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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 The *ECMWF Newsletter* is not peer-reviewed.

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EDITORIAL

# A new era for reanalysis

The fact that this issue of the *ECMWF Newsletter* contains no less than three articles related to reanalysis shows how important this activity is becoming for a range of users that goes far beyond the meteorological community. A first clear indication of this is the designation by ScienceWatch.com of a paper on ERA-40 as a 'current classic'.

Initially developed for meteorological purposes, in particular the monitoring of the global observing system, reanalyses have become indispensable for many activities, first and foremost for climate monitoring and climate research, but also for numerous applications in sectors as diverse as hydrology, health, air quality and biodiversity. This is not surprising as reanalysis is the best, and often only, solution for providing a global representation of many parameters ranging from temperature to wind, radiation or energy fluxes, and this in a consistent way over a long period of time. It is the method itself that allows this, as it creates, for each time-step, a global picture of the atmosphere that is consistent with all available measurements, satellite and in-situ, linking them by the laws of physics.

A reanalysis is not a one-off project but needs to be rerun regularly, say every five to ten years, to keep pace with the constant improvement of the assimilation techniques. The article on the ERA-Interim reanalysis shows very clearly how much this new reanalysis improves on the previous ERA-40 system. However, it covers a limited time period and is not yet fully adapted to satisfy the requirements of the climate community. It is, as indicated by its name, a temporary demonstration that confirms the need for the full-blown next-generation reanalysis.

Much progress is currently being made in the field of reanalysis. One important development is the emergence of regional reanalyses which, coupled with the global one, will support higher resolutions. Another is the launch of the new ESA Climate Initiative, which will provide future reanalyses with long-term records of the Essential Climate Variables and will also need existing reanalyses to develop these records. There are also important developments to come. Future reanalyses will need to be developed towards Earth-system reanalyses, in particular through coupling with ocean and atmospheric chemistry.

All these developments indicate that it is now time to develop a long-term facility providing regularly updated global reanalyses. The long-term support needed to maintain such a facility suggests that the GMES (Global Monitoring for Environment and Security) initiative would be a proper framework for this development, as it would in particular facilitate the necessary co-operation with the other Earth-system communities. We will then enter a new era for reanalysis.

**Dominique Marbouty**

# New items on the ECMWF website

ANDY BRADY

### The 4th European Flood Alert System (EFAS) Annual User Meeting

Presentations are available from the the EFAS Annual User Meeting 2009 which was held at ECMWF at the end of January. The European Flood Alert System (EFAS) was launched in 2003 by the European Commission with the aim to increase warning time for floods in trans-national European river basins. Its two main objectives are to:

- Complement Member States activities on flood preparedness.
- Provide the European Commission with information for improved aid and crisis management in the case of large trans-national flood events that might need intervention on an international level.

Every year DG Joint Research Centre organises annual user workshops with representatives of the EFAS partner network for information and training purposes.

- www.ecmwf.int/newsevents/meetings/workshops/2009/EFAS/

### GEMS Data Access

Coinciding with the Anthony J. Hollingsworth Symposium at the annual meeting of the American Meteorological Society in Phoenix, Arizona, the GEMS team is happy to announce the new GEMS data access; this provides easy public access to the GEMS global and regional fields. Anyone interested in the data behind the maps published on this website is encouraged to take a look. The EU-funded GEMS project aim was to develop comprehensive data analysis and modelling systems for monitoring the global distributions of atmospheric constituents important for climate, air quality and UV radiation, with a focus on Europe.

- gems.ecmwf.int/data.jsp

### ECMWF/NWP-SAF Workshop on the '*Assimilation of IASI in NWP*'

The ECMWF/NWP-SAF Workshop on the '*Assimilation of IASI in NWP*' will be held from 6 to 8 May 2009. Marking nearly two years since METOP-IASI data were first disseminated to NWP centres, the workshop will consider the progress that has been made in the exploitation of these unique hyper-spectral observations. The methods that have been adopted to assimilate clear and cloud affected radiances will be covered, in addition to novel techniques based on the use of principal components and level-2 retrievals. Reflecting the recent expansion of NWP systems to cover environmental monitoring applications, the workshop will also deal with the assimilation of atmospheric constituent information from IASI.

- www.ecmwf.int/newsevents/meetings/workshops/2009/IASI_data/

### The ECMWF 2009 Annual Seminar

From 7 to 10 September 2009, ECMWF will be holding its Annual Seminar. This year the seminar is on '*Diagnosis of Forecasting and Data Assimilation Systems*'. This seminar will give a pedagogical overview of diagnostic techniques that lead to a better understanding of the global circulation or aid forecast system development. Diagnostics targeting observations, data assimilation, NWP, seasonal and climate forecasting and ensemble prediction will be discussed.

- www.ecmwf.int/newsevents/meetings/annual_seminar/2009/

### ECMWF Workshop on '*Diagnostics of Data Assimilation System Performance*'

The Workshop on '*Diagnostics of Data Assimilation System Performance*' will be held from 15 to 17 June 2009. Data assimilation schemes have evolved into complicated systems with millions of degrees of freedom and handling massive amounts of observations. Effective monitoring of these systems is required and emerging techniques are now rapidly developing at most NWP centres. This review of the various methodologies and their effectiveness in diagnosing the impact of observations in NWP is suitably timely.

- www.ecmwf.int/newsevents/meetings/workshops/2009/Diagnostics_DA_System_Performance/

### 12th Workshop on 'Meteorological Operational Systems'

The 12th Workshop on '*Meteorological Operational Systems*' will be held from 2 to 6 November 2009. The objective of the workshop is to:

- Review the state of the art of meteorological operational systems.
- Address future trends in the use and interpretation of medium- and extended-range forecast guidance, operational data management systems and meteorological visualisation applications.

Further information will be provided later.

- www.ecmwf.int/newsevents/meetings/workshops/2009/MOS_12/

### ECMWF/GLASS Workshop

The ECMWF/GLASS Workshop on '*Land Surface Modelling, Data Assimilation and the Implications for Predictability*' will be held from 9 to 12 November 2009. The objectives of the workshop are to review the state-of-the-art and new developments in the area of land surface modelling, data assimilation and land surface related predictability, as well as to address future trends.

- www.ecmwf.int/newsevents/meetings/workshops/2009/Land_surface_modelling/

## Changes to the operational forecasting system

DAVID RICHARDSON

### New cycle (Cy35r2)

A new cycle of the ECMWF forecast and analysis system, Cy35r2, was implemented on 10 March. The main changes included in this cycle are:

- Revised snow scheme including a diagnostic liquid water storage and a new density formulation.
- Revised ozone chemistry.
- Active assimilation of IASI humidity channels and consistent use of AIRS and IASI humidity channels.
- Direct 4D-Var assimilation all-sky of microwave imagers.
- Increase of the weight to GPS radio occultation data above 26 km, and use of the data up to 50 km.
- Satellite-related modifications, including activation of version 9 of the radiative transfer software package RTTOV-9 (developed by NWP-SAF) and revised HIRS cloud detection.
- Optimization of the longwave and shortwave radiation schemes.
- Extension the domain of the wave model from 81° to 90° N.
- Use of ERA-interim analyses for the reforecasts used in the EFI and monthly forecast.

More information can be found at:

- www.ecmwf.int/products/data/operational_system/evolution/evolution_2009.html

## Survey of readers

Readers are invited to complete a questionnaire about the *ECMWF Newsletter* by going to:

- www.ecmwf.int/publications/newsletters/

and following the links.

**Please complete the questionnaire by 31 July 2009.**

## Philippe Bougeault leaves ECMWF

DOMINIQUE MARBOUTY

PHILIPPE BOUGEAULT, Head of the Research Department, left ECMWF on 31 March to join Météo-France as its Director of Research.

Philippe joined ECMWF in July 2003 coming from Météo-France where he had been the head of the mesoscale meteorology group for ten years. His speciality was in the parametrization of physical processes and fine-scale modelling. During that period, he fathered the initial development of the Meso-NH community model and managed several field experiments, in particular the PYREX experiment in 1990 and the Mesoscale Alpine Programme (MAP) in 1999 of which he was one of the 'founder' participants.

Philippe has been with ECMWF for six years but has had a strong impact during this limited period of time. Since joining ECMWF, Philippe has reinforced the high level of ECMWF research. Some of the main milestones during his period were the swift assimilation of many new satellite instruments, in particular from METOP, and the noticeable improvement of the Centre's early warning for severe weather. Also it will come as no surprise that, during his mandate, ECMWF has been undergoing a major upgrade of its physics addressing almost every aspect of the physical parametrizations. The result can be seen in the improvement of severe weather prediction and also in some important aspects of NWP such as the major reduction of the model systematic errors. He was also directly involved in the non-hydrostatic project, ensuring a co-operative long-term future of IFS.

One of Philippe's main areas of interest has always been to develop external co-operations and keep a strong link with the academic research community. For example, he has:

- Been very active in the development of co-operative projects such as NEMOVAR and EC-EARTH.
- Contributed to ECMWF's involvement in THORPEX and TIGGE.
- Participated into several scientific advisory boards such as the ESA's Earth Science Advisory Committee, the GEO Science and Technology Committee, the Hadley Centre Science review group, the Met Office Scientific Advisory Committee, and the NCAS Advisory Committee as its chair.

Philippe has been instrumental in maintaining what is one of ECMWF's main strengths – a very close relationship between research and operations. In particular, he was heavily involved in the process of selecting a new supercomputer and in handling projects in common with the Operations Department, such as the observation monitoring and processing.

I am very confident that in his new position Philippe will further contribute to developing strong collaboration not only between Météo-France and ECMWF but also between Météo-France and the European academic community. I take this opportunity to congratulate him on his appointment, although it means that we have lost an outstanding Head of Research, and I wish him all the best in this new challenge.

# RMetS recognises the achievements of Adrian Simmons and Tim Palmer

PHILIPPE BOUGEAULT

THE ROYAL Meteorological Society (RMetS) has announced its awards for 2008. These include awards to two distinguished members of staff at ECMWF: Tim Palmer (Head of Probabilistic Forecasting and Diagnostics) and Adrian Simmons (Co-ordinator for ECMWF Activities in GMES). The following are extracts from the citations for the awards.

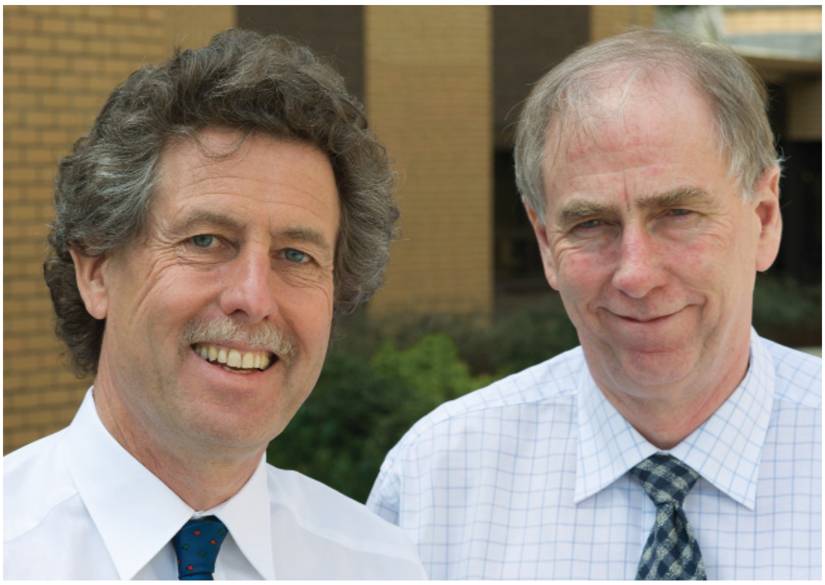
### Symons Gold Medal to Dr Adrian Simmons

*The Symons Gold Medal is awarded biennially for distinguished work in connection with meteorological science. The award for 2008 goes to Dr Adrian Simmons for an exceptionally productive career, almost entirely devoted to the development of the analysis and forecasting systems of ECMWF. He is a leading pioneer in the field of numerical weather prediction (NWP). His research has been prolific and has spanned many aspects of NWP. In addition his research has been fundamental in nature and seminal in its impact. It bears the hallmark of creativity and has opened new vistas for researches in the field.*

### Adrian Gill Prize to Dr Tim Palmer

*The Adrian Gill Prize is awarded annually to a member of the RMetS who has made a significant contribution in the preceding five years to fields that are at the interface between atmospheric science and related disciplines, and who has also been an author of a paper(s) in the Society's journals. The award for 2008 goes to Dr Tim Palmer, who has made many important contributions to the science of medium-range weather forecasting, seasonal forecasting and longer-term climate prediction, having served IPCC on several assessments. His research has advanced not only the basic physics of these subjects, but he has made substantial contributions to the applications of seasonal forecasting to health and agriculture.*

I am delighted that the outstanding contributions of Adrian Simmons and Tim Palmer to the work of ECMWF along with their development of NWP techniques and the underlying science have been recognized.



ECMWF recipients of awards from the Royal Meteorological Society: Tim Palmer (Adrian Gill Prize) and Adrian Simmons (Symons Gold Medal).

# A new Head of Research for ECMWF

DOMINIQUE MARBOUTY

Erland Källén Photo provided by 'Orasis foto/MÅ'.

THE ECMWF Council approved the appointment of Erland Källén as Head of research, following the departure of Philippe Bougeault.

Erland Källén, aged 54, is a Swedish national. He obtained his PhD in 1980 from Stockholm University. From 1979 to 1982 Erland was Education Officer at ECMWF, where he developed a keen interest in operational weather prediction. Then Erland held various academic positions in Sweden and was briefly Head of Research at DMI.

In 1993 Erland became Project Leader for the HIRLAM III project at SMHI. Returning to the academic world, he became full Professor of Dynamic Meteorology in Stockholm in 1997 and has lectured on many aspects of atmospheric sciences since then. In this position he was also responsible for the Department of Meteorology (70 people) for six years from 2000. He has supervised a large number of students, often on research subjects related to operational NWP. In parallel Erland has managed several national projects in climate modelling, initiating for example the Rossby Centre at SMHI. He has also strongly engaged in the IPCC activities.

Erland is a member of a large number of committees in the Swedish academic system, and an active member of the Swedish Academy of Engineering Sciences. Also he is chairing the Mission Advisory Group of the ADM mission of ESA. In addition ECMWF has benefited from Erland's participation in its Scientific Advisory Committee: he was a member for eight years, its vice-chairman for three years and its chairman in 2005.

Erland will start at ECMWF on 6 July. I take this opportunity to congratulate Erland on his appointment and to welcome him to the Centre's management team.

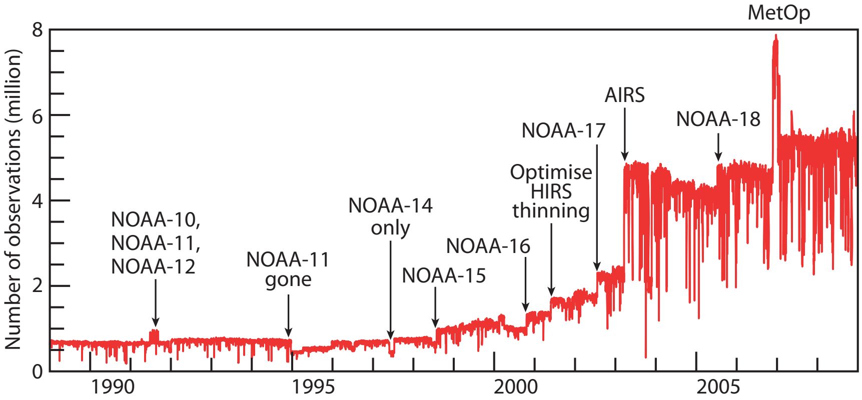
# ERA-Interim for climate monitoring

DICK DEE, PAUL BERRISFORD,
PAUL POLI, MANUEL FUENTES

THE ERA-Interim project has now reached a major milestone after completing 20 years of reanalysis, from 1989 to 2008. The production so far has taken approximately 2.5 years, involved the use of more than $29 \times 10^9$ meteorological observations, and generated 60 terabytes of reanalysis products. Most importantly, ERA-Interim represents the combined expertise and experience of a large number of present and past colleagues at ECMWF and elsewhere.

The ERA-Interim reanalysis will be extended forward in time using the same version (Cy31r2) of the Integrated Forecast System (IFS) to maintain a consistent product quality. The assimilation will use the majority of observations received at ECMWF for operational forecasting, with some exceptions. For example, IASI data from MetOp are not being used, because it would require a major technical upgrade of the assimilation system to do so.

Information about the configuration of the ERA-Interim system and early assessments of the reanalysis product quality can be found in several articles in the *ECMWF Newsletter* (*No. 110*, *No. 111*, *No. 115* and this issue). ERA-Interim daily and monthly averaged products will be updated on MARS on a monthly basis, subject to a two-month delay to allow for careful quality assessment and possible corrections of technical problems with the production. Users from Member States will continue to be able to retrieve all ERA-Interim data from MARS (expver=1, class=ei).

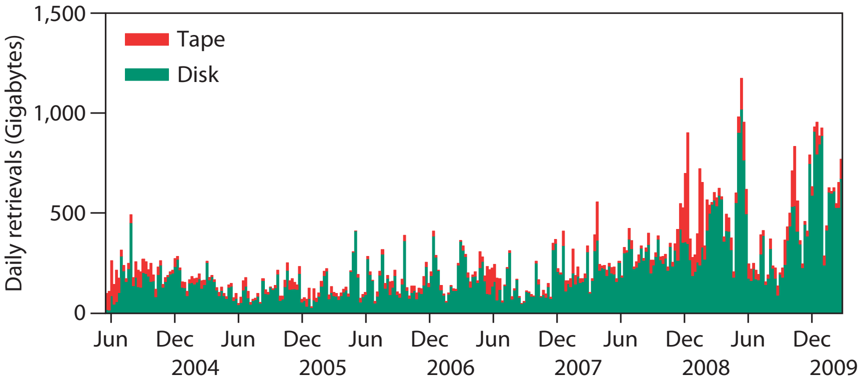



The total number of observations (satellite and conventional) used in the ERA-Interim 12-hourly variational analysis for the period 1989–2008 exceeds $29 \times 10^9$. This is mainly due to a large increase in the availability of satellite observations in the 20-year period.

All other users will be able to download a large subset of the products from the ECMWF Data Server (data.ecmwf.int/data/); the latest data will be available there within one month following the MARS update. For more information and updates on the status of the production please visit the ECMWF reanalysis web pages at

- www.ecmwf.int/research/era.

ECMWF reanalysis data have always served a large number of users. The high demand is well illustrated by the recent MARS usage statistics. On a typical day more than 7,000,000 reanalysis fields are retrieved from a dedicated server on MARS, and this number is growing steadily. In addition, more than 12,000 users have registered on the ECMWF Data Server for public access to ERA-40 data; for ERA-Interim this number is now approaching 1,000. ERA-Interim products are already used extensively at ECMWF for research and diagnostic studies, and for many other purposes such as developing the seasonal forecasting system, and providing climatology for operational verification.

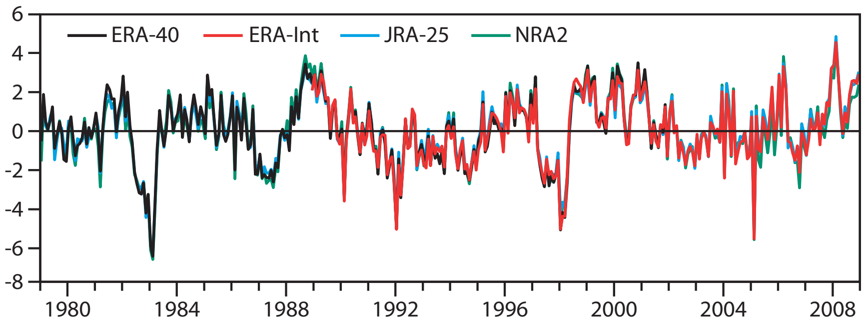



Daily retrievals from the MARS reanalysis server, in Gigabytes. The number of retrievals has been growing steadily.

Users from the academic and wider scientific community increasingly rely on ECMWF reanalysis data for their work, and many have been eagerly awaiting the availability of ERA-Interim products in near-real time.

Due to the rapidly growing interest in climate information, we expect that the demand for high-quality reanalysis products will increase accordingly. The nature of the users and the type of information they demand will evolve as well. ERA-Interim already generates a range of web-based climate monitoring products. These include time series of global and regional mean temperature and precipitation, and standard measures of the large-scale atmospheric circulation. One such measure is the Southern Oscillation Index, which assesses the phase of El Niño/La Niña phenomena.

ERA-Interim will be a test-bed for the development of new monitoring products and data access facilities to better serve the end-users of climate information in government and industry, in support of risk assessment, policy planning and decision making.




Monitoring of climate information using the Southern Oscillation Index which assesses the phase of El Niño/La Niña phenomena. The results are based on monthly averaged data from ERA-40, ERA-Interim, JRA-25, and NRA2. JRA-25 is the Japanese 25-year reanalysis and NRA2 is the NCEP/Department of Energy reanalysis.

# The Call Desk celebrates 15 years of service

HÉLÈNE GARÇON, JANE MILLARD, PETRA BERENDSEN

The Call Desk team: Jane Millard, Hélène Garçon and Petra Berendsen from left to right.

