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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 The ECMWF Newsletter is not peer-reviewed.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

EDITORIAL

A milestone in ECMWF's history

SINCE 2003, ECMWF has, vis-à-vis its Member States, developed the argument for a significant increase in the High Performance Computing (HPC) budget to prevent a decline of ECMWF's leading position in global Numerical Weather Prediction (NWP). Member States were warned that, when replacing the current supercomputer in 2009, a system capable of addressing the scientific requirements would require a doubling of the Centre's HPC money stream.

One year ago the Council adopted the ECMWF strategy for the period 2006–2015, which confirmed that such a budget increase was essential for its implementation. However at the same time the Council signalled that there were serious affordability issues. Obviously meteorology in Europe has to cope with significant budgetary constraints and was facing difficulties in pulling financial resources together.

The 66th ECMWF Council held on 7 and 8 December 2006 has clearly opted for further strengthening European co-operation in NWP. It gave a first strong signal by adopting a budget for 2007 with an increase of £1.5 million in order to allow ECMWF to face the huge increase in electricity cost in the UK, whilst maintaining the level of its human resources. But the most important decision was, without any doubt, the adoption of an increase of £3.5 million for the HPC budget from 2009 onwards, with a second increase of the same amount to be decided in one year's time. These increases will then achieve the required doubling.

This decision was the result of one year of intensive discussion with all national authorities. The rationale was based on the effort required for:

- building a comprehensive warning system for severe weather that includes an early warning component from ECMWF, which is crucial for implementing effective preventive action and complements the short-range activities within the Member States;
- mitigating the impact of climate change which is likely to increase the number of severe weather events, whilst our societies are becoming more vulnerable to weather impacts;
- maintaining Europe's leading position in global NWP through a shared common facility;
- adding value to investments in observing systems, in particular satellites;
- allowing the European economy to benefit from improved medium-range forecasts.

An important contribution to the preparation of this decision came from the review of ECMWF activities and costs conducted by the Programme Task Team established by the Council in July. The Task Team concluded that ECMWF's activities are:

- critically important to the Member States;
- fully compliant with the Centre's mission;
- conducted very efficiently and with the required transparency.

With this decision the ECMWF Council has set a milestone in ECMWF's history and clearly indicated that it wants Europe to maintain its leadership in NWP and it wants to offer to European citizens the very best meteorological services.

Dominique Marbouty

New items on the ECMWF web site

ANDY BRADY

WMO EPSgrams

WMO members are now provided with EPSgrams for a list of selected locations in their country. The WMO Secretariat is collecting these locations directly from the Meteorological Service in each country. The alphabetical page on our web site leads to country names and then to a list of cities chosen by each Meteorological Service of the relevant WMO Member State.

www.ecmwf.int/products/forecasts/d/charts/medium/epsgramswmo/

Presentations from workshops held in 2006

The presentations from the workshops on "*Atmospheric re-analysis*" and "*Parametrization of clouds in large-scale models*" held in 2006 are now available.

www.ecmwf.int/newsevents/meetings/workshops/2006/re-analysis/
www.ecmwf.int/newsevents/meetings/workshops/2006/parametrization_clouds/

Training Course on "Use of Computing Facilities"

The course on "*Use of computing facilities*" is scheduled between 8 February and 9 March. Its objective is to introduce users of ECMWF's computing and archive systems to explain how to use them. The course is divided into five modules (SMS, Intro and MARS, MAGICS, Metview and HPCF).

www.ecmwf.int/newsevents/training/2007/computer/

Training Course on "Use and Interpretation of ECMWF Products"

The objective of the course on "*Use and interpretation of ECMWF products*" is to assist Member States and Co-operating States in advanced training on the operational aspects of the ECMWF forecasting system. The course will be given twice in 2007, plus an additional module specifically for WMO Member States.

www.ecmwf.int/newsevents/training/2007/Products/

Training Course on "Numerical Weather Prediction"

The purpose of the training course on "*Numerical Weather Prediction*" is to assist Member States in advanced training in the field of numerical weather forecasting. The course is divided into four modules dealing with numerical methods, predictability, data assimilation and parametrization.

www.ecmwf.int/newsevents/training/2007/NWP/

Workshop on "Flow-dependent aspects of data assimilation"

The workshop on "*Flow-dependent aspects of data assimilation*" will take place on 11 to 13 June 2007. Consideration will be given to advances in data assimilation methods that address the flow-dependence of the analysis problem. There is an extended description of the workshop on page 5 of this edition of the newsletter.

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

ECMWF 2007 Annual Seminar

The 2007 Annual Seminar will be on the topic of "*Recent developments in the use of satellite observations in Numerical Weather Prediction*" and will take place from 3 to 7 September. It will provide a pedagogical review of the recent advances and future challenges in the use of satellite data in NWP. More information can be found on page 5 of this edition of the newsletter.

www.ecmwf.int/newsevents/meetings/annual_seminar/2007/

Workshop on "Ensemble prediction"

This workshop on "*Ensemble prediction*" aims to review the most recent advances in ensemble techniques applied to data-assimilation and forecast systems for predictions ranging from days, through months and seasons, to multi-annual timescales. It will be held from 7 to 9 November 2007. A detailed description of the workshop is given on page 5 of this edition of the newsletter.

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

Changes to the operational forecasting system

DAVID RICHARDSON

DISSEMINATION of products from the second leg (days 11 to 15) of the new VarEPS forecasting system was implemented on 28 November 2006. New probability products for the range 11 to 15 days have been added to the ECMWF range of graphic products on the web:

www.ecmwf.int/products/forecasts/d/charts/medium/eps/

EPSgrams to 15 days can be accessed by selecting the new "15 day" option on individual EPSgrams.

Passive monitoring of data from the MetOp-A satellite was introduced on 2 November for AMSU-A and 30 November for HIRS and MHS. Operational assimilation of AMSU-A and MHS started on 11 January 2007. More information about the monitoring of MetOp data at ECMWF is given in the news item by Jean-Noël Thépaut and Hans Hersbach on page 11.

A new cycle of the ECMWF system, Cy31r2, was introduced on 12 December 2006. This cycle introduces the assimilation of new satellite data: winds from MTSAT (Japanese GEO satellite), and GPS radio occultation data from CHAMP, GRACE and COSMIC.

ECMWF's plans for 2007

DOMINIQUE MARBOUTY

OUR plans for 2007 flow directly from the four-year programme of activities 2007–2010 adopted by the ECMWF Council at its 66th session in December; the programme is available at

www.ecmwf.int/about/programmatic

Here only the main activities and targets for 2007 are presented, focusing on the users' point of view.

Following the Council's decision on the funding of the next High Performance Computing Facility, a major activity will be the running of the corresponding "Invitation To Tender". This is an important effort, which involves a large team drawn from all the Centre's departments. It will conclude with the decision to be made by the Council at the end of the year for the procurement of the supercomputer for the period 2009–2013.

As a consequence of the MetOp launch on 19 October 2006, assimilation of its various instruments will be a top priority. The assimilation of temperature and moisture information from AMSU-A and MHS started earlier this year, less than 3 months after the launch. Other instruments (HIRS, GRAS, ASCAT) will be introduced over this year. The culmination will be the assimilation of temperature and moisture information with unprecedented accuracy and spectral resolution from IASI by the end of the year. However the activity of assimilating new satellite data will also include other sources such as SSMIS (temperature and moisture), SBUV (ozone), and further development of the assimilation of GPS radio-occultation and rain-affected radiances.

Following last year's implementation of the VarEPS system, which allowed the extension of the Ensemble Prediction System from day 10 to day 15 with a reduced resolution, we plan to develop a unified configuration of the VarEPS which encompasses the monthly forecasting system by the end of the year. This includes the development of the corresponding unified products and re-forecasts suites. Activities in ensemble forecasting will also include assessing combined probabilistic products (based on both the deterministic and ensemble runs), developing calibration and verification methods for the EPS, and exploring the skill of multi-model ensembles using TIGGE data.

Other important deliverables expected this year will include several major upgrades of the model physics and an important upgrade to the European Shelf wave model at higher resolution. Also there will be the production of the interim reanalysis which will be significantly better than ERA-40 (but will only cover the period 1989 to present) – see page 25 for more details. The ensemble approach to data assimilation will be extensively studied, with a view to improving the initial conditions of both the deterministic forecast and the ensemble of perturbed members. Other research activities will concern developing a long-window weak-constraint 4D-Var, validating a non-hydrostatic dynamical core for the IFS, and reducing the stratospheric biases of the IFS.

Concerning seasonal forecasting, the new System 3 will be implemented early this year. Tests have shown that it will improve significantly over the current system. And we will now concentrate on developing System 4 which will include the new NEMO ocean model component. Following the Council's approval of the governing policy for the multi-model seasonal forecasting system EUROSIP, work will address improving the distribution of EUROSIP products and possibly including new contributors.

Distribution of ECMWF's products is an important and growing activity. A key milestone will be the migration of the RMDCN transport technology from Frame Relay to MPLS (Multi-Protocol Label Switching) expected early this year. It will be the achievement of a major planning effort which started several years ago and will involve 44 sites across 41 countries. We also plan a revision of the dissemination schedule, based on the result of a questionnaire issued to all Member States.

ECMWF premises have been considerably upgraded over recent years, including the enlargement of the site, the extension of the computer hall, the new office building and the new car park. This year's priority will now be to finalise these developments and finish the landscaping of the site.

Finally a major goal for this year is to further develop the Centre's contribution to meeting the requirements of the European Union. There is already a solid background through EU funded projects such as ERA (reanalysis) or DEMETER (multi-model ensemble). It was significantly increased recently as a result of our important contribution to the European GMES initiative, in particular with the GEMS project (which deals with global monitoring of atmospheric chemistry and dynamics and improved air-chemistry forecasts), and to the development of a coordinated European contribution to GEO (Group for Earth Observation). We will now be looking for a more systematic approach to the evaluation of the EU requirements and offerings. It will include strengthening our links with several EU bodies. An important milestone will be the preparation of a proposal for the GEMS follow-up phase.

2006 was a successful year which included the introduction of several new major model cycles (in particular an increase in resolution improving severe weather forecast and VarEPS which is a significant step towards a unified ensemble system), and the enhancement of the High Performance Computing Facility. The ambitious plans for 2007 will build upon these achievements and contribute to meeting the increasingly challenging and demanding needs of the Member States and users of our meteorological products.

66th Council session on 7–8 December 2006

MANFRED KLÖPPEL

On the left Mr Wolfgang Kusch (new Vice-President of Council) and on the right Dr Adérito Vicente Serrão (new President of Council).

CHAIRED by its President Anton Eliassen from Norway on the first day and by its Vice-President Adérito Vicente Serrão on the second day, the ECMWF Council held its 66th session in Reading on 7–8 December 2006.

As referred to in the Editorial, the Council made two major decisions.

◆ **HPC Funding**. To allow implementation of the "*ECMWF 10-years strategy*" without major delay, there would be a stepped funding approach with an approved increase of the budget for the High Performance Computing by £3,446k from 2009 onwards, and a second increase from 2011 onwards to be decided in December 2007 at the latest. For further information about the 10-year strategy see

www.ecmwf.int/about/programmatic/2006/

◆ **Budget 2007**. The Member States' contributions to the Budget 2007 would increase by 5.5% to maintain the level of resources and to cope with an increase in electricity costs.

Besides several decisions on financial and legal matters (e.g. the extension of the existing contract for the supply of a Data Handling System) and staff matters (e.g. approval of Reports from the Co-ordinating Committee on Remuneration), the main results of this session were as follows.

◆ **Programme Task Team**. The report of the Programme Task Team (PTT), which had been established at Council's session in summer 2006, confirmed that almost 75% of the Centre's costs were allocated to medium-range forecasts and that the Centre developed supplementary activities at very low cost. It was verified that ECMWF had a lean administration and management with expenditure well below 10% of the total cost. The outcome of a questionnaire, prepared and analysed by the PTT, demonstrated the importance and variety of applications of ECMWF products and services in the Member States. ECMWF's outputs were highly valued by the Member States in contributing to a number of socio-economic areas, with medium-range weather forecasts being of highest priority.

◆ **Four-year Programme of Activities**. The Council unanimously adopted the updated "*Four-Year Programme of Activities*" for the period 2007–2010. For further information see

www.ecmwf.int/about/programmatic/

◆ **Relationship with the EU**. The Director was tasked by the Council to develop further ECMWF's co-operation with the European Commission on the basis of existing opportunities, e.g. GEMS as well as global and regional reanalysis.

◆ **Amendments to the Convention**. Good progress had been made with regard to the ratification process within Member States. Two delegations announced that the official notification of acceptance of the amendments to the Convention was on its way.

◆ **Co-operating States**. The Director was authorised to negotiate a Co-operation Agreement with Montenegro.

◆ **Agreement with JRC**. The Council agreed on the extension of the Co-operation Agreement with the European Commission's Joint Research Centre (JRC) on the development and testing phase of the European Flood Alert System (EFAS) to cover the period 2007–2010.

◆ **EUROSIP**. The Council adopted a policy for EUROSIP (European Multi-model Seasonal to Inter-annual Prediction System), in collaboration with the UK Met Office and Météo-France, regarding coupled seasonal forecasting systems. Graphical EUROSIP multi-model products are made available to the Member States and Co-operating States from the ECMWF web site:

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

◆ **Scientific Advisory Committee**. Prof Heikki Järvinen (Finland) and Prof Jochem Marotzke (Germany) were appointed to the Scientific Advisory Committee for a first term of office, and Dr John Eyre (United Kingdom) for a second term.

◆ **Election of President and Vice-President**. Dr Adérito Vicente Serrão from Portugal was unanimously elected as President and Mr Wolfgang Kusch from Germany as Vice-President of the Council. For both this will be a first term of office of one year.

ECMWF workshops and scientific meetings in 2007

BOB RIDDAWAY

Workshop on Flow-dependent Aspects of Data Assimilation (11 to 13 June 2007)

The workshop will consider advances in data assimilation methods that address the flow-dependence of the analysis problem. Current assimilation methods for operational numerical weather prediction rely on time-averaged covariance statistics that may be close to optimal on average, but which are quite incorrect in extreme situations such as intense baroclinic development, strong organised convection and tropical cyclones. Such cases are of particular interest, both to weather forecasters and to the general public, because of their unusual nature, high intensity, and impact on society. Flow dependence is important in less extreme situations too. Properly accounting for the day-to-day variation of error statistics, as well as their anisotropies and inhomogeneities, has the potential to significantly improve analysis quality.

Flow dependence would also allow more effective use of the available observations, and facilitate quality control that could retain extreme observations. Topics for the workshop will include:

- ◆ Ensemble-assimilation methods.
- ◆ State-dependent modelling of background-error statistics.
- ◆ Flow-dependent quality control.
- ◆ Data selection.
- ◆ Targeting of observations.

Workshop attendance is by invitation only. Further information is available from:

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

ECMWF 2007 Annual Seminar: Recent Developments in the Use of Satellite Observations in Numerical Weather Prediction (3 to 7 September 2007)

Over the past 10 years, satellite observations have become the predominant source of information assimilated in NWP due mainly to improvements in remote sensing instruments, numerical model accuracy and realism, and data assimilation techniques. This seminar will provide a pedagogical review of the recent advances and future challenges in the use of satellite data in NWP. Topics to be covered will include:

- ◆ Exploitation of hyperspectral infrared sounders.
- ◆ Assimilation of cloud and rain-affected radiances.
- ◆ Opportunities offered by future satellite instruments for environment monitoring.

Although focussed on the atmosphere, this seminar will also provide a state-of-the-art review of satellite data assimilation for ocean and land applications.

Some attention will be given to future R&D and operational satellite programmes. In co-sponsorship with the EUMETSAT NWP SAF, a special session will be dedicated to the recently launched EUMETSAT polar satellite METOP and its impact on NWP.

A registration form and further information is available from:

www.ecmwf.int/newsevents/meetings/annual_seminar/2007

11th Workshop on Meteorological Operational Systems (12 to 16 November 2007)

The objective of the workshop is to review the state of the art of meteorological operational systems and to address future trends in:

- ◆ Use and interpretation of medium and extended range forecast guidance.
- ◆ Operational data management systems.
- ◆ Meteorological visualisation applications.

Further information will be available from:

www.ecmwf.int/newsevents/meetings/workshops/2007/MOS_11

Workshop on Ensemble Prediction (7 to 9 November 2007)

This workshop aims to review the most recent advances in ensemble techniques applied to data-assimilation and forecast systems for predictions ranging from days, through months and seasons, to multi-annual timescales. Topics that will be discussed include:

- ◆ Representation of initial uncertainties (ensemble data assimilation, ensemble transform Kalman filter, bred vectors, singular vectors etc.).
- ◆ Representation of model uncertainties (multi-model ensembles, perturbed parameter ensembles, stochastic parametrization etc.).
- ◆ Validation and calibration methods.
- ◆ Applications of ensemble forecasts.

Results of both theoretical and practical research, using both global and limited area models, will be included in the presentations. Lessons drawn from intercomparisons of results on different timescales, as encouraged in the World Climate Research Programme's Strategic Framework on seamless prediction, will be a focus of discussion at the workshop.

Further information about this workshop will be available at:

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

ECMWF events in 2007

11 to 13 June
Workshop on Flow-dependent Aspects of Data Assimilation

3 to 7 September
ECMWF 2007 Annual Seminar: Recent Developments in the Use of Satellite Observations in Numerical Weather Prediction

7 to 9 November
Workshop on Ensemble Prediction

12 to 16 November
11th Workshop on Meteorological Operational Systems

Opening of the new office block at ECMWF

UTE DAHREMÖLLER

WE ARE delighted to announce the opening of the new office block on 27 November 2006.

The opening of the new office block can be considered as a milestone in the development of ECMWF. The Centre needed additional office spaces in order to accommodate its new activities such as Seasonal Forecast, RMDCN and GEMS. The new building contains well-furnished modern offices and bright open areas. With three new meeting rooms and spacious areas on each floor, the new office block will thus provide scientists with additional space where they can meet and exchange views informally. The new office block has been well integrated into the existing buildings, combining the original style of architecture with more modern features such as the bright and spacious atrium.

We would like to thank everybody who has contributed to the success of the project, especially the consultants Alex Birch, Brain Pawsey and, last but not least, Gerd Schultes, who is now enjoying his well-deserved retirement. On top of the regular management of the construction work, they successfully took over the functions of the main contractor, who had gone into receivership in May 2006, when only three-quarters of the work had been finished. Thanks to their joint efforts, the new building could be completed almost on time, the delay due to the insolvency being relatively short.

Staff and consultants of the Research Department have now moved into the building. This has been an opportunity to reorganise the allocation of offices in the old building, so that all sections within a division are located at close quarters. It will now also been possible to dispose of Terrapin Towers, a temporary office building, which had been rented for several years and no longer meets modern office standards.

Some outside work still has to be completed, such as the landscaping and the layout of the area between the conference centre and the new office block. This work is due to start in early 2007 with its completion scheduled for mid 2007.

Workshop on the parametrization of clouds in large-scale models

ADRIAN TOMPKINS

ON 13 to 15 November 2006, ECMWF held a workshop on the parametrization of clouds in large-scale models. Its purpose was to review the most recent developments in this area of research and explore new ideas. This was one of the annual Research Department workshops which helps guide research activities. The main outcome of the workshop was a set of recommendations for future research directions both at ECMWF and more widely within the research community.

Even by ECMWF standards, the workshop was a popular and oversubscribed event, with many more applicants than available spaces, and was considered a success by all who attended. The workshop was organised by Adrian Tompkins, Martin Miller, Anton Beljaars and Els Kooij-Connally.

Workshop presentations

There was an overview session which summarized some of the outstanding issues to be tackled relating to cloud parametrization. Emphasis was put on the additional requirements of a large-scale model, where clouds are a sub-gridbox scale entity. The traditional methods of parametrizing cloud fraction were outlined. It was suggested that statistical cloud schemes, which explicitly represent the nature of the thermodynamical and dynamical fluctuations on scales inferior to that of the model grid, may be the way forward, if the outstanding barriers to their development could be overcome.

A summary was given of what the community has learnt so far from the Intergovernmental Panel on Climate

Change 4th Assessment Report (IPCC AR4) and the GEWEX Cloud System Study (GCSS). As a result of the work done for IPCC AR4, new methods for analysing cloud feedbacks in global models have been developed. In these cloud data is stratified according to large-scale dynamical regimes, using numerical weather prediction global analyses to provide the latter. In this way errors in cloud models can be determined as a function of the cloud regime, giving clues as to the areas of model physics that require attention.

This kind of study is complemented by the case studies of GCSS, which concentrate on specific cloud regimes, such as the Pacific Cross Section experiment in which ECMWF is participating. ECMWF contributed output from its integrated forecast system (IFS) to the model intercomparisons organised under the GCSS umbrella. Consequently ECMWF gained access to output from high-resolution cloud resolving models in addition to processed observations. This approach proved to be an efficient vehicle for assessing the quality of the cloud systems predicted by the IFS.

After the overview session there were three main sessions devoted to:

- Microphysics of clouds in global and regional models.
- Representation of process interactions affecting clouds.
- Validation of clouds.

The session dealing with the microphysics of clouds emphasised the ice-phase, since this is considered to be the most poorly represented in models, partly due to its greater complexity, and partly due to the relative dearth of observations to date. The role aerosols can play in cloud microphysics was also discussed. This has particular relevance for the GEMS project, which aims to provide daily analyses and forecasts of several aerosol species. In addition, consideration was given to the difficulties that were addressed when implementing new microphysical schemes into the UK Met Office Unified Model and the AROME forecast model of Météo-France.

The process interaction session underlined the fact that good representation of cloud properties does not just rely on the quality of the cloud scheme itself, but the simulated clouds are the end result of many interacting processes in the models. The focus was on radiative and convective processes in particular, as well as ice clouds. The session outlined recent advances at ECMWF. The radiation scheme in the IFS will shortly include a Monte Carlo Independent Column Approximation (McICA) approach; this greatly simplifies the handling of vertical cloud fraction overlap, and allows the self-consistent inclusion of the sub-cloud variability. Developments in the representation of shallow convection using a mass-flux/diffusion approach were also presented.

The final session revealed the state-of-the-art in remotely-sensed cloud observations for validation purposes using both ground-based and space-borne sensors, with prominence given to ice observations. The usefulness of the long timeseries of detailed observations available from the Atmospheric Radiation Measurement (ARM) Program and the European network of ground-based stations was described. Raw observations from these stations were processed using identical algorithms under the auspices of the Cloudnet project. Information was provided about the recent development of the Microwave Limb Sounder (MLS) retrieval algorithms for cloud ice, which were used to demonstrate the improvements in the ECMWF system at version Cy31r1. The exciting new Cloudsat platform was also illustrated, which saw the launch of the first space-borne 94 GHz active radar that flies in formation with the Calipso lidar.

Some specific questions for the workshop

These are some of the questions that were posed to the workshop participants prior to the formation of the working groups:

Microphysical issues

- Which microphysical processes are key for climate/NWP?
- How much complexity is required?

Macrophysical issues

- Are statistical cloud schemes the way forward?
- If yes: What complexity of PDF is required?
- How will we parametrize process influence on PDF moments?

Observations

- Where should our priorities lie with cloud observations?
- What timeliness is required for NWP?
- Should models be validated in both NWP modes and climate modes?
- How can we best use the observations we already have?

Workshop recommendations

The three working groups were established to consider the following topics.

- Validation
- Subgrid variability
- Cloud parametrization priorities

The parametrization priorities group emphasized the importance of representing subgrid-variability, and thus recommended further use of cloud resolving models. The group stated that particular attention should be paid to representation of mixed phased clouds, and that in general the wider research community needs to continue efforts to investigate ice and mixed phased processes in controlled environments such as cloud chambers. Interestingly, the group considered aerosol-cloud microphysics interactions too uncertain for inclusion into an NWP framework.

The subgrid-scale variability group agreed with the need to represent subgrid-scale variability in large-scale models, although possibly to justify the existence of the working group! However, the group struck a cautionary note and recommended investigating in which physical parametrizations a simple “all-or-nothing” approach might work. It was noted that statistical cloud schemes permitted a move towards a unified approach for all cloud types.

But it was recognised that each regime has specific difficulties to tackle (such as the need for representing the joint probability density function (PDF) of temperature, water and vertical velocity, or more complex bi-modal PDFs) and therefore an ultimate unified approach may not be achievable. To this end the group highlighted the need for further study to reveal the nature of observed PDFs.

The working group on "validation" highlighted the need for improved observations of the following: near surface winds for evaporation, better resolved boundary layer temperature and moisture structures, soil moisture, aerosol types and their vertical profiles, and lastly of microphysical processes. The group stated that further efforts needed to be made to combine multiple sensors to achieve this aim, and used the example of the NASA 'A'-train to illustrate this approach. It was maintained that the development of new sensors should not be at the expense of maintaining existing platforms, as long-term continuous observations from platforms such as CERES and MODIS were critical. Additionally retaining and developing ground-based networks, such as the ARM and Cloudnet structures, was recommended.

It was noted that observations could and should be usefully supplemented with high-resolution modelling studies.

The working group also paid special attention to data assimilation needs, as often the parametrization developments are made without regard to the linearization demands of variational assimilation systems. Improved integration and communication between the cloud parametrization and data assimilation communities could greatly facilitate the further development of data assimilation. Data assimilation requirements also necessarily demand further efforts towards real-time access to future remotely-sensed information.

