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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 The ECMWF Newsletter is not peer-reviewed.

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Front cover

Picture taken at Admiralty Sound on the east side of the Antarctic Peninsular (original image courtesy of Claus Hillberg).

EDITORIAL

Using MetOp-A data

The successful launch of MetOp-A by EUMETSAT on 19 October 2006 from Baikonur was a major milestone for Numerical Weather Prediction. This new European polar-orbiting satellite carried no less than eight instruments of direct relevance to NWP. And among them the most promising is the Infrared Atmospheric Sounding Interferometer (IASI).

It is then no surprise that the ECMWF's plans for 2007 (see ECMWF Newsletter No. 110) put a top priority on the assimilation of these various instruments. So far our plans have progressed faster that initially envisaged, thanks to the preparatory work over the previous years with similar instruments and to the swift release of the data by EUMETSAT. Since 12 June, data from five of those eight instruments has been used operationally by the Centre's forecasting system.

The first step was taken with the ATOVS instrument suite which comprises a microwave sounder (AMSU-A), a microwave humidity sounder (MHS) and an infrared sounder (HIRS); this suite provides essentially temperature and moisture information. These instruments were already well known as they have been flying on the NOAA satellites since 1998. The first data from AMSU was released on 31 October 2006. It was immediately processed by ECMWF and the operational monitoring on our website started on 2 November, less than two weeks after launch. However the dissemination was interrupted for satellite decontamination and resumed at the end of November. Analyses of the monitoring and impact trials led to the start of operational assimilation of AMSU-A and MHS on 11 January, less than three months after launch. Further impact trials authorised the operational use of HIRS on 19 March.

The second step concerned the use of the scatterometer (ASCAT) whose main contributions are estimated winds over the ocean. This instrument provides data similar to that from ERS which had been assimilated at ECMWF since 1996. The high quality of the ASCAT data was verified as early as November thanks to access to a few orbits. Further work was required concerning calibration and the use of observations around the ice edges. Trials showed a positive impact of ASCAT on the quality of the forecast mainly, as expected, near the surface. Operational assimilation started on 12 June. This was important as there is the potential for ASCAT data to have a positive impact on the analysis of tropical cyclones.

The use of IASI data had been prepared for several years by learning how to use such high-resolution infrared sounder from the AIRS research instrument launched by NASA in 2002. The first IASI data was transmitted to ECMWF on 27 February. Trials showed a significant positive impact on the assimilation by a reduced but properly selected subset of channels. It is worth noting that this impact was obtained whilst using IASI data on top of AIRS data. Operational use of IASI data was implemented on 12 June. Further information about use of this data is given in the news item by Andrew Collard and Tony McNally on page 8.

The remaining instruments are the Ozone spectrometer (GOME-2) and the GPS receiver (GRAS): we will start working on them as soon as their data is distributed, which is expected soon for GRAS. And finally we intend to make use of the imager (AVHRR) for improving our cloud detection and at a later stage via polar wind measurements.

Making early use of all these instruments is crucial for improving our forecast. It is also important in terms of enhancing the value of the EUMETSAT Polar System programme, keeping in mind that gaining six months in using MetOp data is not negligible for a programme that costs about two billion Euros over fifteen years.

Dominique Marbouty

New items on the ECMWF web site

ANDY BRADY

Migration of the IPVPN MPLS network

Another milestone in the RMDCN (Regional Meteorological Data Communications Network) was reached when the IPVPN MPLS migration was successfully completed on 18 June 2007. The migration to the new network technology provides the meteorological community with a state of the art network infrastructure which will give improved service levels and will allow new services to be introduced.

www.ecmwf.int/services/computing/rmdcn/

Services for WMO Members

The services that ECMWF provides to WMO Members, that are available from our web site, have been expanded. Products available now include those dealing with:

- Medium-range forecasts (including EPSgrams for selected locations).
- Tropical cyclones.
- Seasonal forecasts.
- Monitoring the observing system.

More detailed documentation on the availability of ECMWF data on the GTS is also provided as well as GRIB product downloads and data decoding software for GRIB, BUFR and CREX. Note that access to some products requires a registration request via the relevant WMO Permanent Representative.

www.ecmwf.int/about/wmo_nmhs_access/

Presentations from the workshop on "Flow-dependent Aspects of Data Assimilation"

The Workshop on "Flow-dependent Aspects of Data Assimilation" was held from 11 to 13 June 2007. It considered advances in data assimilation methods that address the flow-dependence of the analysis problem. Presentations are available from representatives of ECMWF, NCEP, UK Met Office, NOAA/ESRL, University of Maryland, University of Surrey, University of Reading, HIRLAM, Environment Canada, Météo-France and DWD.

www.ecmwf.int/newsevents/meetings/workshops/2007/data_assimilation/

Presentations from the 2007 Forecast Products – Users Meeting

ECMWF organizes an annual meeting of users of its medium-range and extended-range products. The purpose of the meeting is to give forecasters the opportunity to:

- Discuss their experience with and to exchange views on the use of the medium-range and extended-range products, including the ensemble.
- Review the development of the operational system and to discuss future developments including forecast products.

www.ecmwf.int/newsevents/meetings/forecast_products_user/Presentations2007/

Employment opportunities at ECMWF

A list of all vacant employment positions is always posted on our web site and ECMWF welcomes enquiries from suitably qualified candidates, both male and female. The vacant positions are described in French, German and English.

www.ecmwf.int/newsevents/employment/

EUROSIP seasonal forecasts of tropical storm statistics

Forecasts of the expected frequency and mean genesis location of tropical storms in the coming months are now available from the EUROSIP multi-model seasonal forecast system. These multi-model forecasts complement the "ECMWF only" tropical storm forecasts which have been available on the web for some time. The EUROSIP tropical storm forecasts are available from:

www.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/eurosip/

Changes to the operational forecasting system

DAVID RICHARDSON

Implementation of Cy32r2

A new cycle of the ECMWF forecast and analysis system, Cy32r2, was introduced on 5 June 2007. The new cycle includes important changes to the data assimilation system and a new short-wave radiation scheme. The following changes were included:

- Three-minimization version of 4D-Var assimilation scheme (T95/T159/T255) with improved moist linear physics (cloud and convection).
- Improved parametrization of the heterogeneous ozone chemistry.
- New short-wave radiation scheme (RRTM-SW), plus McICA cloud-radiation interaction and MODIS albedo.
- Retuned ice particle size.
- Revised subgrid-orography scheme.
- Explicit numerical treatment of convection in the moist tangent linear model used in the calculation of tropical singular vectors.

More details can be found at

www.ecmwf.int/products/data/operational_system/evolution/evolution_2007.html

Assimilation of IASI radiances and ASCAT surface winds

Operational assimilation of IASI radiances and ASCAT surface winds started on 12 June. IASI and ASCAT are two major instruments on board EUMETSAT's polar-orbiting MetOp-A satellite, launched on 19 October 2006. The editorial on page 1 provides some additional information about the preparations made at ECMWF for the assimilation of MetOp-A data and plans for using data from some other instruments. Also the impact of assimilating IASI radiances is described in the news item by Andrew Collard and Tony McNally on page 8.

Management changes in the Research Department

PHILIPPE BOUGEAULT

ADRIAN SIMMONS will step down from his current position as Head of the Data Division during the summer, where he will be replaced by Jean-Noël Thépaut (currently Head of the Satellite Section). Jean-Noël will himself be replaced by Peter Bauer. Adrian will join Tony Hollingsworth as coordinator of the GEMS project from 1 September.

On this occasion, I would like to express my most sincere thanks to Adrian for his many contributions to the success of the Centre. Since joining ECMWF on 1 September 1978 he has held the posts of Head of the Numerical Aspects Section, then Head of the Model Division, and finally Head of the Data Division.

Over the years Adrian has delivered tremendous contributions to the Centre's forecasting systems, and most recently played a key role in the long-lasting collaboration with Météo-France on the IFS-ARPEGE shared system. He also developed an ever-growing interest for the re-analysis activity and the optimization of the global observing system. I am sure he will manage to remain active in all of these domains while moving to his new job!

67th Council session on 28–29 June 2007

MANFRED KLÖPPEL

CHAIRED by its President, Dr Adérito Vicente Serrão from Portugal, the ECMWF Council held its 67th session in Reading on 28–29 June 2007.

Besides several decisions on financial and staff matters (e.g. setting up a dedicated Pension Reserve Account for the Budgetised Pension Scheme and approving the Reports from the Co-ordinating Committee on Remuneration), the main results of this session were as follows.

◆ **Amendments to the Convention**. Good progress had been made with the ratification process within Member States. The following Member States have already ratified the amended Convention: Finland, Denmark, Norway, United Kingdom, Netherlands and Switzerland. Two delegations (Italy and Spain) announced that the official notification of acceptance of the amendments to the Convention was on its way.

◆ **Co-operation Agreements**. The Director was authorised to conclude agreements with Israel and with Montenegro, and to start negotiations with Poland.

◆ **European Commission**. The Council requested the Centre to further strengthen its relationship with the European Commission and its institutions.

◆ **Financial Matters**. The Council took note of the Auditor's Report for the financial year 2006 and gave discharge to the Director in respect of the implementation of the budget for 2006. The Council adopted amendments to the Financial Regulations related to gender neutrality and to contributions from new Member States after entry into force of the amendments to the Convention.

◆ **Products of the Centre**. The Council agreed on a pricing of multi-model seasonal products (EUROSIP), on revised Rules for the provision of real-time data, and on modifications to the Catalogue of ECMWF real-time products. The Council further agreed that the Redistribution Licence Fee was removed and adopted amendments to the Rules for the provision of archived data.

◆ **Contracts**. The Council unanimously approved the reappointment of Mr Dominique Marbouty as Director for a three-year period until 30 June 2011, when he reaches the retirement age of 60, and the extension of the contract of Mr Walter Zwieflhofer as Head of Operations Department for a period of five years until 17 June 2013.

◆ **Equal Opportunity Policy**. The Council supported the Centre's 'Equal Opportunity Policy' which was presented by the Director.

Forecast Products Users Meeting, June 2007

DAVID RICHARDSON

THE 2007 Forecast Products Users Meeting was held at ECMWF during 13-15 June. The meeting covered a review of changes to the ECMWF operational forecast systems over the past year, plans for future developments, and reports from users on the application and verification of ECMWF products. The meeting also gave users the opportunity to discuss their experience with and to exchange views on the use of ECMWF products, both with ECMWF and with each other. This year's meeting was well attended, with some 45 external participants representing both National

Meteorological Services and commercial users.

Major developments at ECMWF over the past year included the introduction of the VarEPS system in November 2006, extending the range of the medium-range forecast to 15 days, and a new version of the seasonal forecast (System 3) introduced in March 2007. Future developments will include the integration of the VarEPS and monthly forecast systems to provide a unified forecasting system at variable resolutions from the medium-range to one month. This will lead to a substantial increase in the resolution of the monthly forecast.

Participants reported several developments in the use of products from the ECMWF medium-range deterministic and EPS suites for official duties and commercial use (including products for the media). The 15-day EPS, introduced in November 2006, is already in use in several countries both in the National Meteorological Services and by commercial customers. The new 15-day EPSgrams introduced by ECMWF were found to be useful and examples were shown by several participants. Users reported significant developments for early warnings of severe weather using ECMWF model output. Applications were shown for wind storms (part of the EU PREVIEW project) and precipitation, while several centres reported work on convective activity using different indices derived from the model output. Promising results for tropical cyclone genesis in the ECMWF forecasts and potential new wave forecast products were also reported.

The 15-day EPS was reported to provide useful information to complement the ECMWF monthly forecast output in the preparation of end-user products. Uses of the monthly forecasts include briefings to civil protection agencies to assist in planning activities. Participants also reported developments of seasonal forecast products for specific applications. These complement the general range of products provided by ECMWF and provide tailored information for end users, including commercial customers. Examples presented to the meeting included alternative probability thresholds and timeseries (climagrams) for specific areas, as well as development of applications for crop models and risk assessment of wind storms.

During the meeting, users confirmed their requirements for the ECMWF

ECMWF Product Development

June – December 2006

- Added 10th and 90th centile to EPSgrams
- Extended EPS products to day 15
- Added EPSgram with daily steps (Tmax, Tmin)
- Added probabilities for five-day period day 11 to day 15 (based on existing products for day 6 to day 10)

In development 2007

- Ensemble mean and spread
- Percentile maps
- Revision of clustering
- Wave products
- Clickable EFI maps (shows EPS and climate distribution at a point)
- Wind direction added to EPSgrams

products currently under development. These include revision of the ECMWF clustering, the introduction of more information on the EPSgrams (including wind direction and climate information) and more interactivity on the ECMWF website, such as the clickable interface for the Extreme Forecast Index (EFI) demonstrated during the meeting. A number of these developments will be implemented in operations later this year.

Users also had the opportunity at the meeting to note additional requests for development at ECMWF that will assist users in their operational duties. The development of more products for ocean waves and tracking of extra-tropical cyclones were two such requests. There was a strong interest in the new reforecast datasets that will become available with the introduction of the unified VarEPS and monthly forecast system. It was also noted that the development of a more sophisticated set of routines for interpolation in both space and time would have wide application for users in product generation.

More details of the meeting can be found in the presentations and summary which are available on the ECMWF web site:

www.ecmwf.int/newsevents/meetings/forecast_products_user/Presentations2007

Inauguration of ECMWF's new office block

MANFRED KLÖPPEL

ECMWF celebrated the inauguration of the new office block on 28 June 2007. The ceremony was attended by delegations from ECMWF Member States and Co-operating States, representatives of the UK government, prominent representatives of the meteorological community and officials from the local authorities.

The celebration was opened by Dr Adérito Vicente Serrão, President of the ECMWF Council. He pointed out that from the start "ECMWF quickly established a world leadership position and was able to keep it so far" and that the new building was "essential infrastructure in the deployment of the ambitious ten-year strategy for the period 2006-2015".

Mr Michel Jarraud, Secretary-General of WMO, spoke about ECMWF being one of WMO's major partners – "From the start, ECMWF's interaction with WMO was strong and its positive results were fundamental to both organizations". Also he referred to the wide range of services ECMWF provides to the WMO community, particularly to the developing countries. Mr Jarraud finished by saying that "WMO is very proud of its successful partnership with ECMWF, and wishes to congratulate the Centre wholeheartedly on this auspicious occasion".

Dr Lars Prahm, Director-General of EUMETSAT, noted that the "new office building is an important step towards maintaining the pivotal role of ECMWF for medium-range weather forecasting". Dr Prahm also drew attention to the excellent and mutually beneficial relationship between ECMWF and EUMETSAT, and he illustrated this by praising the contribution of ECMWF to the successful commissioning and utilisation of data from Metop-A launched in October last year.

The cutting of the ribbon at the inauguration of ECMWF's new office block by Councillor Annette Drake (The Worshipful the Mayor of Wokingham Borough), Mr Dominique Marbouty (Director of ECMWF) and Dr Adérito Vicente Serrão (President of the ECMWF Council).

Councillor Annette Drake, The Worshipful the Mayor of Wokingham Borough, said that she was proud that the world's leading organisation in the field of numerical weather forecasting was at Shinfield Park. She also stated that the Borough Council is well aware of the positive contribution that the Centre makes to the local and UK economy. She concluded: "The new and enlarged premises will enhance ECMWF's future in the UK, and I pledge our ongoing support for you and your future development."

Finally Mr Dominique Marbouty, Director of ECMWF, described the background to the building of the new block with its 57 well-furnished modern offices, communal areas on each floor, three new meeting rooms and a bright and spacious atrium. He ended by saying that

A view of the newly landscaped approach to the main entrance of the Centre.

"ECMWF will definitely strive to remain the world's number one in global weather prediction. To do so, we need high performance computing facilities and highly sophisticated numerical models. However, what might be even more important are highly motivated people working at the Centre. I am sure the new office building will contribute to providing the necessary working conditions for staff and consultants to reach this goal."

The ceremony was an enjoyable occasion that celebrated the continuing success of ECMWF as well as marking the inauguration of the new office block.

ECMWF Annual Report for 2006

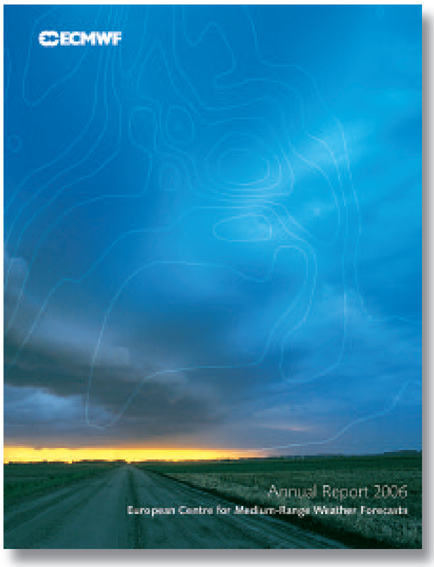
MANFRED KLÖPPEL

The *ECMWF Annual Report 2006* has been published. It is intended to be an important way of maintaining the flow of information to all the people and institutions that have an interest in ECMWF. It can be downloaded from:

www.ecmwf.int/publications/annual_report

Amongst many highlights the report draws attention to some of the key events of 2006.

- **Introduction of IFS Cy30r1**. The new high resolution system became operational. Also access times to products were harmonised and dissemination times were brought forward by an average of 25 minutes (1 February).
- **RMDCN contract signed**. The contract for the amended Regional Meteorological Data Communication Network (RMDCN) was signed, detailing the migration process to the new technology (8 May).
- **Two IBM Phase 4 clusters became operational**. The first of the two IBM Phase 4 clusters of the High Performance Computing Facility began generating operational products (17 August).
- **Introduction of IFS Cy31r1**. A number of important enhancements were introduced into the IFS, including variational bias correction for satellite radiances and major changes to the physical parametrizations (12 September).
- **Products from VarEPS for days 11 to 15 disseminated**. Dissemination of products from the second leg (days 11 to 15) of the new VarEPS forecasting system was implemented (28 November).
- **Introduction of IFS Cy31r2**. Assimilation of winds from MTSAT (Japanese GEO satellite) and GPS radio occultation data from CHAMP, GRACE and COSMIC was introduced into the IFS (12 December).
- **Honours**. The Norbert Gerbier Mumm International Award was presented to the DEMETER team at a ceremony in Geneva in recognition of their paper entitled *'Development of a European Multimodel Ensemble System for Seasonal-to-Interannual Prediction'* (28 June). Also Prof Lennart Bengtsson (Director of ECMWF 1982–1990) was awarded the 51st IMO prize by WMO for his pioneering research in numerical weather prediction (2 October).
- **Co-operation Agreements**. Lithuania became a Co-operating State following ratification of the Co-operation Agreement by its parliament on 20 November, and The Kingdom of Morocco became the first African country to join ECMWF as a Co-operating State on 1 December.



