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Publication policy

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 The *ECMWF Newsletter* is not peer-reviewed.

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EDITORIAL

More success on severe weather

In the last issue of the *ECMWF Newsletter*, Dominique Marbouty commented on some recent successful forecasts of severe weather. Also in a previous issue, I commented on the rapid progress of the IFS physical parametrizations. New developments offer an opportunity for further comment and to link these two topics.

Firstly, the article by Mike Fiorino in this issue eloquently expresses the high appreciation of forecasters at the National Hurricane Center, Miami, for the recent upgrades in resolution and physics of the IFS and their exceptional impact on the quality of the track forecasts of tropical cyclones. He calls it a "record-setting performance". Secondly, the recent exceptional winter storm that hit Spain and South-Western France on 24 January 2009 demonstrated once again the remarkable ability of our forecasts to anticipate a severe event.

How are these successes related to recent changes in our forecasting system? At ECMWF we have improved resolution, all aspects of the physics, and are using more and more satellite data. So should we say that improvements of severe weather forecasts are just a consequence of general improvement? Almost certainly there is some truth in such a statement. However, there are also elements indicating that some specific progress has been achieved for severe weather.

We closely monitor various aspects of the forecast skill and are acutely aware of the difficulty of reaching statistically significant conclusions for severe weather. But all recent studies indicate that forecasts of significant events have progressed more rapidly than 'general forecasts'. In fact, we have implemented a number of upgrades that have had a specific impact on severe weather forecasts. The change in the convection scheme stressed by Mike Fiorino is one of them. In addition the microwave radiances acquired by a number of satellites in rainy regions over the oceans are now being assimilated. This has a maximum impact in tropical regions with high rainfall rates. We are about to implement a major change in the way we control the quality of observations, by comparing them to the background forecasts (the so-called Huber norm). This will enable the use of more observations in severe weather areas. The upcoming implementation of Ensemble Data Assimilation will also help.

Finally the impact of resolution needs to be stressed once more. Severe weather events most often develop at small scale within larger-scale atmospheric features and benefit more from increasing resolution than normal forecasts. The upcoming increase in resolution, that will push the ECMWF deterministic forecasts to a 16-km grid size and the EPS to a 32-km grid size, will bring further improvements.

As I am now leaving ECMWF to face new challenges, I am proud to have been able to contribute to this progress over the last six years. I wish ECMWF success in continuing on this fast track of progress.

Philippe Bougeault

ECMWF's plan for 2009

DOMINIQUE MARBOUTY

THE PLANS for 2009 will build upon our achievements in 2008 which included:

- Merging of the VarEPS and monthly forecasting systems, now designated as the EPS.
- Implementing two new cycles, including in particular several changes to the physics.
- Successful early forecasting of several severe weather events, particularly tropical cyclones (see editorial).
- Installing the first cluster of the new IBM supercomputer.
- Preparing the future Atmospheric and Climate Services of GMES (Global Monitoring for Environment and Security) with our Member States and the European Commission.

The ECMWF plans for 2009 flow directly from the four-year programme of activities 2009–2012, adopted by the ECMWF Council at its 70th session in December 2008 (the programme itself is available at www.ecmwf.int/about/programmatic). The main drivers of this programme are:

- Continuous improvement of early warning for severe weather.
- Support to our Member States, including interoperability, relevant products and feedback into the observing system.
- Preparation for future challenges, in particular non-hydrostatic global modelling and massively parallel supercomputer architecture.

The most visible development will be the resolution upgrade of all forecasting systems. The plan is to increase the horizontal resolutions as quickly as possible after the computer upgrade, hopefully by the end of the year. Experimentation has started with horizontal grids of 16 km for the deterministic and assimilation outer-loop systems and 32/50 km for the EPS. This will be followed by an increase of the vertical grid to about 150 levels in 2010. These upgrades will result in improved forecast skill, in particular for severe weather events.

Another important step will be the implementation of an Ensemble Data Assimilation (EnDA) system as a new component of the operational forecasting system. It will be based on a ten-member ensemble at 50-km outer-loop resolution and will first be used to initialise the EPS. Improvements are expected especially in the tropics, where the spread will increase. The EnDA suite will then be further developed to provide flow-dependent background error variances for use in the high-resolution data assimilation. A positive impact is expected in the regions of severe weather developments.

As usual we will make specific effort to assimilate new satellite data. This includes, in particular, data from sounding instruments on the US satellites NOAA-N' and DMSP-17, and from the Chinese satellite FY-3A. Another development in this area will be the first assimilation of cloud-affected radiances from infrared sounders AIRS and IASI and from SEVIRI. We will also start direct assimilation of rain-affected radiances in 4D-Var.

In addition, many improvements developed in recent years for the different parts of the forecasting system will be implemented in the three new cycles expected this year. This includes:

- An extended Kalman-filter soil-moisture assimilation scheme.
- Coupling of ocean waves with ocean currents.
- New stochastic physics in the EPS and EnDA.
- Several further changes in the physics of the model concerning the representation of clouds, precipitation and snow on the ground.

A routine evaluation of the forecast sensitivity to individual observations by adjoint methods will also be implemented. This will add to our current set of tools to monitor the operational observation system.

Verification enhancement has been an important subject recently. This will continue with emphasis on severe weather and monitoring of long-term progress, in liaison with a dedicated subgroup set up by the Technical Advisory Committee. Also the verification suite will be extended to new areas such as waves, monthly forecasts and the use of the TIGGE database for comparison with other EPSs. More scores will be provided on our website.

The ongoing effort in developing new products for our Member States will focus on the Extreme Forecast Index (EFI), tropical and extra-tropical cyclone tracks, and circulation patterns. We will start re-engineering our external website in order to offer high availability and more interactivity.

The ERA-Interim production will reach present time early in 2009. It will then be continued in delayed mode. A set of new products targeted towards monitoring current climate anomalies (e.g. surface temperature and rainfall) will be progressively developed and made available on the ERA-Interim server.

Two main actions will concern the computing infrastructure.

- The installation of Phase 1 of the new IBM supercomputer will be completed and all operational suites and tools migrated accordingly.
- The procurement process for a new automated tape library will be completed by June and the replacement is expected to start by the end of the year.

In addition, the procurement process for the supercomputer and the latest advances in power consumption management will be reviewed.

Two important long-term internal projects will be further developed. One concerns the reorganisation of our facilities for observation archiving and manipulation. The other deals with preparing the IFS code structure for future massively parallel computers, improved modularisation, and better interoperability with our

Member States' NWP systems.

Increasing the Centre's support to the European Union has been an important element in ECMWF policy over the recent years, in particular within the GMES initiative. In 2009 the pilot atmosphere service project (GEMS) will come to an end and be replaced and expanded with the new Monitoring Atmospheric Composition and Climate (MACC) project, also co-ordinated by ECMWF. Another important area of discussion within GMES will be the possible contribution of ECMWF to the development of Climate Services, specifically with the development of a new-generation reanalysis.

ECMWF will continue to improve its governance and financial management. This year's focus will be on testing the activity-based costing scheme developed in 2008, evaluating the consequences of adopting the International Public Sector Accounting Standards (IPSAS), and starting an IT risk analysis.

The process of accepting the amended Convention is progressing and is expected to be completed this year. It will open the door for new States (or current Co-operating States) to join ECMWF as Members. Also negotiation will be continued with those States that expressed interest in developing co-operation with ECMWF.

Our Member States clearly indicated that they are willing to support this ambitious plan and are confident that its targets will be achieved. We will do our utmost to meet their expectations.

New items on the ECMWF website

ANDY BRADY

Overview of Co-operation

ECMWF pursues extensive scientific and technical collaboration, in particular with its Member States, with satellite agencies and with the European Commission. It participates in several programmes of the World Meteorological Organization (WMO) and contributes to climate monitoring in co-operation with the climate community.

- www.ecmwf.int/about/cooperation/

ECMWF Calendar 2009

The ECMWF Calendar has been released and will be updated throughout the year as new events are organised or existing events are changed. All educational events, workshops, technical and scientific meetings and committee meetings are listed. The page that is on our web site is the definitive version of this information.

- www.ecmwf.int/newsevents/calendar/

13th Workshop on the Use of High Performance Computing in Meteorology

The workshop was held in November and the presentations are now available. Every second year ECMWF hosts a workshop on the use of high performance computing in meteorology. The emphasis of this workshop was on running meteorological applications at sustained teraflops performance in a production environment. Particular emphasis was placed on the future scalability of NWP codes and the tools and development environments to facilitate this. There is information about this workshop on page 5 of this edition of the *ECMWF Newsletter*.

- www.ecmwf.int/newsevents/meetings/workshops/2008/high_performance_computing_13th/

Workshop on Atmosphere-Ocean Interaction

The workshop was held in November and the presentations are now available. The workshop addressed the requirements for ocean-atmosphere coupling from the very short time scales to the monthly time range with focus on ocean near-surface processes.

There is information about this workshop on page 5 of this edition of the *ECMWF Newsletter*.

- www.ecmwf.int/newsevents/meetings/workshops/2008/ocean_atmosphere_interaction/

Workshop on the use of GIS/OGC standards in meteorology

The workshop on GIS/OGC was held at the end of November and the presentations are now available. The workshop was jointly organised by Météo-France, the UK Met Office and ECMWF. The aim of this workshop was to review the use of OGC standards in geo-sciences in Europe and worldwide and to promote collaboration between meteorological services in order to define a set of common standards that will enhance interoperability. There is information about this workshop on page 8 of this edition of the *ECMWF Newsletter*.

- www.ecmwf.int/newsevents/meetings/workshops/2008/OGC_workshop/

ERA-Interim daily and monthly products now available for 1989–2005

Both the MARS and the public ECMWF Data Server now contain daily and monthly products for the ECMWF Interim Reanalysis for the 17-year period 1989–2005.

- www.ecmwf.int/research/era/

Changes to the operational forecasting system

DAVID RICHARDSON

THE FOLLOWING are new data sources that have been monitored in the operational data assimilation system:

- Wind profile data from 38 additional European radar stations since 28 October 2008.
- Cloud motion winds from the Chinese FY-2 geostationary satellite since 25 November 2008.

As preparation is underway to transfer the operational suite to the new high performance computer, there have been no major changes to the operational forecasting system since the last issue of the *ECMWF Newsletter*.

Survey of readers of the *ECMWF Newsletter*

BOB RIDDAWAY

THE FIRST *ECMWF Newsletter* was published in February 1980. Since then there have been significant changes to the content and presentation of articles. During that period, however, the purpose of the *Newsletter* has remained essentially unchanged. It is intended 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. As well as about 1,400 printed copies of the *Newsletter* being distributed each quarter, the *Newsletter* is also available from www.ecmwf.int/publications/newsletters/.

Every effort is made to try to ensure that the *Newsletter* meets the needs of readers, though it is difficult to know whether this is indeed the case. Very occasionally there is some unsolicited feedback but that is not a firm basis for making decisions about the future development of the *Newsletter*. Consequently it has been decided that, after over 100 issues of the *Newsletter* having been published, this is an appropriate time to carry out a survey of readers.

It would be appreciated if readers of the *Newsletter* would find time to fill in a questionnaire that can be accessed by going to www.ecmwf.int/publications/newsletters/ and following the link. The questionnaire has two parts which cover:

- Factual information about the person filling in the questionnaire.
- Views about how various aspects of the *Newsletter* are rated.

As there are only 12 questions it should take just a few minutes to complete the questionnaire. The more people there are that fill in the questionnaire the better able we will be get a true picture of the usefulness and accessibility of the *Newsletter*.

The responses to the questionnaire will be carefully assessed and, if necessary, action will be taken to develop the content and presentation of the *Newsletter* so that it continues to meets the needs of the meteorological community.

70th Council session on 2–3 December 2008

MANFRED KLÖPPEL

CHAIRED by its President, Dr Adérito Vicente Serrão from Portugal, the ECMWF Council held its 70th session in Reading on 2–3 December 2008.

Besides several decisions made on financial and staff matters (e.g. adoption of Reports from the Co-ordinating Committee on Remuneration and amendments to the Financial Regulations), the Council made some milestone decisions.

- ***Pension Scheme***. The Council unanimously decided on a long-term solution to the funding of the Budgetised Pension Scheme.
- ***Budget 2009***. The Council approved the budget for 2009 including increased expenditures for the Centre's new High Performance Computer Facility.
- ***Process regarding accession of new Member States***. The Council unanimously authorised the Director to start negotiations on full membership with those States that have already concluded a co-operation agreement for eventual accession to the ECMWF Convention and with EU Member States that wish to accede to the ECMWF Convention. The Council also adopted template texts for a Council resolution on the accession of a State to the ECMWF Convention, and for an agreement on accession to the ECMWF Convention and related terms and conditions.
- ***GMES (Global Monitoring for Environment and Security) Products***. The Council unanimously agreed that free access to ECMWF data and products will be given to the GMES pre-operational Core Services that have already been decided.
- ***Products for WMO***. The Council unanimously agreed that the resolution of the products made available to WMO Members be increased from the current 2.5° to a 0.5° latitude/longitude grid.
- ***Four-Year Programme of Activities***. The Council unanimously adopted the updated "*Four-Year Programme of Activities*" for the period 2009–2012 (for further information see www.ecmwf.int/about/programmatic/).