Further information

This article only provides an overview of the presentations and findings of the cloud parametrization workshop. The full reports of the working groups and all the presentations from the workshop are available from the ECMWF website at:

www.ecmwf.int/newsevents/meetings/workshops/2006/parametrization_clouds

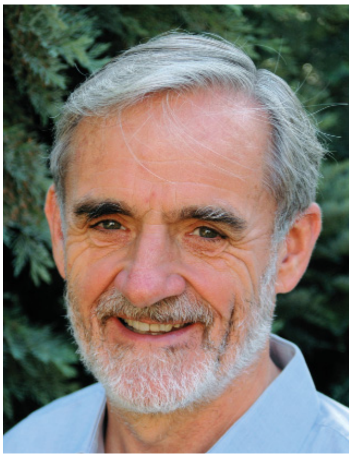
David Anderson awarded the Sverdrup Gold Medal

PHILIPPE BOUGEAULT

THE AMERICAN Meteorological Society has awarded the Sverdrup Gold Medal for 2007 to David Anderson. The award is in recognition of "his extensive contributions to improving the predictability and prediction of climate variability and to better understanding the dynamics of the ocean and of ENSO".

The Sverdrup Gold Medal is granted to researchers who make outstanding contributions to the scientific knowledge of interactions between the oceans and the atmosphere. The award is in the form of a gold medallion and is named after the Norwegian scientist and explorer Harald Ulrik Sverdrup, recognised as the founder of the modern school of physical oceanography. The award was first presented in 1964 to Henry Stommel.

David is a world-class physical oceanographer, with particular interest in the dynamics of ocean circulations in the tropics and extratropics. ECMWF benefited from this expertise when he became Head of the Seasonal Forecast



David Anderson

Section in 1995. Under David's leadership ECMWF has developed a first-class seasonal forecast system which has been running since 1997. Information about the latest version of this system, referred to as System 3, can be found in the article starting on page 19 of this edition of the *ECMWF Newsletter*.

David retired from ECMWF in August 2006. An appreciation of his career appeared on page 5 of *ECMWF Newsletter No. 108*.

Applying for resources for a "Special Project"

UMBERTO MODIGLIANI

THE "SPECIAL PROJECTS" carried out under the auspices of ECMWF are defined as "experiments or investigations of a scientific or technical nature, undertaken by one or more Member States, likely to be of interest to the general scientific community". Users within one of the Member States may apply for resources for a Special Project. In addition some European organisations with which ECMWF has concluded a Co-operation Agreement may apply for Special Project resources. Particularly welcome are Special Projects undertaken in co-operation between several institutions, nationally or internationally.

The allocation of computer resources is decided by the ECMWF Council. The current guidelines state that a maximum of 10% of the computing resources available to Member States may be allocated to Special Projects. In 2007 there are 75 continuation projects and 14 new projects covering a wide range of topics. A summary of these projects can be found on page 41 of this edition of the *ECMWF Newsletter* with further information available from:

www.ecmwf.int/about/special_projects/

A request for the allocation of computer resources for a Special Project starting in 2008 should be made by 30 April 2007. The request should be submitted to the Director of ECMWF by the Principal Investigator via the Director of the meteorological service of the appropriate Member State. For organisations for which there is a co-operation agreement the request should be sent direct to the Director of ECMWF. Further information about how to apply for a special project and the requirements for interim reports can be found at

www.ecmwf.int/about/computer_access_registration/Special_Projects.html

It is important that the application process is followed so as to avoid unnecessary delays. Late application requests can be submitted after the 30 April deadline. In this case applicants may be eligible to receive resources from the 20% of Special Project resources which are set aside specifically for this purpose.

The basic process within ECMWF for approving applications for Special Projects is as follows.

- The Scientific Advisory Committee (SAC) reviews the scientific aspects of each application. The review process takes into account the resources available, the quality of the proposals and their relevance to the Centre's objectives. For continuation projects the quality of the interim reports is also a factor. When an application is made for a new project the quality of any previous final reports from the same team is taken into account. All Special Project applications will be ranked according to the aforementioned criteria and, possibly, only the projects rating above a certain threshold will be allocated the available computer resources.
- The Technical Advisory Committee (TAC) makes a recommendation to Council about the allocation of computer time and archiving resources for Special Projects based on comments from ECMWF and the recommendations of the SAC.
- The Council makes the final decision about the allocation of computer time and resources for Special Projects.

Decisions about the allocation of resources for Special Project for 2008–2010 will be taken by the SAC and TAC in October 2007 and by Council in December 2007.

If there are any queries about the application procedure for Special Projects contact Umberto Modigliani at:

special_projects@ecmwf.int

Co-operation Agreement signed with Morocco

MANFRED KLÖPPEL

The signing of the Co-operation Agreement by Mr Zahoud, sitting on the left, and Mr Marbouty, sitting on the right.

AN AGREEMENT for scientific and technical co-operation between ECMWF and the Kingdom of Morocco was signed in Casablanca by Dominique Marbouty, Director of ECMWF, and Abdelkebir Zahoud, Secretary of State to the Ministry of Territorial Development, Water, & Environment in Charge of Water of the Kingdom of Morocco on 21 November 2006. The Co-operation Agreement entered into force on 1 December 2006.

Mustapha Geanah, Director of Direction de la Météorologie Nationale (DMN) of Morocco, Michel Jarraud, Secretary-General of the World Meteorological Organization, and Pierre-Etienne Bisch, Président-directeur-général of Météo-France, attended the signing ceremony in Casablanca. The Kingdom of Morocco is the first African country to conclude a Co-operation Agreement with ECMWF.

Mr Marbouty said: "ECMWF's worldwide leadership in the field of numerical weather prediction is based on close collaboration with the meteorological community. Governments recognise the necessity of improving the quality and accuracy of advance warnings of severe weather events, such as storms, droughts and floods. Morocco already is a partner to the ALADIN agreement granting access to parts of the Centre's IFS/ARPEGE software.

I am looking forward to closer

collaboration with the Moroccan National Meteorological Service since DMN has excellent skills in the field of numerical weather prediction. I am pleased that DMN will now have access to more of our products, in particular medium-range and seasonal weather forecasts.

I expect another outcome of our collaboration to be verification of our forecasts on the edge between the Atlantic and the Mediterranean Sea."

Mr Zahoud stated: "The European Centre for Medium-Range Weather Forecasts is the world leader in its area of scientific and technical expertise. The European Centre's products will greatly assist the Moroccan National Meteorological Service to fulfil its mission, including the protection of life and property. I am confident that both the ECMWF and the Moroccan National Meteorological Service will benefit from their close co-operation in meteorology."

Mr Geanah emphasised: "This Co-operation Agreement is a significant milestone for meteorology in Morocco. The data from the ECMWF supercomputer system will be vital for improving the overall quality of our forecasting and for our warning services, in advising of the likelihood of extreme weather events. Our meteorological staff will benefit from increasing their contacts with their colleagues at the ECMWF. We will be using the ECMWF's products to extend both the range and the validity of our forecasts to the benefit of the people of Morocco. We very much welcome this Agreement."

Being a Co-operating State, Morocco has the same access to ECMWF products as a Member State. Morocco's contribution to ECMWF's Budget is half it had to pay were it a Member State.

To date, Co-operation Agreements have been signed with the Czech Republic, Estonia, Iceland, Croatia, Hungary, Lithuania, Romania, Serbia and Slovenia.

A celebration of the career of Clive Temperton

PHILIPPE BOUGEAULT

A SPECIAL symposium was held at ECMWF on 10 November 2006 to celebrate the career of Clive Temperton, who retired in September. World leaders in numerical weather prediction from Europe, Canada and the USA, who have worked with Clive during his long career, attended the symposium and gave talks highlighting the many contributions Clive made to NWP. The presentations and some pictures taken during this event can be found on ECMWF's website at

www.ecmwf.int/newsevents/calendar/miscellaneous/temperton_symposium.html

Clive first joined ECMWF in 1976 on secondment from the UK Met Office. His best known achievement during this time is the development of the FFFT (Furiously Fast Fourier Transform) which made him famous worldwide. This algorithm was not only faster than any other FFT at the time, but it also allowed for the first time prime factors different from 2 (3 and 5) for the number of grid points.

Clive Temperton

During this time Clive also developed, with Dave Williamson, the non-linear normal mode initialization. This was essential in the days of optimum interpolation assimilation for preventing gravity-wave noise from contaminating the first-guess fields and destroying the analysis.

Clive returned after five years at ECMWF to the UK Met Office, from where he resigned shortly after. He took up a position at Division de Recherche en Prévision Numérique (RPN) in Montreal, Canada, where he started to work on semi-Lagrangian advection techniques and developed a two-time-level version.

In 1998 Clive returned to the UK and joined ECMWF as a staff member in the Numerical Aspects Section. The contributions Clive made over the years to the dynamical core of the Centre's model are numerous. He was involved in the implementation of the three-time level semi-Lagrangian scheme in the ECMWF model and developed the more efficient two-time level version currently operational at ECMWF. He also coded the tangent-linear and adjoint of the semi-Lagrangian scheme needed for 4D-Var assimilation.

On behalf of Clive's many friends and colleagues from around the world I wish him a very happy retirement. I have no doubt he will get great enjoyment from now being fully occupied as a grandfather, allotment holder and Bracknell Town Councillor.

Gerbier-Mumm Award used for a project on the impacts of climate variability on malaria in Tanzania

RENATE HAGEDORN

EPIDEMIC malaria in Tanzania represents a significant public health problem. Every year, 14 million to 18 million new malaria cases are reported in Tanzania, and 100,000–125,000 deaths occur. The disease represents one of the most important obstacles to economic development and foreign investment in Tanzania. Approximately half of the population is affected by malaria and the Government strives to raise awareness about preventive measures.

Specifically, malaria may be found where and when the climatic conditions are favourable for transmission between the mosquito vector and its human host. It then follows that understanding and monitoring the nature of weather and climate variability and their relationship with malaria incidence is of vital importance to limiting the impacts of the disease.

Such work on the relationship between climate and malaria has been pioneered in the DEMETER project, which has been awarded the Norbert Gerbier-Mumm International Award 2006 (see *ECMWF Newsletter No. 108*, page 6). The project team led by Dr Tim Palmer has decided that the prize money they received in connection with this award will be invested in a project proposed by the Tanzania Meteorological Agency (TMA), studying the impacts of climate variability on malaria in Tanzania.

The main objective of this project is to further develop and apply the DEMETER methodology of integrating seasonal climate forecasts and malaria statistics into an end-to-end early warning system for malaria outbreaks. In order to establish the local relationship between climate conditions and malaria cases in Tanzania, a new database of clinical cases will be collected and made available for the wider scientific community.

Identification of Malaria prone areas and early prediction will help the authorities to mobilize resources for effective control and prevention of malaria transmission and thus limiting or minimizing the impacts of malaria outbreaks.

Monitoring of ATOVS and ASCAT instruments from MetOp at ECMWF

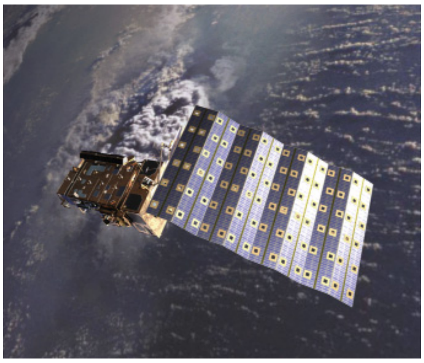
JEAN-NOËL THÉPAUT, HANS HERSBACH

THE EUMETSAT MetOp-A satellite was successfully launched on 19 October 2006. This is the first of a series of three polar orbiting satellites, forming the space segment of EUMETSAT's Polar System (EPS).

As part of the ATOVS (Advanced TIROS Operational Vertical Sounder) configuration carried on MetOp is the instrument AMSU-A. This is a 15-channel microwave sounder that measures atmospheric temperature profiles, even in the presence of non-precipitating clouds. Data from AMSU-A was first made available to NWP users via EUMETCAST on 31 October. These were quickly processed by ECMWF and were being monitored operationally by 2 November. Unfortunately there was then an interruption in the EUMETSAT data dissemination until 29 November. Data from the AMSU-A was resumed and observations from the MHS (Microwave Humidity Sounder) and HIRS (High Resolution Infrared Sounder) on MetOp were also received. Since then data transmission has been robust and all three instruments have been monitored operationally providing invaluable feedback on instrument quality to EUMETSAT. Overview maps, time-averaged mean fields, Hovmoller zonal mean fields and time series of area averages of all AMSU-A instruments, including the one on MetOp, can be found at:

www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/atovs/amsua/

An initial analysis of the monitoring statistics suggests that the noise characteristics of the three instruments are well within specifications and comparable to similar instruments onboard NOAA satellites. While some significant biases are apparent for most of the MetOp AMSU-A channels, they are handled very efficiently by the ECMWF adaptive bias correction procedure.



MetOp-A satellite launched on 19 October 2006 to supply meteorological operational data using eleven instruments provided by EUMETSAT, ESA, the French Space Agency (CNES) and NOAA.

Impact trials are already underway and operational assimilation of data from AMSU-A and MHS started on 11 January 2007. It is expected that soon use will be made of observations from HIRS.

The ASCAT (Advanced Scatterometer) is a new-generation instrument inspired by the successful scatterometers on-board the ERS missions. It uses triplets of radar backscatter to estimate surface vector winds over the global oceans, soil moisture over land, and the extent of land- and sea-ice.

A few tracks of pre-validated backscatter triplets were provided by the ASCAT calibration/validation team on 17 November 2006. Wind inversion at ECMWF indicated a high-quality product within specifications when compared with ECMWF surface winds. The assimilation system at ECMWF has been prepared for the inclusion of ASCAT wind data. This will allow passive monitoring of ASCAT data after the start of the dissemination via EUMETCAST (expected end of January), and will enable the start of impact studies. Operational assimilation is to commence as soon results are satisfactory.

This swift exploitation of the ATOVS package on board MetOp-A has been made possible thanks to the flexible infrastructure here at ECMWF and excellent ongoing collaboration with EUMETSAT. The support of EUMETSAT in this matter is warmly acknowledged.

The assimilation of cloud and rain observations from space

PETER BAUER, PHILIPPE LOPEZ, ALAN GEER, DEBORAH SALMOND

OVER the last 10–15 years satellite data has taken over the role as the major source for observations that constrain the analysis. Today, about 4 million satellite observations are assimilated per 12-hour assimilation window. This is more than 90% of the total number of observations. The bulk of these observations relate to atmospheric temperature and moisture but the near future will add satellite data that contains information on the three-dimensional atmospheric wind field, on land surfaces and, already in operations since June 2005, on clouds and precipitation.

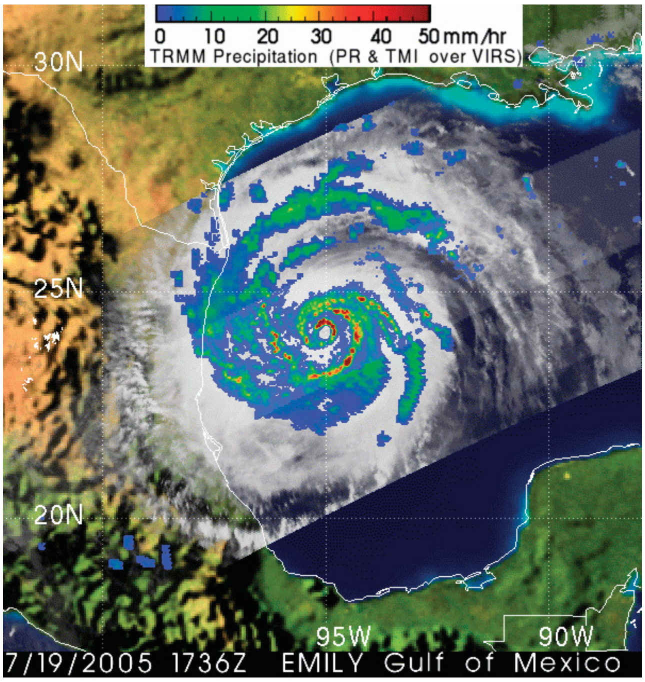


Figure 1 Tropical cyclone Emily on July 19, 2005, as seen by TRMM. Derived surface rainfall from TRMM Microwave Imager (TMI) and Precipitation Radar (PR) (in colour) and Visible Infrared Scanner (VIRS; greyscale). Courtesy NASA.

The use of satellite radiance observations in data assimilation requires running a radiative transfer model that simulates observable radiances given model input fields. These models have to be fast and accurate because information on the atmospheric state is extracted that corresponds to variations of, for example, less than 0.5–1 K in temperature or less than 1–5% in relative humidity. Until recently, fast and accurate models have only been available for clear-sky observations and could not simulate the interaction of radiation with cloud droplets, ice particles, rain and snow. This required the screening of observations that are affected by clouds and precipitation.

Keeping in mind that the global average of cloud cover is about 50% and regional averages of the frequency of rain occurrence amount up to 25% at ECMWF model resolution, a significant part of the atmosphere remains unobserved from space. This means that while the analysis in clear-sky areas is strongly constrained by observations, the analysis in areas affected by clouds and precipitation depends upon conventional observations if they are available, but otherwise it is mainly constrained by the model.

History

It has been clear for many years that we should make better use of cloud and rain affected satellite observations. However fast progress has been prevented by a lack of knowledge on how to do this, and the potential for uncontrollable side-effects from running complex physical schemes in the assimilation. At ECMWF, the first activities in this direction were initiated by the EuroTRMM-project that was co-funded by the European Community (EC) and the European Space Agency (ESA) between 1997 and 2001. The ECMWF contribution to EuroTRMM was led by Jean-François Mahfouf and Virginie Marécal. This project explored the potential use of data from the Tropical Rainfall Measuring Mission (TRMM) in the ECMWF data assimilation system. The TRMM satellite had been launched in November 1997 as the first dedicated rainfall observatory in space with a passive microwave radiometer and the first spaceborne precipitation radar. As an example Figure 1 shows the TRMM rainfall observations for tropical cyclone Emily on July 19, 2005 in the Caribbean Sea.

The initial studies dealt with the main issue in cloud and precipitation assimilation, that is the understanding of the sensitivity of moist physics parametrizations to observed rainfall information. These parametrizations are likely to exhibit non-linear and non-regular behaviour, in particular in the presence of convection. Jean-François Mahfouf and Virginie Marécal implemented a system that performed a one-dimensional variational (1D-Var) retrieval of atmospheric temperature and specific humidity in the presence of clouds and precipitation from TRMM observations of surface rainfall. Following sensitivity studies, 1D-Var experiments and single-observation 4D-Var experiments, they implemented the first system to assimilate TRMM observations. It was based on the 1D-Var retrievals using the simple linearized moist physics parametrizations available at that time, followed by the assimilation of only total column water vapour (TCWV) as a pseudo-observation in 4D-Var. This was performed outside the Integrated Forecasting System (IFS) once per 6-hour assimilation window.

Since then, the ECMWF modelling system has greatly evolved employing refined physical parametrizations, better spatial resolution (from 40 to 25 km) and finer vertical resolution in the planetary boundary layer and the stratosphere (from 60 to 91 model layers), an extended model top (from 0.1 to 0.01 hPa), an improved moisture analysis, and a large number of additional satellite observations. The rain assimilation system has been entirely redesigned but the philosophy of the 1D+4D-Var approach remained. Leading up to the first operational implementation, the most important modifications to the original approach have been as follows.

- ***New observational data processing path.*** An entirely new observational data processing path has been created inside the IFS that paves the way for the use of future observations requiring complex physics operators. 1D-Var retrievals are performed along the first model trajectory at full model resolution and for each time step (currently 25 km and 12 minutes).
- ***Assimilation of microwave radiances.*** We now assimilate microwave radiances rather than derived rain rates, introducing a much improved sensitivity to atmospheric temperature, moisture, cloud water and precipitation at once regardless of the model state. This only became computationally feasible and sufficiently accurate with the inclusion of a fast multiple-scattering radiative transfer code in the radiative transfer model RTTOV (Radiative Transfer for TOVS). For the future, this greatly facilitates the assimilation of radiance observations from a large variety of microwave observations with different sensors such as the Special Sensor Microwave/Imager (SSM/I), its successor the Special Sensor Microwave Imager Sounder (SSMIS), the TRMM Microwave Imager (TMI) and the Advanced Microwave Scanning Radiometer (AMSR-E).
- ***Improved moist physics parametrizations.*** We now have much improved moist physics parametrizations. These represent the best compromise between being the best approximation to the non-linear physics run in the forecast model, whilst giving a more linear and more regular behaviour as required in incremental data assimilation systems. The moist physics parametrization schemes comprise large-scale condensation and convection and were developed by Marta Janisková, Adrian Tompkins and Philippe Lopez. The schemes will become part of the operational linearized physics package with IFS model cycle 32r1 (hereafter referred to as Cy32r1).

Today, the system uses SSM/I radiance observations over oceans at frequencies of 19.35 and 22.235 GHz that are mainly sensitive to the integrated paths of precipitating (and some degree cloud) liquid water, to TCWV and to surface roughness, which depends on near-surface wind-speed. We are still limited to assimilation over ocean surfaces, where there is a better knowledge of the surface emissivity, which is crucial for radiative transfer modelling at these wavelengths.

Impact

Analysis

Before new observations are assimilated it is usual to compare large sets of model simulations with the new observations. This helps to establish bias corrections and indicates the accuracy of the observation operator. In our case, the observation operator consists of the above-mentioned moist physics parametrizations and multiple-scattering radiative transfer model. Since clear-sky SSM/I radiances were already assimilated in a separate stream, it was possible to compare observation versus model statistics in rain and cloud affected areas with those from the existing assimilation, which employs only clear-sky radiative transfer calculations in the observation operator.

Figure 2 shows biases and standard deviations for all seven SSM/I channels from clear-sky and rain-affected observations. Initially, it was expected that the rain-affected simulations would be substantially worse than clear-sky. Instead, it is very encouraging to note that both show biases of similar magnitude and that the standard deviations differ by only a factor of 2–4. The reduction in departures (observations minus their modelled equivalents) between the first guess and the

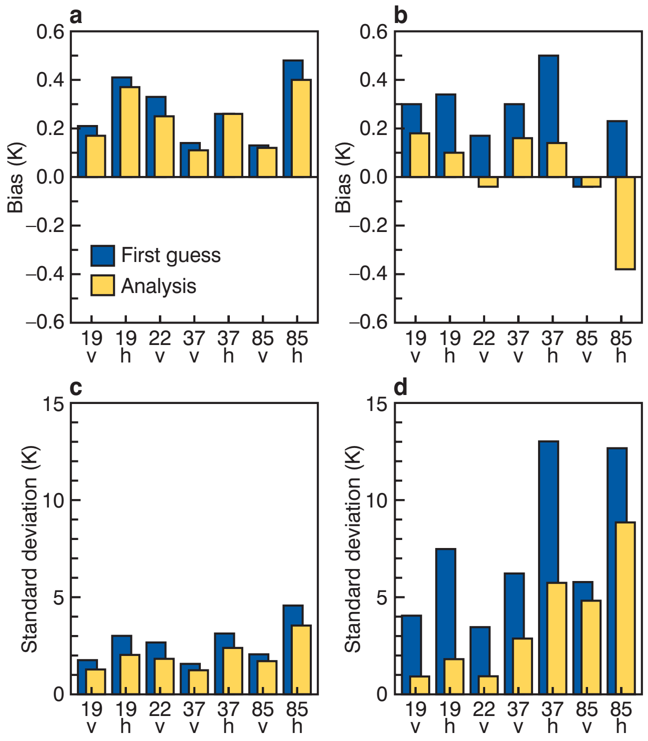


Figure 2 Bias-corrected first-guess and analysis departure statistics (in degrees Kelvin) from clear-sky and rain affected SSM/I radiance assimilation. Mean observation-minus-model differences for (a) clear-sky and (b) rain affected radiances for all SSM/I channels. Standard deviations for (c) clear-sky and (d) rain affected radiances. First-guess departures are in blue and analysis departures are in yellow. The symbols 'v' and 'h' refer to SSM/I channels that measure radiation with a constant polarization that is aligned vertically (v) or horizontally (h) to the plane defined by the paths of the incoming and surface-reflected radiation. The difference between polarizations helps distinguishing between surface and atmospheric signal contributions.

analysis suggests that the 1D-Var retrieval algorithm performs rather well. The departures are consistently reduced by 50–75% in the active channels (channels 1–3; 19.35 GHz v, h, and 22.235 GHz v) and by 20–50% in the passive channels (channels 4–7; 37.0 GHz v, h and 85.5 GHz v, h) – see the caption to Figure 2 for an explanation of the 'v' and 'h' symbols Apart from the accuracy of the observation operator, such performance was the result of a careful estimation of modelling errors, biases and data screening. As a consequence, about 30,000 rain-affected observations are actively assimilated in the operational configuration which roughly matches the number of clear-sky SSM/I observations.

Because each 1D-Var retrieval runs a moist physics operator prior to the radiative transfer, there is also a 'retrieval' of the vertical profile of cloud and precipitation. Though only the retrieved TCWV is assimilated in 4D-Var, it is informative to look at the changes in moisture and rainfall in 1D-Var, which may already give some indications of the potential effect of these new observations in the global analysis. This is illustrated in Figure 3 from a one-month experiment with Cy29r2. TCWV increments are shown in relative terms to avoid the emphasis of increments in areas with large moisture abundance. The increments in surface rainfall are separated into stratiform and convective rain-types and use a logarithmic scale. This scale accounts for the quasi log-normal probability distribution of global rainfall. A change of 1 dBR corresponds to 1⁄10 of an order of magnitude increase or decrease in rainfall.

It is interesting to look at the response of stratiform rainfall to TCWV increments because the large-scale condensation scheme usually shows greater sensitivity to moisture changes. The moisture increments highlight certain areas with systematic drying, in particular in southern mid-latitudes, and smaller-sized regions of systematic moistening in the tropics. The stratiform precipitation increment patterns follow the moisture signal rather closely. Even in areas with small and more localized drying, large areas of stratiform precipitation reduction are produced. This occurs mainly in the northern and southern Pacific and the northern Atlantic where the model's rainfall frequency of occurrence is too high. But also the relative contribution of stratiform and convective to total rainfall is modified in some areas, namely in the southern sub-tropics where rainfall intensity is rather weak. Here, the 1D-Var retrieval tends to suppress convection.