In the late 1980s and early 1990s the ECMWF computer configuration was becoming increasingly advanced in the interaction and interdependency between various machines. This complexity, and the need for a central place to keep track of all incidents, led to the creation of the Call Desk in the Computer Operations Section.

The Call Desk opened its doors and phone lines in March 1994. This was first publicised in *ECMWF Newsletter No. 68* (Winter 1994/1995).

The Call Desk manages incidents through a constant flow of e-mails, entries in the Incident Management System and the continuous communication with relevant support groups within ECMWF. It keeps the ECMWF user community informed via Cosinfo announcements and e-mails about any scheduled work or unscheduled interruption to services. Registration of internal and external users and day-to-day administration of user accounts and requests are, furthermore, an essential part of Call Desk activities.

The Call Desk remains, as was the initial vision, a central place for users to:

- Seek help and information, and report incidents.
- Obtain passwords, non-supercomputer quotas, USB sticks, Actividentity tokens, laptops, mobiles phones, mailing lists, special accounts and specific access to the Centre's various systems.

The Call Desk is proud to celebrate 15 years of service helping our ever expanding user community (registered entities have risen from a couple of hundred in 1995 to over 5,000) and their evolving requirements. We look forward to continuing to contribute to a good service through our daily monitoring, incident tracking and communication with the various groups, as well as providing a friendly place where our visitors and callers always feel welcome and supported.

We would like to thank the various support specialists who assist us in our mission and above all a big thank you to our user community for their patience and ongoing support.

# ECMWF Seminar on 'Diagnosis of Forecasting and Data Assimilation Systems'

ELS KOOIJ-CONNALLY, MARK RODWELL, THOMAS JUNG, CARLA CARDINALI

THE 2009 ECMWF Seminar will run for four days from 7 to 10 September 2009. Invited and ECMWF expert speakers will provide an overview of the diagnosis of forecasting and data assimilation systems.

Powerful and precise diagnostic techniques are required to maintain the present pace of forecast system development. This is partly due to the abundance of new observations of the earth system and growing complexity (and indeed accuracy) of forecasting systems. The seminar will give a pedagogical and wide-ranging overview of diagnostic techniques that lead to a better understanding of the global circulation or aid forecast system development.

The seminar is open to the ECMWF Member States and Co-operating States. Note that:

- The deadline for registration being 14 August 2009.
- There is no registration fee for Member and Co-operating States.
- ECMWF has no financial support available for participants.

Applications from non-Member States can be accepted if places are available following the deadline 14 August for Member State applications. For non-Member States a registration fee is charged. Further information can be obtained by contacting: seminars@ecmwf.int.

The EMS has again made available a Young Scientist Travel Award (YSTA) to support the participation of young scientists at the ECMWF Annual Seminar. This award includes financial support for expenditure on travel. Information about the YSTA can be found at:

- www.emetsoc.org/awards/awards.php.

Further information about the programme of the seminar and how to register is available from:

- www.ecmwf.int/newsevents/seminars

or contact Els Kooij-Connally at: els.kooij@ecmwf.int.


| Presenter | Topic |
|---|---|
| Dominique Marbouty (*ECMWF*) | Welcome |
| Tim Palmer (*ECMWF*) | Introduction |
| Prashant Sardesmukh (*CDC NOAA*) | Global climate system |
| John Methven (*University of Reading*) | Extratropics |
| Duane Waliser (*JPL*) | Tropics |
| Alejandro Bodas-Salcedo (*UK Met Office*) | Forward modelling of A-train observations |
| Dick Dee (*ECMWF*) | ECMWF reanalyses |
| Peter Bauer (*ECMWF*) | Satellite observations |
| Carla Cardinali (*ECMWF*) | Adjoint diagnostics in data assimilation |
| Gérald Desroziers (Météo-France) | Optimality of data assimilation systems |
| Sean Milton (*UK Met Ofice*) | Use of short-range forecasts |
| Mark Rodwell (*ECMWF*) | Diagnosis at ECMWF |
| Robert Pincus (*CIRES*) | Model physics assessment with ensemble data assimilation |
| Nils Wedi (*ECMWF*) | Model numerical core studies |
| David Rind (*NASA GISS*) | Tracer diagnostics |
| Federico Grazzini (*ARPA-SIMC*) | Synoptic perspectives |
| Martin Leutbecher (*ECMWF*) | Ensemble forecasting systems |
| Robert Marsh (*NOC, Southampton*) | Ocean diagnostics |
| Jan Barkmeijer (*KNMI*) | Applications of adjoint techniques |
| Stephen Leroy (*Harvard University*) | Optimal fingerprints of radio occultation data |

# ERA-40 article designated as a 'Current Classic'

DICK DEE, SAKARI UPPALA

AN ARTICLE entitled 'The ERA-40 re-analysis' published in the *Quarterly Journal of the Royal Meteorological Society* (2961–3012, Part B, October 2005) has been designated as a 'Current Classic' in the field of Geoscience. The article was selected for this accolade by ScienceWatch.com which tracks trends and performance in basic research based on the number of citations an article receives from other articles. For more information about the 'Current Classics' go to:

- sciencewatch.com/dr/cc/09-febcc.

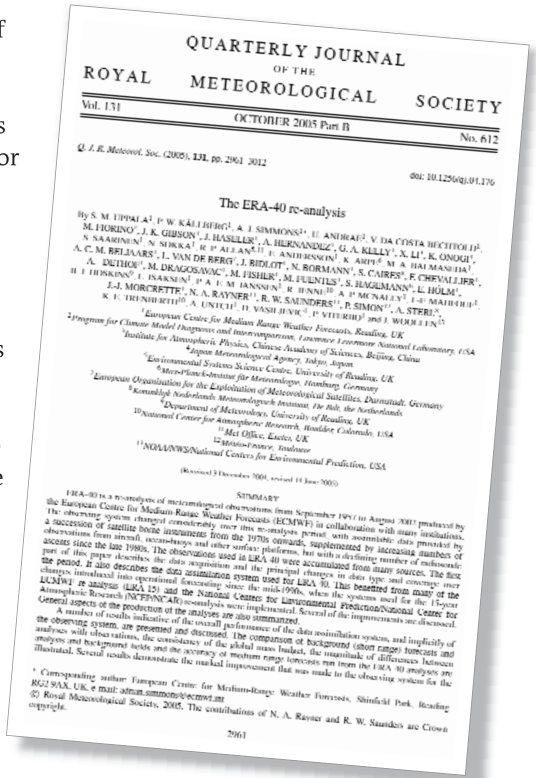
ERA-40 is a reanalysis of meteorological observations from September 1957 to August 2002 produced by ECMWF in collaboration with many institutions. The aim was to reanalyse the record of past observations using a fixed up-to-date data assimilation system. Such reanalyses are more suitable for the study of the long-term variability of the climate than operational analyses. Reanalysis products are used increasingly in many fields that require an observational record of the state of either the atmosphere or its underlying land and ocean surfaces.

Products from ERA-40, and to some extent the earlier reanalysis ERA-15, have been used extensively by Member States and the wider user community. The high number of citations for the article about ERA-40 is a direct indication of the usefulness and quality of the ERA-40 products.

Indeed the positive experience of users has led to innovative and complementary ways to use the products. The reanalysis products are also increasingly important for many core activities at ECMWF, particularly for validating long-term model simulations, helping to develop a seasonal forecasting capability and establishing the climate of EPS forecasts as a basis for constructing forecaster aids (e.g. Extreme Forecast Index).

Sakari Uppala, who was ERA-40 Project Manager at ECMWF before his retirement, has been interviewed by ScienceWatch.com about the ERA-40 article. The interview can be found at:

- sciencewatch.com/dr/erf/2008/08decerf/08decerfUpp/.



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doi: 10.1256/qj.04.176

The ERA-40 re-analysis

SUMMARY

ERA-40 is a re-analysis of meteorological observations from September 1957 to August 2002 produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) in collaboration with many institutions.

The latest reanalysis project at ECMWF is ERA-Interim, which covers the data-rich 20-year period 1989–2008 and will be extended forward in time for several years to come. It is expected that the ERA-Interim products, benefitting from the ERA-40 user experience, will gain even higher attention by the science community.

# Weather forecasting service for the Dronning Maud Land Air Network (DROMLAN)

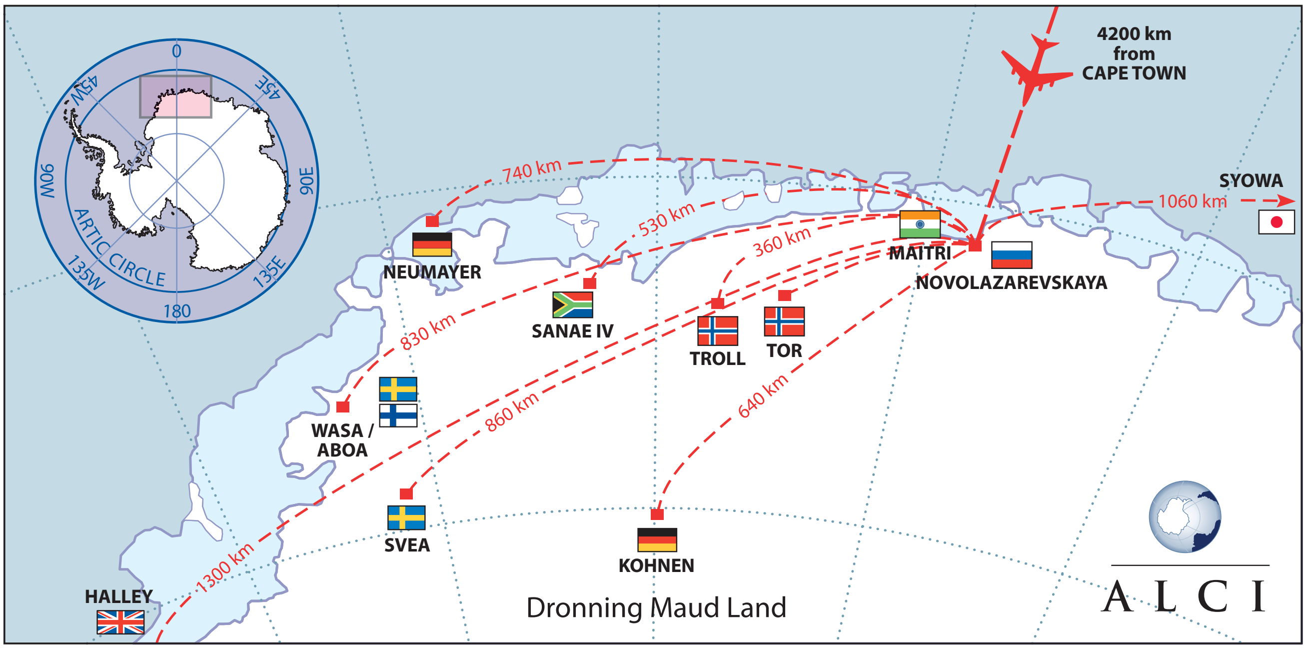
RALF BRAUNER,
DEUTSCHER WETTERDIENST (DWD),
HAMBURG, GERMANY

SINCE 2002 the German Antarctic station Neumayer has offered a detailed and specific weather forecasting service for all activities at Dronning Maud Land. This service is performed in close cooperation between the Alfred-Wegener-Institute for Polar and Marine Research (AWI) and the German Weather Service (DWD). The increasing flight activity within Dronning Maud Land, and especially the intercontinental air link between Cape Town and Novolazarevskaja, has made the forecasting service mandatory.

The aim of the Dronning Maud Land Air Network (DROMLAN) Project is to provide transport to/from and within Dronning Maud Land. The people who prepare weather forecasts for DROMLAN are experienced meteorologists from DWD in Hamburg. They are based at Neumayer Station.

Basler-BT67 (modified old DC3) are used for flights in Antarctic regions.

Neumayer Station has a central position within the Dronning Maud Land due to its good communication facilities. It has the modern infrastructure of a meteorological observatory including a permanent satellite data link (128 kbyte, Intelsat) and a satellite receiving system.




Dronning Maud Land and the various stations run by the DROMLAN national operators. Illustration based on original from Terra Incognita.

The forecasts are based on special model outputs from ECMWF, the US Antarctic Mesoscale Prediction System (AMPS) and the German Global-Model (GME). Model outputs are available twice a day and are received as attachments to e-mails. They are used to cover a forecast period of about one week. The EPSgrams from ECMWF play a key role in preparing the medium- and long-term forecasts.

For short-term forecasts and flight activities the satellite imagery is of great importance. Up to twenty NOAA satellite passes can be obtained. Additionally, all the information transmitted via the Global Telecommunication System (GTS) – including the three-hourly synoptic observations and daily upper-air soundings – is available at any time via the permanent data link. Also measurements from surrounding automatic weather stations not available via the GTS get extracted automatically from the NOAA satellite information.

During the summer season of 2008/09 more than 4,000 forecasts were prepared for field parties, ships, stations and especially aircrafts. It is clear that this service increased the safety of the ambitious projects carried out in Dronning Maud Land. Furthermore, it helps to reduce weather-induced idle time for expensive flight operations.

# Smoke in the air

JOHANNES W. KAISER, OLIVIER BOUCHER, MARIE DOUTRIAUX-BOUCHER, JOHANNES FLEMMING, YVES M. GOVAERTS, JOHN GULLIVER, ANGELIKA HEIL, LUKE JONES, ALESSIO LATTANZIO, JEAN-JACQUES MORCRETTE, MARIA R. PERRONE, MIHA RAZINGER, GARETH ROBERTS, MARTIN G. SCHULTZ, ADRIAN J. SIMMONS, MARTIN SUTTIE, MARTIN J. WOOSTER

SMOKE from forest fires can greatly impact regional air quality and thus human health. The degree of human exposure depends on the fire location, amount of fuel burned, type of fire, and the atmospheric transport of and chemistry in the plume. We have started developing a global fire assimilation system that produces emission estimates for the monitoring and forecasting of fire plumes in the GMES Atmospheric Core Service (GACS), which is developed in the GEMS and MACC projects under the leadership of ECMWF. Note that projects and satellite instruments referred to in this article are briefly described in Box A.

The system currently delivers global fields of observed fire intensity. Figure 1 provides an example that illustrates

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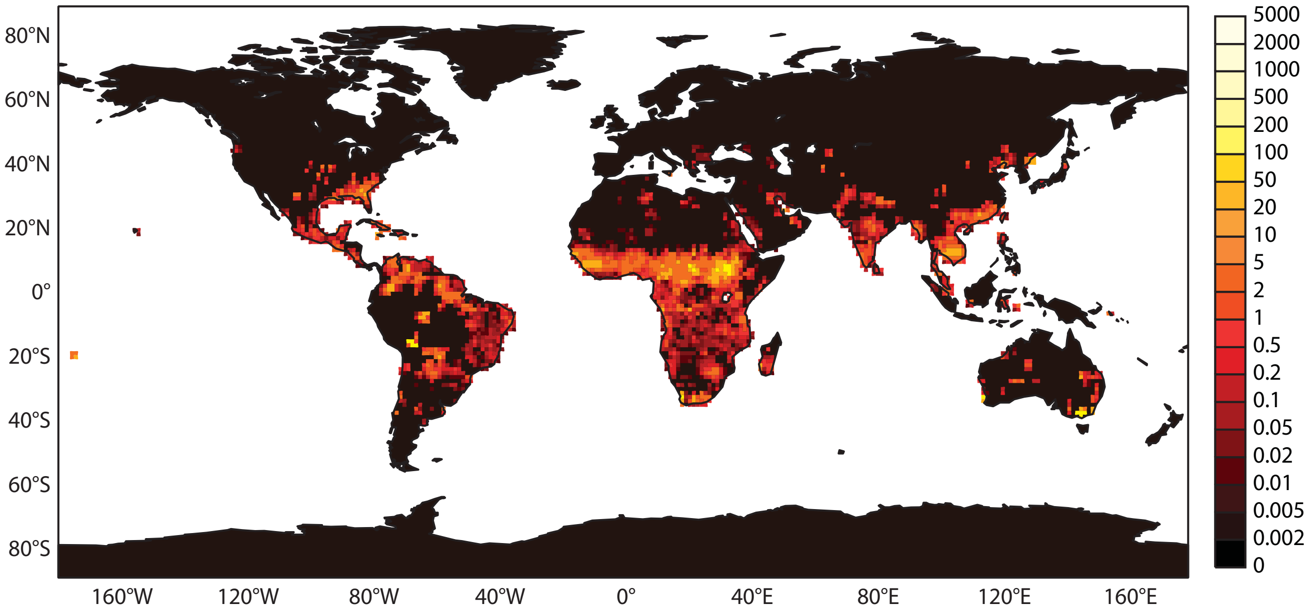


**Figure 1** Daily averaged fire intensity (mW m$^{-2}$, with ~125 km resolution) observed by the two MODIS instruments and SEVIRI on 7 February 2009. Coverage subject to observational limitations illustrated in Figure 2 (http://gems.ecmwf.int/d/products/aer/fire).

the huge range of the global fire intensities. Note that the fire season in Sub-Saharan Africa dominates the global picture. Large fire intensity is also evident in South America, Cambodia and Vietnam. Also note the localized spot of extreme fire intensity in Victoria, in the southeast of Australia, which is associated with the worst bush fires in Australian history in terms of death toll.

Due to the high variability of fires on all time scales from hours to decades, the smoke emissions have to be derived from fire observations. Open fires can be observed from space. The EUMETSAT Land Satellite Application Facility (SAF) in Lisbon, Portugal, has recently started the production of a quantitative fire product from the observations of SEVIRI onboard the geostationary satellite Meteosat-9. It features an unprecedented combination of quantitative accuracy and temporal resolution.

The Greek fires of August 2007 were well observed by SEVIRI because of cloud-free conditions over the whole period. We have used the SEVIRI data to estimate the fire emissions and to simulate the resulting smoke plumes with the GEMS global aerosol model. We found

**Box A**
**Programmes and satellite instruments**

### Programmes

***FREEVAL***. The Fire Radiative Energy Evaluation (FREEVAL) project was funded by EUMETSAT to validate the FRPPIXEL data product from METEOSAT's SEVIRI sensor and explore its potential use in operational systems.

***GACS***. The GMES Atmospheric Core Service (GACS) will provide coherent information on the atmospheric composition at European and global scale in support of European policies and for the benefit of European citizens.

***GEMS***. An EU-funded project to develop comprehensive data analysis and modelling systems for monitoring the global distributions of atmospheric constituents important for climate, air quality and UV radiation, as a baseline for the GACS.

***GMES***. Global Monitoring for Environment and Security (GMES) is a European initiative for the implementation of information services dealing with environment and security.

***MACC***. The EU-funded project Monitoring Atmospheric Composition and Climate (MACC) is the successor to GEMS and the ESA-funded GMES Service Element project PROMOTE.

### Satellite instruments

***MODIS***. This is a key instrument aboard the Terra and Aqua satellites. These instruments view the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands.

***SEVIRI***. This instrument on the Meteosat Second Generation (MSG) satellites delivers daylight images of the weather patterns, plus atmospheric pseudo-soundings and thermal information. It provides image data in visible, near-infrared and infrared channels. The image sampling distance is 3 km at the sub-satellite point for the standard channels and down to 1 km for the so-called High Resolution Visible channel.

good agreement with independent aerosol observations and widespread population exposure to fine mode particulate matter in excess of a World Health Organization (WHO) guideline.

### Satellite-based fire observations

Satellite instruments can either detect the thermal emission during a fire or the burnt area after. The former products are referred to as 'hot spots', 'active fires', 'fire pixels' or 'fire counts', while the latter are known as 'burnt area', 'burnt scar', 'burnt pixel' or 'fire affected area'. Only the hot spot products can be delivered in real time, which is required by the GACS. One example is ESA's ATSR World Fire Atlas (dup.esrin.esa.int/ionia/wfa/).

Hot spot products are typically derived from satellite observations of the thermal emission in a mid-infrared atmospheric window channel near 4 μm wavelength, where fires produce a strong signal with radiance increases of several orders of magnitude. The intensity of fires varies greatly, which is partly due to fires being a sub-pixel size process. Traditional hot spot products from polar orbiting imagers can estimate the likelihood of a fire being present in each pixel, but they are unable to quantify the fire intensity. A quantitative fire product, WF_ABBA, has been available since the 1990s from the GOES satellites; it estimates fire temperature and burning sub-pixel area with a resolution of about 4 km at the sub-satellite point.

Another quantitative hot spot product is available from the two MODIS instruments aboard the Terra and Aqua satellites, the design of which has taken requirements for quantitative fire observations into account. The fire products generated by NASA and NOAA contain a Fire Radiative Power (FRP) estimate that quantifies the thermal radiation emitted by the fires in units of megawatts (MW) with a resolution of about 1 km at the sub-satellite point. FRP is roughly proportional to the chemical energy released by the fires, and thus also to the biomass combustion and pollutant emission rates. Therefore, FRP is considered the most appropriate fire observation product for emission estimation.