The principle objective of ECMWF is to maintain the current rapid rate of improvement of its global medium-range weather forecasting products, with particular emphasis on early warning of severe weather. There are also complementary objectives associated with improving monthly and seasonal-to-interannual forecasts, providing boundary conditions, delivering real-time analyses and forecasts of atmospheric composition, monitoring the climate, and optimising the Global Observing System. The *Annual Report* describes the developments in 2006 which help achieve these objectives. The following aspects of ECMWF's activities are covered in the report:

◆ **Forecasting System**. Evolution of the forecasting system which provides medium-range global weather forecasts, plus forecasts to one and six months ahead. ECMWF maintained a clear lead over other NWP centres in 2006.

◆ **Computing**. The computing facility with its High Performance Computer Facility (i.e. two identical and independent IBM Cluster 1600 supercomputers) and its unique archive of meteorological data collected over three decades and stored in the Data Handling System with its capacity increased by 50% to 4.25 petabytes by the end of 2006.

◆ **Data and Product Distribution**. The distribution of 4,800,000 analysis and forecast products per day to Member States and Co-operating States via the privately managed network and website and to non-members via WMO's Global Telecommunication Network.

◆ **Other Activities**. The collaborative research programmes run by the European Union and WMO including Reanalysis, AMMA, Observing System Experiments, GMES and GEO, GEMS and ENSEMBLES.

◆ **Education, Training, Workshops and Meetings**. The education and training activities aimed at increasing understanding of NWP and ECMWF's computer facilities, plus the workshops and meetings which allow experts from around the world to get together to discuss the latest research and debate future directions.

There is also information in the report about financial matters, ECMWF Council and its committees, publications and externally funded projects.

Workshop on "Flow-dependent Aspects of Data Assimilation"

ERIK ANDERSSON

A three-day workshop on *"Flow-dependent Aspects of Data Assimilation"* took place at ECMWF from 11 to 13 June 2007.

The aim of the workshop was to bring together fifteen European and American experts to discuss ways in which the ECMWF analysis could be made more responsive to observations in those particular locations where significant and potentially severe weather is developing. These locations vary from day to day depending on the 'flow', i.e. the atmospheric conditions. This is illustrated by the figure which shows a developing storm approaching the British Isles and Iberia: the orange-red shading signifies uncertainty in the model-produced "first guess" fields. It is where the model uncertainty is large (shaded areas) that good observations can provide the most beneficial corrections to the model fields through flow-dependent data assimilation.

Ensemble-based methods are well suited to detect and track these areas of higher observation significance as they evolve and develop. The working group participants discussed the techniques for running ensembles of assimilations: how the various sources of error could be represented and accounted for. The workshop recommendations provide a strong endorsement for ECMWF's research in this area, and suggest the avenues to explore in the next couple of years.

The presentations from the workshop can be found by going to:

www.ecmwf.int/newsevents/meetings/workshops/2007/data_assimilation/

Access to TIGGE database

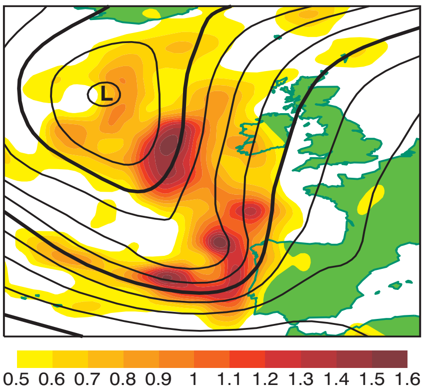
PHILIPPE BOUGEAULT

AS ANNOUNCED in the last issue of the ECMWF Newsletter, the TIGGE project has made rapid progress over the last few months. ECMWF is now receiving routinely forecasts from five providers (Met Office, NCEP, JMA, CMA and ECMWF). The facility to download data on limited area domains has been developed and access to the database is now open for research and education. New TIGGE users can register and download data from the ECMWF TIGGE portal Internet page at:

http://tigge-portal.ecmwf.int/d/tigge

This initial ECMWF access is open also to users from non-ECMWF Member States. However, in order to limit the load on the data servers, it is strongly recommended that users from North America download data from the NCAR TIGGE portal.

The Chinese Meteorological Administration has announced that it expects to open the third data portal before the end of 2007. This should provide a convenient access for Asian users of TIGGE.



A six-hours forecast of the 300 hPa geopotential (used as first-guess in data assimilation) with the colour shading indicating the uncertainty in the corresponding temperature field at model level 58 (near 300 hPa).

German State Secretary visits ECMWF

MANFRED KLÖPPEL

Mr Jörg Hennerkes, State Secretary of the German Federal Ministry of Transport, Building and Urban Affairs, visited ECMWF on 22 June 2007, accompanied by Mr Karl Trauernicht, Head of the Meteorological Service Section at the Ministry, and Mr Friedhelm Bertelsmeier, First Secretary Transport at the German Embassy London.

Senior managers of ECMWF gave an overview of the Centre's main research and operational activities, particularly emphasising how the accuracy of ECMWF's forecast products allowed early warning of severe weather events. Also the intense use of satellite data and the Centre's supercomputing expertise were highlighted.

Friedhelm Bertelsmeier (First Secretary Transport at the German Embassy London), Jörg Hennerkes (State Secretary of the German Federal Ministry of Transport, Building and Urban Affairs), Walter Zwieflhofer (Head of Operations, ECMWF), Karl Trauernicht (Head of the Meteorological Service Section at the Ministry of Transport, Building and Urban Affairs) and Dominique Marbouty (Director, ECMWF).

With regard to the role of the Centre for climate and environmental monitoring, Dominique Marbouty, the Director of ECMWF, drew the State Secretary's attention to an EU-funded project called GEMS, co-ordinated by ECMWF, aimed at building a global assimilation/forecasting system for greenhouse gases, reactive gases and aerosols. Furthermore, he emphasised the role played by ECMWF's reanalysis ERA-40, another EU-funded project co-ordinated by ECMWF, in the context of the final report of the Intergovernmental Panel on Climate Change (IPCC).

Mr Hennerkes was impressed by the high quality of ECMWF's output. Being responsible for the German National Meteorological Service, he said: "I would like to encourage the Director and the staff to continue the excellent services ECMWF provides to the Member States and Co-operating States, complementing the activities of the National Meteorological Services. I am pleased to assure ECMWF of Germany's full support to continue its valuable work."

IASI radiance data operationally assimilated

ANDREW COLLARD AND
TONY MCNALLY

IASI is a major new instrument on board EUMETSAT's polar orbiting MetOp-A satellite, launched on 19 October 2006. IASI radiances were incorporated into the ECMWF operational forecasting system on 12 June 2007. Use of the IASI data has led to significantly improved weather forecasts.

The IASI instrument measures infrared radiation from the Earth's atmosphere with an unprecedented spectral resolution. This fine spectral sampling - captured in 8461 channels - allows detailed atmospheric structures of temperature and composition to be determined more accurately than has previously been possible with any other operational satellite instrument. Following the successful launch of the MetOp-A satellite on 19 October 2006, radiance data from the IASI instrument (Infrared Atmospheric Sounding Interferometer) has been disseminated to NWP centres in near-real-time since the end of February 2007. The observations arrive via the EUMETSAT EUMetCast system at full spectral resolution (i.e. all 8461 channels) and full spatial sampling (all 4 IASI pixels inside every AMSU-A footprint). Full real-time monitoring was established at ECMWF from 8 March onwards.

The quality of the IASI observations has been examined by comparing measured radiance spectra with values computed from the ECMWF short-range forecast inside a passive assimilation system. To ease the burden on resources only 366 of the 8461 IASI channels are monitored in real time (see Figure 1); this restricts the computational overhead to be roughly equivalent to that of the 324 AIRS channels currently processed in ECMWF operations. The selection of the 366 sub-sample of IASI channels

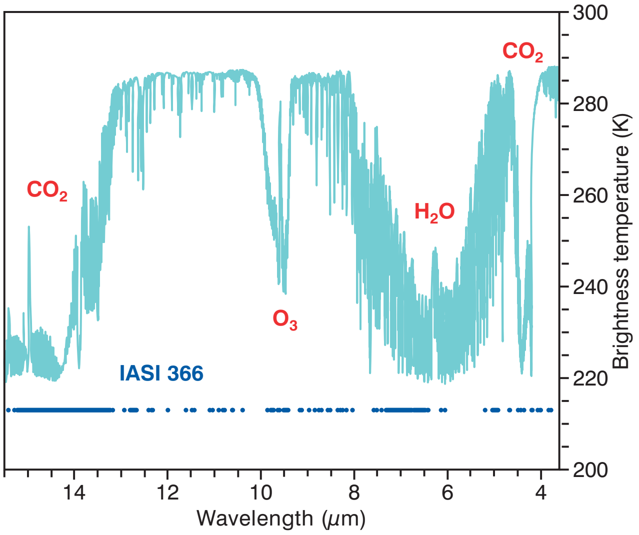


Figure 1 The location of the processed IASI channels in the infrared spectrum. Note the large concentration of channels in the 15 μm CO_2 band region.

focuses on the long-wave temperature sounding band as experience with AIRS indicates that this region gives the greatest impact on assimilation.

IASI departure statistics are shown in Figure 2 together with equivalent departure statistics for AIRS. The most striking difference is seen towards longer wavelengths where the departure statistics suggest that IASI has lower noise values than the equivalent AIRS channels. In general the departure statistics show that IASI is performing excellently.

Active assimilation experiments have been performed where the IASI radiances are used in a configuration that broadly follows the operational usage of AIRS data to test

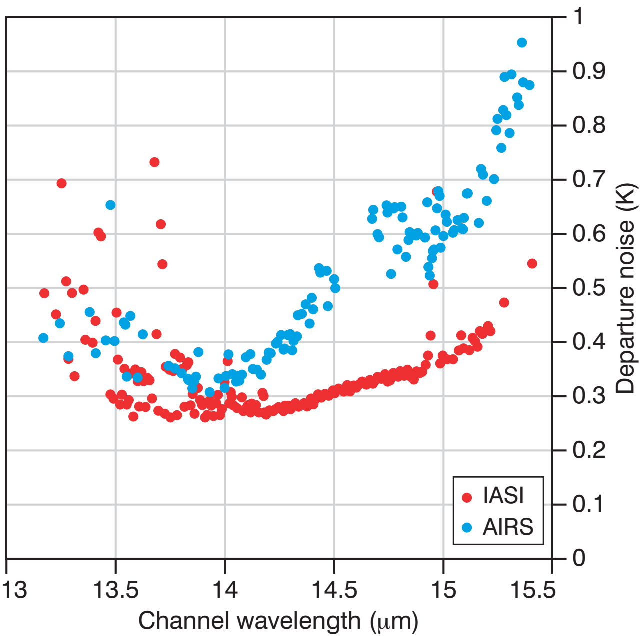


Figure 2 Standard deviations of globally averaged observed minus computed radiance departure for the infrared long-wave band. The improved performance of IASI compared to AIRS in channels with wavelengths greater than 14 μm can be seen.

the impact of IASI over the full operational observing system. The main difference with the AIRS configuration is that 168 IASI channels are assimilated with all channels coming from the 15 µm CO2 band with wavelengths greater than 11.2 µm. For comparison 154 AIRS channels are assimilated with 88 coming from the 15 µm CO_2 band. In addition, IASI data is currently used only over sea whereas 48 AIRS channels may also be used over land.

The experiments, which began with the start of IASI real-time monitoring on the 8 March 2007 and more than two months of testing, have been completed.

No substantial mean changes to the analyses are observed when IASI data are used – primarily because the VarBC system has quickly adapted radiance bias corrections to remove any large systematic forcing. The overall statistics of analysis increments are not significantly changed by the assimilation of IASI nor are the fits to other observations (conventional and satellite). Forecasts have been run from the IASI and control assimilation systems and verified using operational analyses. The changes in scores for 500 hPa geopotential are shown in Figure 3 and are positive in both hemispheres, with some statistically significant improvement at day 5 in the southern hemisphere. A geographical analysis of the forecast improvement (not shown) suggests the benefit is evenly spread throughout the hemisphere and does not identify gains in any particular locality. In the tropics vector wind scores at 850 hPa and 200 hPa are completely neutral.

Following on from the above experiments, operational assimilation of IASI data began on 12 June 2007.

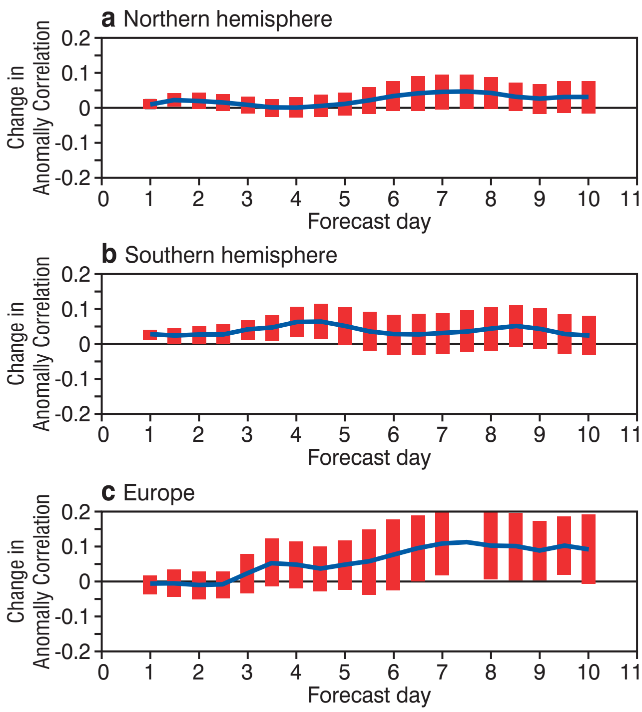


Figure 3 The impact of the assimilation of IASI data on 500 hPa height anomaly correlation forecast scores in (a) northern hemisphere, (b) southern hemisphere and (c) Europe. Positive values indicate an improvement in the forecast skill. The bars indicate the 95% confidence limits.

Data assimilation in the polar regions

ERIK ANDERSSON

THE POLAR regions provide challenging environments for data assimilation. In situ meteorological stations are difficult and costly to establish and maintain, and remote sensing is often hampered by extensive cloudiness. Therefore, there used to be a general lack of data for initialization of higher-resolution models. Lower-resolution models are inadequate in the areas of extreme topography encountered in parts of Antarctica and Greenland. The shifting surface conditions (ice, snow and open water) gives rise to highly varying surface emissivity, which impacts the satellite measurements and makes their interpretation in terms of atmospheric parameters more difficult. In the last five years, however, tremendous progress has been made due to the availability of new satellite instruments and improved data assimilation techniques. This article contrasts 2001 with 2006 in terms of analysis accuracy in the Arctic and Antarctic.

Observations and the assimilation system

Concerted efforts to exploit more satellite observations (*Thépaut & Andersson*, 2003, *ECMWF Newsletter No. 97*) have led to a five-fold increase in the number of observations used in global data assimilation, from about 1.4 million data items per day in 2001 to 7 million in 2006. Several of the assimilated data types are obtained from instruments onboard polar-orbiting satellites which naturally provide very good data coverage over the polar regions. The availability of meteorological observations in the polar regions is reviewed in Box A.

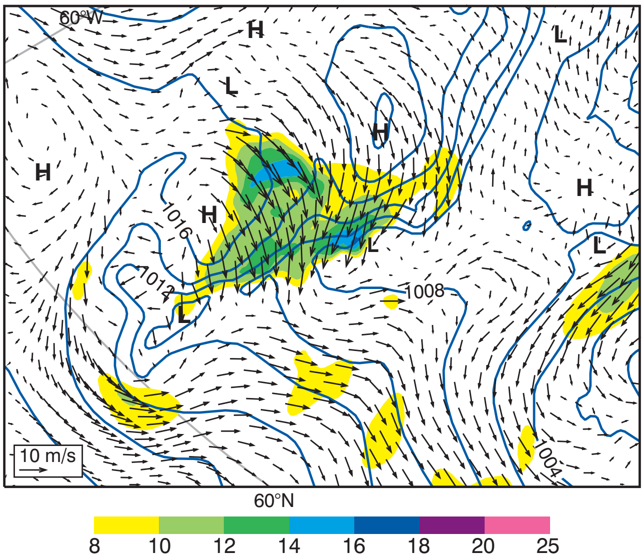


Figure 2 ECMWF analysis of a relatively large-scale katabatic wind event and associated formation of lee cyclones along the east coast of Southern Greenland, 12 UTC on 1 July 2006. The wind arrows show wind speed and direction, the shading shows wind speed (m s^{-1}, see legend) and blue contours show mean sea-level pressure (2 hPa interval).

At ECMWF, the data assimilation system is run at the same resolution as the operational forecast model. In February 2006 the model was upgraded to T799L91 (approx. 25 km and 91 model levels, *Untch et al.*, 2006, *ECMWF Newsletter No. 108*) with 4D-Var analysis increments at T255 (~80 km). The resolution increases clearly improve the representation of steep topography, as seen in Figure 1 for the area surrounding Ross Island and the McMurdo station in Antarctica. Improved topography allows a more accurate comparison between model and observations, and enables increased use of surface pressure observations and winds in the assimilation system.