Figure 4(a) shows an example of mean 4D-Var TCWV-increment differences from a pair of three-month experiments in 2004. One experiment employed the operational rainfall assimilation scheme in Cy29r2 (RAIN) while these observations were withdrawn from the other (NORAIN). The increment patterns that were produced by the 1D-Var retrieval can also be identified in the moisture analysis of the 4D-Var system. However, those areas in which the effect of the rainfall observations was a drying of the analysis were amplified in the course of 4D-Var analysis. These are now much more widespread and cover the part of the East Pacific along the American continent, the North Pacific and the South-Eastern Atlantic. During the forecast, the areas with reduced moisture survive longer while the more localized moistening remains only for 24 hrs because of the removal of additional moisture through precipitation, often known as "rain out". Figures 4(b) and 4(c) show the corresponding mean analysis differences of mean sea-level pressure and 850 hPa divergence differences. Together, these results nicely illustrate the response of the model dynamics to these moisture observations, namely by increasing low-level convergence and by reducing surface pressure in areas of moistening and vice versa. The hatched areas indicate that these mean signals are statistically significant and by comparing RAIN with NORAIN, we can safely assume that these increments originate from the rain-affected observations.

While it is possible that there may be model biases with respect to moisture, it is most likely that the overall drying effect of the rain and cloud assimilation comes from the set-up of the 4D-Var moisture analysis. In clouds and precipitation, the variational analysis performs near

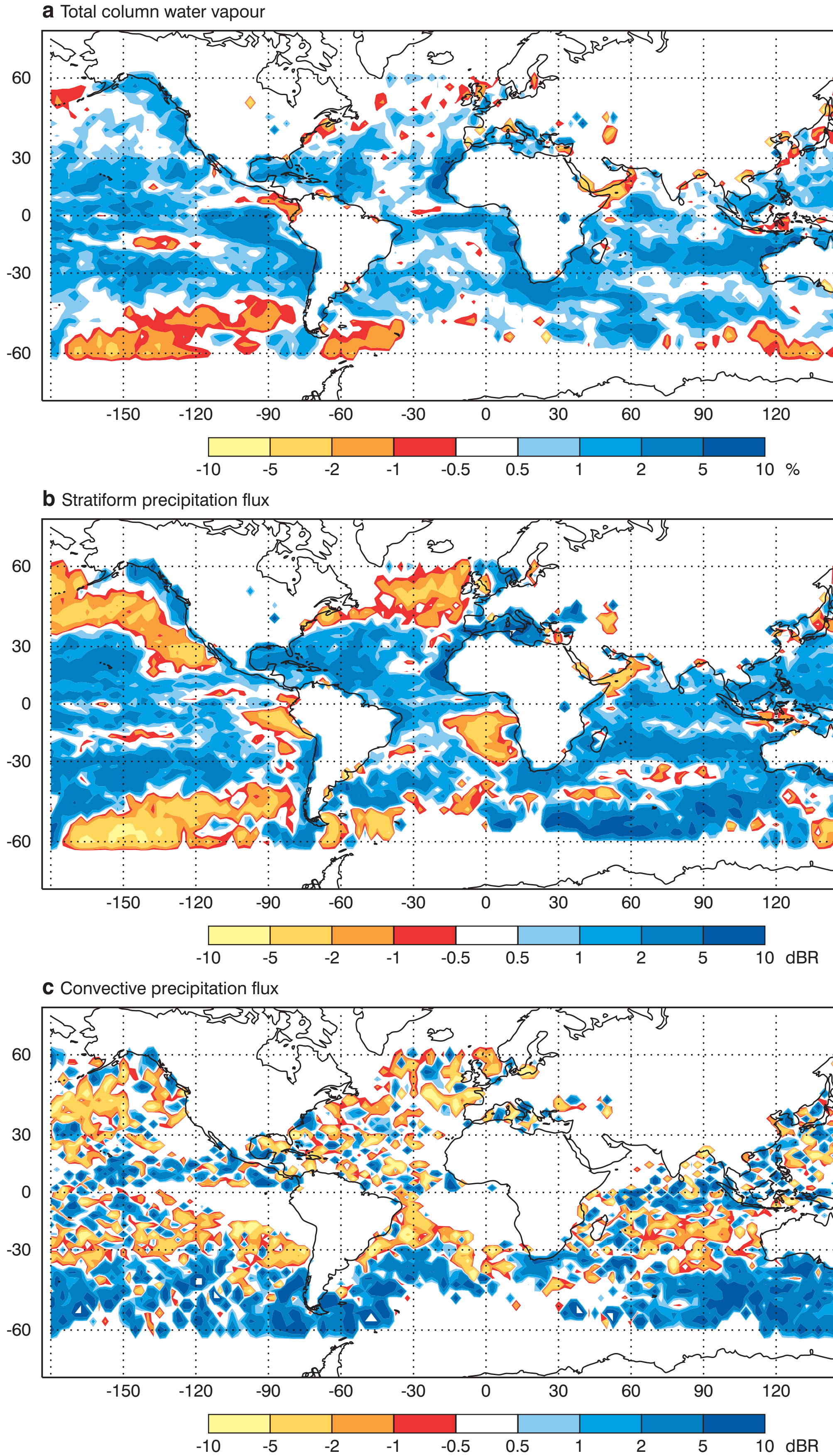


Figure 3 Global increment distribution of (a) total column water vapour (%), (b) stratiform precipitation flux (dBR), and (c) convective precipitation flux (dBR) from 1D-Var retrievals in September 2004 binned to 2.5° resolution.

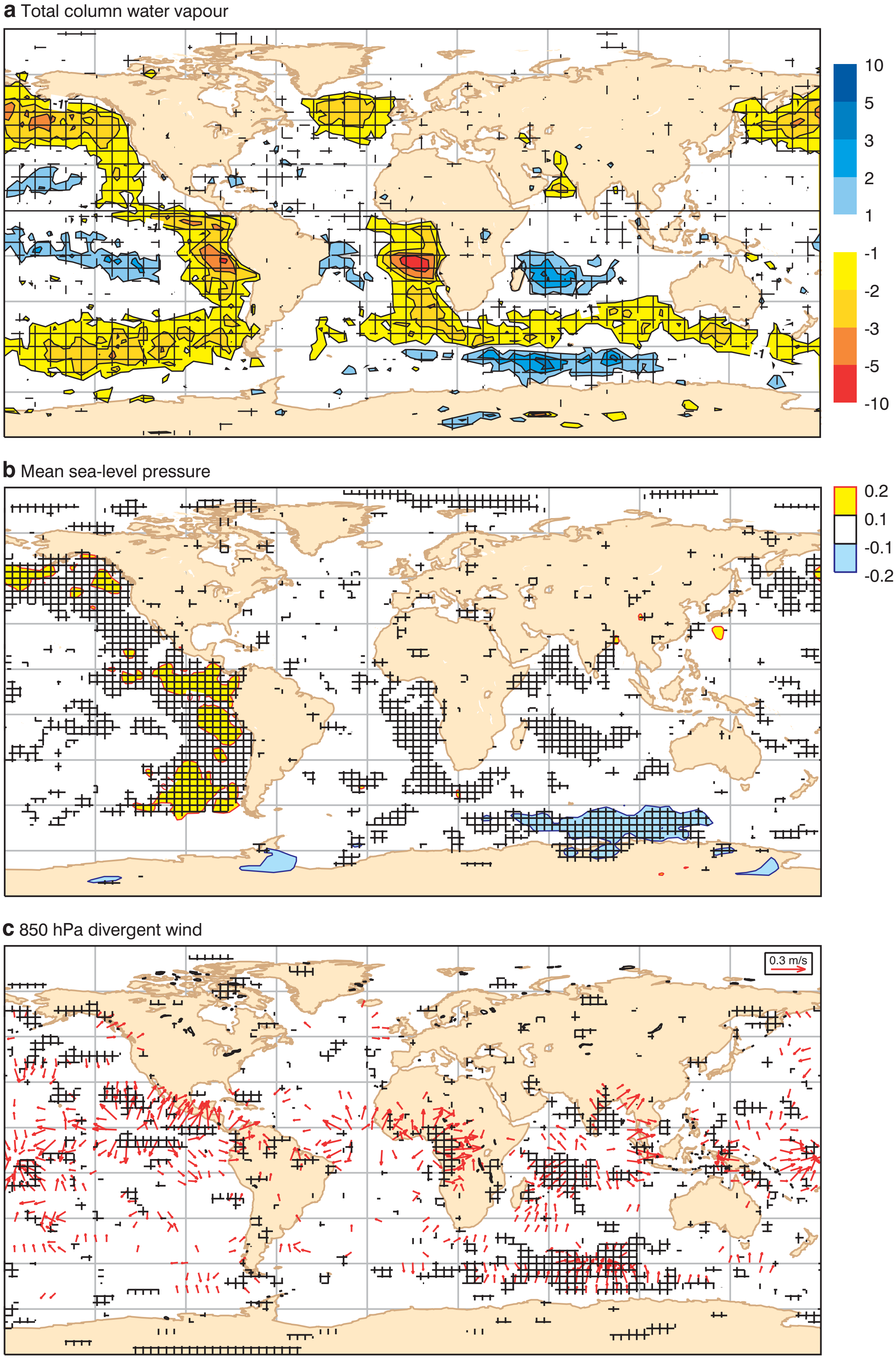


Figure 4 Mean normalized analysis difference of (a) total column water vapour (%), (b) mean sea-level pressure (hPa), and (c) 850 hPa divergent wind fields (ms^{-1}) between RAIN and NORAIN experiments for period August–October 2004 (hatching denotes 95% significance interval with t-test on analysis differences against zero-difference).

saturation. This means that in already saturated areas further moistening is penalized by upper thresholds and by the formulation of humidity background errors. From case studies, we noticed that in these areas many of the positive humidity increments that are produced by the 1D-Var disappear in the 4D-Var analysis. This effect may be unwanted and clearly requires more research focused on the definition of analysis control variables and moisture background error formulation.

Forecast

Between the operational implementation in 2005 and today, numerous impact experiments have been run to assess the contribution of the new cloud and rain-affected observations to forecast skill. The change of skill between Cy29r2 and Cy31r1 reflects the improvements that have been introduced to the 1D-Var algorithm and to the 4D-Var assimilation of TCWV as well as the evolution of model physics, data assimilation system, and the introduction of new observations.

As an illustration, Figure 5 shows zonal cross-sections of normalized root-mean-square (RMS) 48-hour forecast error differences for relative humidity and temperature. The reference is the own analysis in each case, and

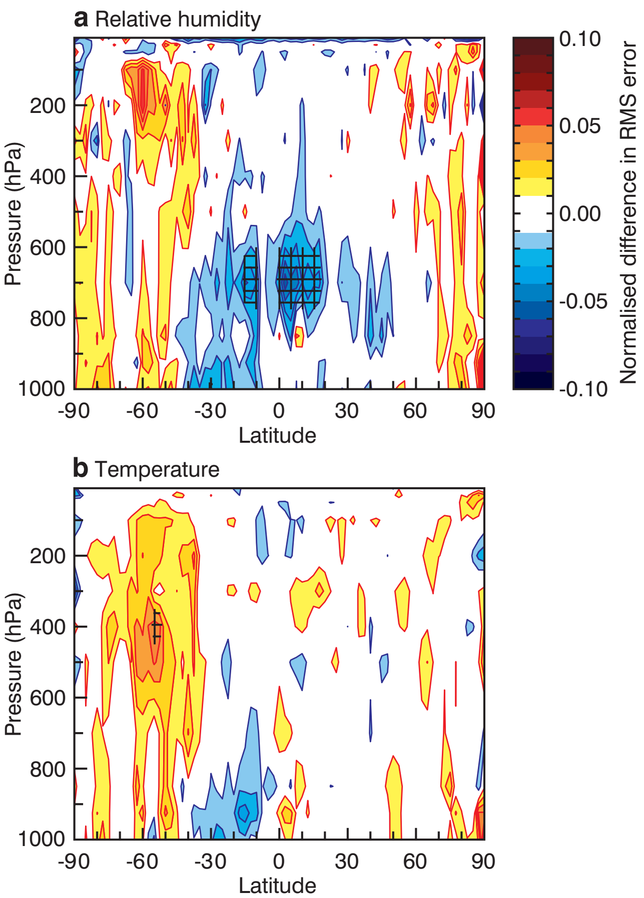


Figure 5 Zonal cross-section of normalized root-mean-square (RMS) 48-hour forecast error RAIN-NORAIN differences for (a) relative humidity and (b) temperature for August–October 2004 based on Cy29r2 where 0.1 corresponds to 10% RMS (hatching denotes 90% significance interval with t-test on analysis differences against zero-difference).

the scores were calculated from forecasts between August and October 2004 based on the original implementation of cloudy and rainy SSM/I assimilation in Cy29r2. As above, the difference refers to RAIN minus NORAIN. Negative numbers indicate forecast improvements by RAIN and positive numbers indicate deterioration.

The biggest statistically significant improvements are seen in the tropics (here ±30° latitude) over most altitude levels. But also smaller areas of negative impact can be identified which seem to have little statistical significance but still dominate an area, for example, near the surface, poleward of 60°S. What was causing these degradations in the southern winter? Our first investigation focused on near-surface wind-speed because it affects sea-surface emissivity at microwave frequencies. The Southern Ocean is prone to high wind-speeds for which a potential model bias could alias into the TCWV-retrievals. Another candidate was that most of the precipitation column in these areas is composed of frozen particles, to which the active microwave channels exhibit little sensitivity.

Consequently, the rain assimilation was upgraded with a more conservative data screening in the presence of frozen precipitation, the inclusion of 10-metre wind-speed in the 1D-Var control vector, an improved bias-correction for the rain-affected radiances and a more detailed definition of TCWV-observation errors in 4D-Var. All these improvements originated from the post-operational experience with the system and most proved to produce forecast skill improvements in the critical areas when tested independently.

Along with Cy31r1, other significant model upgrades were introduced. Among these are the variational bias-correction (VarBC, see *ECMWF Newsletter, No. 107*) and the increase of super-saturation in the presence of ice – both affect the moisture analysis. The first RAIN-NORAIN experiments with Cy31r1 exhibited problems in areas where previously none had been found. Tropical scores of temperature and geopotential near 200–300 hPa as well as relative humidity near the surface and at 200 hPa were worse in the RAIN experiments.

The subsequent evaluation revealed that Cy31r1 was affected by an increased temperature spin-down at these levels, which only developed during the forecast and therefore indicated a physical feedback initiated by the moisture analysis. The improvements made between Cy29r2 and Cy31r1 resulted in a reduction in the first guess departures biases in the TCWV pseudo-observations, and this would usually be considered an improvement. However, we found that in the original implementation at Cy29r2, a small moist bias in the tropical TCWV departures had been offsetting the tendency of the 4D-Var analysis to cause a net drying when presented with observations in areas near saturation. The offsetting moist bias in the rainy TCWV observations was largely removed at Cy31r1, with the result that the RAIN analyses are now slightly drier than the NORAIN analyses in the tropics. A drier tropics leads to less convection and less latent heating of the upper troposphere over the forecast period.

However, the introduction of VarBC at Cy31r1 requires a much more careful experiment set-up than before. In a similar framework, a large number of impact experiments have been conducted in collaboration with EUMETSAT by Graeme Kelly and Jean-Noël Thépaut in 2006. For the bulk of the operationally assimilated satellite observations Observing System Experiments (OSEs) were performed to address the individual impact of sensors when denied from the full operational system or when added to a poor baseline observing system. These experiments were set up with an initial two-week period allowing for model and VarBC to spin up, followed by 8 weeks with fixed bias-correction. Initial conditions came from operational analyses from 2006 that already use VarBC. With such a set-up, it is hoped that any effects coming from the spin-up of VarBC can be reduced.

The results of the observing system experiments are shown in Figure 6. This shows that RAIN assimilation leads to bigger improvements in the relative humidity forecast than before (Figure 5). The temperature forecasts, while showing a better picture than our early experiments, still show an ambiguous picture; there is a stronger positive impact near 200 hPa and everywhere in the southern hemisphere but also a stronger negative impact localized at 300 hPa. In general, the cloud and rain-affected observations improve the forecast skill but there are small areas in the tropics where the slight tropical drying in the RAIN experiments appears to reduce skill through feedbacks into temperature. It is good to note, however, that in the southern winter where RAIN was previously causing a slight forecast degradation (Figure 5), our modifications now allow RAIN to make a small positive impact on the forecasts here (Figure 6).

In the course of experiment evaluation, the fit of the analysis to conventional observations that are also assimilated was shown to improve. For example, the model's fit to drop-sonde temperature and wind observations in the Caribbean became better while it remained neutral with respect to other satellite observations (e.g. Advanced Microwave Sounding Unit, AMSU-B) that are sensitive to moisture. Independent comparisons to TCWV obtained from radiometer measurements onboard the Jason-1 oceanographic satellite mission showed that RAIN led to improved mean TCWV analyses in Cy29r2.

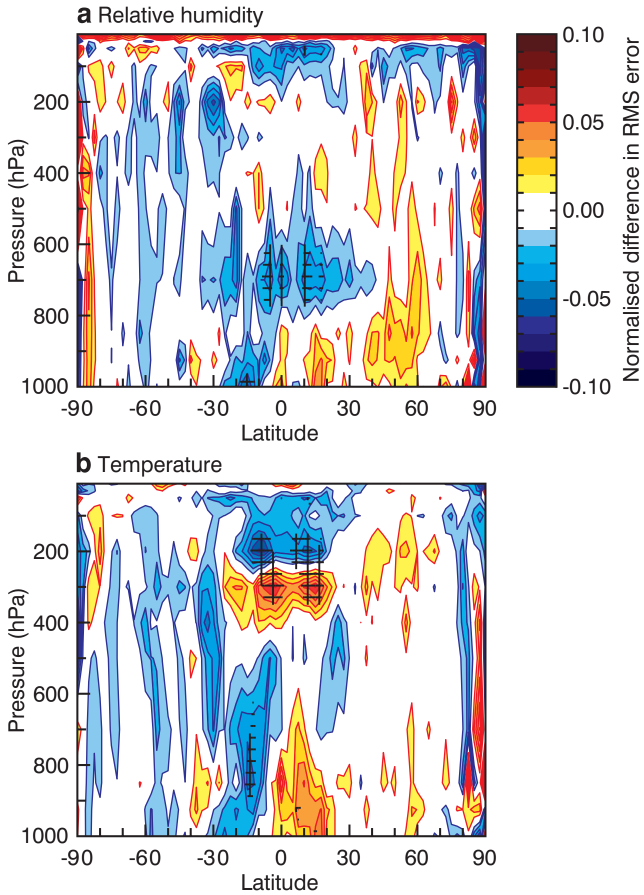


Figure 6 As Figure 5 from Cy31r1 EUCOS OSEs for 15 June to 15 August 2006.

Future

Ten years ago, the idea of assimilating cloud and precipitation-affected satellite observations was deemed impossible. The results that are obtained with the current operational system at ECMWF on this area can be considered a big success. Already, research activities towards the assimilation of Atmospheric Infrared Sounder (AIRS onboard Aqua) and Spinning Enhanced Visible and Infra-Red Imager (SEVIRI onboard Meteosat Second Generation satellites) radiances are pursued at ECMWF that will be complemented by similar studies for microwave sounders (AMSU-A/B) in the near future. From this, it can be expected that the observational coverage of cloud-affected areas will greatly improve.

With regard to microwave imagers, there are three main areas of development for the period 2007–8:

- Extension of the 1D+4D-Var system. The extension of the 1D+4D-Var system to other microwave sensors such as AMSR-E, TMI and SSMIS. This will greatly improve data coverage along 6/12-hour assimilation windows and produce an impact that is geographically more balanced. Even redundant data coverage is of advantage in case of sensor failure. The inclusion of multiple satellites also allows observing system impact studies in preparation of the Global Precipitation Measurement (GPM) mission. GPM is a NASA/JAXA satellite constellation dedicated to precipitation observation from space planned for 2013.
- Assimilation of radiances over land surfaces. The assimilation of rain-affected (and clear-sky) radiances over land surfaces is currently exploited with the support of visiting scientists funded through the EUMETSAT Satellite Application Facilities (SAFs) for Numerical Weather Prediction (Fatima Karbou) and Hydrology (Chris O'Dell).

- Direct assimilation of radiances in 4D-Var. For optimizing the impact of rain-affected radiances in 4D-Var and to alleviate the side-effects of channelling this impact through a moisture pseudo-observation, the direct assimilation of radiances in 4D-Var is envisaged as done for all other clear-sky radiances. The technical implementation of this has already been carried out in 2006 and will be tested in 2007. Once successful, its activation in the operational system will mark another milestone of advanced data assimilation realized at ECMWF.

Other meteorological services are following similar routes.

- The Met Office will soon implement the assimilation of cloud-affected AMSU-A radiances.
- The Meteorological Service of Canada is preparing a 1D+4D-Var procedure using the ECMWF methodology.
- Météo-France is focusing on the assimilation of ground-based precipitation radar data in the regional Application de la Recherche à l'Opérationnel à Méso Échelle (AROME) project.

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Seasonal Forecast System 3

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ECMWF HAS been running a seasonal forecast system since 1997. During that time there have only been two versions of the forecast system, called System 1 (S1) and System 2 (S2). A system consists of the atmospheric and oceanic components of the coupled model as well as the data assimilation scheme to create initial conditions for the ocean, the coupling interface linking the two components and the strategy for ensemble generation. For all systems so far, there is no dynamic sea-ice model; the initial conditions are based on the observed sea-ice limit but thereafter the sea-ice evolves according to damped persistence.

S1 became effectively operational in late 1997, and S2 started running in August 2001. During the last few years, work has proceeded with developing System 3 (S3). Major changes have taken place in the ocean analysis system for S3, though not in the ocean model itself. The atmospheric model is cycle 31r1 (Cy31r1). The horizontal resolution has been increased from TL95 to TL159 (with the corresponding grid mesh reduced from 1.875° to 1.125°), and the vertical resolution is increased from 40 levels to 62 levels, extending up to ~5 hPa.

As in S2, the ocean initial conditions in S3 are provided not from a single ocean analysis but from a 5-member ensemble of ocean analyses. The atmospheric initial conditions, including land conditions, come from ERA-40 for the period 1981 to 2002 and from Operations from 2003 onwards.

For S3 the forecast ensemble generation is not the same as S2: there are changes in the calibration period and size and in the way the ensemble is generated. The real-time ensemble set consists of 41 members in S3, and the calibration set consists of 11 members spanning the 25-year period 1981–2005, so creating a calibration probability distribution function of 275 members. Each of these ensembles has a start date of the first of the month. The initial atmospheric conditions are perturbed with singular vectors and the ocean initial conditions are perturbed by adding sea surface temperature perturbations to the 5 member ensemble of ocean analyses. Stochastic physics is active throughout the coupled forecast period.

S3 seasonal integrations are 7 months long (rather than the present 6 months). Additionally, once per quarter an 11-member ensemble runs to 13 months, specifically designed to give an "ENSO outlook". Back integrations have also been made to this range, once per quarter, with a 5-member ensemble.

The data from S3 are archived into the multi-model seasonal forecast streams (MMSF). This gives consistency in the data archive between all members of the multi-model forecasting system (called EURO-SIP). For users accessing data, the switch to the new streams should be straightforward. ECMWF is acting as a focus for the development of a real-time multi-model seasonal forecast system. Currently, the participants in EURO-SIP are ECMWF, the Met Office and Météo-France, but other members are expected to join in the future.

S3 is presently running in parallel with S2, and will become the operational ECWMF seasonal forecast system in early 2007. For technical information on the system, including the latest status and how to retrieve data, please see

www.ecmwf.int/products/changes/system3.

The ocean analysis

A new ocean analysis system has been implemented to provide initial conditions for S3 forecasts. The ocean analysis extends back to 1959 and provides initial conditions for both real-time seasonal forecasts and the calibrating hindcasts which are based on the period 1981–2005. Although only the ocean analyses from 1981 onwards are used for S3, the earlier ocean analyses will be used for analysing climate variability, and by the ENSEMBLES project for seasonal and decadal forecasts.

As for S2, the ocean data assimilation system for S3 is based on HOPE-OI (i.e. the optimum interpolation scheme developed for the Hamburg Ocean Primitive Equation model), but major upgrades have been introduced. In addition to subsurface temperature, the optimum interpolation (OI) scheme now assimilates altimeter derived sea-level anomalies and salinity data. In S3, the observations come from the quality controlled data set prepared for the ENACT and ENSEMBLES projects until 2002 and from the GTS thereafter. The OI scheme is now three-dimensional, the analysis being performed at all levels simultaneously down to 2000 m, whereas in S2, the analysis was carried out on each model level independently and only to 400 m. In S3 there is also a multivariate bias-correction algorithm consisting of a prescribed a priori correction to temperature, salinity and pressure gradient, as well as a time-dependent bias term estimated on-line. The on-line bias correction is adaptive and allows for flow-dependent errors. Because of the a priori bias-correction term, the subsurface relaxation to climatology has been weakened, from a time scale of 18 months in S2 to 10 years in S3. Due to the large uncertainties in the fresh water flux, the relaxation to climatology is stronger for surface salinity (approximately 3-year time scale), but still weaker than in S2 (approximately 6 months).

In order to obtain a first-guess as input to the OI analysis, it is necessary to force the ocean model with atmospheric fluxes.

- In S2 the fluxes were from ERA-15 until 1992 and then from the NWP operational analysis.
- In S3 the fluxes were from ERA-40 from January 1959 to June 2002, and then from the NWP operational analysis.

