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PUBLICATION POLICY

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 The *ECMWF Newsletter* is not peer-reviewed.

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www.ecmwf.int/publications/newsletter/guidance.pdf

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Using feedback and improving forecasts

A critical goal of ECMWF is to produce as accurate and reliable forecasts as possible, and of course we assess the skill of the forecasts continuously. One of the headline scores by which we assess the skill showed that for this past summer in the northern hemisphere extratropics the range of useful forecasts was around 6 days – this is the best ever summer skill achieved over ECMWF's history. Interestingly this measure of skill is better than that of the generally more-skilful winter forecasts about ten years ago.

The improvement in the overall skill is an impressive achievement but of course there are some regions where the skill is not so good. An example is the near-surface temperature forecasts in winter and spring for Finland, Norway and Sweden. Last winter the average monthly bias in maximum temperature forecasts for Finland has been about -1.5°C. This low quality of the temperature forecast was noticed by the Finnish media and general public. ECMWF responded to this by investigating the cold bias and identifying that a revision to the formulation of the cloud micro-physics scheme (i.e. improving the description of supercooled liquid water layers) is specifically beneficial for reducing this bias. But further work is needed to investigate other sources of bias. Improvements in the representation of physical processes, such as those involving cloud microphysics, surface processes, snow and radiative interactions, are crucial in reducing such biases.

This is a good reminder that, whilst spatially-averaged skill scores might be at a high level, the weather systems such as clouds and cyclones in the forecast may still have significant deficiencies in comparison to reality. The solution lies in further research and development. Also we know that the representation of clouds and their microphysical processes are very sensitive to the spatial resolution of the model. This is evidence, if we needed it, of why increases in resolution are so critical.

Sometimes one hears questions about why ECMWF is quite so focused on increasing the spatial resolution of its models. We should remember that the mathematical equations governing fluid dynamics used in models involve spatial derivatives which can only be accurately quantified if the effective spacing between the grid points is very small. Also phenomena need to be described by several grid-points and so, for example, when we say the horizontal resolution of our forecasts is 16 km in fact we cannot really claim to represent phenomena on scales much below, say, 60 km with any degree of accuracy.

With greater resolution comes the need for more computer power with which to calculate the forecasts. We are currently gearing up for the next supercomputer procurement and as usual this is a critical aspect of enabling ECMWF to retain its world-leading position. The economic downturn makes finding the funds to finance enhancements in supercomputer capability particularly difficult at the moment.

Two further reflections on temperature biases for Finland, Norway and Sweden. It was immensely helpful to obtain specific feedback from forecasters in those countries and I hope others can be encouraged to give us feedback both positive and negative. Finally it is a reminder of how crucial the second of ECMWF's four strategic themes is: on improved quality of near-surface weather products.

Alan Thorpe

Departure of Ute Dahremöller

ALAN THORPE

Ute Dahremöller joined the Centre in April 2006 as Head of the Administration Department on the retirement of Dr Gerd Schultes. One of the significant issues she had to address was how to fund the budgetised pension scheme. This issue had been looming for years and she proposed various solutions that led to the decision made by Council to fund it by step increases. Ute's background, especially as Head of Finance Division of the German Federal Agency for Post and Telecommunications, had prepared her well for seeing through this demanding task that was essential for the long-term financial stability of the Centre.

It is difficult to choose just a few examples from the wide range of other important developments that benefited from Ute's leadership, but these include:

- legal adviser position was created enabling the Centre to better deal with the variety of legal issues with which it is faced.
- Developing ECMWF's relationship with other International Organisations including those based in the UK.
- An Equal Opportunity Policy and a charter of ethics were introduced.
- Significant progress was made towards the Centre being compliant with International Public Sector Accounting Standards (IPSAS).
- The North Building was constructed which has provided additional high-quality accommodation.
- Improving the site, including the entrance, to better reflect ECMWF's status and visibility.

After a successful period of Director of Administration, Ute has now left the Centre to take up the position of Director General of Administration at the Council of Europe in Strasbourg, France, starting on 1 October 2011. In her final message to staff at the Centre Ute said "As you know, the decision to change jobs was not an easy one for me as I have thoroughly enjoyed working for ECMWF for more than five years, but I also realised that this was an opportunity for further professional development which should not be missed." She added "I would also like to thank you for the excellent cooperation over the past years for which I am very grateful. I will certainly miss you."

I wish Ute every success in her new post and thank her for the important contributions she made to developments at the Centre during her five-years as Head of Administration and as a key member of the Directorate.

Flow-dependent background error variance in 4D-Var

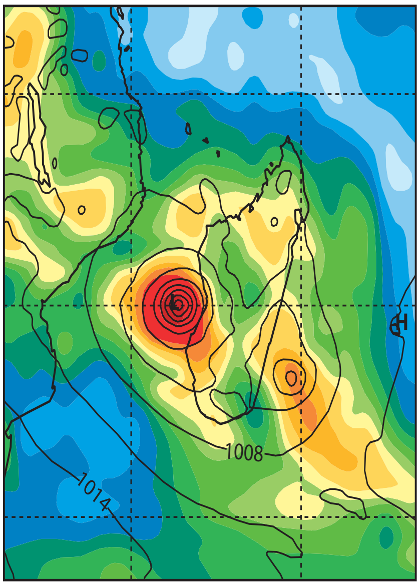
LARS ISAKSEN

Since May 2011 (IFS Cycle 37r2) the Ensemble of Data Assimilations (EDA) has provided flow-dependent estimates of background error variance for the operational 4D-Var assimilation system. A similar approach was pioneered and implemented at Météo-France in 2008. The EDA gives an estimate of the error-of-the-day and influences the weight given to observations in the analysis. This has shown a clear positive impact on the skill of the deterministic forecast and has contributed to making Cy37r2 one of the most successful upgrades of the IFS over the past decade.

The EDA provides more realistic background error estimates, especially in proximity of active weather systems such as extra-tropical and tropical cyclones. Spatial filtering of the ensemble spread is required in order to reduce its random noise, and an adaptive rescaling step which adjusts the magnitude of the ensemble spread is also needed.

This implementation is only the first step towards a hybrid data assimilation system that will use a fully flow-dependent representation of background error covariance. The availability of the larger EDA in the future will ultimately make it possible to replace the static covariance by ones updated in real time.

In the next *ECMWF Newsletter* this significant upgrade of our assimilation system will be described in more detail.



Intensity of the EDA sampled background errors tropical cyclone Fanele. Shown is the intensity of the sampled background errors based on the logarithm of surface pressure computed from a 20-member EDA. There is a clear maximum near the centre of the storm as it approaches the coast of Madagascar at 09 UTC on 20 January 2009. The errors tend to be more localized around the areas characterized by larger uncertainties and sparser observational coverage.

Election of Dominique Marbouty as EMS President

BOB RIDDAWAY

Jean-François Geleyn receiving the EMS Silver Medal at the EMS Annual Meeting in Berlin. Dominique Marbouty (EMS President Elect, left) and Fritz Neuwirth (EMS President, right) with Jean-François Geleyn when he received the EMS Silver Medal for his outstanding contributions to the fostering of cooperation among scientists in European countries, particularly in the field of numerical weather prediction. Jean-François worked at ECMWF from1976 to December 1982 and was involved in the development of its first operational model. Photo courtesy of Radim Tolasz (Czech Hydrometeorological Institute).

The Council of the European Meteorological Society (EMS) has elected Dominique Marbouty (ECMWF's former Director-General) as the EMS President for 2011 to 2014. He takes over from Fritz Neuwirth who was the director of the Austrian Weather Service, ZAMG, until his retirement in 2009.

Dominique is the second former Director-General of ECMWF to be EMS President. From 2005 to 2008 the position was held by David Burridge.

Dominique's duties as President started at the end of the 11th EMS Annual Meeting and 10th European Conference on Applications of Meteorology (ECAM) that were held in Berlin from 12 to 16 September. These events were a great success with over 700 participants from about 50 countries. In 2012 the Annual Meeting and European Conference on Applied Climatology will be held in Łódź, Poland, from 10 to 14 September.

The aim of the EMS is to:

- Advance the science, profession and application of meteorology, and of sciences related to it, at the Europe-wide level, for the benefit of the whole population.
- Help EMS Member Societies and Associate Members to achieve better communication and understanding to benefit all classes of their membership.

At present the EMS has 34 Member Societies. Also there are 30 Associate Members that include non-European Meteorological Societies, National Meteorological and Hydrological Services, companies with interests in meteorology, related sciences and their applications, and Europe-wide bodies with similar interests.

Information about the EMS can be found at:

- http://www.emetsoc.org

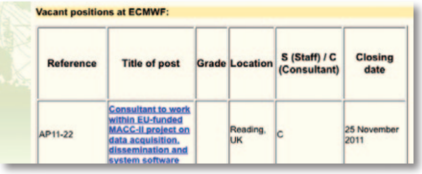
or by contacting Martina Junge, EMS Executive Secretary, at:

- ems-sec@emetsoc.org

New items on the ECMWF website

ANDY BRADY

Employment Vacancies Mailing List



Vacant positions at ECMWF:

Reference	Title of post	Grade	Location	S (Staff) / C (Consultant)	Closing date
AP11-22	Consultant to work within EU-funded MACC-II project on data acquisition, dissemination and system software		Reading, UK	C	25 November 2011

A mailing list about ECMWF vacant positions is now available. Subscribers to this list will receive emails when new positions are available at ECMWF.

- http://www.ecmwf.int/newsevents/employment/en/

Extension of the ERA-Interim reanalysis

The ERA-Interim reanalysis dataset has been extended by ten years, and now covers dates from 1 January 1979. The newly added data are available in MARS and on the Data Server. A paper describing the extension and the continuity of the dataset as a whole is in preparation.

- http://www.ecmwf.int/publications/cms/get/ecmwfnews/282
- http://www.ecmwf.int/research/era/

ECMWF Annual Seminar 2011

ECMWF 2011 Annual Seminar

Seminar on Data assimilation for atmosphere and ocean,
6 - 9 September 2011

- Registration is now closed
- Programme update 31.8.2011
- List of invited speakers and participants
- Useful links
- Presentations
- Proceedings (to follow)

ECMWF SEMINAR

The subject of the seminar this year was 'Data assimilation for atmosphere and ocean'. The seminar was held from 6 to 9 September 2011. Presentations are now available.

- http://www.ecmwf.int/newsevents/meetings/annual_seminar/2011/

ECMWF workshops and scientific meetings in 2012

BOB RIDDAWAY

Forecast Products Users' Meeting (20 to 22 June 2012)

ECMWF organizes annually a meeting of users of its medium-range and extended-range products. The purpose of the meetings is to:

◆ Give forecasters the opportunity to discuss their experience with and to exchange views on the use of the medium-range and extended-range products, including the ensemble.

◆ Review the development of the operational system and to discuss future developments including forecast products.

User registration from Member States and Co-operating States should be communicated via the National Meteorological Service of that country.

Invitations will be mailed to the Member States early in April.

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

Workshop on 'Ocean wave modelling' (25 to 27 June 2012)

The quality of wind and wave forecasts has steadily improved following advances in many aspects of the atmosphere and wave models. Better forecast guidance can now be issued, including warning about dangerous sea states. Nevertheless, it is now recognised that the modelling interface between the atmosphere and the wave should also include the upper ocean component, leading to a more fully coupled system for air and oceans (water and ice). In addition, different scales are inherently present in waves with fairly uniform wave fields in the open oceans to rapidly changing wave conditions near coasts and strong surface currents. A truly global operational system should be able to tackle these different scales.

Recent field campaigns and theoretical developments have shown that the current parametrizations for the different input source terms might need revision. Also novel approaches need to be developed on how to best use wave observations from in-situ or space-borne platforms.

This workshop, with attendance by invitation only, is seeking advice from the wider community on how to carry forward improvements in ocean wave modelling.

- http://www.ecmwf.int/newsevents/meetings/workshops/2012/ocean_waves/index.html

ECMWF 2012 Annual Seminar on 'Seasonal prediction: Science and Applications' (4 to 7 September 2012)

In the past decade, ensemble-based, probabilistic seasonal forecasts have become more accurate and reliable, building on the continuous improvements of coupled atmosphere and ocean modelling, and on advances in the simulation of initial and model uncertainties. Seasonal prediction systems are now part of routine operational suites at leading numerical weather prediction centres, and seasonal forecasts are increasingly used in a range of applications to improve weather-associated risk management (e.g. to prevent losses due to severe flood and drought conditions, and to prepare for health-related emergencies). The seminar will review:

◆ Principles behind seasonal predictions.

◆ Recent scientific developments in probabilistic, coupled seasonal prediction.

◆ Value of seasonal prediction in weather-risk reduction.

A registration form and further information will be available from:

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

Workshop on 'Parametrization of clouds and precipitation across model resolution' (6 to 9 November 2012)

The ECMWF strategy for the development of physical parametrizations over the next decade places particular emphasis on moist physics and there are many questions of how best to represent the hydrological, radiative and dynamical impacts of cloud and precipitation across an increasing range of model resolutions.

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

◆ The appropriate level of complexity and numerical formulation of microphysics.

◆ How to represent the impacts of

sub-grid heterogeneity efficiently and consistently across the range of model resolutions.

◆ How to get the most benefit from observations with an emphasis on evaluating and constraining cloud and precipitation processes.

Workshop attendance is by invitation only.

- http://www.ecmwf.int/newsevents/meetings/workshops/2012/moist_physics/index.html

15th ECMWF Workshop on 'High Performance Computing in Meteorology' (autumn 2012 – to be confirmed)

The emphasis of this biennial workshop will be on running meteorological applications at sustained teraflops performance in a production environment. Particular emphasis will be placed on the future scalability of NWP codes and the tools and development environments to facilitate this. The aim is to provide a venue where:

◆ Users from our Member States and around the world can report on their experience and achievements in the field of high performance computing during the last two years and present plans for the future and requirements for computing power.

◆ Vendors of supercomputers will have the opportunity to talk to managers and end users of meteorological computer centres about their current and future products.

◆ Meteorological scientists can present their achievements in the development of parallel computing techniques and algorithms, and can exchange ideas on the use of supercomputers in future research.

◆ Computer scientists can give an update on their efforts in providing tools which will help users to exploit the power of supercomputers in the field of meteorology.

◆ The challenges of creating a computer centre infrastructure for HPC can be discussed.

Workshop attendance is by invitation. If you are interested in attending, go to:

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

Data assimilation for atmosphere and ocean

LARS ISAKSEN, JEAN-NOËL THÉPAUT

This year's ECMWF Annual Seminar on data assimilation methods for the atmosphere and ocean attracted a large number of participants, with more than 90 scientists coming from member states and international research centres.

The lectures covered all aspects of data assimilation, both describing the basic methods and current operational implementations as well as giving visions of possible future techniques, such as particle filters. Variational methods were described in detail as well as the ensemble approach including ensemble Kalman filters and hybrid techniques. Both atmosphere, land and ocean data

Andrew Lorenc (*UK Met-Office*)	Developments in variational data assimilation
Jeff Whitaker (*NOAA*)	Developments in ensemble data assimilation
Dale Barker (*UK Met-Office*)	Hybrid variational/ensemble data assimilation
Florence Rabier (*Météo-France*)	Pre- and post-processing in data assimilation
Saroja Polavarapu (*Environment Canada*)	Stratospheric and mesospheric data assimilation
Sue Ballard (*Met-Office, Reading*)	Convective scale data assimilation and nowcasting
Michele Rienecker (*GMAO*)	The Global Observing System in the data assimilation context
John Derber (*NCEP*)	Current status and future of satellite data assimilation
Gerald Desroziers (*Météo-France*)	Observation error specification
Carla Cardinali (*ECMWF*)	Monitoring the assimilation and forecast system performance
Jean-Francois Mahfouf (*Météo-France*)	Data assimilation of the hydrological cycle
Patricia de Rosnay (*ECMWF*)	Land surface data assimilation
Massimo Bonavita (*ECMWF*)	Ensemble of data assimilations and uncertainty estimation
Chris Snyder (*UCAR, Colorado*)	Non-linear data assimilation
Peter Jan v Leeuwen (*Reading University*)	Nonlinear large-dimensional data assimilation: the potential of particle filters
Mike Fisher (*ECMWF*)	Long window weak-constraint 4D-Var
Andy Moore (*University of California*)	Recent developments in ocean data assimilation
Paul Poli (*ECMWF*)	Reanalysis
Keith Haines (*ESSC*)	Coupled Data Assimilation – ocean, mixed layer, land and atmosphere interaction
Adrian Simmons (*ECMWF*)	Coupled data assimilation for atmospheric constituents
Lars Isaksen (*ECMWF*)	Data Assimilation on future computer architectures

Presentations given at the ECMWF Annual Seminar on 'Data assimilation for atmosphere and ocean'.

assimilation were covered; in addition future prospects for coupled ocean-atmosphere-land surface assimilation were discussed. Atmospheric composition assimilation is a novel area being developed at ECMWF and was also presented.

The discussions both inside and outside the lecture theatre were intense. In addition to hearing about the latest developments in data assimilation the participants also took the opportunity to meet and learn from each other.

The presentations from the seminar are available at:

- http://www.ecmwf.int/newsevents/ meetings/annual_seminar/2011/presentations/index.html

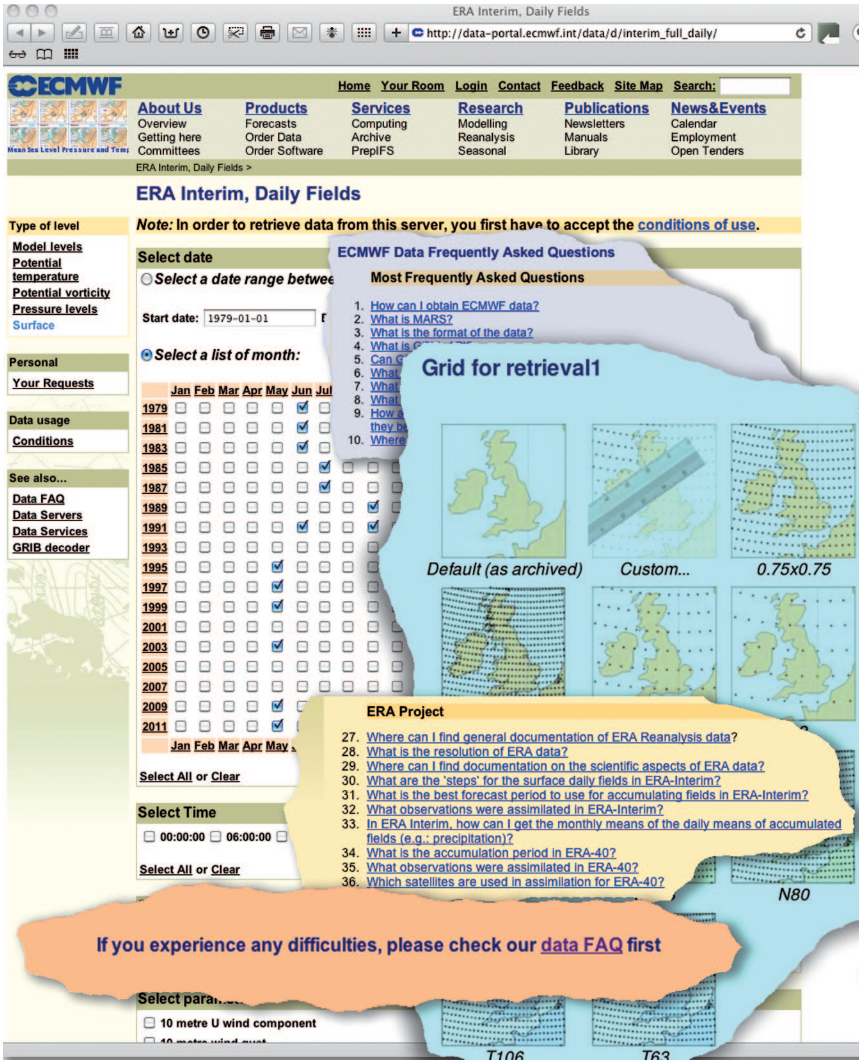
Better Internet access to ERA-Interim

DAVID TAN, PAUL BERRISFORD, DICK DEE, MANUEL FUENTES, BAUDOUIN RAOULT

The popularity of ERA-Interim data continues to grow: with new applications emerging regularly and many categories of users around the world, the number of registered users now numbers in the thousands. Recent developments mean that 2011 is an opportune time to build on this success – these developments include ECMWF's wish to make some ERA-Interim data available free of charge, the decision of Member States to abolish the information charge, the proven user-friendliness of the existing Internet-based data server, and the scope to extend access to commercial users.