The main shortcoming of the MODIS observations is that the polar orbits of the satellites limit the sampling frequency. The potential for fire observations is also reduced by the presence of clouds. Figure 2a illustrates the observation return periods of potential fire observations that have actually been achieved during a given 24-hour period. Water, ice, cloud and snow pixels are not processed. The satellite orbits induce stripey patterns (e.g. over the Sub-Saharan region) and persistent cloud cover inhibits observations in several regions. Otherwise there is coverage with indicative return periods typically between 4 and 12 hours.

In March 2008 the EUMETSAT Land SAF started real-time production of a newly developed FRP product generated from SEVIRI observations. This product maintains SEVIRI's return (sampling) period of 15 minutes. It is therefore capable of resolving the diurnal cycle of open fires in Africa and Southern Europe with unprecedented accuracy. The high sampling frequency also helps to take advantage of brief cloud-free spells for fire observations in mostly cloudy regions.

Figure 2b illustrates the return periods of potential observations of fires for SEVIRI. The FRP product is limited to the geographical disk visible from Meteosat-9. But, within this disk, it covers higher latitudes than the MODIS fire products since snow/ice pixels are being processed. It is apparent, however, that the observational capabilities of SEVIRI are affected by the same cloud pattern as in the MODIS data. For example, the ITCZ over Central Africa is particularly persistent in this respect. Nevertheless return periods of around 30 minutes in the SEVIRI disk constitute a major improvement over those of the MODIS instruments.

### Smoke from the Greek fires in August 2007

The EUMETSAT project FREEVAL and GEMS have combined SEVIRI FRP data with the global atmospheric aerosol model developed by GEMS to test how accurately the combined system can simulate smoke plumes. The catastrophic Greek fires in August 2007 were selected as a test case.

The total FRP observed over Greece during the huge fire event in August 2007 is shown in Figure 3. It exhibits strong diurnal and day-to-day variations with the maximum fire intensity occurring on the afternoon of 25 August around 15:45 local time. The fire behaviour of burning continuously through the night is typical for large fire events in middle and high latitudes, while tropical fires mostly extinguish during night-time. The plot highlights the high temporal resolution of the SEVIRI data.

Smoke aerosols are represented as black carbon and organic matter in the GEMS model. The emission coefficient relating FRP ($W\,m^{-2}$) to the total aerosol emission rate ($kg\,s^{-1}\,m^{-2}$) has been taken from a previous study of FRP and aerosol optical depth (AOD) observed by MODIS. The partitioning of the aerosol species is prescribed according to the Global Fire Emissions Database (GFED). Thus the smoke aerosol fluxes for the entire fire episode have been calculated from the SEVIRI data with a spatial resolution of ~25 km (T799) and a temporal resolution of 1 hour.

The global GEMS products are generally produced at 125-km (T159) resolution. For this study we have operated the model with the higher resolution of T799 because it is more typical for present-day regional air quality models, which are the primary tool for forecasting European population health impacts. The atmospheric simulation was set up in a 'cycling' mode, in which the meteorological fields are calculated in a series of consecutive 12-hour forecasts that are initialised from the operational analysis. In contrast the aerosol fields are solely governed by the model parametrization and the surface flux input. The SEVIRI-derived fluxes were injected into the lowest model level.

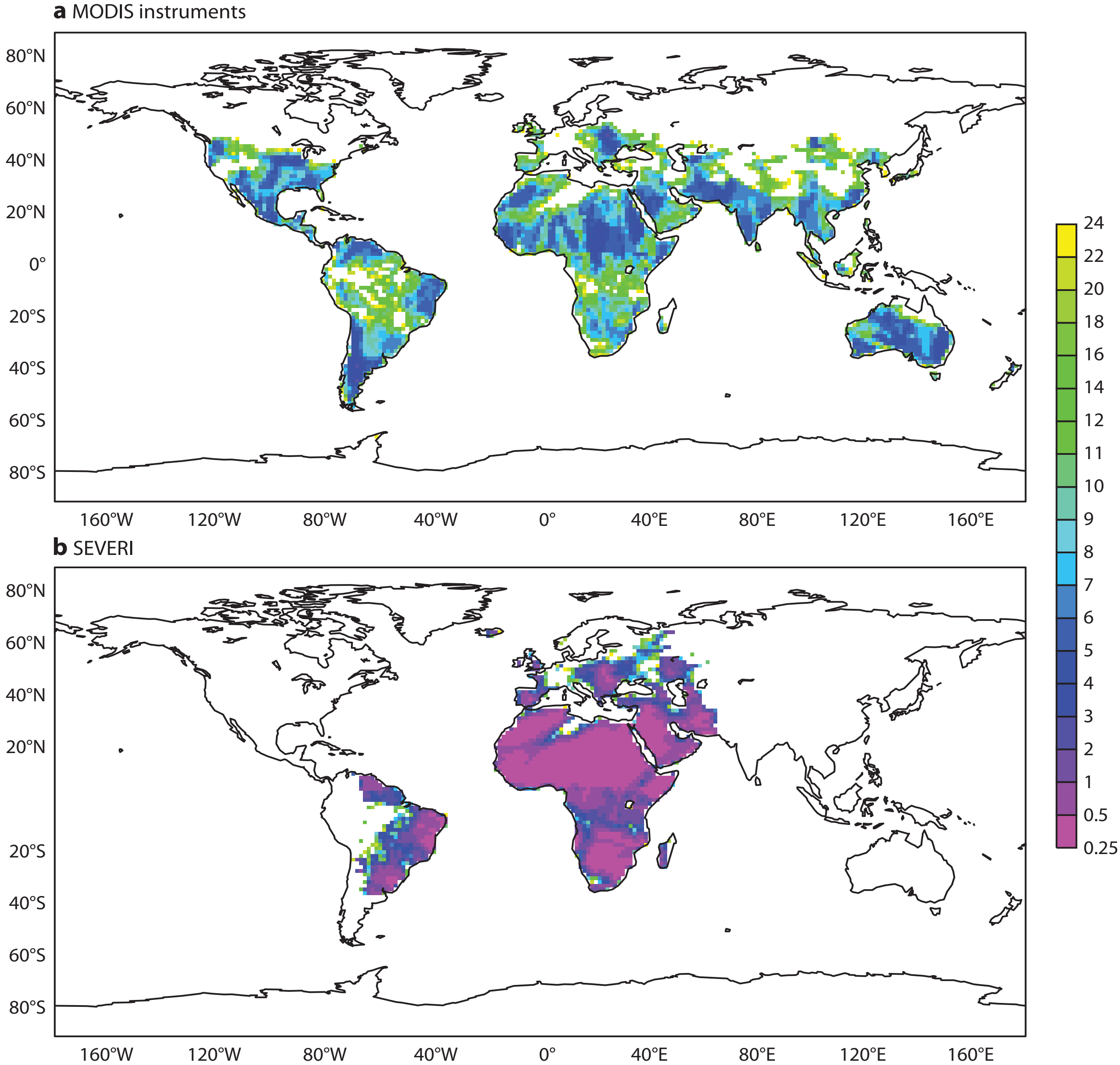


**Figure 2** Indicative return periods (hours) for observations with the potential to detect a fire by (a) the two MODIS instruments and (b) SEVIRI on 7 February 2009.

Figure 4a shows the observed FRP at 25-km resolution and the AOD of the modelled smoke aerosols at 12 UTC on 25 August. For comparison, Figure 4b shows a visible composite of concurrent MODIS observations that is overlaid with red markers for MODIS hot spot fire detections. SEVIRI and MODIS agree well on the locations of the fires.

Figure 4b shows that the smoke is blown in a southwesterly direction over the Mediterranean Sea to Northern Africa. The modelled smoke plumes in Figure 4a reproduce the main observed features. In particular, the observations show that the plume is structured in a series of 'pulses' originating from the daily fire intensity maxima. Clearly visible just off the Peloponnesian coast is the pulse emitted by the fire earlier in the day. The pulse emitted the day before just reaches Libya; the landfall is well reproduced while the timing is slightly shifted. Also it is apparent that the widening of the plume over the central Mediterranean Sea is well represented.

SEVIRI also detected strong fires in Algeria on 28–30 August 2007. We have simulated the transport of the emitted smoke plumes, mixed with a larger desert dust plume, northwards over the Mediterranean. Ground-based AOD observations in Lecce, Southern Italy, confirm the plume simulation quantitatively.

Simulating the separation of the plume into pulses from the Greek fires obviously depends on the high temporal resolution and quantitative nature of the SEVIRI FRP product. Also the good representation of the plume transport is a testament to the accuracy of tropospheric winds produced by ECMWF's Integrated

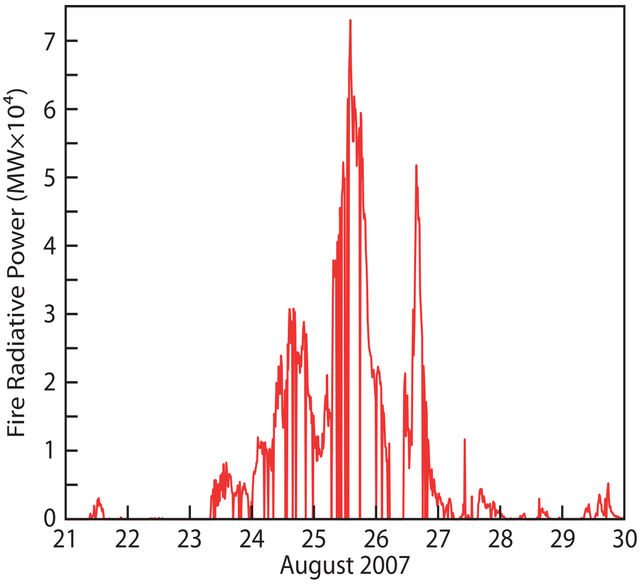


**Figure 3** Total Fire Radiative Power (FRP) observed over Greece by SEVIRI. Date ticks at 00 UTC, 2 a.m. local time. The results are derived from a test version of the operational Land SAF product.

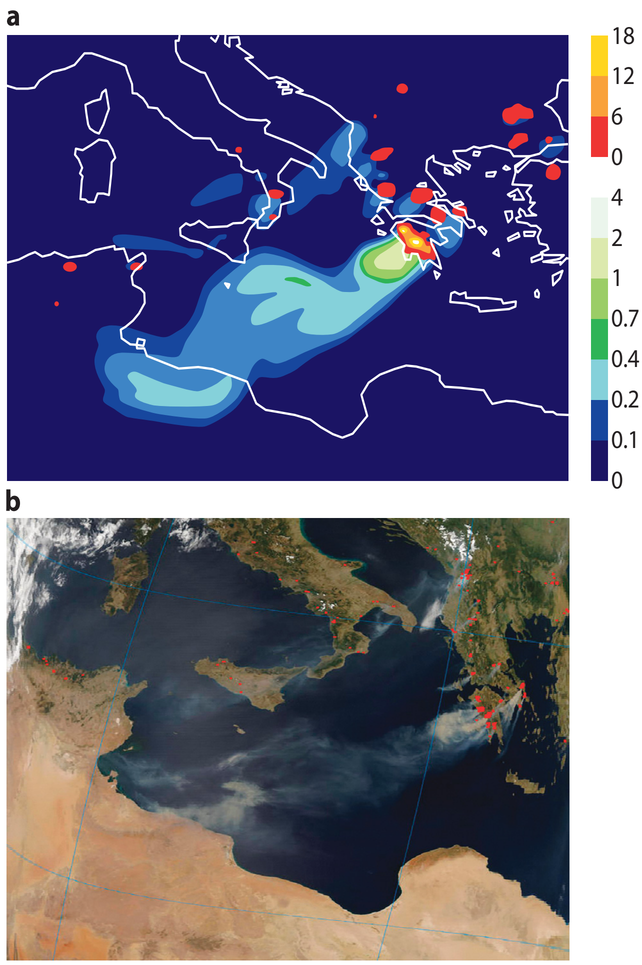


**Figure 4** (a) FRP observed by SEVIRI (reddish, W $m^{-2}$, with ~25 km resolution) and modelled smoke column optical depth (blueish) compared to (b) observed hot spots (red) and true colour image by MODIS aboard Aqua at 1205 UTC on 25 August 2007 (http://rapidfire.sci.gsfc.nasa.gov).

Forecast System (IFS). The remaining discrepancies are primarily attributed to shortcomings of our approach in the very active research fields dealing with plume rise and emission factors that scale FRP to the individual species fluxes, depending on fuel type and meteorological conditions.

In order to relate the plume simulations directly to regional air quality and its impact on human health, we have calculated the respirable fine mode (i.e. PM2.5) concentration in the smoke by assuming that two thirds of the smoke is of type PM2.5, which is a conservative estimate. An example of the resulting surface concentrations is plotted in Figure 5.

The World Health Organization (WHO) has determined an air quality guideline of the PM2.5 concentration not exceeding 25 µg $m^{-3}$ for any 24-hour average. A comparison of our simulation with a population density map indicates that more than 40 million people were exposed to smoke PM2.5 concentrations exceeding the WHO guideline due to the large fires in Greece and Algeria and smaller fires in neighboring countries. It is recognized, however, that the injection of all fire emissions into the lowest model level may introduce some overestimation. On the other hand, the exposure to PM2.5 from other sources, such as traffic, also needs to be taken into account. While this case study highlights the potential of ingesting SEVIRI FRP products into regional air quality models, extensive validation is needed before such a system is used for epidemiological studies. Such studies are use to quantify the toxic potentials of the different chemical component of air pollution.

## Development of a Global Fire Assimilation System

Based on the success of the case study concerning the Greek fires, GEMS has started to implement a fire assimilation system at ECMWF that merges FRP observations from SEVIRI and other instruments to achieve global coverage. It provides real-time estimates of pollutant fluxes from fires that are ultimately intended for use in all global atmospheric composition and regional air quality systems in the GACS.

While SEVIRI was able to observe the diurnal variability of the Greek fires directly, cloud cover may generally get in the way. Outside the SEVIRI disk, the MODIS instruments provide global coverage, albeit with large data gaps (see Figure 2). Since the operation of the GACS will require continuous global flux input that resolves diurnal variations, complementary observations from several satellite instruments must be merged. Also the remaining observational gaps must be filled by data assimilation with a numerical model of the fire intensity.

As a first development step, the FRP products of SEVIRI and MODIS are acquired and pre-processed for use in a dedicated fire assimilation system. We obtain the SEVIRI FRP pixel product with a time lag of 30 minutes via EUMETCast and the MODIS fire products with a time lag of 3–4 hours by ftp from NOAA. The way in which

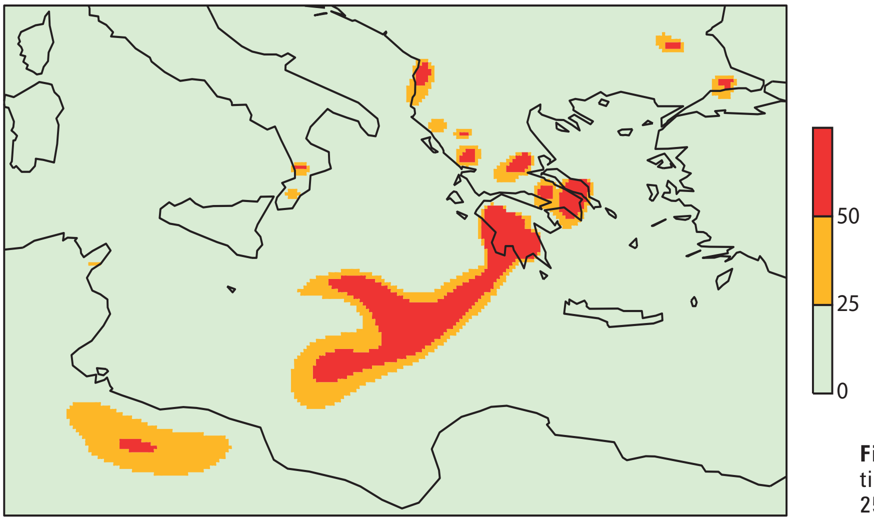


**Figure 5** Simulated surface-level concentration of fine mode aerosol ($\mu$g m$^{-3}$) at 12 UTC on 25 August 2007.

the Fire Radiative Power (FRP) products are merged to derive the distribution of the fire intensity on a global grid for a given time period is described in Box B.

The observations are currently merged to generate daily observed FRP maps with T159 resolution that are published on the GEMS web site, see Figure 1 for an example. The daily observed FRP maps are already used to calculate carbon monoxide emission fluxes. Based on these fluxes, the GEMS global reactive gas system has forecast fire plumes in support of the POLARCAT campaign that was part of the International Polar Year.

## Outlook

In the future, the global fire assimilation system will be implemented to provide hourly fire emission estimates of the various smoke constituents, based on the observations by an increasing number of satellite instruments. A spatial resolution of 10 km is planned to meet the requirements of regional air quality modelling. To achieve this, the work on fires will be intensified in a dedicated subproject in the GEMS follow-up project MACC.

Our study of population exposure to fine mode particulate matter from smoke demonstrates the potential for retrospective assessments, including epidemiological studies. In view of the established accuracy of atmospheric wind forecasts, we conclude that the new SEVIRI FRP product can, and will, be used for air quality forecasts, too. It will thus contribute to emergency preparedness in relation to hospital admissions and preventive medication in Europe and Africa.

In addition to its local and regional effects on human health, biomass burning is a significant source for the global distributions of atmospheric black carbon, organic matter, sulphate aerosols, carbon monoxide and dioxide, nitrogen oxides and other species. Therefore biomass burning needs to be accurately observed and modelled for the quantitative mapping of long-range transport of air pollutants and the carbon cycle.

Finally, the interactions of fires with weather are manifold: Weather influences fires with wind and precipitation being major factors in the development and

**Box B**

**Converting FRP satellite products to global gridded fields**

We merge Fire Radiative Power (FRP) products from several satellite-based instruments to derive the distribution of the fire intensity on a global grid for a given time period (e.g. for one day).

A gridded field of FRP is generated from each individual observation product by averaging the observed FRP values [W m$^{-2}$] of all cloud-free land pixels in each grid cell. Additionally, the observed pixel sizes are summed in another field. This field of 'observed area' provides quantitative information on the accuracy of the corresponding FRP field. Several FRP fields can subsequently be merged consistently in space and time by interpreting the observed area as inverse variance of the FRP error. Quasi-global coverage can be achieved by merging observation fields from sufficiently many complementary instruments and a sufficiently long period of time.

The observed area fields are also calculated for the merged FRP fields. The ratio of a grid cell size to its merged observation area indicates the observation return period. An example is shown in Figure 2. Note that the so-called butterfly effect of the MODIS observation geometry leads to duplicate observations along the edges of its swath and an arguably spurious decrease in the calculated return periods.

Our approach is unique in so far as it avoids ad-hoc assumptions on the diurnal cycle or on the burning duration of the fires by also processing no-fire (FRP = 0) observations. Their inclusion will also enable an assimilation system to remove a fire once its extinction is observed. It requires the processing of large volumes of satellite products, though currently about 12 Gigabyte per day.

propagation of wildfires. Vice versa, fires influence the weather as the smoke aerosol particles efficiently absorb solar radiation and act as cloud condensation nuclei. In extreme cases, fires have been observed to generate so-called pyroconvection that may even penetrate the tropopause. Proper description of these effects has a potential for improving future numerical weather predictions and, with the help of the new global fire products, MACC will be able to quantify all these effects more accurately.

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# Parametrization of convective gusts

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GUSTS are defined as wind extremes and constitute an important forecast parameter in particular for air, ship and road traffic guidance, and warnings concerning environmental damage. The latter is related to the force the wind exerts on an obstacle which is proportional to the square of the wind speed. Therefore it is not only necessary to know the mean wind speed, in general the near-surface 10-metre wind speed is used as the relevant quantity, but also the wind extremes.

Until recently the gust formulation has been based on an assessment of the turbulent gustiness in the boundary layer. However, this takes no account of gustiness associated with convective situations. A new formulation has been developed which overcomes this limitation.

### Representation of gusts

Practically, gusts are defined as extreme winds observed by anemometer. A 3-second running average is applied to the data. The reporting practice is such that gusts are reported as extremes over the preceding 3 or 6 hours. Until IFS cycle 33r1 (Cy33r1) the ECMWF model wind gusts have been parametrized as the sum of the instantaneous 10-metre wind speed and a turbulent gustiness depending on the static stability of the boundary layer:

$$U_{10\ \mathrm{gust}} = U_{10} + 7.71\,u_*[1 + f(z/L)]$$

where $u_*$ is the friction velocity, itself a function of the 10-metre wind speed, $z$ is the height, and $L$ is the Monin-Obukhov length-scale. This is an empirical relation based on observed turbulence spectra. Post-processing is applied to the model data in accordance with the reporting practice.

This formulation has proven quite successful when compared to standard SYNOP, METAR and Buoy reports. However, it cannot represent gusts that are generated in deep convective situations either through organized downdraughts in a sheared environment or evaporatively driven downdraughts. Following reports from Deutsche Wetterdienst (DWD) and other meteorological centres about the underestimation of wind gusts over land, the introduction of a convective contribution to the wind gusts was put forward for implementation in Cy35r1 (30 September 2008). Indeed, this seemed feasible as since Cy32r3 (7 November 2007) the model deep convection has a reasonably smooth spatial structure and a decent diurnal cycle in the extra-tropics.