The representation of the upper ocean interannual variability is improved when using the ERA-40 wind stress, although the stresses are biased weak in the equatorial Pacific. The fresh water flux from ERA-40 (precipitation minus evaporation) is known to be inaccurate. A better but by no means perfect estimate was obtained by 'correcting' the ERA-40 precipitation values (*Troccoli & Kållberg*, 2004) as part of the EU ENACT project.

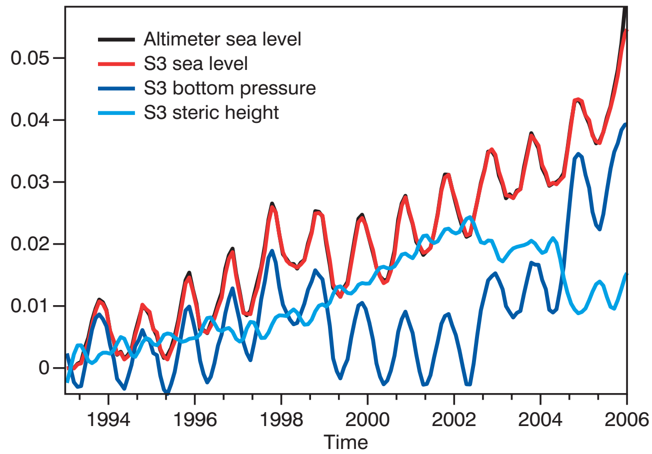

Figure 1 Global trends in sea level and associated quantities. Sea level data from the altimeter (black) and from S3 analysis (red) are almost indistinguishable. S3 steric height (light blue) represents the analysed change due to expansion of water, while the diagnosed equivalent bottom pressure (dark blue) represents changes in mass.

The temperature bias in the both the eastern and western equatorial Pacific in S2 has been significantly reduced in S3, where the east-west slope of the thermocline is now better represented. Also assimilating the salinity data is especially beneficial in the Western Pacific. The correlation of the model currents with the observed currents at different mooring locations on the equator in the equatorial Pacific is better in S3.

The variability in the upper ocean temperature in the north Atlantic is dominated by a warming trend, starting around the mid 1980s. Figure 1 from *Balmaseda et al.* (2007) shows the time evolution of the global sea level from altimeter data and from the S3 analysis. The similarity between the two curves is not surprising, since the global mean sea level trend has been assimilated. Figure 1 also shows the evolution of the global steric height, associated with changes in sea level due to thermal expansion and the time evolution of the global bottom pressure, indicative of changes in the global mass. It can be seen that till 2002 the global trend in global mean sea level (2 mm/year) is mainly due to thermal expansion. In mid 2002 and mid 2004 there are dramatic changes in the mass field as indicated by the bottom pressure. The change in 2002 may be due to the switch in the forcing from ERA-40 to operational analyses, where there is a noticeable increase in the global fresh water flux; the change in mid 2004 is less understood. Observing system experiments are being carried out to determine the information provided by the recently developed ARGO ocean subsurface float network, how it interacts with the information given by the altimeter and the impact of the observing system on climate variability.

Comparison of the time evolution of meridional transport in the North Atlantic at 30°N with the 'observed' values shows that, although there is broad agreement between the two, the S3 ocean analyses indicate that the decadal variability is large. This means that sampling is an issue when drawing conclusions about the slowing down of the thermohaline circulation from the sparse observations.

Data assimilation has a significant impact on the mean state and variability of the upper ocean heat content.

- In the Equatorial Pacific, it steepens the thermocline and increases the amplitude of the interannual variability.
- In the Indian Ocean it sharpens the thermocline, making it shallower, and it increases both the ENSO-related and Indian Dipole variability.
- In the Equatorial Atlantic it makes the cold phase of the seasonal cycle more pronounced, and increases the amplitude of the interannual variability.
- ARGO has a large impact on the salinity field on a global scale.

The impact of the S3 analysis on seasonal forecasts is beneficial nearly everywhere, but especially in the west Pacific. A region where there is little impact is the equatorial Atlantic. A fuller description of the ocean analysis system can be found in *Balmaseda et al.* (2007).

Assessment of forecast skill

At the time of writing, the full set of operational reforecasts for S3 is not yet complete. Results presented here are instead based on an experiment carried out in the ECMWF Research Department, which we will refer to as S3TEST, consisting of a five-member ensemble for four start dates per year, starting in 1987. The starting point for a seasonal forecasting system is its skill in predicting sea surface temperature (SST). Comparing anomaly correlation and rms errors in forecasts of Nino 3.4 and Nino 4 SST in S3TEST with those for S1 and S2 shows clear progress.

Figure 2 shows the rms error for the Nino 4 index, indicating that S3 is considerably better than S1 and S2 in this region, a more difficult region to predict than those to the east (Nino 3 and Nino 3.4). Scatter diagrams, showing all available forecasts for which S2 and S3TEST can be compared, indicate that the improvements in S3TEST are significant in all areas of the tropical Pacific. However, the strong improvement does not extend to all parts of the globe – outside the equatorial Pacific, changes in SST forecast skill are largely close to neutral, although there is a clear positive benefit in the north subtropical Atlantic.

The climatology of the atmospheric component of S3TEST shows substantial improvements with respect to S2. Systematic errors in geopotential height, sea-level pressure and lower-tropospheric temperature have been substantially reduced in both the tropical and the northern extra-tropical regions. As an example, Figures 3(a) and 3(b) show systematic errors in 500 hPa height for January-March at a 4–6 month forecast range for S2 and S3TEST. A notable reduction in the model bias is found over the North-Pacific, where a large positive bias exceeding 12 dam in S2 has been reduced by almost a factor of 3. Mean errors over North America, which in S2 acted to decrease the amplitude of the stationary wave pattern, have also been substantially reduced, leading to a notable improvement in the zonally-asymmetric component of the time-mean flow.

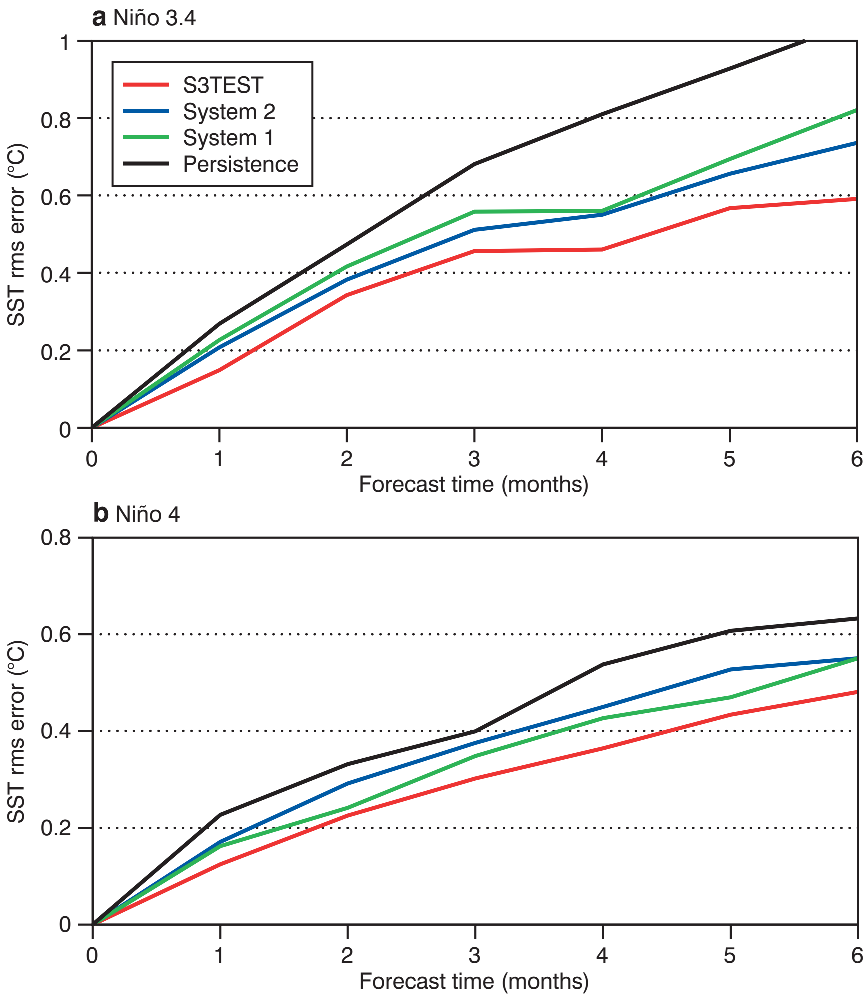

Figure 2 (a) RMS errors for Nino 3.4 SST forecasts from System 1 (green), System 2 (blue) and S3TEST (red), for 64 forecasts in the period 1987-2002. (b) As (a) but for Nino 4. Note that System 2 was worse than the original System 1, but this has more than been made up by S3TEST.

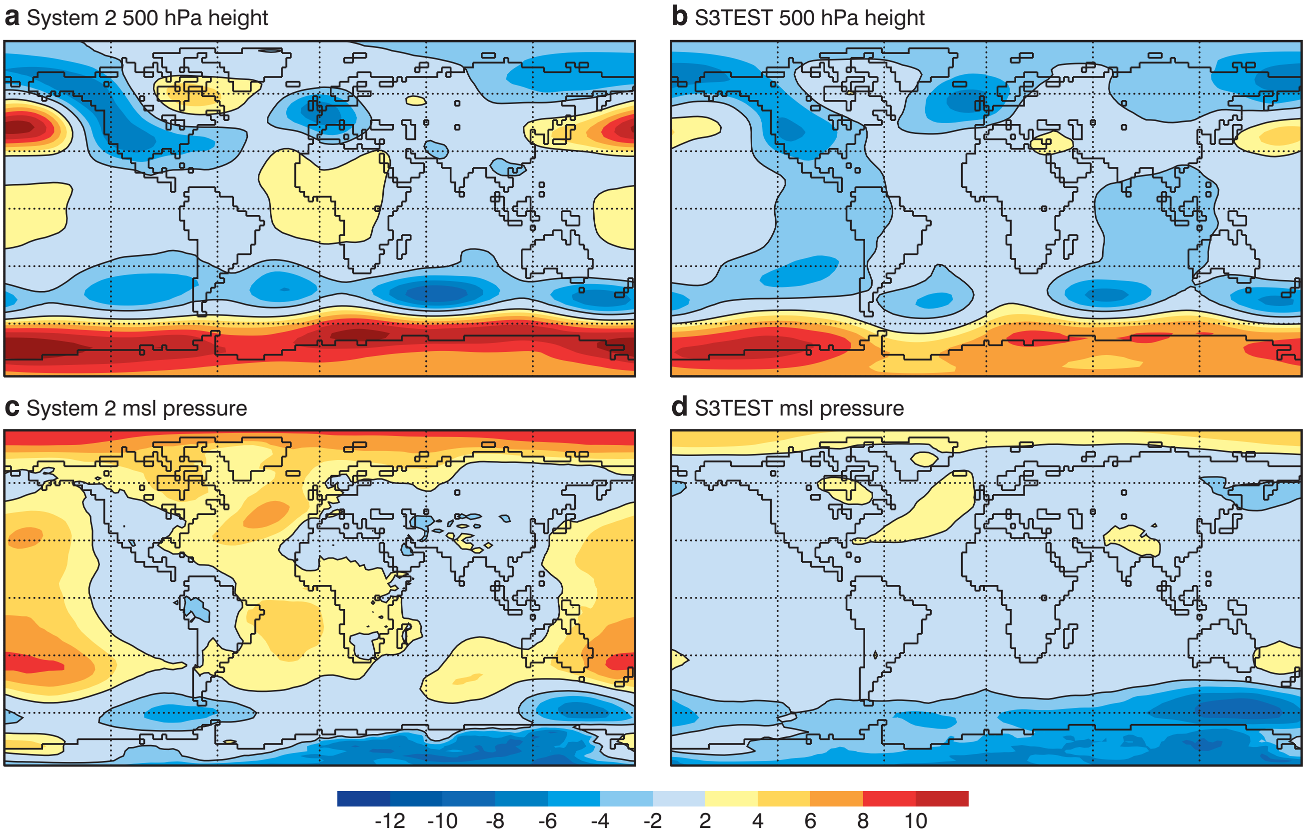

Figure 3 Systematic errors of 500 hPa height (dam) for (a) System 2 and (b) S3TEST for January–March for experiments in the 4-to-6-month forecast range. (c) and (d) As (a) and (b) but for msl pressure (hPa) in July–September.

A negative bias of about 6 dam over Western Europe has been shifted to the north-west, unfortunately without any noticeable reduction.

The location of the negative bias over Western Europe in S3TEST is close to the region of highest blocking frequency in the East Atlantic sector, and therefore prevents any improvement in the simulated blocking statistics. Both S2 and S3TEST simulate the maxima of blocking frequency over the Euro-Atlantic and North Pacific regions, but winter hindcasts underestimate the blocking frequency over most of the northern hemisphere. The bias is more obvious over the North Pacific, although the western Atlantic blocking is also underestimated. These differences are significant with a 95% confidence over most longitudes. The results are representative of the model behaviour in other seasons. Experiment S3TEST is no better than S2 in this regard, as can be seen in Figure 4.

Figures 3(c) and 3(d) show biases in the msl pressure field for the boreal summer for S2 and S3TEST. Positive errors in the regions of the subtropical anticyclones over both the northern and southern oceans were present in S2, with amplitude between 4 and 8 hPa. These errors have been substantially reduced in S3TEST. A positive bias over the Arctic Ocean has also been reduced by about a factor of 2, but the negative bias over the southern polar regions has been partially increased.

In S3TEST, both the seasonal mean and the interannual variability of rainfall over the tropical oceans are generally reduced compared to S2 values, bringing the model climatology into closer agreement with observational data from GPCP (Global Precipitation Climatology Project). The spatial distribution of modelled rainfall is notably improved in the tropical Pacific during the boreal winter. While in S2 rainfall in the eastern Pacific ITCZ exceeds observations by (at least) a factor of 2, S3TEST simulates a more correct ratio between rainfall in the western and eastern parts of the ocean. The improvement in the mean field is reflected in the distribution of rainfall interannual variability. Comparing the standard deviation of January–March rainfall in the ensembles run with S2 and S3TEST shows that the S2 variability shows two distinct maxima (with similar amplitude) in the western and eastern tropical Pacific. However, S3TEST simulates a single variability maximum located just west of the dateline, in closer agreement with observations.

Internal atmospheric variability is generally higher in S3TEST than in S2, both in tropical and extratropical regions. For the tropics, a notable improvement is found in the amplitude of intraseasonal variability in the frequency range of 20 to 70-days, which includes the Madden-Julian Oscillation (MJO). The standard deviation of tropical velocity potential anomalies at 200 hPa in the October-to-March season is calculated for ERA-40, S2 and S3TEST, using a bandpass filter to isolate oscillations with periods between 20 and 70 days. Although the location of the variability maxima over the

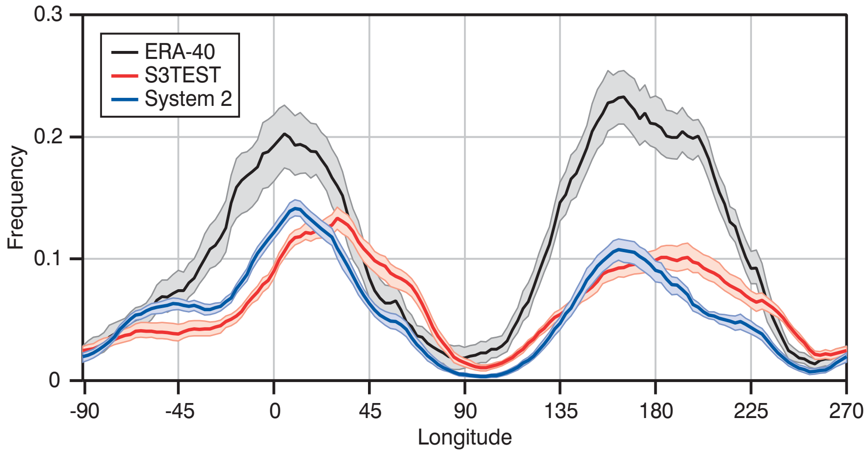

Figure 4 Northern hemisphere winter average blocking frequency for ERA-40 (black line), System 2 (blue line) and S3TEST (red line) for the period 1987–2004. The model index has been computed using five-member ensembles initialized on the 1 October and the results shown are for the season December to February. The shaded areas around each bold line correspond to the 95% confidence interval computed using a bootstrap with a sample size of 500.

Indian and west Pacific oceans is in good agreement with re-analysis data, the amplitude is underestimated by both systems. However, in S3TEST the amplitude is considerably closer to ERA-40 than it is in S2. The spectral distribution of the velocity potential variability is further analysed as a function of longitude and oscillation period. As shown in Figure 5, although the S3TEST results represent an improvement with respect to S2 simulations, S3TEST fails to generate a variance maximum in the MJO frequency range as good as that simulated by Cy30r2. Unfortunately, Cy30r2 was not an acceptable cycle: it was never used operationally for medium-range forecasts, and it gave substantially worse forecasts of west equatorial Pacific sea surface temperatures as well as developing unrealistic upper-troposphere moisture distributions.

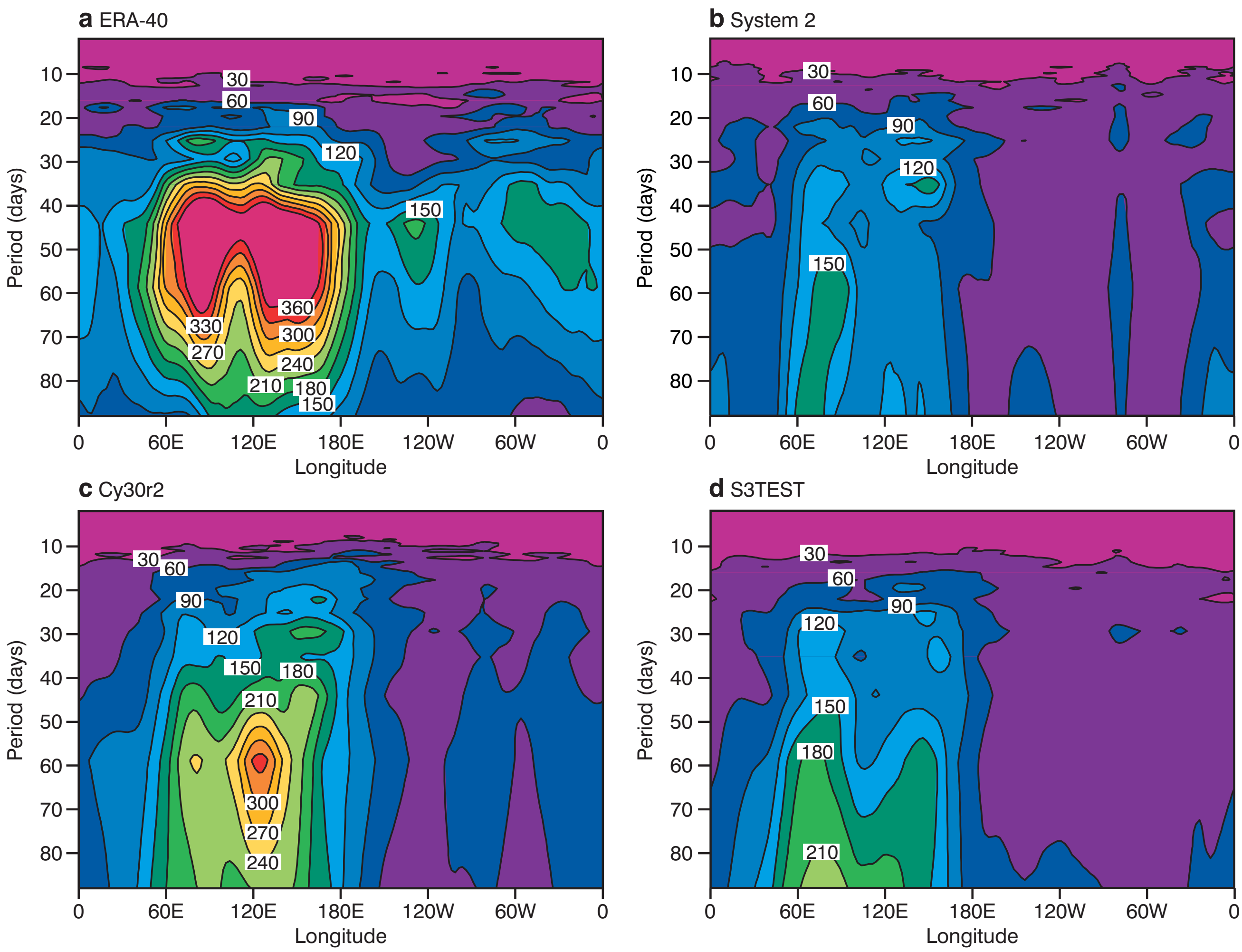

Figure 5 Spectra of 200-hPa velocity potential anomalies in the October–March season as a function of longitude and period for (a) ERA-40 (b) System 2, (c) Cycle 30r2 and (d) S3TEST experiments.

The number of tropical storms detected in S2 and S3TEST has been averaged over the period 1987–2004, the five ensemble members and the four annual starting dates for each individual ocean basin. Comparing the mean annual frequency of tropical storms for each ocean basin with observations shows that S3TEST produces more tropical storms than S2 over all the ocean basins. A possible explanation is the increased horizontal resolution (T159 instead of T95). The increased number of storms is more realistic, although in many areas the number of storms is still underestimated. The tropical storm tracks are clearly much longer and realistic in S3TEST than in S2, as expected from the increased horizontal resolution. Figure 6 shows an example of tracks over the eastern North Pacific and the North Atlantic. These figures show storms that last longer and recurve. This property seems to hold good in other areas also and may indicate that it is feasible to assess the model's ability to predict when tropical storms are more likely to make landfall. Currently only information on frequency and genesis region is made available.

The performance of S3TEST was also assessed in terms of the overall predictive skill of the system for seasonal means of weather parameters such as rainfall and surface air temperature. For a seasonal prediction system, probabilistic indices are usually preferred as a measure of skill. However, given the small size of the ensemble experiments used for this preliminary assessment (five members only), such indices may be subject to considerable sampling errors and so only a preliminary estimate can be given. A variety of scores were examined for different seasons and lead times, but a fair summary of the results can be given based on a subset of the Relative Operative Characteristics (ROC) scores. Specifically, the subset includes scores for:

- Below-average two-metre temperature anomalies in (boreal) winter (January–March) and above-average temperature anomalies in summer (July–September) for Europe and North America.
- Below-average rainfall for both of these seasons for the whole tropical band.

The ROC scores confirm the indications which emerged from the analysis of individual processes: in general, S3TEST has more predictive skill than S2 for the tropical regions, while in the northern extratropics improvements are mostly evident during the summer season. The slight but possibly real decrease of skill scores during the boreal winter may be related to a partial reduction of the wintertime diabatic heating anomalies in the central tropical Pacific during ENSO episodes, and to an increased level of internal atmospheric variability. Both of these decrease the signal-to- noise ratio for northern hemisphere interannual variability during winter. In S2, such a ratio was enhanced by larger than observed rainfall amounts in the tropical Pacific, which partially compensated the reduction in the SST anomaly amplitude occurring during the coupled integrations.

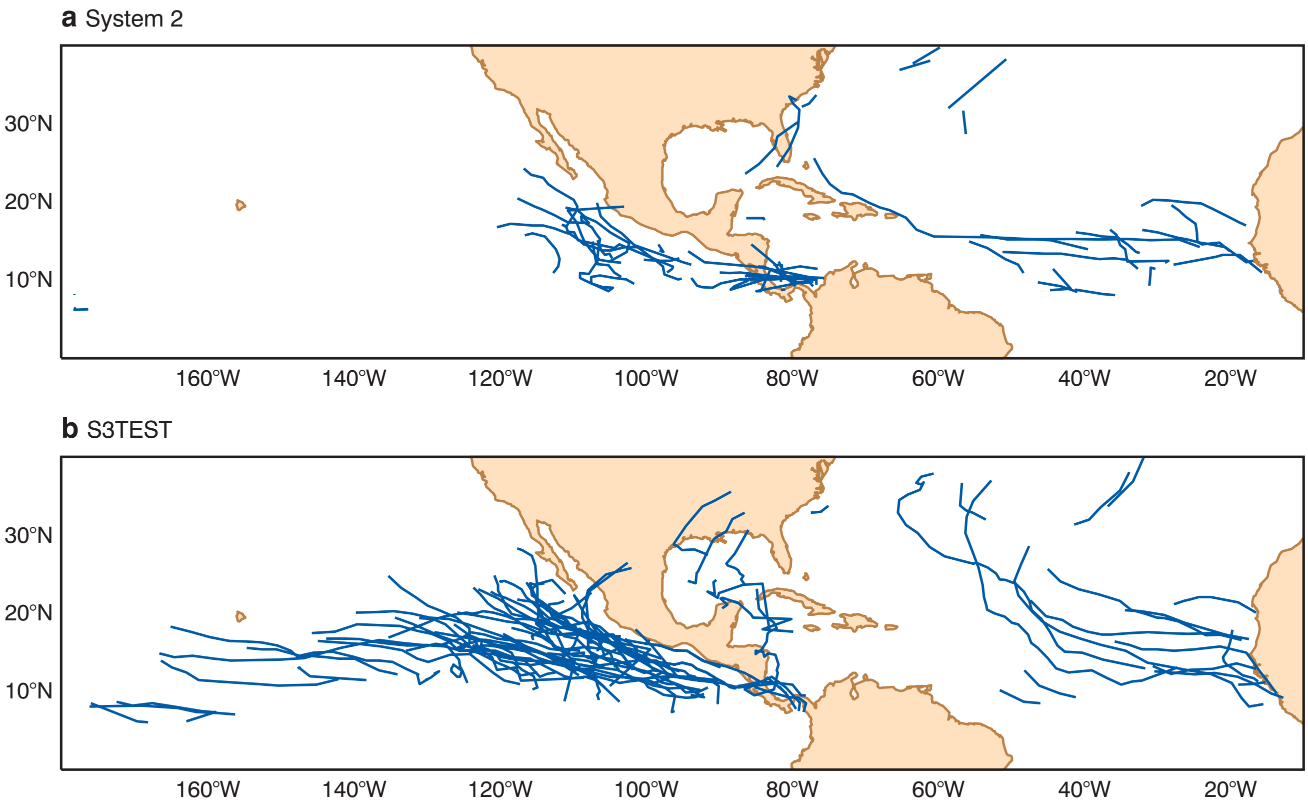

Figure 6 Model tropical storm tracks in the Atlantic and Eastern North Pacific for (a) System 2 and (b) S3TEST. Forecasts start on 1 July 2004.