To improve Internet-based user access to ERA-Interim data, ECMWF has implemented a new 'full-resolution' data server. The complete ERA-Interim dataset, which has been extended back to 1979 (see *Newsletter No. 128*) and continues to be updated close to near-real-time, remains available through MARS (ECMWF's Meteorological Archive and Retrieval System). The new ERA-Interim data server offers a more comprehensive subset than before and includes additional features, notably:

- Access to data on model levels.
- A choice of horizontal grids including the 'full-resolution' (N128) reduced Gaussian grid and a comparable 0.75° regular latitude-longitude grid.
- New terms and conditions on use of the data have been formulated to allow use for commercial purposes as well as for research.
- Support to users has also been improved by revising and extending the data FAQs (frequently asked questions).



ERA Interim, Daily Fields

http://data-portal.ecmwf.int/data/d/interim_full_daily/

ERA Interim, Daily Fields

Note: In order to retrieve data from this server, you first have to accept the conditions of use.

Start date: 1979-01-01

ECMWF Data Frequently Asked Questions

Most Frequently Asked Questions

1. How can I obtain ECMWF data?
2. What is MARS?
3. What is the format of the data?

Grid for retrieval1

ERA Project

27. Where can I find general documentation of ERA Reanalysis data?
28. What is the resolution of ERA data?
29. Where can I find documentation on the scientific aspects of ERA data?
30. What are the 'steps' for the surface daily fields in ERA-Interim?
31. What is the best forecast period to use for accumulating fields in ERA-Interim?
32. What observations were assimilated in ERA-Interim?
33. In ERA Interim, how can I get the monthly means of the daily means of accumulated fields (e.g.: precipitation)?
34. What is the accumulation period in ERA-40?
35. What observations were assimilated in ERA-40?
36. Which satellites are used in assimilation for ERA-40?

If you experience any difficulties, please check our data FAQ first

The new ERA-Interim data server. The data server, which also provides links to the revised FAQs, is available at http://data-portal.ecmwf.int/data/d/interim_full_daily/. For new features, see text.

As before, a range of monthly-averaged and instantaneous daily parameters from ERA-Interim are available via the server. For the daily data, the analysis-based fields have validity times of 00, 06, 12 or 18 UTC, and the forecast-based fields (from forecasts run twice daily from the 00 and 12 UTC analyses) have forecast steps of 3, 6, 9 or 12 hours.

The key Internet links are:

- http://data-portal.ecmwf.int/data/d/interim_full_daily/

for the point-and-click interface to the new server.

- http://www.ecmwf.int/products/data/archive/data_faq.html

for the answers to FAQs.

For large-volume data retrievals, an alternative is to submit batch mode requests written in Perl or Python – guidance on this is available from the same point-and-click interface.

The capacity of the data server is finite so users' requests are processed in a controlled manner, and high demand may lead to longer retrieval times. We strongly advise anyone requesting large amounts of data to use the MARS client directly, if they are registered users of ECMWF, or make use of the service provided by ECMWF Data Services

- http://www.ecmwf.int/products/data/

which can deliver data on various media, against a handling charge.

The improved Internet access should benefit all users of ERA-Interim, including projects such as ESA's Climate Change Initiative (CCI). The CCI is part of ESA's efforts to produce long-term climate-quality datasets for a number of Essential Climate Variables (ECVs) through reprocessing of existing satellite data. ECMWF's Reanalysis Section participates in the CCI through the sub-project known as the Climate Modelling Users Group (CMUG) which is managed by the Met Office (Exeter, Roger Saunders and Paul van der Linden) and includes partners at Météo-France and CNES (both Toulouse), and MPI (Hamburg).

The CMUG interacts with all ECV sub-projects (there are ten currently), providing a cross-cutting user perspective and feedback on product development. It fosters the links between CCI and the wider modelling community, and is preparing to evaluate/exploit future CCI datasets. ECMWF has made its reanalysis products available to the ECV teams, as requested for product generation (e.g. when algorithms require a prior estimate of the atmospheric state) and also for product evaluation. The new data server will make it easier for ECV teams to acquire ERA-Interim for such purposes.

The increasing use of ERA-Interim for climate monitoring can be seen in the Bulletin of the *American Meteorological Society* ('State of the Climate in 2009', 2010, **91**, S1-S224 and 'State of the Climate in 2010', 2011, **92**, S1-S266) – these publications are the two most recent in the BAMS series of annual assessments of the state of the climate. Within the 2011 assessment, *Dee et al.* (S34-S35) give an overview of the use and interpretation of reanalysis data for climate monitoring, and ERA-Interim appears in sections covering surface parameters (2-metre temperature, surface wind, surface humidity) and upper-air parameters (lower-tropospheric temperature, lower-stratospheric temperature). Precipitation from ERA-Interim is also included but subject to less confidence because it is only indirectly constrained by observations.

We look forward to even greater use, and many new applications, of ERA-Interim data in future.

Late News

Monday run of the monthly forecast

A second weekly run of the monthly forecast, run every Monday at 00 UTC, has been introduced to provide an update to the Thursday forecast. The Monday run was declared operational on 10 October 2011.

A new set of web pages has been prepared, showing the graphical products from both Thursday and Monday runs. Time-averaged fields are shown for the same 7-day calendar weeks (Monday-Sunday) as for the Thursday run. The web pages have been reorganised to allow users to easily compare the latest forecast with the previous ones for the same verifying period.

The monthly forecasts can be found at:

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

MACC -II

A second phase of funding for the pre-operational GMES atmospheric monitoring and forecasting provided by MACC (Monitoring Atmospheric Composition and Climate) has been secured until July 2014. The grant agreement for a continuation project, MACC-II, funded under the European Union's Seventh Framework Programme, entered into force on 14 October.

MACC-II will largely continue the production streams and developmental effort of MACC, but will no longer include support for supply of national air-quality data or study of downstream test cases. There will be increased coordination of validation activities and increased effort on estimation of emissions. Services, including this website, will continue to be provided under the name MACC.

ECMWF Newsletter No. 129 – Autumn 2011


Anders Persson

Increasing trust in medium-range weather forecasts


Bob Riddaway

ANDERS PERSSON, BOB RIDDAWAY

The fifth edition '*User guide to ECMWF forecast products*' has been published and can be found at: http://www.ecmwf.int/products/forecasts/guide/. The following is a record of a conversation between Anders Persson, the author of the Guide, and Bob Riddaway, the Editor of the *ECMWF Newsletter* on the best use of the ECMWF products and how to really 'add value' to them.

Contents of the User Guide

Bob Riddaway (BR) You have just finished a new edition of the '*User guide to ECMWF forecast products*'. Could you briefly summarize its contents?

Anders Persson (AP) I hope it will facilitate the use of the numerical weather prediction (NWP) products from the ECMWF forecasting system, in particular the medium-range forecast products. The way forecasters deal with medium-range NWP output differs in many ways from how they deal with the short-range NWP on one hand, and monthly and seasonal NWP on the other.

BR The ECMWF medium-range forecasts are the best in the world, skilful up to a week or more. Do we really need a 'User Guide'; can't the forecasts just be used straight away?

AP This might be true for ordinary weather a few days ahead, but not for unusual, dangerous or extreme weather events. Decisions about postponing operations or evacuations cannot be made just by blindly following computer output. Consider what happens with a modern aircraft. The more they become equipped with advanced instruments and sophisticated techniques the thicker the manuals and the more demanding is the training on how to operate them. Although there are autopilots we all prefer to have trained pilots in the cockpit!

BR So I assume the Guide is primarily written for weather forecasters. But what about other groups of meteorologists, and even non-meteorologists?

AP It is intended that scientists and NWP modellers will find it a convenient reference to the ECMWF forecasting systems, as might non-meteorological users of our products. To this end, I have put in a lot of effort into maintaining an informal and non-technical style.

BR Very little has been written on the use of NWP in practical forecasting.

AP There are good textbooks and courses in NWP and dynamic meteorology but, as far as I know, nothing has been documented about what the forecasters should do when, for example, the short-range NWP conflicts with more recent observations. What to do when successive runs from the same NWP model differ widely? Or when various NWP models offer different solutions? Most forecast experience of the synoptic-scale weather systems is derived from the short range, where the forecasters modify their positions and intensities, and do not have to question their coming into existence as often is the case in the medium-range.

BR That being so, on which sources have you based your advice in the Guide?

AP I have drawn on my own experiences, and discussions over the years with forecasters, scientists and statistically-interested meteorologists. It has helped me find out which forecast rules of thumb seem to work and which don't, as well which new rules could be suggested on theoretical grounds. As one of my Swedish professors (Tor Bergeron) once told me: "*Behind good forecast practice is often hidden good theories; equally, good theories should provide a basis for good forecast practice*". That's why it is important the take notice of how experienced forecasters work. What I became aware of during the work with the Guide, and found particularly interesting, is the relationship between how experienced forecasters work and statistical concepts.

BR So that is why you have put a lot of emphasis on statistics in the Guide?

AP To a large extent operational weather forecasting involves assessing, combining and correcting information, to which you must apply a statistical approach. Forecasters collect and evaluate their forecast experience of NWP. *That's statistics*. They look for systematic errors or typical characteristics in the NWP. *That's statistics*. They update or modify their preliminary forecast in light of new information. *That's statistics*; in particular what is called Bayesian statistics. An intuitive use of statistical know-how seems to count as much as synoptic experience, in particular in the medium range. The Guide is also intended to encourage a statistical approach by showing it has a scientific basis.

BR When we think about statistics in relation to weather forecasting we normally think about verification and statistical interpretation.

AP Forecasters use forecast verification both for product control and as a way to improve the forecasts. Two chapters of the Guide provide information on how to validate and verify the deterministic and probabilistic forecasts. This can be quite counterintuitive. "*What looks bad might be good, what looks good might be bad*" is one of the recurring themes in the Guide. Statistical interpretation is just given a short introduction, but much more could be written about it.

The main messages in the Guide

BR Another recurring theme in the Guide is a warning not to over-interpret the details of the NWP output.

AP What are considered the strong aspects of the high-resolution NWP models are also their weakest. Although a 10-day forecast of mean-sea-level pressure looks as realistic as an analysed map, most of the synoptic details are usually misleading: for example, features might have the wrong intensity, the wrong position or perhaps not come into existence at all. If these smaller non-predictable synoptic details were disregarded or removed, the remaining large-scale flow pattern would provide enough information to form a basis for useful forecasts.

BR You make it almost sound as if increasing the model resolution would be detrimental to the developments of more skilful NWP models!

AP On the contrary, the Guide makes clear that the higher the resolution the better the forecasting system's ability to simulate atmospheric processes, facilitate the assimilation of observations and enable a better representation of mountains and coastlines, and their effect on the large-scale flow. Even if the smallest atmospheric features that can be resolved by the high-resolution might only be predictable for a few hours, their representation is nevertheless necessary for the energetic exchange between different scales. But just because the forecasts are *calculated* at very high resolution doesn't mean that they have to be *presented* at that resolution.

BR But these smallest scales are not just numerical noise. There are numerous cases when small-scale developments, often involving extreme weather, have been correctly forecast several days in advance.

AP But the average predictive skill for the smallest scales is much lower than for the larger scales. Consequently this forecast information should generally not be presented in a categorical way – rather a probabilistic approach should be taken. This approach has found its best realization in the EPS (Ensemble Prediction System); the ensemble mean represents the most predictable part of the flow and the probabilities are based on the less predictable synoptic features that are not seen in the ensemble mean.

Probabilistic forecasts

BR A common opinion seems to be that probability forecasting is just a cheap means of escape for the forecaster!

AP It is true that it is more satisfying for the forecasters to express forecasts for severe events in probabilistic terms. But they do not do that to 'cover their backs'. The main advantage with probabilities lies with the users of the forecast. Since we, as everybody knows, cannot make perfect forecasts, users are better served if we acknowledge our uncertainty rather than pretend there is none. Verification of manually made probability forecasts has shown that the forecasters generally underestimate their uncertainty.

BR It is often said that people do not understand probabilities.

AP I think they do. If someone is told there is a 30% probability of rain he or she will ignore the warning if it is just a matter of hanging out the washing, but not if it is about an outdoor exhibition of expensive art.

BR But how can we make the public and other users appreciate probability forecasts?

AP It might sound preposterous but I think that the public and other users should, in some gentle way, be made aware that part of the responsibility for 'bad forecasts' rests on them! They do not always ask the right questions. After "What will the weather be?" they should follow up with: "How sure are you about this? What else could happen?" Unfortunately by not doing this they are in effect asking the meteorologists to make the decisions for them. This had the 'advantage' that any criticism of decisions made can be diverted to the meteorologists. We meteorologists appear partly to be paid to act as scapegoats!

BR Another argument against probability forecasts is that they by definition are never right or wrong, except when 0% or 100% have been forecast.

AP The real value of weather forecasting is not primarily about getting it 'right' or 'wrong' but to support decision making. This is best achieved through the use of probabilities. Although they cannot be verified individually, their overall performance can. It has been shown that such forecasts have skill of great value to users who know how to interpret probabilistic information. In the Guide I quote Ed Lorenz who once said that what the critics of probability forecasting fail to recognize, or else are reluctant to acknowledge, is that a forecaster is paid not for exhibiting skill but for providing information to the public. A probability forecast conveys more information than a simple categorical forecast of rain or no rain.

BR In the Guide you introduce the usefulness of probabilities by showing that that in some uncertain weather situations it is actually better for most users not to be given a forecast at all rather than one with a misleading high certainty. What is your thinking behind that rather unusual approach?

AP I wanted to challenge the common view of members of the public that in very uncertain weather situations, it is "better that the forecasters make the guesses than the laymen". I would argue that in such situations nobody should make any 'guesses' but take note of the uncertainty itself – information that only the forecasters can judge. Fittingly, another recurring theme in the Guide is the value of knowing one's uncertainty – it is better to know that we do not know than to believe that we know when we don't. Users can then interpret this 'total uncertainty' according to their own interest. From this thought-provoking example it follows that if the forecasters express their uncertainty in more elaborate ways, for example by probabilities, the usefulness of their forecasts will further increase.

Deterministic and categorical forecasts

BR Turning for a while to the operational, deterministic model, I gather that the Guide doesn't recommend the use of this by itself, particularly at longer ranges.

AP It is pointed out several times that the errors of the deterministic NWP forecasts increase to rather high levels, ultimately towards the level of a persistence forecast or a guess. These are significantly higher than the error level of using a climatological average as a forecast. So a forecast practice which blindly follows the deterministic output far out in the medium range might at some stage provide worse guidance than use of climatological information (Figure 1).

BR Another difficulty faced by forecasters is 'jumpiness' in the forecasts.

AP An NWP model must by necessity be 'jumpy'; some changes between forecast runs are necessary to enable the forecasts to improve. There is, however, no reason to convey this 'jumpiness' to the end-users. Nothing degrades the public's confidence more than 'jumpy' forecasts, in particular in connection with anomalous or extreme weather events. A bad five-day forecast will be identified as such only after five days; a 'jumpy' forecast will be identified immediately. Users also tend to draw the logical conclusion that the previous, disowned forecast must have been wrong.

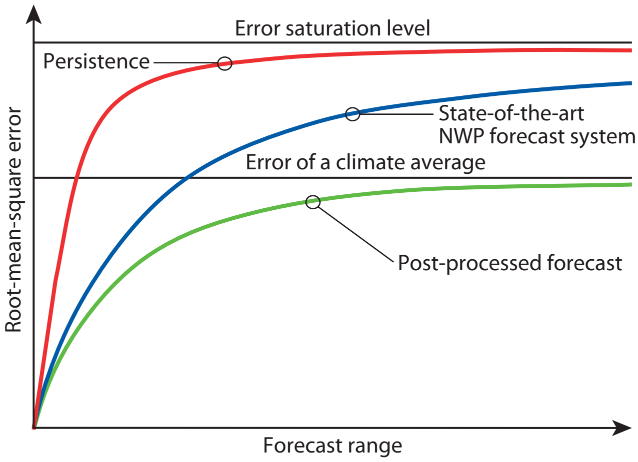


Figure 1 A schematic illustration of the forecast error development of a state-of-art NWP forecast system and persistence, whose errors asymptotically approach a higher error level (the so called 'error saturation level' which is the average error of a guess) than post-processed forecasts, which approach a lower level defined by the 'error of a climate average'.

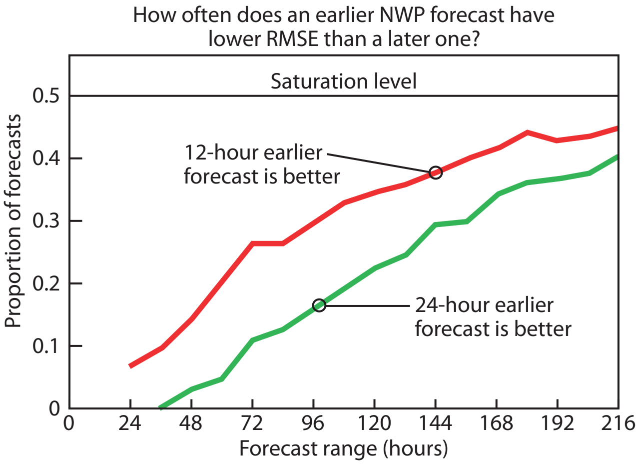


Figure 2 The likelihood that a 12-hour or 24-hour earlier forecast is 'better' (in terms of root-mean-square error) than today's forecast. The parameter is the mean-sea-level pressure for Northern Europe for October 2009 to September 2010. The result is almost identical if the anomaly correlation coefficient is used as the verification measure. For very long forecast lead times both forecasts are almost without skill and the chance that a previous forecast is better becomes almost random and the likelihood approaches the 50% level (also called the 'saturation level').

I think that many complaints about 'bad' forecasts actually refer to 'jumpy' forecasts.

BR Does the Guide give any advice how to tackle this 'jumpiness' problem?

AP Of course, the ultimate solution lies in the ensemble technique. This approach can also be applied to the deterministic forecasts. There is significant skill in previous forecasts. Just because the latest is on *average* best, doesn't mean that it is *always* so (Figure 2). A 'mini-ensemble' or 'consensus forecast' of the latest 3 or 4 deterministic forecasts displays similar characteristics as the EPS. When averaged, their mean has an increased accuracy and a higher degree of day-to-day consistency than the latest forecast. As with the EPS, the relative reduction of forecast 'jumpiness' in the 'mini-ensembel' is about three times larger than the relative reduction in forecast error. It is suggested in the Guide that forming a mini-ensemble is a fruitful way of combining output from the deterministic model and EPS.

Relationship between categorical and probabilistic forecasts

BR What does the Guide say about the relation between categorical and probabilistic forecasts?