Other important results of this session were as follows.

- ***IPSAS and INTOSAI***. The Council agreed an action plan for consideration of IPSAS and INTOSAI financial standards in order to prepare a final decision by the end of 2009.
- ***RMDCN***. The Council agreed that the ECMWF funded RMDCN (Regional Meteorological Data Communication Network) basic package for Member

States be upgraded.

- ***EUROSIP***. The Council agreed the provision of a set of real-time seasonal forecast data to WMO Lead Centres for Long Range Forecast Multi-Model Ensemble.
- ***Scientific Advisory Committee***. Council appointed Dr Piero Lionello, Dr Robert Vautard, and Dr Jan Barkmeijer to the Scientific Advisory Committee for a first term of office.
- ***Election of President and Vice-President***. Dr Adérito Vicente Serrão from Portugal and Mr Wolfgang Kusch from Germany were re-elected as President and Vice-President of the Council, respectively, both for a third term of office of one year.

Dr Adrian Simmons (Co-ordinator for ECMWF activities in GMES) gave a lecture to the Council on "*Achievements of the GEMS Project*".

The 71st Council session will take place on 25–26 June 2009.

Use of high performance computing in meteorology

GEORGE MOZDZYNSKI

EVERY second year ECMWF hosts a workshop on the use of high performance computing in meteorology. The 13th workshop in this series took place from 3 to 7 November 2008 and was attended by over 100 participants from Meteorological Services, research institutions and computer vendors, coming from 25 different countries in Europe, Asia, Africa, the Americas and Australia. The emphasis of this workshop was on running meteorological applications at sustained teraflops performance in a production environment, and in particular on the future scalability of NWP codes and the tools and development environments to facilitate this.

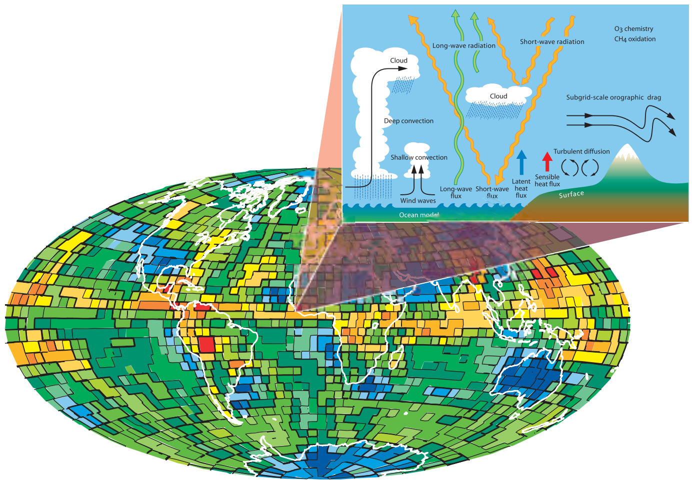
At the workshop there were 36 presentations covering a wide range of topics including:

- High performance computing at various forecasting centres.
- Current and future products from vendors of supercomputers.
- Developments in parallel computing techniques.
- Tools to exploit the power of supercomputers.

Presentations from this workshop can be found at the following web location:

- www.ecmwf.int/newsevents/meetings/workshops/2008/high_performance_computing_13th/presentations/

The figure shows the logo for this workshop. It illustrates the computational imbalance in IFS physics for a T799 model running with 2048 processors over a 6-hour period. Partitions coloured dark blue indicate the lowest computational cost, while those at the other end of the spectrum (i.e. red) indicate the highest computational cost. Such dynamic imbalances are just one of the areas being investigated as part of a project to improve IFS scalability.



This is the logo for this workshop which illustrates the computational imbalance in IFS physics for a T799 model running with 2048 processors over a 6-hour period. See the text for more information.

Atmosphere-Ocean Interaction

ANTON BELJAARS, FREDERIC VITART, PETER JANSSEN

A WORKSHOP on '*Atmosphere-Ocean Interaction*' was held at ECMWF from 10 to 12 November 2008. The objective of the workshop was to address the requirements for ocean-atmosphere coupling from the very short time ranges to the seasonal time range with focus on ocean near-surface processes. Also the following questions were to be considered.

- Which processes need to be taken into account (e.g. ocean waves, currents, diurnal cycle of SST, ocean mixed layer dynamics and horizontal resolution of SST)?
- What is the impact of air-sea processes on atmospheric phenomena, including extreme events (e.g. tropical cyclones, extra-tropical explosive genesis, monsoons and MJO)?
- Which models are the most appropriate at different time scales, and what are the implications for seamless forecasting?

This workshop attracted about 25 scientists from outside ECMWF and 14 scientists from France, Germany,

Sweden, UK and USA were invited to give a presentation. The talks were organized in two sessions – see the information in the box.

The presentations were followed by two working groups that reviewed an area of research and made recommendations for further research. Consideration was given to three time scales: short to 10 days, monthly, and seasonal.

Working group I: Processes of atmosphere-ocean interaction

The discussion was organized around three topics: ocean processes, forcing and technical implementation, and consideration was given to three time scales: short to 10 days, monthly, and seasonal.

For all topics it was emphasized that verification through comparison with observations should play an important role in any model development. Also it was recognized that ocean initialization of sea surface temperatures (SSTs) is key for good forecasts at all time scales. The deeper ocean needs to have compatible temperature to avoid any shock effects. Initialization of sea ice concentration is similarly important.

A good representation of the diurnal cycle in SST was generally considered as a high priority for all time scales because it affects the intra-seasonal variability through coupling with convective systems. It was further argued that relatively simple single column models of the upper ocean could be a useful way of providing coupling with the ocean up to the monthly time scale, without having the complexity of a full ocean circulation model.

Representation of the evolution of sea ice concentration is important for the seasonal time scale but can even play a non-negligible regional role in the short range. Fluxes from open fractions within the sea ice (leads) are substantial and need to be represented in models.

Having high-resolution ocean models is important for the representation of, for example, the western boundary currents, but it was considered that eddy resolving models do not provide sufficient benefit to justify the costs.

New results on turbulent exchange in the atmospheric surface layer were discussed extensively. It is generally accepted now that Monin-Obukhov similarity also applies to the marine boundary layer and that the same stability functions can be used as over land. The other good news is that a consensus seems to exist among observationalists about transfer coefficients. The uncertainty is only about 10% and the ECMWF scheme is within this range.

Wave effects are generally accepted as an important factor in the air-sea exchange processes. With the operational wave model, ECMWF is in a very good position to explore various mechanisms related to waves. The transfer coefficients are already wave dependent, but also momentum transfer from swell to the atmosphere and directional effects on the surface stress should be explored. Also currents are seen as a non-negligible aspect of the coupling, not in the least because they affect the interpretation of scatterometer data.

The software aspects of coupling different models (atmosphere model, diurnal cycle model, one-dimensional ocean mixing model, wave model and ocean circulation model) can be quite overwhelming. Different technical solutions exist (ranging from universal coupling software to models integrated in one executable), but the optimal

Workshop presentations

Session 1: Atmosphere-ocean interaction processes

Presentations were given on ocean mixing models, air-sea transfer, wind/SST coupling, and the effects of waves and currents. The role of the diurnal warm layer and the ocean-mixing layer were emphasized including its interaction with atmospheric convection and intra-seasonal variability.

Session 2: Impact of air-sea interaction on the atmosphere

Several talks showed that air-sea interaction was important for the prediction of tropical cyclones, extratropical transition of tropical cyclones, extratropical cyclones, the Indian monsoon, the Madden Julian Oscillation and ENSO. For example, it was shown that a good representation of ocean processes can lead to a better prediction of tropical cyclone intensity. Other talks discussed the importance of a good representation of sea ice for medium-range and seasonal forecasting. A final presentation discussed several software techniques for coupling the oceanic and atmospheric models.

The workshop programme and the presentations are available at:

- www.ecmwf.int/newsevents/meetings/workshops/2008/ocean_atmosphere_interaction/

solution depends very much on the particular software environment.

Working group 2: The impact of atmosphere-ocean interaction on the atmosphere

The discussions of this working group were organized around four time scales: diurnal, meso-synoptic, intra-seasonal and seasonal.

The diurnal cycle of SSTs is recognized as having an impact on the Madden Julian Oscillation (MJO), the Indian monsoon and possibly ENSO. For the MJO, the rectification of the diurnal heating of the upper-ocean warm layer on the intra-seasonal timescale helps maintain the amplitude of intra-seasonal fluctuations in SST associated with the MJO. High resolution in the upper ocean (e.g. one metre for the upper ten metres) is essential to partially resolve the diurnal cycle in SST, but mixing processes have to be well treated.

On meso to synoptic scales, prediction of cyclones, including tropical cyclones (TCs), extratropical transitions (ETs) and extratropical cyclones (ECs), remains a challenge. It has been demonstrated that ocean-atmosphere coupling and more accurate SSTs may improve the intensity forecasts of TCs and ETs. This improvement, however, may require the eye wall structure to be fully resolved (1–2 km resolution). It is not clear whether prediction of TCs and ETs by lower-resolution models (e.g. T799 or T1279) would benefit from ocean-atmosphere coupling.

Surface fluxes are important for the development of ETs and ECs. This suggests that it is crucial to have more accurate SST gradients, even for uncoupled forecasts. The effect of air-sea coupling for ECs requires more studies so that it can be quantified. Waves are known to play an important role, and wave information needs to be included in sea spray parametrizations. Sea-ice is recognized to have an impact on ECs. Interactions between an EC and sea ice can happen on synoptic time scales, as demonstrated in Canada. A 25-km horizontal resolution and 6-hourly coupling frequency is thought to be adequate for sea ice models for 10-day forecasts.

On intra-seasonal time scales, the MJO is a main source of predictability. Improvement in MJO prediction has been reported when coupling to a one-dimensional ocean mixed layer model, instead of forcing the atmospheric model with prescribed SSTs. The benefit of coupling the atmospheric model to a three-dimensional OGCM (Oceanic General Circulation Model) with the same high vertical resolution as the ocean mixed-layer model needs to be investigated and quantified.

On seasonal time scales, the dominant source of predictability is ENSO. Better representation of upper-ocean mixing and currents in the tropical oceans is likely to give positive impacts on forecasts of tropical SST. Outside the tropics, sea ice is important to seasonal forecasts, both locally and regionally. Seasonal forecasts would also benefit from a more accurate representation of fine structures of SST, as in the Gulf Stream.

The workshop was very successful and the recommendations of the two working groups will help guide research and development activities at ECMWF.

The full report of the workshop will be available by going to:

- www.ecmwf.int/publications/

and following the links.

Applying for computing resources for Special Projects

UMBERTO MODIGLIANI

EACH YEAR users within one of ECMWF's Member States may apply for computing resources as a 'Special Project'. These are of a scientific or technical nature and are likely to be of interest to the general scientific community. Such projects can be undertaken in co-operation between several institutions, nationally or internationally. The decision to treat a project request as a Special Project application is made ultimately by the Director of the National Meteorological Service of the project's Principal Investigator. Certain European organisations with which ECMWF has concluded Co-operation Agreements may apply for resources for a Special Project, with such a request to be considered by the Director of ECMWF. The Special Projects that are continuing or starting in 2009 are given in the item starting on page 27 of this edition of the *ECMWF Newsletter*.

The allocation of computing resources for Special Projects is decided by the ECMWF Council. The guidelines for distribution currently state that a maximum of 10% of the computing resources available to Member States may be allocated to Special Projects. 20% of that 10% is set aside as a reserve for allocation by ECMWF directly (following consultation with the Chairs of the Technical Advisory Committee and the Scientific Advisory Committee) either to late applicants or to projects which have exhausted their allocation before the end of the year.

If you wish to begin work on a Special Project in 2010 then an application form should be completed and sent to ECMWF via the Director of the appropriate National Meteorological Service. The form needs to reach ECMWF by 30 April 2009. Requests will be reviewed by the Scientific Advisory Committee and Technical Advisory Committee in October and then approved (or not) by the ECMWF Council at its meeting in December 2009. If the 30 April deadline is missed, applications can still be made as limited resources are set aside specifically for ad hoc allocations. The various application forms are available from:

- www.ecmwf.int/about/special_projects.

