted in the left panels while results of the PC-SCORE experiment are plotted in the right panels. A negative value of the forecast score means that the use of IASI data improves forecast accuracy compared to the BASE. Due to the relatively short duration of the experiments, some caution should be exercised when evaluating the results. This said, results suggest that the forecast scores produced by the assimilation of 20 PCs are statistically equivalent to those produced by the assimilation of 165 radiances, confirming the conclusion from the analysis diagnostics. This means that the PC-score assimilation system performs as well as the radiance system.

Summing up

The operational ECMWF 4D-Var has been adapted to allow the direct assimilation of PC scores derived from infrared sounders with a high spectral resolution. The primary aim is to develop an efficient use of the entire measured spectrum that could not be achieved by traditional radiance assimilation. The system presented in this study uses 20 PCs instead of 165 IASI long-wave radiances thereby achieving an eight-fold reduction in data volume and a 25% reduction in the overall cost of assimilation. These figures have been achieved with a rather conservative setting of the tuneable accuracy of the PC_RTTOV radiative transfer model and further computational savings could be achieved.

The new scheme has been extensively tested in a full observing system where IASI observations were used either as PC scores or radiances. Testing over a period of three months suggests that the quality of the analyses produced by the assimilation of 20 IASI PCs is almost identical to that obtained when 165 IASI radiances are assimilated. The verification of forecasts launched from these test analyses further confirms that there is no loss of skill from the assimilation of PC scores compared to that of radiances.

While this study considered only data in the IASI long-wave region, it follows a previous investigation into the use of PC scores to represent the IASI short-wave spectrum. A logical future step is to consider the extraction of information from the dedicated IASI water vapour and ozone bands towards the exploitation of all IASI spectral regions. Furthermore, within each spectral band we aim to use the largest possible number of channels to maximise the exploitation of the IASI instrument.

To summarise, the results obtained from the direct assimilation of IASI PC scores are very encouraging. They demonstrate the viability of an alternative route to radiance assimilation for the exploitation of high spectral resolution data from infrared sounders. Progress in this area is very timely – at the time of writing there were four such instruments in space (i.e. IASI on Metop-A and B, AIRS on AQUA and CrIS on NPP). Work is now needed to take this prototype system forward to a stage where it can be considered as an option for the safe and efficient operational exploitation of these crucial instruments.

FURTHER READING

Collard, **A.D.** & **A.P. McNally**, 2009: Assimilation of IASI radiances at ECMWF. *Q. J. R. Meteorol. Soc.*, **135**, 1044–1058.

Joliffe, **I.T.**, 2002: *Principal Component Analysis*, Springer: New York.

Matricardi, **M.** & **A.P. McNally**, 2013: The direct assimilation of principal components of IASI spectra in the ECMWF 4D-Var. *Q. J. R. Meteorol. Soc.*, **140**, 573–582.

ECMWF publications

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

Technical Memoranda

744 **Tavolato**, **C.** & **L. Isaksen**: On the use of a Huber norm for observation quality control in the ECMWF 4D-Var. *November 2014*

743 **Bonavita**, **M.**, **E. Holm**, **L. Isaksen** & **M. Fisher**: The evolution of the ECMWF hybrid data assimilation system. *December 2014*

742 **Haiden**, **T.**, **M. Janousek**, **P. Bauer**, **J. Bidlot**, **L. Ferranti**, **T. Hewson**, **F. Prates**, **D.S. Richardson** & **F. Vitart**: Evaluation of ECMWF forecasts, including 2013-2014 upgrades. *December 2014*

741 **Geer**, **A.J.**, **F. Baordo**, **N. Bormann** & **S. English**: All-sky assimilation of microwave humidity sounders. *November 2014*

739 **Buizza**, **R.**: The TIGGE global, medium-range ensembles. *November 2014*

735 **Albergel**, **C.**, **E. Dutra**, **J. Muñoz-Sabater**, **T. Haiden**, **G. Balsamo**, **A. Beljaars**, **L. Isaksen**, **P. de Rosnay**, **I. Sandu** & **N. Wedi**: Soil temperature at ECMWF: an assessment using ground-based observations. *November 2014*