Summary of System 3 performance

Throughout the extensive development period of System 3 various atmospheric model cycles were tested as they became available. Progress was not monotonic. Although each cycle improved or was at least neutral for the medium-range forecasts this was not so for the seasonal forecast range, where new cycles sometimes led to a significant drop in skill. However, the last few cycles have resulted in strong and significant gains in SST prediction skill, and the model version used in System 3 is the best we have yet seen when assessed by its ability to predict the important El Nino SST variations in the Pacific.

System 3 still has clear deficiencies, however, and there are certain aspects where other model versions show that better performance is possible. For example, Cy30r2 had a better representation of the intraseasonal oscillation than Cy31r1, despite its other failings. In the northern hemisphere extratropics the improvements in S3TEST are mainly seen in the summer season, and it is possible that northern hemisphere winter mid-latitude forecast skill is marginally worse than S2. The ensemble size is only five at this stage of assessment, and only a subset of dates have been considered, so a proper evaluation of System 3 for regions where the signal-to-noise ratio is small must await the full set of calibration forecasts. The skill scores will be published on the ECMWF web pages when they become available.

Blocking in the northern hemisphere is not well handled in either S2 or S3TEST, and remains a serious model deficiency which should be given more attention in future developments. Although the MJO is better represented in S3TEST than in S2, it is still not as well represented as we would like, and continued effort on improving this model deficiency is desirable. Improvements in blocking and the MJO would be beneficial to the extended VAREPS and monthly forecast systems as well as to the seasonal range. The coupled model is now quite well integrated into the ECMWF system making it easier to test model changes on the seasonal (and monthly) range at an earlier stage.

Several other major features of System 3 should be highlighted. The ocean analysis/reanalysis is a major product in its own right. The increased ensemble size and especially the larger set of back integrations (25 years rather than 15 years) increases the accuracy of the forecast products. This is a big step forward for those wishing to process the model output themselves to create tailored seasonal forecast products. The new experimental ENSO outlook forecasts extending to 13 months give a longer-range outlook on one of the major factors that drives seasonal climate anomalies.

There is still scope for substantial improvements in the future, but we hope that System 3 will be a useful step on the road to developing numerical systems that fully exploit the predictability that exists on seasonal timescales.

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ERA-Interim: New ECMWF reanalysis products from 1989 onwards

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DICK DEE, SHINYA KOBAYASHI

OVER the past decade, reanalyses of multi-decadal series of past observations have become established as an important and widely utilized resource for the study of atmospheric and oceanic processes and predictability. Produced using fixed, modern versions of the data assimilation systems developed for numerical weather prediction, they also are being applied increasingly in many other fields that require a record of the state of either the atmosphere or its underlying land and ocean surfaces. Estimation of renewable energy resources, calculation of microwave telecommunication signal losses and study of bird migration are just three examples.

High-resolution operational forecasting systems provide good quality analyses for study of recent conditions. However, the pace of improvement of these systems is such that lower-resolution reanalyses produced using up-to-date assimilation systems provide products for all but the last few years that are generally superior to those available from the archives of past operational products. Reanalysis products are, by design, more suitable than their operational counterparts for use in studies of longer-term variability in climate, although they remain susceptible to changes in the observing system that can make accurate depiction of long-term trends problematic.

Two major ECMWF reanalyses have exploited the substantial advances made in the ECMWF forecasting system and technical infrastructure since operations began in 1979. The first project, ERA-15 (1979–1993), was launched in 1993 and the second "extended" reanalysis project, ERA-40 (1957–2002), in 1998; for details see *ECMWF Newsletters No. 73* and *No. 101*. The products of these reanalyses have been used extensively within the Member States and by the wider user community. They have also been used extensively within ECMWF in support of other activities, particularly for validating long-term model simulations, helping develop seasonal forecasting (enabling the DEMETER hindcasts, for example) and establishing the "climate" of EPS (Ensemble Prediction System) forecasts needed for construction of forecaster-aids such as the Extreme Forecast Index.

Reanalysis as an iterative and ongoing process

The recent ECMWF/GEO Workshop on Atmospheric Reanalysis (*ECMWF Newsletter No. 109*) emphasized that instead of being viewed as a series of largely independent "one-off" exercises, reanalysis has come to be seen more as an iterative process. In this process, developments in modelling, data-analysis techniques and computing power are allied with new data rescue efforts and data and experience from reanalyses carried out elsewhere, to produce a succession of reanalyses of increasing quality, accounting increasingly well for changes in the observing system.

Notwithstanding this, users often express a requirement for reanalyses to be extended in close to real time, in what is known as Climate Data Assimilation System (CDAS) mode. This has been adopted by the National Centers for Environmental Prediction (NCEP) for its two global reanalyses (NCEP/NCAR and NCEP/DOE) and more recently by the Japan Meteorological Agency in extending its JRA-25 (1979–2004) reanalysis. Whilst this approach provides users with up-to-date data in a conveniently familiar form, if continued too long it results in products of significantly lower quality than would be produced by a replacement reanalysis. In particular a fixed, older analysis system is unlikely to exploit well, if at all, new types of data from the evolving observing system.

The ERA-40 project was designed so that its production could be supported by funding of limited duration from the European Union's Fifth Framework Programme. Production finished in April 2003, when the Fujitsu computer system on which it was running was decommissioned. With limited human resources available from then onwards, it was decided not to migrate the ERA-40 production system to the new IBM computers that had been installed. Instead, effort would be devoted to development of a new reanalysis system derived from the latest version of the operational ECMWF system. Tests had already indicated that several of the problems experienced in ERA-40 would be eliminated or significantly reduced: most notably a too-strong tropical oceanic precipitation that was marked from

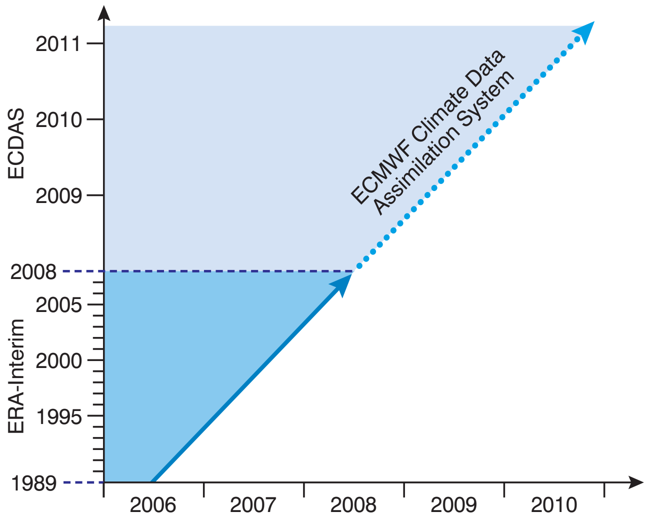

Figure 1 The schedule for ERA-Interim and its transition to ECMWF Climate Data Assimilation System (ECDAS). Note the change of scale beyond 2008 on the vertical axis.

the early 1990s onwards and a too-strong Brewer-Dobson circulation in the stratosphere. This new reanalysis system would be used to produce an interim reanalysis that would be run for the data-rich 1990s and 2000s, and continued as an ECMWF Climate Data Assimilation System (ECDAS) until superseded by a new extended reanalysis - see Figure 1.

The ERA-Interim reanalysis system

With increased computer power available, the use of 4D-Var, tried-and-tested in operations since 1997, became feasible for ERA-Interim. Preparatory experiments were thus carried out to evaluate 4D-Var, with 6- and 12-hourly cycling, in comparison with 6-hour 3D-Var as used for ERA-40. The tests employed the T159L60 model resolution used for ERA-40, but a newer version of the forecasting system, IFS Cy29r1. Also tested was a new variational bias correction scheme (VarBC) for radiance data.

Experimental assimilations were carried out mainly for two periods: August 1999 to December 2000, and January to December 1989, the starting year for ERA-Interim. The benefit of using 4D-Var was seen in systematically better forecast performance, especially in the southern hemisphere. 12-hour 4D-Var was more resilient than 6-hour 3D-Var over a period during which data was lost from one of the two polar-orbiting satellites operating at the time. Important improvements were seen in the hydrological cycle, with 12-hour 4D-Var having the smallest model spin-up/down. Precipitation-minus-evaporation was much closer globally to zero than in ERA-40. The new reanalyses also were tested by Beatriz Monge-Sanz (University of Leeds) for application in chemical transport modelling; they gave a larger, more realistic "age-of-air" in the stratosphere than seen using either ERA-40 or operational analyses for the year 2000.

The quality of analyses was also validated by other means: fit of background forecasts to the observations used, fit of surface winds to independent buoy winds, agreement with independent tropical-cyclone track data, and comparison of precipitation with independent estimates from the Global Precipitation Climatology Project (GPCP). All pointed to a small but systematic edge in favour of 12-hour 4D-Var with VarBC.

Production of ERA-Interim, from 1989 onwards, began in summer 2006. Enhanced computer power enabled horizontal resolution to be increased to T255, but vertical resolution was kept at the 60 levels used for ERA-40. The latest cycle of the model (IFS Cy31r1/2) was adopted, as introduced operationally in September and chosen for the next version of the ECMWF seasonal forecasting system. In summary, the main advances of the ERA-Interim data assimilation over the ERA-40 system, including the changes in the use of observations, are given in Box A.

Handling of biases

Observations of the atmosphere are prone to biases, and it is important to adjust data to remove these biases if an assimilation system is to make optimal use of a wide variety of observations. Biases tend to change over time due to often-undocumented changes in instrumentation and in the processing carried out by data providers. Consequently bias correction is particularly important and challenging in a reanalysis that is to be used to study climatic trends and low frequency variability. The use of a comprehensive forecast model to generate background estimates for the data assimilation system provides a powerful tool to aid this bias correction.

ERA-40 used a scheme for correcting systematic errors in radiosonde temperatures due to short-wave radiation and other effects. Stations were separated into groups representing different countries or areas where it was assumed that similar types of sonde were used at any one time. Mean differences between background forecasts and observations were accumulated for each station group over at least twelve months for different classes of solar elevation. It was then decided manually for each group whether to apply a correction and if so whether to adjust for the complete bias or (more commonly) only for the component dependent on solar elevation. The corrections were reassessed from time to time and revised if necessary. The scheme was applied only from 1980 onwards.

Using statistics archived from ERA-40 and subsequent operational data assimilation, observation-minus-background time series for individual radiosonde stations have been used to derive a homogenization scheme, in which discontinuities in the mean temperature record due to equipment or data-processing changes are identified and removed. This work was started by Leopold Haimberger at ECMWF, and has been continued by him at the University of Vienna. The resulting homogenized radiosonde temperatures are being used in ERA-Interim. The homogenisation does not account for seasonal variations in solar heating, which are dealt with by applying a revised version of the ERA-40 bias correction scheme to the homogenised data.

Biases in satellite radiances in ERA-Interim are estimated and corrected using the variational bias correction

Box A

Differences in data assimilation and use of observations between ERA-40 and ERA-Interim

Data assimilation

The main advances in the ERA-Interim data assimilation compared to ERA-40 are:

- 12 hour 4D-Var.
- T255 horizontal resolution.
- Better formulation of background error constraint.
- New humidity analysis.
- Improved model physics.
- Data quality control that draws on experience from ERA-40 and JRA-25.
- Variational bias correction of satellite radiance data, and other improvements in bias handling.
- More extensive use of radiances, and improved fast radiative transfer model.

Observations

ERA-Interim uses mostly the sets of observations acquired for ERA-40, supplemented by data for later years from ECMWF's operational archive. There are, however, a few noteworthy exceptions:

- ***Altimeter wave-heights***. A new ERS altimeter wave-height dataset has been acquired from ESA, providing data of more uniform quality than the Fast Delivery Dataset used from August 1991 onwards in ERA-40.
- ***Winds and clear-sky radiances***. EUMETSAT provided reprocessed winds and clear-sky radiances from Meteosat-2 (1982-1988) for ERA-40 and are currently reprocessing later Meteosat data for ERA-Interim.
- ***Ozone profiles***. Reprocessed GOME data from the Rutherford Appleton Laboratory will provide ozone profile information from 1995 onwards.
- ***Radio occultation measurements***. CHAMP GPS radio occultation measurements, processed and archived at UCAR, have been obtained to cover the period from mid 2001 to mid 2006. Subsequent occultation data, from the constellation of CHAMP, GRACE and COSMIC receivers, has been received operationally.

Boundary forcing fields

Boundary forcing fields are taken from ERA-40 until 2001, and from ECMWF operations for later dates.

(VarBC) scheme described in *ECMWF Newsletter No. 107*. Regression parameters describing the biases for each radiance channel are estimated during the data assimilation by treating them as additional degrees of freedom in the 4D-Var minimisation. This radiance bias correction scheme is adaptive and self-contained, in that it does not require any external information about satellite biases. It performed well in the preparatory experiments for ERA-Interim, and has been used in operations since September 2006. It solves most of the technical problems experienced with manual bias tuning, smoothly corrects bias drifts, handles data gaps, and can quickly develop bias corrections for new sensors. Variational bias correction of all radiance data simultaneously with the adjustment of the model state appears to remove many of the detrimental side effects of sub-optimal and/or conflicting bias corrections seen in ERA-40. As a result, the fit to conventional data improves, and the system is able to assimilate larger numbers of observations overall.

The stability of the adaptive scheme depends on the amount of information about the biases available from other observations. To test and illustrate this, a simple experiment was performed in which all observations were withheld from one of two otherwise identical assimilations during a period of two weeks, causing the two systems to drift apart considerably. Figure 2 shows the divergence of the global mean analysed temperatures in the two systems, due to model bias, followed by a re-convergence after the reintroduction of observations. Re-convergence in the uppermost levels is relatively slow, consistent with the lack of observations at those levels. Further discussion of the performance of VarBC at these levels is given in the following section.

An automatic, adaptive scheme to correct various systematic errors in surface-pressure data has also been developed and implemented in operations, as described in *ECMWF Newsletter No. 108*. The scheme is especially important for reanalysis, which makes use of several historical data sources with varying characteristics and poorer metadata than available today. The reported surface pressure observations (SYNOP, SHIP, DRIBU) are corrected if a systematic deviation from the background forecast is detected that is not supported by neighbouring observations. The error can be due to incorrect station-elevation data or a buoy-sensor that

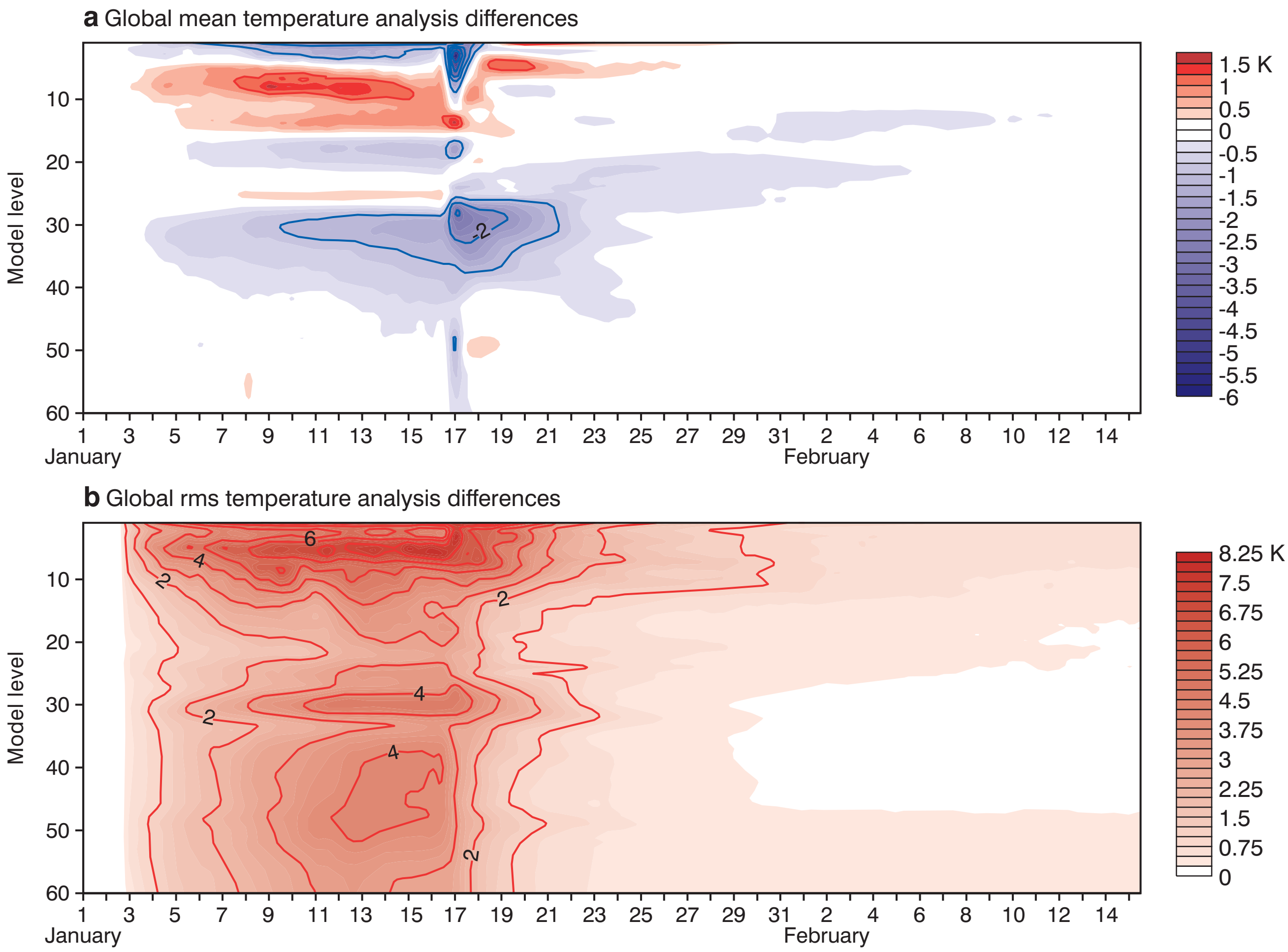

Figure 2 Evolution of (a) global mean and (b) root-mean-square temperature differences between a control assimilation (using all available observations and variational bias correction on all radiance data) and an experimental assimilation in which all observations were withheld from 3–17 January. The divergence in global mean temperature is due to model bias.

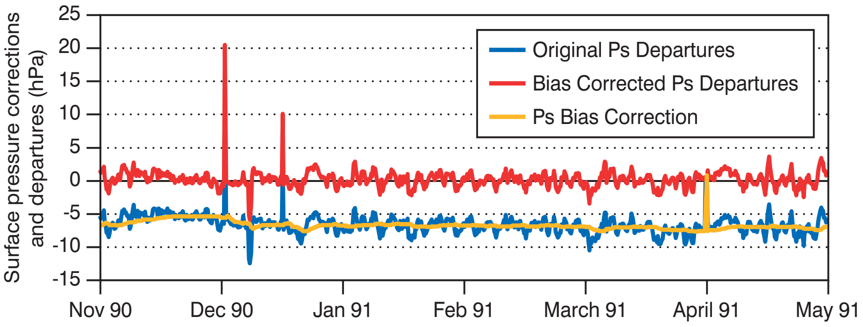

Figure 3 Correction of surface pressure for the Vostok station (78° 27'S, 106° 52'E) in Antarctica, which has a wrong station height in the historical data records. The blue line shows the original departures (i.e. the observed pressure minus the pressure interpolated from the background forecast to the incorrect station altitude). The yellow line shows the applied bias corrections and the red line shows the departures after the bias correction. The bias correction scheme retains the high-frequency signal from the observations.

reports biased values. In current ECMWF operations the number of corrected stations can exceed 1,000 and in ERA-Interim even more. The Vostok station in Antarctica provides a good illustration of the scheme's performance. For ERA-15, David Bromwich and colleagues (Ohio State University) found that moisture transport over the eastern Antarctic was unrealistic. By investigating the geopotential increments, analysis-minus-background, a systematic difference was found to stem from an error of about 60 m in the height of the station. In ERA-40 the elevation was corrected before the data entered analysis. In ERA-Interim the bias has been identified and corrected automatically by the scheme, as illustrated in Figure 3.

The altimeter wave height data from the European Remote Sensing satellites ERS-1 and ERS-2 have been compared with buoy measurements and bias corrections have been calculated for use in ERA-Interim. ERS scatterometer data have also been re-calibrated, based on triple collocation with buoy measurements and ERA-40 background 10-metre wind speeds. The study also showed ERA-40 winds to be 0.25–0.40 m s^{-1} weaker than the buoy winds. Figure 4 shows time series comparing the ERS scatterometer data with bias-corrected ERA-40 winds.

Performance of the data assimilation

Monitoring the performance of the data assimilation is an essential part of reanalysis production and there are several complementary ways to do this. Under normal circumstances, 10–15 days of analyses are produced every actual day. Statistics are needed over quite long periods, and have to be examined regularly. Based on experience with ERA-15 and ERA-40, comprehensive monitoring

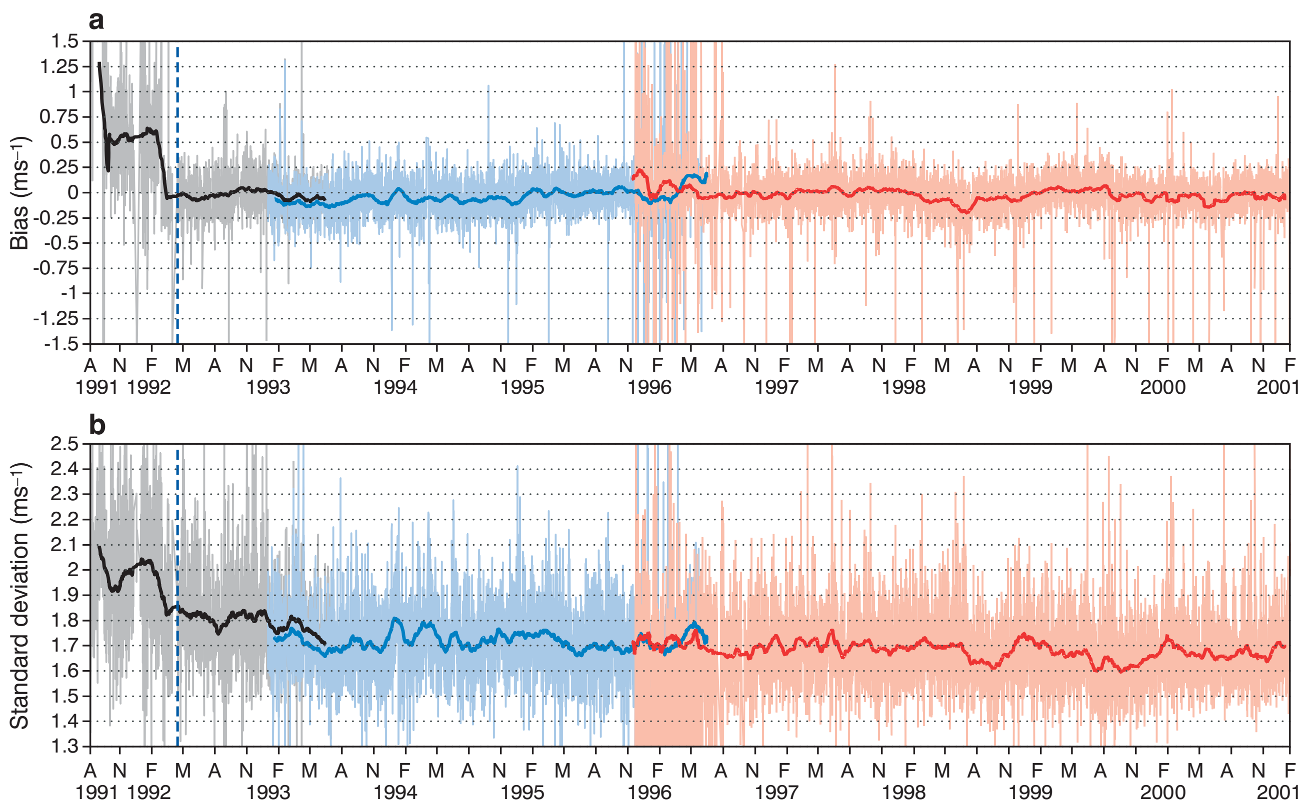

Figure 4 Time series of (a) mean and (b) standard deviation of the differences between recalibrated ERS scatterometer wind speeds and the bias-corrected ERA-40 background winds. In blue and red are ERS-1 and ERS-2 data as used in ERA40; in black are ERS-1 data that were not assimilated in ERA-40. Also shown are the 30-day moving averages. The blue vertical dashed line indicates how far back in time the assimilation of ERS-1 data could start using the re-calibrated data.

diagnostics with routine web-based display have been further developed for ERA-Interim. They include:

- Time series and monthly-means (maps and cross-sections), for quantities such as basic analysed and forecast variables, and their differences from ERA-40.
- Means and standard deviations of the analysis-minus-background increments and the observation-minus-background and observation-minus-analysis departures for all assimilated observations.
- Number of used, blacklisted and rejected conventional data.
- Radiosonde bias correction statistics.
- Predictors and corrections from the VarBC scheme for radiances.