AP The provision of categorical and probabilistic forecasts to the end-users support and complement each other. Issuing skilful categorical weather forecasts during normal weather conditions builds up trust with the users. If users have confidence in the weather service's ability to 'get it right' in normal weather conditions they will of course more likely trust its forecasts, even probabilistic ones, in cases of extreme weather.

BR But sometimes deterministic NWP forecasts might conflict with the probabilistic guidance from the EPS.

AP This is a very challenging problem and it is discussed in the Guide, but perhaps not as extensively as I would have liked because this topic requires more investigation. In principle, when the EPS spread is small one would expect the deterministic forecast to be within the ensemble, not display any ‘jumpiness’ and have good skill. But the opposite might not necessarily be true. At present there is a good overall agreement between the behaviour of the deterministic forecast and the EPS spread. But there is still room for improvement of the EPS, in particular with respect to its own ‘jumpiness’.

BR Why do you think there is some reluctance amongst forecasters to make use of the ensemble mean, the arithmetic average of all the ensemble members?

AP It is said that such average fields do not constitute genuine dynamically three-dimensional representation of the atmosphere, cannot represent bi-modal solutions, and is not able to represent extreme or anomalous weather events. This is quite true, but if forecasts of extreme events *are* fully reliable they will not be smoothed out in the ensemble mean. If they are not reliable they will instead appear as probabilities. Bi-modal solutions , when the synoptic evolution sets off in two rather different directions, are quite rare so that is not a significant problem. Apart from providing deterministic weather forecasts with optimal accuracy and consistency the ensemble mean of, for example, the mean-sea-level pressure serves as a useful background for displaying probabilistic weather information, since it puts the probabilities into a synoptic context (Figure 3).

BR It is also said that ensemble averaging might lead to inconsistencies between different weather parameters.

AP Also true, but this problem can also be found in deterministic output, for example between forecasts of instantaneous cloud and 6-hour accumulated precipitation. The popularity of the EPSgrams is not lessened by its inability to show the interconnections between the four different weather parameters or bi-modal solutions.

Increase the trust in medium-range forecasts

BR Estimations at the time the ECMWF was founded indicated that large economic gains would benefit society thanks to medium-range weather forecasts. At present, forecasts are, on average, synoptically useful for up to a week or more. What can be done to further increase the use of medium-range weather forecasts?

AP One way is of course to further improve the overall skill of the deterministic forecasting system. It has increased by about a day each decade and it is likely that this trend will continue thanks to planned improvements (increased resolution, improved physics and even better use of observations) in the next decade.

BR But is this enough? Although the decision makers always have had high confidence in the skill of the ECMWF forecasts in general, there seems to be less confidence about the skill of specific forecasts for a particular event, for example when extreme weather is likely.

AP I think a keyword here is ‘trust’. Good forecasts that are not trusted have little value, irrespective of how well they verify. The EPS system is able to pin-point which deterministic forecasts can be relied on and thereby increase the willingness of users to make decisions based on these good forecasts.

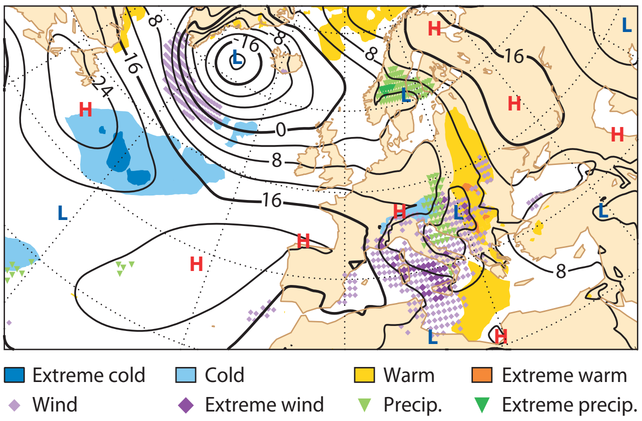


Figure 3 The ‘Anomalous Weather’ or ‘Interactive EFI’ chart from 72 to +96 hours based on the EPS from 00 UTC on 16 September 2011. It shows the geographical distribution of the extreme forecast index (EFI) for maximum wind gust, 24-hour precipitation and 2-metre temperature, overlaid with the ensemble mean of the 1000 hPa geopotential height.

BR Occasionally the EPS spread, and perhaps forecast ‘jumpiness’, tells us that the weather situation is difficult to predict. Can useful forecasts be provided in these circumstances?

AP It is my impression is that at present many users think that only very skilful medium-range forecasts, like those we have in the short range, can be used for decisions in extreme weather situations. But one of the most important points in the Guide is that useful decisions can also be made when there is low predictability and the deterministic forecast is likely to be wrong – *provided that the forecasters are aware of this uncertainty!*

Role of medium-range forecasters

BR That brings us to the question of the role of the human forecasters. What is their role given the steadily increasing skill of the deterministic forecasts and the EPS?

AP Almost since the start of NWP the demise of weather forecasters “within 5 to 10 years” has been announced. But the forecasters obviously serve a purpose, because today there are more carrying out operational duties than ever before, and increasingly so in the commercial sector. Of course automatic forecasts on the Internet and elsewhere might satisfy the need of weather information during normal conditions, but in situations with extreme or high-impact weather nobody would base their decisions just on automated output. In addition, in these critical situations, there will always be more than one source of automatic NWP information and they are unlikely to give a consistent message.

BR Do you think that most forecasters ‘can add value’ to NWP products in terms of root-mean-square error or any other verification score?

AP I do not want to interpret ‘adding value’ in this way. Competing with the computer in terms of verification scores is an internal meteorological contest and without much relevance outside the meteorological community. On the other hand, if there really were a contest, NWP models would be easily ‘beaten’, in particular in the medium range, because

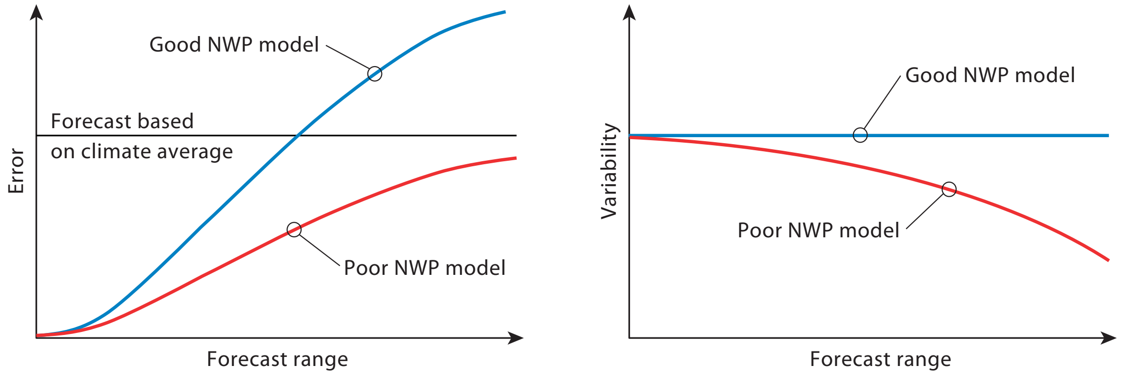


Figure 4 The root-mean-square error and variability of two NWP systems: one a good state-of-the-art high-resolution NWP model, the other a poor NWP model due to excessive diffusion or coarse numerical resolution. The errors of the good model (blue line in the left panel) approach a high error level because the model is able to represent the whole spectrum of resolvable atmospheric scales throughout the forecast (blue line in the right panel), while the errors of the poor model approach a lower level (red line in the left panel) because the model suffers from a gradual reduction of the scales and thereby the variability (red line in the right panel).

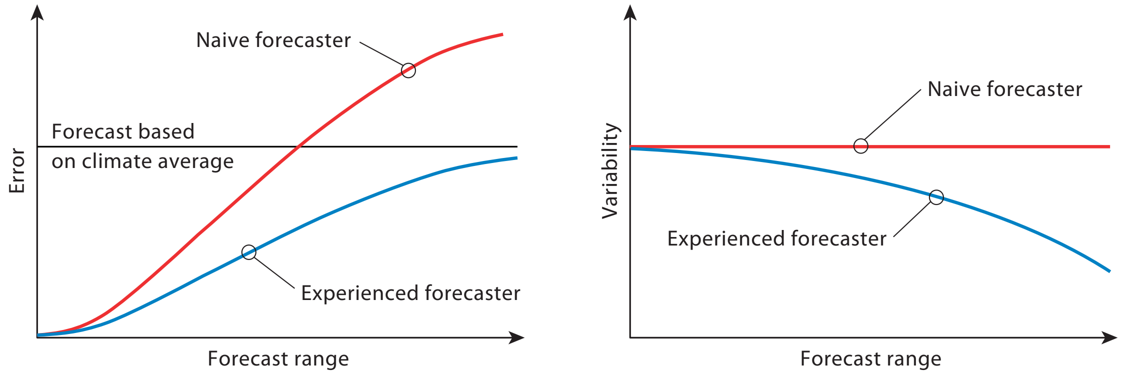


Figure 5 The root-mean-square error and variability of two forecast practices: one experienced forecaster who disregards or damps less likely synoptic features, while the other naively reads off the raw output from a state-of-the-art NWP model. The errors of the experienced forecaster (blue line in the left panel) approach a low error level because of a gradual reduction of the less predictable scales and thereby the forecast variability (blue line in the right panel), while the errors of the naive forecaster approach a higher error level (red line in the left panel) because the forecasts maintain the whole spectrum of resolvable atmospheric scales for all lead times irrespective of whether they are predictable or not (red line in the right).

NWP modellers and forecasters play different games, like cricket versus baseball or football versus handball. NWP modellers strive to provide forecast systems with optimum accuracy with the over-riding condition that the atmospheric motions contains all scales – irrespective of whether they are predictable or not (Figure 4). Weather forecasters do the opposite, they disregard and damp unpredictable features in order to improve the accuracy and reduce the 'jumpiness' of their categorical forecasts (Figure 5). This means there is no contest between NWP modellers and forecasters! So I do not think it is constructive to define 'added value' in terms like that since weather forecasting is to support decision making.

BR Am I right in thinking that throughout the Guide you advise the forecasters not to try to imitate an NWP system?

AP When I summarized the recommendations in the Guide they boiled down to the general advice to "do the opposite to computers":

Deterministic NWP output provides highly-detailed synoptic scenarios, irrespective of their predictability; forecasters are advised, with increasing forecast range, to avoid adding detailed information to the NWP, but rather remove information.

Deterministic NWP must change run by run; forecasters are advised to dampen any forecast 'jumpiness' in order to increase the confidence in the deterministic forecast.

Deterministic NWP gives an impression of very high certainty; forecasters are advised to make positive use of uncertainty and thereby increase the usefulness of the forecasts.

BR So in your view there is a role for the forecasters if they take on the challenge to use the forecast uncertainty in a positive, productive way?

AP Yes, in this respect the meteorologists' forecast experience coupled with knowledge of modern NWP remains crucial. What distinguishes the professionals is their ability to make use of uncertainty. This is quite obvious to anybody who follows a weather briefing, for example on radio or TV. In highly predictable weather situations anybody can confidently tell "what it is going to be". But in difficult weather situations it is only the professionals who can clearly express uncertainty: "There is a chance that this cold air might be delayed...The rain might exceed 50 mm in places... We cannot exclude hurricane force wind gusts." Knowing the uncertainty enables those who have to make decisions to give the weather information the weight it deserves and thereby in an optimal way take other non-weather related factors into consideration. It is the uncertainty information that really adds 'extra value' to the forecasts.

An improved representation of cloud and precipitation

RICHARD FORBES, ADRIAN TOMPKINS

A major upgrade to the parametrization of stratiform cloud and precipitation was implemented in the Integrated Forecasting System (IFS) cycle 36r4, operational from 9 November 2010. This change is part of the continuing programme of development of moist physics parametrizations in the IFS, which remains a key area for improvement for Numerical Weather Prediction and an important part of the ECMWF model development strategy.

Three additional prognostic variables have been introduced to enable a more physically based representation of mixed-phase (liquid/ice) cloud and precipitating rain and snow. It is the most significant change to the structure of the cloud parametrization since the Tiedtke scheme was introduced operationally in 1995.

Many aspects of the model are systematically improved including the skill of precipitation forecasts, the spatial distribution of cloud ice and precipitating snow in the troposphere, the physical processes in mixed-phase cloud, and the impact of cloud and precipitation on radiation. In addition, the new scheme provides a more physically based framework for further development of the parametrization, particularly as model resolution is projected to increase in the future.

A brief history of the IFS cloud scheme is first described to put the recent changes into context, followed by the primary motivations for the upgrade and description of the new scheme. A few examples of evaluation against observations are used to highlight the improved representation of cloud and precipitation in the IFS, and the article concludes with a summary and outlook for the future.

A brief history of IFS cloud scheme developments

The Tiedtke cloud scheme, described fully in *Tiedtke* (1993), has served the IFS well over the last 15 years. The approach of parametrizing the sources and sinks of a set of prognostic cloud variables due to all the major cloud generation and dissipation processes, including convection and microphysics, made the IFS scheme unique in its time. The original Tiedtke scheme has two prognostics parameters for cloud; the first describing the fraction of the grid box covered by cloud, and the second representing the mass mixing ratio of total cloud condensate, divided into separate liquid and ice categories diagnostically according to temperature. Precipitating rain and snow are also treated diagnostically. Figure 1a shows a schematic representing the Tiedtke cloud scheme operational in the IFS from 1995 to 2010.

Since the original implementation, the scheme has been under continual development with many numerical and microphysical aspects of the scheme changed. Some of the main developments include improvements to the following.

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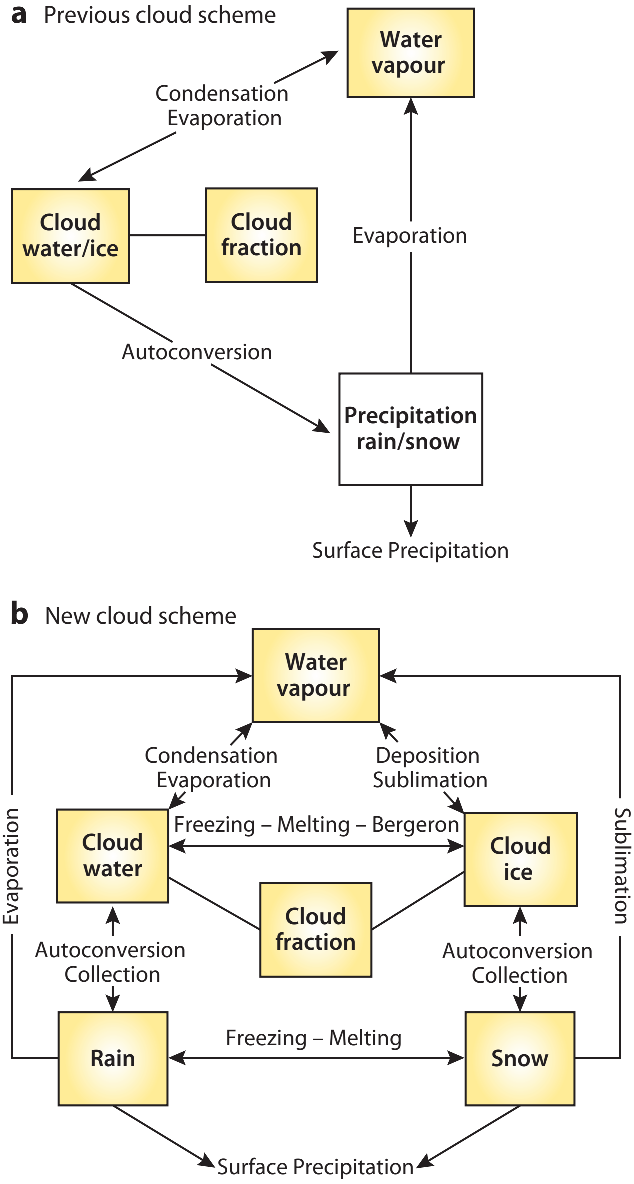


Figure 1 Schematic of the IFS cloud scheme: (a) the Tiedtke scheme with three moisture related prognostic variables operational from 1995 to 2010 (before IFS Cy36r4) and (b) the new cloud scheme with six moisture related prognostic variables (Cy36r4 onwards). Yellow boxes indicate prognostic variables.

- Ice sedimentation and autoconversion to snow.
- Subgrid precipitation coverage and evaporation.
- Numerical treatment of the cloud condensate and cloud fraction equations.
- Representation of ice supersaturation in cloud-free air.

Although the scheme has evolved significantly, the basic structure has remained essentially the same, with a prognostic cloud fraction variable and a single prognostic variable to represent cloud condensate. With increasing emphasis on cloud and precipitation in NWP and increasing resolution of the IFS model, it was clear that a number of changes were required to enable the continued improvement of the scheme both now and looking ahead for the future. Particular issues that needed to be addressed concerning precipitation advection, mixed-phase cloud, numerical issues and the physical realism of the scheme are now discussed in more detail.

Precipitation advection

Higher horizontal resolution and shorter timesteps mean the original diagnostic assumptions for precipitation become less valid. The diagnostic approach assumes the time taken for precipitation to fall from cloud to ground is small compared to the timestep of the model and that horizontal advection can be neglected on the spatial scale of the model grid resolution. A prognostic representation of precipitation is therefore required as the model resolution and timestep increase, particularly for snow particles which have a lower density and slower terminal fall speed than raindrops.

Mixed-phase cloud

The diagnostic approach to the mixed phase, which partitions the cloud condensate into liquid and ice according to temperature in the range 0°C to –23°C, means that both ice and supercooled liquid are always present in cloud in this temperature regime and no liquid water is allowed at colder temperatures than –23°C. The reality can be very different. For example in this sub-zero temperature range, emerging convective clouds are often all liquid, established frontal clouds often all ice and thin mid-level cloud often topped with a shallow supercooled liquid water layer with ice particles precipitating out below. Supercooled liquid water is observed down to temperatures of –30°C and colder. If the model is to begin to capture these aspects, then an additional degree of freedom is required with separate prognostic variables for liquid and ice condensate.

Numerical issues

The diagnostic mixed-phase approach also leads to a number of unrealistic numerical artefacts in the formulation of the microphysical processes, leading to a discontinuity in ice supersaturation and autoconversion of ice to snow at the mixed-phase temperature threshold (–23°C) and a lack of sedimentation of ice in the mixed phase. This significantly affects the physical representation and the spatial distribution of ice in the mixed-phase temperature range. In addition, the diagnostic approach assumes a single saturation curve in the mixed phase varying from water saturation at 0°C to ice saturation at –23°C. In reality different microphysical processes respond differently to ice saturation and water saturation, such as the deposition growth of ice crystals at the expense of water drops (the Wegener-Bergeron-Findeisen mechanism).

Physical realism

The representation of cloud with just two variables leads to a number of simplifications and approximations in the scheme. Additional degrees of freedom allows for a more physically realistic representation of cloud and precipitation microphysics that can be verified with observations.

The new cloud and precipitation scheme

The new parametrization of stratiform cloud and precipitation increases the number of prognostic variables from two (cloud fraction, cloud condensate) to five (cloud fraction, cloud liquid water, cloud ice, rain and snow). The philosophy of the original Tiedtke scheme is retained with regards to a prognostic cloud fraction and sources and sinks of all cloud variables due to the major generation and destruction processes, including detrainment from convection. However, water and ice clouds are now independent, addressing many of the issues identified above and allowing a more physically realistic representation of supercooled liquid water cloud. Rain and snow precipitation are also now able to precipitate with a determined terminal fall speed and can be advected by the three-dimensional wind.

A new multi-dimensional implicit solver is implemented for the numerical solution of the cloud and precipitation prognostic equations. Overall, the number of lines of executable code in the cloud scheme has almost doubled through the increased complexity.