TAC Representatives, Computing Representatives and Meteorological Contact Points

Member States	TAC Representatives	Computer Representatives	Meteorological Contact Points
Austria	Dr G. Kaindl	Mr M. Langer	Dr A. Schaffhauser
Belgium	Mr D. Gellens	Mrs L. Frappez	Dr J. Nemeghaire
Denmark	Mr C. Simonsen	Mr T. Lorenzen	Mr H. Gisselø
Finland	Mr J. Hyrkkänen	Mr M. Aalto	Mr A. Vähämäki
France	Mr J.-M. Carrière	Miss C. Allouache	Ms N. Girardot
Germany	Dr D. Schroeder	Dr E. Krenzien	Mr T. Schumann
Greece	Mr A. Emmanouil	Mr. N. Andritsas	Mr A. Lalos Ms C. Petrou Mr P. Skrimizeas Ms T. Tzeferi
Iceland	Mr T. Hervarsson	Mr V. Gislason	Mrs K. Hermannsdóttir
Ireland	Ms S. O'Reilly	Mr T. Daly	Mr G. Fleming
Italy	Lt. Col. L. Torrisi	Mr A. Vocino	Dr T. La Rocca
Luxembourg	Mrs M. Reckwerth	Mrs. M. Reckwerth	Mrs. M. Reckwerth
Netherlands	Mr R. van Lier	Mr H. de Vries	Mr J. Diepeveen
Norway	Mrs C. Husum Vold	Mr K. Steinar Dale	Dr B Røsting
Portugal	Ms V. Costa	Mr B. Anjos	Mr N. M. Moreira
Slovenia	Mr J. Jerman	Mr P. Hitij	Mr B. Gregorčič
Spain	Mr P. del Rio	Mr R. Corredor	Mr. A. Alcazar
Sweden	Mr F. Linde	Mr R. Urrutia	Mr F. Linde
Switzerland	Dr P. Steiner	Mr P. Roth	Mr E. Müller
Turkey	Mr M. Fatih Büyükkasabbaşi	Mr M. Emre Yakut	Mr A. Guser
United Kingdom	Mr I. Forsyth	Mr W. Roseblade	Mr I. Forsyth
Co-operating States			
Bulgaria	Ms I. Etropolska	Ms I. Etropolska	Mrs A. Stoycheva
Croatia	Ms B. Matjacic	Mr V. Malović	Ms B. Matjacic
Czech Republic	Ms A. Trojakova	Mr K. Ostatnický	Mr F. Sopko
Estonia	Mr A. Männik	Mr H. Kaukver	Mrs M. Merilain Mrs T. Paljak
The former Yugoslav Republic of Macedonia	Mr V. Dimitriev	Mr B. Sekirarski	Ms N. Aleksovska
Hungary	Mr I. Ihász	Mr I. Ihász	Mr I. Ihász
Israel	Mr I. Rom	Mr V. Meerson	Mr N. Stav
Latvia	Mr A. Bukšs	Mr A. Bukšs	Ms A. Niznika
Lithuania	Mrs V. Auguliene	Mr M. Kazlauskas	Mrs V. Raliene
Montenegro	Mr A. Marčev	Mr A. Marčev	Mr B. Micev
Morocco	Mr H. Haddouch	Mr M. Jidane	Mr K. Lahlal
Romania	Mrs A. Ristici	Ms C. Ostroveanu	Ms M. Georgescu
Serbia	Ms L. Dekic	Mr V. Dimitrijević	Mr B. Bijelic
Slovakia	Mr J. Vivoda	Dr O. Španiel	Dr M. Benko Dr J. Csaplar
Observers			
EUMETSAT	Mr A. Ratier	Dr S. Elliott	
WMO	Mr M. Jarraud		

ECMWF Council and its committees

The following provides some information about the responsibilities of the ECMWF Council and its committees. More detail can be found at:
http://www.ecmwf.int/about/committees

Council

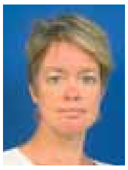
The Council adopts measures to implement the ECMWF Convention; the responsibilities include admission of new members, authorising the Director-General to negotiate and conclude co-operation agreements, and adopting the annual budget, the scale of financial contributions of the Member States, the Financial Regulations and the Staff Regulations, the long-term strategy and the programme of activities of the Centre.

President Prof Dr Gerhard Adrian *(Germany)*

Vice President Dr Miguel Miranda *(Portugal)*

Policy Advisory Committee (PAC)

The PAC provides the Council with opinions and recommendations on any matters concerning ECMWF policy submitted to it by the Council, especially those arising out of the Four-Year Programme of Activities and the Long-term Strategy.



Chair Mrs Marianne Thyrring *(Denmark)*

Vice Chair Mr Arni Snorrason *(Iceland)*

Finance Committee (FC)

The FC provides the Council with opinions and recommendations on all administrative and financial matters submitted to the Council and shall exercise the financial powers delegated to it by the Council.