The monthly-mean meridional cross-sections of zonal-mean temperature show some marked differences between ERA-Interim and ERA-40 in the stratosphere, particularly at the higher levels where only radiance data are available for assimilation. Figure 5 presents an example, for August 1990. ERA-40 was prone to the occurrence of a spurious oscillatory structure in the vertical profile of temperature in polar regions, which was most marked over Antarctica in late winter and spring. In ERA-Interim, this oscillatory structure is much reduced in amplitude, as illustrated in Figure 5. This is because VarBC, in the absence of other "anchoring" data (mainly radiosonde temperatures), absorbs most of the model bias into the radiance adjustments and reduces the analysis increments dramatically in the upper stratosphere. The source of the oscillatory structure in ERA-40 was the large temperature increments made to reduce differences between model and observed radiances originating from quite deep layers centred in the upper stratosphere.

In addition, ERA-Interim is generally much warmer than ERA-40 in the upper stratosphere, by some 7 to 11 K at around 3 hPa. Away from the poles, the difference shown in Figure 5 is similar to that seen in the annual mean for 1990. An assessment of uncertainties in climatologies of wind and temperature in the stratosphere and mesosphere by the SPARC (Stratospheric Processes and their Role in Climate) project has shown that the ERA-40 analyses for the early 1990s have an upper stratospheric cold bias of up to 5 K compared with the consensus of other climatologies. The warmer mean upper-stratospheric temperatures in ERA-Interim indicate that the bias has shifted from cold to warm for these years, but not changed much in magnitude. The upper stratospheric temperature bias in ERA-Interim is in fact similar to the bias seen in ERA-40 for the years prior to the availability of satellite radiance data. This is because VarBC adjusts the measured radiances towards the preferred warm state of the background model in the absence of other types of observation. Recent experimental results suggest that the upper stratospheric model bias is better controlled by not applying bias correction to SSU channel-3 radiances, which have maximum sensitivity to temperatures at 1.5 hPa.

Differences are much smaller at lower levels, but still exceed 1 K at the tropical tropopause, with ERA-Interim colder than ERA-40. They can exceed 0.5 K lower in the troposphere. Because of these mean differences, unadjusted ERA-Interim and ERA-40 products should not be mixed in time-series analysis of trends and low-frequency variability.

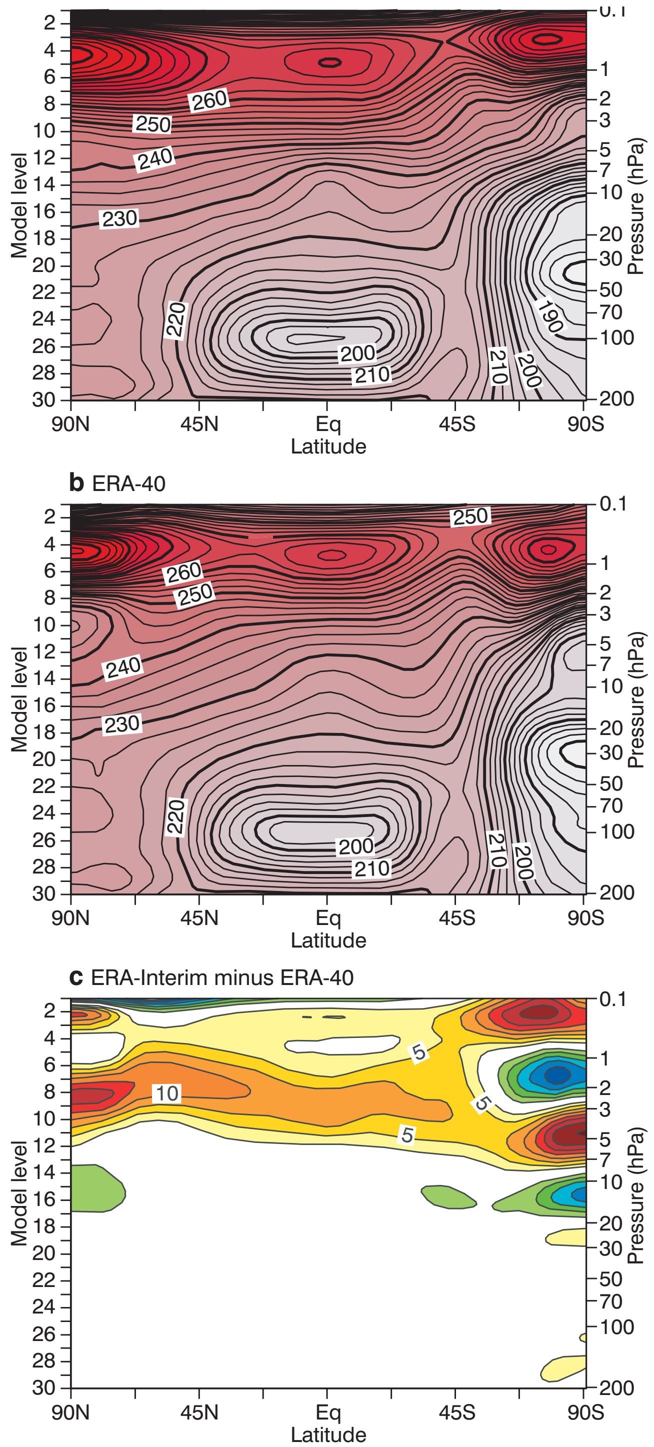

Figure 5 Meridional cross-sections showing the zonal-mean temperature analysis averaged for the month of August 1990 from (a) ERA-Interim and (b) ERA-40. (c) Difference between (a) and (b). The contour interval is 2.5 K. For the difference plot, the zero contour is suppressed, and negative values are denoted by green and blue shading.

Figure 6 shows root-mean-square and mean differences between radiosonde temperature measurements and the background and analysed values from ERA-40 and ERA-Interim. The root-mean-square differences between the observations and background are generally smaller in ERA-Interim. The 12-hour 4D-Var analysis used for ERA-Interim does not fit the data quite as closely as ERA-40's 6-hour 3D-Var, but the improved fit of the background forecasts (which are at 9-hour range for ERA-Interim compared with 6-hour range for ERA-40) is indicative of a generally better analysis. The bias in ERA-Interim is mostly smaller and less oscillatory in structure than in ERA-40, although it is larger and of opposite sign (warm for ERA-Interim and cold for ERA-40) for the small numbers of observations at the 5 hPa level. ERA-Interim accepts slightly fewer data at most levels, though more are used near the surface and tropopause.

The hydrological cycle

In ERA-40, historical HIRS, MSU and SSU radiance data were assimilated directly for the first time and SSM/I radiance data were used in a 1D-Var retrieval of total-column water vapour (TCWV) that was used to supply input data for the analysis. These data had a

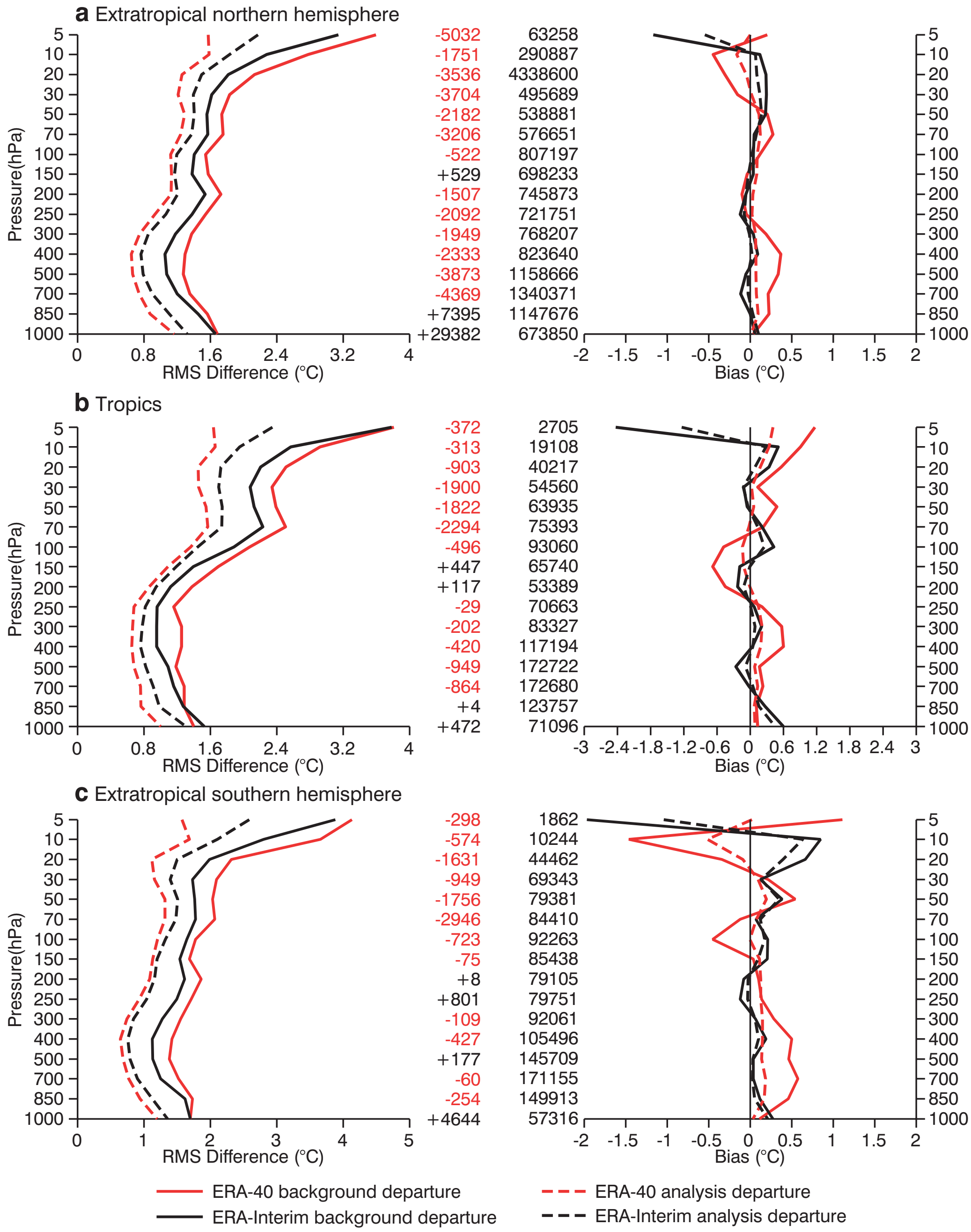

Figure 6 The root-mean-square difference and bias between radiosonde temperature measurements and the background (solid lines) and analysed values (dotted lines) from ERA-40 (red) and ERA-Interim (black) for (a) extratropical northern hemisphere, (b) tropics and (c) extratropical southern hemisphere for all 12 UTC soundings made in 1990. The two columns of numbers indicate the difference in number of data used (left; ERA-Interim minus ERA-40) and the number of data used by ERA-Interim (right).

profound impact on the humidity analysis and related products derived from the hydrological cycle of the background model. These products thus have different characteristics during the ERA-40 period depending on whether or which radiance data were assimilated. The ERA-40 assimilation system used the radiance data to correct a too-dry background model state in non-precipitating regions over the tropical oceans. The analysis system in use at the time spread much of this moistening also into precipitating regions, where the assimilating model rejected almost all the moisture added by the analysis. This resulted in excessive precipitation over the tropical oceans, excessive associated latent heating and a feedback process that enhanced the moistening further. Problems were exacerbated following the eruption of Mount Pinatubo in June 1991, when the effect of volcanic aerosols on HIRS radiances was misinterpreted as a moisture signal, and were locked in by subsequent bias corrections and the feedback process.

ERA-Interim benefits from several subsequent developments of the ECMWF forecasting system, some of them a direct response to the problems experienced in ERA-40. These include:

- ◆ The new humidity analysis and improved model physics.
- ◆ Direct assimilation of SSM/I radiances and more selective use of HIRS radiances.
- ◆ Variational bias correction and use of 4D-Var.

All of these influence precipitation over the tropical oceans in the background forecasts.

It is interesting to compare the annual-mean precip-

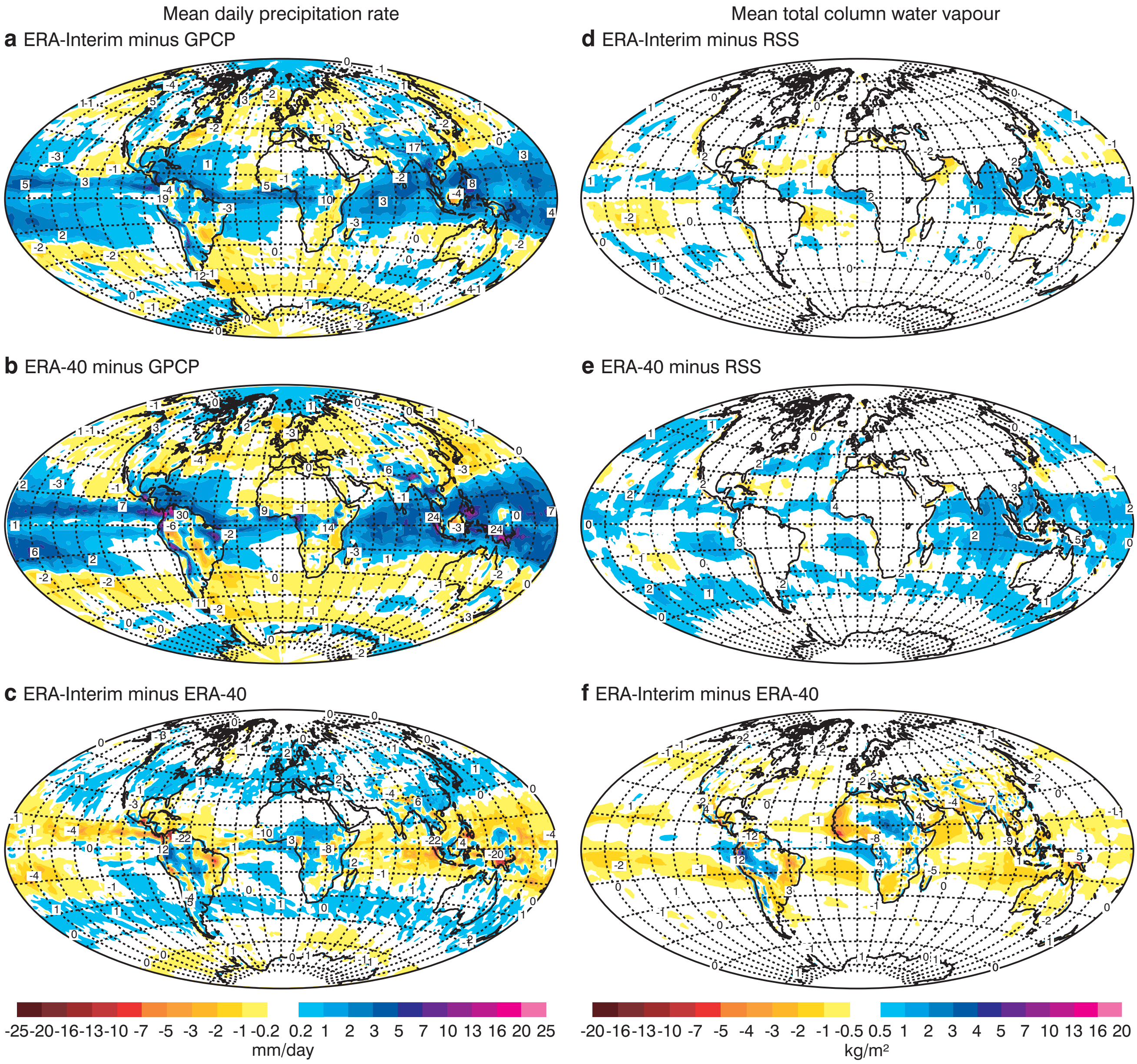

Figure 7 Left: the difference in the mean daily precipitation rate for 1990 (mm/day) for (a) ERA-Interim minus GPCP, (b) ERA-40 minus GPCP and (c) ERA-Interim minus ERA-40 (bottom). Right: the difference in mean total column water vapour for 1990 (kg m^{-2}) for (d) ERA-Interim minus RSS, (e) ERA-40 minus RSS and (f) ERA-Interim minus ERA-40. RSS denotes the version-6 retrievals from SSM/I produced by Remote Sensing Systems.

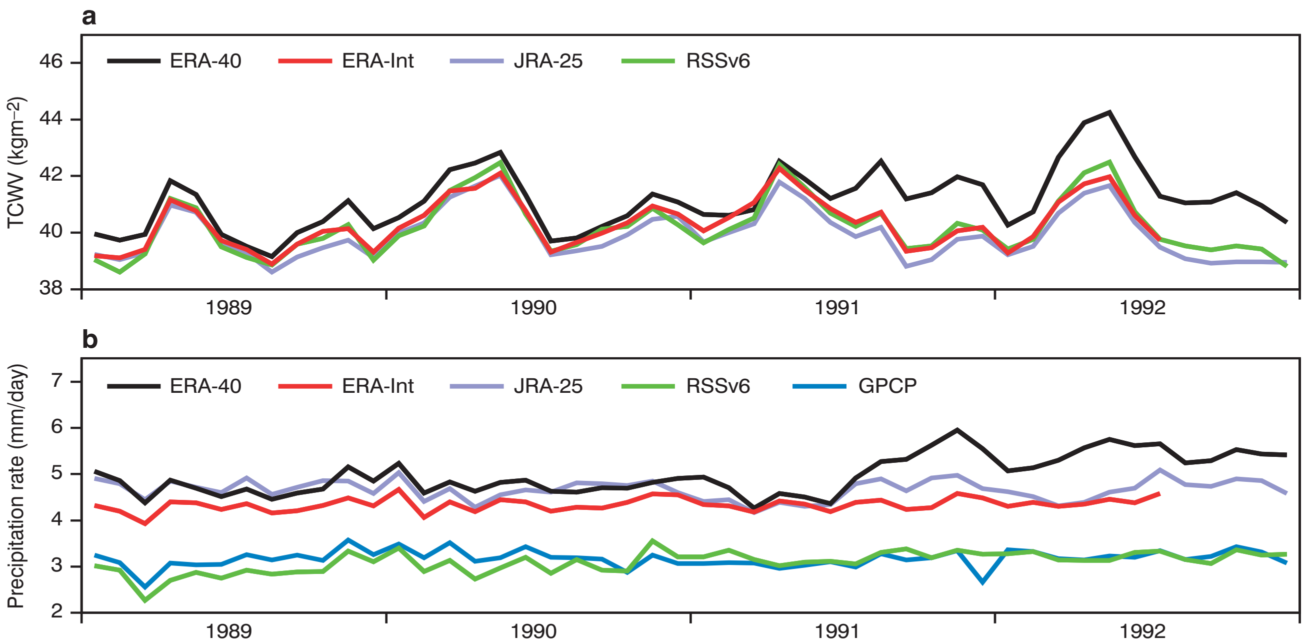

Figure 8 Time series of (a) monthly-mean total column water vapour (kg m^{-2}) and (b) precipitation rate (mm day^{-1}) averaged over tropical oceans, from the ERA-40, ERA-Interim and JRA-25 reanalyses, from version-6 SSM/I retrievals produced by Remote Sensing Systems and (for precipitation only) from GPCP.

itation rates from ERA-Interim and ERA-40 with the observation-based estimates of the Global Precipitation Climatology Project (GPCP). The left-hand panels of Figure 7 present differences between ERA-Interim and GPCP, ERA-40 and GPCP, and ERA-Interim and ERA-40 for 1990. The right-hand panels show the corresponding differences in TCWV based on the version-6 SSM/I retrievals over oceans produced by Remote Sensing Systems (RSS). Precipitation is higher in both ERA-Interim and ERA-40 than in GPCP over the tropical oceans. ERA-Interim is the closer to GPCP, but ERA-40 and ERA-Interim are nevertheless in closer agreement with each other than either is to the GPCP estimate. At higher latitudes, ERA-Interim is in closer agreement with GPCP than ERA-40. TCWV from ERA-Interim is significantly lower than from ERA-40, and closer to RSS.

Figure 8 shows corresponding time series from 1989 to 1992 of monthly-mean TCWV and precipitation rate averaged over the tropical oceans, including results from the recently completed JRA-25 reanalysis as well as those from the older ERA-40 reanalysis and the newer ERA-Interim reanalysis. Precipitation estimates from the RSS retrievals are included as well as the GPCP estimates. Neither JRA-25 nor ERA-Interim shows the increase in TCWV and precipitation following the eruption of Pinatubo in June 1991 seen for ERA-40. TCWV from JRA-25 is close to the RSS retrievals, but tends to be a little lower. ERA-Interim is in very good agreement with the RSS retrievals. In this regard, it should be noted that the ERA reanalyses use SSM/I radiances calibrated by RSS, whereas JRA-25 obtained SSM/I radiances from the National Climatic Data Center (NCDC). Precipitation from JRA-25 is somewhat higher than from ERA-Interim, and both are quite substantially higher than the GPCP and RSS estimates.

A further indication of improvement of the hydrological cycle in ERA-Interim comes from diagnosis of the global balance of precipitation and evaporation. The excess of precipitation over evaporation seen in ERA-40 is much reduced in ERA-Interim. Precipitation remains higher than evaporation, however, consistent with the indications from Figures 7 and 8 that rainfall over the tropical oceans is still somewhat too high, notwithstanding uncertainties in the accuracy of the observation-based estimates.

Stratospheric transport

The studies of "age of air" in the preparatory assimilations indicate that ERA-Interim will provide much better datasets than ERA-40 for driving models of stratospheric chemical transport and stratosphere/troposphere exchange. Further evidence for this is provided by examination of the representation of stratospheric humidity in ERA-Interim. As in ERA-40, no change to the stratospheric humidity is made by the ERA-Interim analysis other than removal of any supersaturation. This means that the distribution of humidity is determined primarily in the sequence of 12-hour background forecasts, by tropospheric exchange, by the upper-level moistening due to parametrized methane oxidation and by advection, with some loss due to precipitation in the cold polar night.

In the tropical stratosphere, relatively dry air introduced at the tropical tropopause in boreal winter, and relatively moist air introduced in boreal summer, are transported slowly upwards. This transport was much too strong in ERA-40, with successive layers of moist and dry air reaching above 10 hPa in well under a year, as illustrated in Figure 9(a). In ERA-Interim, the upward transport is slower, as indicated by the shallower slope of

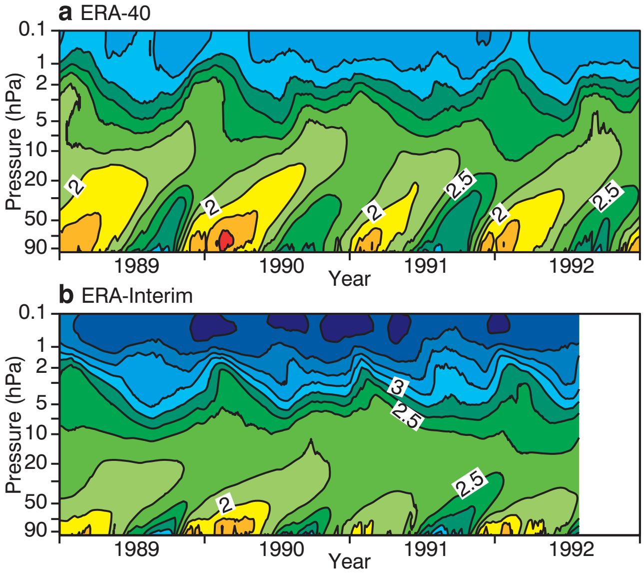

Figure 9 Pressure/time cross-sections showing specific humidity averaged from 10°N to 10°S from (a) ERA-40 and (b) ERA-Interim. The contour interval is 0.25 mg/kg.

contours in the lower stratosphere in Figure 9(b). The stratosphere is also generally moister in ERA-Interim. This is because of a revised treatment of clouds that allows significant near-tropopause supersaturation (countering a drying effect due to colder tropical-tropopause temperatures) and a stronger near-stratopause source from methane oxidation. The changes bring the ERA-Interim analyses of stratospheric moisture into closer agreement with the picture gained from occultation and limb-sounding data from a number of satellite missions.

Improved forecasts

Ten-day forecasts were run 12-hourly from the ERA-40 analyses, and the same is being done for ERA-Interim. Comparison of the accuracy of these forecasts with those from operations provides further evidence of the improvement of forecasting systems over the years. Figure 10 presents anomaly correlations of 500 hPa height forecasts for the extratropical northern and southern hemispheres averaged from January 1989 to December 1990 for the ERA-40 and ERA-Interim versions of the forecasting system, and for the original operations. Also shown are the corresponding operational results for the two-year period from January 2005 to December 2006. A related plot for 850 hPa tropical winds was included in the workshop report published in ECMWF Newsletter No. 109.

Figure 10 shows a substantial improvement in forecast skill of ERA-40 over ECMWF operations for 1989/90. ERA-Interim in turn improves substantially on ERA-40, especially in the southern hemisphere. The use of 4D-Var in ERA-Interim is likely to be a key factor behind the larger improvement in the southern hemisphere, where using a more sophisticated assimilation technique compensates for the much poorer in-situ data coverage.

ERA-Interim for 1989/90 cannot match ECMWF's operational performance for the past two years, as measured by most scores. This is due partly to the lower resolution of the ERA-Interim data assimilation system and partly to improvements in the observing system over the past one and a half decades. These differences tend to predominate over the advantage ERA-Interim has of using the very latest version of the model and data assimilation system. Only for specific regions and variables for which forecasts have been markedly improved very recently, most notably temperature in the tropical troposphere, does the benefit of using the latest version of the forecasting system outweigh the other effects.