High resolution is also key to successful simulation of katabatic winds and the associated formation of small-scale cyclones which can be strong and frequent in areas of steep orography around Antarctica and Greenland. In the vicinity of Ross Island this type of event is a dominant feature of the weather and can occur as often as once or twice per week. This requires a dense network of surface stations and mesoscale assimilation systems with a resolution of a few kilometres. In the 25-km resolution (T799) global system of ECMWF, this type of event can only be captured if occurring at large-enough scale, such as seen in Figure 2. However, there are difficult issues about how to extrapolate information from coastal stations to the relatively data void inland and ocean areas. Not surprisingly, many smaller-scale events are poorly represented or missing altogether in

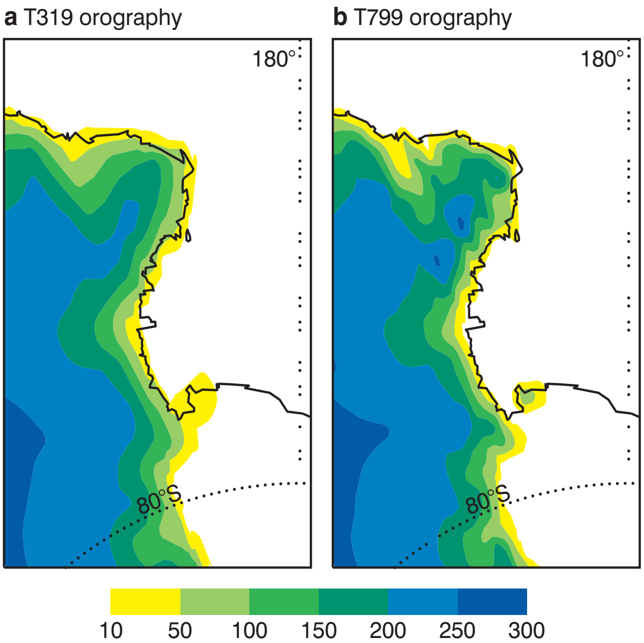


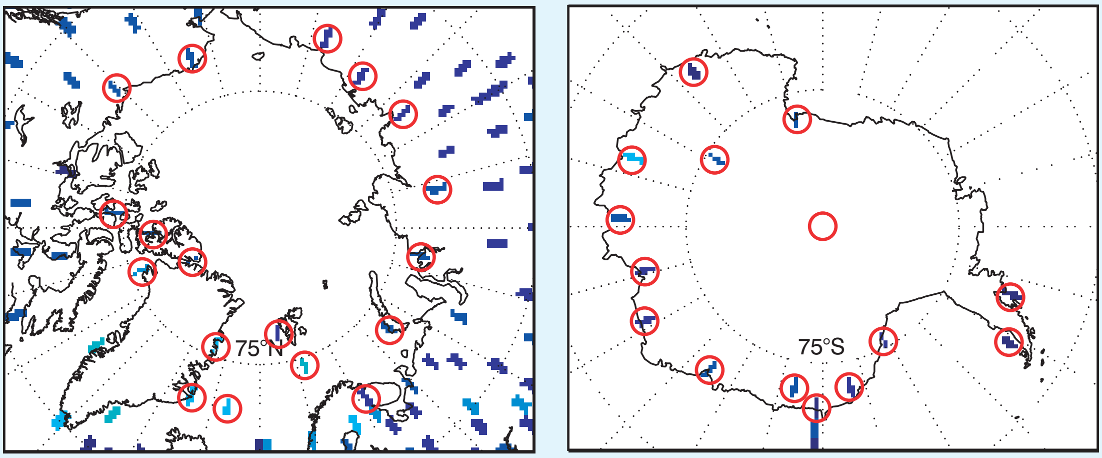
Figure 1 Model orography as represented by (a) T319 resolution model (~63 km) operational until January 2001 and (b) T799 model (~25 km) introduced in February 2006.

Box A

Meteorological observations in polar regions

The Arctic has good **radiosonde** coverage up to 70–75°N, and even to 80°N in the Canadian Islands and Northwest Greenland (left panel). The Antarctic coast at 65–70°S (right panel) is well covered apart from a major data gap in western Antarctica, where ice conditions prevent research stations from being maintained on a permanent basis. There are two radiosonde stations, Vostok and the South Pole, in the Antarctic interior.

The provision of **surface pressure observations** from SYNOP stations, SHIPs and BUOYs is reasonably good in most parts of the Arctic, except in the interior of Greenland, and in the Arctic Ocean. In the Antarctic area, there are a good number of stations along the coast and many drifting buoys in the open ocean reporting hourly surface pressure data, but there are large data voids in the areas of frozen sea and in the interior.



Radiosonde observations in the Arctic and Antarctic. The marker at each station indicates the number of reports received in July 2006: dark blue indicates one TEMP per day and light blue indicates two TEMPs per day.

There is an increasing number of temperature and wind observations in the Arctic provided by **commercial aircraft**, primarily en route between Europe, North America and Japan. This data provides important information around flight level (typically ~10 km) over Greenland, Canada, Alaska and Siberia. Only a very small number of flights cross the Artic Ocean, which therefore remains almost entirely void of such data. The Antarctic has no aircraft data. Occasionally in the South Indian Ocean, flights between Australia and South Africa reach just south of 60°S.

MODIS winds have been assimilated at ECMWF since January 2003 (TERRA) and April 2004 (AQUA). This data provides unprecedented coverage of wind observations throughout the regions poleward of 65°N and 65°S. Observing system experiments comparing assimilations with and without MODIS data have shown very substantial impact of these data on analysis and forecast quality

There is a very comprehensive coverage of **satellite radiance** data from infrared (AIRS and HIRS) and microwave (AMSU-A and AMSU-B) instruments on polar-orbiting satellites. The current constellation of spacecraft provides frequent data from partly overlapping orbits at high latitudes.

ECMWF analyses: in the Ross Sea area, visual inspection of ECMWF surface wind and pressure analyses in the 2006 season showed about one such event per month (i.e. an under-representation by a factor 4 to 8).

The assessment of analysis accuracy which will now discussed is entirely based on ECMWF's global system, and is thus limited to synoptic-scale features; the error contributions due to misrepresentation of smaller-scale features are neglected.

Performance improvements and comparison between ECMWF and Met Office polar analyses

Twice a day, based on the available observations in the last 12 hours, the data assimilation system calculates corrections to the model atmosphere. These corrections are the analysis increments. A well-performing data assimilation system built around an accurate forecast model needs to make only small corrections to keep the model in step with the real atmosphere. The amplitude of the analysis increments can thus be used as an indicator of analysis performance.

Here we compare the standard deviations of analysis increments in ECMWF's operational analyses in July 2001 against July 2006. Figure 3 shows the results for the Arctic and the Antarctic. The plots show a dramatic reduction in analysis increments between 2001 (left panels) and 2006 (right panels). The radiosondes in the Canadian Arctic, northern Greenland and Spitzbergen

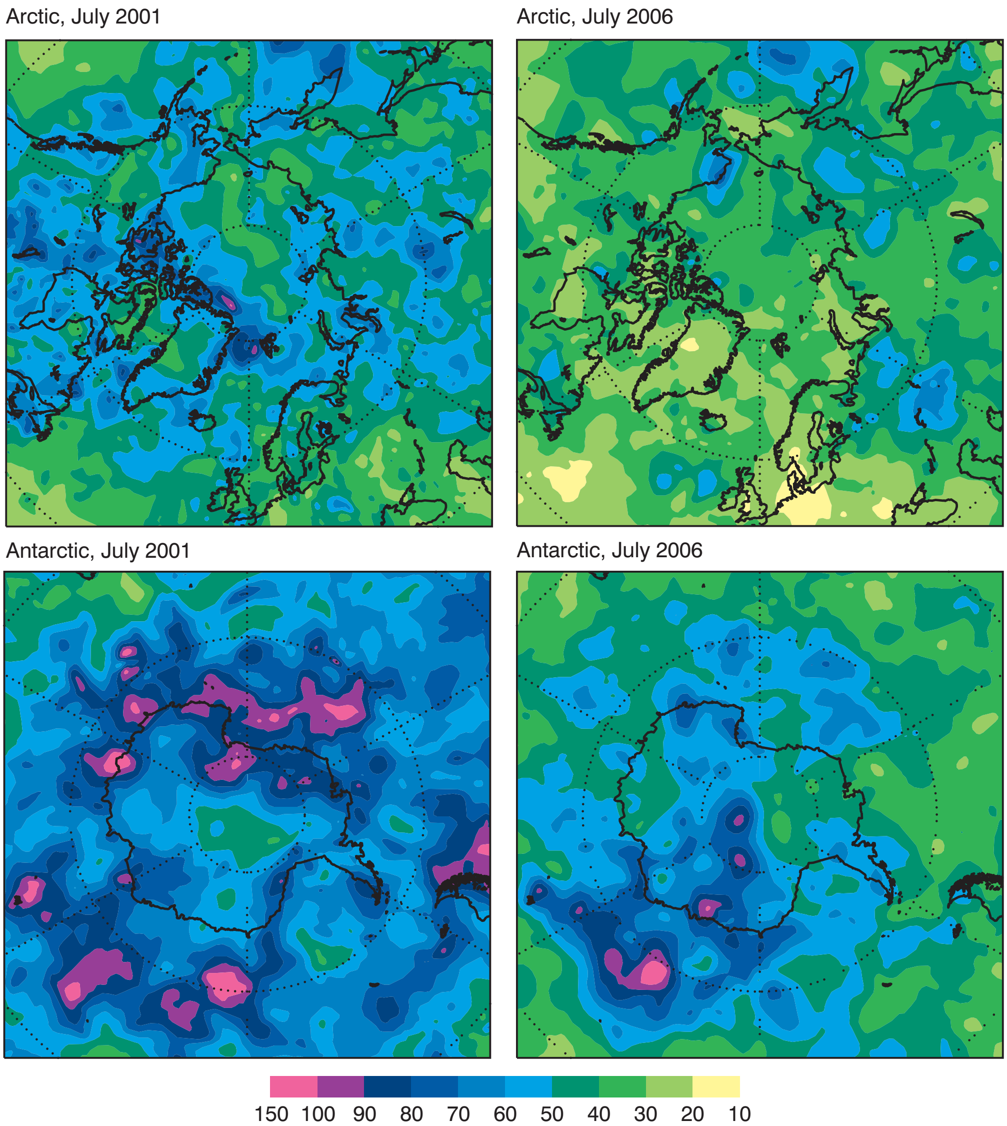


Figure 3 Standard deviation of 500 hPa geopotential analysis increments (shaded in m^2s^{-2}, see legend) comparing July 2001 (left) and July 2006 (right), for the Arctic (top) and Antarctic (bottom).

created analysis increments that were about twice as large in 2001 than in 2006. We interpret this as an indication that analysis and short-range forecast errors developing in the Arctic Ocean have been very significantly reduced in the recent five-year period. Similarly, in 2001 the radiosondes along the Antarctic coast and the south tip of South America had to do a lot of 'work' in the assimilation to correct errors developing in the data sparse upstream areas. In 2006 these increments have drastically reduced, indicating reduced upstream errors, presumably due to more extensive use of satellite data.

The United Kingdom Met Office runs a similar global data assimilation system to ECMWF's. The Met Office analyses can serve as an independent external reference against which we can compare the ECMWF analyses. Both NWP centres have benefited from improved availability of satellite data in the polar regions. The comparisons are shown in Figure 4 for the Arctic and the Antarctic in terms of standard deviations of differences in 500 hPa geopotential analyses. We can see that from July 2001 (left panels) to July 2006 (right panels) the differences in the Arctic Ocean region have decreased significantly. This convergence between ECMWF and the Met Office reflects the analysis improvement at both centres. The convergence of analyses has been even more dramatic in the Antarctic region. These charts support the conclusion that NWP analyses and models have become much more accurate over the recent five-year period, and the improvement has been most rapid in parts of the polar regions. In 2006 there is nevertheless a very noticeable contrast between land and sea areas in the northern hemisphere, indicating that there are still significant differences in satellite data usage at ECMWF and the Met Office.

Assessment of analysis uncertainty in 2003

Now consider an assessment of uncertainty based on an ensemble of ten cycling 4D-Var assimilations from 6

September to 7 October 2003. The spread between members of the ensemble provides a measure of analysis uncertainty. Figure 5 shows analysis uncertainty as estimated from the 2003 ensemble for the Arctic (left panels) and Antarctica (right panels).

From Figure 5(a) we see that in terms of 500 hPa height the analysis uncertainty in the Arctic is largest north of the Siberian coast. The corresponding results for Antarctica clearly show the beneficial impact of the radiosondes along the eastern coast of the continent, whereas the lack of stations along the western coast results in significantly larger analysis uncertainty there. It appears that these errors continue to grow as they propagate eastwards over the Weddle Sea area.

Figures 5(b) and 5(c) show analysis uncertainty in terms of 850 hPa temperature and 300 hPa wind. Note that the temperature in the lower troposphere remains uncertain in these analyses; this is due to the difficulty in distinguishing between surface and atmospheric contributions in the measured radiances, especially over ice covered surfaces, and in cloudy conditions. However, thanks to the availability of MODIS wind observations, the analysis uncertainty for wind is relatively small.

Comparison with radiosonde profiles from the Odin Arctic Expedition in 2001

During the summer of 2001, the Swedish Polar Research Secretariat carried out a two-month expedition to the high Arctic (*Tjernström*, 2002). The ice breaker Oden (Figure 6(a)) was anchored to drifting sea ice very close to the north pole for a period of three weeks. During this time, a total of 80 TEMPSHIP radiosonde launches were carried out, and these were made available to NWP users via the GTS. The data was received at ECMWF, and used in the operational assimilation system. The data set provides a very rare opportunity to validate the analyses and short-range forecasts against in situ data in the Arctic. For the purpose of this comparison

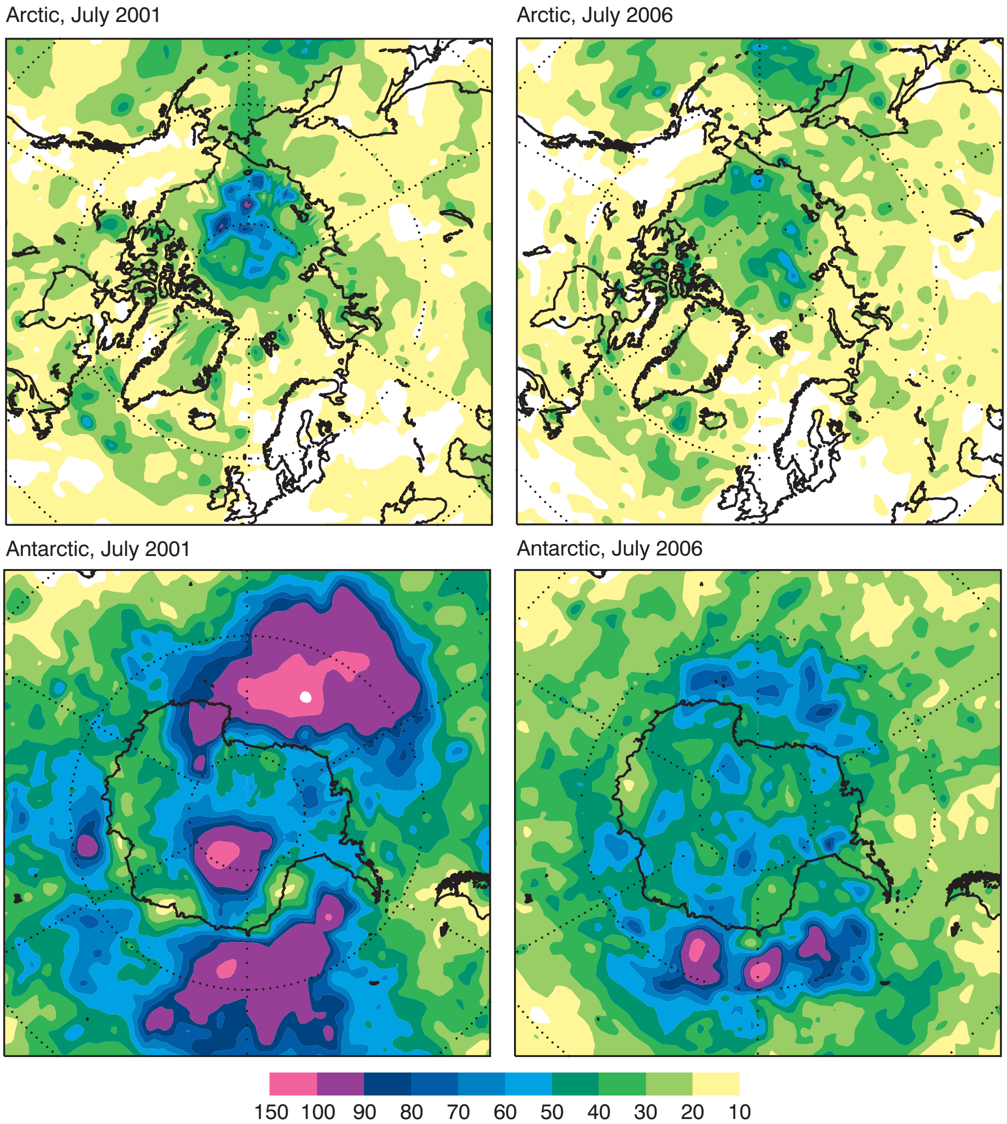


Figure 4 Standard deviation of 500 hPa geopotential analysis differences between ECMWF and the Met Office ($m^2 s^{-2}$, see legend) comparing July 2001 (left) and July 2006 (right), for the Arctic (top) and Antarctic (bottom).