Due to the large oversubscription of computing resources available to

Special Projects, a new procedure was implemented in 2008 for the handling of applications for computing resources for Special Projects. The main changes are:

- Each project will have a well-defined duration, up to a maximum of three years, agreed at the beginning of the project.
- The amount of resources requested by each project for each year cannot exceed more than 8% of the total amount of resources available for that year. For 2009 the maximum resource that could be allocated to any project was designated as 4,960 kunits of HPCF and 16,000 gigabytes of Data Storage.
- To avoid accepted Special Project requests needing a reduction by more than 20%, the lowest ranking Special Projects requesting large amounts of computing resources may not be accepted.

More information about Special Projects can be found at the web address that has already been given.

Use of GIS/OGC standards in meteorology

BAUDOUIN RAOULT, STEPHAN SIEMEN (ECMWF),
FRÉDÉRIC GUILLAUD, CATHERINE BECHIR (MÉTÉO-FRANCE),
JEREMY TANDY, PETER TREVELYAN, BRUCE WRIGHT (UK MET OFFICE),
JON BLOWER (UNIVERSITY OF READING)

FOLLOWING the recommendations made during the 11th workshop on Meteorological Operational Systems held at ECMWF in November 2007, Météo-France, the UK Met Office and ECMWF jointly organised a dedicated workshop on the use of GIS (Geographic Information Systems) in meteorology. The workshop was held at ECMWF from 24 to 26 November 2008. Its aim was to:

- Review the use of OGC (Open Geospatial Consortium) standards in geo-sciences in Europe and worldwide.
- Promote collaboration between meteorological services in order to define a set of common standards that will enhance interoperability

The workshop was a great success with over one hundred participants from various disciplines and organisations worldwide. Talks covered topics such as:

- Standards, with representatives from OGC, WMO and INSPIRE.
- Commercial solutions.
- Ongoing developments at several National Meteorological Services worldwide.
- Progress made by other communities, such as ESA and EUROCONTROL.

Forty-three presentations from institutions provided an overview of where developments are progressing. These presentations can be found at

- www.ecmwf.int/newsevents/meetings/workshops/2008/OGC_workshop/

From the presentations it became clear that closer co-operation in the meteorological community will be necessary to achieve interoperability in the future. Only if agreements on conventions can be achieved will it be possible to exchange data and maps between each others' servers and clients.

The outcome of the workshop is the establishment of a roadmap for further collaboration within the meteorological community and the setting up of testbeds to promote interoperability of OGC compliant web services for meteorological data and visualisation. This work should lead to a set of recommendations to WMO.

Four working groups discussed the roadmap and technical issues surrounding the web standards.

Roadmap for collaboration

The first working group discussed a roadmap for collaboration amongst the meteorological community on the development of common usage practices for existing standards and contribution to the evolution of standards to ensure they meet community needs.

It was agreed to form a Meteorological Domain Working Group (DWG) with joint ownership from WMO and OGC. The charter (terms of reference) for the DWG will be presented for endorsement at the OGC Technical Committee meeting in Athens (March 2009) and communicated to WMO. The DWG will set up and moderate a collaboration website for knowledge sharing amongst community members.

The main focus of the DWG will be to drive a series of 'interoperability experiments' lasting approximately six months with the goal of validating standards and best practices based on implementation experience. Each iteration will focus on a particular demonstration scenario to provide coherence to the technological activities deployed within a 'testbed'.

The first iteration will focus on the creation of a WMS (Web Map Service) profile for the meteorological community.

It is proposed that the second iteration may look at validating the operational meteorology domain model developed within the proposed WMO inter-programme expert team on metadata and data interoperability (WMO IPET-MDI) being considered at CBS XIV in March 2009.

Use of GML and coverage services

The use of the GML (Geography Markup Language) and coverage services was the topic considered by the second working group. The group discussed the development and maintenance of a small set of conceptual models, to which mappings from the various implementation forms can be maintained.

The proposed approach was to start with a real problem, develop clear, specific test cases, formalise the problem (e.g. agreeing use case, data, query), develop the conceptual model (building on existing standards such as Observations & Measures and CSML), and validate and refine through implementation. A key recommendation was the establishment of international governance for core packages required by the meteorological community, supported by the necessary registry infrastructure.

Use of the OGC Web Mapping Service

The third working group discussed the use of the OGC Web Mapping Service (WMS) in meteorology. WMS has seen the most implementations and uses of all the services.

From the presentations and discussions it became clear that although the WMS can be easily implemented to deliver maps, some further work is required to ensure that the WMS standard can be used to best effect within the meteorological community. In particular, the meteorological community must agree upon common styles for maps to ensure that maps that are shared between organizations are comprehensible.

The group identified some areas of the WMS standard that will require clarification or expansion, such as the handling of vertical and temporal dimensions. It is therefore recommended that the community should work together, in collaboration with the OGC, to develop a 'meteorological profile' of WMS.

Security and access control

The final working group discussed issues regarding security and access control within OGC web services. The scope of the discussions was limited to true interoperability, i.e. when using client and server software from different vendors or open source projects.

The group first reviewed the security requirements (authorization, access control, data policies, data integrity etc.) and the various technical solutions, such as the work done by the BADC (British Atmospheric Data Centre) as part of the NERC data grid, or the geoXACML project. It was concluded that none of the solutions were yet mature and that in the meantime security could be implemented at a lower level (SSL, VPN, IP filtering). The group recommended that security should be delegated to proxies, so that the web services (WMS, WCS, WFS) would not have to deal with it. Finally, it was recommended that:

(a) Access control should be role based

(b) For inter-organisation deployment, a virtual organisation should be setup by establishing trust relationships between the partners.

Météo-France has offered to host the next Workshop in Toulouse in 2009.

Additional ERA-Interim products available

DICK DEE

ERA-Interim daily and monthly products for the period 1989–2007 are now available on MARS (`expver=1, class=ei`) for users from Member States, and on the ECMWF data server

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

for all other users.

ERA-Interim is the global atmospheric reanalysis currently in production at ECMWF, described in *ECMWF Newsletter No. 110* and *No. 115*. The reanalysis is expected to reach real time during the first quarter of 2009, after which it will continue to be maintained as a climate monitoring tool with monthly updates to the product archive and data server.

Information about the status of the production and known data issues will be posted on the ERA web pages at:

- www.ecmwf.int/research/era.

ECMWF workshops and scientific meetings in 2009

BOB RIDDAWAY

Workshop on 'Assimilation of IASI in NWP' (6 to 8 May 2009)

In collaboration with the EUMETSAT NWP-SAF the ECMWF will host a workshop on the "Use of IASI in NWP". The event comes nearly two years after IASI was first declared 'operational' by EUMETSAT. The topics covered will include:

- Detailed validation of the IASI observations and associated radiative transfer models.
- Experience of NWP centres with the assimilation of the level-1/level-2 data.
- A special session on novel applications of IASI in the context of environmental monitoring.

In addition to formal lectures by invited speakers, the workshop will aim to formulate recommendations to guide future research and development.

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

Forecast Products – Users Meeting (11 to 13 June 2009)

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

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

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

Workshop on 'Diagnostics of Data Assimilation System Performance' (15 to 17 June 2009)

Data assimilation schemes have evolved into complicated systems with millions of degrees of freedom and handling massive amounts of observations. Effective monitoring of these systems is required and emerging techniques are now rapidly developing at most NWP centres. This review of the various methodologies and their effectiveness in diagnosing the impact of observations in NWP is suitably timely. Workshop attendance is by invitation only.

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

ECMWF 2009 Annual Seminar on 'Diagnosis of Forecasting and Data Assimilation Systems' (7 to 10 September 2009)

Powerful and precise diagnostic techniques are required to maintain the present pace of forecast system development. This is partly due to the abundance of new observations of the Earth system and the growing complexity (and indeed accuracy) of forecast models.

This seminar will give a pedagogical overview of diagnostic techniques used to understand the deficiencies in NWP, seasonal and climate forecasting systems. Diagnostics targeting observations, data assimilation systems, models and ensemble prediction will be discussed. Additional lectures will focus on identifying new sources of forecast skill.

A registration form and further information is available from:

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

12th Workshop on 'Meteorological Operational Systems' (2 to 6 November 2009)

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

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

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

Workshop on 'Non-hydrostatic Modelling' (dates not decided)

The workshop will review recent progress made in non-hydrostatic modelling worldwide, with some emphasis on global model developments. It will consider the strengths and weaknesses of different approaches taken in the development of non-hydrostatic dynamical cores and exchange ideas about efficient ways of testing the performance of these models at all scales. Workshop attendance is by invitation only.

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

EUROSIP: multi-model seasonal forecasting

TIM STOCKDALE, FRANCISCO J. DOBLAS-REYES, LAURA FERRANTI

ECMWF has run a seasonal forecast system for more than 10 years, and is presently on its third generation system. The forecast system is good at predicting El Niño related sea surface temperature (SST) anomalies in the Pacific, which are the major source of predictable seasonal variations in the weather around the globe. However, performance in predicting actual weather anomalies in many parts of the world is still substantially below the theoretical limits of what is possible.

Research has shown that combining forecasts from several different coupled ocean-atmosphere models is a robust and effective way to increase seasonal forecast skill. This is because combining models both averages out some of the individual model forecast errors, and also gives a better idea of the uncertainties in the forecast. ECMWF, the Met Office and Météo-France agreed some time ago to work together to develop an operational multi-model seasonal forecasting system, and EUROSIP was born. (Seasonal forecasting is often referred to in the research community as Seasonal to Interannual (or S/I) Prediction, which is the reason behind the "EUROSIP" name.) The cooperation of the scientific teams at Météo-France and the Met Office in developing the EUROSIP project is acknowledged.

Here we review the present status of EUROSIP and the performance of the multi-model forecast system.

How does a multi-model forecast help?

Despite successful El Niño predictions and constant efforts at model development, model error is still a major problem for seasonal forecasting. By 'model error' we mean the generic inaccuracies in the numerical model's representation of the real world. The problem is not specific to ECMWF – all existing models in the world have errors that limit the accuracy of seasonal prediction. Model error gives rise to model-induced forecast errors; these are errors in the individual forecasts that are due to the model. On a seasonal timescale, forecasts are inherently probabilistic, and so even a hypothetical 'perfect model' ensemble forecast of a particular variable would only give a probability density function (pdf). An ensemble of forecasts from an imperfect model will also generate a pdf, but it will differ from the 'true' pdf. We will refer to the difference between the pdfs as the model forecast error.

The most obvious model forecast error is bias – a model may be systematically too warm or too cold at some location, for example. Bias is estimated from a set of hindcasts (or reforecasts) made with each model, and this estimate can easily be removed from the real-time forecasts. However, the non-stationary component of forecast errors and non-linear effects are not accounted for by bias removal, and empirical corrections for these errors cannot easily be estimated from the limited number of past cases. Further, the forecast 'signal' that we are trying to predict is in most cases a relatively modest shift in the pdf from its climatology. Model forecast errors can easily overwhelm these signals, particularly away from areas of strong forcing such as the equatorial Pacific. Although model errors are being reduced, and will continue to be so in the future, the requirements for model accuracy are so exacting that model error is expected to be the dominant problem in seasonal prediction for decades to come.

So model forecast errors are endemic, hard to reduce, impossible to eliminate by a posteriori correction, and have a major impact on our forecasts. What can we do? A pragmatic approach starts by noting that although all models have errors, different models have different errors. Thus a multi-model combination can be useful – if we average the forecasts of several different models, some of the model forecast errors will be averaged out, while the forecast signal will remain undiminished. In practice, model forecast errors are likely to be partly correlated, and so averaging even a large number of models will not eliminate the error entirely. The number of independent models available is also limited. Nonetheless, averaging is able to reduce model forecast error to some extent.

A multi-model forecast system also helps by giving better information on the uncertainty of the forecast. A forecast pdf derived from a multi-model combination will typically be broader than one derived from a single model because the multi-model pdf naturally takes account of model uncertainty. The broader pdfs of multi-model forecasts increase their reliability, and allow them to gain higher verification scores when probabilistic measures are used. Forecast pdfs from a single model can be relaxed towards the climatological pdf to increase reliability, but this comes at the expense of 'damping' the forecast signal. Multi-model forecasts typically have increased reliability without loss of the mean forecast signal captured by the models.

A final benefit of a multi-model system is as a safeguard against the (hopefully small) risk of a real-time forecast system being corrupted in some way so as to produce misleading forecasts. For example, a real-time system might be inadvertently changed so that it systematically differs from the hindcasts; or it might fail to handle correctly a change in an external data stream; or data might be corrupted. Diagnosis of a problem by verification of the real-time forecasts is likely to be slow, and comparison with other forecasts might help to identify a problem much more quickly. Even for unrecognized errors, robustly constructed multi-model products will be much less impacted than the single affected model.

The benefits of multi-model combination

The EU-funded DEMETER project coordinated at ECMWF was a major step forward in establishing the practical benefits of multi-model seasonal prediction. Seven European coupled ocean-atmosphere models were used to make seasonal 'forecasts' covering recent decades, and the results of multi-model combinations were examined.