The convective gusts are simply estimated as proportional to the low-level wind shear:

$$U_{10\ \mathrm{gust,\ conv}} = \alpha \max\,(0,\ U_{850} - U_{950})$$

with $\alpha = 0.6$ a tunable 'mixing' parameter and $U_{850} - U_{950}$

the difference between the 850 hPa and 950 hPa wind speeds, representing the low-level wind shear. The total gustiness is simply given as the sum of the turbulent gustiness and the convective gustiness, the latter being only computed in regions where deep convection is active as identified by the model's convection scheme. This formulation is close to the forecasters' practice which is to estimate in extreme conditions the near-surface gusts from the 850 hPa wind speed. It also has the advantage that its contribution is only significant in situations with strong wind shear as, for example, in frontal systems and long-lived organized mesoscale convective systems. We also experimented with other parametrizations of convective gusts (depending, for example, on the downdraught vertical velocity close to the surface to represent outflow gustiness in squall-lines), but the spatial structure and amplitude produced by these formulations were unsatisfactory.

### A summer and wintertime case

The impact of the convective gust parametrization is best illustrated by case studies such as that illustrated in Figure 1. Figure 1a shows the infrared satellite signature of an intense synoptic system at 18 UTC on 22 February 2008 over the Baltic Sea that produced heavy gusts of up to 35 m s$^{-1}$ between 18 and 21 UTC within a narrow cold frontal band over Denmark, North Germany and the Baltic coast as assessed from available SYNOP and METAR reports (Figure 1b). This case was brought to our attention by the Deutsche Wetterdienst as the operational 21-hour gust forecast (Figure 1c) generally reproduced the observations but underestimated by up to 10 m s$^{-1}$ the maxima over land close to the Baltic coast and over Denmark. However, Figure 1d shows that the diagnostic convective gust parametrization is able to produce additional gustiness of around 5–8 m s$^{-1}$ in the desired regions, namely mainly over land along the frontal system, and to the rear of the cyclone over sea.

In Figure 2 a recent case of continental summertime convection is illustrated. Football fans might still remember this day as it was actually this convective event that led to the interruption of the transmission of the Euro 2008 match on 25 June between Turkey and Germany because of thunderstorms in Vienna. The

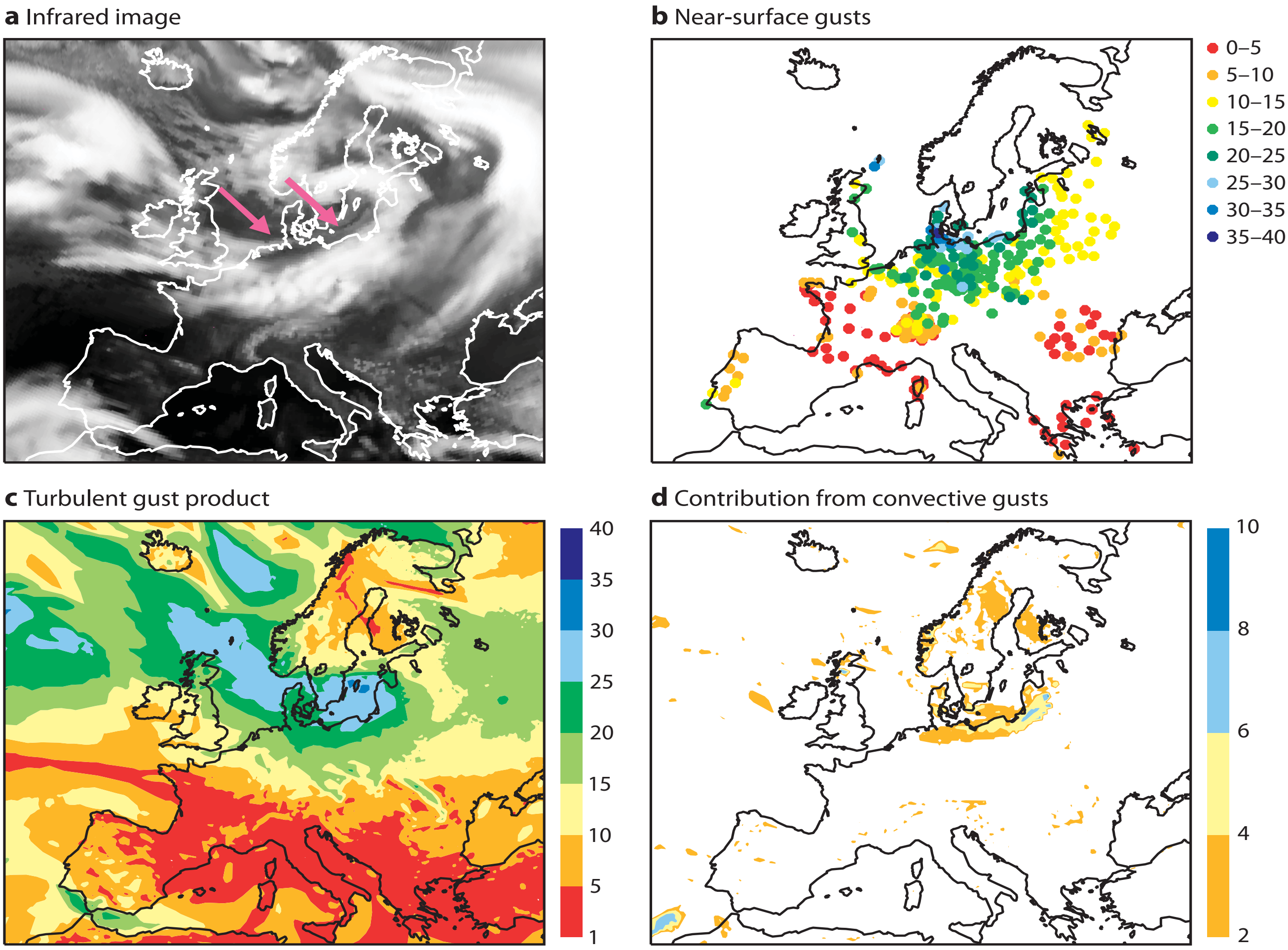



**Figure 1** (a) ECMWF forecast infrared satellite image for 18 UTC on 22 February 2008 with the gust front marked by the arrows, (b) near-surface wind gusts (m s$^{-1}$) for 21 UTC on 22 February 2008 from SYNOP and METAR reports, (c) 21-hour operational forecast with Cy33r1 using the 'turbulent' gust product, and (d) the additional contribution from the convective gusts. A different colour scale is used in (d) compared to (b) and (c). Note that the reporting practice, including the minimum wind speed to be considered as a gust, varies widely between countries.

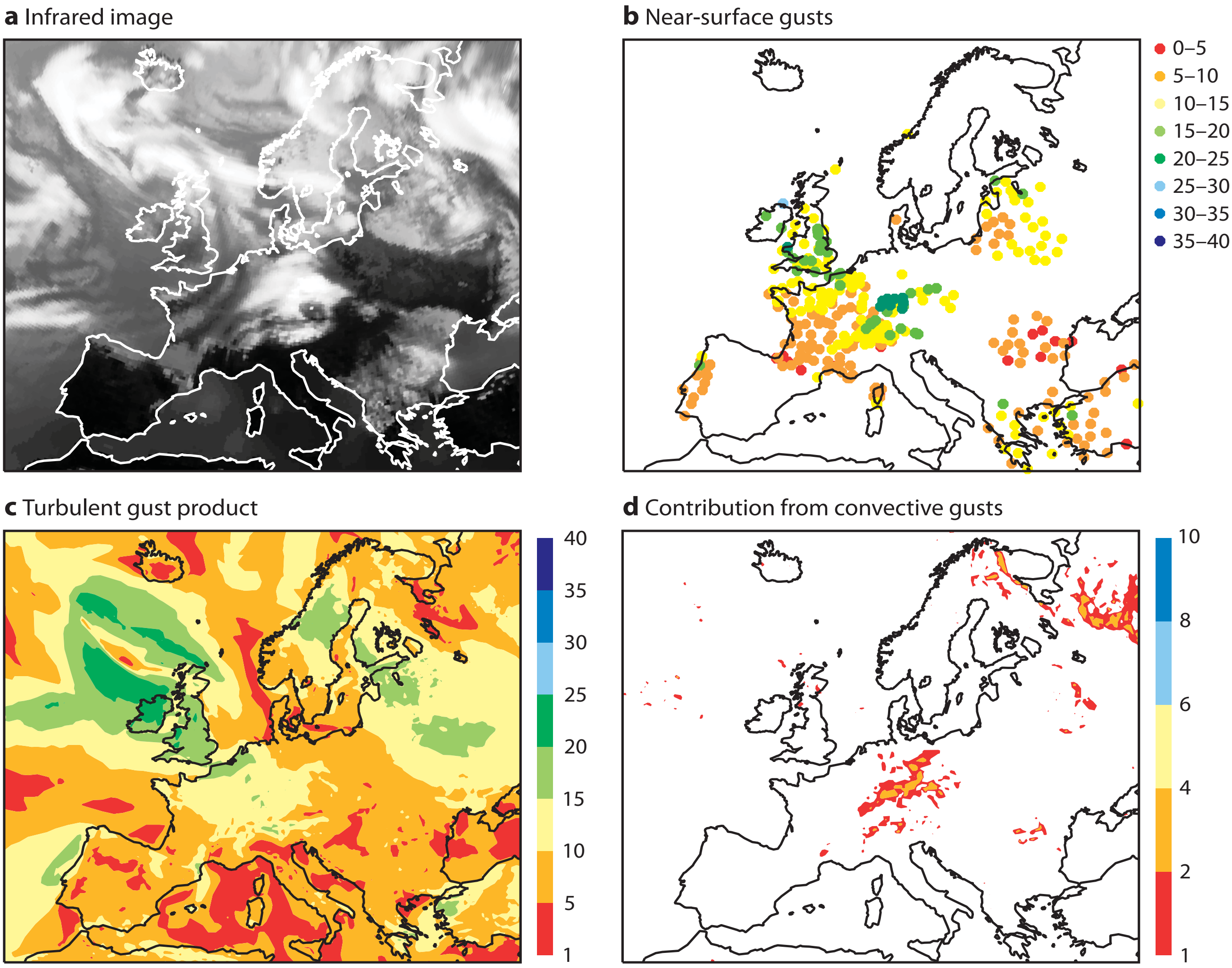



**Figure 2** Same as Figure 1, but with the satellite image for 12 UTC on 25 June 2008, and the gusts observed and modelled between 12 and 15 UTC.

satellite image for 12 UTC on 25 June (Figure 2a) indicates an extended mesoscale convective system over Central Europe and deep convection over parts of Russia. Observations for Central Europe (Figure 2b) reveal wind gusts of 20–25 m s$^{-1}$ between 12 and 15 UTC in the vicinity of the convective system. The operational forecast from 00 UTC on 25 June (Figure 2c) was able to produce maximum winds approximately in the right location, but underestimated the maxima by about 5–10 m s$^{-1}$. The convective gust parametrization (Figure 2d) is able to locally increase wind speeds by roughly 4 m s$^{-1}$ in the convective areas.

### Time evolution

The north of the Iberian peninsula and the south of France were hit by an intense cyclone on 24 January 2009, during which record wind speeds of 191 km h$^{-1}$ (~53 m s$^{-1}$, Galicia) and 184 km h$^{-1}$ (~51 m s$^{-1}$, Perpignan) have been registered. We were lucky to obtain half-hourly observations of mean winds and gusts from our colleagues Jean-Luc Attié and Pierre Durand from Laboratoire d'Aérologie/Université Paul Sabatier Toulouse who maintain a meteorological station on the roof of a building: (http://ufrpca-phy.ups-tlse.fr/meteo/). The wind measurements where derived from 35 kHz sonic anemometer data, with the anemometer being at an absolute height of around 25 metres above ground.

In Figure 3 we compare the observed evolution of the mean wind and wind gusts for 24 January 2009 to the 3-hourly model output for the instantaneous wind, and the model wind gusts from the operational deterministic forecast from 12 UTC on 23 January 2009 using Cy35r1. There is a very good agreement between the forecast and the observations both in terms of time evolution and magnitude of the mean wind speeds and gustiness, with the observed gusts attaining speeds of 100–144 km h$^{-1}$ (~28–40 m s$^{-1}$) between 06 and 18 UTC, whereas the model gusts attain speeds of around 120 km h$^{-1}$ (~33 m s$^{-1}$). Note that the mean wind speed is considerably lower than the gusts during that period with values of around 45 km h$^{-1}$ (~12 m s$^{-1}$) in the observations and 50 km h$^{-1}$ (~14 m s$^{-1}$) in the model. We have also displayed the convective contribution to the forecast gusts. The convective contribution is moderate but significant before the onset of the main storm, and overall leads to a better fit to the observations.

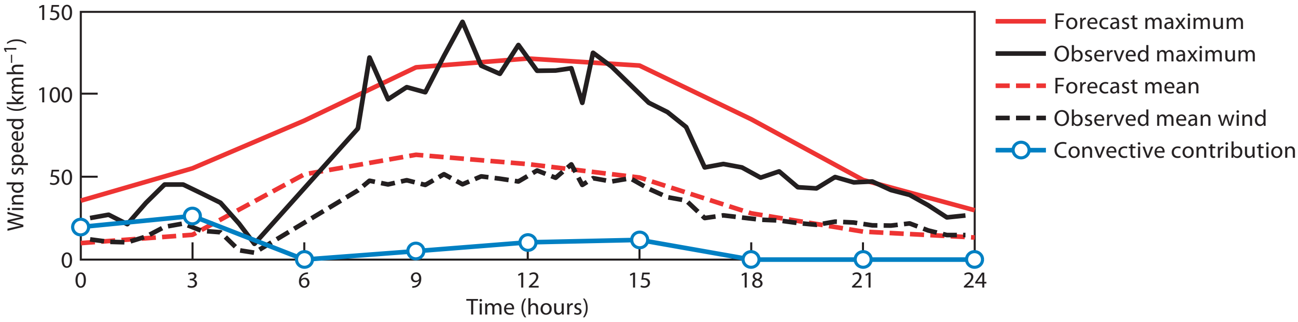



**Figure 3** Observed mean wind speed (dashed black line) and maximum wind speed (solid black line) for 24 January 2009 at a meteorological station at Toulouse University, France at 43.82°N/1.2°E (courtesy Jean-Luc Attié and Pierre Durand), together with corresponding 3-hourly forecast values (red lines) from the operational deterministic forecast from 12 UTC on 23 January. The blue line denotes the convective contribution to the gusts.

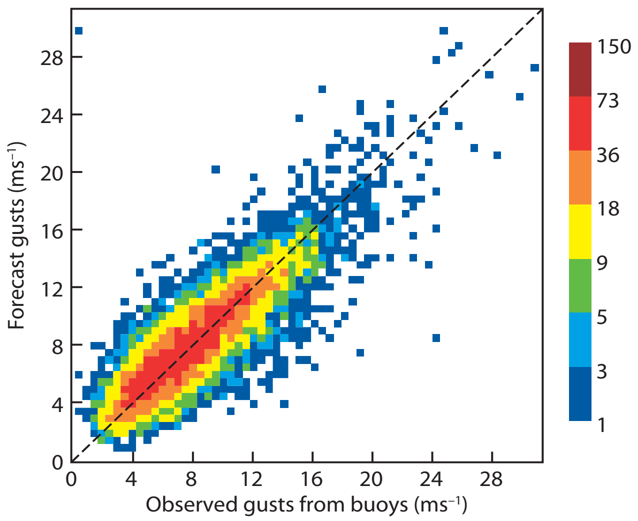



**Figure 4** Scatter diagram of 24-hour forecast wind gusts (m $s^{-1}$) over sea obtained from pre-operational test runs with Cy35r1 versus buoy observations for the period July to August 2008. Colours denote data entries in each bin; the total number of observations is 8251.

## Concluding remarks

The very simple convective addition to the model gusts is able to enhance the gustiness in convective frontal situations and when mesoscale organized convection with shear is present. This is desirable over land where use of only the turbulent gust formulation prior to Cy35r1 probably underestimates the extremes. We think it is important to represent an estimation of these extremes if possible, as these extremes produce the most (or all) damage. The danger of such a parametrization is, however, that it might introduce a bias in the representation of gusts. This is, however, not the case as is shown in Figure 4, where the new model wind gusts (turbulent + convective) from 24-hour forecasts with Cy35r1 have been evaluated against all available buoy observations for the period July to August 2008. The rms error is just below 2 m $s^{-1}$ and is therefore slightly better than for the previous gust product (turbulent gust only), in spite of a bias that is slightly increased from near zero in the previous product to a value of 0.05 m $s^{-1}$. Remaining errors in the ECMWF gust product, such as errors in the diurnal cycle or specific errors over land, are likely due to forecast errors in the mean 10-metre wind.

The convective contribution was added to the wind gusts in post-processing with the implementation of Cy35r1 on 30 September 2008.

# Solar biases in the TRMM microwave imager (TMI)

ALAN GEER

ECMWF assimilates observations sensitive to atmospheric moisture, cloud and rain from a number of microwave instruments including TMI (TRMM Microwave Imager), which was launched in 1997. Data from TMI has been assimilated at ECMWF since 2007. While the majority of these instruments have a steady calibration, monitoring over the past year has shown a 42-day cycle in the bias of TMI. This is not corrected by variational bias correction, and the bias turns out to be due to changes in the solar heating of the instrument through the satellite's orbit. Here we discuss the measures that have been taken at ECMWF to deal with this problem.

## Analysing the problem

Figure 1a shows that the bias in the brightness temperature from TMI has a peak-to-peak variation of about 3 K, which is significantly greater than the changes seen in other microwave imagers that we assimilate, such as Special Sensor Microwave Imager (SSM/I, Figure 1b). While the TMI bias does not appear to have affected the quality of the ECMWF forecasts, it will be significant for users of TMI's long observational record.

TMI flies on the Tropical Rainfall Measuring Mission (TRMM), a satellite with a 35° inclined orbit designed to restrict sampling to the tropics and subtropics. It

Alan Geer's work at ECMWF is funded by the EUMETSAT fellowship programme.

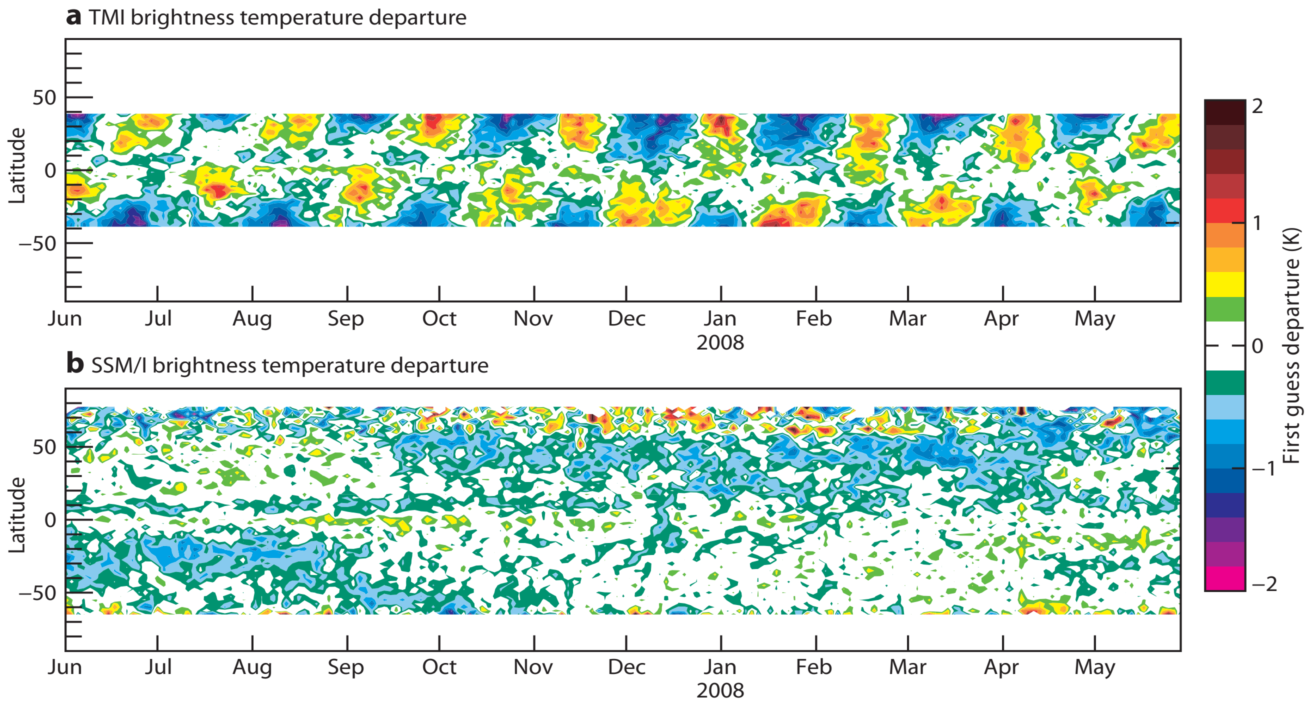



**Figure 1** Zonal mean first guess departures (observation minus ECMWF first guess) of brightness temperature in two-day bins from June 2007 to May 2008 for (a) TMI and (b) SSM/I. TMI has a clear periodic variation that is not seen in the SSM/I observations.

samples the entire daily cycle over the course of 42 days. The cycle in the ECMWF departures was obviously linked to this, and when plotted against local solar time, the bias had a clear diurnal cycle (Figure 2). Could this indicate a diurnal bias in the ECMWF model? The other microwave imagers we assimilate, SSM/I and Advanced Microwave Sounder for EOS (AMSR-E), are in polar orbits and have roughly fixed local solar times, which allow us to check parts of the diurnal cycle. There are in fact no large diurnal variations in the SSM/I and AMSR-E observations (Figure 2), which suggests the ECMWF model has no diurnally varying errors that would be significant here.