Figure 1b shows a schematic of the new scheme and further information can be found in *Forbes et al.* (2011). The main changes are discussed in more detail below with examples of evaluation of different aspects of the scheme against observations.

Improved representation of precipitation

Both rain and snow precipitation are now prognostic variables, which are stored from timestep to timestep, precipitate with a terminal fall velocity and are advected by the wind. As before, the precipitation processes of generation through autoconversion from cloud, collection of cloud particles (accretion, aggregation), melting (from snow to rain) and evaporation are all included. However, there is no longer an instantaneous response of surface precipitation to the microphysical processes in the local atmospheric grid column above. With the prognostic representation, precipitation can be blown by the wind as it falls over multiple timesteps, which results in a spatially and temporally smoother precipitation field.

The advection of snow by the wind can be particularly significant in regions of orographic forcing producing persistent geographically locked precipitation. With a diagnostic precipitation scheme, precipitation often falls on the upslope and peaks of orography as an instantaneous response in the vertical to the local forcing, whereas the effect of horizontal advection by the atmospheric winds results in a downstream shift of the precipitation towards the lee of the orography and a different hydrological catchment. This effect is more significant for snow than for rain, due to the slower fall speed of snow particles and potentially longer residence time in the atmosphere.

The changes contribute to a significant improvement in global precipitation skill shown by the 1-SEEPS score in Figure 2. SEEPS (Stable Equitable Error in Probability Space) is a supplementary headline score at ECMWF used for verification of deterministic precipitation forecasts and 1-SEEPS is used so that higher values correspond to higher skill. It is an equitable score using three categories; dry, light precipitation and heavy precipitation defined by the local climatology. For more information, there is an article in the summer 2011 issue of the *ECMWF Newsletter* (*Rodwell et al.*, 2011).

Improved global distribution of cloud ice and snow

Modifications to the representation of ice and snow in the new scheme result in significant changes to the three-dimensional distribution of frozen particles in the model. The two-category approach is a way of representing small and large particles in the scheme. Smaller ice particles with low fall velocities associated with cloud that grows primarily by deposition are represented by the 'ice' category and 'snow' represents larger ice particles with higher fall velocities that grow through collection (aggregation). The process of 'autoconversion' is used to represent the onset of broadening of the particle size distribution through aggregation, leading to conversion of mass from the 'ice category' to the 'snow category'. The latter, representing larger particles, then precipitates at a faster rate.

Previously, the autoconversion of ice to snow only operated in the pure ice-phase temperature zone (colder than –23°C) with all cloud condensate treated by the less efficient rain autoconversion process at temperatures warmer than this threshold. Another necessary condition of the diagnostic approach to the mixed phase in the previous scheme was an assumption of zero fall velocity for ice cloud between 0°C and –23°C which then gradually increased in the pure-ice phase at colder temperatures above. These two restrictions meant the only sink of ice in the mixed-phase zone was the repartitioning into liquid and ice at every timestep and this led to artificially high ice cloud mass in the mixed-phase zone.

The new scheme has a consistent treatment of autoconversion and sedimentation for the new prognostic ice variable throughout the temperature range and therefore avoids any discontinuities at –23°C and significantly reduces the amount of ice at temperatures warmer than –23°C. Figure 3 shows the zonal cross section of the annual mean cloud ice content for the previous cloud scheme, the new scheme and an estimate derived from the CloudSat radar. All 1.7 km CloudSat footprint profiles that are estimated to be either precipitating or convective in the observation data have been removed in order to capture the 'ice cloud' part of the total cloud mass. The zonal distribution of ice in the new scheme is closer to that derived from CloudSat and no longer contains the artificial peaks seen in the diagnostic scheme in the 0°C to –23°C temperature zone.

The distribution and amount of ice cloud has important radiative impacts. Consequently the root mean square error of both net shortwave and longwave annual mean radiative fluxes at the top of the atmosphere are reduced in the new scheme compared to observations from the CERES (Clouds and the Earth's Radiant Energy System) satellite instrument. In addition the prognostic snow category is now radiatively active and one effect is to warm the troposphere.

Figure 4 shows the geographical distribution of the annual mean vertically integrated cloud ice water path from

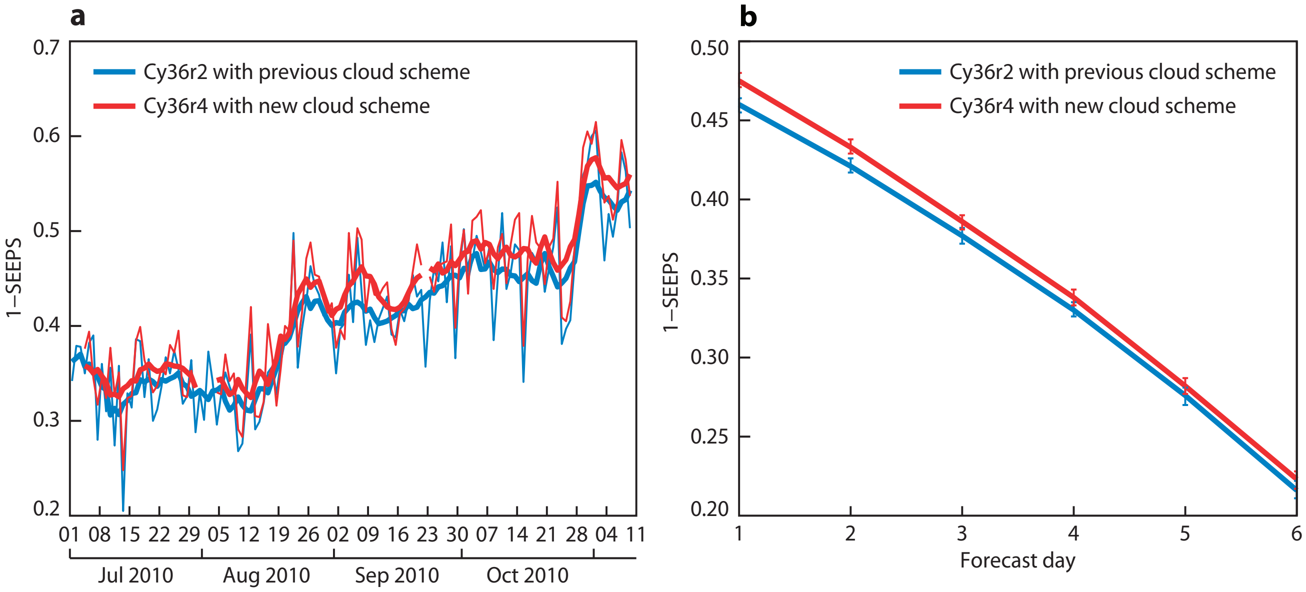
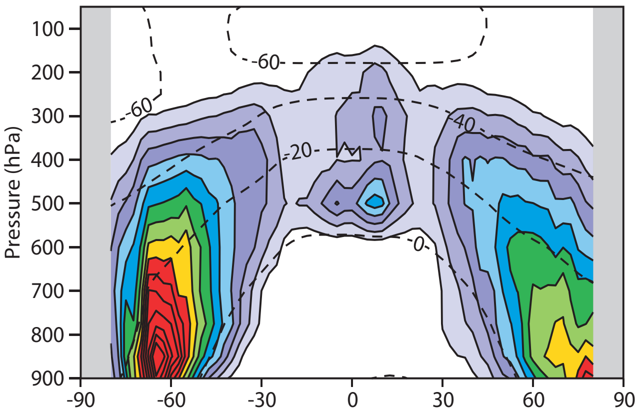
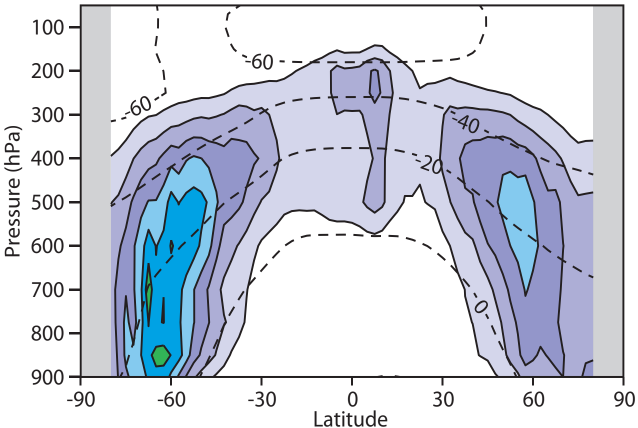


Figure 2 (a) Global precipitation skill score (1-SEEPS) for Cy36r4 with the new cloud scheme and the previous operational cycle Cy36r2 for the period 1 July to 9 November 2010 (24- to 48-hour forecast accumulations from 00 UTC forecasts). Thin lines: daily values, bold lines: running weekly average. (b) Global 1-SEEPS score averaged over the same period as a function of lead time (24-hour accumulations from 12 UTC forecasts). Higher values represent higher skill. Error bars show 95% confidence intervals.

a Previous cloud scheme



b New cloud scheme



c CloudSat estimate

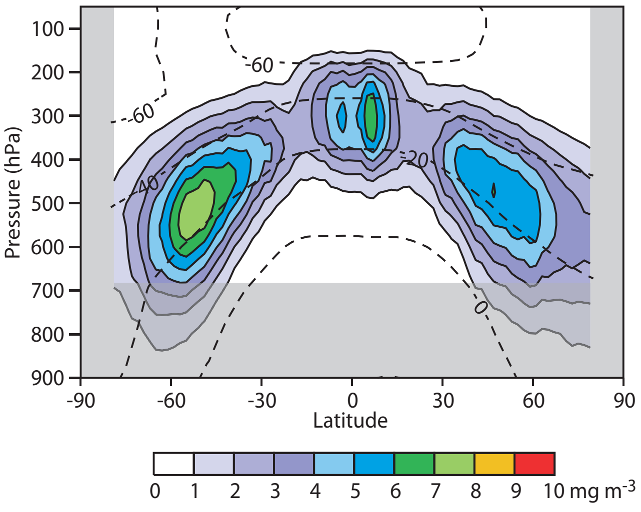
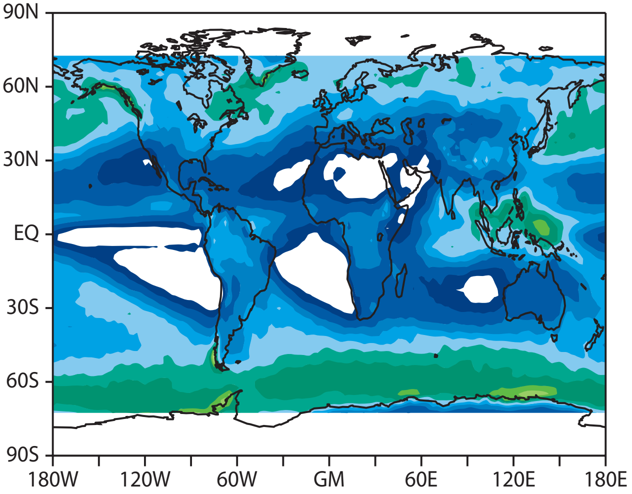
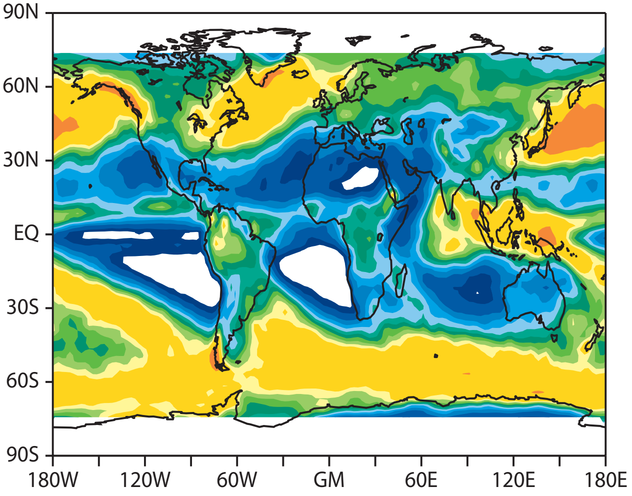


Figure 3 Zonal cross-section of annual mean cloud ice for (a) the previous IFS cloud scheme with a diagnostic mixed phase, (b) the new IFS cloud scheme with a consistent treatment of cloud ice at all temperatures and (c) the estimate derived from CloudSat (82°S to 82°N) filtering out all observed precipitating and convective profiles to obtain a closer equivalent to the model cloud ice field. Annual mean temperature is shown as dashed contours (°C). The shading indicates areas where data is absent or particularly uncertain. Note the CloudSat product has limitations; there is no reliable signal close to the surface due to contamination by surface backscatter, thin cirrus cloud is often not observed and there are assumptions about the ice/liquid partition in the mixed-phase temperature regime which will tend to lead to an underestimate of ice as temperatures approach 0°C.

a Previous cloud scheme



b New cloud scheme



c CloudSat estimate

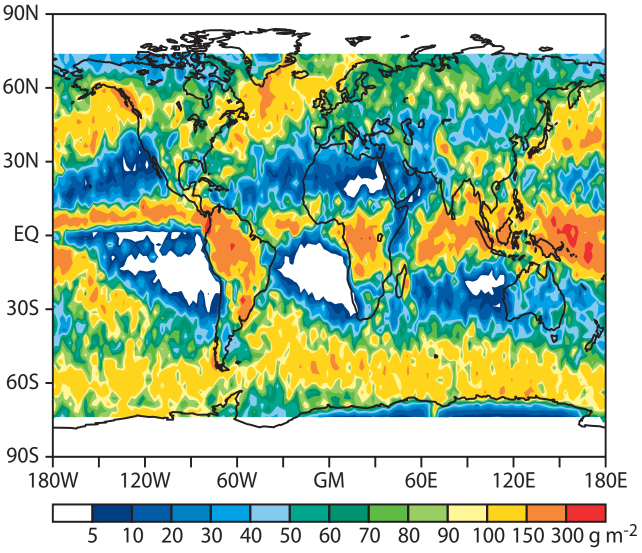


Figure 4 Annual mean vertically integrated ice water path for (a) radiatively active cloud ice from the previous cloud scheme, (b) radiatively active total cloud ice and snow from the new cloud scheme, and (c) estimate derived from CloudSat (August 2006 to July 2007), (*Waliser et al.*, 2009). The convective core precipitating snow is not included in the model output which accounts for the underestimate of ice water path in the tropics.

the previous cloud scheme and the combined prognostic ice and snow water path from the new scheme, as well as the estimated total ice water path derived from CloudSat. In the extra-tropics there is good agreement between the spatial distribution and magnitude of the total stratiform ice and snow water path from the new scheme and the observed estimate. The differences in the tropics over Africa, South America and the Inter-Tropical Convergence Zone (ITCZ) are where precipitation from deep convection dominates in the observations. Ice and snow in convective cores are currently not included in the model output for deriving ice water path, and this, along with the interaction of convective cores with the radiation, are potential areas for future research.

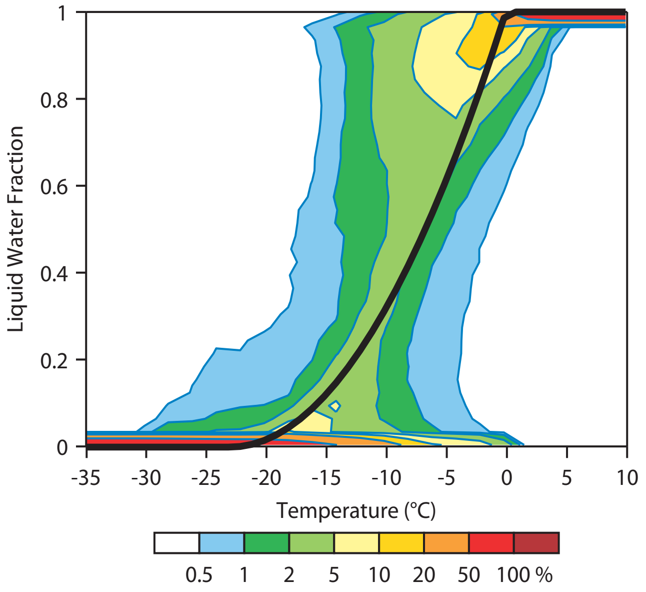


Figure 5 Global percentage occurrence (for a given temperature) of the liquid water fraction of cloud condensate for the previous diagnostic temperature-dependent mixed-phase scheme (thick black line) and the new prognostic ice/liquid scheme (shading) for a range of temperatures (on 10 January 2011). The mode of the distribution still approximately follows the temperature-dependent function, but variability is significantly increased. For example, 100% of cloud is all ice at −35°C, 100% is all liquid at +10°C, but at −10°C the cloud can vary from all ice, through varying fractions of supercooled liquid water, to all water.

Improved representation of supercooled liquid water cloud

The separate treatment of ice and water clouds now results in a wider variability of occurrence of supercooled water.

Any supersaturation with respect to water at temperatures warmer than the homogeneous freezing temperature (–38°C) is condensed as water droplets, and the new processes of ice nucleation and depositional growth of ice crystals, representing the growth of ice crystals at the expense of water droplets through the Wegener-Bergeron-Findeisen mechanism, act to transfer water mass to the ice particles. If ice is nucleated in a cloud at water saturation, the ice crystals are in an environment supersaturated with respect to ice and grow by deposition, reducing the water vapour and leading to subsaturation with respect to water. Water droplets then evaporate and the process continues with ice growth until the water droplets are completely evaporated and the water vapour is depleted to the ice saturation level. The model assumes cloud is at water saturation if liquid water is present, but reduced to ice saturation if all the water has been depleted and only ice is present.

Figure 5 shows the distribution of liquid water fractions in cloud as a function of temperature for the diagnostic temperature-dependent scheme and the wide spread of possible values for the new prognostic scheme.