Key conclusions from DEMETER

Figure 1 shows a comparison of skill between multi-model combinations and single model ensemble forecasts from the DEMETER project. The ranked probability skill score (RPSS), a measure of probabilistic forecast quality, is shown for forecasts of June/July/August seasonal mean 2-metre temperature at points in the northern hemisphere extratropics as a function of the ensemble size.

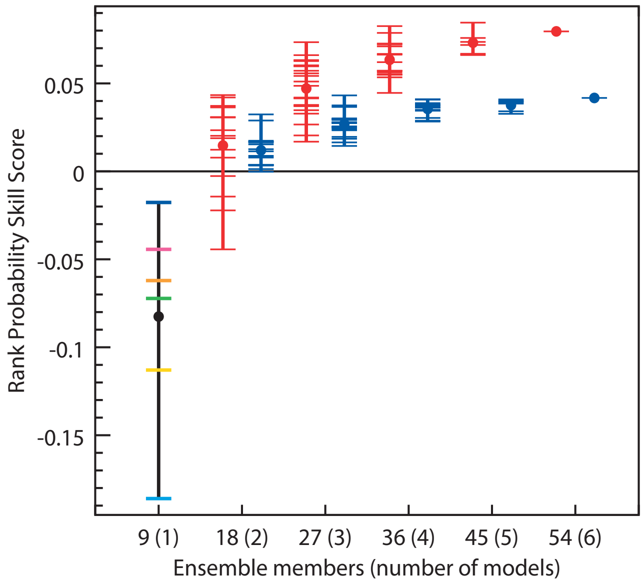


Figure 1 The ranked probability skill score (RPSS) for forecasts of June/July/August seasonal mean 2-metre temperature at points in the northern hemisphere extratropics as a function of the ensemble size, from the DEMETER project. The forecasts start from 1 May for the years 1987–1999. Red lines show the skill of multi-model combination, which is generally higher than the skill of similarly sized ensembles of the best single model shown by the blue lines. See text for details.

- *Single model (blue lines)*. These results are drawn from a 54 member ensemble of forecasts from the ECMWF model, which for this particular forecast quantity and verification period is the best individual model. Each blue horizontal tick mark shows the result of one possible combination of members drawn from the total set of 54 members actually run. This means that the vertical spread in the blue lines represents sampling uncertainty in the generation of the ensemble.
- *Multi-model combination (red lines)*. Results are shown for possible multi-model combinations, drawn from between 2 and 6 models (the number of models is shown in brackets by the side of the ensemble size). Since each model has nine ensemble members, the total ensemble size used is the same for the multi-model combination and the corresponding single model ensemble.

The vertical spread of the results from the multi-model combination (red tick marks) is typically larger than that of the single model (blue tick marks) since the skill of a multi-model combination depends on which models are combined.

The results in the left-most column of Figure 1 (coloured tick marks) show the skill of the individual 9-member model ensembles. Note that even a combination of three other models is likely to be better than a similar sized ensemble using a single model. By the time we get to four models, even the worst example of a four model combination beats the best result possible from the best single model. This general result is robust across many different variables, regions and seasons – for probabilistic forecasts, a multi-model combination is surprisingly effective when compared against a single model.

Key conclusions from DEMETER are that:

- Multi-model combinations are more skilful than single models.
- The benefit is not just from having a larger total number of ensemble members.
- Adding a model with less-than-average skill to a multi-model combination is still usually of some benefit.
- A simple unweighted combination of models is usually the best approach, given the typically small sample sizes available for estimating model skill.

These very robust conclusions on the practical benefit of a multi-model combination were what drove ECMWF and its partners towards establishing an operational multi-model seasonal forecasting system.

Quality of the multi-model forecasts

The first consideration of a seasonal forecast system is the quality of the El Niño SST forecasts. Figure 2 shows the root mean square (rms) error of SST forecasts for the NINO3.4 index for the individual models of the present operational EUROSIP configuration (blue, green and orange) and the multi-model combination (red). The rms error of a simple anomaly persistence forecast is shown in black for reference. The multi-model combination is much better than the average of the models, and is fractionally better than the best single model.

Also shown in Figure 2 is the standard deviation of the ensemble forecast for a single model (dashed blue) and the multi-model combination (dashed red). The single model underestimates the uncertainty in its own forecasts, but the average spread of the multi-model forecasts almost matches the rms error of the forecasts.

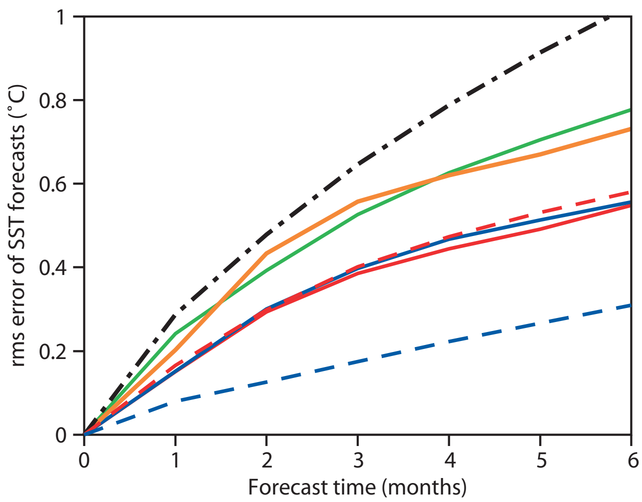


Figure 2 Root mean square errors of Nino 3.4 SST index forecasts from the EUROSIP multi-model combination (red line), anomaly persistence forecast (black line) and individual models (blue, green and orange lines). The multi-model combination is much better than the average of the models, and is fractionally better than the best single model. Also shown is the ensemble spread of the multi-model combination (dashed red) and the best single model (dashed blue).

Despite this, the forecasts from the multi-model combination are still not properly calibrated – inspection of the individual forecasts shows that sometimes the multi-model combination clearly overestimates the uncertainty of a forecast, and sometimes it strongly underestimates the uncertainty. Preliminary results from a Bayesian calibration of the Niño plumes developed at ECMWF show a better scaling of the ensemble spread.

A further comparison between scores of operational ECMWF-only seasonal forecasts and those of the operational EUROSIP multi-model system is shown in Figure 3. This shows the ROC (Relative Operating Characteristic) skill scores of June/July/August seasonal mean 2-metre temperatures predicted from May for the years 1987–2005 for (a) the ECMWF model alone and (b) EUROSIP. The ROC skill score is effective at measuring the signal contained in a set of probabilistic forecasts and it does not punish forecasts for having poorly calibrated probabilities. Overall, the EUROSIP multi-model scores more highly, although the effect is relatively modest. The skill in summer temperature forecasts over southern Europe is apparent in both plots, and again the multi-model combination brings only modest gains. Note that the scores are fairly noisy and are only based on nineteen years of data – sampling uncertainties mean that detailed local comparisons are not appropriate. Plots of other variables and other seasons tell the same story – the EUROSIP forecasts are, overall, modestly more informative than the ECMWF-only forecasts.

The reliability diagram in Figure 4 demonstrates the benefit of the multi-model system for the reliability of probability forecasts. Figure 4a shows the reliability of probability forecasts from the ECMWF model for seasonal mean 2-metre temperature being below the lower tercile for December/January/February for forecasts in the northern hemisphere extratropics. A reliable set of forecasts would have the observed frequency of occurrence matching the forecast probability – i.e. the points would be on the diagonal. Although the ECMWF forecasts have some ability to discriminate between different likelihoods of a cold winter, they are clearly a long way from being reliable. Figure 4b shows the result from the multi-model forecasts. The result is still not perfectly reliable, but is a big improvement on the single model result: note, for example, the change in the forecasts of a very low probability of a cold winter. The multi-model combination makes such a prediction less often (the size of the plotted circle represents the frequency with which the forecast probability is issued), but when such a forecast is made, it is much more reliable.

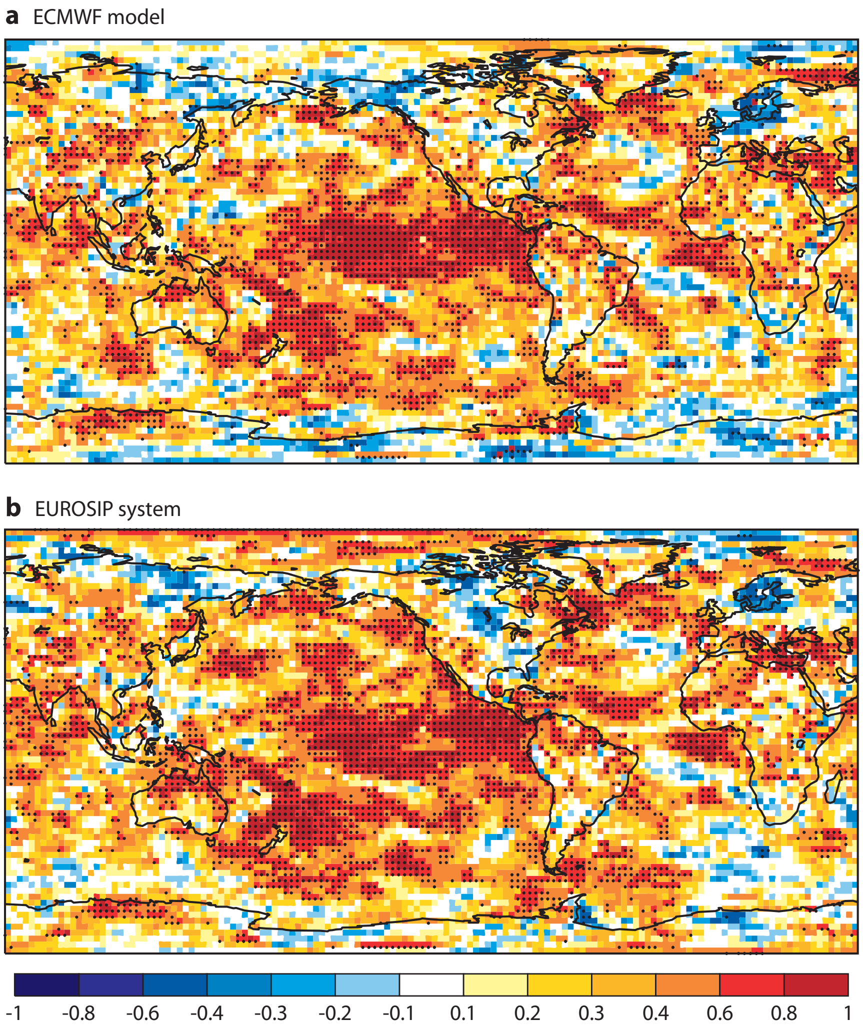


Figure 3 ROC skill scores for (a) the ECMWF model and (b) the EUROSIP system, for the event of the June/July/August seasonal mean 2-metre temperature being above the climatological median, as forecast from 1 May for the years 1987–2005. Black dots indicate values significantly different from zero with 95% probability. Scores are locally noisy, but the overall skill level of the EUROSIP system is higher.

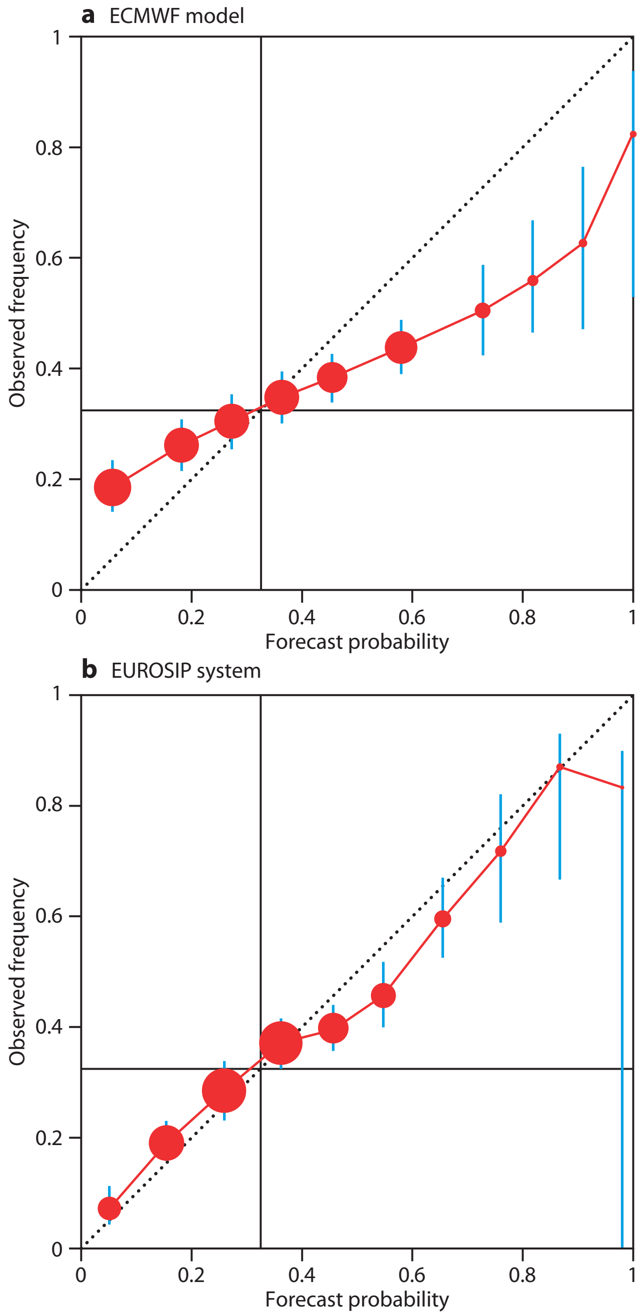


Figure 4 Reliability diagrams for (a) the ECMWF model and (b) the EUROSIP system for the event of the December/January/February seasonal mean 2-metre temperature being below the lower tercile of climatology, as forecast from 1 November, for the years 1987–2005. The red dots show the observed frequency of the event binned according to the probability its occurrence was predicted to have, with the blue error bars showing the effect of sampling uncertainty. The relative size of the red dots indicates the number of cases included in each bin. The black lines show the climatological frequency of the event. For a reliable system, the observed frequency should match the forecast probability in each bin. The EUROSIP system has a substantially higher reliability than the single model.