Early on in the TMI mission, it was found that the instrument's main reflector was not perfectly reflective. This means that the instrument measures a combination of earth emission and the temperature of the reflector. This problem was discovered during a number of 'deep space' manoeuvres, which rotate the whole satellite so that the instrument observes space rather than the earth.

The cosmic microwave background radiation can be used as a calibration source, since it has been accurately determined to 2.7 K by astronomical missions like COBE (Cosmic Background Explorer). The temperature of the TMI reflector is not measured on the spacecraft itself, and though the reflector was intended to be perfect, it is thought that its coating flaked off once in space, leaving a graphite under-surface. Based on the deep space manoeuvre and on intercalibration with SSM/I, a team led by Frank Wentz estimated the TMI reflector's properties. Their results suggested that about 4% of the measured signal came from the reflector, rather than the earth, and that the reflector's temperature was about 295 K. The data providers at NASA Goddard then made a correction based on these measurements and so the observations that ECMWF assimilates should in theory be free from this problem. However, the diurnal variations in ECMWF departures (Figure 2) suggested otherwise.

Satellites in low earth orbit experience large temperature variations, passing into and out of the earth's

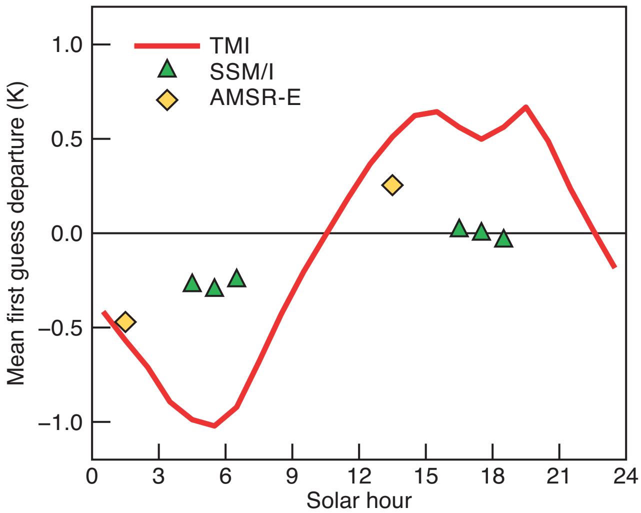



**Figure 2** Mean first guess departures (observation minus ECMWF first guess) of brightness temperature over the period 1 June 2007 to 31 May 2008 and the latitudes 40°S to 40°N. Observations have been binned by solar hour for TMI channel 21v (solid line), SSM/I channel 22v on DMSP-F13 and F-14 (triangles) and AMSR-E channel 24v (diamonds). Diurnal variations in TMI are much larger than in the other imagers, suggesting a problem with the observations rather than the first guess.

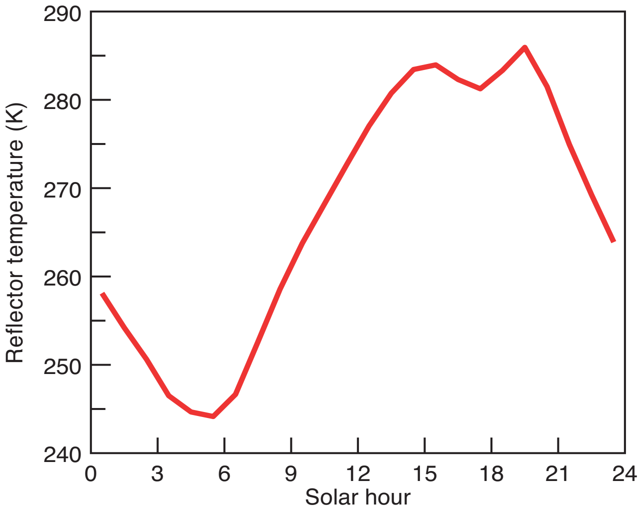



**Figure 3** TMI reflector temperature estimated from the first guess departures for TMI channel 21v.

shadow during the course of 90 minutes. It seemed unlikely that the reflector's temperature would be constant, despite that assumption having been made in the NASA correction. With the ECMWF first guess as a calibration reference, it was possible to estimate the reflector's true temperature variation. It is necessary to assume that all differences between ECMWF simulated observations and the actual observations come from changes in the reflector's temperature. Of course, for any one observation, the main difference comes from forecast error, but averaged over an entire year these random errors should disappear. However, the estimate is also affected, like all observations, by systematic bias between ECMWF first guess and observation. Hence, it is possible to estimate the changes in the reflector's temperature with solar illumination, but not the absolute magnitude of that temperature.

Figure 3 shows the yearly-mean reflector temperature for TMI, estimated from the data in Figure 2. The satellite emerges from the earth's shadow at a local solar time of around 4.30 am, earlier than would be experienced on the earth's surface since it flies 400 km higher up. Here, at the satellite's dawn, the reflector temperature is approaching its coldest for the day at around 245 K. Through the day, it appears that the sun warms the reflector, which peaks at a temperature of 285 K at around the satellite's dusk, at around 7.30 pm. The reflector's temperature then drops off through the night. This is a yearly mean, but the satellite's illumination conditions vary quite considerably through the 42-day orbital precession cycle. To resolve this better, the temperature can also be estimated as a function of solar zenith and azimuth. The plots are not shown here, but they reveal an even larger temperature variation, of up to 75 K. Figure 3 is based just on the 21 GHz channel, but reflector temperature can be estimated from all the different channels on TMI. Though the absolute temperature cannot be determined, the amplitude of the temperature variation is very similar.

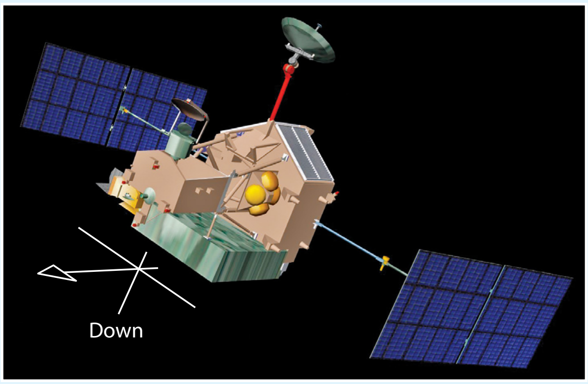
### Box A – Microwave imagers

Microwave instruments are an important part of the global observing system because they use much longer wavelengths than infrared or visible radiation, where the radiative effect of clouds and rain is in general smaller and easier to simulate. When the wavelength becomes much longer than the size of particles such as cloud droplets, these particles no longer act as scatterers, but as absorbers. This means that cloud liquid water absorption and emission can be accounted for quite simply in some circumstances.

Microwave instruments come in two main designs: those that scan across the satellite track and those that use conical scanning. The cross-track design is usually used for sounding instruments such as AMSU-A, AMSU-B and MHS, where the main observable is temperature or moisture. However, instruments of this design have a field of view which is much larger at the ends of the scan than in the middle.

Conical scanning is used for imaging instruments, such as SSM/I, TMI, AMSR-E and SSMIS, because the zenith angle and the size of the field of view are kept constant. A fixed zenith angle makes it easier to deal with the polarisation of light by the sea surface. Also a fixed field of view has proved useful for observing cloud and rain, whose radiative influence is highly dependent on the scale of the observations.

Conical scanning uses a spinning reflector to rotate the observing beam. To collect sufficient radiation, these reflectors need to be large and are typically 0.5 m to 2 m in size. The size of the reflector leads to one problem in the design of the instrument: the reflector itself cannot be included in the instrument's calibration path. Hence, these instruments can only be properly calibrated by cross-calibration to other satellites or to analyses such as those from ECMWF, or by rotating the whole satellite in a deep space manoeuvre.




**The TRMM spacecraft**. The arrow indicates its direction of travel and 'down' shows the direction in which the earth would be found. TMI is the instrument at the front of the spacecraft at the top. Its main reflector is the obvious downward pointing dish, which rotates at 32 rpm about a parallel to the 'down' axis. To protect instruments from direct sunlight, TRMM flies about half the time in this configuration with the TMI instrument forward, and half the time yawed by 180° with TMI behind. Image courtesy NASA.

There still remain unknowns in this analysis, such as the dip in reflector temperature at around 5 pm. Many causes can be speculated, such as shadowing from other parts of the satellite such as its solar panels. However, a full diagnosis would require a simulation of the illumination conditions and the thermal properties of the instrument in space. Nevertheless, it is clear that the current NASA correction is erroneous in assuming a fixed reflector temperature, and should instead account for the variation through the satellite's orbit. The TMI calibration team has independently noticed the problem and they hope to have a fix in place when version 7 of the TMI data is released in 2010. Comparison to ECMWF analyses will be able to show if it works correctly.

### Current situation

TMI is not the only microwave imager that has experienced this problem. Similar issues affected the reflector on SSMIS (Special Sensor Microwave Imager/Sounder) and a bias correction was developed by Bill Bell at the Met Office in collaboration with the Naval Research Laboratory (NRL) which processes the data. For the longer term, it is clear that instrument builders need to take great care when designing these kinds of instruments. Reflectors need to be better designed and their temperature variations carefully monitored.

A number of measures have been taken to mitigate the problem at ECMWF, since the corrected TMI product will only be released in 2010. Figure 1 is based on bias corrected departures and shows that the 42-day cycle of bias is not currently corrected by the Variational Bias correction scheme (VarBC). As a precautionary measure, TMI has been removed from assimilation with cycle 35r2 (Cy35r2) of the ECMWF IFS (Integrated Forecast System) that was implemented in March 2009. However, recent problems with some of the SSM/I instruments and the continuing issues with its successor SSMIS mean that we are quite short of microwave imagers to assimilate. The only operational instrument available is the SSM/I on the DMSP F-13 satellite, which is now 14 years old. VarBC has been extended with a new predictor based on solar hour and taking a functional form similar to Figure 2. This reduces the diurnal amplitude of bias from 1.4 K to 0.6 K, which is comparable with the typical variations of AMSR-E and SSM/I. This will allow TMI to be reintroduced in Cy35r3 if one of the other imagers fails.

### Outlook

Microwave imager observations have an important influence on tropical forecasts of humidity and wind. Beyond this, they are also the first instruments to have been assimilated in cloudy and rainy conditions, giving better coverage in areas that were previously difficult to observe. A big development is the all-sky assimilation approach which is being introduced in Cy35r2. Here, clear-sky, cloudy and rainy observations are all assimilated together, which increases our ability to constrain and improve the cloud and precipitation parts of the water cycle. For these reasons it is important to maintain our capability to assimilate microwave imagers. Unfortunately a number of instruments have been affected by technical problems in recent years, but as we have seen, expertise is being developed to overcome these problems, both at ECMWF and elsewhere.


**FURTHER READING**

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# Variational bias correction in ERA-Interim

DICK DEE, SAKARI UPPALA

REANALYSIS has a long history at ECMWF, beginning with the first reanalysis of observations from the First GARP Global Experiment (FGGE) in 1979. Since then, two major reanalysis projects have exploited the substantial advances made in operational weather forecasting at ECMWF. The first of these, ERA-15 (1979–1993), was completed in 1995 (*ECMWF Newsletter No. 73*, page 7) and the second extended reanalysis project, ERA-40 (1957–2002), in 2002 (*ECMWF Newsletter No. 101*, page 4). Products of ERA-15 and ERA-40 have been used extensively by the ECMWF Member States and the scientific community at large (*ECMWF Newsletter No. 104*, page 5). The ERA-40 public data server currently has 12,000 registered users world-wide. Reanalysis is also increasingly important to many of the ECMWF's core activities, for example:

- Providing the climatology needed for forecast verification.

- Serving as a reference for the validation of long-term model simulations.
- Allowing the development of a seasonal forecasting capability.
- Establishing the climate of EPS (Ensemble Prediction System) forecasts needed for construction of forecaster-aids such as the Extreme Forecast Index.

ECMWF is now producing ERA-Interim, a global reanalysis of the data-rich period since 1989 based on cycle 31r2 (Cy31r2) of the Integrated Forecast System (IFS).

A key component of ERA-Interim is the variational bias correction system for satellite radiances. In this article we describe the performance of this system based on the first nineteen years (1989–2007) of production of ERA-Interim.

## ERA-Interim

ERA-Interim represents a step towards ECMWF's next-generation reanalysis system, to be developed in the next few years if the necessary funding can be obtained. Relative to the ERA-40 system, which was based on IFS Cy23r4, ERA-Interim incorporates many improvements in the model physics as well as in analysis methodology. The configuration of the ERA-Interim system and many aspects of its performance are described in *ECMWF Newsletter No. 110* (page 25) and *No. 115* (page 12). When it reaches real-time in early 2009 ERA-Interim will be maintained as a Climate Data Assimilation System (CDAS), opening new opportunities for climate monitoring.

The variational bias correction system for satellite radiances used in ERA-Interim was developed at ECMWF and implemented in operations in 2006 (*ECMWF Newsletter No. 107*, page 18). This system detects the appearance of a new satellite data stream, and it then initialises, updates, and keeps track of bias estimates for radiance observations from all channels for each sensor flying on the satellite. The bias estimates are updated during each analysis cycle by including parameters for that purpose in the control vector used to minimise the 4D-Var cost function. This ensures that radiance bias estimates are continuously adjusted to optimise the consistency of the corrected radiances with all other information used in the analysis (i.e. the conventional observations as well as the model background). An important practical advantage of this approach is that it removes the need for manual tuning procedures, which are prone to error and simply impractical in the modern age.

ERA-Interim is the first ever reanalysis produced with a fully automated bias correction system. Previous operational experience with variational bias correction of radiance data has been confined to numerical weather prediction (NWP) applications, first at NCEP (National Centers for Environmental Prediction) and more recently at ECMWF. For an NWP system the ability to automatically detect new data and quickly develop bias estimates without human interference is not as crucial as it is for reanalysis, where data events happen much faster than they do in real time. And since the natural mindset in the NWP context is to look forward rather than backward, the long-term performance and stability of the adaptive approach to bias correction has not previously been documented.

A major concern in reanalysis is the ability to accurately represent climate trends and variability. This is a key requirement for the ERA-Interim CDAS and future reanalysis systems, if they are to be useful for climate monitoring and the assessment of climate change. The main difficulty is that changes in the observing system, combined with the presence of biases in models and observations, can cause shifts and trends in reanalyses that interfere with true climate signals. There is a general tendency over time towards increasing data coverage in all dimensions, but this occurs in bursts and spurts, rather than continuously. Most satellite observations require bias corrections before they can be usefully assimilated, and the biases often depend not only on instrument characteristics but also on atmospheric conditions. The challenge for reanalysis is to smoothly handle data events and bias changes, to minimise their effect on the representation of trends and variability, and, where possible, to quantify the expected uncertainties in the reanalysis products.

## Basic performance aspects

As in any modern NWP system, the quality of a reanalysis increasingly depends on the way that satellite data are handled. This is certainly the case for ERA-Interim which covers the data-rich period from 1989 onward. The ability of the analysis system to generate optimal bias corrections for satellite observations should therefore be reflected in standard quality measures, such as the fit to conventional observations and the quality of forecasts initialised with ERA-Interim analyses.

Figure 1 compares the fit to radiosonde temperature observations in the southern hemisphere of ERA-Interim with that of ERA-40. These results pertain to a particular month (August 2001), but are representative for the entire period 1989–2002 when ERA-Interim and ERA-40 overlap. Figure 1b shows that the mean fit of ERA-Interim reanalysed temperatures to radiosondes is better than that of ERA-40. This indicates that the variational analysis is able to generate bias corrections for the radiance data that render them consistent with the radiosondes, even though the former greatly outnumber the latter. In terms of the root mean square fit, Figure 1a shows that the ERA-40 analysis fits the radiosonde data slightly better than ERA-Interim, but the background errors for ERA-Interim are much smaller. This implies that the time-consistency of the assimilation has improved in ERA-Interim; ERA-40 draws closer to the individual station data but requires large corrections (analysis increments) to do so.

Figure 2 shows the quality improvements in ERA-Interim as measured by forecast skill. For reference,

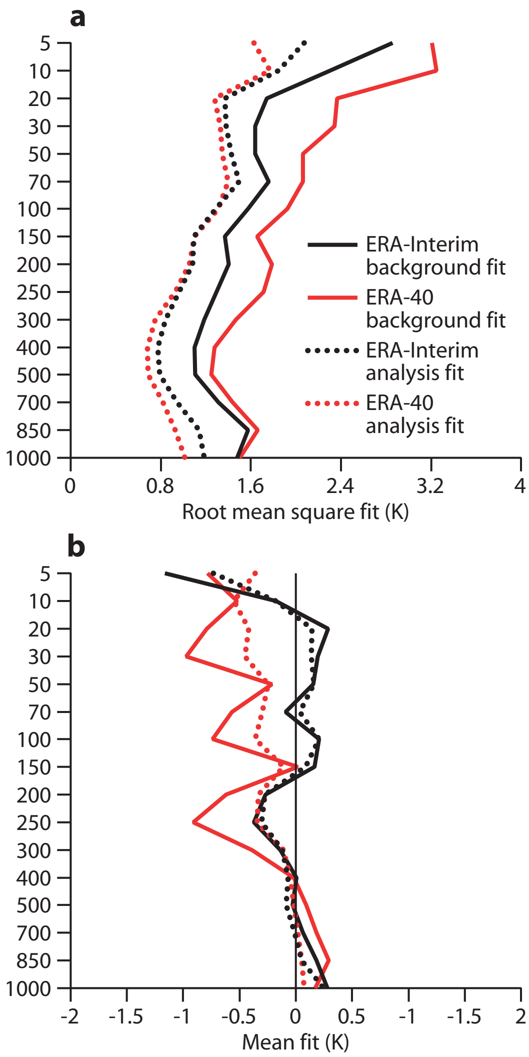


**Figure 1** (a) Root-mean-square and (b) mean fit to southern-hemisphere radiosonde temperature reports for August 2001. Black curves are for ERA-Interim and red for ERA-40; dashed curves for analysis fit and solid for background fit.

Figure 2a shows the evolution since 1989 of the skill of the ECMWF operational forecasting system, in terms of anomaly correlations of 500 hPa height forecasts for both hemispheres. The corresponding results for ERA-Interim and ERA-40 are shown in Figure 2b. By this measure, the quality of the ERA-Interim reanalysis is impressively uniform in time and space. Throughout the reanalysis period the forecast skill is similar to that of the operational system around 2002, when the spectral resolution of the model was T511 (compared to T255 for ERA-Interim).

Many other aspects of ERA-Interim product quality have improved substantially relative to ERA-40, as described in *ECMWF Newsletter No. 110* (page 25) and *No. 115* (page 12). These include well-documented difficulties such as the representation of the hydrological cycle and the strength of the Brewer-Dobson circulation. Since the observations assimilated in ERA-Interim are largely those used in ERA-40, much of the improvement is due to progress in modelling and data assimilation achieved at ECMWF since the production of ERA-40. The precise contribution of improved radiance bias corrections to this general picture is not known. However, as we shall see below, it can be clearly demonstrated in some situations that the variational approach to bias correction results in better use of observations, and is therefore beneficial to the reanalysis.

## MSU instrument errors

The long record of radiance bias estimates produced in ERA-Interim for multiple sensors flown on different satellites provides a wealth of information. Here we specifically focus on radiance data from MSU channel 2, which measures temperatures in a deep layer of the middle troposphere, with maximum sensitivity near 600 hPa. Figure 3 shows the global mean bias estimates for this channel for 1989–2007, for each of the four NOAA satellites that carried the MSU sensor during this period.