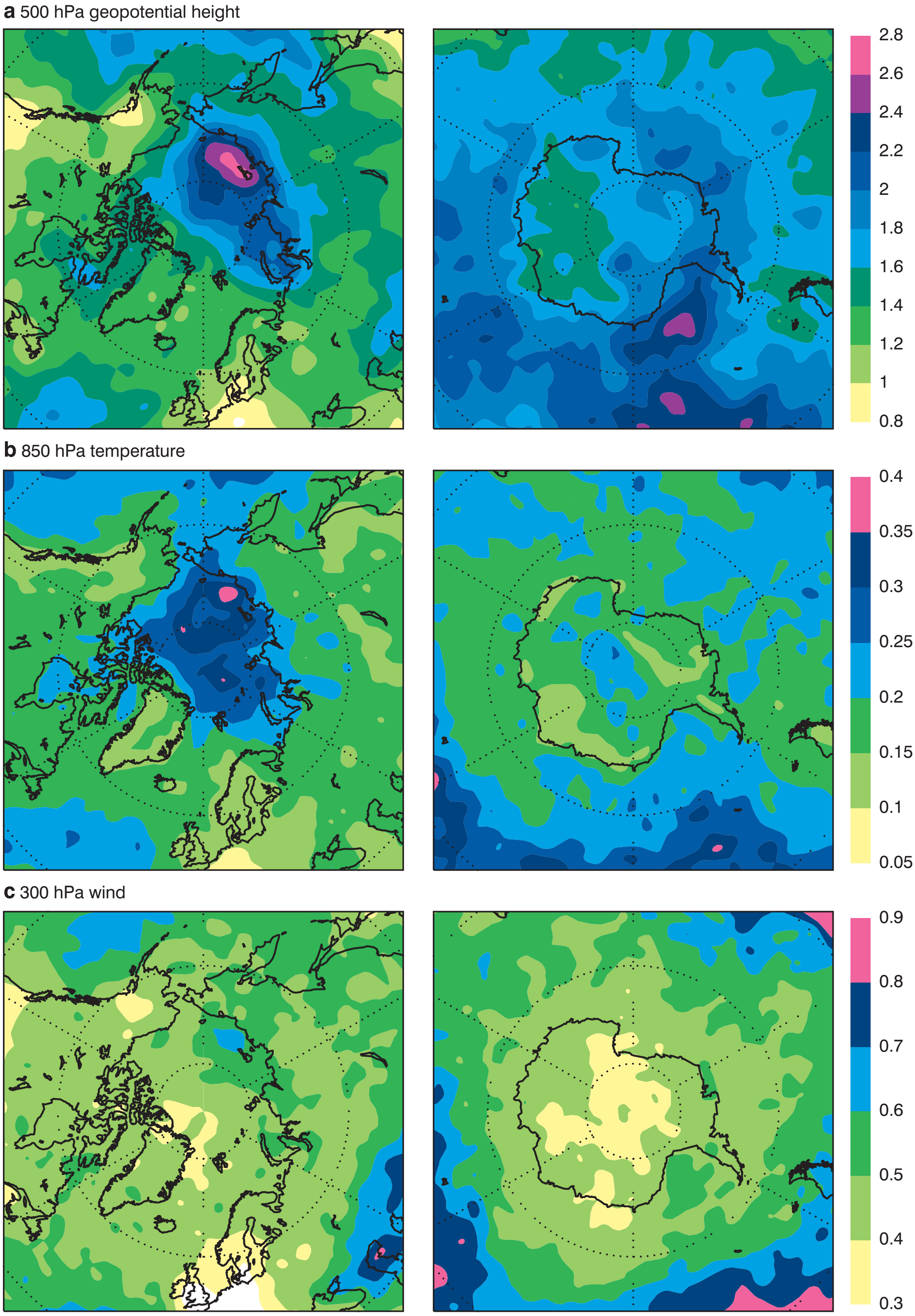


Figure 5 Average daily standard deviations of differences between members of an ensemble (i.e. spread) of independently cycling assimilations, 6 September to 7 October 2003 for the Arctic (left) and Antarctic (right): (a) 500 hPa geopotential height (m, shading see legend), (b) 850 hPa temperature (K, shaded) and (c) 300 hPa wind (ms^{-1}, shaded).

we can assume that the short-range forecast at Oden's position is nearly independent of previous Oden data assimilated in earlier analysis cycles.

The results of the comparison are shown in Figure 6(b) in terms of standard deviations of temperature differences. We see that the analyses and short-range forecasts agree very well with the radiosonde data in the mid troposphere and stratosphere. Much larger differences are seen close to the surface and around tropopause level. It appears that the satellite sounding data, which dominate the temperature analyses in the Arctic, constrain the large-scale structures in the free atmosphere. However, the sharp temperature inversion at the tropopause and the surface layer are poorly resolved by the satellites. The latter is consistent with the results shown in Figure 5(b). Wind errors (differences between Oden radiosondes and ECMWF short-range forecasts) were around 3 m s^{-1} (500–250 hPa), and around 2 m s^{-1} in the boundary layer and 200–100 hPa.

Summary and outlook

The current work was presented at the 2006 ECMWF Seminar devoted to the impending International Polar Year (IPY, www.ipy.org). Comparing ECMWF's operational analyses for 2001 and 2006 we found that there has been a very significant improvement in analysis quality over the past five years in both polar regions, and particularly so in the Antarctic. The magnitude of analysis increments has been reduced, and the difference between ECMWF and Met Office analyses has also reduced significantly. This is likely due to more extensive use of polar-orbiting satellite data at both NWP centres, and improved forecast models in general. In the five-year period to 2006, additional temperature soundings using infrared and microwave data are being assimilated, and MODIS winds have been introduced.

Comparison with a unique set of radiosonde measurements at the north pole provided by the 2001 Oden expedition showed good temperature accuracy in the free atmosphere of the ECMWF operational analyses. The short-range forecast error (~6 hours) was 1 K or less between 700–400 hPa, and also between 150–50 hPa. This is a very good result considering that there are no regular, in situ, upper-air data in the Arctic Ocean. Within the boundary layer and around the tropopause, however, the errors reach 2 K. This can be explained by the relatively poor vertical resolution of satellite sounding data, and the difficulties in distinguishing between surface and atmospheric influences on radiance measurements that partly sense the ground. Based on these 2001 results and the documented improvement since then, we have reason to expect that 2006 results would be even better in the free atmosphere.

The analysis of the high-latitude tropopause may have benefited from the use of radiances from AIRS (Atmospheric InfraRed Sounder), assimilated at ECMWF since October 2003; this data has a better vertical resolution than data from HIRS and AMSU-A. Also the improved representation of the background errors at high latitudes provided by the "wavelet Jb" formulation (*Fisher*, 2005, *ECMWF Newsletter No. 106*) may have been beneficial. In addition the recent introduction of radio-occultation data into operations (*Healy*, 2007, *ECMWF Newsletter No. 111*) now provides vertically resolved temperature data with good accuracy in the upper troposphere and lower stratosphere.

It is expected that in a few years' time the ADM-Aeolus satellite (*Tan & Andersson*, 2005, *ECMWF Newsletter No. 103*) in polar orbit will provide wind-profile measurements with similar accuracy to radiosondes. This will further improve the analyses in polar regions.

FURTHER READING

Tjernström, M., 2002: Arctic Ocean 2001 expedition. *Vaisala News*, **159**, 6–10.

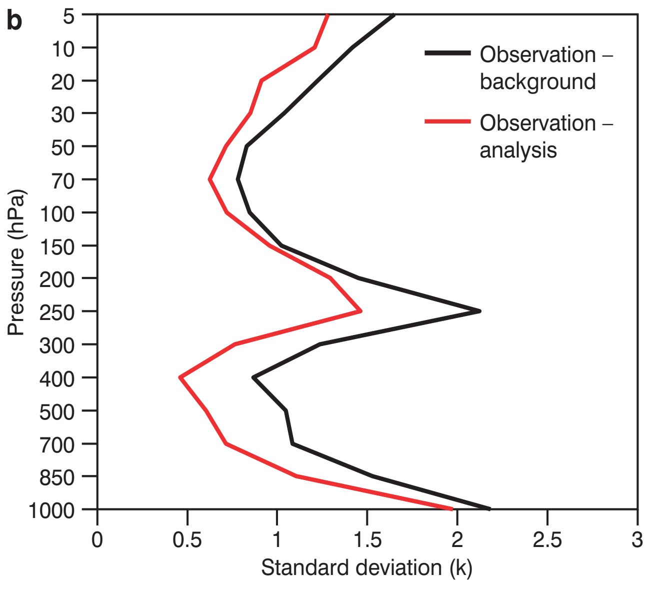


Figure 6 (a) The Swedish icebreaker Oden from which temperature soundings were made in polar regions. (b) Comparison between ECMWF operational assimilation and temperature sounding data during a three-week period (1 to 22 August 2001) when Oden was anchored to the drifting sea ice very close to the north pole. The two curves show the standard deviation of temperature differences (K) between observations and analysis (red line) and observations and background (black line).

Seasonal forecasting of tropical storm frequency

FRÉDÉRIC VITART, TIM STOCKDALE, LAURA FERRANTI

TROPICAL storms (tropical cyclones with a maximum wind speed larger than 17 m s^{-1}) give rise to some of the most devastating natural disasters. During the past 50 years, hundred of thousands of lives have been lost because of tropical storm landfalls, often because of the landslides and floods caused by the heavy precipitations associated to the storm. The total number of tropical storms is remarkably stable from one year to another (about 90 per year), but their frequency can vary strongly from one year to another over a specific ocean basin. For instance, only 3 Atlantic tropical storms were observed in 1983, compared to 27 in 2005. As a consequence the damage caused by tropical storms, especially by the most intense ones (hurricanes or typhoons), can vary significantly from one season to another. Therefore making accurate seasonal forecasts of tropical storm frequency is a very valuable tool to help people prepare for such disasters. Predicting their exact occurrence months in advance is of course out of reach, but predicting their probability of occurrence may be possible.

As tropical storms form in very specific locations and are highly seasonal; specific environmental conditions are required to accomplish the transition from a loosely organized disturbance to an intense vortex. *Gray* (1979) identified six main environmental factors related to the frequency of tropical cyclones:

- Above average low-level vorticity.
- A location a few degree poleward of the equator (the Coriolis force plays an important role in the generation of cyclones).
- Weak vertical shear of the horizontal wind.
- Sea surface temperature exceeding 26°C.
- Conditional instability through a deep layer in the atmosphere.
- Above-average moisture in the middle levels of the atmosphere.

Those parameters, which are not independent, can explain the seasonal cycle of tropical cyclone activity and why tropical storms form only in specific regions. They can also explain changes in the frequency of tropical cyclones from one year to another. For instance the Atlantic tropical cyclone activity is significantly reduced during El Niño years. The proposed mechanism is that the eastward shift of positive sea-surface temperature anomalies associated with El Niño causes an increase of deep convection over the Equatorial Eastern Pacific. This increased convection enhances the upper-level westerly zonal winds and, as a consequence, the vertical wind shear over the region where most Atlantic tropical storms develop. As discussed previously, the increased vertical wind shear reduces the Atlantic tropical storm activity.

Tropical storms in the ECMWF seasonal forecasting system

At present most seasonal forecasts of tropical cyclone activity (forecasts from Colorado State University, NOAA or Tropical Storm Risk Consortium) are produced using statistical or empirical methods. An alternative to those methods is the use of dynamical models that have skill in predicting a few months in advance the large-scale parameters that have an impact on the frequency of tropical storms.

The current operational version of the ECMWF seasonal forecasting system, System 3, is described in *Anderson et al.* (2007) and its products in *Molteni et al.* (2007). This system has some skill in predicting the evolution of sea surface temperatures (SSTs) a few months in advance in the tropics, most especially the SST anomalies associated with ENSO in the tropical Pacific. Therefore, this system could be used for the prediction of tropical storms by building a simple statistical model based on the predicted SSTs: for instance, if the coupled model predicts colder Atlantic SST and an El Niño event during the peak of the Atlantic tropical storm season (August-September-October), then it is likely that the Atlantic tropical storm season will be inactive. Another method consists of counting the "tropical storms" produced explicitly by the dynamical model. This is the method we use to produce the ECMWF seasonal forecasts of tropical storms. It has the advantage over the statistical method of a better handling of non-linear effects on tropical storm frequency and of allowing the explicit representation of tropical storm tracks.

Although the horizontal resolution of global operational dynamical seasonal forecasting models is insufficient to simulate the intensity of hurricanes, simulated tropical cyclonic systems are nevertheless realistic in other respects. For example, the number of dynamically-simulated Atlantic tropical storms developed over the course of a season is sensitive to the underlying SSTs (*Vitart & Anderson*, 2001). In addition, dynamically-simulated tropical storms develop a warm temperature anomaly above the centre of the vortex (warm core). This warm-core structure is crucial to the intensification of tropical storms, and plays an important role in understanding the inter-annual variability of observed tropical storms: an increase in vertical wind shear prevents the formation of a warm core structure. Numerical experiments have shown that this mechanism can be simulated in dynamical models (*Vitart & Anderson*, 2001). These results form the scientific basis for dynamically-based seasonal forecasting of tropical storms.

Seasonal forecasts of tropical storms have been issued each month since 2001 at ECMWF. The seasonal forecast of tropical storm frequency (see example in Figure 1) and the mean genesis location (see example in Figure 2)

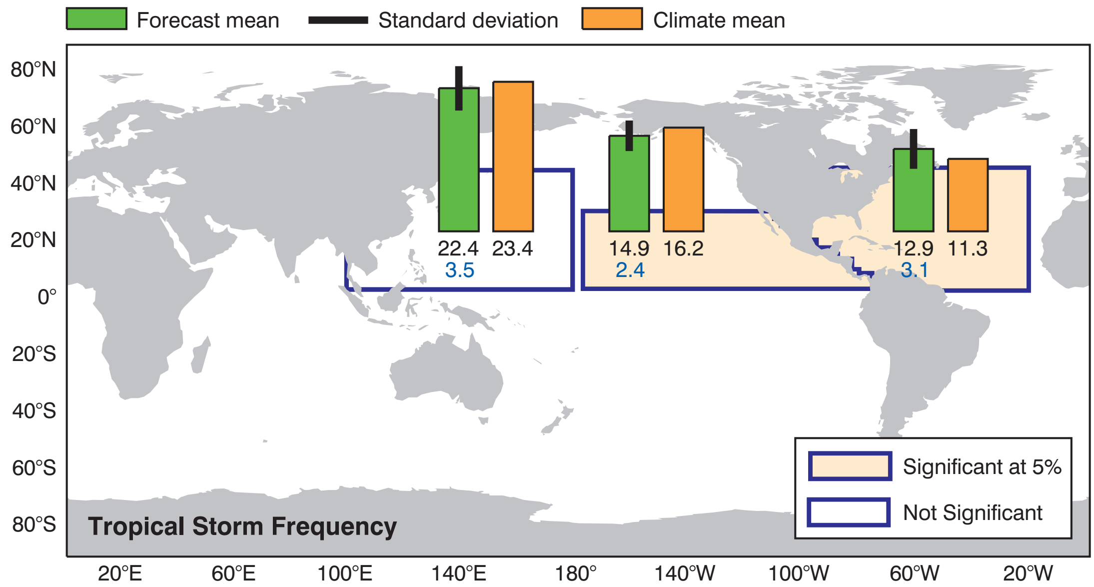


Figure 1 Frequency of model tropical storms. The 41-member ensemble forecast starting on 1 May 2007 for June to October is compared with the climatology for 1981–2005. A Wilcoxon-Mann-Whitney (WMW) test is then applied to evaluate if the predicted tropical storm frequency is significantly different from the climatology. The ocean basins where the WMW test detects a significance larger than 90% have a shaded background. Green bars represent the ensemble mean of the forecast and orange bars represent climatology. The values of each bar are written in black. The black bars represent ±1 standard deviation within the ensemble distribution, these values are indicated by the blue numbers.

are displayed on the ECMWF web site. Because of the seasonality of tropical storms, forecasts over the North Atlantic, Eastern North Pacific and Western North Pacific are issued only from March to August, and forecasts over the southern hemisphere are issued only from September to February. The first month of the forecast is excluded since the forecasts are issued on the 15th of the first month. Since April 2007, the forecasts are produced using ECMWF System 3 instead of ECMWF System 2. The products are available to ECMWF Member States and WMO users.

The forecasts are produced by tracking the tropical storms in the atmospheric component of the ECMWF seasonal forecasting system. The number of model tropical storms is counted over each basin. Dynamical models tend to drift towards a climate that is different from the observed climate. The effect of the drift on the model calculations is estimated from integrations of the model for previous years (the re-forecast). The drift is then removed from the model solution *a posteriori* (the calibration). For most model variables, including sea-surface temperature, the drift is treated as a bias and removed

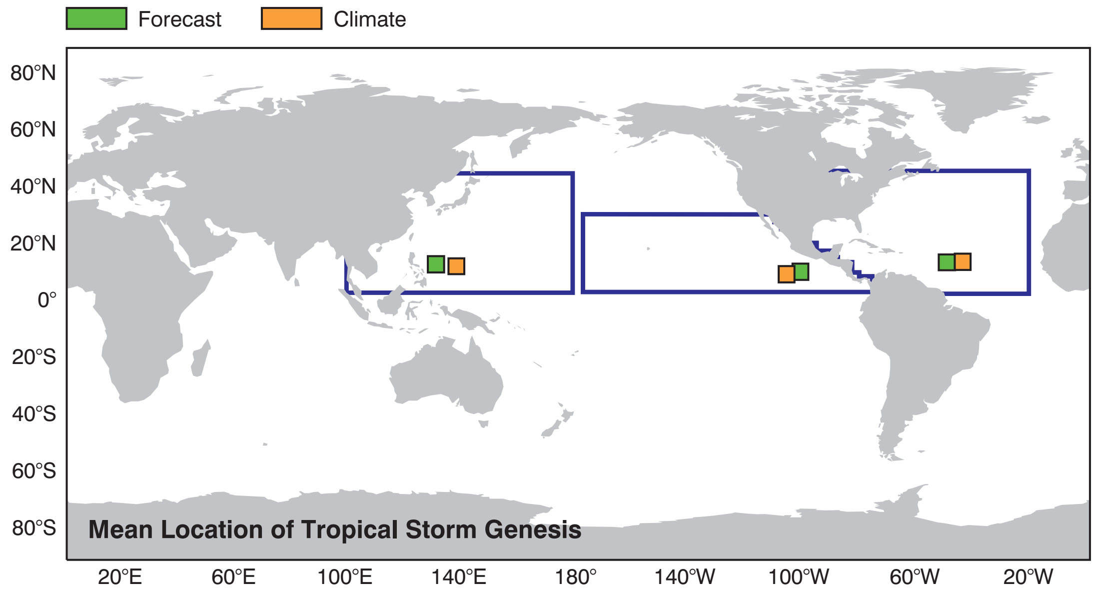


Figure 2 Mean genesis locations of model tropical storms. The green square represents the mean location from the ensemble forecast starting on 1 May 2007 for June to October, and the orange square the mean genesis location from the model climate for 1981–2005.

additively. For tropical storm numbers, the model climate can differ substantially from the observed climate. In this case, we calibrate the number of tropical storms in a given year by considering it relative to the central distribution of the climate; that is we multiply the number of model storms by a factor such that the central distribution of the model climate equals the central distribution of the observed climate. It would be possible to estimate both a mean offset and a correction of the model variance independently. However, this introduces an additional degree of freedom which is undesirable in such a small dataset.

Tropical storm detection

A major problem when tracking storms from model forecasts and analyses consists of detecting as many tropical storms as possible without detecting extra-tropical storms or weak tropical depressions that have a different inter-annual variability. Therefore, the criteria for detecting a model tropical storm have been chosen to be harsh enough so that, when applied to ECMWF analyses projected on the same low resolution as the dynamical model outputs, almost all systems detected correspond to observed tropical storms. The algorithm to detect the simulated tropical storms is the following.

1.1 A local maximum of vorticity more than 3.5×10^{-5} s^{-1} at 850 hPa is located and the closest minimum sea level pressure is defined as the centre of the storm.