The substantial improvement in reliability relative to the ECMWF model is a general property of the EUROSIP forecasts, seen across other seasons and variables. Scores which are sensitive to the reliability of the probabilistic forecasts, such as RPSS, also benefit from the multi-model combination.

The present status of EUROSIP

The EUROSIP project presently involves ECMWF, the Met Office and Météo-France as partners – each partner contributes forecasts from a coupled atmosphere-ocean model to the multi-model system. Other organizations from ECMWF Member States or Co-operating States who would like to contribute can request to become EUROSIP partners. The German weather service (DWD) in collaboration with the Max-Planck-Institute for Meteorology intends to join the EUROSIP project in the future. Since spring 2005 graphical products from the multi-model system have been available to users in Member States. A formal data policy for EUROSIP was established by the ECMWF Council in December 2006, and in December 2007 the Council authorized the addition of a selection of EUROSIP multi-model data to the commercial catalogue.

The multi-model system works by combining the data from the operational versions of each contributing model. The main output of the multi-model system is a set of graphical forecast products that are discussed in the next section. Whenever one of the individual models is upgraded, the EUROSIP system will include the updated version. Typically, test data from a new model is made available for several months before the actual operational change, although this is not guaranteed. Each individual model is used to produce forecasts and also a corresponding set of hindcasts (or reforecasts). The hindcast data is used to estimate both model biases and also forecast skill. EUROSIP multi-model products always use the hindcast data corresponding to the real-time forecast data, so when a model version changes a new set of hindcast data is used. Information on the dates of changes in the various model components is available on the web.

In addition to graphical multi-model products on the web, certain EUROSIP products – based on the combined output of all of the models – are made available in digital form. These EUROSIP multi-model products are created together with equivalent hindcast multi-model products to allow skill estimation of the products.

The raw data for each individual model belongs to the contributing centre, and any commercial use of this data requires negotiation of terms with the owner. However, permission is granted to all Member States and Co-operating States to use the data for their official duty, and the data is also available for non-commercial research and education.

Full documentation of the EUROSIP system, including details of MARS access to the various datasets, is available on the web at

www.ecmwf.int/products/forecasts/seasonal/documentation/eurosip/

Graphical forecast products and issues of interpretation

The EUROSIP graphical products are similar to those of the ECMWF System 3 forecasts, though with some

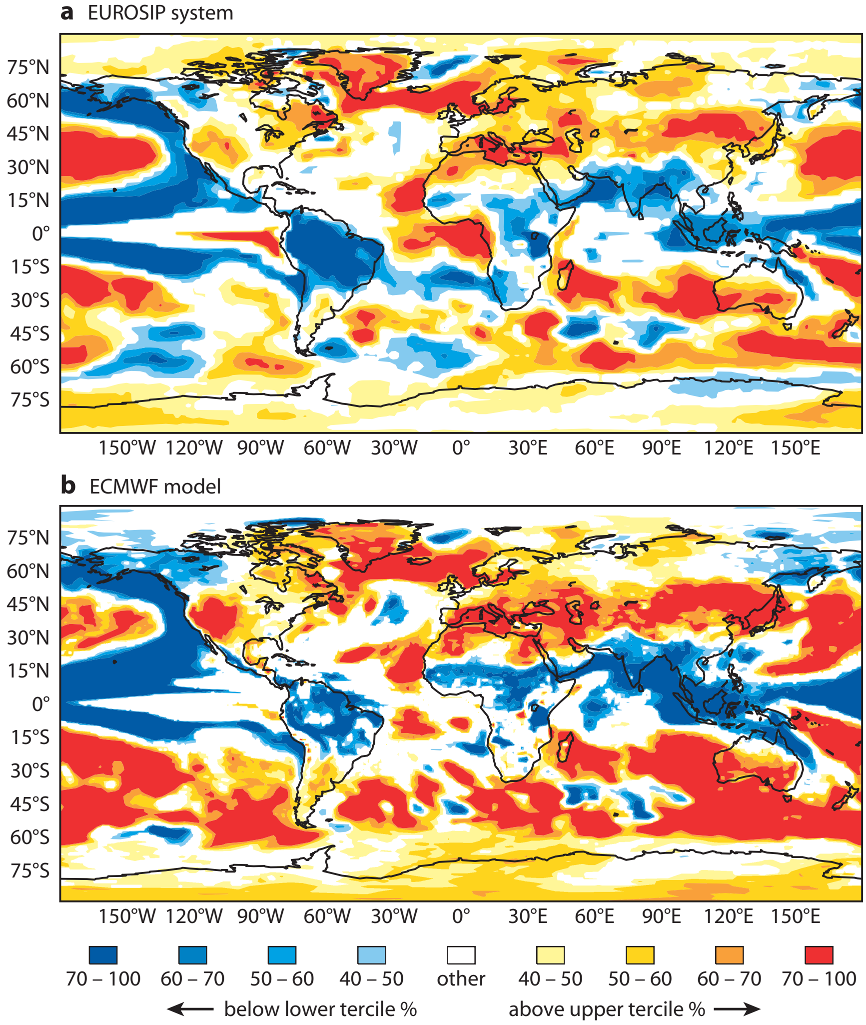


Figure 5 Forecasts for seasonal mean 2-metre temperature tercile categories for June/July/August 2008 from (a) the EUROSIP system and (b) the ECMWF model issued in May 2008. The forecasts are generally consistent, but EUROSIP tends to shift some of the higher probabilities (e.g. 70–100%) downwards towards lower values.

differences. Products available include SST anomalies for key regions of the Equatorial Pacific (Niño plumes), probability maps for a range of atmospheric parameters, and predictions of tropical storm activity. The products are published on the web on the 15th of each month at

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

Niño Plumes

El Niño predictions are an important tool to anticipate the relative likelihood of regional climate anomalies. Niño plumes show the full set of SST anomaly plumes from all of the models, plotted together but without any adjustment or calibration.

Probability maps

Figure 5 shows an example of a multi-model forecast of 2-metre temperature for June/July/August 2008, and how it compares to the corresponding ECMWF-only forecast. The maps represent the probability of the most likely category of the seasonal mean 2-metre temperature being either above the 67% or below the 33% value of the model climate distribution. The forecasts are reasonably consistent, and the general tendency for the multi-model forecast to give slightly weaker probabilities (i.e. to be less confident) than the ECMWF forecast is visible. Sometimes the consistency between the ECMWF and multi-model forecast is lower than in this figure, reflecting the fact that the models disagree.

The consistency between the forecasts is not a reliable guide to either accurate or inaccurate forecasts, but it can give some information additional to that of the average past performance. In some cases inconsistencies between forecasts are related to the way individual models represent specific physical processes.

Tropical storms

EUROSIP predictions of tropical cyclones are produced by combining the calibrated forecasts of the individual models using equal weights. As discussed in *Vitart et al.* (2007), the skill of EUROSIP forecasts is generally higher than that of the individual models.

Outlook for EUROSIP

The EUROSIP multi-model forecast system will continue to be maintained, and will benefit from each new forecast version that the contributors provide. Any increase in the number of models will also be beneficial.

There is also much scope to improve the accuracy, robustness and optimality of the combination methods used, and to consider the most effective ways of representing graphically the estimated signals and their uncertainties. Indeed, the proper calibration of probabilistic forecasts to account for model error is an issue for both single model and multi-model products. Collaboration with our Member States and others will be crucial in this area.

Finally, multi-model combination is not the ultimate tool for improving seasonal forecasts - there is no substitute for improving the individual forecasting systems themselves. Better models, run at the appropriate resolutions, will enable the impact of SST anomalies on the atmospheric circulation to be more accurately captured. Also more careful inclusion of other time-varying processes in the climate system (e.g. soil moisture, sea-ice, stratospheric dynamics, ozone, tropospheric and stratospheric aerosols) may lead to additional sources of non-negligible seasonal predictability. They may also give a better representation of the decade to decade changes in the Earth's climate that form an important part of the practical seasonal prediction problem. A multi-model combination will remain a valuable tool for many years to come, but it is only a complement to much other work that is needed.

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Using ECMWF products in global marine drift forecasting services

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AS A PART of the EU-funded project MERSEA, a global marine drift forecasting system has become operational at the Norwegian Meteorological Institute, hereafter referred to as met.no. The system relies heavily on global forecast products from the ECMWF wave and atmospheric models. In addition, a new wave parameter (the Stokes drift) was implemented for the proper treatment of the surface particle drift. Here, this forecasting system will be presented with emphasis on the use of global products from ECMWF. Also an example of an oil drift forecast will be given.

Importance of drift forecasts

It is of great societal importance to have safe shipping and oil production at sea. Unfortunately, accidents happen so from time to time there are releases of oil in connection with shipping accidents or discharges from oil rigs. Besides accidental spills, there is also illegal dumping of oil and pollutants for which authorities need back-tracking predictions of the oil spill to find who is responsible. In addition to the tracking of oil spills, there is a vital interest in tracking people lost at sea, drifting ships, containers and other objects.

Today, most countries have one or more authorities responsible for detecting and tracking drifting objects and oil. Observations by satellites, aircraft and ships, as well as drift predictions, are important parts in the complex interplay governing any search and rescue or oil spill recovery action. For instance, in Norway the Joint Rescue Coordination Centres are the operational authority for search and rescue, while for oil spill recovery the responsibility is shared between the Coastal Administration (a government agency) and NOFO (a joint offshore industry enterprise charged with carrying out remedial action at sea). The responsibility of Norwegian authorities covers the Norwegian economic zone, but adjacent waters, such as the Nordic Seas and Arctic, are also of importance. Other countries have similar interests in their national and adjacent waters. However, there is also an interest in being able to monitor and forecast incidents in other waters.

Shipping and marine pollution are truly global and for many areas it is not clear which authority is responsible for remedial action. While there are international agreements ensuring the provision of metocean forecasts in maritime emergencies (MPERSS), there is still a need for drift forecasts at the local level. For example, when a Norwegian ship is involved in an accident, it may be of interest for Norwegian authorities and for the shipping company responsible for the ship in question to obtain monitoring and forecasting information. Therefore, it is an added value to have organizations capable of forecasting the track of oil spills and drifting objects on the global scale.

In many situations there are large uncertainties in the drift forecast that reduce the value of the forecast of, for example, an oil spill. One way to improve the accuracy of the forecast, or for estimating the uncertainty of the forecast, is to use ensemble forecasts. Here it is worth emphasizing that there are two types of ensemble forecasts:

- Traditional ensemble forecast using an ensemble of forcing fields (e.g. different wind forcing).
- An ensemble of different oil drift models.

The latter type of ensemble requires different oil drift models and arrangements to ensure that data from different models is made available. Today, there is much pan-European focus on exchanging data on drift forecasts from various centres through different EU projects (MERSEA, ECOOP, MYOCEAN and a new EU call for downstream services). However, presently these model ensembles are probably not used to their full extent but it is foreseen that this matter may improve as forecasts from different centres become available and the cooperation between European countries intensifies.

Modelling oil spills

In principle, the drift of various objects at sea follows the same physical principles and are subject to the same geophysical forces (i.e. the drift of an object can be calculated from the forces on the object and its mass). However, different objects (e.g. ships, containers, small boats, wind surfers, icebergs and oil) have very different geometries and rely on diverse parametrizations, and so models have been developed separately for various kinds of drifting objects. This means that in many circumstances very different models are used for different objects. Here, we will describe the drift of oil, but many objects will behave in a rather similar way.