The 60% value for the 1989/90 mean of the anomaly correlations of 500 hPa height for operations is reached at about 6½ days range for the northern hemisphere and 5½ days for the southern hemisphere. For 2005/6, the corresponding value is 8 days for both hemispheres. In operations, the southern hemisphere especially has benefited from improvements in technique such as 4D-Var and the direct assimilation of radiances, and from improvements in the satellite component of the observing system. ERA-40 provided evidence for the latter for the period up to 2001, and ERA-Interim in due course will determine the extent to which this continues beyond 2001.

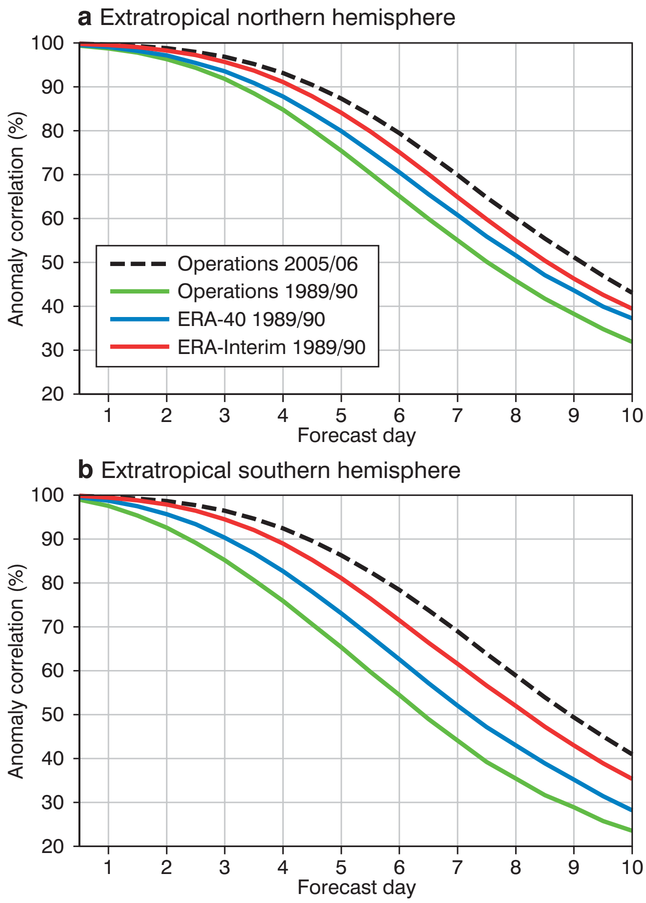

Figure 10 Anomaly correlation (%) of 500 hPa height forecasts averaged over all daily forecasts from 12 UTC for the period from January 1989 to December 1990 for (a) extratropical northern hemisphere and (b) extratropical southern hemisphere for Operations 2005/06, Operations 1989/90, ERA-40 1989/90 and ERA-Interim 1989/90.

Outlook

ERA-Interim represents a substantial step forward over ERA-40 in several respects. Its products, however, have yet to be scrutinized to the extent that was possible in the more fully funded ERA-40 project. Feedback from users based on their experience with the first release of data will be important in assessing the requirements for further work. Current activites at ECMWF include ongoing model improvement, with some emphasis on biases at the uppermost levels, and refinement of the 91-level version of the assimilation system introduced into operations in February 2006. Work to limit the effect of remaining model biases through weak-constraint 4D-Var is giving encouraging results, and re-evaluation and adjustment of the variational radiance bias-correction scheme will be undertaken based on its long-term performance in ERA-Interim.

The current production run of ERA-Interim is likely to catch up with real time in the first half of 2008. Around that time a decision will be made whether simply to continue with this run or to carry out a second complete run for the same period using an upgraded, 91-level version of the assimilation system. In the former case, a rerun of the first three or so years of production to correct the minor problems encountered to date may be undertaken. Decisions will depend on the level of funding secured for core reanalysis activities, of which ERA-Interim is a part, and the prospects for the extra, shorter-term funding needed to carry out a comprehensive, extended reanalysis to replace fully ERA-40. The latter will require development work to:

- Improve handling of the early satellite radiance data.
- Specify more appropriate background error statistics for the pre-satellite period.
- Acquire and utilize additional or replacement data from a variety of sources of past observations.

Availability of the ERA-Interim products

The first formal release of ERA-Interim products, for 1989, 1990 and 1991, will be made soon. Member-State users with MARS access will be able to obtain these data by specifying EXPVER=5 and class=EI. Other users will be able to obtain the data from ECMWF's Data Services. The first products for these years should be regarded as provisional, since the re-processed Meteosat winds have yet to be used and several small problems were detected and corrected on-the-fly in the assimilation for these first years. Data from subsequent years will be released once production for each year is completed and validated.

A second release, of updated products, will be considered once the outlook for reanalysis activities at ECMWF has become clearer.

Public access to a selection of products on the external ECMWF Data Server will be provided after ERA-Interim has reached August 2002, the end of ERA-40. Data for subsequent years will be added periodically. Since ERA-Interim is being undertaken with limited funding as part of ECMWF's general programme of research and development, the extent and timing of the public service will depend on the availability of resources.

For additional information on the progress of ERA-Interim and on the availability of data, users are advised to consult the ECMWF re-analysis web pages

www.ecmwf.int/ research/era

and the web pages of ECMWF Data Services

www.ecmwf.int/products/data

Final remarks

The successful launch of ERA-Interim has been due to the willingness of institutions to provide data and the high level of cooperation and commitment shown by colleagues involved in the project. We are appreciative of the substantial effort by EUMETSAT to reprocess the historical Meteosat data, ESA for providing the ERS altimeter wave-height dataset, Rutherford Appleton Laboratory for providing the ozone profile data and UCAR for providing the radio occultation measurements. In addition we would like to acknowledge the contributions made by Ulf Andrae, Peter Bauer, Jean Bidlot, Claire Delsol, Hans Hersbach, Lars Isaksen, Per Kållberg, Ioannis Mallas and Carole Peubey from ECMWF, Byoung-Kwon Park on secondment from Korean Meteorological Institute, and many others from ECMWF and the Member States who have supported the development of ERA-Interim. The Japanese Meteorological Agency has engaged in ongoing cooperation with ECMWF on reanalysis, and this has included supporting the secondment of Shinya Kobayashi to ECMWF.

The development of ERA-Interim has demonstrated what can be achieved when many people work effectively together to a common purpose. There is no doubt that all this effort will be of great benefit to the meteorological and climate community.

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The next generation of ECMWF's meteorological graphics library – Magics++

STEPHAN SIEMEN, SYLVIE LAMY-THÉPAUT, FERNANDO II, IAIN RUSSELL

SINCE 1984 the MAGICS (Meteorological Application Graphics Integrated Colour System) graphics library has been at the heart of the plotting of weather maps at ECMWF, its Member States and other weather services around the world. At ECMWF alone, hundreds of maps are produced and printed every day for the MetOps room. Also thousands of plots are produced for the ECMWF web page, and this last number is steadily growing.

MAGICS is not only used directly through its FORTRAN interface, but it is also used to produce graphics inside ECMWF's Metview and Météo-France's Synergie graphical user interfaces.

Why redesign MAGICS?

MAGICS source code has been developed over the past 20 years which brings with it a large legacy. It became hard to extend and incorporate new features. To take advantage of recent developments in software engineering and to clean the code of the legacy the decision was made to rewrite MAGICS. As MAGICS was first designed, techniques such as user interactivity and new media such as the internet were not anticipated. The next generation of MAGICS, called Magics++ to avoid confusion, will make use of these new technologies.

MAGICS was originally designed to provide paper printouts of weather maps, but over the last few years the majority of plots have been produced for the web. An example of how times have changed can be seen in the way text is formatted. Magics++ uses HTML-style formatting that will increase the number of supported fonts (currently three) and improve the setting of special characters (currently non standard).

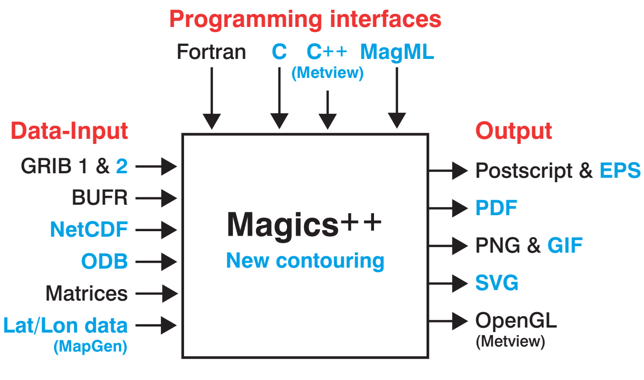

Figure 1 Magics++ as the user will see it. Features new to Magics++ are in blue.

With Intel's IA-64 and AMD64 appearing as new platforms, MAGICS was in need of a major overhaul because the 64 bit pointers of these platforms were incompatible with the design of MAGICS. The new design is independent of the size of pointers.

Magics++ will also have a new installation procedure which makes it easier to install than the imake based installation of MAGICS. The configure tool has been chosen because it is widely used for many software packages on Unix systems.

Even though the design of MAGICS is changing, the FORTRAN interface used by many programs will be maintained in order to be as backwards compatible as possible with the old MAGICS. However, small changes are necessary (e.g. default coastline colour changed from yellow to black) and newer interactive features may not be used through the FORTRAN interface.

The new architecture

Though Magics++ is programmed in C++ the user should have no problems using the old FORTRAN interface. Figure 1 gives an overview of the old and new features of Magics++.

Run-time information, such as descriptions of observational symbols, is now stored in separate text files. This has the advantage that the information can be changed without a recompilation of the library itself.

Algorithms developed by Hiroshi Akima (ACM Transactions on Mathematical Sciences) will be the basis of the new contouring. The algorithms were chosen because of their flexibility and their support of gridded and scattered data. INPE/CPTEC (Brazil) has successfully incorporated the latest version of the Akima interpolation algorithm in Terralib, their GIS (geographic information system), which is used by Magics++.

Figures 2 shows an example of a field contoured with CONICON of MAGICS 6 and the Akima interpolation in Magics++.

Data formats

Magics++ is one of the first users of ECMWF's new GribAPI library and so not only supports GRIB version 1 but also version 2. NetCDF is now also supported with its own action routine PNETCDF.

Besides complex data formats, such as GRIB and NetCDF, Magics++ is also able to read simple ASCII MapGen data files containing latitude-longitude coordinates. These can be plotted as polylines or polygons. This enables users to easily generate their own overlay of vector information, such as borders or rivers.

Also new is the general support for both retrieving data from databases and plotting it directly in Magics++.

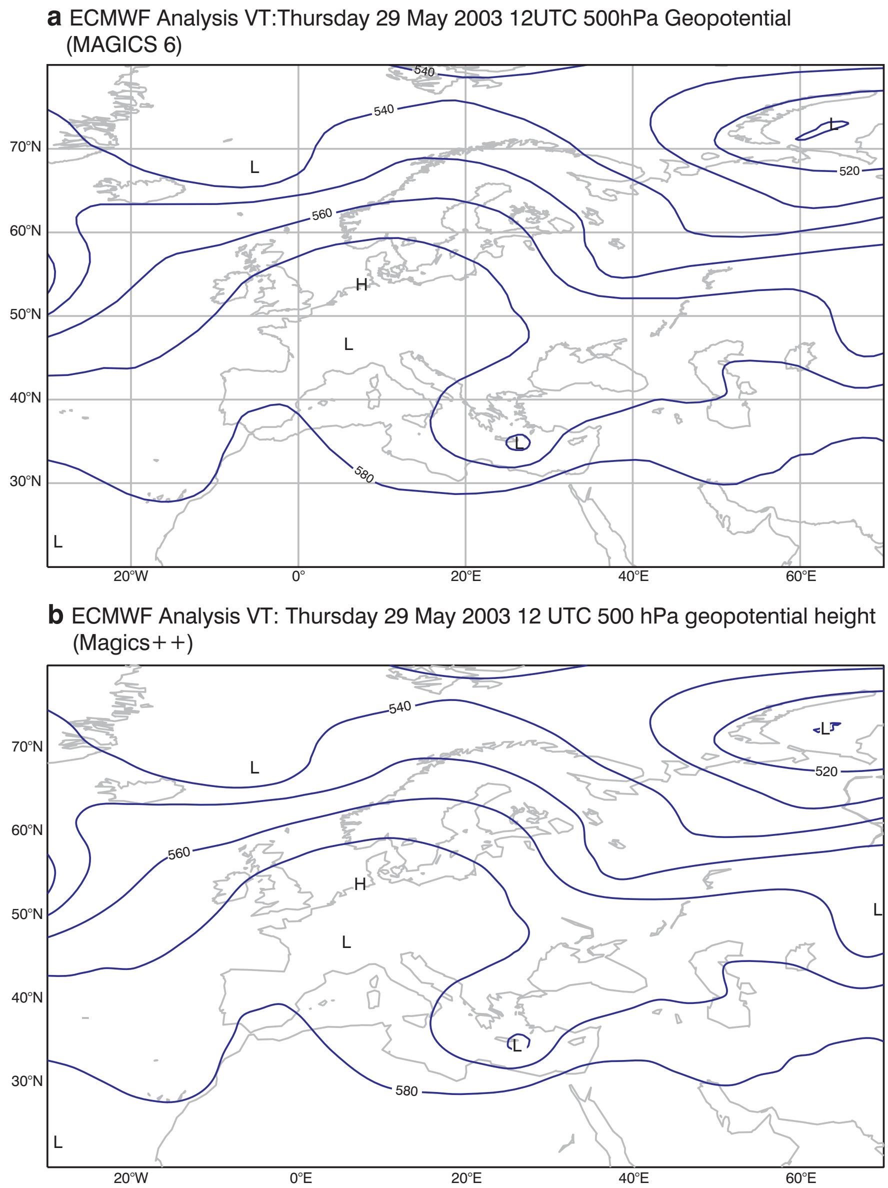

Figure 2 Examples of a field contoured with (a) CONICON of MAGICS 6 and (b) Akima interpolation in Magics++.

In particular ECMWF's ODB (Observational Data Base) is supported and can be directly accessed with Magics++. This is especially challenging because of the large amounts of data involved. These improvements have already led to the development of a Metview icon allowing the access to ODB data, and the plotting and overlaying of the results with other data.

The following is an example of an ODB request in Magics++. The resulting plot is shown in Figure 3.

```
call psetc('odb_database','odb://njord/tmp/odb_data/
ECMA.conv/ECMA')
call psetc ('odb_query', 'select lat, lon, obsvalue from hdr,
body where varno=$t2m and obsvalue is not null')
call psetc ('odb_latitude', 'lat@hdr')
call psetc ('odb_longitude', 'lon@hdr')
call psetc ('odb_observation', 'obsvalue@body')
call podb
```

Programming interfaces

Until now MAGICS has only been usable through its FORTRAN interface. This will change with Magics++. Beside the familiar FORTRAN interface there is now also a C interface and a descriptive interface called MagML. The latter is based on the Extensible Markup Language (XML) and will be of interest for automatic production of plots, such as for web pages.

The C interface

Magics++ provides a new C programming interface. This is identical to the FORTRAN interface in terms of functionality, but with different action routine names in order to avoid conflicts with some C standard library names.

Example programs and instructions on how to compile C Magics++ programs can be found on the Magics++ webpage. Listing 1 gives an example of a Magics++ C program.

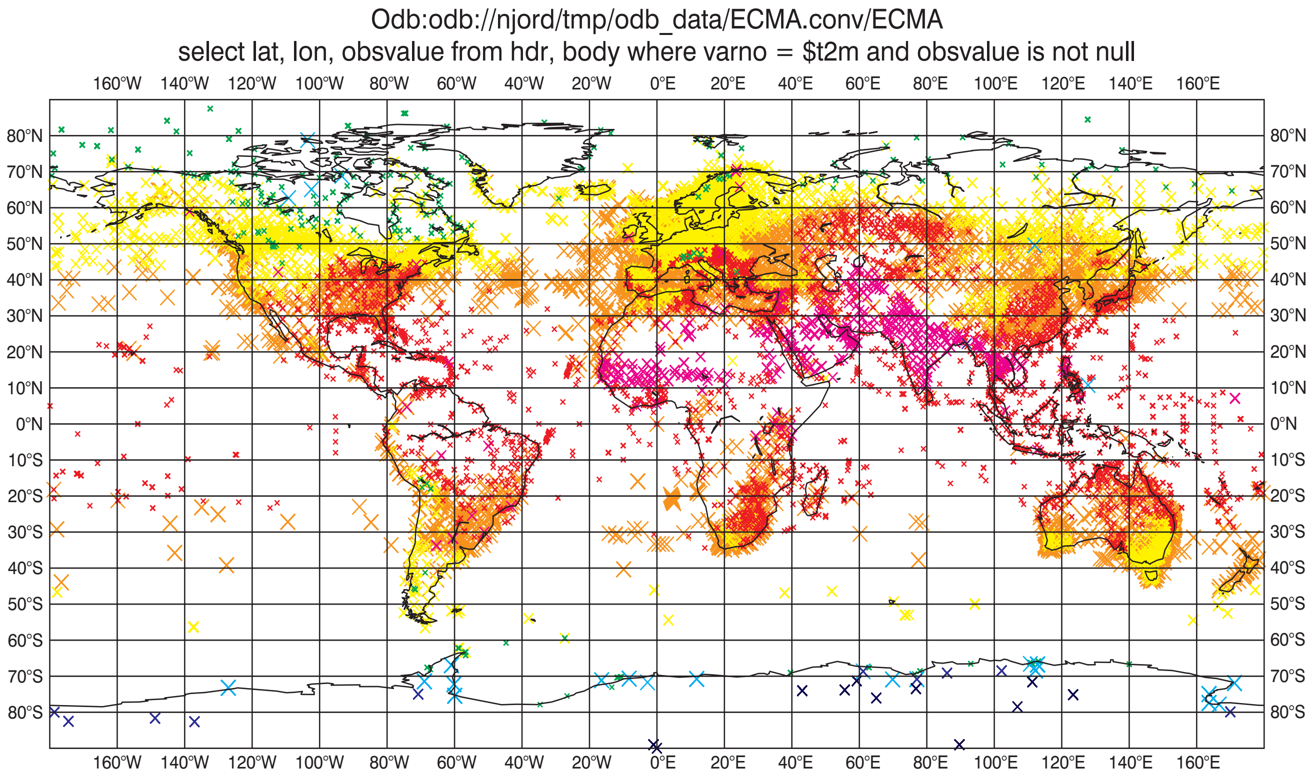

Figure 3 Magics++ and ODB. The title shows details of the request.

The MagML interface

Magics++ offers a new interface, based on XML, to describe Magics plots. This interface is different to other interfaces, which use programming languages to describe a Magics plot. In contrast to programming languages, MagML is a descriptive language with basic support for variables. A plot is described through a hierarchy of objects. Data access is possible by defining an input data file or a database request. Listing 2 shows an example of a MagML description.

MagML offers users a way to describe their plots in a text file. The MagML interpreter program, called magml, reads this text file and generates the plots; this process eliminates the need for compiling a FORTRAN, C or C++ program.

```
#include <magics_api.h>
int main()
{
/* open magics and set the output device */
mag_open ();
mag_setc ("output_format", "ps");
mag_setc ("output_name", "cont_colours");
/* load the data */
mag_setc ("grib_input_type", "file");
mag_setc ("grib_input_file_name", "data/z500.grb");
mag_grib ();
/* define the contouring parameters */
mag_setc ("contour", "on");
mag_setc ("contour_line_colour", "sky");
mag_setc ("CONTOUR_HIGHLIGHT_COLOUR", "GREEN");
mag_setc ("contour_label", "on");
mag_cont ();
/* plot the title text and the coastlines */
mag_text ();
mag_coast ();
mag_close ();
return 0;
}
```

Listing 1 An example of a Magics++ C program.

Output formats

In addition to the output formats of MAGICS (PostScript, JPEG, PNG), Magics++ will support EPS (Encapsulated PostScript), PDF, GIF and SVG. The EPS output is geared to be more easily usable for text processors (Word, LaTeX) and submissions for journals. PDF and GIF outputs will reduce post-processing times for web pages because conversions of file formats are not necessary anymore.

Scalable Vector Graphics (SVG) is a vector format defined by the internet standard body W3C and is supported by many browsers directly or indirectly through plug-ins. This vector format not only visualises but also allows interaction with the user. SVG can be used on its own or in cooperation with web services.

As a further support for web pages, in future Magics++ will produce transparent PNGs and JavaScript code describing the dimensions and geographical projections allowing the navigation of raster images. The latter can

```
<magics version='1.0'>
    <!— Set up our page and subpage specifications —>
    <page format ='a4' orientation = 'landscape' >
    <subpage>
       <!— Describe our view (projection / geographic area)  —>
       <mapview>
          <cylindrical>
            <corners min_longitude = '-20'
                     min_latitude   = '20'
                     max_longitude = '30'
                     max_latitude   = '60' />
          </cylindrical>
       </mapview>
       <!— Describe the coastlines  —>
       <coastlines>
         <coast colour = 'red' />
       </coastlines>
        <!— Describe a new layer (data + visual definitions)  —>
        <layer>
            <grib path = 'data/z500.grb'/>
            <geocontour/>
        </layer>
        <!— Describe our title text  —>
        <text font = 'Times-Roman' colour = 'rgb(0.1,0.6,0.2)'>Z500 Contour Plot</text>
    </subpage>
    </page>
</magics>
```

Listing 2 An example MagML description to read and visualise a GRIB file.

then be embedded in HTML code to develop web pages which allow users to interact with the display.

New ways of using output drivers

Magics++ introduces new parameters to control the output formats. Although Magics++ supports all output related parameters from MAGICS, the new ones are preferred, and the old parameters are deprecated.

By default, the output format for a MAGICS plot is PostScript. A different output format can be selected by setting parameter OUTPUT_FORMAT to one of those given in Table 1.

The command to set the output to PDF for example is:

```
CALL PSETC ('OUTPUT_FORMAT', 'PDF')
```

Multiple output formats

Magics++ can generate plots in multiple output formats. For instance, a single Magics++ program can create the same plot in both PostScript and GIF formats in a single run. This approach has a performance advantage over running the program separately for each output format as much of the processing is performed only once. The parameter to set is OUTPUT_FORMATS (note the 'S' on the end). The following code shows how to set two output devices.

```
CHARACTER*10   FORMATS
DIMENSION      FORMATS(2)
DATA           FORMATS /'PS', 'GIF'/

CALL POPEN
CALL PSET1C    ('OUTPUT_FORMATS',    FORMATS, 2)
CALL PSETC     ('OUTPUT_NAME',       'multiformat')
```

For a single-page plot, the above code will produce two files: multiformat.ps and multiformat.1.gif.

New graphical features

Besides supporting new data and output formats, Magics++ also introduces many new graphical features. For example, as shown in Figure 4, Magics++ lets the user now plot maps beyond 360° in longitude with data plotted on all areas.

With more and more plots showing statistical information Magics++ has started to support new techniques of visualising them. For example the box-plots seen in Metgram plots are now also available to users. Through a more flexible design Magics++ allows quick implementations of new displays, such as Taylor diagrams or the new extended Metgrams.

For all these new features there are examples on the Magics++ web page. An article later this year in the ECMWF Newsletter will go into more detail and present more graphical features.

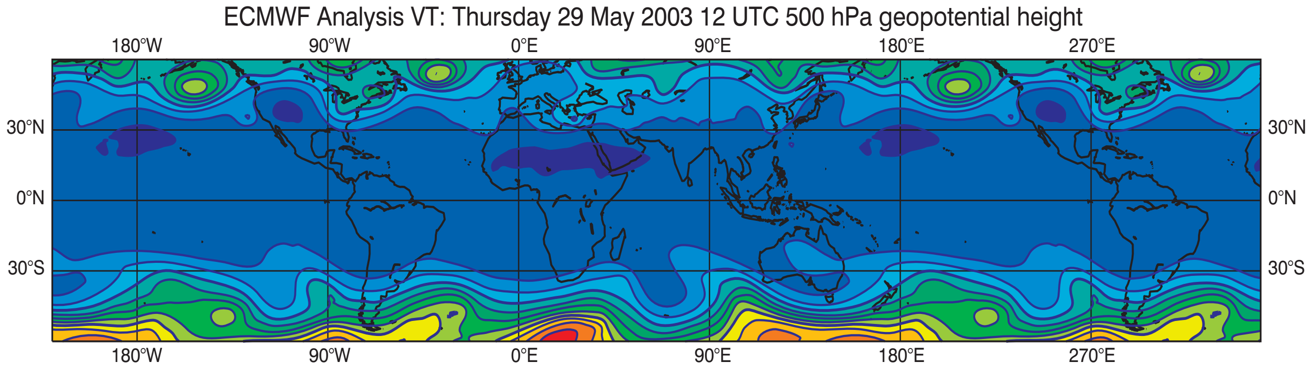

Figure 4 Example of a field plot covering more than 360° in longitude.

Command	Output
PS	single multipage file*
PDF	single file
EPS	multiple files
GIF	multiple files
GIF_ANIMATION	single file
PNG	multiple files
JPEG	multiple files
SVG	multiple files

* This can be changed – see parameter 'OUTPUT_PS_SPLIT'

Table 1 Magics++ output formats.

Using Magics++

Magics++ is currently configured with use scripts at ECMWF, but work is in progress to implement modules scripts for the new software configuration set-up. Users who use their own setup should be aware that the Magics++ library has been split up into various smaller libraries and not all parts might be needed. For example, the ODB support is located in a separate library called libMagPlusODB.a and needs only to be linked if the user accesses the ODB.

Future benefits for Metview

Many new features of Magics++ will naturally also benefit Metview which

Figure 5 Example of a new 15-day Metgram produced by Magics++.

is currently based on MAGICS. The present MAGICS uses the FORTRAN language, wheras Metview and Magics++ are written in C++. Taking advantage of an object oriented language, the internal communication system will be based on objects instead of the current metadata methodology. The initial advantages of this new approach will be straight forward error/warning/text messages handling and simpler program code. This implies higher robustness and better maintainability.