1.2 The closest local maximum of averaged temperature between 500 and 200 hPa is located and is defined as the centre of the warm core. The distance between the centre of the warm core and the centre of the storm must not exceed 2° latitude. From the centre of the warm core the temperature must decrease by at least 0.5°C in all directions within a distance of 8° latitude.

1.3 The closest local maximum thickness between 1000 and 200 hPa is located. The distance between this local maximum and the centre of the storm must not exceed 2° latitude. From this local maximum, the thickness must decrease by at least 50 m in all directions within a distance of 8° latitude.

To locate the position of the centre with a higher precision than the model resolution, bicubic splines interpolate the fields from the grid-point values and then a conjugate gradient algorithm locates the position of a maximum or a minimum of the fields. After the storms are located for each day, the following objective procedure is applied to find storm trajectories.

2.1 For a given storm, it is determined whether there are storms that appear on the following day at a distance of less than a maximum distance which depends on the model resolution.

2.2 If there is no such storm, the trajectory is considered to have stopped. If there is more than one storm, a preference is given to a westward and poleward trajectory since the majority of tropical storms move in that direction.

2.3 To be considered a tropical storm trajectory, a trajectory must last at least two days, and have a maximum wind velocity within an 8o circle centred in the middle of the storm, which must be larger than a certain threshold at 850 hPa. The threshold is dependent on the model resolution.

Cases satisfying these criteria are referred to as model tropical storms. In order to get longer trajectories that include the phase when the tropical storm is a tropical depression, criteria 1.2, 1.3 and 2.3 need to be verified only during two days.

Comparison of results from System 2 and System 3

Tropical cyclone tracks

Tropical storms have been tracked in the ECMWF seasonal forecasting system using the algorithm described above. The model tropical storms appear in the same regions as those observed. As in observations, there are no model tropical storms in the South East Pacific and they are very rare in the South Atlantic.

The realism of the model tropical storm tracks is strongly related to the resolution of the atmospheric model and there has been a clear improvement in the realism of the model tropical storm tracks between System 2 with a T95 resolution and System 3 which has a higher horizontal resolution of T159. Figure 3 gives an example of some cyclone trajectories produced by System 2 and System 3.

Frequency of model tropical storms

Figure 4 shows the mean number of tropical storms per year during the period 1987–2004 over each ocean basin obtained with Systems 2 and 3, along with the observed annual frequency from operational centres such as the National Hurricane Center (NHC). System 2, which has a coarser resolution than System 3, produces globally about half the number of observed tropical storms. On the other hand System 3 has a more realistic climatology with about 80 tropical storms per year globally compared to 90 observed tropical storms. However, System 3 still underestimates strongly the number of tropical storms over the Eastern North Pacific, although the deficit in this basin is smaller than in System 2.

Seasonal variability

The number of model tropical storms has been calculated for each month. Over the North Atlantic the ECMWF seasonal forecasting system has a peak activity in August-September-October as observed (Figure 5). However, the model has too many Atlantic tropical storms at the beginning of the season and too few during the peak season. Over the Eastern and Western North Pacific basins, the model tropical storms occur at the same time as those observed, but the peak period is one month too late. Over the southern hemisphere the model simulates storms from September to April as observed. The North Indian Ocean is the only basin where the model seasonal cycle is badly wrong. There

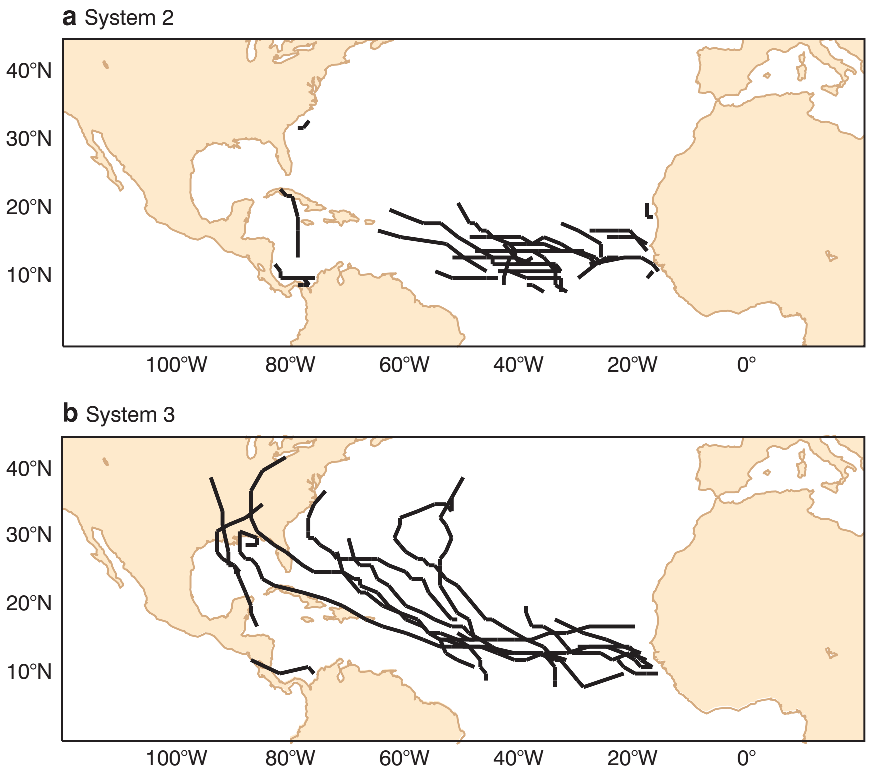


Figure 3 An example of an ensemble of trajectories in (a) System 2 and (b) System 3. The tracks are produced by forecasts starting on 1 June 2000. For reason of clarity just three ensemble members are shown.

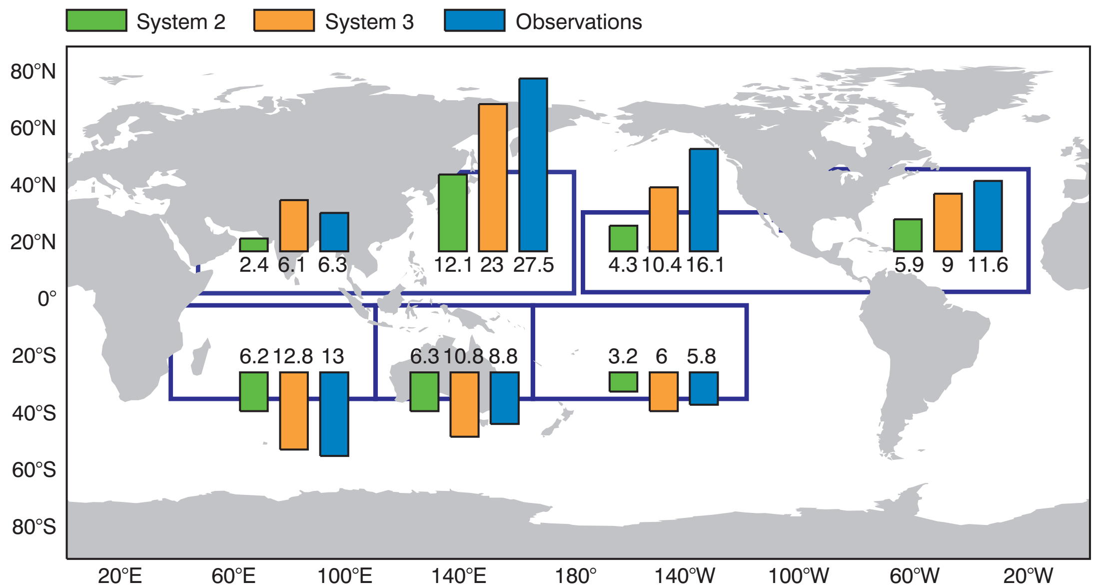


Figure 4 Number of tropical storms per year over the period 1987–2004. The green bars represent the number of tropical storms simulated by System 2. The orange bars represent the number of tropical storms simulated by System 3. The blue bars represent the observed frequency.

are two tropical cyclone seasons over the Indian Ocean: from April to June and from September to December. The model tropical storms display only one season over the North Indian Ocean, which peaks in July and August. This is probably because monsoons troughs are wrongly identified as tropical cyclones. For this reason, seasonal forecast of tropical storms over the North Indian Ocean are not issued.

Calibration factor

As discussed above, the number of tropical storms predicted by the seasonal forecasting system is calibrated a posteriori by multiplying it by a factor such that the central distribution of the model climate equals the central distribution of the observed climate. Table 1 shows the calibration factors applied with System 2 and System 3 for the forecasts starting on 1 June over the

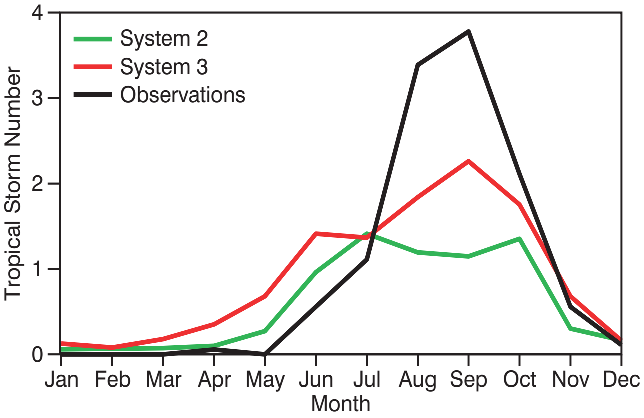


Figure 5 Seasonal cycle of tropical storm frequency over the North Atlantic in System 2, System 3 and observations for 1987–2004.

	ATL	ENP	WNP	SIN	AUS	SPC
System 2	2.6	4.4	2.5	2.1	1.4	2.9
System 3	1.6	1.5	1.6	1.03	0.99	1.0

Table 1 Calibration factors applied to the number of tropical storms predicted by the seasonal forecasting systems over the north Atlantic Basin (ATL), Eastern North Pacific (ENP), Western North Pacific (WNP), South Indian Ocean (SIN), Australian Basin (AUS) and the South Pacific (SPC). The calibration factor depends on the forecast starting dates. Displayed are the calibration factors for the forecasts starting on 1 June for the basins in the northern hemisphere and 1 October for the basins in the southern hemisphere.

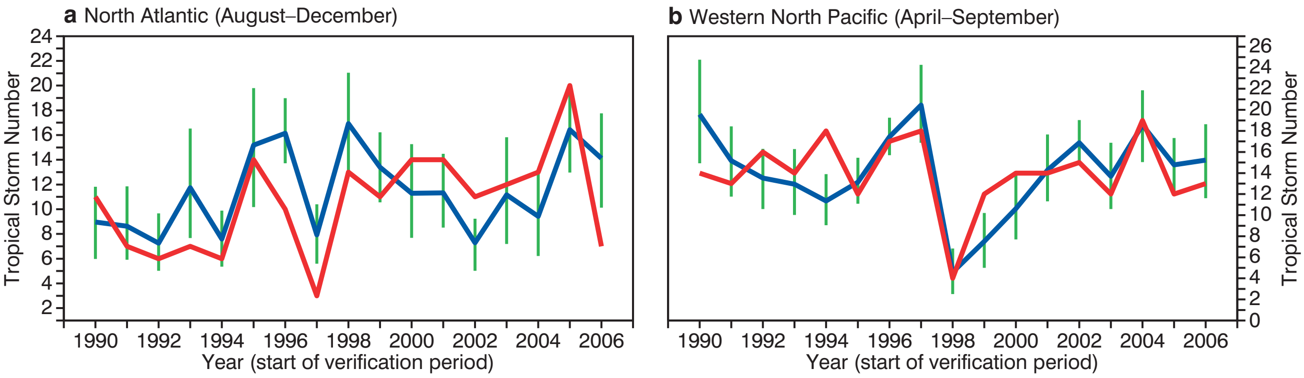
northern hemisphere and 1 October over the southern hemisphere. With System 3, the calibration factors are closer to 1 than with System 2 confirming that the tropical storm climatology is more realistic with System 3 than with System 2. With System 3 the coefficients are indeed very close to 1 in the southern hemisphere. Over the northern hemisphere they are still larger than 1 indicating that the seasonal forecasting System 3 produces too few tropical storms over the period July–October (as can be seen in Figure 5 for the North Atlantic).

Interannual variability

The skill of the ECMWF seasonal forecasting System 3 to predict the frequency of tropical storms is assessed by tracking the model tropical storms in the 11-member re-forecasts and comparing their frequency to observations from operational centres over the period 1990 to 2006. The period 1990–2006 was chosen because it is long enough to assess the skill of the model to predict the interannual variability of tropical storms, and short enough to reduce the impact of decadal variability.

The skill of System 3 to predict the interannual variability of tropical storms depends strongly on the starting date and the basin. Over the North Atlantic, the model has some moderate skill in predicting the number of tropical storms a few months in advance, with a linear correlation with observations of the order of 0.5 for the forecasts starting from April to August. Figure 6(a) shows the interannual variability of tropical storms for the forecasts starting on 1 July. The linear correlation is 0.56 and the RMS error is 3.6, which is lower than the RMS error of 4.3 obtained with climatology.

The model displays the strongest skill in predicting the interannual variability of tropical storm frequency over the Western North Pacific for the forecasts start-



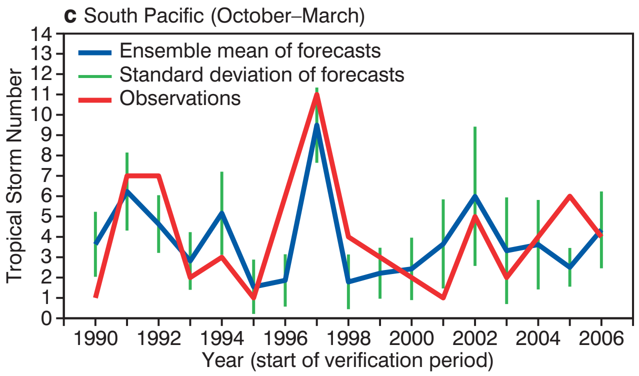


Figure 6 (a) Ensemble mean of the number of tropical storms over the North Atlantic for the period August to December from forecasts starting on 1 July for 1990 to 2005 using System 3. The solid blue line represents the ensemble mean of the forecast starting on 1 July and the vertical green line represents two standard deviations. The dotted red line corresponds to the observed number of tropical storms. (b) As (a) but for the Western North Pacific with the forecasts starting on 1 March and covering the period April to September. (c) As (a) but for the South Pacific with the forecasts starting on 1 September and covering the period October to March.

Start of forecasts	Linear Correlation	
	ECMWF	EUROSIP
1 April forecast	0.49	0.68
1 May forecast	0.50	0.71
1 June forecast	0.51	0.74

Table 2 Linear correlation between the predicted number of tropical storms and the observed frequency during the period 1993–2006 (one of the EUROSIP models has no re-forecasts before 1993).

ing from January to April (see example in Figure 6(b) for the forecasts starting on 1 March) and the South Pacific for the forecasts starting from July to September (see example in Figure 6(c) for the forecasts starting on 1 September). Over those basins the linear correlation with observations exceeds 0.7. Over the other ocean basins the model has generally no skill in predicting the interannual variability of tropical storms, except maybe over the Australian basin for the forecasts starting in November and December.

Multi-model operational forecasting

EUROSIP combines real-time seasonal forecasts from ECMWF System 3, the Met Office System 3 and Météo-France System 2. A detailed description of EUROSIP can be found at:

www.ecmwf.int/products/forecasts/seasonal/forecast/forecast_charts/eurosip_doc.htm.

EUROSIP seasonal forecasts of tropical storms are produced by combining the forecasts of the individual models. The combination is performed by giving the same weight to all the models. Figure 7 shows an example of a EUROSIP forecast.

The skill of EUROSIP in predicting seasonal forecast of tropical storms has been assessed. Results suggest that the skill of EUROSIP is generally larger than that of the individual models. Over the North Atlantic for instance EUROSIP has stronger skill in predicting the interannual variability of tropical storms than ECMWF System 3 alone (see Table 2). The linear correlation between EUROSIP and observations exceeds 0.6 for the Atlantic forecasts starting from April to June.

What's next?

Seasonal forecasts of tropical storm activity (frequency and mean genesis location) have been issued on a regular basis using the ECMWF seasonal forecasting system since 2001. Since March 2007, those forecasts are produced using System 3 instead of System 2. The increased resolution in System 3 helped to produce a more realistic climatology of tropical storms.

The present system has some skill in predicting the interannual variability of tropical storms over basins such as the Atlantic, Western North Pacific, Australian basin and the South Pacific. This is mostly a consequence of the skill of the ECMWF seasonal forecasting system to predict ENSO and tropical SST variability in general.

Future plans include investigating the skill of the model to predict the risk of landfall over specific regions. The clear improvement in tropical storm tracks from System 2 to System 3 might make it possible to produce direct forecasts of tropical storm landfall. Alternatively, statistical techniques could be applied to infer landfall probabilities from model outputs. The skill of the model to predict heavy precipitations associated to the tropical storms will also be investigated. This could be important for predicting the risk of floods or landslides.

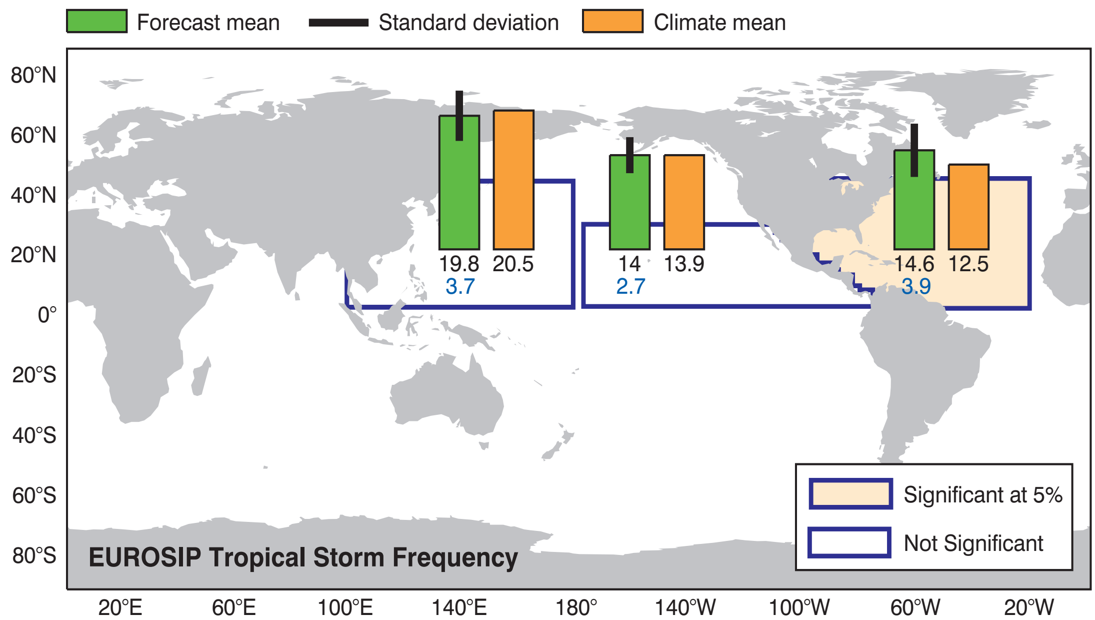


Figure 7 Same as Figure 1 but from EUROSIP and for the period June to October instead of June to November (EUROSIP forecasts are six-month long, whereas ECMWF System 3 forecasts are seven-months long).