The results in Figure 3 have several notable features. There is considerable variability in the bias estimates on monthly and interannual time scales. The results for hemispheric averages (not shown) are very similar, implying that the variation in time is mainly due to global changes in the bias (i.e. the spatial structure of the bias as shown in Figure 3 is approximately stationary). There

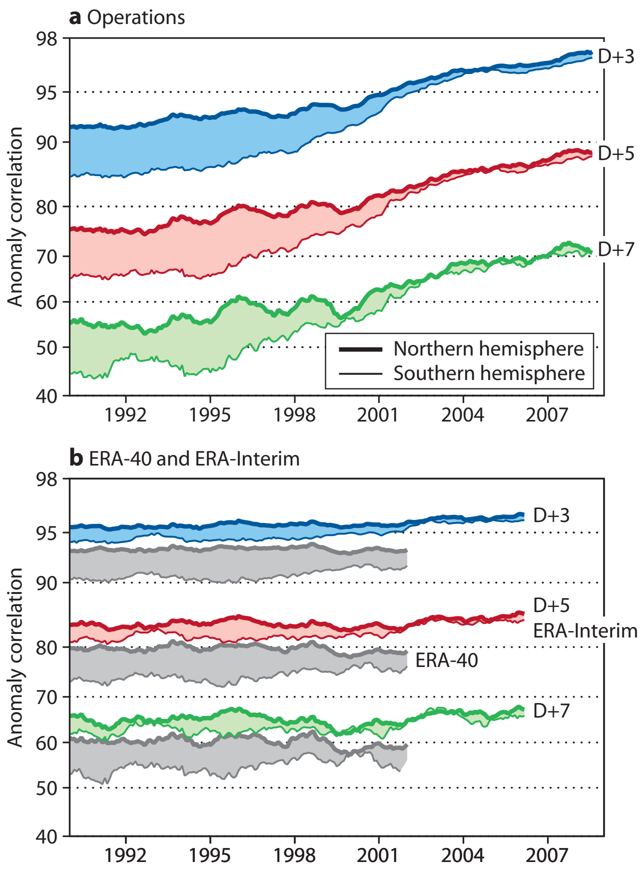


**Figure 2** Mean anomaly correlations for 3-day, 5-day, and 7-day forecasts of 500 hPa geopotential height in northern and southern hemispheres for (a) operational forecasts and (b) ERA-Interim and ERA-40 forecasts. All forecasts are verified against their own analyses.

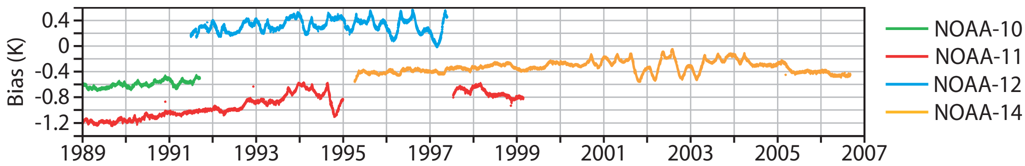


**Figure 3** Global mean bias estimates for MSU channel 2 radiance data from NOAA-10 (green), NOAA-11 (red), NOAA-12 (purple), and NOAA-14 (orange).

is some drift, especially for NOAA-11 during its first five years of operation, but this feature is not shared by other satellites and is therefore most likely due to an instrument-specific calibration issue. The global mean bias estimates for each satellite are stable, in the sense that they do not appear to drift indefinitely. Instruments on different satellites are biased relative to each other; for example, the offset between NOAA-11 and NOAA-12 is about 1.2 K on average.

The remarkable pattern of variability in the bias estimates begs an explanation. The MSU record, which extends back to late 1978, is considered a key data set for the assessment of climate change in the free atmosphere. MSU data have been used by various research groups to reconstruct the tropospheric temperature record in order to estimate trends and other climate signals. This involves the application of corrections to the data that account for calibration errors associated with each sensor, due to, for example, drift and/or decay of the satellite orbits. There is no universal agreement on the optimal method of correction, but each method relies to some extent on overlaps between pairs of satellites, comparisons with radiosonde observations, and modelling of physically-based calibration errors.

In deriving their corrections to the MSU record, *Grody et al.* (2004) used a calibration model for the instrument that includes the effect of orbital drift of the satellite. The change in equator crossing time due to the drift causes a variation in the total heat budget of the spacecraft, which in turn affects the temperature of the on-board warm target used for calibration. Figure 4b, taken from *Grody et al.* (2004), shows the NOAA-14 MSU warm target temperature changes during the lifetime of the instrument. These changes are remarkably similar to the bias estimates obtained in ERA-Interim, duplicated in Figure 4a to facilitate the comparison. It appears that the reanalysis is quite successful in detecting and correcting the complex calibration errors in the MSU observations.

This example clearly demonstrates the power of the adaptive approach to bias estimation, which can account for large and relatively rapid changes in the error characteristics of the instrument. Such an approach needs lots of information in order to succeed. In reanalysis, the variational bias correction is fundamentally a statistical method for cross-calibration of observations. It uses all the available data from multiple instruments, in addition to physical constraints provided by the forecast model.

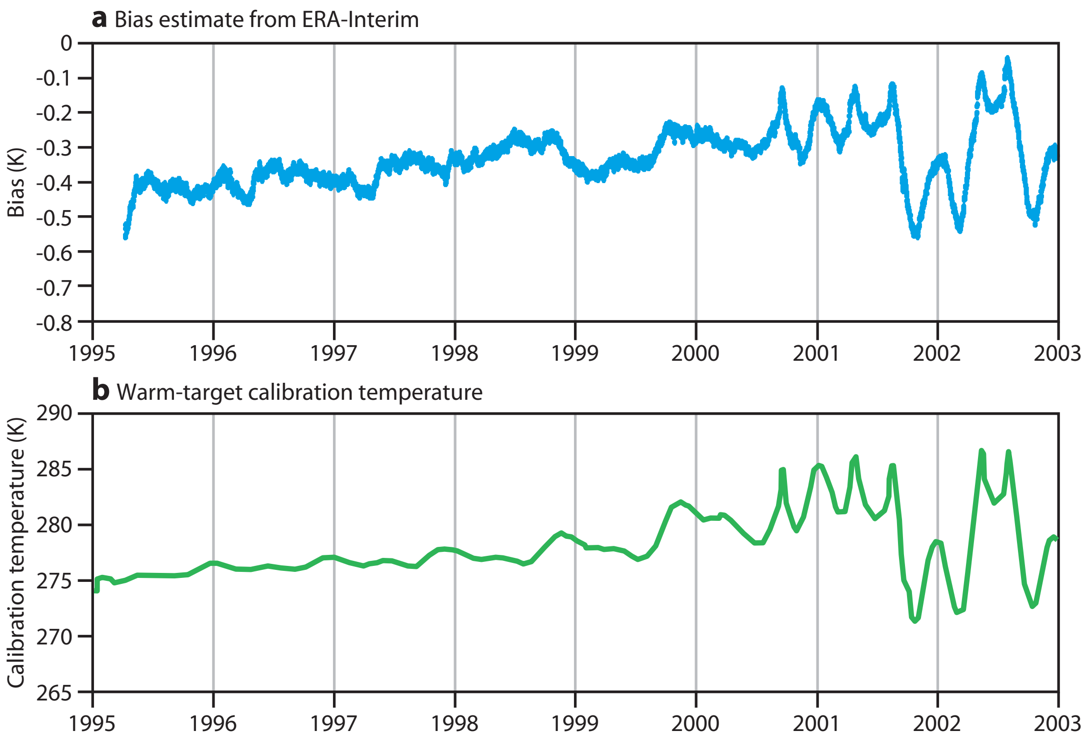


**Figure 4** (a) Global mean bias estimates from ERA-Interim for NOAA-14 MSU channel 2, as in Figure 3. (b) Recorded variations of the warm-target calibration temperature on board NOAA-14 from *Grody et al.* (2004).

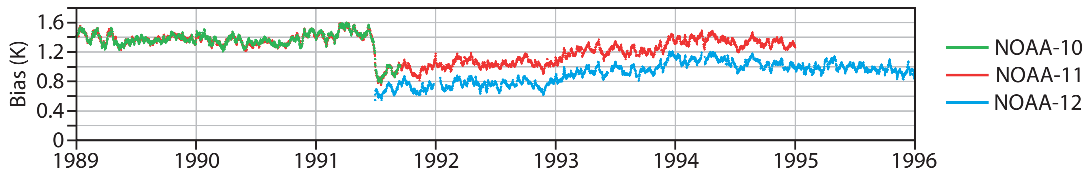


**Figure 5** Tropical averages of variational bias estimates for HIRS channel 11 radiance data from (a) NOAA-10, (b) NOAA-11 and (c) NOAA-12.

## Response to the Pinatubo eruption

A well-known problem with the ERA-40 reanalysis is the excessive precipitation over the tropical oceans after 1991. This was partly due to the method used for analysing humidity at the time, combined with the effect of assimilating increasing numbers of humidity-sensitive radiance observations from HIRS and SSM/I during the 1990s. The humidity analysis methodology used in the IFS (and, consequently, in ERA-Interim) was completely revised as a result of the lessons learned in ERA-40.

The tropical precipitation problem in ERA-40 was exacerbated by effects of the eruption of Mt. Pinatubo in June 1991. Large amounts of aerosol were injected in the lower stratosphere, resulting in significant cooling of the HIRS infrared radiances. During the weeks following the eruption, the radiances in the water vapour band (channels 11 and 12) changed by approximately 0.5 K when averaged over tropical latitudes. The aerosols from the eruption persisted in the atmosphere for several years. However, the radiative transfer model used for the data assimilation does not account for this type of change in aerosol concentration, nor does the assimilating forecast model. This means that the large signal seen by the HIRS data cannot be properly represented in the analysis. The response of the ERA-40 analysis was to adjust the humidity field in order to maintain the fit to HIRS data, causing a large injection of excess moisture in the tropical atmosphere. Introduction of NOAA-12 on 1 July 1991 with a second HIRS sensor made matters worse.

This situation presents an interesting challenge for the variational bias correction. In the absence of a realistic representation of the aerosols in the radiative transfer model, the only way to properly use the remaining information in the HIRS observations is to absorb the aerosol signal in the bias estimates. Figure 5 shows that this is in fact what happens in ERA-Interim. In the tropics, the bias estimates for HIRS channel 11 on NOAA-10 and NOAA-11 drop swiftly during the second half of June 1991 to remove the aerosol effect from the signal. The estimates for NOAA-12 HIRS when introduced immediately reflect the prevailing situation. A gradual return of the bias estimates to normal (pre-Pinatubo) values then takes place during the next few years.

The effect of the Pinatubo eruption on MSU and SSM/I radiances is different. Due to the long wavelengths in the microwave spectrum these instruments are not directly sensitive to the stratospheric aerosols produced by the eruption. On the other hand, absorption of radiation by the aerosols causes an increase in lower-stratospheric temperatures by several degrees. This signal is accurately measured by MSU channel 4, which has its peak sensitivity slightly above the tropical tropopause. The forecast model does not know about the anomalous stratospheric aerosol in this situation and therefore cannot predict its effect on temperature. As a result a slight cold bias develops in the model background, resulting in systematic departures from the MSU channel 4 radiances in the tropics.

The appropriate response in this case would be to correct the model bias in order to improve the agreement with the radiance observations, but the analysis system is not equipped to do this. Instead the system gradually increases the radiance bias estimates for MSU channel 4 during the second half of 1991, by approximately 0.45 K in the tropics, as shown in Figure 6. The amplitude of the signal in the uncorrected radiance departures during this period is nearly 3 K, so that the true signal in the data is reduced by about 15%. This has a small, but nevertheless adverse, effect on the representation of the temperature signal in the lower stratosphere. The impact is ultimately limited by the other assimilated data, including the lower-peaking MSU channels, temperature observations from radiosondes, and the HIRS radiances as previously discussed.

## Impact of model errors

The adjustment of the MSU data following the Pinatubo eruption illustrates a potential weakness of the variational bias correction scheme in the presence of systematic

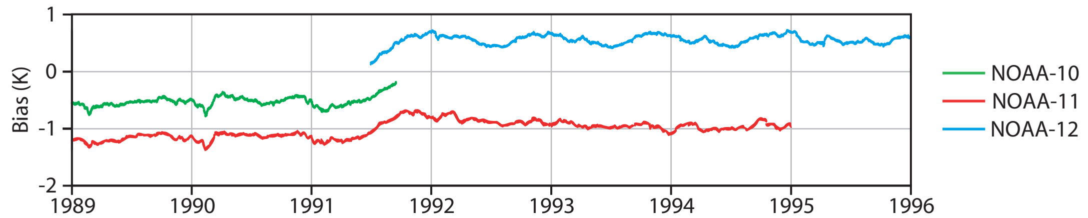


**Figure 6** Tropical averages of variational bias estimates for MSU channel 4 radiance data from (a) NOAA-10, (b) NOAA-11 and (c) NOAA-12.

model errors. It shows that the variational analysis adjusts the observations in order to control the bias in the departures, regardless of its source. The obvious danger is that the data are falsely corrected to compensate for model bias, which could then cause the assimilation to drift toward the model climate. However, there are two distinct factors that limit the potential for such a scenario.

First, the nature of the bias model (i.e. the choice of bias predictors) determines the types of corrections that can be made, and this can restrict the possibilities for aliasing with systematic model errors. For example, the use of scan bias predictors for radiance data that depend only on the viewing angle of the instrument is likely to produce corrections that truly reflect biases in the data and/or in the radiative transfer model. On the other hand, the air-mass dependent predictors often used for radiance bias correction could potentially explain model biases as well.

Second, the cost of making adjustments to any subset of observations depends on the resulting fit of the analysis to all other observations. The bias corrections produced for different channels and sensors must therefore be consistent with each other as well as with any other data used in the analysis. This is a powerful feature of the variational approach to bias correction, which provides it with a major advantage over alternative schemes that estimate biases relative to a fixed reference state.

The risk of contaminating observations by the effect of model biases on the variational bias corrections is therefore highest in sparsely observed situations where there are large-scale errors in the model background. Given the reality that forecast models do – and probably always will – have biases, the assimilation system requires a certain amount of anchoring information to remain stable, in the form of uncorrected (and preferably unbiased) observations. It is not clear how much and what kind of anchoring information is needed for this.

In ERA-Interim, the effect of model biases on the data assimilation is most clearly seen in the stratosphere. To avoid excessive drift, it was decided (see *ECMWF Newsletter No 111*, page 5) to constrain the upper layers of the model by using uncorrected radiance observations from the highest-peaking channels on successive Stratospheric Sounding Units (SSU) and Advanced Microwave Sounding Units (AMSU-A). Since each instrument has slightly different characteristics, this has resulted in spurious shifts in the reanalysis of the upper stratosphere that are visible, for example, in time series of global mean temperatures at 5 hPa and higher.

### Drift in AMSU-A radiance observations

The benefits of microwave radiance data from the AMSU-A sensor for NWP at ECMWF and elsewhere are well known. AMSU-A is a 15-channel sounder measuring atmospheric temperature and humidity profiles. It represents an improvement over MSU in terms of spatial resolution, both horizontally and vertically. At the time of this writing AMSU-A sensors on five polar orbiting satellites are available for NWP, providing almost complete coverage of the earth every four hours. These data will become a mainstay of climate monitoring information for the ERA-Interim CDAS. However, since the AMSU-A record is still relatively short its suitability for this purpose has not yet been carefully assessed.

Figure 7 shows globally averaged bias estimates produced in ERA-Interim for AMSU-A channels 7, 6, and 5, for four different satellites. These three channels with overlapping weighting functions provide the bulk of information about tropospheric temperature; channel 7

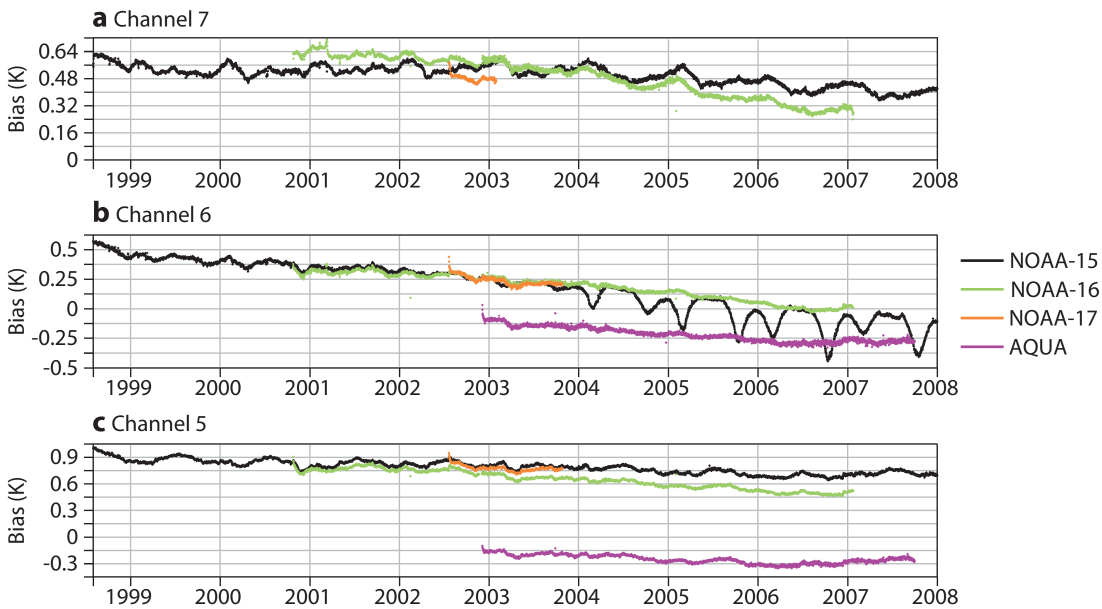


**Figure 7** Global mean bias estimates for (a) channel 7, (b) channel 6 and (c) channel 5 of AMSU-A from NOAA-15, NOAA-16, NOAA-17 and AQUA.

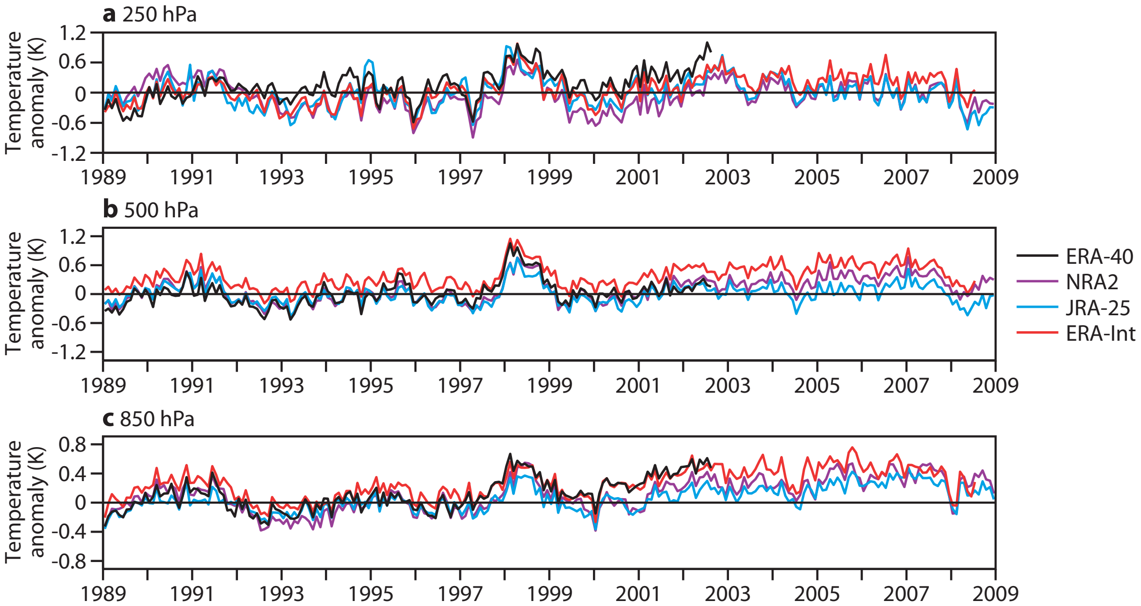


**Figure 8** Global mean tropospheric temperature anomalies at (a) 250 hPa (b) 500 hPa and (c) 850 hPa from ERA-Interim (red), ERA-40 (black), JRA-25 (blue), and NRA2 (purple). ERA-Interim anomalies are defined relative to the ERA-40 climatology; anomalies for all other products are relative to their own climatologies. JRA-25 is the Japanese 25-year reanalysis and NRA2 is the NCEP/Department of Energy reanalysis.

peaks in the upper troposphere (400–150 hPa), channel 6 in the middle troposphere (600–300 hPa), and channel 5 in the lower troposphere (850–500 hPa).

The most noticeable feature in Figure 7 is the collective, nearly linear, downward trend in the bias estimates. When averaged over either hemisphere or tropical latitudes rather than globally the curves look similar. This implies that the trends and other variations in time of the bias estimates reflect global shifts rather than seasonal or regional changes. The downward trend is largest for channel 6 on NOAA-15 (nearly 0.5 K per decade), and this appears consistent with the other satellites. For channel 5 the bias estimates reduce by approximately 0.15 K per decade for NOAA-15, with less consistency among the different satellites. The bias estimates for channel 7 are decreasing at inconsistent rates. On all three NOAA satellites the bias estimates are positive for all channels, implying that the measured radiances are biased warm relative to the analysis. The estimates for the AQUA satellite are of the opposite sign, probably because of different pre-processing algorithms used by the data provider.

In view of the reputation of the AMSU-A instrument, these results are unexpected and, at first glance, rather disconcerting. The first worry is that the trend in the bias estimates reflects a slow drift of the reanalysis towards the model climate, similar to the drift in the upper stratosphere mentioned in the previous section. However, the model is known to have a slight cold bias in the troposphere. If the true bias in the AMSU-A data were constant in time, then a drift toward a colder model climate could only be accomplished by increasing the bias corrections, because the data would appear increasingly warm relative to the analysis. Instead, the corrections are decreasing, so that the analysis moves closer to the uncorrected data in a direction that opposes the model bias. This is confirmed by the globally averaged temperature increments produced in the troposphere, which are systematically positive in the reanalysis.