After operational implementation of the scheme in November 2010, feedback from Member States' forecasters in January 2011 highlighted a problem with excessively cold temperatures in certain meteorological conditions. This quickly led to the identification of a problem in the new scheme related to the representation of supercooled liquid water. In weakly forced relatively calm overcast conditions with low cloud in the 0°C to –30°C range, there was less supercooled water in the cloud compared to the previous diagnostic scheme and sometimes it was absent. This resulted in screen-level temperatures that were systematically too cold due to excessive long-wave radiative cooling in a shallow near-surface layer through the night. Observations from aircraft and lidar remote sensing show supercooled liquid water occurs frequently at cloud top in low and midlevel

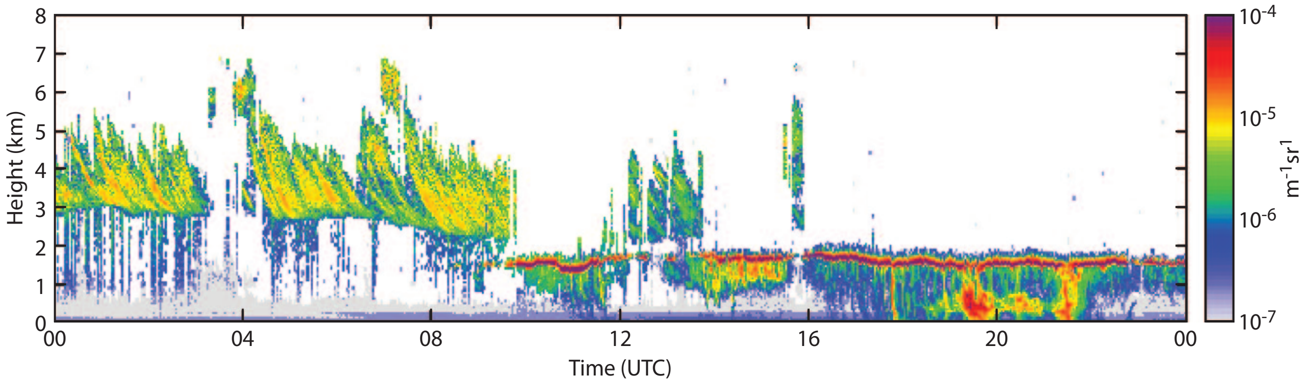


Figure 6 Timeseries of lidar backscatter coefficient from Sodankylä in northern Finland on 14 January 2011 showing the thin supercooled liquid water layers. The layer of high values of backscatter at about 1.5 km altitude after 10 UTC is typical of these latitudes and is associated with a thin liquid water layer with ice precipitating out below. (Courtesy of Finnish Meteorological Institute)

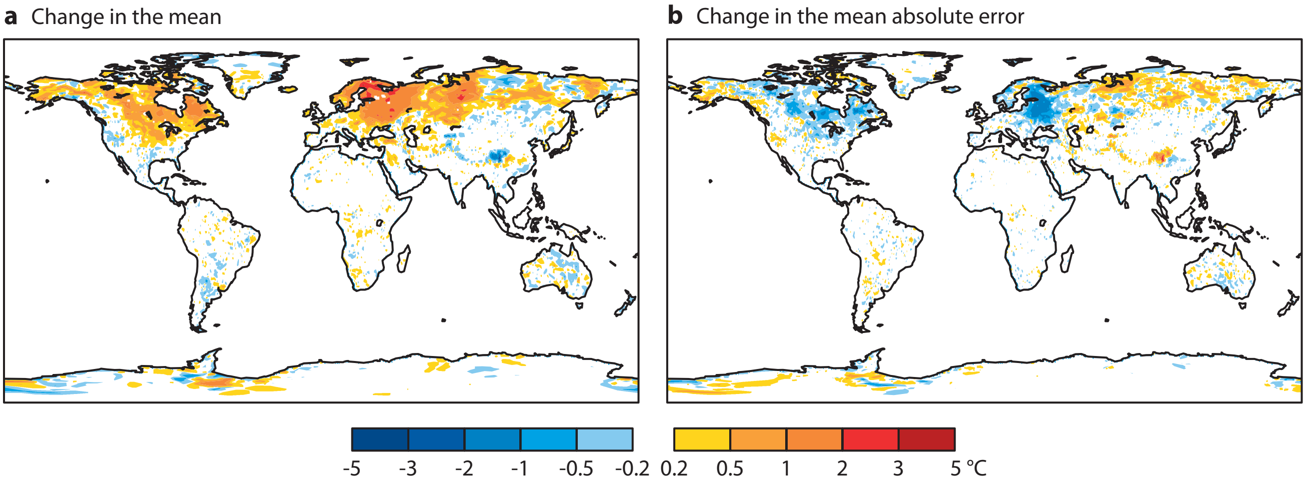


Figure 7 The impact of the mixed-phase cloud changes for IFS Cy37r3 on the 72-hour forecast of 2-metre temperature over land at 00 UTC averaged for three weeks in January 2011: (a) change in the mean and (b) change in the mean absolute error. There is a significant warming and reduction of error in regions over Europe and North America where supercooled liquid water layers most commonly occur at this time of year.

clouds in the atmosphere in the form of thin layers a few hundred metres thick, often with ice precipitating out below (see Figure 6).

The supercooled liquid water layers are the result of a fine balance between radiative cooling driving small-scale turbulent motions, production of water saturation and cloud liquid water droplets, the availability of ice nuclei, nucleation of ice crystals, deposition growth removing water vapour and fall-out of ice particles under gravity. The previous version of the model cloud scheme is not able to represent these thin supercooled layers, as by definition all cloud between 0°C and –23°C contains supercooled water. In contrast, the new scheme does represent much of the basic physics needed to represent the characteristics of these layers, but is limited partly by the coarse vertical resolution of the model and partly by remaining deficiencies in the representation of the complex microphysical processes in mixed-phase clouds.

The observations of thin supercooled liquid water layers and identified model deficiencies in weakly forced conditions inspired an improved parametrization, modifying the generation terms for supercooled liquid water and reducing the ice deposition rate near cloud top. Temperature at screen level is affected by many processes including radiation, clouds, land surface, turbulent exchange and local effects, but the two metre temperature errors associated with supercooled liquid water cloud have been significantly reduced by the changes to the cloud scheme, particularly in the winter months over north-east Europe and North America. These changes are included in the new IFS Cycle 37r3. Figure 7 shows the positive impact of these changes on the 72-hour forecast of temperature during January 2011 (i.e. warming and reduction of mean absolute error).

Summary and outlook

The upgrade to the representation of cloud and precipitation in the IFS has significantly modified the cloud parametrization in terms of the number of prognostic variables, formulation of mixed-phase and precipitation processes and cloud scheme numerics. Liquid and ice cloud condensates are now determined by explicit microphysical processes rather than by a fixed function of temperature, resulting in wider variability of supercooled liquid water occurrence. Rain and snow are now advected by the wind and precipitation skill is improved.

Overall, this has been a major change to the representation of moist physics and a significant milestone towards a more physically based cloud and precipitation parametrization scheme in the IFS model. The parametrization framework is now more appropriate for a wider range of model resolutions and is closer to the typical single-moment schemes used in higher-resolution limited-area NWP and cloud resolving models (CRMs).

There are many opportunities for further development of the scheme and the focus will shift towards improving the formulation of cloud and precipitation microphysical processes to provide a stronger physical basis, improved internal consistency and a more direct link to observable parameters such as particle size distributions and particle characteristics. Ongoing evaluation against a wide range of ground based and satellite observations is a further vital activity for continued parametrization development in the IFS and improved forecasts of cloud and precipitation in NWP.

FURTHER READING

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Representing model uncertainty: stochastic parametrizations at ECMWF

GLENN SHUTTS, MARTIN LEUTBECHER, ANTJE WEISHEIMER, TIM STOCKDALE, LARS ISAKSEN, MASSIMO BONAVITA

When it was introduced, the ECMWF Ensemble Prediction System (EPS) was based on the assumption that errors in medium-range forecasts are mainly associated with errors in initial conditions. Later it was recognised that uncertainties in the model formulation may also be a significant factor. In particular, the physical parametrizations can be a significant source of random error. This led to the development of a stochastic representation of physical parametrization uncertainty (now known as the Stochastic Perturbed Parametrization Tendency (SPPT) scheme). The SPPT scheme has been used in the operational EPS since October 1998 – this version will be referred to as SPPT-98. Through the judicious application of random number multipliers to forecast tendencies, there has been an increase in ensemble spread in the EPS and improved probability skill scores (*Buizza et al.*, 1999).

Investigation of the performance of the EPS has shown that there would be benefits in enhancing the representation of model errors. This resulted in recent operational changes. The impacts of those changes are outlined in this article.

The Ensemble of Data Assimilations (EDA) was introduced in June 2010 to generate initial perturbations for the ensemble from ten independent 4D-Var assimilations with representations of observation and model errors (see, for example, *Bonavita*, 2011 and *Isaksen et al.*, 2010). EDA-based perturbations replaced the evolved singular vectors and the initial singular vectors were retained to ensure sufficient spread in the medium-range. In the EDA, SPPT plays an essential role in providing different realizations of the physics tendencies within each ensemble member. Importantly, EDA provides a means by which stochastic model error representations may be confronted with observational reality.

Improved representation of model errors

The SPPT scheme has been significantly revised in September 2009 and was further refined in November 2010. The revisions provided substantial improvements in ensemble spread: reduction in the error of the ensemble-mean and improved skill scores (e.g. Brier Skill Score and Continuous Ranked Probability Skill Score). These improvements followed from a more realistic version that uses a single spatially-smooth random pattern generator to perturb all parametrization tendency variables rather than independent, piecewise constant patterns for each variable as in the original scheme. The latest version of the SPPT scheme (November 2010) will be referred to as SPPT3 – for more detail see Box A.

Random error in physical parametrization is not the only source of model uncertainty so deficiencies in the dynamical component of the forecast model also need to be addressed. The upscale cascade of energy from sub-grid scales (or those scales that are poorly resolved in the model) is thought to be such a source of model error and considerable effort has been expended on formulating a Stochastic Kinetic Energy Backscatter (SKEB) scheme (also known as SPBS in earlier documentation; see *Shutts*, 2005 and *Berner et al.*, 2008).

The SKEB technique randomly forces vorticity perturbations into the model flow in such a way that the average energy input is a fraction of some measure of the local energy dissipation rate. Numerical dissipation and the implicit energy dissipation in the mountain wave drag and convection parametrization schemes are all regarded as sources of kinetic energy to be backscattered upscale. The SKEB scheme was introduced into the operational EPS in November 2010 to be used alongside the revised version of the SPPT scheme already implemented. More detail about the SKEB scheme is given in Box B.

Impact on medium-range and seasonal-range ensemble forecasts

The relative impacts of the SPPT3, SKEB and SPPT-98 schemes have been assessed using an operational configuration of the EPS (as in model cycle Cy36r4). The horizontal resolution is T639 up to day 10 and T319 thereafter. The ensemble is initialized with perturbations from the EDA combined with initial singular vector perturbations with a 50% reduced amplitude compared to the previous operational model cycle (Cy36r2). Each 15-day ensemble forecast has one control member and 50 perturbed members. The evaluation period consists of 19 equally-spaced dates in August/September 2008 and 21 equally-spaced dates in October/December 2009.

Figure 1 shows the root-mean-square (r.m.s.) error of the ensemble-mean 500 hPa geopotential and the ensemble spread (also measured as a root-mean-square) as a function of time for various representations of the model error: SPPT3+SKEB, SPPT3, SKEB and SPPT-98. Also shown are results from the EPS with only initial perturbations (labelled CONTROL) which acts as a baseline against which the effect of different model error representations can be judged. It can readily be seen that without accounting for model error, the EPS is under-spread (i.e. the ensemble

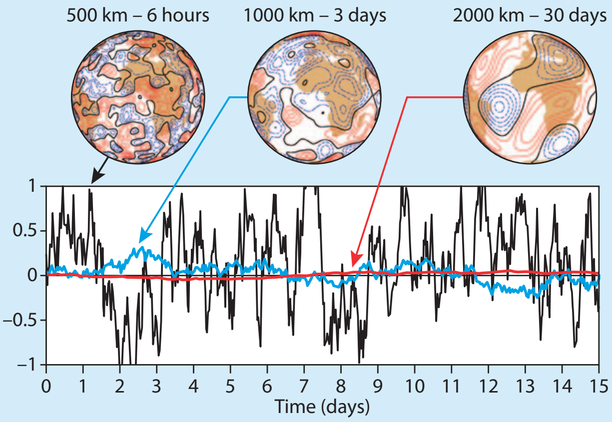
The Stochastic Perturbed Parametrization Tendency (SPPT) scheme

A

In the revised SPPT scheme the total physical parametrization tendency is multiplied by a randomly-evolving, global pattern field whose average value at any point is unity and whose standard deviation is prescribed. The pattern field is composed of three independent patterns, each generated from triangularly-truncated spherical harmonic expansions which have the property that their spatial auto-correlation function is independent of position on the sphere. Each spherical harmonic mode in each expansion is evolved in time using a first-order autoregressive process with fixed decorrelation time and wavenumber-dependent noise term. This three-pattern version of SPPT is referred to as SPPT3.

In the current operational implementation, the three patterns have quasi-Gaussian mean power spectra with horizontal correlations scales of 500 km, 1000 km and 2000 km, standard deviations of 0.52, 0.18 and 0.06, and decorrelation times of 6 hours, 3 days and 30 days respectively (see the figure in this box).

The above nine numbers characterizing SPPT3 are meant to span the uncertainty at mesoscale, synoptic scale and planetary space and time scales with pattern 1 (500 km decorrelation scale) being the starting point and most important component for the medium-range EPS. The other two patterns particularly improve the spread in seasonal forecast ensembles for which perturbations created using pattern 1 are insufficient. The decorrelation time of about 6 hours assumed in pattern 1 is loosely identified with a characteristic mesoscale time scale (e.g. for a mesoscale convective system). The longer decorrelation times used for the other two patterns in SPPT3 can be thought of as more persistent but smaller amplitude parameterization error that depends on the weather regime and thus exhibits variations on the medium-range to intra-seasonal timescales. Note that the standard deviation of the intermediate scale and large-scale patterns are much smaller (0.18 and 0.06 respectively) than that of the fastest pattern (0.52).



The three patterns underlying the SPPT3 scheme. The numbers next to the spheres indicate the horizontal spatial and temporal correlation scales in kilometres and hours. The three curves on the graph show time series of the pattern values at a point employed in the operational scheme The colour of the arrows relates the patterns to the time series.

The Stochastic Kinetic Energy Backscatter (SKEB) scheme

B

As with SPPT3, the SKEB scheme is based on the product of a spectrally-generated pattern field and a derived model field. However, instead of using model tendencies, the backscatter scheme uses a horizontally-smoothed dissipation rate field to modulate the pattern field and defines this to be a streamfunction forcing function. The pattern uses a noise term with a different wavenumber dependence to that used in SPPT3 and one that gives a power law spectrum. This choice was determined by coarse-graining the streamfunction tendency (obtained from the u and v tendencies) in high-resolution forecasts and comparing with their counterparts in low resolution forecasts (see the section on coarse-graining).

Unlike SPPT3, the backscatter scheme allows for pattern variation with height and does this by randomly shifting the phase of each spectral mode using a first-order autoregressive process based on a Laplace probability distribution function. Again, coarse-graining results have been used to calibrate the dependence on pressure and wavenumber.

The kinetic energy dissipation rate field calculated here is not actually a true dissipation rate at all but is meant to provide an estimate of the sub-gridscale production of kinetic energy. For instance, the convective dissipation rate component is the product of the kinetic energy based on a vertically-averaged, updraught velocity multiplied by the convective mass flux detrainment rate – both terms being obtained from the convection parametrization scheme.

Parametrized mountain form drag and gravity wave drag remove energy from the forecast model yet some of this energy loss should go into sub-gridscale quasi-balanced eddies rather than turbulent energy dissipation. These eddies, although not represented explicitly, could interact with the resolved flow and cascade their energy upscale as a kind of backscatter process. Similarly, numerical dissipation of energy via explicit horizontal diffusion terms (or through the smoothing effect of interpolation in the semi-Lagrangian advection scheme) loses energy from the model without any relation to what should truly be dissipated into thermal energy. A certain fraction of this lost energy should therefore be backscattered to the resolved scales and this is what the SKEB scheme aims to do.

Thanks go to Martin Steinheimer (now at Austro Control GmbH, Vienna) for his substantial contribution to the development of SKEB.

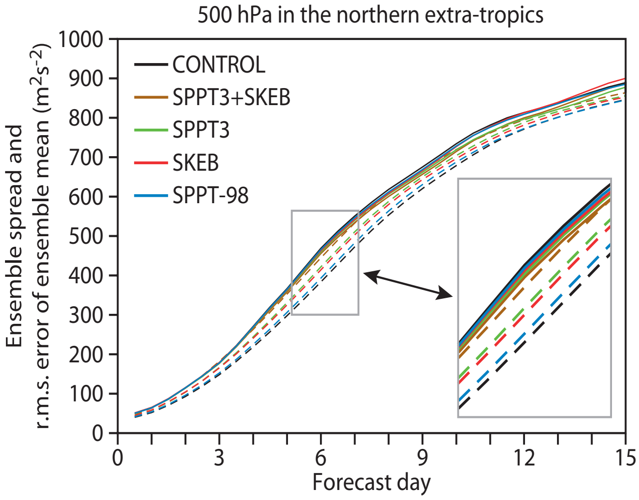


Figure 1 The r.m.s. error of the ensemble-mean (solid lines) and ensemble spread (dashed lines) versus forecast time (in days) for 500 hPa geopotential in the northern extra-tropics (20°–90°N) for various representations of model error: SPPT3+SKEB, SPPT3, SKEB and SPPT-98. Also results for the EPS with only initial perturbations are shown (CONTROL). All 40 EPS forecasts have 51 members and use initial perturbations from the Ensemble of Data Assimilations and initial singular vectors. The horizontal resolution of the forecasts is T639 and the number of model levels is 62. An expanded view of the marked rectangular region is shown for clarity.

spread is less than the r.ms. error of the ensemble mean). With SPPT-98 there is some small increase in spread and reduction in r.m.s. error but considerably less than both SPPT3 and SKEB. The combination of SPPT3 and SKEB gives a close match of spread to error.

The relative merits of the different model error choices are clearly seen in the Continuous Ignorance Score (CIS) with the lowest values representing the most skilful prediction (Figure 2). It is clear from Figure 1 that SKEB generates more spread than the SPPT-98 scheme and Figure 2 shows that this results in more skilful forecasts. Acting on their own, SKEB and SPPT3 give similar increases in spread over the 'no model error' case and yet SPPT3 seems to provide better improvements in the CIS. When combined with SPPT3, SKEB gives some modest additional reduction in CIS.

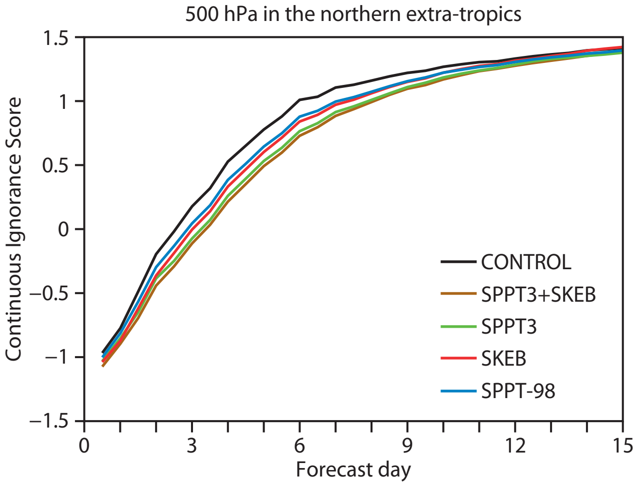


Figure 2 Continuous Ignorance Score for 500 hPa geopotential height in the northern extra-tropics for various representations of model error: SPPT3+SKEB, SPPT3, SKEB and SPPT-98 plus CONTROL. Note that the CIS is computed as the logarithmic score of the Gaussian distribution with mean and variance corresponding to the ensemble mean and ensemble variance.

In the tropics, the EPS versions without SPPT3 are substantially under-spread and skill is low – presumably due to the inability of the forecast model to represent the interaction between parametrized convection and its local environment. Figure 3 shows that here, SKEB is less effective than the SPPT-98 scheme in generating spread in the 850 hPa temperature for the tropics. Presumably SKEB's wind forcing only generates weak temperature perturbations since the small Coriolis parameter there is unable to support balanced, horizontal temperature gradients.

Figure 3 shows, on the other hand, that SPPT3 is highly effective in generating spread and this results in substantially more skilful CIS (see Figure 4).

Seasonal range

The impact of the new stochastic parametrization schemes has also been tested in ECMWF's seasonal-range, coupled ocean-atmosphere ensemble forecasting system. A set of retrospective ensemble forecasts with 11 ensemble members over the re-forecast period 1989–2005 has been carried out where 4-month long forecasts were initialised on 1 May and 1 November each year. The forecasts were made with a system that closely resembles the new Seasonal Forecast System 4 which is due to become the operational seasonal forecasting system at the end of 2011. The simulations were run with T255L91 resolution and used IFS Cycle 36r4, coupled to the 1°-NEMO ocean model.

The El Niño Southern Oscillation (ENSO) phenomenon is of crucial importance for seasonal forecasting and thus we focus our comparison on the performance of predicting tropical Pacific sea surface temperatures (SSTs), specifically for the Niño3 region (5°S–5°N, 150°W–90°W).