The skill of the seasonal forecasting system to predict the frequency of hurricanes or typhoons (tropical storms with a maximum wind speed exceeding 32 m s^{-1}) and some hurricane activity indices like ACE (Accumulated Cyclone Energy) is also being explored. Such statistics may be more useful than the current tropical storm predictions, since most of the damage is caused by hurricanes rather than by weak tropical storms. Thanks to its relative high resolution, System 3 produces a reasonable number of hurricanes, although none of them reach category 5. This makes it possible to issue hurricane forecasts using System 3.

Preliminary results suggest that System 3 has some skill in predicting the interannual variability of hurricanes or typhoons, particularly over the North Atlantic and Western North Pacific. For instance, the linear correlation between the observed number of hurricanes and the ensemble mean of the 1 July forecasts over the North Atlantic from 1990 to 2006 is 0.71.

FURTHER READING

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A new radiation package: McRad

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A NEW radiation package (McRad) became operational in the ECMWF Integrated Forecast System (IFS) on 5 June 2007 (Cy32r2). It includes a new short-wave radiation scheme and a revised cloud optical properties. In addition the Monte-Carlo Independent Column Approximation (McICA) for radiation transfer is used to ensure an unbiased, though noisy, description of the radiative fields over appropriate time and space scales. This package was extensively tested in all the IFS model configurations: in high-resolution T799L91 deterministic ten-day forecasts, as part of the T399L62 Ensemble Prediction System (EPS), and in lower-resolution (T159) versions of the ECMWF model used for model development and seasonal forecasts. A new specification of the land surface albedo derived from MODIS (Moderate-resolution Imaging Spectroradiometer) observations is also part of the McRad package.

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The impact of McRad on year-long simulations with a low-resolution (T159L91) version of the model and on ten-day forecasts at high resolution is illustrated in this article, with comparisons made against observations and the previous operational model configuration (Cy31r2). In long simulations, McRad has a marked effect in reducing some systematic errors in the position of tropical convection. This is due to change in the overall distribution of diabatic heating over the vertical, inducing a geographical redistribution of the centres of convection. At high resolution, with respect to simulations with the standard radiation schemes, McRad has a marked positive impact on tropical temperatures and winds, and a small but positive impact on objective scores for the geopotential.

Computing radiative fluxes

The common perception of clouds is that they are eminently variable in shape, texture, horizontal and vertical extent. However, their representation in a large-scale atmospheric model (LSAM), such as the ECMWF forecasting system, is one of the major challenges in the parametrization of physical processes.

At the grid-scale of the ECMWF model (i.e. between 25 km at T799 and 125 km at T159), domain-averaged radiative fluxes in clouds with substantial horizontal and vertical variability could in principle be determined quite accurately using the plane-parallel independent column approximation (ICA) by averaging the flux computed for each class of cloud in turn. Unfortunately, such an ICA-based method is too computationally expensive for dealing with radiation transfer in a LSAM.

Various approximations have been introduced over the years to compute domain-averaged radiative fluxes for internally variable clouds, all invoking assumptions about the nature of the horizontal variability or how cloud layers are linked in the vertical. Regardless of what assumptions are made about these unresolved structures, estimates of radiative heating should theoretically become increasingly unbiased at increasingly large spatial and temporal scales. However, this is generally not the case, and climate simulations have been shown to be very sensitive to seemingly small, but systematic, alterations to cloud optical properties.

Recently, *Barker et al.* (2003) and *Pincus et al.* (2003) introduced a new method for computing broadband radiative fluxes in LSAMs yielding unbiased radiative fluxes with respect to ICA over an ensemble average of one-dimensional radiation transfer simulations. It is referred to as the Monte-Carlo Independent Column Approximation (McICA). The most attractive features of McICA are two-fold.

- McICA extricates the description of the sub-grid scale cloud structure from the radiative transfer algorithm through a cloud generator. This provides the cloud parameters for the radiation schemes by sampling the cloud information randomly from the cloud fraction and water profiles provided by the LSAM.
- The radiative fluxes from McICA, unbiased with respect to ICA, are consistent with assumptions made about the unresolved structure in other parts of the model. In practice, this sub-grid scale cloud structure is related either to the overlapping of the cloud layers in the vertical and/or to the horizontal variability of the cloud characteristics.

Whether in the vertical or the horizontal, the cloud characteristics referred to above correspond to input parameters in a traditional radiation transfer scheme. These are the distribution of condensed water in various phases and the distribution of the particle effective dimension; together with the distribution of intervening gases these input parameters should define the radiation exchange on the vertical within a grid of the LSAM. As with ICA, McICA does not account for true three-dimensional transfer effects, but those can generally be neglected.

The rest of this article will cover the following topics.

- The impact of the new land surface albedo.
- The McICA approach, with some details about the cloud generator and the long-wave and short-wave radiation schemes that use the cloud information.
- The impact of using a radiation grid different from the one used for the dynamics and other physical calculations.
- Comparisons of forecasts from the extended experimental suite that ran parallel to the operational suite from December 2006 to April 2007.
- Results obtained with McRad in annual simulations with the T159L91 version of the model.

A summary and some perspectives are given at the end of the article.

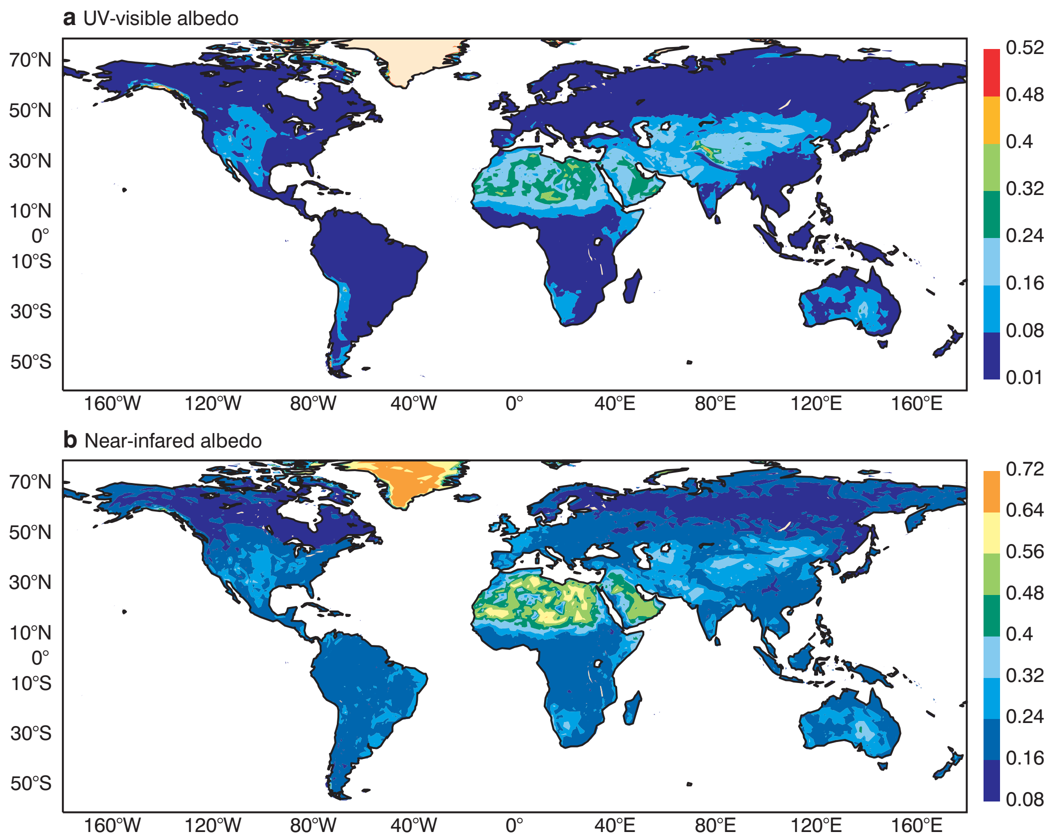


Figure 1 The land surface albedo derived from MODIS observations for April at TL799 for (a) UV-visible (0.3–0.7 μm) and (b) near-infrared (0.7–5.0 μm) part of the short-wave spectrum.

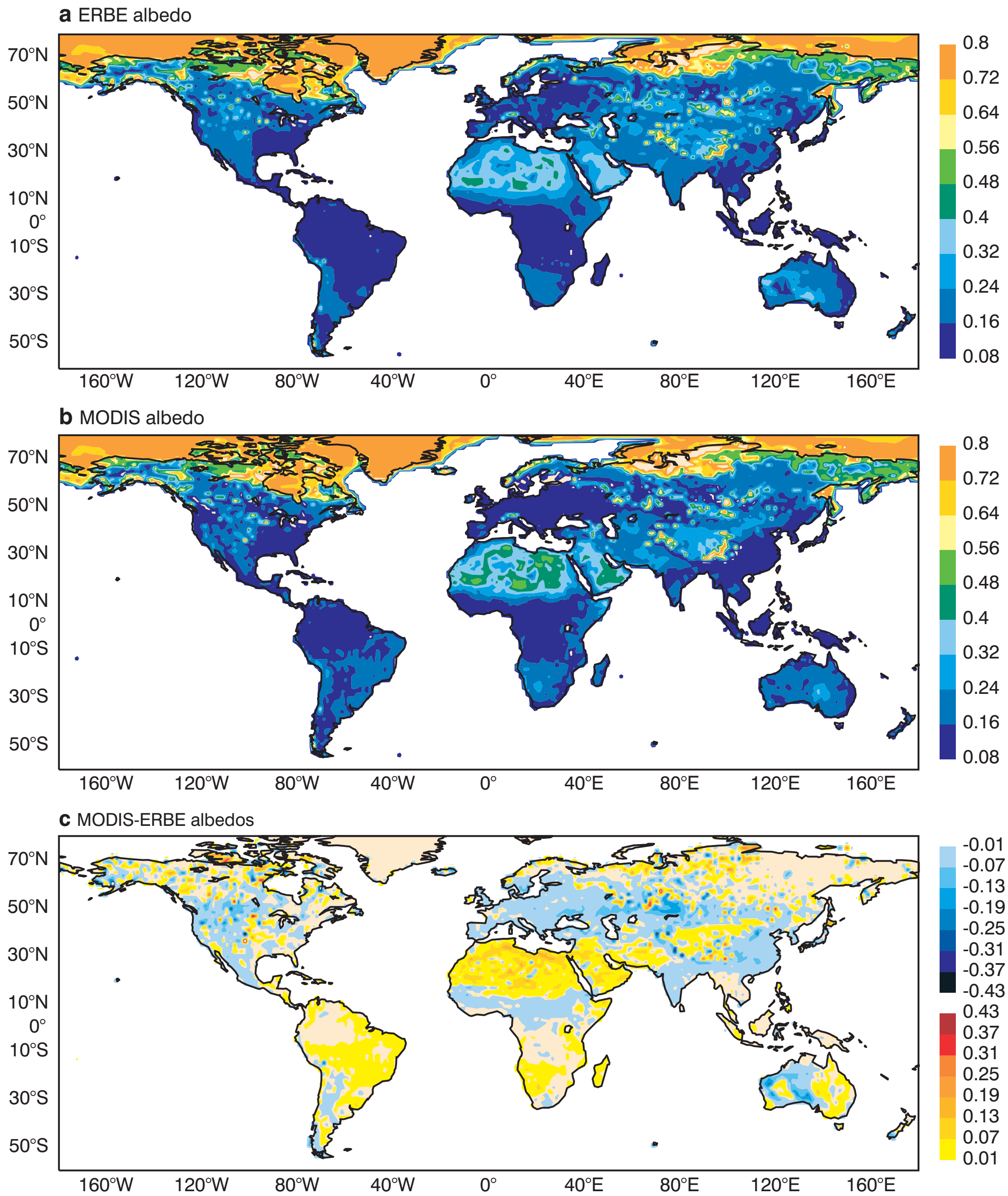


Figure 2 (a) The land surface albedo over the entire short-wave spectrum for April as seen by the model at T799 using the spectrally flat ERBE-derived albedo. (b) As (a) but using the various MODIS components to derive the albedo. (c) Difference between the MODIS and ERBE albedos.

A climatology of land surface albedo derived from MODIS observations

A new climatology of land surface albedo has been introduced into the IFS to be used as boundary conditions in short-wave flux computations. The albedo has been derived from more recent and more spatially detailed satellite observations than the previously operational land surface albedo derived from ERBE (Earth Radiation Budget Experiment) observations. In addition this MODIS albedo will be consistent with the MODIS-derived surface reflectances that will be used when computing synthetic MODIS radiances for aerosol analysis as part of the GEMS Aerosol Project (a project aimed at providing operational aerosol products). This new climatology was derived from the 2001–2004 datasets produced at Boston University (*Schaaf et al.*, 2002) by processing the MODIS observations at 1 km spatial resolution over 16-day periods. The wide-band albedo, given for direct and diffuse radiation in both the UV-visible and near-infrared parts of the short-wave spectrum, replaces the monthly mean spectrally flat albedo previously derived from ERBE observations.

Figure 1 presents the UV-visible (0.3–0.7 μm) and near-infrared (0.7–5.0 μm) components of the short-wave albedo for April derived from MODIS, showing the large difference between these two components over most surfaces. The higher near-infrared values over vegetated areas increase the cloud-surface interactions. Figure 2 compares the previous operational spectrally flat (0.3–5.0 μm) land surface albedo derived from

ERBE observations with the equivalent surface albedo obtained from the ratio of the upward and downward short-wave fluxes with the new albedo. The impact on objective scores in ten-day forecasts at T799L91 from the change in surface albedo is marginal.

The Monte-Carlo Independent Column Approximation

The McICA approach is an approximation to the full Independent Column Approximation (ICA). The full ICA calculation of a cloudy flux (say, at the top of the atmosphere) is a two-dimensional integral with wavelength varying in one dimension and cloud state in the other. Rather than computing the contribution of every cloud state to every wavelength interval, McICA approximates the flux by choosing a cloud state at random for each spectral interval (see Box A for more details).

McICA can in principle be used within any radiation transfer scheme provided a cloud generator is used to define how the cloud information is distributed over each spectral element in the radiation spectrum. However, to take full benefit of the McICA approach, radiation schemes with a sufficiently large number of transmission calculations are required. With the version of the ECMWF model used for this study, the long-wave radiation fluxes are computed using the Rapid Radiation Transfer Model ($RRTM_{LW}$) already in use at ECMWF since June 2000. For consistency in terms of radiative transfer solution and database of spectroscopic parameters, the short-wave radiation fluxes are now computed with $RRTM_{SW}$. The application of the McICA approach involves using a cloud generator together with slightly modified but otherwise standard radiation schemes.

The main features of the McRad radiation package are summarised in Box B. The McICA versions of $RRTM_{LW}$ and $RRTM_{SW}$ differ from the original versions in two respects.

- Avoiding any explicit reference to cloud fraction greatly simplifies the part of the algorithms devoted to the vertical integration, which now deals simply with optical thicknesses. Any cloudy calculation only involves modifying the optical parameters.
- Using McICA enables the removal of the 0.7 correction factor multiplying the cloud optical thickness, which was introduced in December 1997 into the IFS to take approximate account of the effect of cloud inhomogeneities at the sub-grid level.

As stated earlier, the McICA representation of cloud-radiation interactions requires the cloud information to be distributed by a cloud generator over the vertical with the constraint that the total cloudiness and cloud water loading for a grid-point is conserved.

The purpose of the cloud generator is, starting from a cloud profile (cloud fraction and cloud water content) provided by a traditional cloud scheme, to distribute randomly the cloud information (in terms of presence (1) or absence (0)) into each of the layers covered by the original cloud profile. This distribution is done N times (McICA with N going to infinity would be equal to ICA) with the constraint that a summation over the N profiles would recreate the original vertical distribution of partial cloudiness. In the ECMWF model, for each radiation time-step (every one hour of model time for the T799L91 forecast) and each radiation grid-point, the cloud generator is used twice: it produces two cloud distributions relevant to the long-wave and short-wave radiation schemes. We use the cloud generator of *Räisänen et al.* (2004) that can distribute vertically either the cloud cover according to a maximum-random overlap assumption or both the cloud cover and cloud water assuming a generalized overlap (*Hogan & Illingworth*, 2000). The results presented hereafter correspond to the operational McRad configuration with a generalized overlap with decorrelation lengths of 2 km for cloud cover and 1 km for cloud water, and a normalized standard deviation of 1 for the cloud condensate.

Box A

The McICA approach

For the full independent column approximation (ICA), the average monochromatic radiative flux, over a domain sub-divided in N columns, in which each layer can only have a cloud fraction of 0 or 1, is

$$\langle F \rangle = \frac{1}{N}\sum_{n=1}^{N} F_n \quad (1)$$

In sub-column n, using a radiation parametrization (plane-parallel, and considering a homogeneous cloud water distribution in all overcast layers) with a correlated k-distribution (CKD) approach to deal with absorption, the total flux F_n is

$$F_n = \sum_{k=1}^{K} c_k F_{n,k} \quad (2)$$

Combining (1) and (2) gives

$$\langle F \rangle = \frac{1}{N}\sum_{n=1}^{N}\sum_{k=1}^{K} c_k F_{n,k} \quad (3)$$

A radiation code explicitly integrating the double sum in (3) would be far too expensive for LSAM applications. The McICA solution to this problem is to approximate (3) as

$$\langle F \rangle_M = \sum_{k=1}^{K} F_{n_k,k} \quad (4)$$

where $F_{n_k,k}$ is the monochromatic radiative flux for a single randomly selected sub-column nk.