We can state with confidence, therefore, that there is no insidious drift toward the model climate. An alternative explanation is that the changes in the tropospheric AMSU-A biases found in ERA-Interim are real and reflect actual instrument errors. This is partly supported in a recent study by *Mears & Wentz* (2008), in which they attempted to merge recent AMSU-A data with the MSU record from earlier NOAA satellites in an effort to extend their MSU-based climate trend analysis for tropospheric temperatures. They found similar trends and inconsistencies in the AMSU-radiances from NOAA-15 and NOAA-16, and, in fact, most of these data were not included in their merged dataset.

The question remains: which information in the reanalysis is responsible for warming the troposphere? Figure 8 shows global mean temperature anomalies obtained from four different reanalyses (ERA-Interim, ERA-40, JRA-25, and NRA2) at three pressure levels (850, 500, and 250 hPa) for the period 1989–2007. ERA-Interim is consistently warmer in the lower troposphere, and its rate of warming during the AMSU-A period is at least equal to (and perhaps slightly exceeds) that in the other reanalyses. All radiance data (from AMSU-A, but also from HIRS, SSM/I, and GOES) are subject to variational bias correction, which effectively removes their mean signal and calibrates them to all non-radiance data used in the analysis. For tropospheric temperatures in particular, the latter primarily

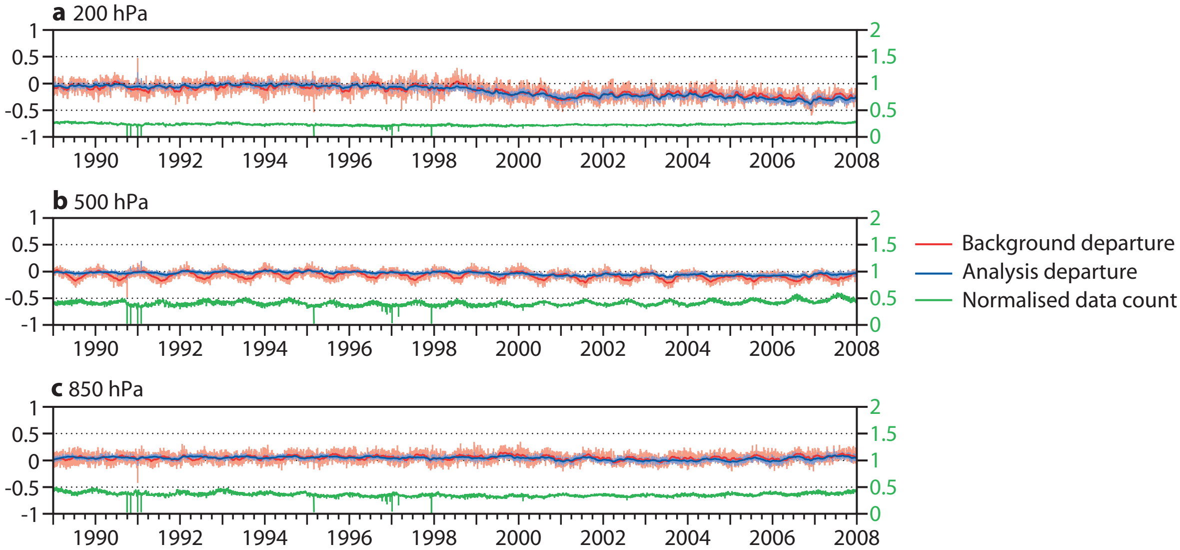


**Figure 9** Global mean departures from radiosonde temperature observations at (a) 200 hPa, (b) 500 hPa and (c) 850 hPa. The thin curves show the mean background (red) and analysis (blue) departures for each analysis cycle; thick curves are 30-day running means; values in degrees Kelvin indicated on the left axes. Normalised data counts in green; in units of 10,000 per day indicated on the right axes.

consist of radiosonde and aircraft observations. It must therefore be the case that the tropospheric warming in ERA-Interim largely responds to information from radiosondes and aircraft.

To check this, Figures 9 and 10 show the time series of global mean departures for temperature data from radiosondes and aircraft, for three tropospheric layers that approximately correspond to AMSU-A channels 5–7. When interpreting statistics for conventional observations one needs to consider their numbers and locations that are highly irregular in space and time. Both radiosonde and aircraft reports are concentrated in the northern hemisphere. Most of the temperature measurements from aircraft occur at the jet-stream level; lower-level reports are predominately over land and especially in the vicinity of airports. Global radiosonde data counts have declined somewhat in the 1990s, but are relatively steady compared with the large variations in aircraft data. The number of temperature data from aircraft is small during the first few years (hence the noisy departure statistics), but increases dramatically in 1999. This explains the sudden shift in mean departures with respect to the higher-level aircraft data noticeable in Figure 10.

It has been known for some time that temperature measurements for many types of aircraft are biased warm relative to radiosondes, and this has been confirmed in a number of studies performed at ECMWF and elsewhere. Together with the increasing number of aircraft reports, this explains the opposing mean departures for the two types of data, both at the 200 hPa and 500 hPa levels. It is not clear, however, why the increase in bias with respect to radiosondes at higher levels apparently precedes the major increase in aircraft data

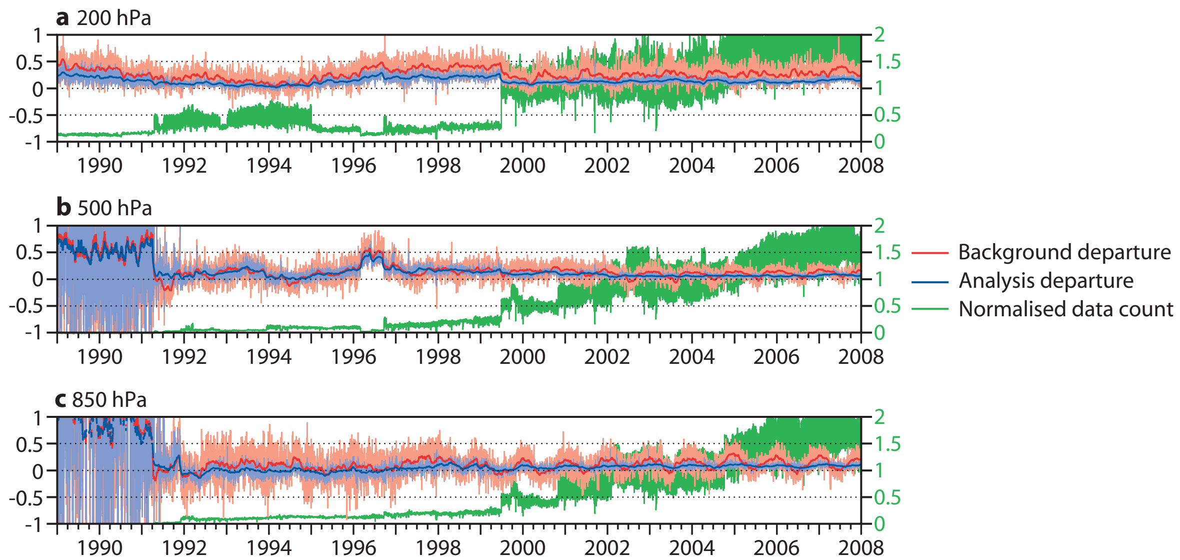


**Figure 10** As Figure 9, but for aircraft temperature reports.

counts by about 6–9 months. After 1999 the mean analysed temperatures are increasingly determined by aircraft data, which greatly outnumber radiosonde reports at all levels. This also affects the anchoring of the radiance data from the AMSU-A tropospheric channels and may explain the slow decrease in bias corrections for these channels. The problem can be alleviated by correcting the aircraft temperature data in order to render them consistent with the information from radiosondes. This would have a global impact on reanalysed temperatures via the variational bias corrections of the AMSU-A channels. The net effect would be to cool the reanalysis in the upper troposphere, possibly by as much as a few tenths of a degree Kelvin, and by a lesser amount in the lower troposphere.

### Long-term assessments and climate monitoring

The hardest challenge in reanalysis is to properly manage all the changes in the observing system, and to avoid any negative effects that these changes may have on product quality. In ERA-Interim much of the data handling has been automated, including the detection and smooth introduction of new satellite data, estimating and correcting the biases in these data, managing data gaps, etc. This has allowed the reanalysis production to proceed with minimal interruption at a steady pace, without major mishaps.

Having completed nearly 20 years of ERA-Interim, we can now assess the long-term behaviour of the variational bias correction system. We have seen that the system is quite good at removing relative biases among different types of observations, which has helped reduce the occurrence of spurious shifts and other artefacts in the reanalysed fields. On the other hand, model errors can affect the bias corrections, especially in sparsely observed situations. The importance of anchoring data – trusted observations that do not require bias correction – is evident, as is the need to further improve the forecast model, especially in the stratosphere.

Is it possible to obtain accurate trend estimates for climate monitoring from a reanalysis system? We think yes and, in fact, reanalysis offers the best approach to this end. Any study involving the analysis of long data records requires observational quality control and bias correction, based on an assessment of uncertainties in the data. This can only be done by making use of additional information, from independent observations or in the form of physical laws as expressed in a forecast model. Reanalysis provides just the framework for integrating and reconciling all this information.

**FURTHER READING**

This article is an abridged version of a paper prepared for the 37th Session of the ECMWF Scientific Advisory Committee. The complete paper is available as *ECMWF Tech. Memo. No. 575* (www.ecmwf.int/publications/library/do/references/show?id=88715).

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# Use of ECMWF lateral boundary conditions and surface assimilation for the operational ALADIN model in Hungary

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Since October 2008 ECMWF data is being used to provide the lateral boundary conditions (LBCs) for the operational ALADIN limited area model run at the Hungarian Meteorological Service (OMSZ). This model was originally coupled with the ARPEGE French global model for its LBCs. In the last two years several attempts have been made to use LBC data from the ECMWF IFS (Integrated Forecast System) in an experimental framework, i.e. in a non-real-time manner (*Kertész*, 2007). These investigations were mostly done as part of the ECMWF “SPFRCOUP” Special Project led by Météo-France with the participation of several ALADIN partners. Results suggested a potential improvement of the ALADIN forecasts when using LBC data from the IFS model.

Following a request from OMSZ, ECMWF started to provide LBC data for Hungary on a daily basis for pre-operational testing in May 2008. This made it possible to run real-time parallel tests at OMSZ to compare the forecast accuracy using ARPEGE and ECMWF LBC data. At the same time the optimal interpolation surface assimilation scheme was also tested. The parallel tests showed that ALADIN forecasts using ECMWF LBC data had a better performance and this led to the operational use of ECMWF LBC data since the beginning of October 2008.

This article will briefly describe the most important technicalities associated with the preparation of LBC data for the ALADIN model from the ECMWF global fields. Results of the parallel tests using ECMWF LBC data, including various options for the use of surface initial conditions, will be presented and recent experience of the operational use of the ECMWF LBC data will be discussed.

## Preparation of the ECMWF LBC data for ALADIN

The preparation of LBC data for ALADIN from ECMWF forecast information consists of running appropriate configurations of the ARPEGE/ALADIN software. Initially it is necessary to prepare a global dataset using the ARPEGE file format (ARPEGE configuration 901). Then the global ARPEGE file needs to be interpolated to the limited area (ARPEGE/ALADIN configuration e927). Besides the format change, the first step includes an adjustment of the surface fields to convert the ECMWF (TESSEL surface scheme) surface variables into those used in ARPEGE/ALADIN (ISBA surface scheme). This is necessary because the surface schemes in the two global models are rather different, e.g. they have different number of surface layers. Refer to *Saez* (2008), *Ivatek-Sahdan* & *Bölöni* (2005) and *Kertész* (2006) for more detailed technical descriptions of the ALADIN LBC data preparation from ECMWF global data.

ECMWF started to run the abovementioned applications for OMSZ in May 2008 and to disseminate the LBC files to our service. Following approval of the ECMWF Technical Advisory Committee, the Centre has undertaken the regular running of this application while its maintenance (preparation of the executables, testing of changes when the resolution of the ECMWF LBC data is increased, etc.) remains an OMSZ responsibility. It is worth noting that the same ECMWF LBC data prepared for Hungary can be used by all RC LACE (Regional Cooperation for Limited Area Modelling in Central Europe) countries as either an alternative or as a backup of the ARPEGE LBC data. Both the Czech Hydrometeorological Institute (CHMI) and the Environmental Agency of the Republic of Slovenia (ARSO) have already taken up this option.

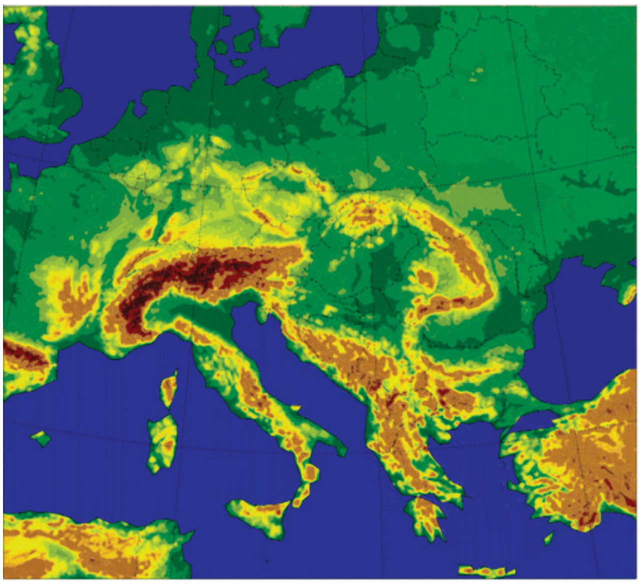

**Figure 1** The operational ALADIN domain and its orography at OMSZ.

## Use of ECMWF LBC data in an experimental phase

During the summer of 2008 tests were carried out using the pre-operational real-time LBC data from ECMWF. The main purpose was to investigate the impact of using ECMWF instead of ARPEGE as LBC data both in the assimilation cycle and in the production forecasts. Due to data availability constraints, our ALADIN integrations used LBC files from the previous ECMWF BC run, that is, with a lag of 6 hours.

The experiments included local atmospheric initial conditions provided by a three-dimensional variational (3D-Var) data assimilation in the same way as in the operational model at that time (*Randriamampianina*, 2006 and *Bölöni*, 2006). On the other hand several strategies were tried for the use of surface initial conditions. To explain the necessity of tackling the issue of surface ICs, we have to mention that at the time of these experiments the operational ALADIN model in Hungary did not include a local surface assimilation but used interpolated ARPEGE analysis to initialize the surface fields. A local OI surface assimilation was tested since the beginning of 2008 but still in an ARPEGE LBC framework. In order to define the best possible operational setup a natural idea was to perform the experiments with ECMWF LBC data including various options for the use of surface ICs. Based on these considerations the following experiments were run:

- ***ECM1***. Surface initial conditions and lateral boundary conditions from ECMWF.
- ***ECM2***. Surface initial conditions from ARPEGE and lateral boundary conditions from ECMWF.
- ***ECM3***. Local surface assimilation (OI) and lateral boundary conditions from ECMWF.

These three experiments were compared with our actual operational run at that time, using ARPEGE LBCs both in the assimilation cycle and the production forecasts. As mentioned earlier, no local surface assimilation was included in this control run (HUN) but the interpolated ARPEGE analysis was used as surface IC. Verification of the forecasts was carried out against SYNOP and TEMP observations over the whole operational model domain (Figure 1). The experiments and the obtained results will now be discussed.

### *Surface initial conditions and lateral boundary conditions from ECMWF (ECM1)*

In this experiment all ARPEGE fields were replaced by ECMWF fields. This means that ECMWF fields were used both for surface ICs and LBCs. In all other aspects the experiment is the same as HUN. The parallel test was run for the period 17 to 29 July 2008. Some results

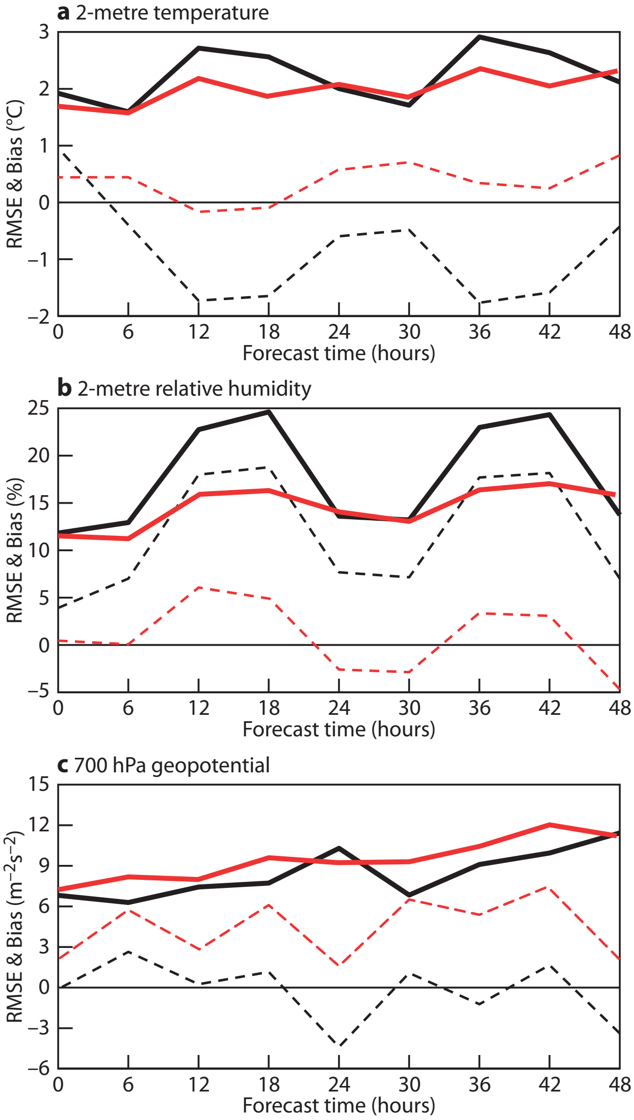


**Figure 2** RMSE (full lines) and bias (dashed lines) for (a) 2-metre temperature, (b) 2-metre relative humidity and (c) 700 hPa geopotential for experiments ECM1 (black lines) and HUN (red lines) for 17 to 29 July 2008.

are shown in Figure 2 in terms of the bias and root mean square error (RMSE).

Verification results reflect a degradation of the forecast for ECM1 compared to HUN near the surface. This degradation is most pronounced for 2-metre temperature and relative humidity as illustrated in Figures 2a and 2b. A similar feature was found in our earlier tests (*Kertész*, 2007) and the degradation is, in our understanding, purely due to the surface ICs. This is consistent with the fact that far from the surface (above 850 hPa) ECM1 performs better than HUN for most of the variables. To illustrate this point, results for the 700 hPa geopotential are given in Figure 2c.

The reason for the inferior results near the surface when using surface ICs generated from ECMWF fields is most likely associated with the different surface schemes applied in ARPEGE and ECMWF (ISBA and TESSEL respectively). The surface schemes differ in several aspects and a detailed investigation would be needed to identify the origin of the problem and to improve configuration 901 of the ARPEGE/ALADIN software in this aspect. It is worth noting that Figure 2 shows results from the 00 UTC runs but results from the 12 UTC runs are very similar.

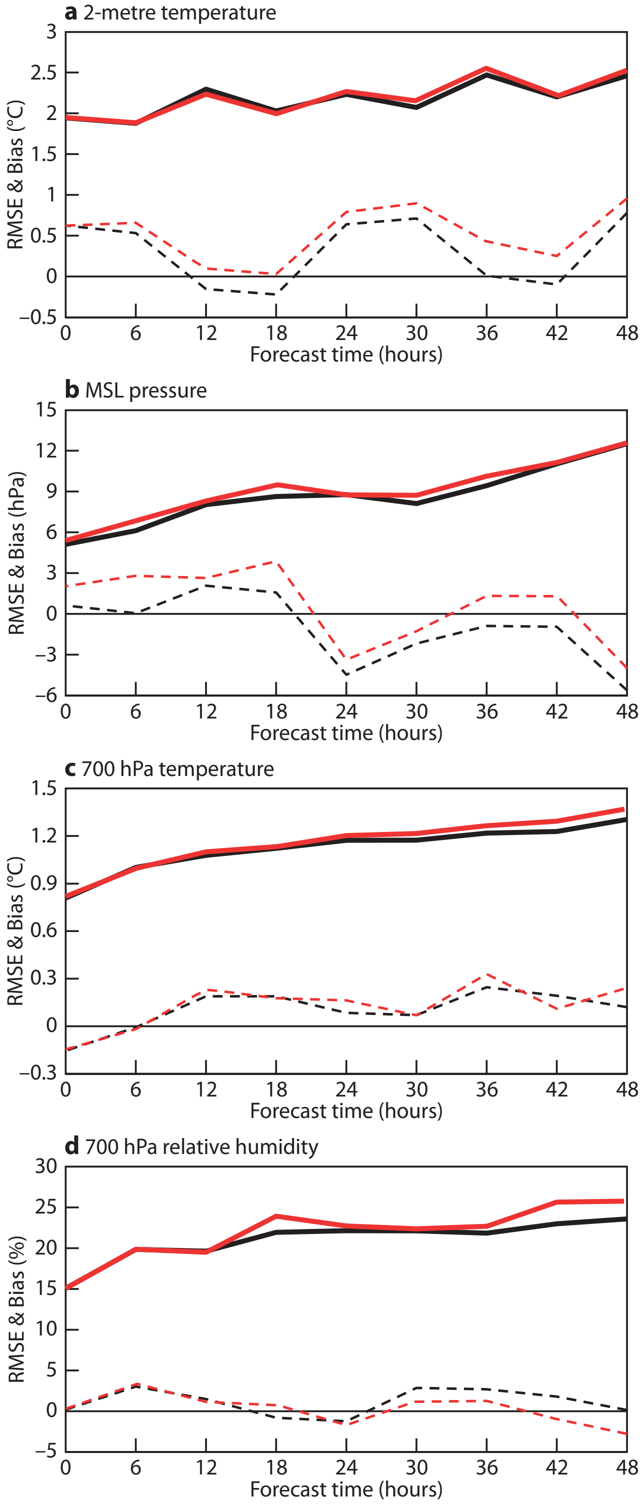


**Figure 3** RMSE (full lines) and bias (dashed lines) for (a) 2-metre temperature, (b) mean sea level pressure, (c) 700 hPa temperature and (d) 700 hPa relative humidity for experiments ECM2 (black lines) and HUN (red lines) for 1 to 14 August 2008.