Drifting objects and substances at sea are influenced by:

- Atmospheric winds
- Ocean currents
- Wave drift and wave forces
- Coriolis force

The wind acts directly on a drifting object or oil, forcing it to move with the wind. A classical observation is that an oil slick drifts with typically 2–4% of wind speed with a 0–20° deflection towards the right (north hemisphere). This parametrization provides a simple model for the upper ocean currents: it is simple and easy to implement, but does not cover situations in which wind-drift is not the dominant current component (e.g. in cases with strong tidal currents, density-driven currents or strong swell conditions). Accordingly, if we describe the ocean currents in a better way, we may be able to improve the prediction of those currents and the resulting drift forecasts.

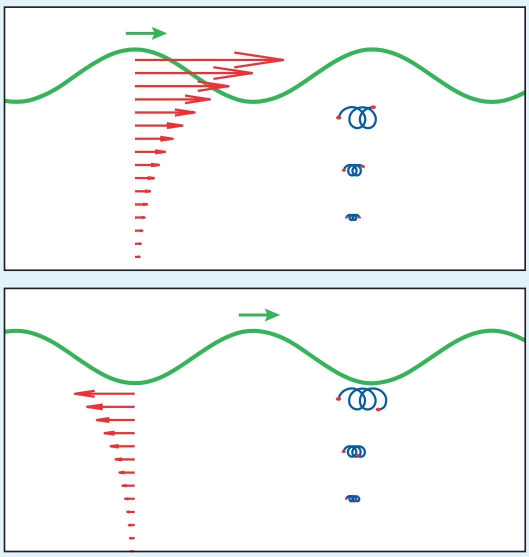
In addition to the ocean current, waves will also affect objects by the wave radiation stress and/or by the Stokes drift. Waves have a certain momentum and when they interact with, for example, a solid body there is an exchange of momentum between the waves and the object; this is called the radiation stress. The Stokes drift is described in Box A.

Box A
The Stokes drift

The Stokes drift is the mean velocity of the fluid particles due to the presence of a wave.

If we look at a particle under a wave train, see the figure, it will move faster under the wave crest where the water parcel is higher up in the water column and thus experience stronger positive wave orbital motion than under wave trough where the water parcel is lower in the water column and experience negative and weaker orbital motions. In addition, the particle moves in the direction of the wave propagation under the crest and against it under the trough and is therefore exposed to drift in the wave direction longer. Drifting particles under the action of waves will therefore move in the direction of the wave, and this is called the Stokes Drift.

To further enhance the picture it should be noted that the Stokes drift is an inherently Lagrangian process; particles move but if we take the mean velocity at a fixed position (Eulerian mean) the transport is identically zero (as can be imagined from the figure). In the Eulerian description the wave transport is located between the deepest wave trough and the highest wave crest, while in the Lagrangian description it is distributed as $\exp(-2kz)$, where k is the wave number. However, the deviation between the Lagrangian and the Eulerian description can be resolved by considering the wave-induced motion in between isopycnal layers. This formulation is similar to the estimate of horizontal transport in isopycnal coordinates as is commonly used in atmospheric and oceanic science to describe the transport in an eddy field.



Motions of particles at different depths (blue lines) due to the passage of an idealized surface wave travelling to the right (green line) for two cases separated by half a wave period. The position of particles during each wave period is shown with the red points indicating the beginning and end positions. The red arrows indicate horizontal velocities.

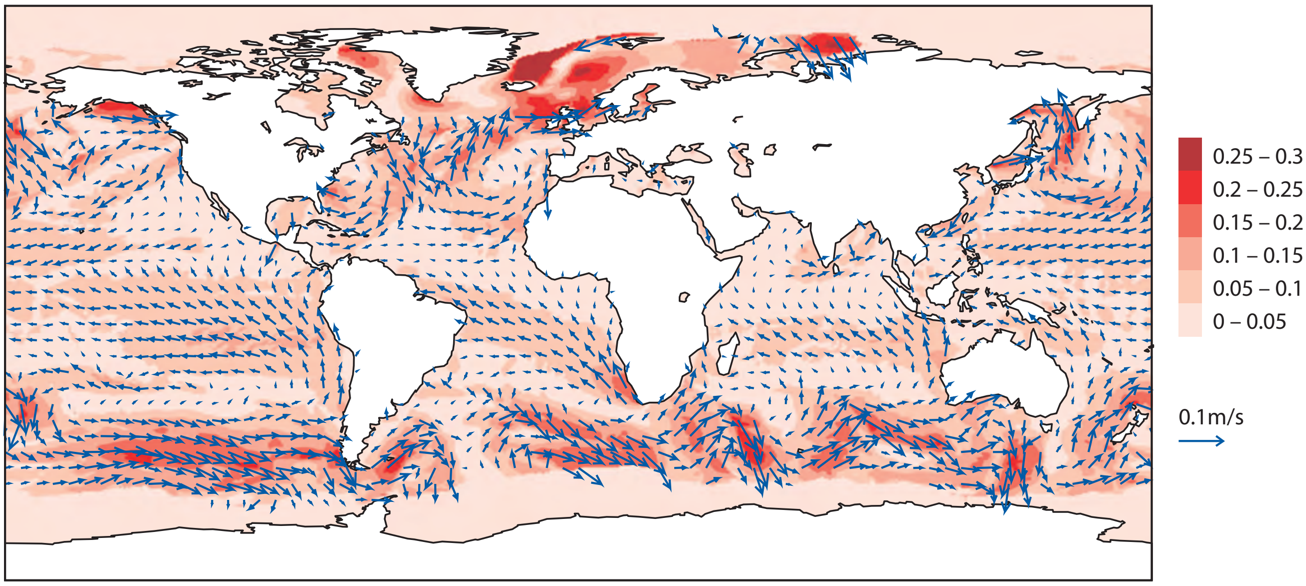


Figure 1 The Stokes drift calculated from the ECMWF forecast on 25 October 2008. We see that the Stokes drift is about 0.1–0.3 ms^{-1}. To first order there is essentially a linear relation between the Stokes drift and the significant wave height and a Stokes drift of 0.3 ms^{-1} corresponds to a significant wave height of about 8 metres.

In operational drift models, the Stokes drift component is often parametrized from the wind speed. However, in some cases, such as the met.no oil drift system (Oil Drift in 3 Dimensions, OD3D), the Stokes drift is taken directly from a wave model. In that case the strength and direction of the Stokes drift can be calculated directly from a two-dimensional wave spectrum provided by an ocean wave model.

Currently, the Stokes drift is not a product routinely delivered by the ECMWF system. Since this is a required component of the met.no marine drift model, the calculation of the global Stokes drift from the ECMWF wave spectra was implemented by met.no under the MERSEA project for use in a global service. To calculate the Stokes drift the full two-dimensional wave spectra are needed. Under met.no's Member State account at ECMWF a routine has been set up that retrieves the wave spectra and performs the calculations. Twice daily, five day forecasts of global 6-hourly Stokes drift are then computed and transmitted to met no via an automatic ftp routine and provided as forcing to the marine drift forecasting system. It is our opinion that this might be a potentially valuable product for other Member States and therefore we suggest that Stokes drift is introduced as an operational product at ECMWF. Figure 1 shows an example of a global Stokes drift forecast based on the ECMWF wave spectra.

From a forecast/nowcast point of view, atmospheric winds are described with rather good accuracy. This is because there are a variety of atmospheric observations covering the dynamical scales of atmospheric flow. Waves depend essentially on the wind speed: as the wind speed (and direction) is accurately forecast, waves will also be described in a satisfactory way. Due to lack of oceanographic data for constraining the oceanic eddy field, it is generally the forecast of the oceanic current field that is the weakest point in the forecast model for floating objects and oil.

Returning to the question of the Stokes drift, we know that a large part of the drift in the upper ocean is due to the Stokes drift. Also, we expect to have a good forecast of the Stokes drift. It therefore seems to be advantageous to use this forecast together with the currents from the ocean model. However, standard ocean models are not based on a correct separation of the Stokes drift and Eulerian ocean currents (i.e. the momentum flow from the atmosphere is not separated into wave and Eulerian mean momentum in the ocean model), and in principle we would need an improved ocean model to separate ocean currents into Stokes drift and Eulerian mean motion. This has, however, not been done in the present forecast system albeit we are working on developing a more consistent wave-mean flow ocean model system.

An example of an oil drift forecast

On 12 December 2007 there was a large accidental oil spill (4,400 tons) from the Stafjord A platform in the Norwegian Sea (near 61.3°N, 1.9°E). The cause of the accident was a large-diameter loading hose that ruptured during the filling of an oil tanker. On the day of the accident the weather was relatively severe; the Statfjord A platform reported wind speed of 45 knots from the south and a wave height of about 7 metres though the forecast values of wind and wave height were somewhat lower. The heavy seas and strong winds persisted for the following days and caused the oil to separate into drifting streaks (see Figure 2); note that the oil drift is north-eastwards in the direction of the waves.

The severe weather had a strong influence on the oil spill so much of it evaporated very quickly, and the remaining oil dispersed quickly in the horizontal as

Figure 2 Aerial photo of the Statfjord A oil slick on 12 December 2008. In the lower left corner is the loading buoy, while the Statfjord A platform is near the centre of the photo. (Photo: Kystverket/Scanpix)

well as being mixed down in the upper ocean. By 14 December the oil slick had been reduced so much that all remedial action was cancelled by the authorities, and by 16 December the oil spill was no longer detectable from ships or by flight recognisance.

met.no was responsible for the initial forecast of the oil drift, and within 30 minutes from the first call a forecast by the OD3D system was delivered to the authorities and NOFO. Figure 3 shows some drift forecasts.

- ◆ ***met.no Nordic4***. This drift forecast used prognostic forcing data from the in-house atmospheric model HIRLAM, ocean model MIPOM (Meteorological Institute POM model), and the met.no wave model based on the WAM model.

In addition to the standard forecast several alternative forecasts were produced as part of the Mersea Integrated Project (www.mersea.eu.org). These simulations used the ECMWF global forecasts for atmospheric wind and Stokes drift and three different ocean current data sets.

- ◆ ***Mercator Global***. Forecast using OD3D drift model forced by the global model run by the MERCATOR ocean forecast system (www.mercator-ocean.fr).
- ◆ ***Mercator N. Atlantic***. Forecast using OD3D drift model forced by North Atlantic model run by the MERCATOR ocean forecast system.
- ◆ ***met.no Bio4***. Forecast using OD3D drift model forced using a second version of MIPOM.

In Figure 3 we see that the net forecast drift is to the east or north-east in all simulations. There were a few observations on the actual movement of the oil slick, and these show that the main oil drift was in the eastward direction with a large dispersion in north-south direction. One interpretation is that the oil at the surface moves north-eastward (due to Stokes drift; note that the oil at the surface moves in the direction of the waves in Figure 2) while the oil dispersed in the water column moved south-eastward with the ocean currents. It is clear that the Stokes drift has a big influence since the Stokes drift is of the same magnitude as the ocean currents at the sea surface. As a final comment we note that the local met.no operational model gave the best results and this is in agreement with the main results from the MERSEA study. However, the 'imported' models provided good forecasts and will thus complement the local model; we now have some confidence in using these models outside the domain of the local model.

The differences between the oil drift predictions are mainly due to the use of currents from different models. As the different forecasts give similar results, the OD3D forecast appears to be robust. This proved to be important information for the operator responsible for the forecast, and for the authorities responsible for the action.