From this definition, the McICA solution (4) equals the ICA solution only when all N sub-columns are identical or $N = 1$. As discussed in *Räisänen & Barker* (2004), McICA's incomplete pairing of sub-columns and spectral intervals ensures that its solution will contain random, but unbiased, errors.

Clouds when present occupy the full horizontal extent of the layer, and the vertical distribution of such clouds (of 0 or 1 cloud cover) is defined independently for the long-wave and short-wave schemes by the cloud generator, with the constraint that the total cloudiness and cloud water loading for a grid-point is conserved when *N* tends to infinity.

In all comparisons discussed hereafter, the pre-McRad model (Cy31r2) uses the ECMWF six spectral interval version of the short-wave radiation code, with a slightly different set of cloud optical properties. In tests not discussed here, it was shown that replacing the operational short-wave radiation scheme by $RRTM_{SW}$ alone or changing the cloud optical properties, while affecting the radiation fields, did not have much affect on the systematic errors shown by the ECMWF IFS in 13-month simulations at T159L91. Only the full McRad package with the suppression of the 0.7 inhomogeneity factor, the use of the McICA approach within $RRTM_{LW}$ and $RRTM_{SW}$, and the revised cloud optical properties shows the positive impact discussed below.

Box B

Main features of the McRad radiation package

The main features of the McRad radiation package are summarised in the table

	$RRTM_{LW}$	$RRTM_{SW}$
Solution of Radiation Transfer Equation	Two-stream method	Two-stream method
Number of spectral intervals	16 (140 g-points)	14 (112 g-points)
Absorbers	H_2O, CO_2, O_3, CH_4, N_2O, CFC_{11}, CFC_{12}, aerosols	H_2O, CO_2, O_3, CH_4, N_2O, CFC_{11}, CFC_{12}, aerosols
Spectroscopic database	HITRAN, 1996	HITRAN, 1996
Absorption coefficients	From LBLRTM line-by-line model	From LBLRTM line-by-line model
Cloud handling	True cloud fraction	True cloud fraction
Cloud optical properties method	16-band spectral emissivity	14-band τ, g, ω
Data: ice clouds	Ebert & Curry, 1992 Fu et al., 1998*	Ebert & Curry, 1992 Fu, 1996*
Data: water clouds	Smith & Shi, 1992 Lindner & Li, 2000*	Fouquart, 1987 Slingo, 1989*
Cloud overlap assumption set up in cloud generator	Maximum-random or generalised*	Maximum-random or generalised*
References	Mlawer et al., 1997 Morcrette et al., 2001	Mlawer & Clough, 1997

Characteristics of the long-wave and short-wave radiation schemes in McRad. The items marked with * refer to the configuration operational with McRad.

The ECMWF version of $RRTM_{LW}$ describes the long-wave spectrum with 16 spectral intervals, corresponding to a total of K=140 g-points. In a nutshell, a g-point is a point in the space of the line intensities within a spectral interval. $RRTM_{SW}$ (*Mlawer & Clough*, 1997) describes the short-wave spectrum with 14 spectral intervals, corresponding to K = 112 g-points. For each of these g-points, an essentially monochromatic type radiation transfer is carried out using a two-stream method using an approximate provision for the long-wave scattering and using a Delta two-stream method with scattering in the short-wave. For a given g-point, a cloud when present fully occupies a model layer.

A different radiation grid for McRad

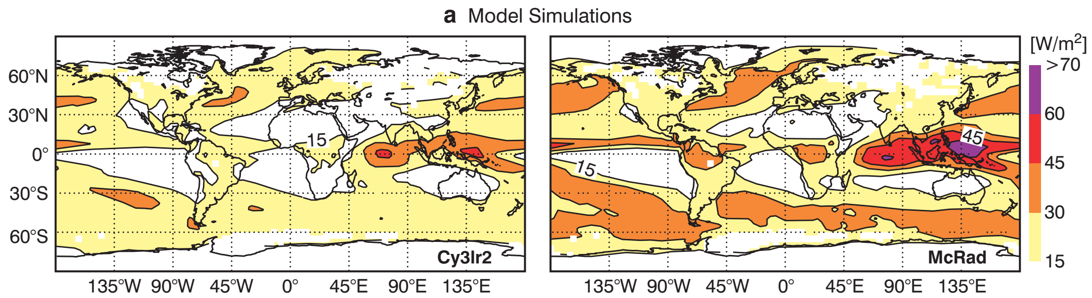
A new interface for radiation computations was developed and implemented in October 2003. Radiation calculations are performed on a grid with a coarser resolution than the current model grid. Interpolations between model and radiation grids are performed using interfaces existing within the IFS libraries and as a result this helps reduce code maintenance. This radiation grid had been used since October 2003, with a coarsening factor of two in both latitude and longitude with respect to the rest of the model.

The implementation of the more computer-intensive McRad, through its use of $RRTM_{SW}$ with an increased number of spectral intervals, has led to the search for an optimal radiation grid for the different weather forecasting applications run at ECMWF. Depending on the model resolution, and the associated time-step and the frequency for calling the full radiation schemes, the cost of the model integration drastically increased. However, comparisons of results with the different radiation grids (from *R*399 to *R*95 for the T799L91 high-resolution model, from *R*255 to *R*31 for the T399L62 model run in the Ensemble Prediction System, from *R*159 to *R*31 for the T59L91 model used for seasonal forecasts) were systematically carried out. For the radiation grid, a best compromise was chosen (*R*319 for T799, *R*95 for T399, *R*63 for T159), which allows the maximum benefit of McRad within the time constraints for delivering the various operational products.

Results for seasonal simulations

Now consider the results from 13-month seasonal simulation at T159L91 using the previous operational model (Cy31r2) and McRad model.

McRad improves the behaviour of the model in a number of aspects: a change in the balance between long-wave and short-wave radiation heating leads to a noticeable shift in the location of the tropical cloudiness (see Figures 3 and 4). This is mainly a feature of McICA,



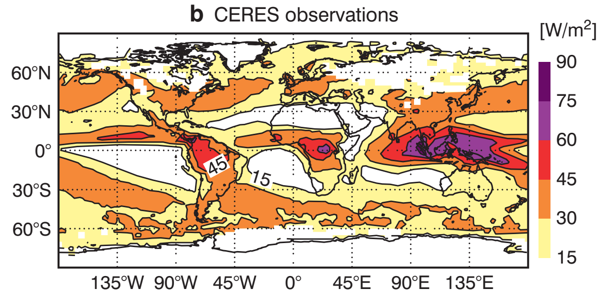
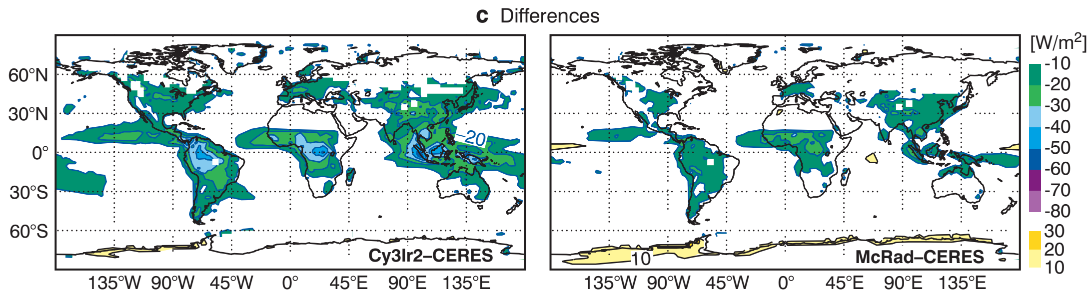
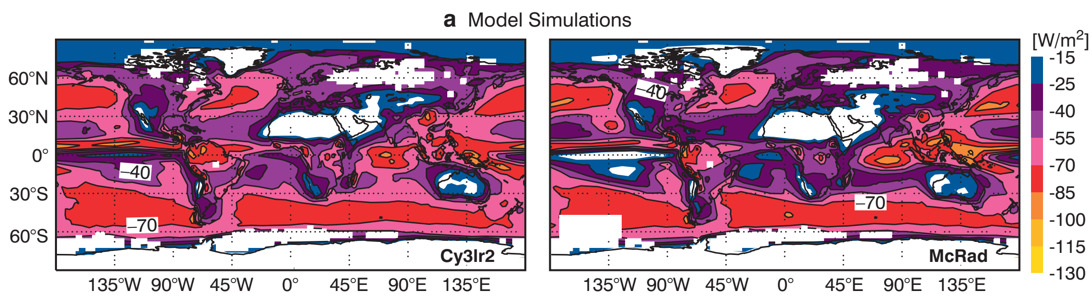


Figure 3 (a) The long-wave cloud forcing (in W m^{-2}) from the seasonal simulation using the Cy31r1 model (left) and McRad model (right). (b) Long-wave cloud forcing (in W m^{-2}) derived from CERES observations. (c) Differences in long-wave cloud forcing (in W m^{-2}) between the Cy31r1 model simulation and CERES observations (left) and between the McRad model simulation and CERES observations (right).





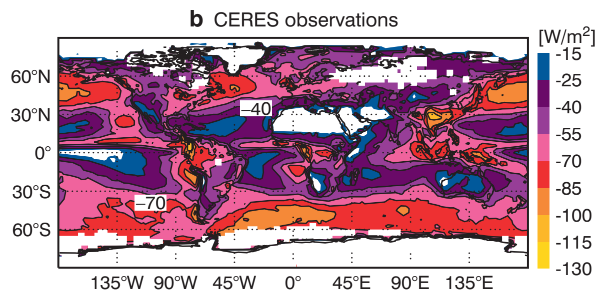
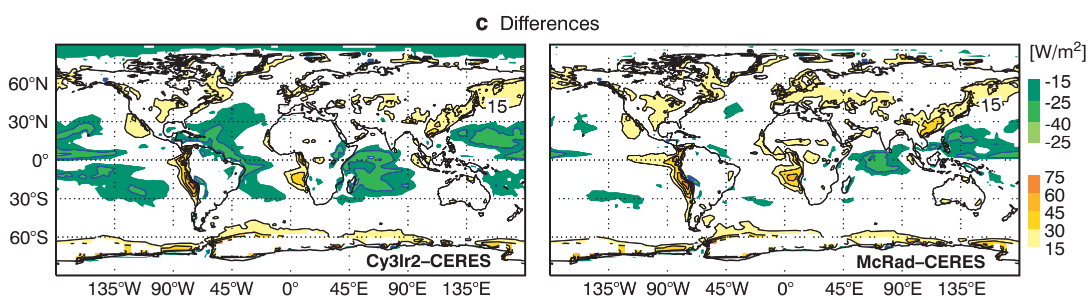


Figure 4 The short-wave cloud forcing (in W m^{-2}) from the seasonal simulation using the Cy31r1 model (left) and McRad model (right). (b) Short-wave cloud forcing (in W m^{-2}) derived from CERES observations. (c) Differences in long-wave cloud forcing (in W m^{-2}) between the Cy31r1 model simulation and CERES observations (left) and between the McRad model simulation and CERES observations (right).



as preliminary tests using $RRTM_{SW}$ (without the McICA approach) instead of the operational short-wave radiation code, or with a different set of cloud optical properties, changed somewhat the overall radiation budget at the top of the atmosphere, but without affecting the negative bias linked to the cloudiness over South America, Africa and the Tropical West Pacific being too small.

Table 1 shows that McRad improves markedly on the top of atmosphere (TOA) radiation biases over these areas. Differences with observations from CERES (Clouds and Earth's Radiant Energy System) are reduced with McRad, with the global annual mean bias changing from -8.1 to -3.2 $W m^{-2}$ for the outgoing long-wave radiation (OLR), from -10.0 to -5.8 $W m^{-2}$ for the absorbed short-wave radiation at the top of the atmosphere (ASW), from -9.6 to -4.0 $W m^{-2}$ for the clear-sky downward long-wave flux (LWCF), and from -5.2 to -0.2 $W m^{-2}$ for the clear-sky downward short-wave flux (SWCF). Table 1 confirms that these improvements happen over the whole year, with a general improvement on the TOA radiative parameters also appearing in winter (December–February) and summer (June–August).

Table 1 also shows that the overall climate of the model is improved in terms of total column water vapour (TCWV), total cloud cover (TCC), total column liquid water (TCLW), and total precipitation (TP). A significant improvement is also seen in terms of temperature and specific humidity, as shown in Figure 5 by comparing the differences between the Cy31r2 seasonal simulation and ERA-40 analysis with the corresponding differences for the McRad simulation.

	OLR ($W m^{-2}$)	ASW ($W m^{-2}$)	LWCF ($W m^{-2}$)	SWCF ($W m^{-2}$)
Observed	–239	244	27.3	–48.7
Cy31r2–Observed	–8.1 (12.7)	10.0 (17.5)	9.6 (13.6)	–5.2 (15.4)
McRad–Observed	–3.2 (7.9)	–5.8 (14.2)	–4.0 (7.9)	–0.2 (12.9)
	TCWV ($kg m^{-2}$)	**TCC** (%)	**TCLW** ($g m^{-2}$)	**TP** (mm/day)
Observed	29.0	62.2	82.2	2.61
Cy31r2–Observed	–2.10 (3.65)	–6.0 (10.3)	1.67 (22.1)	0.45 (1.39)
McRad–Observed	–1.67 (3.13)	–5.3 (9.5)	0.86 (22.4)	0.40 (1.21)

Table 1 Results from 13-month simulations at T159L91 in terms of the bias and standard deviation (in parentheses) for the previous operational model (Cy31r2) and McRad model. Radiative fluxes at TOA are compared to CERES measurements for outgoing long-wave radiation (OLR), absorbed short-wave radiation at the top of the atmosphere (ASW), clear-sky downward long-wave flux (LWCF), and clear-sky downward short-wave flux (SWCF). Also total cloud cover (TCC) is compared ISCCP D2 data, total column water vapour (TCWV) and liquid water (TCLW) to SSM/I data, and total precipitation (TP) to GPCP data.

With McRad, the surface short-wave radiation is increased; this results in a worse agreement with the Da Silva climatology (over oceans only). However, for the ECMWF model run with an interactive ocean, the better geographical distribution of short-wave surface fluxes produced by the new radiation package has been found to be beneficial to the forecasts of ocean surface temperature.

A more extensive discussion of the impact of McRad on 13-month simulations at T159L91 with specified SSTs can be found in *Morcrette* (2006). Here we just point out the major improvements brought by McRad.

Impact on high-resolution ten-day forecasts

An experimental suite, parallel to the operational suite at T799L91, was run from July 2006 to April 2007. This included McRad and some other modifications to the IFS that are unlikely to affect the response of the model beyond the first few days. Results are presented here for December 2006 to April 2007, with some more results specific to January 2007.

The main impact of McRad, compared to the previously operational radiation scheme, is to modify separately the vertical distributions of the additional long-wave and short-wave heatings induced by the presence of the clouds. This is linked to several factors: the revised cloud optical properties, particularly for ice clouds where the effective particle size is now diagnosed from temperature and the local ice water content (only temperature up to Cy31r2) contributes to more radiatively active ice clouds particularly at high latitudes. Through the McICA approach, the effect of the previous 0.7 inhomogeneity factor scaling all cloud optical thicknesses in the long-wave and short-wave parts of the spectrum is replaced by the inherent variability in cloud optical thickness provided by the cloud generator.

The change in radiative heating profiles directly impacts the position of the convective activity, as can be seen in Figure 6. This presents the change in outgoing long-wave radiation (OLR) and absorbed short-wave radiation (ASR) during the first 24 and last 24 hours of the ten-day forecasts for January 2007. In the tropical area the decrease in OLR (a negative quantity) and increase in ASR (a positive quantity) indicates more high level cloudiness over South America, Southern part of Africa and the Tropical West Pacific. The impact over Sahara is linked to the revised surface albedo.

The improvements brought by McRad can be seen in various objective scores. Figure 7 presents the variation in the RMS error of geopotential at 200, 500 and 1000 hPa for the European area computed over the period 1 December 2006 to 30 April 2007. A small but systematic improvement is seen over most of the ten days of the forecasts over Europe. The same kind of improvement is found for the northern and southern hemispheres. The improvement in the location of the major tropical cloud systems has a direct impact on the tropical scores at all heights in the troposphere, as illustrated in Figure 8 for the RMS error of the vector wind at 850 and 200 hPa.

Impact on medium resolution ten-day forecasts used in the Ensemble Prediction System

For ECMWF's Ensemble Prediction System (EPS), the model uncertainties deriving from parametrized physical processes are simulated by applying a random number between 0.5 and 1.5 to the sum of the physical tendencies within a 10°×10° box over three hours. The scaled physical tendencies are then passed to the thermodynamic equation to be solved. Therefore, introducing a more approximate treatment of the radiation tendencies (as through the use of a more reduced radiation grid) is not likely to deteriorate the quality of the EPS forecasts.