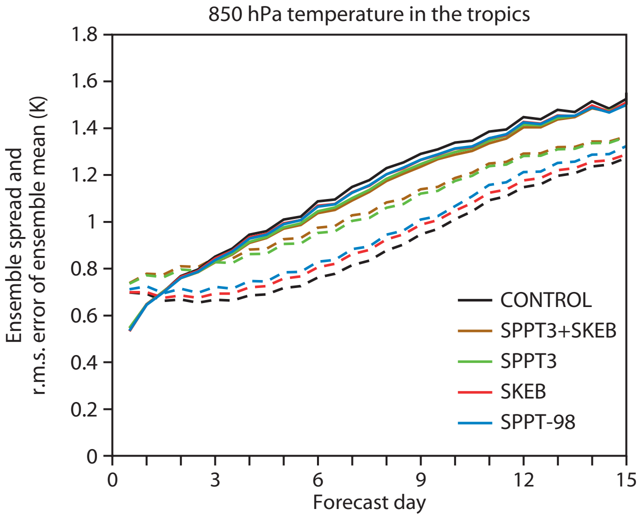


Figure 3 As Figure 1 but for temperature at 850 hPa in the tropics versus time.

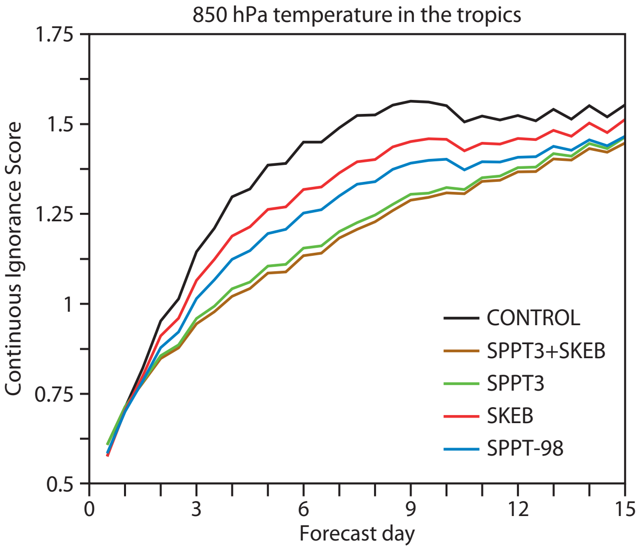


Figure 4 As Figure 2 but for temperature at 850 hPa in the tropics versus time.

Figure 5 shows the impact of the new schemes in forecasting SST anomalies in terms of the evolution of the ensemble-mean r.m.s. error (solid curves) and ensemble spread (dashed curves) over lead time. In Figure 5a, the simulations using the new model uncertainty representation (SPPT3 +SKEB) are shown along with the control simulation without any representation of model error (CONTROL). For comparison, the r.m.s. error of a simple persistence forecast is shown (PERSISTENCE). For a well-calibrated forecasting system one would expect that the ensemble-mean r.m.s. error would match the ensemble spread. This is clearly not the case for the simulations shown in Figure 5a. Here, the forecasting system is under-dispersive, or over-confident, by not generating enough ensemble spread. However, it can be seen that the stochastic tendency perturbation schemes have an overall positive effect on the problem of over-confidence by noticeably increasing the spread and slightly reducing the ensemble-mean r.m.s. error.

What are the relative contributions of SPPT3 and SKEB schemes to increasing ensemble spread and reducing the RMSE? Figure 5b shows results from ensemble forecasts where each scheme was switched on individually. As can be seen, the biggest impact in terms of spread and r.m.s. error comes from the SPPT3 scheme. The SKEB scheme also tends to increase the ensemble spread but to a much smaller extent.

Model uncertainty can be represented in different ways and stochastic physical parametrization is a newly-emerging field for long-range forecasts. The ‘traditional’ approach to address model uncertainty on seasonal and longer time-scales is the multi-model ensemble which relies on the assumption that individual models were developed quasi-independently. It is considered to be an ‘ensemble-of-opportunity’ for sampling model error. In the past, multi-model ensembles have been very successful in improving the skill of seasonal forecasts by reducing the over-confidence of the individual model ensembles. The ENSEMBLES multi-model ensemble (*Weisheimer et al.*, 2009), shown in Figure 5c, demonstrates the very good spread-skill relationship obtained by the multi-model approach.

Another method for modelling uncertainty uses ensemble forecasts with perturbed physical model parameters.

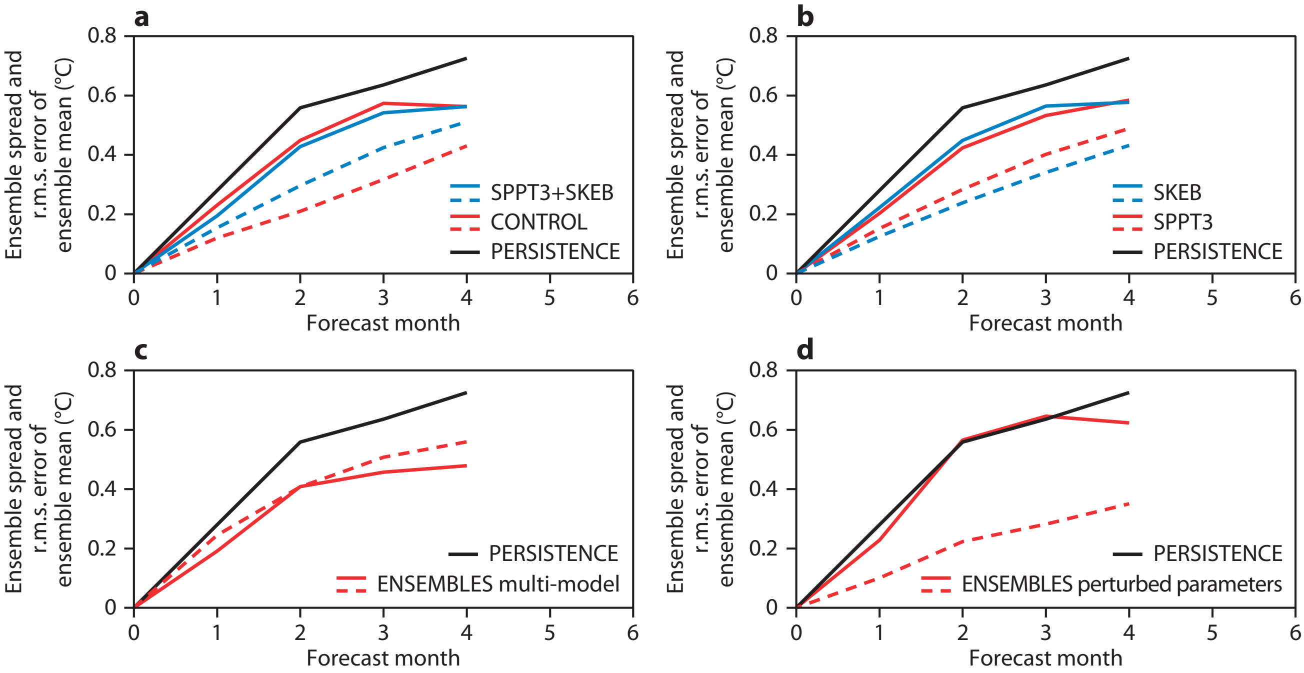
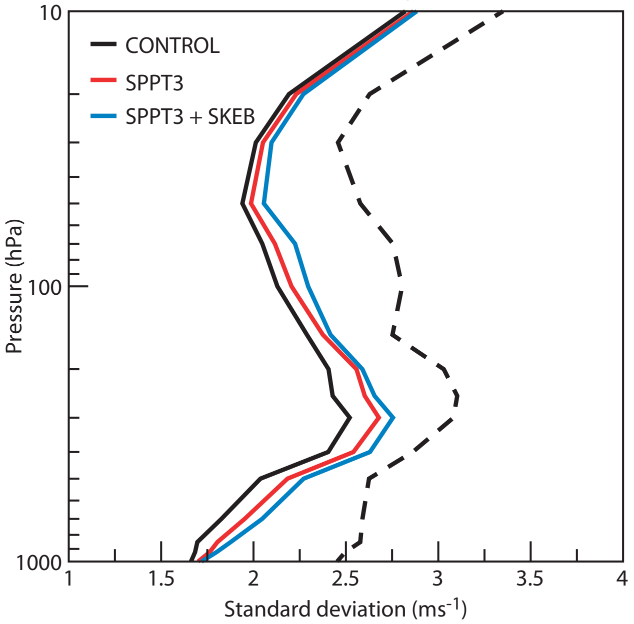


Figure 5 Quality of the SST anomaly forecast for the Niño3 region. Solid coloured lines indicate the r.m.s. error of the ensemble mean and dashed coloured lines show the ensemble standard deviation. The black lines show, as a reference, the r.m.s. error of a simple persistence forecast (PERSISTENCE). (a) Blue: SPPT3 + SKEB; red: CONTROL. (b) Blue: sensitivity simulations with SKEB only; red: sensitivity simulations with SPPT3 only. (c) Red: ENSEMBLES multi-model ensemble. (d) Red: ENSEMBLES perturbed parameters ensemble.

For comparison, Figure 5d shows results from seasonal forecast experiments with perturbed parameters carried out in the ENSEMBLES project.

From Figure 5 it can be concluded that the stochastic physical parametrization provides a powerful alternative to other approaches for representing model uncertainty in seasonal forecasts and it is suggested that these schemes should now be developed for multi-decadal climate predictions using Earth System Models as well (*Weisheimer et al.*, 2011).

a Zonal wind in northern extra-tropics



b Vorticity in southern extra-tropics

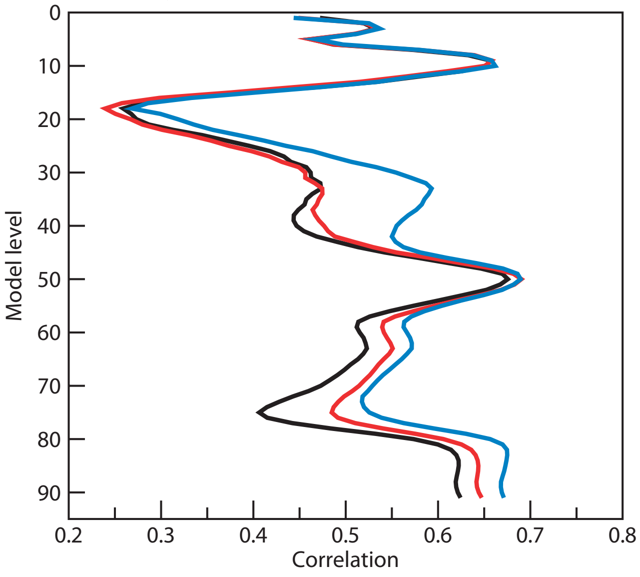


Figure 6 (a) Radiosonde innovation standard deviations for zonal wind in the northern extra-tropics (dashed line) and predicted innovation standard deviations for an EDA experiment without model error (CONTROL), with SPPT3 active (SPPT3) and with both SPPT3 and SKEB active (SPPT3+SKEB). (b) Spatial correlation of the EDA vorticity spread with the EDA mean background error vorticity field in the southern extra-tropics (model levels on the y axis).

Model error parameterizations in the EDA

The ECMWF Ensemble of Data Assimilations (EDA) is a system of *N* (*N*=10 at the time of writing) independent, reduced-resolution, assimilation cycles which differ by using randomly-perturbed observations, sea-surface temperature fields and model physics tendencies. If the perturbations are drawn from the true distributions of observation and model error, then the spread of the EDA about the control (unperturbed) analysis will be representative of the analysis error (*Isaksen et al.*, 2010). The use of EDA perturbations has already proved to have a beneficial impact on the representation of initial uncertainties in the EPS and on the estimation of flow-dependent background errors in the deterministic 4D-Var assimilation system (*Isaksen et al.*, 2010).

The ability of the EDA to correctly capture the analysis and background errors of the reference analysis is based on an accurate representation of all the relevant sources of uncertainty in the deterministic analysis cycle, among which model error plays an important role. It is then important to evaluate how the different model error schemes affect the performance of the EDA. This is, in fact, a very stringent test of their ability to represent the true sources of model error because the effects of using a certain model error representation accumulate in time over the analysis cycles and they are confronted with the observational reality, both directly and through the EDA-sampled statistics used in the deterministic high-resolution analysis. A further distinction is that in an EPS context, one is typically concerned with the verification and use of univariate probability distributions at a given lead time and location, while one of the main uses of the EDA is to diagnose spatial and multivariate covariances. Finally, background errors (i.e. forecast errors at 12 hours lead times, in the present case) have been shown to span a much larger portion of the error space than errors at longer forecast lead times, since they have not collapsed yet on to the dominant modes of instability of the system. This obviously makes their estimation a more challenging problem.

Figure 6 shows two diagnostics of the impact of SPPT3 and SKEB on the EDA variances. Figure 6a compares the observed radiosonde innovation standard deviations for the zonal wind component in the northern extra-tropics with the expected innovations (square root of the sum of the EDA variance and observation error variance) for three different EDA systems: one with no model error representation (CONTROL), one with SPPT3 active (SPPT3), and one with both SPPT3 and SKEB active (SPPT3+SKEB). Since a statistically-consistent EDA should have matching observed and expected innovation standard deviations, it is apparent that the use of model error parametrizations improves the reliability characteristics of the EDA. This is confirmed by Figure 6 (b) which plots, as a function of model level, the spatial correlation coefficient of the EDA mean background error vorticity field with the corresponding EDA vorticity spread for the three EDA experiments.

The impact of the model error parametrizations on the EDA sample covariances is the subject of ongoing investigation. Preliminary results indicate that while the SPPT3 scheme has an overall neutral impact, the SKEB parametrization tends to slightly degrade the quality of the EDA covariances. This result, if confirmed, could be an indication that the spatially-correlated error structures introduced in the SKEB scheme in the EPS configuration are not appropriate for the estimation of background errors.

Improving the stochastic schemes by coarse-graining

Considerable effort is currently aimed at calibrating the schemes, or at the very least, providing some justification for the chosen parameters (e.g. like the standard deviation of the random pattern values about their mean value of unity). The coarse-graining method compares high- and low-resolution forecasts to infer the statistical character of tendency error in the low-resolution forecast, e.g. by coarse-graining operational T1279 and matching T159 forecasts.

Estimates made so far suggest a somewhat lower standard deviation than that currently assumed in SPPT3 although this is to be expected since a T1279 forecast parametrizes convection and much of the gravity wave spectrum. Coarse-graining using model data (cloud-resolving model and IFS forecasts) has also been used to determine the power spectrum of streamfunction forcing and the probability distribution function of vertical phase shifts in SKEB (*Palmer et al.*, 2009).

Current research is aimed at better targeting the uncertainty in physical parametrization and in backscatter. For instance it may be wrong to perturb the radiative temperature tendency in SPPT3 since the origin of radiative flux uncertainty lies in the representation of cloud principally. If we assume that the dominant uncertainty arises from spatial truncation, coarse-graining will be able to quantify the uncertainties associated with lower resolution versions of the model.

Future developments

SPPT3 is fairly straightforward to code in the forecast model whereas the SKEB scheme is complex and costly. In spite of its complex implementation, the approach upon which SKEB is based is quite crude and, for instance, there is no phase relationship between the streamfunction forcing and individual flow features. Work is underway to devise schemes which generate backscatter vorticity perturbations from the model's instantaneous vorticity field and in such a way that energy is more directly transferred to large-scale flow features. This type of 'negative viscosity' effect has been shown in recent studies by *Thuburn* (2011) which used the barotropic vorticity equation and has also been revealed by coarse-graining IFS forecasts.

Refinement of SPPT3 using the coarse-graining methodology is currently focused on assessing the uncertainty associated with individual processes and improved representation of the pattern generator. The assumption that the standard deviation of the perturbations is proportional to the magnitude of the tendency is currently under scrutiny and there is evidence from coarse-graining that the variance of the perturbations is proportional to the mean.

The performance of ensemble data assimilation with different formulations of random model error provides a more stringent test on their underlying physical basis than their impact on medium-range probability skill scores. Indeed it may even be possible to use EDA to determine optimal parameter settings in the stochastic algorithms. Ultimately, it would be desirable to have stochastic forcing formulations that work across all time scales from those of data assimilation to climate modelling. Only then can one be confident in the physical basis for the chosen model error representations.

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Use of ECMWF's ensemble vertical profiles at the Hungarian Meteorological Service

ISTVÁN IHÁSZ, DÁVID TAJTI

The Hungarian Meteorological Service has made extensive use of ECMWF's deterministic and ensemble forecasts since 1994 when Hungary became a Co-operating State of ECMWF. Several locally-developed tools have been used operationally to extract information from the ECMWF forecasts. For example, based on data from the EPS (Ensemble Prediction System), these tools are used for clustering EPS members for the Central European domain, deriving a wide range of probability forecasts (among others EPS histograms), displaying several types of the EPS plumes (ECMWF, 2010), and performing ensemble calibration (*Ihász et al.*, 2010).

Deterministic vertical profiles based on the ALADIN/HU limited-area model and ECMWF global model have been used for a long time. In 2009 we started to plan the development of a new tool to visualize the vertical distribution of probabilistic forecasts for temperature, humidity, and wind speed and direction. These new products were verified on standard pressure levels and 62 EPS model-level fields for a one-year period (April 2010 to March 2011). Also a few case studies have been performed to prove the usefulness of this new tool in different weather situations.

The new visualization tool was implemented for standard pressure levels in May 2011 and it was introduced for 62 EPS model level fields in July 2011.

In this article we describe the use of ensemble vertical profiles and the way in which they can be verified. In addition, the usefulness of the ensemble vertical profile is illustrated with three case studied.

Use of ensemble vertical profiles based on standard pressure levels

Ensemble forecasts of temperature, relative humidity and horizontal wind components are currently available every three hours up to 144 hours (and 6 hours from 144 to 360 hours) with a horizontal resolution of 0.25° by 0.25° (*Buizza et al.*, 2010). This data is available from MARS (Meteorological Archival and Retrieval System) and also it is disseminated by ECMWF. At the Hungarian Meteorological Service programs use ECMWF's GRIB API grib decoder software and ECMWF's MAGICS++ software (*Siemen & Lamy-Thépaut*, 2010) to manipulate the data.

This new visualization tool can provide a quick overview of the complexity of forecasts of meteorological variables in the vertical. One can easily see the levels and layers where small and high probabilities occur, and interactions between different variables can easily be recognized by operational forecasters. Time evolution of probabilities is also easily studied.

It is important to note that even ensemble vertical profiles based on standard pressure level fields are very useful for viewing probabilistic information, but they could not be support the recognition of all the required details in some specific weather situations. For example, in the case of a winter inversion in the lower troposphere, the vertical profile derived from the three lowest standard pressure levels (1000, 925 and 850 hPa) could not describe the fine vertical structure. ECMWF's numerical models use a hybrid co-ordinate system containing a lot of model levels in the lower troposphere, so use of all the model-level data would be beneficial.

Use of an ensemble vertical profiles based on model levels

Having encouraging results from an ensemble of vertical profiles based on 11 standard pressure levels between 1000 and 100 hPa, the next step was to develop a similar tool based on 62 EPS model levels. However, , it is important to be aware that EPS model-level fields are not archived in MARS, but the latest two forecasts are available from the FDB (Forecast Data Base). In addition, EPS model-level fields are available via ECMWF dissemination system.

At the Hungarian Meteorological Service the EPS model-level fields have been archived for the Central European domain with 0.25° by 0.25° horizontal resolution since April 2010. Consequently it was possible to compare standard pressure level and model-level forecasts over quite a long period. After solving a few technical tasks, ensemble vertical profiles based on model-level fields became available in the same two main types as developed for standard pressure levels. To see detailed vertical structures, the program can easily change the vertical interval depending on what is of interest to the forecaster. Two main types of visualization were developed using the EPS forecasts:

- Probability forecasts of temperature and dew point in the vertical (Figure 1).
- Probability of the wind speed and wind direction shown as a wind rose (Figure 2).