### *Surface initial conditions from ARPEGE and lateral boundary conditions from ECMWF (ECM2)*

This experiment is the same as ECM1 except that it uses surface ICs from ARPEGE as in HUN. In other words, this experiment differs from HUN only in the use of the LBCs and not in the use of the ICs. The experiment was run for the period 1 to 14 August 2008. Figure 3 shows some results from these experiments.

Results near the surface are rather neutral for most of the parameters, though a small improvement in RMSE for 2-metre temperature bias and mean sea level pressure can be seen in Figures 3a and 3b. Higher in the atmosphere ECM2 has a slightly smaller error than HUN for most of the variables. This is illustrated by the results for 700 hPa temperature and relative humidity that are shown in Figures 3c and 3d. Results based on the 12 UTC runs are again very similar to those shown for 00 UTC.

### *Optimal interpolation (OI) surface assimilation and lateral boundary conditions from ECMWF (ECM3)*

ECM3 differs from the other two experiments in the treatment of surface ICs, namely by running a local OI assimilation for the surface instead of using interpolated ARPEGE or ECMWF analysis fields.

Before carrying out the two LBC tests already described (i.e. ECM1 and ECM2), the local surface assimilation was found to improve the forecast at 2 metres and so a decision was taken to implement it operationally. However, before this operational implementation, we wanted to repeat the surface assimilation test using LBCs from ECMWF instead of ARPEGE to see the interaction of both modifications compared to the operational run by that time (HUN). Some results are shown in Figure 4.

Results from this test show an improvement in the 2-metre forecast (Figures 4a and 4b); this is mostly due to the surface assimilation. In addition, due mainly to the use of LBCs from ECMWF, there are also improvements higher in the atmosphere (Figures 4c and 4d). One should notice, however, that the bias in 2-metre relative humidity is degraded during the day (forecast ranges +12 hours, +36 hours in the 00 UTC runs). This seems to be a shortcoming of the local surface assimilation and certainly needs further investigation. At the same time the RMSE of 2-metre relative humidity has improved.

## Use of ECMWF LBC data in the fully operational context

Based on the parallel tests, the operational ALADIN model in Hungary has been coupled with ECMWF LBC data since the beginning of October 2008. We now summarize the performance of the operational model during the autumn and winter of 2008. It should be noted, however, that it is not easy to choose a good measure of performance, as we have not been running a reference model coupled with ARPEGE LBCs since the operational switch in October. Another consideration is that the change in the LBC forcing was introduced together with the local surface assimilation; therefore it is not easy to distinguish between the impact of these two elements. Nevertheless, we have tried to find signals of the LBC change in our objective verification scores which are now described.

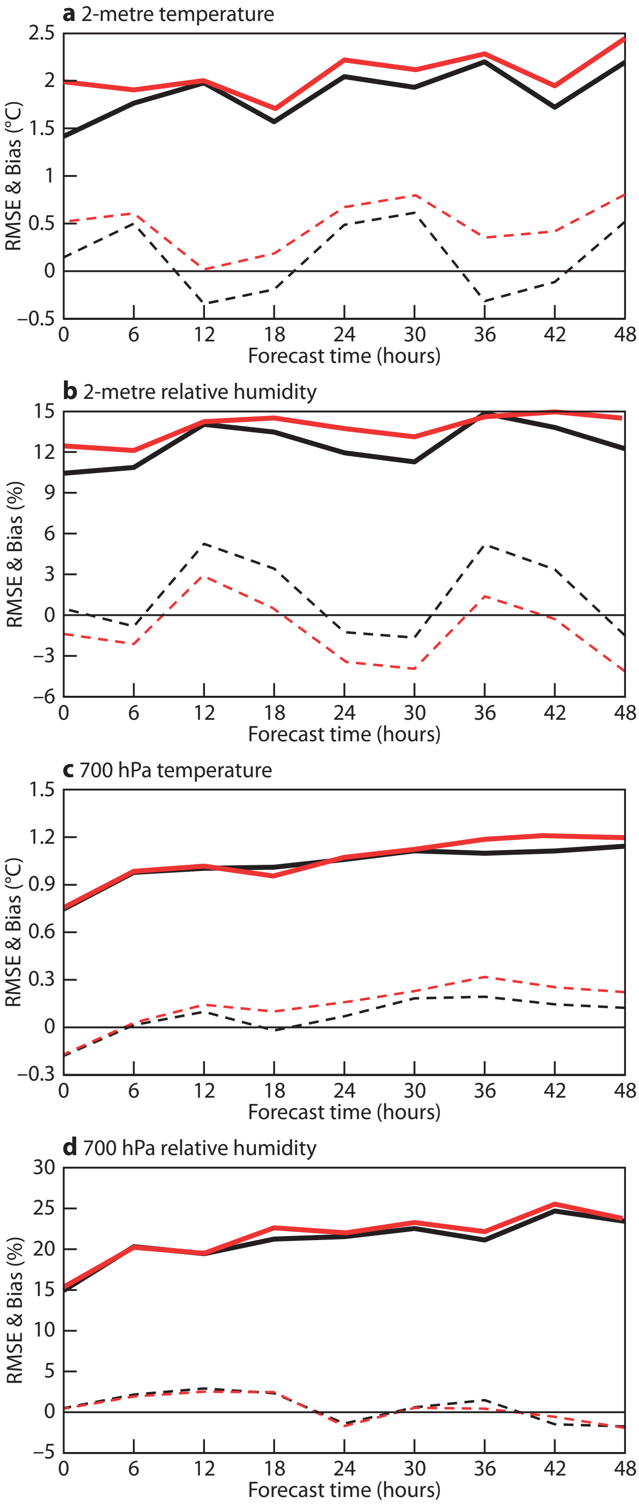


**Figure 4** RMSE (full lines) and bias (dashed lines) for (a) 2-metre temperature, (b) 2-metre relative humidity, (c) 700 hPa temperature and (d) 700 hPa relative humidity for experiments ECM3 (black lines) and HUN (red lines) for 22 August to 7 September 2008.

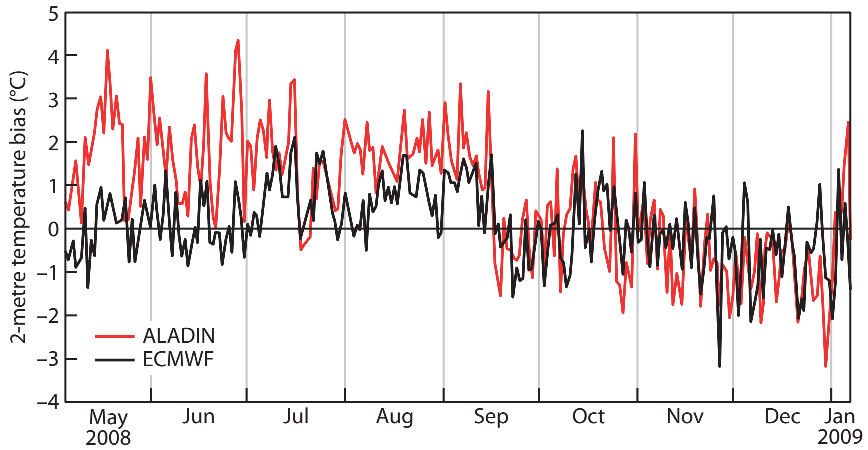


**Figure 5** Temporal evolution of the 2-metre temperature bias for the operational ALADIN model and the deterministic ECMWF model (T799) for Hungary for the 24-hour forecasts for 1 May 2008 to 7 January 2009.

### *Temporal evolution of the bias*

One approach is to plot the time evolution of bias and RMSE scores for a long period (1 May 2008 to 7 January 2009) and see if a noticeable change appears when the operational changes are implemented.

In Figure 5 the 2-metre temperature bias scores are shown for the 24-hour forecasts. These results show a pronounced bias reduction around mid-September - values near to zero till mid-November and then slightly increasing again with an opposite sign. Thus, for these scores, the LBC change realised in October does not show up clearly. We can also state that the dependence of the bias on the actual weather was stronger than the dependence on the changes in the operational suite in this period. This statement is also strengthened by the fact that the bias of the ECMWF model (T799 deterministic) changed in a similar way to that of the ALADIN model. One might also notice that the ECMWF and ALADIN results are closer in the second half of the period (i.e. when the LBC switch in ALADIN was implemented). However this fact does not match the exact date of the switch. A last consideration is that, beside the LBC change, the 2-metre scores shown in Figure 5 might also reflect the other component of the operational change, namely the implementation of the OI surface assimilation.

In order to analyze the impact of the LBC change more independently from that of the surface assimilation we show the bias time evolutions for 700 hPa temperature and relative humidity in Figure 6 for a somewhat shorter period (September – October 2008). It can be seen that for both parameters the bias runs a bit closer to zero in the second half of the period, which might be due to the use of new LBC data. However, one should also notice that the temperature bias is significantly increased by the end of October, and even grew larger than earlier in the period. Therefore, we cannot state firmly that the change to using ECMWF LBCs is clearly visible in the time evolution of bias scores within this period.

### *Seasonal and monthly averages*

Another way of trying to find a signal for the impact of the change in the operational use of LBCs is to compare the average bias for three months (October to December) in 2007 with that for 2008, assuming that a long period behaviour of the weather can be considered as similar in these two consecutive years. Figure 7 compares the bias and RMSE of 2-metre temperature for the two years. One can observe an improvement in the bias in 2008. This may be due to both the OI surface assimilation and the use of ECMWF LBC data. The

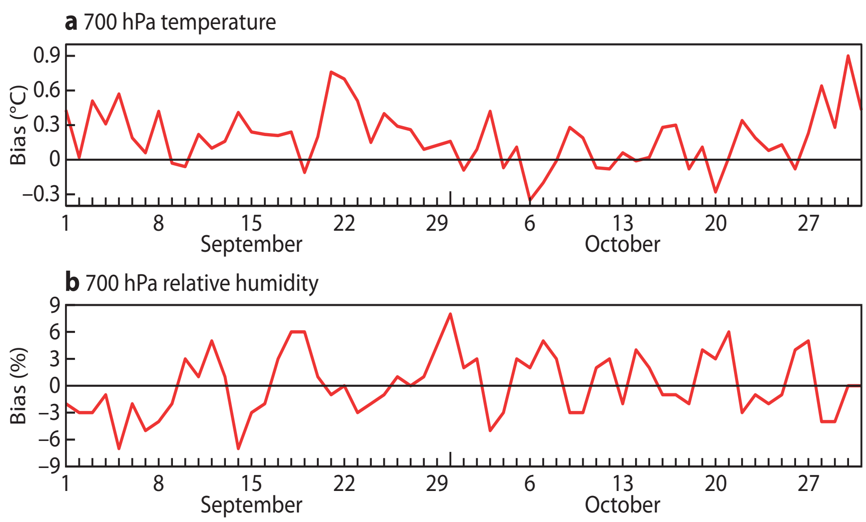


**Figure 6** Temporal evolution of the bias of (a) temperature and (b) relative humidity at 700 hPa for the operational ALADIN model in Hungary for the 24-hour forecasts for 1 September to 31 October 2008.

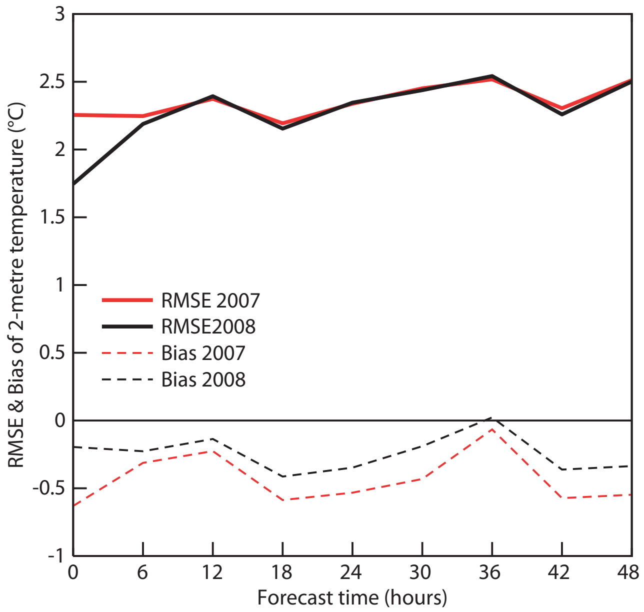


**Figure 7** RMSE and bias of the 2-metre temperature for the operational ALADIN model for Hungary for the periods: 1 October 2007 to 10 January 2008 and 1 October 2008 to 10 January 2009.

RMSE scores are rather similar for 2007 and 2008, except the analysis that appears much better for 2008, very probably due to the OI surface assimilation.

A similar comparison was done for higher in the atmosphere. The temperature and relative humidity scores are shown for 850 hPa in Figure 8 for October 2007 and 2008. These scores indicate an improvement for the year 2008, which can possibly be attributed to the use of the ECMWF LBC data but also might come from the fact that October 2008 was more predictable than October 2007 (the relative humidity bias is especially impressive for 2008 being almost zero all over the integration range).

## Concluding remarks and recommendations

The parallel tests of the experimental phase indicate that ALADIN forecasts can be improved by using LBC data from the ECMWF model if a local atmospheric and surface assimilation provides the initial conditions. Following our tests, ECMWF data are, at the moment, not recommended to be used as ICs for the surface because the ALADIN model seems to be very sensitive to the inconsistencies between the TESSEL and ISBA surface physics. This problem might be solved in the framework of the SRNWP Interoperability Programme of EUMETNET. In addition, due to the lagged use of ECMWF LBC data (LBC fields are used from the run 6-hours earlier), we do not recommend the use of ECMWF fields as atmospheric ICs, as in this case 6-hour ECMWF forecasts would be used as ICs for ALADIN (*Kertész*, 2007). The most obvious cure to this problem is to run a local atmospheric analysis within the ALADIN model itself.

The use of ECMWF LBC data together with surface assimilation was implemented operationally in Budapest at the beginning of October due to the promising results found in the parallel tests. In the operational phase we found it rather difficult to show clear signals of improvements in the objective scores due to the fact that a reference forecast using ARPEGE LBC data was not available. However, we found some improvement of the statistical scores computed for the autumn and winter of 2008 compared to those of computed for 2007. A part of this improvement may possibly come from the change in the LBC use.

This investigation has been of great value to the operational activities at OMSZ and many people have contributed to its success. First of all we are very grateful to Iván Mersich (former president of OMSZ) for his anticipation in entering the Boundary Condition Project many years ago in order to keep the possibility for using IFS data as LBCs for the ALADIN model. Thanks are due to the SPFRCOUP Special Project in general and to Claude Fischer and Francois Bouttier from Météo-France in particular for supporting the idea of a Special Project and for the ALADIN partners for taking care of its coordination. In addition the first exploratory work of the use of ECMWF lateral boundary conditions by Sándor Kertész is greatly appreciated. Last, but not least, we are very grateful to ECMWF staff (especially Umberto Modigliani, Alfred Hofstadler, Dominique Lucas and Axel Bonet) for making it possible to carry out the tests described and also for providing the LBC data with a very high reliability in the last 9 months.

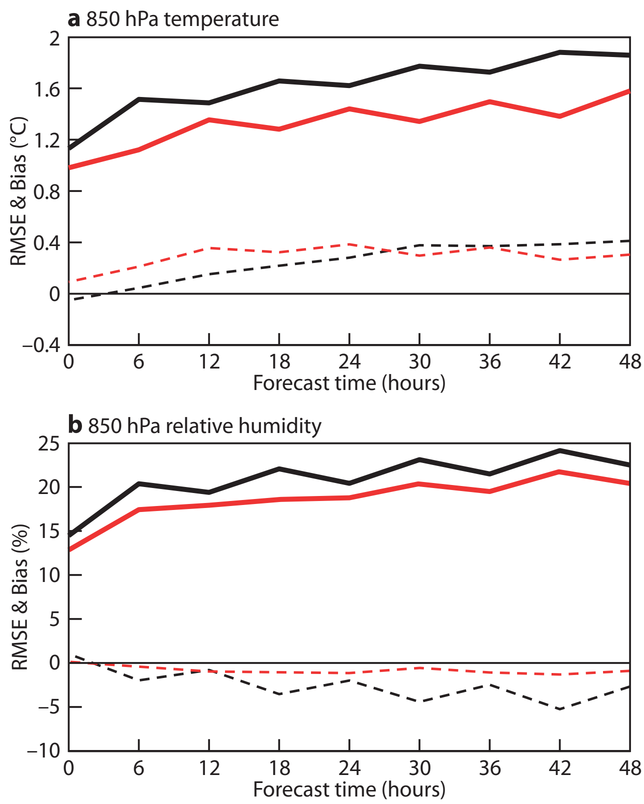


**Figure 8** RMSE (full lines) and bias (dashed lines) for (a) temperature and (b) relative humidity at 850 hPa for the operational ALADIN model for Hungary for October 2007 (black lines) and October 2008 (red lines).

**FURTHER READING**

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# ECMWF Calendar 2009

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| Jun 1–5 | Training Course – Use and interpretation of ECMWF products |
| Jun 10–12 | Forecast Products – Users' Meeting |
| Jun 15–17 | Workshop on "Diagnostics of Data Assimilation System Performance" |
| Jun 25–26 | Council (*71st Session*) |
| Sep 7–10 | Seminar on "Diagnosis of Forecasting and Data Assimilation Systems" |
| Sep 14–16 | ESF Exploratory Workshop on 'Improved Quantitative Fire Description with Multi-species Inversions of Observed Plumes' |
| Sep 30–Oct 2 | Scientific Advisory Committee (*38th Session*) |
| Oct 7–9 | Technical Advisory Committee (*40th Session*) |
| Oct 12–16 | Training Course – Use and interpretation of ECMWF products for WMO Members |
| Oct 12–13 | Finance Committee (*83rd Session*) |
| Oct 13–14 | Policy Advisory Committee (*28th Session*) |
| Oct 19 | Advisory Committee of Co-operating States (*15th Session*) |
| Nov 2–6 | 12th Workshop on "Meteorological Operational Systems" |
| Nov 9–11 | ECMWF/GLASS Workshop on 'Land Surface Modelling, Data Assimilation and the Implications for Predictability' |
| Nov 23–26 | Workshop on 'Monitoring Atmospheric Composition and Climate (MACC)' |
| Dec 8–9 | Council (*72nd Session*) |

# ECMWF publications

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

### Technical Memoranda

586 **Bormann, N., D. Salmond, M. Matricardi, A. Geer & M. Hamrud**: The RTTOV-9 upgrade for clear-sky radiance assimilation in the IFS. *March 2009*

585 **Matricardi, M.**: An assessment of the accuracy of the RTTOV fast radiative transfer model using IASI data. *February 2009*

584 **Kobayashi, S., M. Matricardi, D. Dee & S. Uppala**: Toward a consistent reanalysis of the upper stratosphere based on radiance measurements from SSU and AMSU-A. *February 2009*

583 **Bell, W., S. Di Michele, P. Bauer, T. McNally, S.J. English, N. Atkinson & J. Charlton**: The radiometric sensitivity requirements for satellite microwave temperature sounding instruments for NWP. *February 2009*

582 **Wu, C.-C., J.-H. Chen, S.J. Majumdar, M.S. Peng, C.A. Reynolds, S.D. Aberson, R. Buizza, S.-G. Chen, M. Yamaguchi, T. Nakazawa & K.-H. Cho**: Intercomparison of targeted observation guidance for tropical cyclones in the North Western Pacific. *February 2009*

580 **Mujumdar, M., F. Molteni, A. Ghelli, F. Vitart, P. Dando & J. Slingo**: Assessment of ECMWF forecasts: widespread rainfall events during the Indian summer monsoon. *January 2009*

### ESA Contract Report

**Dragani, R.**: Monitoring and assimilation of SCIAMACHY, GOMOS and MIPAS retrievals at ECMWF. Annual Report for ESA contract 21519/08/I-OL: Technical support for global validation of ENVISAT data products. *February 2009*

### Proceedings

ECMWF Seminar on Parametrization of Subgrid Physical Processes. *1–4 September 2008*

ECMWF Workshop on Atmosphere-Ocean Interactions. *10–12 November 2008*

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