A new visualisation module will be developed to take advantage of all the benefits provided by Magics++. These benefits include:

- Improvements in user interactivity, such as legend and text handling.
- The ability to dynamically toggle certain graphical objects, such as contour labels and maxima/minima.
- Being able to query the properties of graphical objects displayed on screen.

The way ahead

The existing MAGICS manual for the FORTRAN interface has been updated to include the new features and changes since MAGICS 6. Additional information about the C and MagML interface are provided on the Magics++ webpage at:

www.ecmwf.int/publications/manuals/magics

On this page users will find many examples which show how Magics++ can be used.

Magics++ has already been used at ECMWF for the operational Metgrams as shown in Figure 5, the ERA-40 catalogue and is being tested for the service-on-demand project. With the release of version 2.0 Magics++ is now also accessible to users outside ECMWF.

Special Project computer allocations for 2007–2009

Member State		Institution	Project title	2007		2008		2009	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Continuation Projects									
Austria	1	Univ. Vienna (Beck)	Alpine regional downscaling of reanalysis data using the LAM ALADIN	0	10	0	20	0	20
	2	Univ. Innsbruck (Ehrendorfer)	Mesoscale predictability and ensemble prediction	8,000	5	X	X	X	X
	3	Univ. Vienna (Haimberger)	Homogenization of the global radiosonde temperature and wind dataset	5,000	500	5,000	500	X	X
	4	Univ. Vienna (Hantel)	Convective fluxes diagnosed from gridscale ECMWF analyses	7,500	730	1,000	100	X	X
	5	Univ. Graz (Kirchengast)	Climate monitoring by advanced spaceborne sounding and atmospheric modelling	17,500	250	40,000	400	45,000	450
	6	Univ. of Natural Resources and Applied Life Sciences, Vienna (Kromp-Kolb)	Modelling of Tracer Transport (MoTT)	5,000	40	10,000	50	10,000	50
	7	Univ. Vienna (Steinacker)	MESOCLIM – Mesoscale Alpine Climatology	50	10	100	10	100	10
	8	Univ. Vienna (Steinacker)	4D OMEGA FORM – 4 dimensional objective mesogamma analysis of foehn in the Rhine Valley during MAP	50	10	0	0	0	0
Denmark	9	DMI (Amstrup)	EUCOS/EUMETSAT data impact studies	237,000	3,750	800,000	9,000	700,000	7,000
Finland	10	FMI (Jarvinen)	Stochastic sub-grid scale parameterizations for coupled earth system models	108,000	1,180	260,000	1,840	260,000	1,840

Member State		Institution	Project title	2007		2008		2009	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Continuation Projects									
France	11	CNRM/GMAP, Météo-France (Fischer)	Investigation of coupling the ALADIN and AROME models to boundary conditions from ECMWF and ERA model data	25,000	700	30,000	800	30,000	800
	12	CERFACS (Morel)	PALM: Universal software for data assimilation	5,000	180	5,000	180	5,000	180
	13	CERFACS (Rogel)	Seasonal to interannual predictability of a coupled ocean-atmosphere model	10,000	150	10,000	150	10,000	150
	14	CERFACS (Weaver)	Variational data assimilation with the OPA OGCM	100,000	1,500	100,000	1,500	100,000	1,500
Germany	15	MPI, Hamburg (Bengtsson)	Numerical experimentation with a coupled ocean/atmosphere model	75,000	3,290	360,000	8,400	432,000	10,080
	16	MPI, Hamburg (Bengtsson)	Regional downscaling of ERA40 data and validation of the hydrological cycle	189,000	2,180	500,000	3,800	600,000	4,600
	17	MPI, Hamburg (Budich)	Global atmospheric chemistry modelling	154,000	2,860	500,000	7,000	500,000	9,000
	18	Freie Univ. Berlin (Cubasch, Kirchner)	Investigation of systematic tendency changes and their influence on the general circulation simulated with climate models	5,000	580	10,000	1,000	2,000	1,500
	19	ISET (Czisch)	Evaluation of the global potential of energy towers	33	10	100	20	X	X
	20	DLR (Doernbrack)	Influence of non-hydrostatic gravity waves on the stratospheric flow field above Scandinavia	75,000	60	150,000	80	150,000	80
	21	Univ. Munich (Egger)	Landsurface-atmosphere interaction	37	10	150	10	150	10
	22	Univ. Cologne (Elbern)	GEMS: work package WP_RAQ_2	80,000	500	80,000	500	8,000	500
	23	DLR & MPI Chemistry, Mainz (Eyring, Steil)	Impact of anthropogenic emissions on tropospheric chemistry with a special focus on ship emissions	181,000	2,910	400,000	4,000	400,000	4,000
	24	DLR (Gierens)	Ice-supersaturation and cirrus clouds	181,000	100	200,000	100	200,000	100
	25	Univ. Göttingen (Gravenhorst)	Downscaling of ECMWF seasonal forecast in the tropical region Central Sulawesi, Indonesia using the climate limited area model CLM of the German Weather Service	100,000	200	100,000	200	100,000	200
	26	DLR (Hoinka)	Climatology of the global tropopause	1,600	10	5,000	10	5,000	10
	27	Univ. Karlsruhe (Jones)	The impact of tropical cyclones on extratropical predictability	262,000	400	300,000	450	300,000	450
	28	DLR (Keil, Craig)	Ensemble modelling for the improvement of short range quantitative precipitation forecasts	50,000	70	100,000	100	100,000	100
	29	Univ. Karlsruhe (Kottmeier)	Mesoscale modelling using the DWD Lokal-Modell	5,000	40	10,000	50	10,000	50
	30	Leibniz-Institut, Univ. Kiel (Latif)	Seasonal to decadal forecasting with coupled ocean-atmosphere general circulation models	612,000	6,250	1,000,000	5,000	1,000,000	5,000

Member State		Institution	Project title	2007		2008		2009	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Continuation Projects									
Germany	31	IMK-IFU (Laux)	Statistical analysis of the onset of the rainy season in the Volta Basin (West Africa)	5,000	10	X	X	X	X
Germany	32	DLR (Mayer)	Remote sensing of water and ice clouds with Meteosat Second Generation	12,500	10	50,000	20	50,000	20
Germany	33	Ruhr-University Bochum (Pahlow)	Optimisation of water management by using ensemble forecasts	25,000	10	75,000	10	75,000	10
Germany	34	Alfred Wegener Institute, Potsdam (Rex)	Ozone and water vapour transport with the residual circulation	66	110	200	200	200	200
Germany	35	Alfred Wegener Institute, Potsdam (Rinke)	Sensitivity of HIRHAM	100	10	200	20	200	20
Germany	36	Univ. Köln (Speth)	Interpretation and calculation of energy budgets	55	10	120	15	120	15
Germany	37	MPI, Hamburg (von Storch)	Numerical experimentation with a high-resolution ocean model	120,000	3,290	600,000	8,000	720,000	9,000
Germany	38	Univ. Bremen (Weber)	Chemical and dynamical influences on decadal ozone change (CANDIDOZ)	100	20	100	20	100	20
Germany	39	Univ. Mainz (Wirth)	Water vapour in the upper troposphere	500	10	1,000	20	1,000	20
Germany	40	Univ. Hohenheim (Wulfmeyer, Bauer)	Real-time assimilation of observations of key prognostic variables and the development of aerosol operators (RAPTOR)	181,000	2,000	150,000	1,000	150,000	1,000
Ireland	41	Met Éireann (McGrath)	Community Climate Change Consortium for Ireland (C4I)	100,000	1,140	300,000	2,000	X	X
Ireland	42	Univ. College Cork & Ruhr-University Bochum (Moehrlen, Joergensen, Pahlow)	Using ensembles to predict and hydro to balance wind power forecast errors	10,500	10	21,000	10	21,000	10
Italy	43	ISMAR-CNR (Cavaleri)	Evaluation of the performance of the ECMWF meteorological model at high resolution	221,500	300	300,000	300	350,000	300
Italy	44	SAR, Sardegna (Chessa)	Local Multimodel Prediction System	100,000	360	200,000	500	200,000	500
Italy	45	INGV, Bologna (Manzini)	Middle atmosphere modelling	136,500	1,240	320,000	2,000	350,000	2,300
Italy	46	Osservatorio Astrofisico di Arcetri, Firenze (Masciadri)	Forecasting of the optical turbulence for Astronomy applications with the MesoNH mesoscale model coupled with ECMWF products	2,000	20	4,000	30	4,000	30
Italy	47	ARPA-SMR, Emilia Romagna & UK Met Office (Montani, Mylne)	Limited-area ensemble forecasts of windstorms over Northern Europe	262,000	390	1,300,000	830	1,400,000	840
Italy	48	ARPA-SMR, Emilia Romagna & MétéoSwiss (Montani, Walser)	Improvements of COSMO limited-area ensemble forecasts	110,500	560	190,000	690	210,000	710

Member State		Institution	Project title	2007		2008		2009	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Continuation Projects									
Italy	49	ARPA-SMR, Emilia Romagna & Italian Met. Service (Paccagnella, Montani, Ferri)	Limited area model targeted ensemble prediction system (LAM-TEPS)	28,9000	210	600,000	260	700,000	270
	50	Univ. Genova (Parodi)	High resolution numerical modelling of intense convective rain cells	25,000	150	50,000	200	50,000	200
	51	ARPA-SMR, Emilia Romagna & UCEA (Pavan, Esposito)	Seasonal prediction for Italian agriculture (SPIA)	500	70	1,000	100	1,000	100
Netherlands	52	KNMI (Drijfhout)	Water mass pathways in a high-resolution isopycnic model	140,500	30	150,000	40	300,000	40
	53	KNMI (Hazeleger)	Patterns of climate change: coupled modelling activities	104,000	30	210,000	40	210,000	40
	54	Univ. Utrecht (Leeuwenburgh)	Bias and balance in the ensemble Kalman filter	50,000	0	X	X	X	X
	55	KNMI (Onvlee)	The Hirlam-A project	279,000	3,590	1,250,000	7,500	1,250,000	7,500
	56	KNMI (Siebesma)	Rain in cumulus	30,000	30	35,000	50	40,000	50
	57	KNMI (van Meijgaard)	Multi-annual integrations with the KNMI regional climate model RACMO2	221,500	1,820	500,000	2,500	500,000	2,500
	58	KNMI (van Velthoven)	Chemical reanalyses and sensitivity studies with the chemistry-transport model TM4	100,000	100	X	X	X	X
Norway	59	DNMI (Frogner)	NORLAMEPS: Limited Area Ensemble Prediction System for Norway	66,500	290	200,000	500	200,000	500
	60	DNMI (Iversen, Frogner)	REGCLIM: optimal forcing perturbations for the atmosphere	181,000	730	X	X	X	X
	61	Univ. Oslo (Isaksen)	Ozone as a climate gas	16,600	5	50,000	5	50,000	5
Portugal	62	Univ. Lisbon (Soares)	HIPOCAS-SPEC	0	10	0	10	0	10
Spain	63	Univ. Illes Balears (Cuxart)	Study of the stably stratified atmospheric boundary layer through large-eddy simulations and high resolution mesoscale modelling	66,500	170	130,000	250	130,000	250
	64	Univ. Basque Country (Saenz)	Mesoscale meteorological reanalysis over the Iberian Peninsula	136,500	730	290,000	1,000	50,000	1,000
Switzerland	65	Institute for Atmospheric and Climate Science, ETH Zurich (Lohmann)	Cloud aerosol interactions	120,000	150	250,000	200	250,000	200
United Kingdom	66	ESSC, Univ. Reading (Bengtsson)	Predictability studies with emphasis on extra-tropical and tropical storm-tracks and their dependence on the global observing systems	140,500	220	350,000	300	400,000	300
	67	Univ. Reading (Haines)	Using data assimilation in a high-resolution ocean model to determine the thermohaline circulation	587,000	1,500	700,000	2,000	X	X
	68	Univ. Oxford (Hanlon)	Attribution of changes in extreme weather risk using large ensembles of climate model simulations	25,000	110	50,000	150	50,000	150

Member State		Institution	Project title	2007		2008		2009	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Continuation Projects									
	69	DARC, Univ. Reading (Lahoz)	How good are simulated water vapour distributions in the UTLS region?	70,000	250	70,000	250	20,000	70
	70	DARC, Univ. Reading (O'Neill)	Assimilation of retrieved products from EOS MLS	384,000	2,180	900,000	3,000	300,000	3,000
	71	Keele University (Shrira)	Direct numerical simulations of 2-d freak waves	100,000	100	100,000	100	100,000	100
	72	BAS, Cambridge (Turner)	Assessment of ECMWF forecasts over the high latitude areas of the southern hemisphere	0	1	0	1	0	1
ICTP	73	ICTP (Kucharski)	Dynamical downscaling of seasonal predictions with a regional climate model	25,000	360	50,000	500	50,000	500
	74	ICTP (Kucharski)	Decadal interactions between the tropical Indo-Pacific Ocean and extratropical modes of variability in an intermediate coupled model	25,000	220	50,000	300	50,000	300
JRC	75	JRC-IES (Dentener)	The linkage of climate and air pollution: simulations with the global 2-way nested model TM5	66,500	80	250,000	160	300,000	180
New Projects									
Germany	1	MPI, Hamburg (Feichter)	Climate impact of specific economic sectors	96,000	4,360	192,000	6,000	96,000	3,000
	2	MPI, Hamburg (Jacob)	Regional ensemble prediction	34,000	3,270	76,000	5,500	84,000	6,500
	3	MPI, Hamburg (Jungclaus)	Community simulations of the last millennium (COMSIMM)	469,500	1,010	2,000,000	2,000	2,000,000	2,000
Italy	4	CNMCA (Bonavita, Torrisi)	Limited area ensemble Kalman filter	221,500	270	1,000,000	500	1,200,000	500
	5	ARPA-SIM (Di Giuseppe, Marsigli)	Flow dependent error statistic for satellite data assimilation in regional model (FEAR)	371,500	100	1,000,000	150	1,000,000	150
Nether-lands	6	KNMI (Eskes)	Chemical data-assimilation of satellite observations with TM5	181,000	100	200,000	100	200,000	100
	7	KNMI (van den Brink)	Climate change studies using the IFS system	201,500	500	225,000	500	X	X
	8	KNMI (van Weele)	Global chemistry-transport modelling of natural reactive greenhouse gases	100,000	10	100,000	10	100,000	10
Norway	9	DNMI (Tveter)	Optimisation of operational NWP at met.no	140,500	730	X	X	X	X
Spain	10	Univ. de Castilla LaMancha (Gaertner)	Analysis of land surface-atmosphere interactions through mesoscale simulations	50,000	150	100,000	200	100,000	200
Sweden	11	SMHI (Gustafsson)	GLAMEPS – Grand Limited Area Model Ensemble Prediction System	206,000	2,500	1,000,000	6,000	1,000,000	6000
United Kingdom	12	Univ. Reading (Hoskins)	Moist singular vectors and African easterly waves	20,000	40	20,000	40	20,000	40
	13	Univ. Reading (Migliorini)	Assimilation of geostationary ozone measurements for global ozone monitoring	50,000	730	X	X	X	X
	14	Univ. Reading (O'Neill)	Use of data assimilation to analyse the impact of gravity-wave drag parametrization on the dynamics and circulation of the IFS model	181,000	3,000	100,000	3,000	X	X
Total requested				**9,358,191**	**67,891**	**20,736,970**	**104,351**	**19,299,870**	**98,441**

Member State computer allocations for 2007

Member State	HPCF (kunits)	Data Storage (Gbytes)
Belgium	3,899	28,326
Denmark	3,296	23,944
Germany	16,735	121,579
Spain	7,043	51,169
France	12,819	93,131
Greece	3,038	22,069
Ireland	2,782	20,212
Italy	10,723	77,898
Luxembourg	2,192	15,925
Netherlands	5,082	36,919
Norway	3,404	24,733

Member State	HPCF (kunits)	Data Storage (Gbytes)
Austria	3,558	25,848
Portugal	2,914	21,170
Switzerland	4,145	30,110
Finland	3,015	21,903
Sweden	3,822	27,767
Turkey	3,364	24,443
United Kingdom	13,469	97,854
Allocated to Special Projects	9,358	67,891
Reserved for Special Projects	2,342	17,109
Total	**117,00**	**850,000**

ECMWF Council and its committees

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

Council

The Council adopts measures to implement the ECMWF Convention; the responsibilities include admission of new members, authorising the Director to negotiate and conclude co-operation agreements, and adopting the annual budget, the scale of financial contributions of the Member States, the Financial Regulations and the Staff Regulations, the long-term strategy and the programme of activities of the Centre.
President: Dr Adérito Vicente Serrão (*Portugal*)
Vice President: Mr Wolfgang Kusch (*Germany*)

Policy Advisory Committee (PAC)

The PAC provides the Council with opinions and recommendations on any matters concerning ECMWF policy submitted to it by the Council, especially those arising out of the Four-Year Programme of Activities and the Long-term Strategy.
Chair: Generale Massimo Capaldo (*Italy*)
Vice Chair: Dr Fritz Neuwirth (*Austria*)

Finance Committee (FC)

The FC provides the Council with opinions and recommendations on all financial matters submitted to the Council and shall exercise the financial powers delegated to it by the Council.
Chair: Ms Laurence Frachon (*France*)
Vice Chair: Ms Monika Köhler (*Austria*)

Scientific Advisory Committee (SAC)

The SAC provides the Council with opinions and recommendations on the draft programme of activities of the Centre drawn up by the Director and on any other matters submitted to it by the Council. The 12 members of the SAC are appointed in their personal capacity and are selected from among the scientists of the Member States.
Chair: Prof Gerhard Adrian (*Deutscher Wetterdienst*)
Vice Chair: Prof Dr Martin Ehrendorfer (*Universität Innsbruck*)
The other members of the SAC are:
Dr François Bouttier (*Météo-France*)
Dr Luigi Cavaleri (*ISMAR*)
Dr John Eyre (*Met Office*)
Dr Hans Huang (*Danish Meteorological Institute*)
Dr Henny Kelder (*KNMI*)
Dr Ernesto Rodriguez-Camino (*Instituto Nacional de Meteorologia*)
Prof Julia Slingo (*University of Reading*)
Prof Michael Tjernström (*Stockholm University*)
Prof Heikki J Järvinen (*Finnish Meteorological Institute*)
Prof Jochem Marotzke (*DKRZ*)

Technical Advisory Committee (TAC)

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

Chair: Mrs Kristiina Soini (*Finland*)
Vice Chair: Dr Alan Dickinson (*United Kingdom*)

Advisory Committee for Data Policy (ACDP)

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

Chair: Dr Lillian Wester-Andersen (*Denmark*)
Vice Chair: Mr Collin Cuthbert (*United Kingdom*)

Advisory Committee for Co-operating States (ACCS)

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

Chair: Mr Jozef Roskar (*Slovenia*)
Vice Chair: Mr Ion Sandu (*Romania*)

ECMWF Calendar 2007

Mar 12–16	Training Course – Use and interpretation of ECMWF products
Mar 19–May 18	Training Course – Numerical Weather Prediction
Mar 19–28	*Numerical methods and adiabatic formulation of models*
Apr 16–24	*Predictability, diagnostics and seasonal forecasting*
Apr 25–May 4	*Data assimilation and use of satellite data*
May 8–18	*Parametrization of diabatic processes*
Apr 23–24	Finance Committee (*78th Session*)
Apr 26–27	Policy Advisory Committee (*25th Session*)
May 2	Advisory Committee on Data Policy (8th Session)
May 8–9	Expert Meeting on VarEPS/monthly forecast product definition and scheduling
May 21–22	Security Representatives' Meeting
May 22–24	Computer Representatives' Meeting
Jun 4–8	Training Course – Use and interpretation of ECMWF products
Jun 11–13	Workshop – Flow-dependent aspects of data assimilation
Jun 13–15	Forecast Products – Users' Meeting
Jun 28–29	Council (*67th Session*)
Aug 28–31	Eumetcal Workshop
Sep 3–7	Seminar – Recent developments in the use of satellite observations in numerical weather prediction
Oct 8–10	Scientific Advisory Committee (*36th Session*)
Oct 10–12	Technical Advisory Committee (*37th Session*)
Oct 15–19	Training Course – Use and interpretation of ECMWF products for WMO Members
Oct 15–16	Finance Committee (*79th Session*)
Oct 17–18	Policy Advisory Committee (*26th Session*)
Oct 26	Advisory Committee of Co-operating States (*13th Session*)
Nov 7–9	Workshop – Ensemble prediction
Nov 12–16	Workshop – Meteorological Operational Systems (*11th Workshop*)
Dec 10–11	Council (*68th Session*)

TAC Representatives, Computing Representatives and Meteorological Contact Points

Member States	TAC Representatives	Computer Representatives	Meteorological Contact Points
Belgium	Dr D. Gellens	Mrs L. Frappez	Dr J. Nemeghaire
Denmark	Mr L. Laursen	Mr T. Lorenzen	Mr G. Larsen
Germany	Mr H. Ladwig	Dr E. Krenzien	Mr T. Schumann
Spain	Mr P. del Rio	Mr E. Monreal	Ms A. Casals Carro
France	Mr B. Strauss	Mrs M. Pithon	Mr J. Clochard
Greece	Mr D. Kapniaris	Mr N. Kamperakis	Dr I. Papageorgiou Mr P. Xirakis
Ireland	Mr J. Logue	Mr P. Halton	Mr M. Walsh
Italy	Dr S. Pasquini	Dr C. Gambuzza Dr G. Leonforte	Dr T. La Rocca
Luxembourg	Mr C. Alesch	Mr C. Alesch	Mr C. Alesch
Netherlands	Mr T. Moene	Mr H. de Vries	Mr J. Diepeveen
Norway	Mr J. Sunde	Ms R. Rudsar	Mr P. Evensen
Austria	Dr G. Kaindl	Dr G. Kaindl	Dr H. Gmoser
Portugal	Mrs T. Abrantes	Mrs M. da C. Periera Santos Mr J. Monteiro	Mrs I. Soares
Switzerland	Dr S. Sandmeier	Mr P. Roth	Mr R. Mühlebach
Finland	Mrs K. Soini	Mr K. Niemelä	Mr P. Nurmi
Sweden	Mr I. Karro	Mr R. Urrutia	Mr M. Hellgren
Turkey	Mr M. Fatih Büyükkasabbaşi	Mr F. Kocaman	Mr M. Kayhan
United Kingdom	Dr A. Dickinson	Mr R. Sharp	Mr A. Radford
Co-operating States			
Croatia	Mr I. Čačić	Mr V. Malović	Mr Č. Branković
Czech Republic	Mr M. Janoušek	Mr K. Ostatnický	Mr F. Sopko
Estonia	Mr T. Kaldma	Mr T. Kaldma	Mrs M. Merilain Mrs T. Paljak
Hungary	Dr Z. Dunkel	Mr I. Ihász	Mr I. Ihász
Iceland	Mr H. Björnsson	Mr V. Gislason	Mrs S. Karlsdottir
Lithuania	To be decided	To be decided	To be decided
Morocco	To be decided	To be decided	To be decided
Romania	Dr I. Pescaru	Mr R. Cotariu	Mrs T. Cumpanasu
Slovenia	Mr J. Jerman	Mr P. Hitij	Mr B. Gregorčič
Serbia	Ms L. Dekic	Mr V. Dimitrijević	Mr B. Bijelic
Observers			
EUMETSAT	Mr M. Rattenborg	Dr K. Holmlund	
WMO	Mr M. Jarraud		

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

Technical Memoranda

510 **Tan, D.G.H., E. Andersson, M. Fisher & L. Isaksen**: Observing system impact assessment using a data assimilation ensemble technique: Application to the ADM-Aeolus wind profiling mission. *January 2007*

507 **Branković, Č, B. Matjačić, S. Ivatek-Šahdan & R. Buizza**: Dynamical downscaling of ECMWF EPS forecasts applied to cases of severe weather in Croatia. *January 2007*

506 **Greatbatch, R.J. & T. Jung**: Local versus tropical diabatic heating and the winter North Atlantic Oscillation. *November 2006*

505 **Weissmann, M. & C. Cardinali**: The impact of airborne Doppler lidar observations on ECMWF forecasts. *November 2006*

504 **Richardson, D.J. Bidlot, R. Buizza, L. Ferranti, A. Ghelli, G. van der Grijn & E. Zsoter**: Verification statistics and evaluations of ECMWF forecasts in 2005–2006. *November 2006*

502 **Bauer, P., P. Lopez, D. Salmond & A. Geer**: Assimilation of cloud and precipitation affected microwave radiances. *November 2006*

498 **Prior, P.** (compiler): Report on the eighteenth meeting of Computing Representatives 8–9 June 2006. *November 2006*

ERA-40 Project Report Series

26 **Betts, A.K., J.H. Ball, A.G. Barr, T.A. Black, J.H. McCaughey & P. Viterbo**: Assessing land-surface-atmosphere coupling in the ERA-40 reanalysis with boreal forest data. *August 2006*

Workshop Proceedings

ECMWF/GEO Workshop on Atmospheric Re-analysis. 19 to 22 June 2006.

Index of past newsletter articles

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

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Telephone number of an individual at the Centre is:

International: +44 118 949 9 + three digit extension
UK: (0118) 949 9 + three digit extension
Internal: 2 + three digit extension

e.g. the Director's number is:
+44 118 949 9001 (international),
(0118) 949 9001 (UK) and 2001 (internal).

E-mail

The e-mail address of an individual at the Centre is:
firstinitial.lastname@ecmwf.int

e.g. the Director's address is: D.Marbouty@ecmwf.int

For double-barrelled names use a hyphen
e.g. J-N.Name-Name@ecmwf.int

Internet web site

ECMWF's public web site is: http://www.ecmwf.int

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