These two types could also be combined.

62 level EPS fields are used for temperature, dew point and wind components from the operational dissemination. The area chosen covers all Hungary and some neighbouring regions, and the ensemble vertical profiles are generated for a few predefined location by using time-critical job on ecgate (ECMWF's Member State server). In addition, products can be generated locally within our meteorological service. Consequently vertical profiles can be made for any location

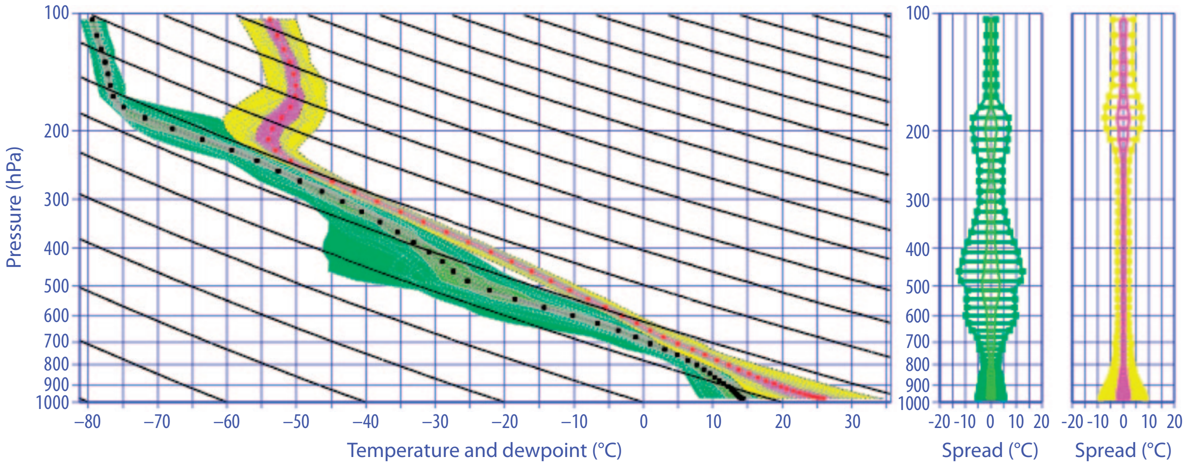


Figure 1 84-hour ensemble forecast of temperature and dew point on model levels. The forecast was issued at 00 UTC on 17 July 2011 for Budapest. The colours indicate ranges of probability. For dew point the green part shows 0–25% and 75–100%, and avocado shows 25–75%. For temperature the yellow part shows 0–25% and 75–100%, and magenta shows 25–75%. In subsequent figures of a similar kind, the diagrams are simplified by using pressure/temperature rectangular axes and not including the dry adiabats. Note that in reality 2% of all cases are outside the EPS range.

of interest to the forecaster. Generating these products needs only a couple of minutes.

Verification of ensemble forecasts on standard pressure levels

Many methods of verifying ensemble forecasts are available, but most of them are typically used for local weather elements (e.g. 2-metre temperature, precipitation and wind speed). In this case, however, we want to assess the quality of the ensemble vertical profiles – this can be achieved using Talagrand diagrams and the area under the Relative Operating Characteristic (ROC) curves. Ensemble forecasts at 00 UTC were verified for an area defined by a rectangle covering the territory of Hungary. Here we will give some examples of the verification results based on Talagrand diagrams.

Talagrand diagrams give a measure of how well the ensemble spread of the forecast represents the variability of the observations, though they give no indication of the skill of the forecasts. In an ideal system the long-term distribution in the diagram should be flat. If the distribution is slightly U-shaped, this indicates that the ensemble spread is too small with many observations falling outside the extremes of the ensemble (i.e. over-representation of cases when the verification falls outside the ensemble and under-representation when it falls in the centre of the ensemble). However, a J-shape or L-shape indicate that the system has a bias: a J-shape shows systematic underestimation and L-shape shows systematic overestimation.

Talagrand diagrams were produced for all standard pressure levels and displayed together. They were calculated for temperature, wind speed and humidity for one year (April 2010 to March 2011) (*Tajti*, 2011). As well as verification of the individual ensemble members, verification of the ensemble mean is also applied and results are easily displayed in the vertical. Verification results will now be presented for two important meteorological elements: temperature and relative humidity.

Figure 3 shows the Talagrand diagrams for forecasts of temperature on standard pressure levels in 2010 for two forecast ranges (36 and 132 hours). It can be seen that the forecasts are quite good around the mid-troposphere for both time steps. However, a systematic overestimation(L shape – warm bias) is found at lower levels at short time ranges but it disappears at longer time ranges. In the lower stratosphere a systematic underestimation (J shape – cold bias) is found.

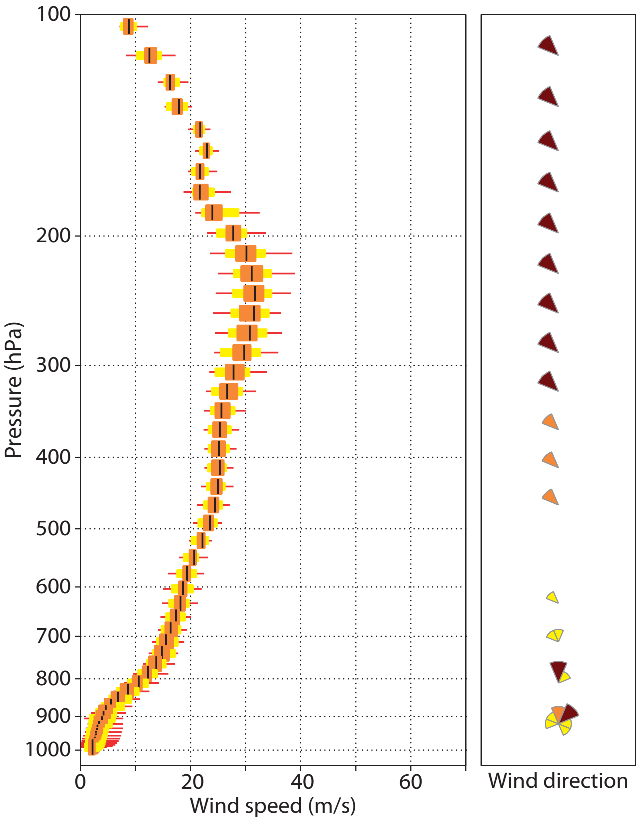
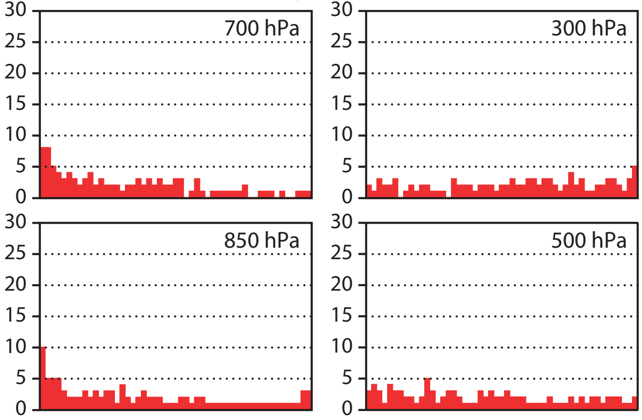


Figure 2 84-hour forecast of ensemble wind speed and wind rose based on model levels. The forecast was issued at 00 UTC on 17 July 2011 for Budapest. The colours indicate ranges of probability. For wind speed (left panel) yellow shows 10–25% and 75–90%, and orange shows 25–75%. For the wind rose (right panel) yellow shows less than 5%, orange shows between 5% and 25%, and brown shows more than 25%. Note that in reality 2% of all cases are outside the EPS range.

a 36-hour forecast of temperature



b 132-hour forecast of temperature

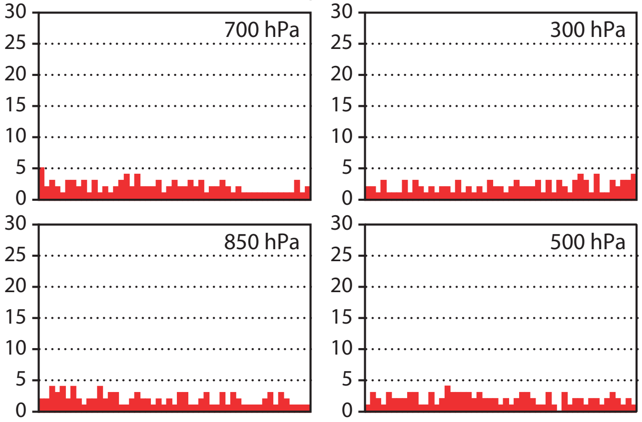
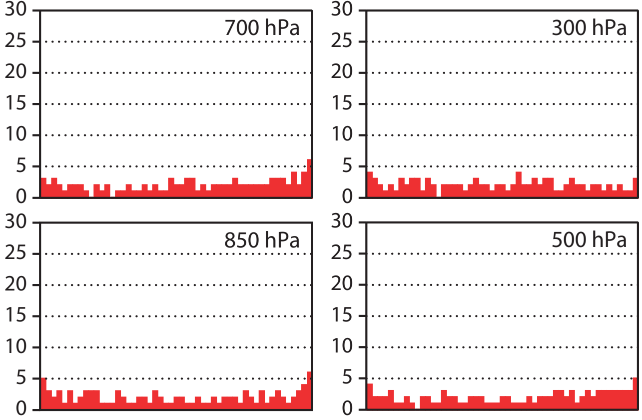


Figure 3 Talagrand diagram for (a) 36-hour and (b) 132-hour forecasts of temperature at 850, 700, 500 and 300 hPa in 2010.

a 24-hour forecast of relative humidity



b 36-hour forecast of relative humidity

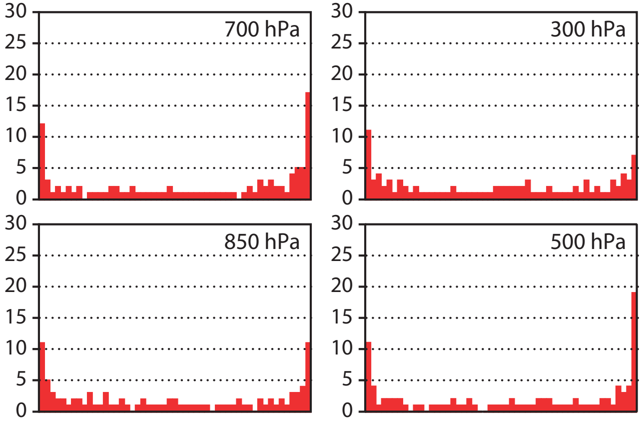


Figure 4 Talagrand diagram for (a) 24-hour and (b) 36-hour forecasts of relative humidity at 850, 700, 500 and 300 hPa in 2010.

For relative humidity the situation is more complex. There are typical features in the diurnal and seasonal scales; also there are some characteristic changes with the forecast time range. Figure 4 shows the Talagrand diagrams for forecasts of relative humidity for two short forecast ranges (24 and 36 hours). In terms of the annual average near to the surface, relative humidity is typically overestimated during the night as illustrated by the results for the 24-hour forecasts. However, especially at short time ranges, the spread is underestimated around noon – see the results for 36-hour forecasts. In addition, the spread at 700 hPa is underestimated but in the lower stratosphere overestimation is found. As already mentioned there is a seasonal variability too, so it is useful if users or potential users are aware of the reliability of the forecacting system and influences of the model upgrades.

Three case studies

The use of the ensemble vertical profiles will now be illustrated by three case studies associated with situations where there is summer convection, winter inversion and cold vortex in the middle troposphere.

Summer convection

In operational practice it is often necessary to estimate the type, vertical extent and base of cloudiness from profiles of temperature and humidity. Studying the EPS vertical profile we can assess the area of high vertical instability and thereby estimate the type of cloud formation in different layers. In addition, the ensemble vertical profiles can be used to derive ensemble meteograms containing convective indices (e.g. Convective Available Potential Energy (CAPE), wind shear between 500 hPa and 10 m, and average relative humidity between 850 and 500 hPa) that indicate whether severe events, such as heavy thunderstorms, are likely to occur. Also regions where turbulence might occur can be assessed from the wind shear.

On 16 August 2010 the weather of the Carpathian basin was determined by low pressure with a few local minima. In the morning a few thunderstorms occurred in the western part of Hungary and, due to the large-scale intensive convection, severe thunderstorms appeared in the eastern part in the afternoon. A red warning and an alarm of severe events were issued to the public. The ECMWF ensemble forecast provided useful early warning of this situation (Figure 5a) even though there was high uncertainty in the wind speed and dew point in the layer between 850 and 300 hPa. The very short-range (12 hour) ensemble forecast indicated low uncertainty in the temperature throughout the troposphere but higher uncertainty about the wind direction in the lower stratosphere and dew point around the tropopause (Figure 5b). Indeed, there are two relatively narrow regions (around 600 and 200 hPa) where there is a high uncertainty in the dew point.

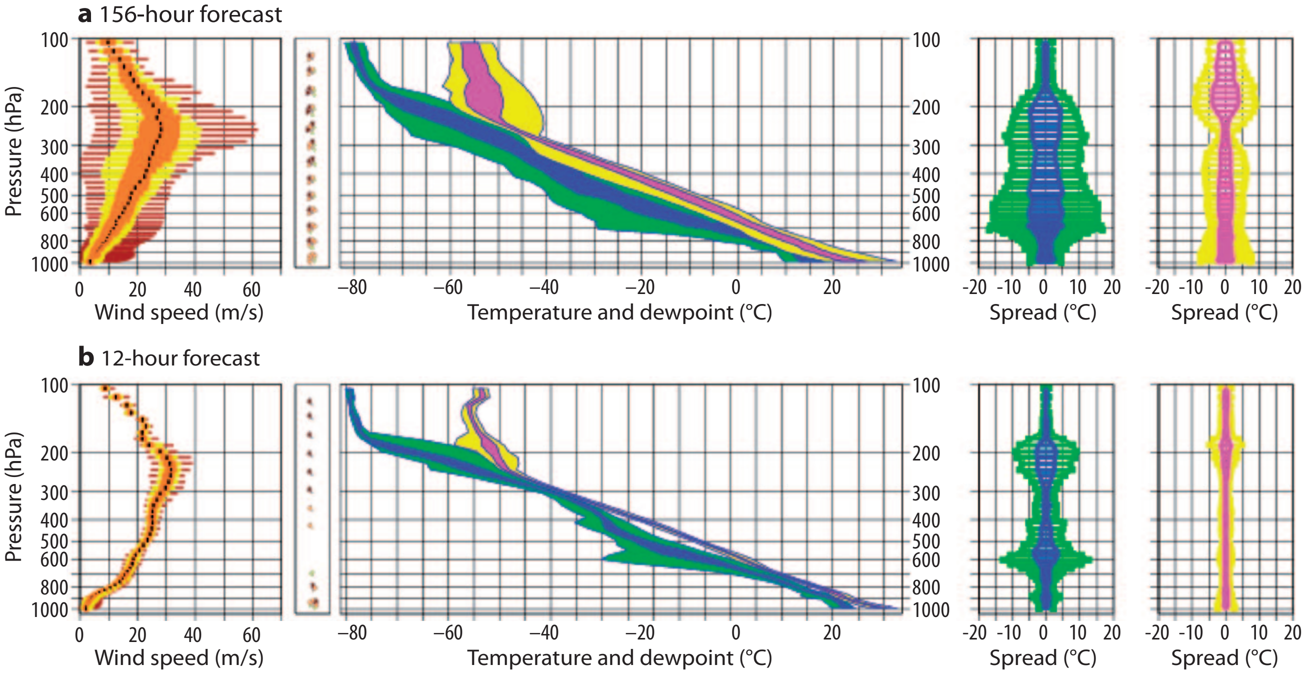


Figure 5 (a) 156-hour forecast issued at 00 UTC on 10 August 2010 and (b) 12-hour forecast issued at 00 UTC on 16 August 2010 of the ensemble wind speed, temperature and dew point based on model levels for Budapest. The colours have the same meaning as in Figures 1 and 2.

Winter inversion

Having a wintertime inversion is quite typical in the Carpathian basin. During inversion situations the accurate forecasts of temperature and humidity in the lowest 1.5 km are quite important for determining the type of precipitation, particularly freezing rain and frozen rain as these have a strong influence on traffic conditions. In addition, correctly estimating the top of the inversion could help with forecasting these dangerous events as well as the occurrence of fog. Incorrect forecasts during wintertime inversion situations can also have a strong influence on energy consumption because the maximum temperature could differ by 8–10°C depending on the amount of cloudiness.

ECMWF forecasts have improved significantly in the last decade, but there are still a few cases when increasing or decreasing the strength of the inversion is not well captured. In these cases strong biases can appear in the maximum and minimum 2-metre temperatures due to the absence of the low-level cloudiness. The 36-hour deterministic forecast for 00 UTC on 31 January 2011 predicted a clear sky across Hungary, but actually there were low-level clouds everywhere. The inversion was quite well predicted, but less humidity was forecast than happened. In this situation it very useful having the ensemble vertical profile to provide guidance about the probability of the low-level cloudiness connected to the inversion (Figure 6). Note that the dew point changes very rapidly in the vertical.

Cold vortex in the middle troposphere

The successful forecast of the position and intensity of the

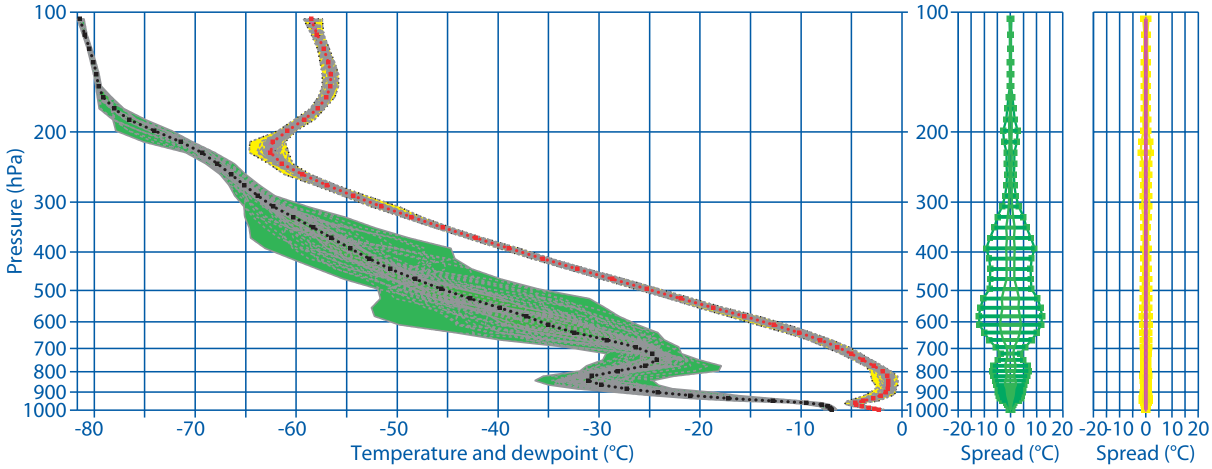


Figure 6 36-hour forecast of temperature and dew point based on model levels. The forecast was issued at 00 UTC on 31 January 2011 for Budapest. The colours have the same meaning as in Figure 1.