Discussion

In this short communication we have described some new developments that have taken place within the European community regarding the drift of objects and oil at sea. The development focuses on (a) sharing forecasts made at different national centres to provide an ensemble forecast and (b) a widening of the forecast product range to include areas beyond the national responsibility. One challenge is to go to the global scale; another challenge is to be able to use a variety of data from different forecast centres and to find the most

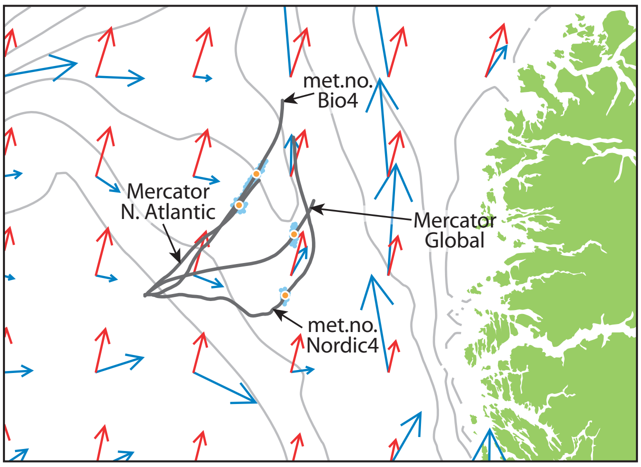


Figure 3 Example of model ensemble forecasts for the Statfjord A incident on 0900 UTC on 12 December, 2007. *met.no Nordic4* is met.no's drift model in standard configuration (i.e. the local Princeton ocean model with 4 km resolution, a local version of the WAM model for the Stokes drift, and winds from the HIRLAM model); note that this simulation ends at 1200 UTC on 19 December. *met.no Bio4* is a version of Nordic 4 that uses winds and waves from the ECMWF global operational forecast. *Mercator Global* and *Mercator N. Atlantic* are $\frac{1}{4}$° and $\frac{1}{15}$° MERCATOR operational models that use winds and Stokes drift taken from the ECMWF global forecast. Grey curves show the mean trajectories up to 0000 UTC on 17 December (1200 UTC on December 19 for Nordic 4). Clouds of purple dots (the model is set up using many particles that are advected with currents and also describes a random walk) represent the oil slicks at 1600 UTC on 16 December (about 3.5 days after the spill). Red dots are the mean position of oil particles at the same time as the purple clouds. Blue arrows are examples of surface currents from the Mercator N.Atl model. Red arrows are the Stokes drift from the ECMWF WAM model.

reliable model for a given region. It is clear that major atmospheric centres such as the ECMWF will play a crucial role for such developments as they can provide atmospheric and wave forecast data for regions where national centres do not operate.

We also point to the 'new' product for calculating the Stokes drift provided by ECMWF. This is not routinely incorporated into drift models, but we advocate using the Stokes drift as it is a reliable forecast product that will probably enhance the forecast of drifting objects and substances. At present, the basic spectral data used to calculate the Stokes drift are only available up to day 5 of the forecast. Since all other the global forcing data sets applied in this study extend to at least day 10, it is the availability of wave data that limits the forecast period for global marine drift forecasting to five days.

Record-setting performance of the ECMWF IFS in medium-range tropical cyclone track prediction

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In November 2007 a number of significant changes in model physics were introduced in Cycle 32r3 (Cy32r3) of the ECMWF Integrated Forecast System (IFS), most notably a reformulation of convective entrainment. The net result was a "beneficial increase in activity" in the tropics (*ECMWF*, 2009) and such parametrization changes are known to have substantial impacts on forecast skill in the convectively-forced components of the tropical circulation and tropical cyclones (TCs) in particular.

The primary forecast aid in operational TC track forecasting is *consensus*, produced from an ensemble of quasi-independent deterministic model runs. Since Cy32r3, ECMWF's TC track forecasts at the medium-range (72 hours or day 3) have been ~20% *better* than model consensus globally. No individual model has ever consistently out-performed consensus by such a large margin. If this skill gain continues, it would mark a major breakthrough in TC track prediction, greater than the 100% improvement in official forecasts from the mid 1990s to 2008 that came from advanced global models.

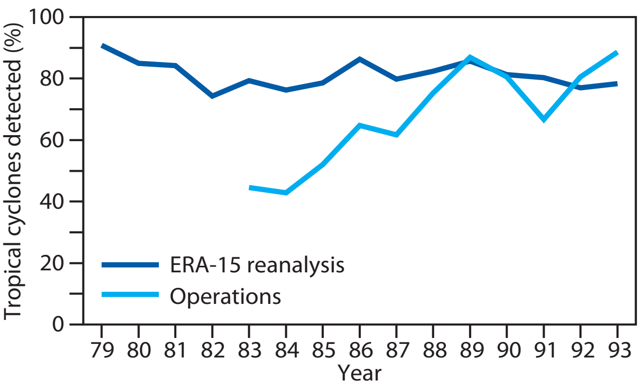

Figure 1 Detection of tropical cyclones (maximum wind > 34 knots) in the northern hemisphere for the ECMWF ERA-15 reanalysis (dark blue line) and operations (light blue line).

This article reviews:

- The relationship between model physics, TC analysis and forecasts and the tropical general circulation.
- Dynamical medium-range TC track prediction and the role of multi-model consensus.

Some personal views about the implication of these results for medium-range TC track prediction are given in the conclusion, as the primary objective of the study was to better understand the critical modelling factors.

Tropical large-scale flow, TCs and model changes

Tropical cyclones are not only the greatest high-impact weather event in the tropics, but can be an excellent indicator of general model performance.

For example, one of the more remarkable results from the first ECMWF reanalysis (ERA-15) was the strong dependence of the analysis of TCs on the model, rather than the observations as shown in Figure 1 taken from *Serrano* (1998). The ERA-15 analysis consistently detects about 85% of observed TCs from 1979-1994, but the operational ECMWF model only reaches that detection rate in 1989. The primary difference between the operational and ERA-15 analysis is the model and data assimilation scheme, as the reanalysis used essentially the same observations as in operations. The poor quality of the operational model analysis of TCs was not caused by insufficient observations, but by the modelling.

Next consider changes in the standard ECMWF tropical wind forecast skill score for the period 1980-2008 shown in Figure 2. Comparing this smoothed time series (red line) to TC detection in operations (light blue line in Figure 1), we see a strong correlation between TC detection and the 850 hPa tropical wind forecast score (*ECMWF*, 2008). Similar correlations have been found in the NCEP-NCAR reanalysis and in the second ECMWF reanalysis, ERA-40 (*Uppala et al.*, 2005).

A detailed review of model changes (not given here) suggests that the big jump in tropical forecast skill in 1989 was not due to resolution increases, but more likely

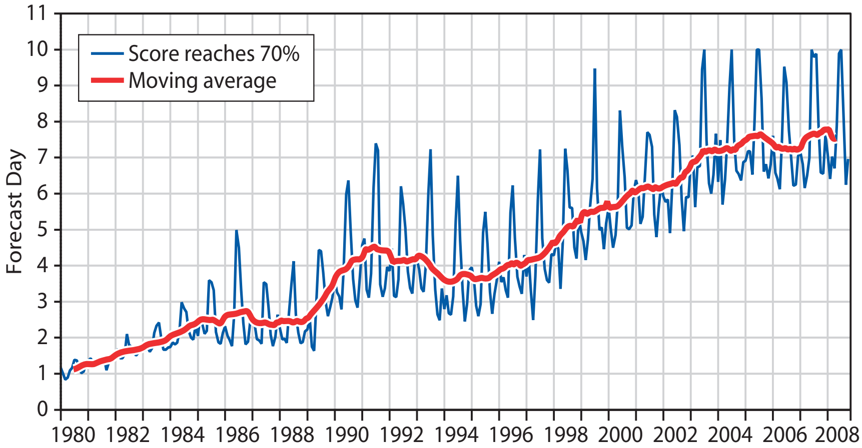

Figure 2 Tropical skill score indicating time in days when the correlation between the analyzed and forecast 850 hPa winds at 12 UTC in the tropics (20°N to 20°S) drops to 70%. Blue line is the monthly score and the red line is the 12-month moving average.

from the use of a mass-flux cumulus convection scheme.

Another important feature in Figure 2 is the near 100% improvement in the score from four days in 1995 to seven days in 2005. This improvement can be attributed to the implementation of 3D-Var and 4D-Var in the mid 1990s and general model development, i.e. steady improvements in global numerical weather prediction (NWP). By 2004, the ECMWF deterministic TC track predictions became competitive with the best models of the day, both for global (UK Met Office, NOGAPS and NCEP GFS) and limited-area (GFDL) models, as demonstrated for the Atlantic in Figure 3. Details about these models are given in Table 1.

The strong correlation of the tropical wind score and TC track prediction has also been found with other models and in the reanalyses. This correlation is consistent with our understanding of the dynamics of tropical cyclone motion (*Fiorino & Elsberry*, 1989) and its dependence on the global/large scales of the tropical general circulation. Not only are TCs high-amplitude weather events that challenge a model and push the physics to the limit, but TC track prediction is consistent with other measures of the quality of the large-scale tropical wind field.

Medium-range TC track prediction and multi-model consensus

The large improvement in the ECMWF tropical wind score circa 1990 also marked the beginning of a period of unprecedented gain in dynamical TC forecast skill; that resulted in a near 100% improvement in official TC track predictions from the early 1980s to early 2000s, especially at the 72-hour forecast time or the 'medium-range'.

There are many reasons to focus on the medium range, both operational and in a modelling sense, but the main reason for concentrating on the 72-hour forecast is because of its value as a model diagnostic. Simply put, the model has to 'get everything right' to make a good medium-range track forecast.

By three days into the integration, the model has lost a strong connection with the initial conditions and even a perfect analysis cannot prevent intrinsic model error growth and chaos from causing significant error (~20%) in the solution. Furthermore, TCs are observed to make substantial changes in direction and speed of motion in three days. This change often results from the interaction of the vortex with mid-latitude features such as a break in the subtropical ridge. Thus, model track skill depends on both the forecast of the large-scale 'steering' flow and on vortex-large scale interaction that itself

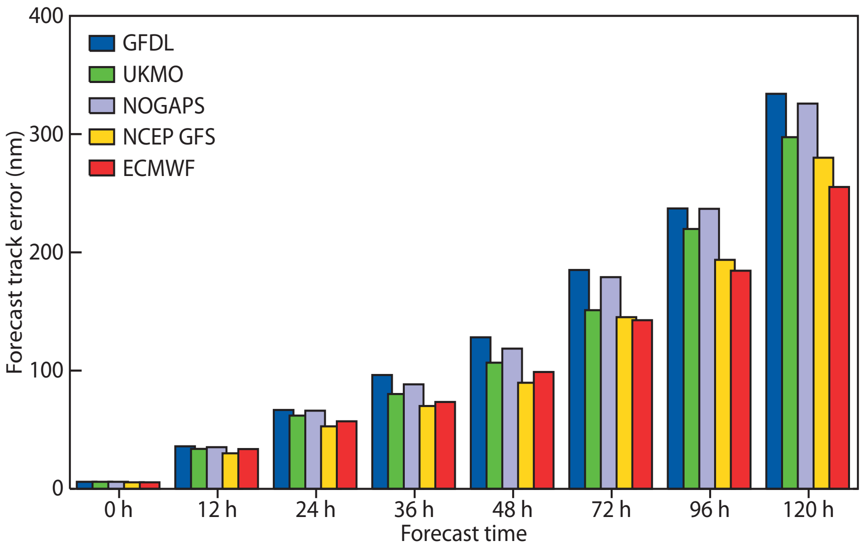

Figure 3 ECMWF track forecast error in the Atlantic basin for 2004, compared to GFDL, UKMO, NOGAPS and NCEP GFS. All raw model output has been post processed in the same way as at the US operational forecast centres. Statistics are homogeneous with ECMWF.

Source	Description
NHC or OFCL	The official track forecast made by the hurricane specialists of the National Hurricane Center (NHC), Miami, Florida, USA.
NOGAPS	US Navy global model; first formal evaluation in 1994 by Joint Typhoon Warning Center (JTWC), Pearl Harbor, Hawaii, USA. From 1992–2001 available twice daily and then four times daily from 2002-2008.
GFDL	Geophysical Fluid Dynamics Laboratory (GFDL) hurricane model run at NCEP. Very few cases in 1992-1993 and run twice daily 1994–1999.
ECMWF	ECMWF global model, deterministic 10-day integration.
UKMO	UK Met Office Unified Model, global operational version. Available 1996-2008 in the Atlantic and 1991-2008 in western North Pacific (WPAC). Model run twice daily at 00 and 12 UTC.
NCEP GFS	US National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) model.
CLIPER	CLlimatology and PERsistence no-skill statistical model.
BCON	Best/Baseline model CONsensus made at the operational forecast centres.

Table 1 Description of the TC track data from NHC and various models.

depends on changes in the vortex, i.e. the model has to forecast well both vortex and synoptic scales.

For global models, the dynamics of vortex/large-scale flow interaction critical to motion occurs on scales resolved by large-scale models (*Fiorino & Elsberry*, 1989). Thus, high resolution (~10–20 km) is not an *a priori* requirement for skilful medium-range TC track forecasts as indicated by the excellent performance of the global models.

Another milestone in medium-range TC track prediction was when the ECMWF tropical wind score reached seven days in 2003. This milestone coincided with the first operational application of multi-model consensus forecasting in which an ensemble of quasi-independent deterministic model runs are combined to produce a consensus forecast. While a number of schemes for combining the forecasts have been used, a simple average of the tracks has proven as successful as, or better than, more elegant approaches.

The skill of consensus depends on two key factors: (a) the degree of decorrelation of the errors between the individual models and (b) all members must have skill similar to, or close to, the best model (*Goerss*, 2000). The important result from operations is that in the mean, consensus generally has more skill than any of the individual model used in the consensus.