Chair Mr Marko Viljanen *(Finland)*

Vice Chair Mr Mark Hodkinson *(United Kingdom)*

Scientific Advisory Committee (SAC)

The SAC provides the Council with opinions and recommendations on the draft programme of activities of the Centre drawn up by the Director and on any other matters submitted to it by the Council. The 12 members of the SAC are appointed in their personal capacity and are selected from among the scientists of the Member States.

Chair Dr Jan Barkmeijer *(KNMI)*

Vice Chair Prof Sarah Jones *(Deutscher Wetterdienst)*

Technical Advisory Committee (TAC)

The TAC provides the Council with advice on the technical and operational aspects of the Centre including the communications network, computer system, operational activities directly affecting Member States, and technical aspects of the four-year programme of activities.

Chair Dr Daniel Gellens *(Belgium)*

Vice Chair Mr Jean-Marie Carrière *(France)*

Advisory Committee for Data Policy (ACDP)

The ACDP provides the Council with opinions and recommendations on matters concerning ECMWF Data Policy and its implementation.

Chair Mr Frank Lantsheer *(Netherlands)*

Vice Chair Mr Soren Olufsen *(Denmark)*

Advisory Committee of Co-operating States (ACCS)

The ACCS provides the Council with opinions and recommendations on the programme of activities of the Centre, and on any matter submitted to it by the Council.

Chair Mr Martin Benko *(Slovakia)*

Vice Chair Ms Inita Stikute *(Latvia)*

ECMWF Calendar 2015

Mar 2–6	Computer User Training Course: Introduction for New Users/MARS
Mar 3–6	Copernicus Climate Data Store Infrastructure Workshop
Mar 9–10	Stochastic Workshop
Mar 9–13	Computer User Training Course: Data Analysis and Visualisation using Metview
Mar 16-20	NWP Training Course: Data Assimilation
Mar 23-27	EUMETSAT/ECMWF NWP SAF Training Course: Assimilation of Satellite Data
Mar 31	EUMETSAT Licensing Agents Workshop and Data Policy Group
Apr 1	Advisory Committee for Data Policy
Apr 2	ECOMET Working Group
Apr 13–17	Computer User Training Course: HPCF – Use of the New Cray System
Apr 20–29	NWP Training Course: Predictability and Ocean-Atmosphere Ensemble Forecasting
Apr 21	Policy Advisory Committee
Apr 22–23	Finance Committee
May 5–6	EC-Earth Meeting
May 11–21	NWP Training Course: Parametrization of Subgrid Physical Processes
May 18–19	Security Representatives' Meetings
May 19–21	Computing Representatives' Meetings
Jun 1–5	NWP Training Course: Advanced Numerical Methods for Earth-System Modelling
Jun 8–10	Using ECMWF's Forecasts (UEF2015)
Jun 10–12	OpenIFS Workshop
Jun 15–18	Workshop on Advancing Training and Teaching in Numerical Weather Prediction
Jun 25–26	Council
Jun 29–Jul 3	ERA-CLIM2 Workshop on Observations for Earth System Reanalysis
Sep 1–4	Annual Seminar
Sep 28–30	Visualisation Week: Workshop on Meteorological Operational Systems
Sep 29–Oct 1	Visualisation Week: European Working Group on Operational Meteorological Workstations (EGOWS)
Oct 1 (pm)	Visualisation Week: RMetS Seminar on Visualisation in Meteorology
Oct 2 (am)	Visualisation Week: OGC MetOcean Interoperability Session
Oct 5–7	Training Course: Use and Interpretation of ECMWF Products
Oct 12–14	Scientific Advisory Committee
Oct 15–16	Technical Advisory Committee
Oct 21	Policy Advisory Committee
Oct 22–23	Finance Committee
Nov 2-6	Workshop on Extended Range Predictability

Contact information

ECMWF, Shinfield Park, Reading, Berkshire RG2 9AX, UK

Telephone National 0118 949 9000

Telephone International +44 118 949 9000

Fax +44 118 986 9450

ECMWF's public website http://www.ecmwf.int/

E-mail: The e-mail address of an individual at the Centre is firstinitial.lastname@ecmwf.int. For double-barrelled names use a hyphen (e.g. j-n.name-name@ecmwf.int).

Problems, queries and advice	Contact
General problems, fault reporting, web access and service queries	calldesk@ecmwf.int
Advice on the usage of computing and archiving services	advisory@ecmwf.int
Queries regarding access to data	data.services@ecmwf.int
Queries regarding the installation of ECMWF software packages	software.support@ecmwf.int
Queries or feedback regarding the forecast products	forecast_user@ecmwf.int

Index of newsletter articles

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

ECMWF
Newsletter | Number 142 – Winter 2014/15
European Centre for Medium-Range Weather Forecasts
www.ecmwf.int