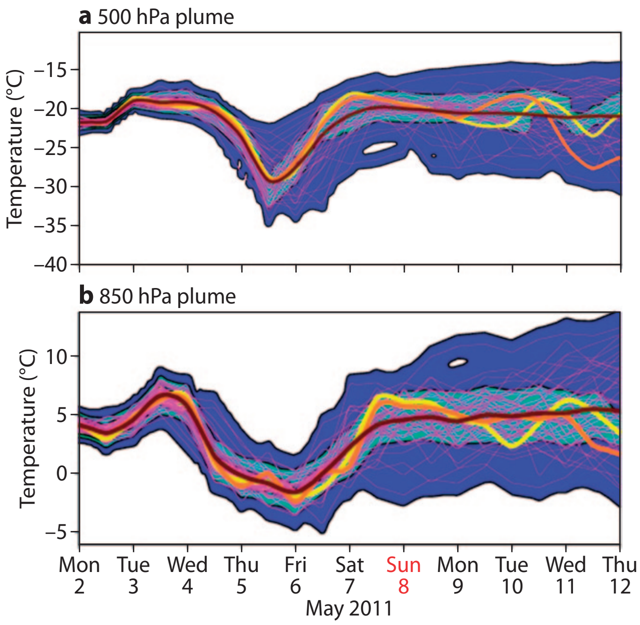


Figure 7 Standard 10-day ensemble temperature plume on (a) 500 hPa and (b) 850 hPa. The forecast was issued at 00 UTC on 2 May 2011 for Budapest. Ensemble mean is brown, deterministic model is yellow, and control model is orange.

cold vortex in the middle troposphere is a real challenge, especially in medium-range forecasts. In these circumstances, the weather can be very changeable; for example intensive showers and thunderstorms are quite typical in some regions but at the same time sunny and calm weather is found not far away. Around 5 May 2011 such a weather situation appeared as can be seen in the temperature plume at 500 hPa (Figure 7a) – the uncertainty is quite high. In contrast, cooling occurred much earlier at 850 hPa (Figure 7b). The ensemble vertical profile based on model-level fields provided a better localization of uncertainties in the vertical (Figure 8).

Overview and further developments

A new visualization tool, displaying an ensemble vertical profile, was developed at the Hungarian Meteorological Service. This enables ensemble vertical profiles of temperature, humidity, wind speed and wind rose to be generated operationally for pre-defined locations in addition to places of particular interest to forecasters because of the specific weather situation. The profiles have been created from forecasts of the 62 EPS model levels as well as using data from standard pressure levels.

Forecasters have found that having access to these profiles is of value in interpreting EPS output. The new tool provides a quick overview of the vertical structure of all important meteorological variables and interconnections among the variables. Based on such information, important meteorological situations, such as winter inversions and summer convective cases, can be better predicted.

We plan to investigate the improvement in the ensemble vertical profiles when the planned increase in the number of the ensemble model levels takes place in 2012.

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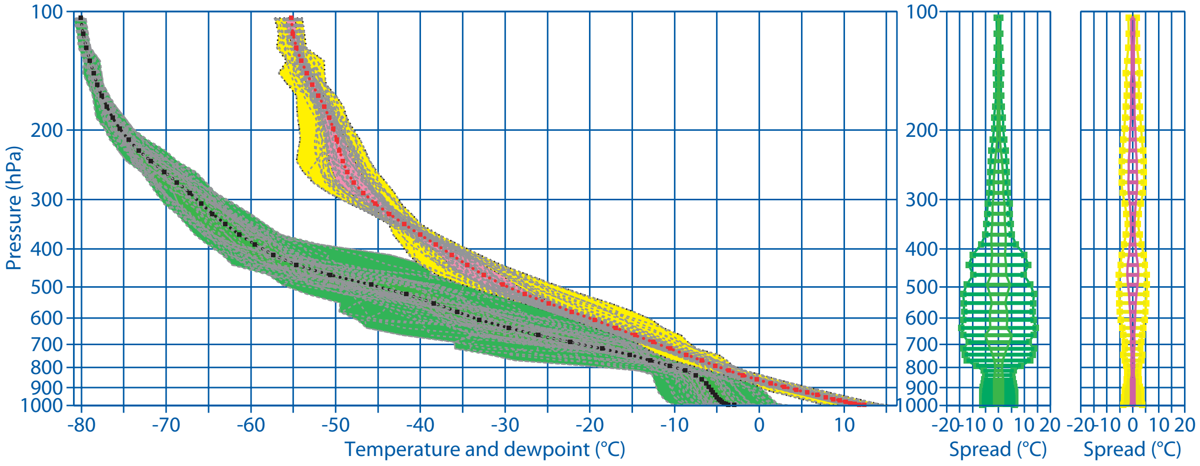

Figure 8 84-hour forecast of temperature and dew point based on model levels. The forecast was issued at 00 UTC on 2 May 2011 for Budapest. The colours have the same meaning as in Figure 1.

ECMWF Newsletter No. 129 – Autumn 2011

Managing work flows with ecFlow

AVI BAHRA

For almost three decades ECMWF has used the SMS (Supervisor Monitoring Scheduler) package to control the workflow for the Centre's operational models and systems. Written at ECMWF, it allows the design, submission and monitoring of jobs both in the Research and Operations Departments, and provides common tools for scientists, analysts and operators to cooperate. A large number of organisations also use SMS (from both Member and non-Member States). Development of SMS has now stopped. The software will be supported only on the currently tested computer platforms, not on any new ones.

The replacement, ecFlow, will supersede SMS in the near future. It is a complete rewrite using object oriented methodology and modern standardised components; it will act as a comprehensive replacement for SMS. The rewrite will help improve maintainability, allow easier modification and introduce object orientated features. Proprietary script languages, such as CDP, have been replaced by Python.

Once ecFlow has been fully validated at ECMWF, it will be made available to Member States.

Key features of ecFlow

ecFlow is a work-flow manager that enables users to run a large number of programs, with dependencies on each other and on time, in a controlled environment. It provides tolerance, for hardware and software failures, combined with good restart capabilities.

ecFlow runs as a server receiving requests from clients. The command line interface, the graphical interface (ecFlowview), scripts and the Python API (application interface) are the clients. The server is based on C++/boost ASIO and uses TCP/IP for communication. Multiple servers can be run on the same hardware. ecFlow submits tasks (jobs) and receives acknowledgements from tasks via specific commands embedded in the scripts. The relationship between tasks is stored in ecFlow, and it is able to submit tasks dependent on the status of other tasks and attributes like time.

The command line interface for ecFlow allows the suite definition to be loaded and retrieved from the server. Also it provides a rich set of commands for communication with the server and provides similar capabilities to SMS. For example, the Python API allows the entire suite definition structure to be specified and loaded into the server. A suite is a collection of interrelated tasks. In ecFlow suites are described by a definition file. The Python API also provides functionality for client to server communication. In addition, it allows checking of the suite, testing the defined interrelations between tasks, and other references and limits.

ecFlow comes with a user manual, online tutorial, Python API and reference documentation.

Other features of ecFlow

ecFlow is written to be as platform independent as possible by using standardised libraries. We have built and are testing ecFlow on the following operating systems: Linux (SUSE 10.3/11.3 and SLES 11), HP-UX (11.23) and AIX (5.3).

Another feature of ecFlow is the simulator. It can validate suites before the real job submission. The simulator can be run without the need for scripts or the server. Some suites have attributes that allow it run without ever completing; however others, that are known to complete, can be checked for programming deadlocks with the simulator. An interim graphical interface to ecFlow, ecFlowview, is used to visualise and manage the suite hierarchy.

'Child commands' are embedded in submitted scripts that communicate with the ecFlow server. It supports variable inheritance and also has a white list file for authentication of read/write client requests. It shares the ability to dynamically add or remove whole suites on the fly using the command line interface or the Python API.

The default script extension has been changed to reflect the software change with the ".ecf" extension used rather than ".sms". There is a pre-processor to handle include files and variable substitution in ecFlow, though SMS variables have been replaced with ECF_ labelled equivalents (e.g. the SMS variable SMSHOME is replaced with ECF_HOME). These naming conventions are easy to migrate by using a script to substitutes one set of names with the other. In this way the investment users have made in developing their SMS suites can be preserved.

Design features

With the use of standardised libraries and by designing it in an object orientated way, maintenance and enhancement of ecFlow is easier. ecFlow has been written and developed with C++ and Python. The development of ecFlow has been test driven, with a large set of unit and regression tests. These tests validate the expected behaviour and detect regressions in functionality and performance. They are run on each of the supported platforms. ecFlow also works on 64-bit operating systems like AIX and Linux.

The command line interface, along with the Python API, replaces the CDP text interface. The Python API provides two main functions. It allows the suite definition to be built and it provides functionality for interaction between the client and server. This enables the suite definition to be loaded and retrieved from the server. However, the use of Python is not mandatory: the suite definition file can be built using any language and loaded into the ecFlow server via the command line interface.

When a task loses communication with its submitting server it is called a zombie. ecFlow has been extended to allow for customisable handling of zombies. A new attribute specifies how zombies are handled by the client or server. For example, we can add a zombie attribute so that child label commands no longer block scripts from progressing. This can be added at different levels in the node tree hierarchy.

The log file in ecFlow records each request and any resulting state changes. We can quickly determine the number of requests per minute that the server is handling. This allows for better load management (i.e. by splitting the load onto multiple servers). Additionally the ecFlow client can produce a graphical plot (using gnuplot) showing the proportional impact of child versus user requests and the total number of requests per minute.

ecFlow has also been designed with better error checking, such as the following.

- Trigger expressions checking is improved. When a definition is loaded external references are checked in the server. This provides early warnings on trigger expression that never evaluate.
- Job generation can be checked before loading the definition into the server. This will check that script can be located, the pre-processor can expand the include files and variable substitution works. Recursive use of “include” files is also detected and flagged.
- References to limits are checked to ensure they exist. Also the tokens specified on the in-limit are checked to make sure that they are not larger than the limit size.
- Correct by construction approach is used when building the suite definition with the Python API. See Box A for an example.
- The abort child command now has an option to allow a reason for the abort to be provided, thus facilitating better handling of script problems.
- Definition files can be simulated without the need for underlying scripts or server.

Examples of expression, job and deadlock checking are shown in Box B.

Incompatibilities

ecFlow is a replacement for SMS providing similar capabilities. Hence not all the functionality will be present in the first release. Currently auto-restore and auto-migrate constructs have not been implemented. This functionality might be added in a future version. Some SMS constructs (i.e. owner, action, text and abort) are no longer supported.

ecFlow does not provide, looping and conditional statements or function definitions. However, since we will have a defined file format, any language can be used to generate the structure of the definition file. Python integration replaces CDP and will provide looping and conditional statements and functions. It should be noted, however, that the new Python interface offers the opportunity to re-design and re-write suite definition in an object-oriented way. This has the distinct advantage of allowing a more compact, more easily maintainable and re-usable representation of suite definitions.

Correct by construction

A

The following examples show usage of the new Python API. The API supports a correct by construction approach. For example, adding tasks of the same name at the same level will throw a RuntimeError exception:

Example 1

```
  import ecflow
  defs = ecflow.Defs()
  suite = defs.add_suite(“s1”)
  suite.add_task(“t1”)
  suite.add_task(“t1”) # RuntimeError exception thrown
>> RuntimeError: Add Task failed: A task of name ‘t1’
already exist on node SUITE:/s1
```

Example 2

Adding dependencies, such as dates, are also checked:

```
  import ecflow
  defs = ecflow.Defs()
  suite = defs.add_suite(“s1”)
  task t1 = suite.add_task(“t1”)
  t1.add_date(1,14,2007) # day,month,year, month is
  not valid
>> IndexError: Invalid Date(day,month,year): the month
>=0 and month <= 12, where 0 means wild card
```

Migration

ecFlow is currently undergoing internal validation and testing by the Operations Department at ECMWF. A series of internal and external training courses have been organised for September 2011 to give initial access to a beta version of the software. These courses are designed for current users of SMS who want to migrate to ecFlow. These initial user tests should identify any missing features or issues with the new software that could be added or fixed before the general release of the software early in 2012. The computer user training course organised for Member States in spring 2012 will only be covering the ecFlow software.

The migration of ECMWF Operations is closely linked with the migration of the ECMWF Research environment (especially PrepIFS) as Operations and Research are sharing the same technical framework. It is planned to use the migration process to harmonise the suite definition and scripts files even further, which should allow an improved transfer of changes between Operations and Research. It is planned to finish this migration process and remove any operational dependencies on SMS by the end of 2012.

Technology used

Building ecFlow uses the latest C++ compilers. Currently we have tested building with the following compilers: gcc version 4.2.1/4.5 on Linux (SUSE 10.3/11.3), aCC-A.06.20 on HP-UX and xlC version 11.1 on AIX(ibm_power6/rs6000). We have also made use of Python version 2.5–2.7.

B

Checking

Expression checking

Some checking has to be deferred until the definition is fully defined. Here is a simple example showing the checking of trigger expressions:

```
import ecflow
defs = ecflow.Defs()
suite = defs.add_suite("s1");
suite.add_task("t2")
suite.add_task("t1").add_trigger("t2 == active)")
assert len(defs.check()) != 0, "Expected Error: miss-
matched brackets in expression."
```

Job checking

Job creation is the process of locating an '.ecf' script corresponding to a task and then generating a job file. This can be checked before a definition is loaded into the server using the Python API.

```
# Generate jobs for the *ALL* tasks in the definition given
by variable 'defs'
# and print errors to standard out.
import ecflow
defs = ecflow.Defs()
suite = defs.add_suite("s1");
suite.add_task("t1")
job_ctrl = JobCreationCtrl()
defs.check_job_creation( job_ctrl )
print job_ctrl.get_error_msg()
```

Job control provides additional functionality to control which nodes are generated and control over the directory used for job generation.

Dead lock checking

Simulation allows a suite definition to be checked without the need for scripts or a server. By default the simulation will run for a year before quitting. This can take a couple a seconds to a few minutes depending on the complexity of the suite definition. However, it is most useful where we have a definition which is known to complete. Here is an example which will cause a deadlock that is detectable by the simulator.

```
import os
from ecflow import *
defs = Defs()
suite = defs.add_suite("dead_lock")
fam = suite.add_family("family")
fam.add_task("t1").add_trigger("t2 == complete")
fam.add_task("t2").add_trigger("t1 == complete")
theResult = defs.simulate();
assert len(theResult) != 0, "Expected simulation to return
errors, but found none"
print theResult
os.remove("defs.depth") # provides reason why simula-
tion could not complete  os.remove("defs.flat") #
provides reason why simulation could not complete
```

Early checking of the suite definition will help to speed up the development of suites.

To support the generation of online documentation we use Sphinx-poco. This allows the online tutorial Python samples to be compiled separately and to be used in the documentation. Sphinx also supports documentation of the Python API by loading the ecFlow Python extension and automatically extracting the doc strings.

We use the Boost C++ libraries. They are a set of free peer-reviewed portable C++ source libraries in preparation for inclusion in future C++ standard libraries. These libraries are described in Box C.

To build the project we use the bjam command-line tool that drives the Boost Build system. It provides the build and test mechanism that allows ecFlow to be constructed in the same way across different platforms. In addition, it allows debug, release and profile builds without knowledge of the compiler options on each platform.

Future developments

The ecFlow user interface (ecFlowview) uses the same technology and user paradigm as XCDP. The graphical user interface (GUI) is X-Windows based. This places limits on the machines where user interface can be run, since the X windows libraries will require a separate installation. This will be replaced in the near future, with a more intuitive and up to date GUI.

When ecFlow is released the online documentation and tutorial can be accessed from:

- http://www.ecmwf.int/publications/manuals/ecflow/

C

Boost C++ libraries used in ecFlow

Boost-ASIO library is used to provide the core of the client-server implementation. It also provides a deadline timer for polling and support for time outs.

- Boost-Python library enables seamless interoperability between C++ and the Python programming language.
- Boost-Program options are used to parse the client and server program options, and they provide the corresponding help strings.
- Boost-Spirit provides the parsing for expressions. The abstract syntax tree is then created from the spirit nodes.
- Boost-Test library is used for unit and regression tests of the C++ and Python code.
- Boost-Date-Time library is used in the suite calendar, time based attributes and polling.
- Boost-File System library is used for file queries in a platform independent manner.

We welcome feedback on any aspect of ecFlow. Suggestions for further developments will be assessed and, where appropriate, they will be prioritised and fed into future versions.

ECMWF Calendar 2012

January 30 – February 3	Training Course – Use and interpretation of ECMWF products
February 6 – 10	Training Course – Use and interpretation of ECMWF products
February 28 – March 28	Training Course – Use of computing facilities
February 28 – March 2	*GRIB API: library and tools*
March 5 – 9	*Introduction for new users/MARS*
March 12 – 13	*MAGICS*
March 14 – 16	*METVIEW*
March 19 – 23	*Use of supercomputing resources*
March 26 – 28	*Introduction to ecFlow*
February 27 – March 2	First MACC-II General Assembly
March 22 – 23	Working Group on Long-Term Building and Refurbishment Requirements
April 16 – May 31	Training Course – Numerical Weather Prediction
April 16 – 20	*Numerical methods, adiabatic formulation of models and ocean wave forecasting*
April 23 – May 2	*Data assimilation and use of satellite data*
May 9 – 18	*Predictability, diagnostics and extended-range forecasting*
May 21 – 31	*Parametrization of subgrid physical processes*
April 17 – 18	Advisory Committee for Data Policy (*13th Session*)

April 24 – 25	Finance Committee (*90th Session*)
April 26 – 27	Policy Advisory Committee (*33rd Session*)
May 21 – 22	Security Representatives' Meeting
May 22 – 24	Computer Representatives' Meeting
June 13 – 14	Council (*77th Session*)
June 20 – 22	Forecast Products Users' Meeting
June 25 – 27	Workshop on 'Ocean wave modelling'
September 4 – 7	Annual Seminar on 'Seasonal prediction: Science and Applications'
October 8 – 12	Training Course – Use and interpretation of ECMWF products for WMO Members
October 15 – 17	Scientific Advisory Committee (*41st Session*)
October 18 – 19	Technical Advisory Committee (*44th Session*)
October 22 – 23	Finance Committee (*91st Session*)
October 24 – 25	Policy Advisory Committee (*34th Session*)
October 29	Advisory Committee of Co-operating States (*18th Session*)
Autumn – dates to be confirmed	15th Workshop on 'High performance computing in meteorology'
November 6 – 9	Workshop on 'Parametrization of clouds and precipitation across model resolution'
December 4 – 5	Council (*78th Session*)

ECMWF publications (see http://www.ecmwf.int/publications/)

Technical Memoranda

652 **Albergel, C., P. de Rosnay, C. Gruhier, J. Muñoz-Sabater, S., Hasenauer, L. Isaksen, Y. Kerr & W. Wagner:** Evaluation of remotely sensed and modelled soil moisture products using global ground-based in situ observations. *October 2011*

651 **Albergel, C., P. de Rosnay, G. Balsamo, L. Isaksen & J. Muñoz-Sabater:** Soil moisture analyses at ECMWF: evaluation using global ground-based in situ observations. *October 2011*

650 **Bormann, N., A. Geer & T. Wilhelmsson:** Operational implementation of RTTOV-10 in the IFS. *September 2011*

648 **Balsamo, G., R. Salgado, E. Dutra, S. Boussetta, T. Stockdale & M. Potes:** On the contribution of lakes in predicting near-surface temperature in a global weather forecasting model. *September 2011*

ESA Contract Report

Muñoz Sabater, J., T. Wilhelmsson, P. de Rosnay & L. Isaksen: Technical Note – Phase II – WP1200 SMOS Report on Data Thinning. ESA/ESRIN Contract 4000101703/10/NL/FF/fk. *August 2010*

Proceedings

ECMWF-JCSDA Workshop on Assimilating Satellite Observations of Clouds and Precipitation into NWP Models, *15–17 June 2010*

ECMWF Workshop on Non-hydrostatic Modelling, *8–10 November 2010*

Index of newsletter articles

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

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