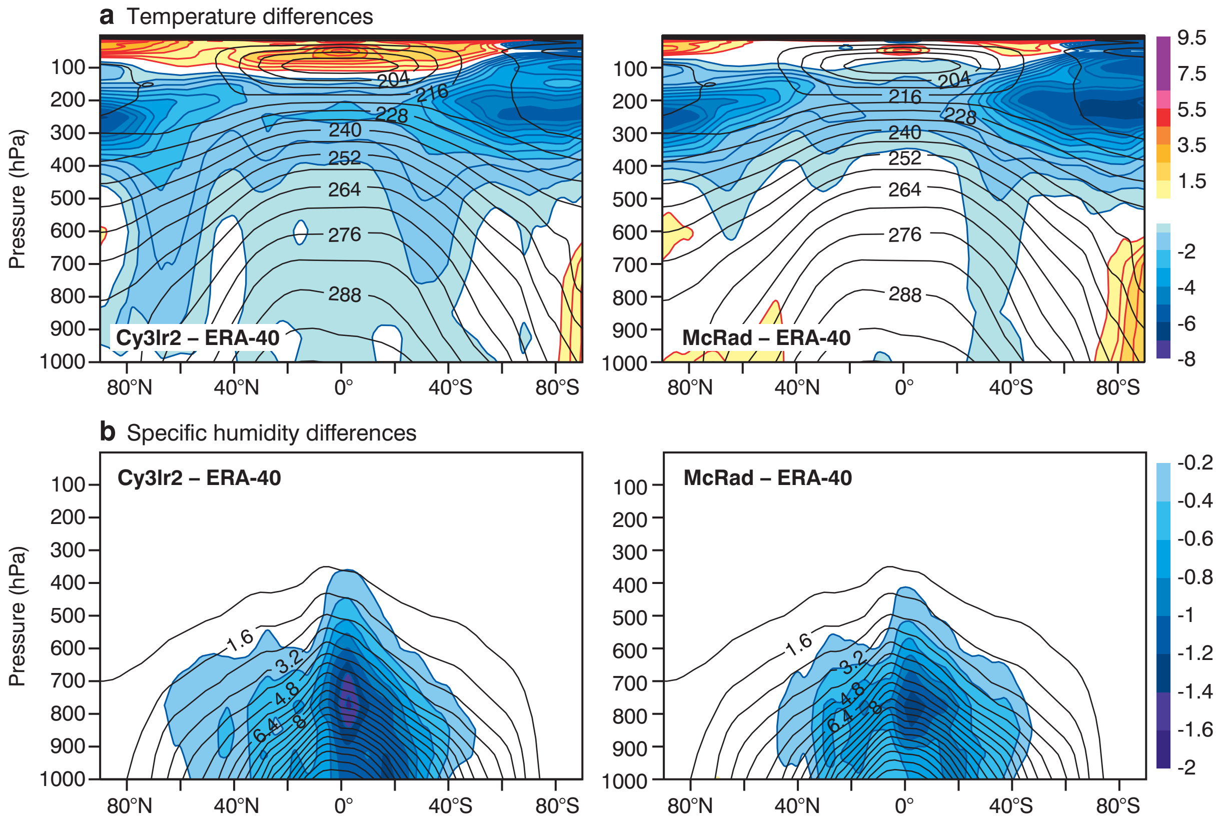


Figure 5 (a) Comparison of the difference between the Cy31r2 seasonal simulation and ERA-40 analysis (left) with the corresponding difference for the McRad simulation (right) for zonal mean temperature (K). (b) As (a) but for specific humidity (kg kg^{-1}).

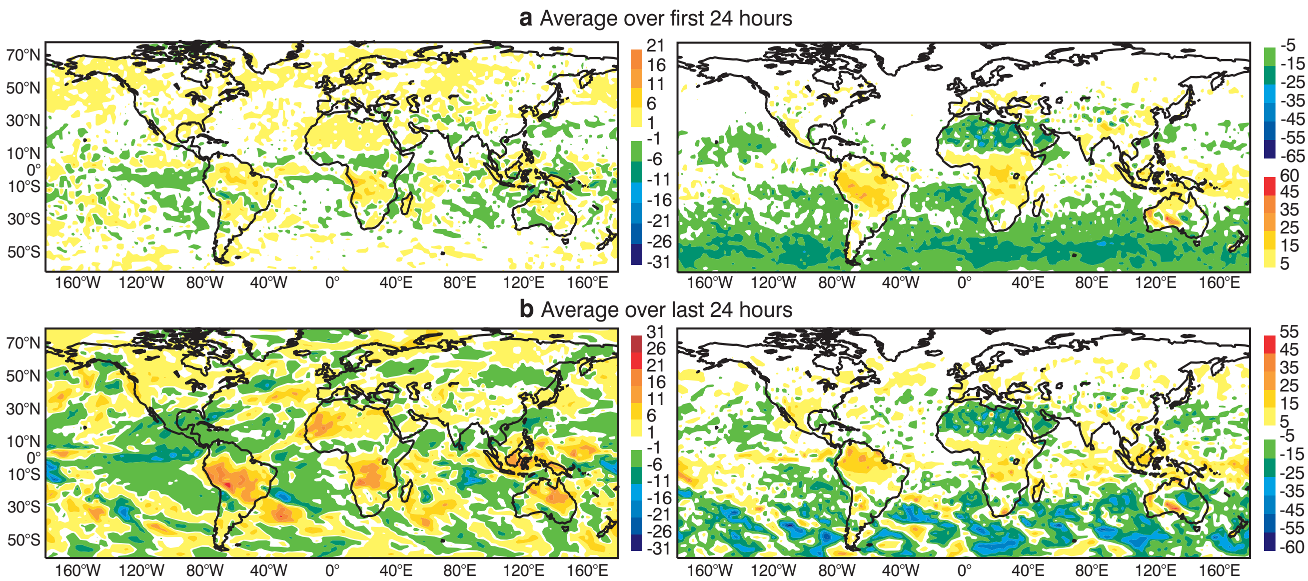


Figure 6 (a) The difference in outgoing long-wave radiation (OLW, left) and absorbed short-wave radiation (ASW, right) at the top of the atmosphere between the McRad and the Cy31r2 simulations averaged over the first 24-hour of the forecasts for the month of January 2007. (b) As (a) but for forecasts averaged over the last 24-hour of the ten-day forecasts. All quantities in W m^{-2}.

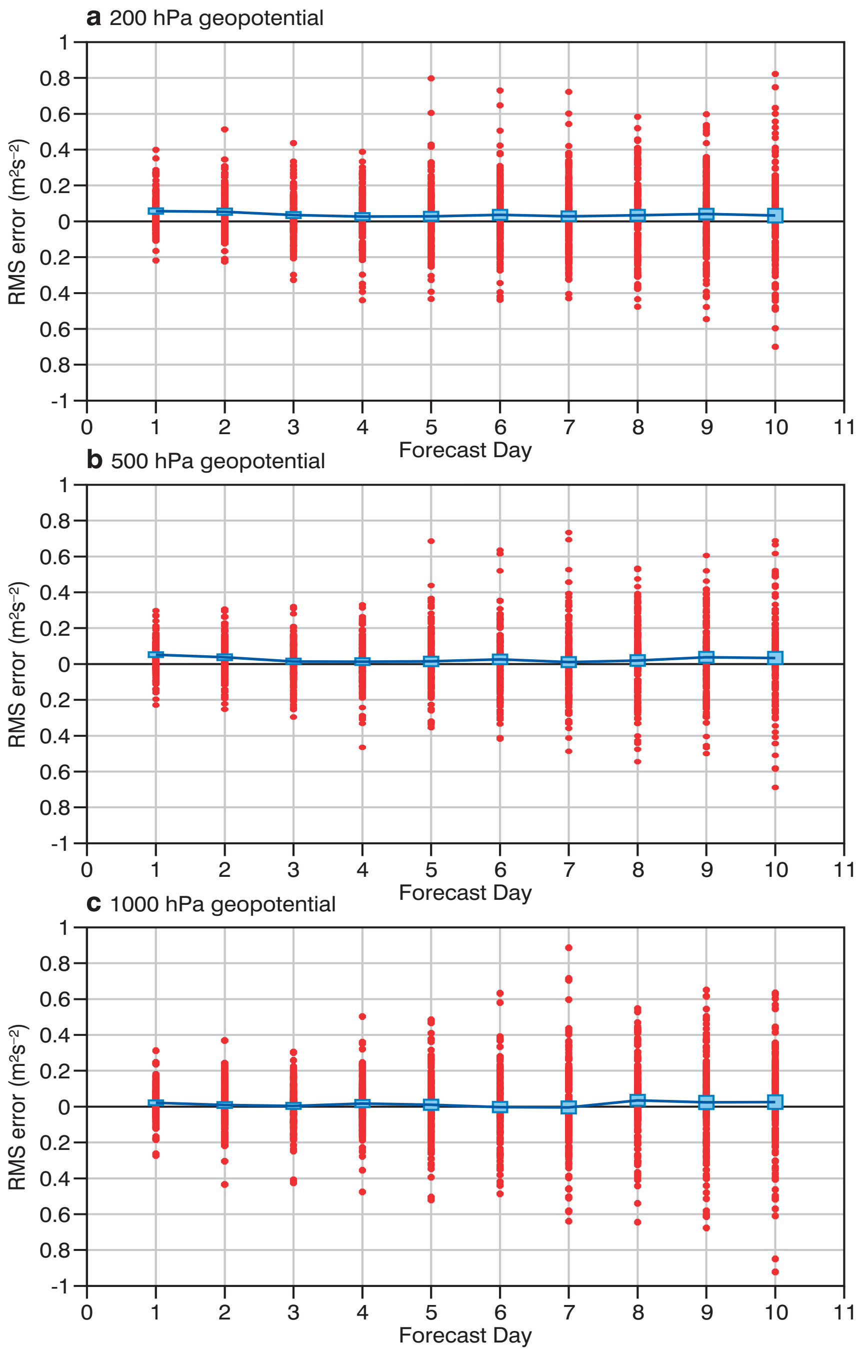


Figure 7 Variation of RMS error of the geopotential in the European area at (a) 200, (b) 500 and (c) 1000 hPa over the period 1 December 2006 to 30 April 2007.

In ten-day forecasts with McRad running the T399L62 model with various resolutions for the radiation grid, the impact on the objective scores was small. For example, Figure 9 presents the RMS error of the temperature at 850 and 200 hPa (the most sensitive parameter) in the tropics for sets of 93 forecasts starting every fourth day spanning a year from 2 February 2006 to 5 February 2007. For these sets of forecasts with the resolution of the radiation grid being reduced from *R*255 to *R*31, the impact on the geopotential is small and does not appear before day 6 of the forecasts. Similarly small is the impact on the RMS error of temperature at 850 and 200 hPa. Only the mean error in temperature at 850 hPa for all areas (northern and southern hemispheres, and tropical area) and the mean error in temperature at 200 hPa in the tropics show a distinct signal. However, the difference between *R*255 and *R*31 (i.e. a radiation grid coarsening from $[0.70°]^2$ to $[5.625°]^2$) is at most 0.06 K. In the tropics, where these differences in temperature between the various radiation grids are the most marked, the impact on the wind is very small. So after further testing of the EPS in pre-operational mode, it was found that reducing somewhat the radiation grid allows for a decreased cost of the EPS without affecting its overall quality. Therefore, from 5 June 2007, the EPS including McRad is being run at T399L62 *R*95 for 10 days, then at T255L62 *R*63 up to 15 days.

Summary and outlook

The new radiation package McRad presented in this article was made operational with model cycle Cy32r2 on 5 June 2007. It includes a new short-wave radiation scheme, revised cloud optical properties, the MODIS-derived land surface albedo and the McICA approach to radiation transfer in cloudy atmospheres. In addition there can be a more extensive use of a flexible radiation grid; the grid can be made coarser when the highest accuracy of the radiative heating rates is not essential for the application, as with the EPS.

McICA is the most important change as it simplifies the radiation transfer schemes by suppressing all references to partial cloud cover, the subsequent separate calculations for clear-sky and cloudy parts of the layers, and the inherent complexity of the vertical integration accounting for the overlapping of these clear and cloudy quantitites (reflectances/transmittances or fluxes). The cloud generator used here (*Räisänen et al.*, 2004) being independent from the radiation transfer can now handle any overlap situation, and is used here with a definition of the overlap of cloud layers through decorrelation lengths (*Hogan & Illingworth*, 2000).

The impact of McRad was studied in seasonal simulations, and ten-day forecasts, and it was shown to benefit the representation of most parameters at both short and longer time-scales, relative to the previous operational version.

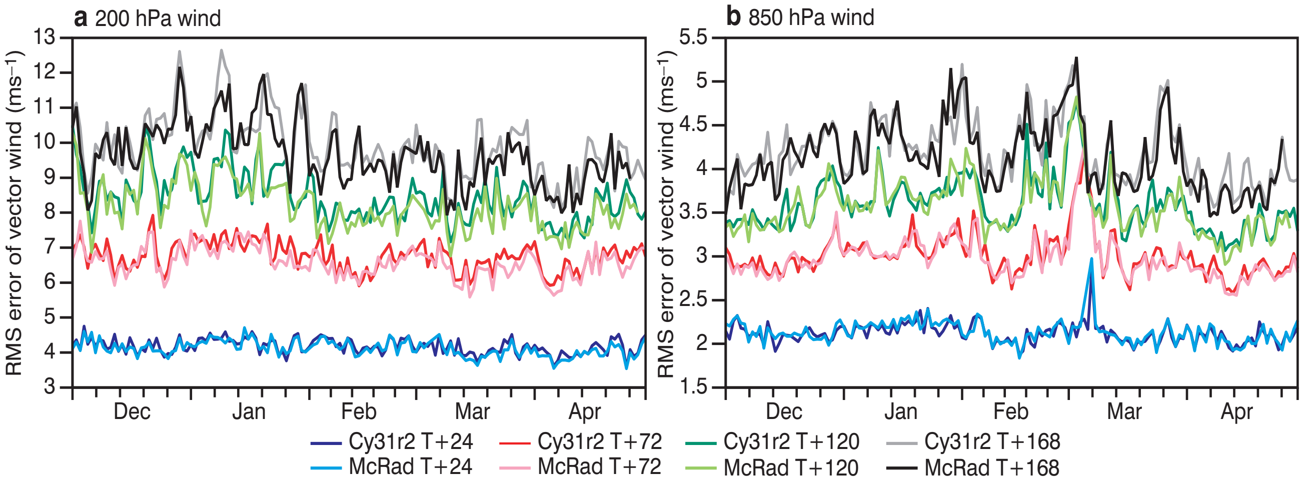


Figure 8 The time-series of the RMS error of the vector wind in the tropics (20°N–20°S) at (a) 200 and (b) 850 hPa over the period 1 December 2006 to 30 April 2007.

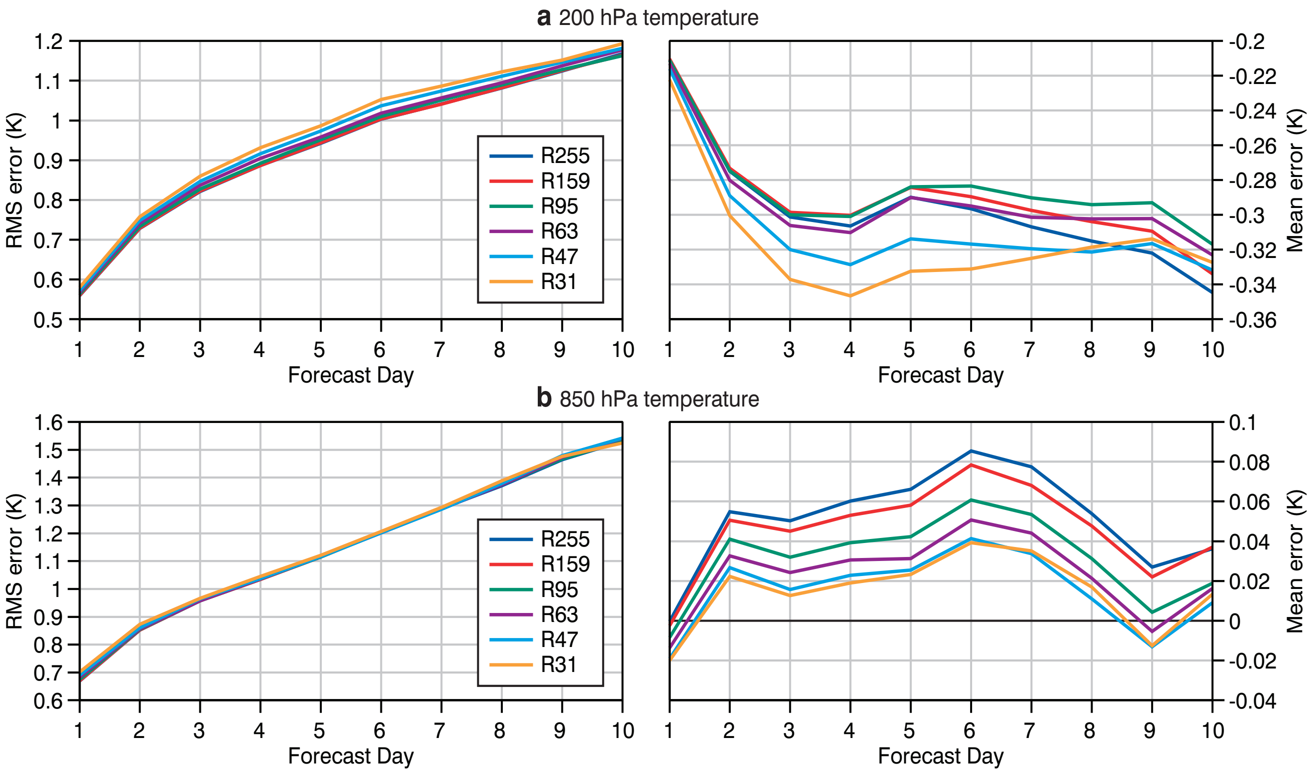


Figure 9 (a) RMS error (left) and mean error (right) of the temperature at 200 hPa for McRad ten-day forecasts at T399L62, started every 96 hours from 12 December 2006 to 12 May 2007, and using the six different radiation grids from *R*255 to *R*31. (b) As (a) but for 850 hPa temperature.

McRad allows the same overlap assumption to be used for radiation transfer and precipitation/evaporation processes, a problem previously solved either only approximately or through additional calculations. In the future, it will help connect the radiation transfer calculations with cloud information derived from cloud schemes based on a probability distribution function or from observations of the vertical profiles of the condensed water as made available from CALIPSO-type measurements.

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September 3–7	Seminar – Recent developments in the use of satellite observations in numerical weather prediction
October 8–10	Scientific Advisory Committee (*36th Session*)
October 10–12	Technical Advisory Committee (*37th Session*)
October 15–19	Training Course – Use and interpretation of ECMWF products for WMO Members
October 15–16	Finance Committee (*79th Session*)
October 17–18	Policy Advisory Committee (*26th Session*)
October 26	Advisory Committee of Co-operating States (*13th Session*)
November 7–9	Workshop – Ensemble prediction
November 12–16	Workshop – Meteorological Operational Systems (*11th Workshop*)
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530 **Janssen, P.A.E.M.** & **M. Köhler**: Notes on the exact solution of moist updraught equations. *July 2007*

529 **Janssen. P.A.E.M.**: Progress in ocean wave forecasting. *June 2007*

528 **Morcrette, J.-J.** & **A. Arola**: A processor to get UV-B and UV-A radiation products in/from the ECMWF IFS. *June 2007*

525 **Matricardi, M.**: An inter-comparison of line-by-line radiative transfer models. *May 2007*

523 **Kelly, G.**: The evaluation of the HIRS/4 instrument on Metop A by using the ECMWF data assimilation system to provide a reference to compare with other sensors. *May 2007*

522 **Xavier, P.K.**, **J.-P. Duvel** & **F.J. Doblas-Reyes**: Representation of the tropical intraseasonal variability and its impact on seasonal predictability in a multi-model ensemble. *April 2007*

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