Trends in the Atlantic basin

The discussion points in the preceding section are illustrated in Figure 4 where we show a time series of the annual-mean 72-hour forecast error (great circle distance between observed 'best track' position and the model forecast) for two representative 'best' models (GFDL and UKMO), CLIPER (the standard no-skill climatology and persistence aid), BCON (best/baseline multi-model consensus aid) and the official National Hurricane Center (NHC) forecast (Table 1 gives details on the models).

In the Atlantic basin, the most consistently skilful model with a long record is the GFDL hurricane model (*Bender et al.*, 2007), but before discussing the models and consensus note the variation in the error of the climatology aid CLIPER. There is a notable downward trend and an oscillation with a roughly 10-year period. A lower CLIPER error implies the hurricanes are behaving in a more climatological manner. However, the CLIPER model was updated in 2000 and the forecast extended from 72 hours to 120 hours, so that part of the change is because of the improved TC databases used in the model development. Nonetheless, there seems to be a downward trend from 2000 to 2007, but a rise in 2008. The significance of the rise is that before 2008, the

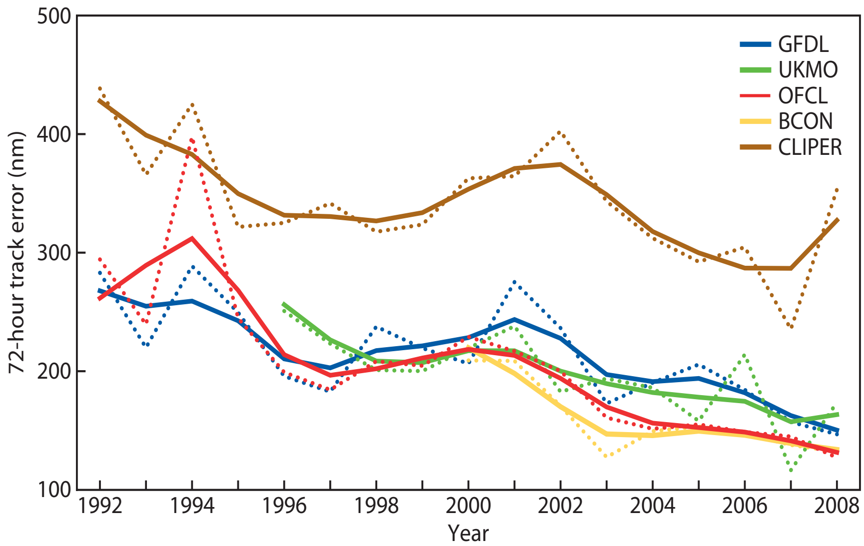

Figure 4 Medium-range (72 hour) mean forecast error in the Atlantic basin for the years 1992–2008 for: a "best" dynamical model (GFDL – blue); the UKMO global Unified Model (UKMO – green), the best/baseline consensus (BCON – yellow), the official NHC forecast (OFCL – red) and the no-skill baseline aid (CLIPER – brown). The solid line is a smoothed version of the dotted time series. The dynamical model track was post-processed to be consistent with operations and the other aids. BCON is only available from 2000 to 2008 and the statistics are homogenous with CLIPER.

model and consensus error tended to generally follow CLIPER, but in 2008 model error moved downward despite TC motion being less climatological than in previous years.

From 1992 to 1997 the GFDL model had lower error than the official NHC forecast. However, the number of cases was very small in 1992 and 1993 since the model was still experimental, but by 1995 the model had high availability to the forecasters and was run twice daily. Since 2000, the GFDL model is run at the same frequency as the official forecasts – four times daily. The larger point is not that the GFDL model 'beat' the official human forecasts, but that the model showed skill and that the forecasters were able to successfully use the guidance.

Notice how the models show more year-to-year variability until 2004 when the ECMWF tropical score reached seven days. Skill consistency is perhaps the result of the 'stability' (smaller run-to-run variability) a large observing system gives the global model. This stability is significant for the limited-area GFDL model as the global model (NCEP GFS) provides both initial and lateral boundary conditions that determine the large-scale flow in the outer grid of the GFDL model.

Another feature in Figure 4 is how both the models and the official forecast error slowly vary in a similar manner as CLIPER: rising in the early 2000s and then falling until 2007–2008. The main use of CLIPER is to measure forecast difficulty as high CLIPER errors imply that the TCs did not behave in a climatology manner for that year. If model skill did not follow CLIPER upward in 2008, then the global model analysis may have had even higher quality than in previous years.

The main point is that model and official forecast skill is much greater than CLIPER, with a clear downward trend in the error of both, and that the official forecast is slightly lower than the models. Consequently, from 1992 to 2008 the official forecast error has been cut in more than half from 294 nm (nautical miles) to 127 nm – a greater than 100% improvement. The GFDL model improvement over that time period was not as dramatic, but consensus (BCON) was better than the model and on par with the NHC forecast. Similarly, the track forecasts of the UK Met Office (UKMO) global model show a similar trend.

An alternative view of the error statistics is to calculate a percentage gain or improvement against some baseline as shown in Figure 5. The standard comparison baseline is CLIPER with positive values indicating how much better (lower) the mean forecast error is relative to the baseline (*Franklin*, 2008). The general improvement trend is less pronounced over the 17-year period, but what is more interesting is how the model and consensus are becoming even better vis-à-vis CLIPER from 2006–2008 to over 50%.

To bring the comparison into sharper focus we use the consensus aid BCON as the baseline instead of CLIPER in Figure 6. Clearly the GFDL model is not as skilful as BCON and is ~25% worse. The results from the UK Met Office model are similar to those of the GFDL model, but with much larger year-to-year swings. However, the +16% gain on BCON in 2007 is not significant because of very few cases/storms in the Atlantic for that year. Statistical significance is not addressed here as our purpose is to examine broad trends and relationships (more cases) and not to focus on year-to-year differences.

The degree of degradation varies with the model and year, but what we do not find is a model that is consistently better than consensus at 72 hours. A model can outperform consensus only if it has much lower error than its peers. That is, skill does not come from error compensation, but from better meteorology - good results for physically more-correct reasons.

The main conclusion of this review of medium-range dynamical TC track prediction is that while the models/consensus have steadily improved, no individual model or single deterministic run has ever been more than 10% better than consensus in any one year or any one basin, and on a 5–10 year time scale the individual models are typically 15–20% worse.

Dependence of ECMWF track prediction skill on model changes

We now consider two recent changes to the ECMWF model that would be expected to affect TC track prediction – increased horizontal resolution and improved model physics, especially convection. In February 2006, model resolution increased from T511 to T799 or approximately from 40 km to 25 km. The second change concerns the cumulus parametrization in November 2007.

We collected about one year of TC forecasts before and after each model change to determine if there are detectable impacts on medium-range track prediction. The period between the resolution increase to T799 (February 2006) and the physics change (November 2007) is 21 months and includes two northern hemisphere TC seasons and one for the southern hemisphere. However, the number of northern hemisphere cases in this longer period is not much greater than in the one-year periods because of unusually weak TC activity in 2007. Details of the periods and model

Period	Model changes	Number of cases at 72 hours
February 2005–February 2006	T511 resolution (~ 40 km)	400
February 2006–November 2007	T799 resolution (~ 25 km)	460
November 2007–January 2009	T799 resolution plus modified cumulus convection	432

Table 2 The three time periods considered and main characteristics of the ECMWF model.

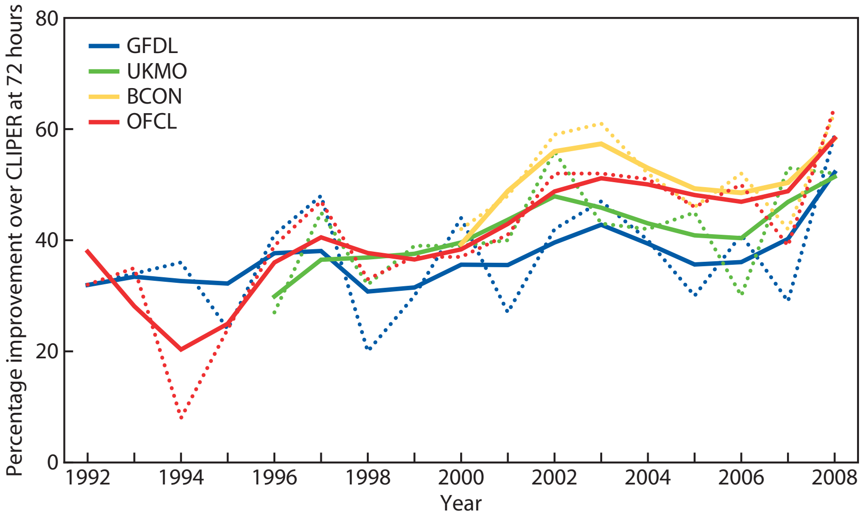

Figure 5 Gain or percentage improvement of forecast error at 72 hours of the GFDL model (blue), UK Met Office model (UKMO – green), concensus forecast (BCON – yellow) and the official NHC forecast (OFCL – red) relative to CLIPER. The solid line is a smoothed version of the dotted time series. Positive values indicate lower forecast error than CLIPER.

changes are given in Table 2, but note that number of verifiable model forecast at 72 hours is similar. Thus, intercomparison between the three periods is not overly biased by differences in number of cases.

The mean forecast error at the standard forecast times for the ECMWF model versus best/baseline consensus, BCON, for all TCs is given in Figure 7. The lower error for the model versus consensus after the physics change is apparent at each forecast time (i.e. compare the difference between the dark and light green bars with that between the dark and light yellow bars). However, showing relative gain makes the difference clearer as seen in Figure 8. The percentage gain/loss of the ECMWF model versus consensus is calculated in the same way as in Figures 5 and 6, but here

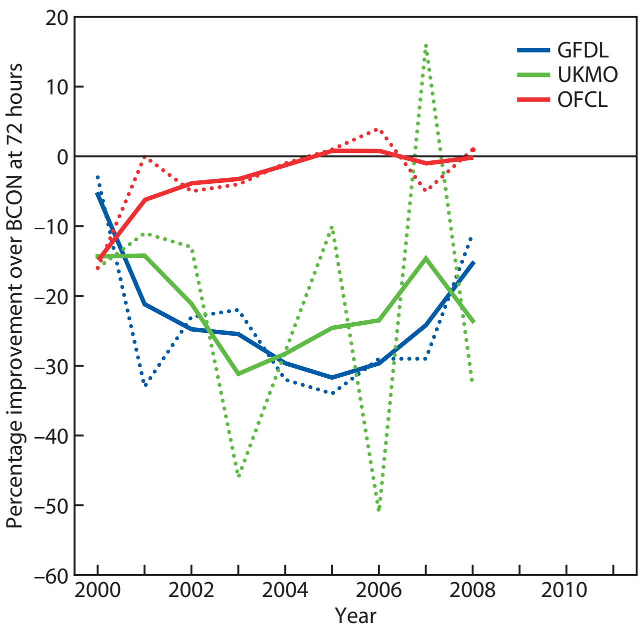

Figure 6 As in Figure 5 but for the percentage improvement of forecast error at 72 hours of the GFDL model (blue), UK Met Office model (UKMO – green) and the official NHC forecast (OFCL – red) relative to consensus (BCON). The solid line is a smoothed version of the dotted time series. Negative values indicate the aid is poorer (higher forecast error) than the baseline.

for three versions of the ECMWF model, again for all TCs globally.

First note how the T511 version of the model was about 20–15% worse (higher mean forecast error) than BCON at all forecast times. This relationship with consensus is typical or slightly better than the best models in the Atlantic (Figure 6) that are 15–25% poorer.

The resolution increase to T799 (yellow versus red bars) shows a distinct improvement in relative skill, particularly at the medium-range, so that by 120 hours the model was on par, or better than consensus. The gains at the longer forecast times likely come from model improvements (e.g. slower error growth).

The 15–20% *gain* after the physics changes in Cy32r3 (green versus yellow bars) is simply unprecedented and indicates a fundamental advancement in performance for the ECMWF model. The gains at the short-range are particularly impressive and imply an improved analysis as well as a better model.

An important requirement for successful data assimilation is small differences between high-quality observations and the model forecast background (the innovation). A model that makes a short-range forecast (typically six hours) close to these good observations will produce smaller innovations and thereby there is a higher probability the observations will make a positive contribution to the model analysis and forecasts. Simply put, the better the model, the smaller the innovations and the better the analysis/forecast, especially in the short-range (12–36 hours for TCs).

The model changes in November 2007 resulted in a fundamental improvement on scales/meteorology significant to TC track prediction, but the tropical wind score shows only a modest jump in 2007 (Figure 2). While the tropical skill measure does detect fundamental quality, the TC results suggest a more comprehensive metric is needed and that TCs measure another dimension of model skill in the tropics.

The percentage gain was also calculated separately for the Atlantic and western North Pacific (WPAC) basins, though these results are not shown. The pattern

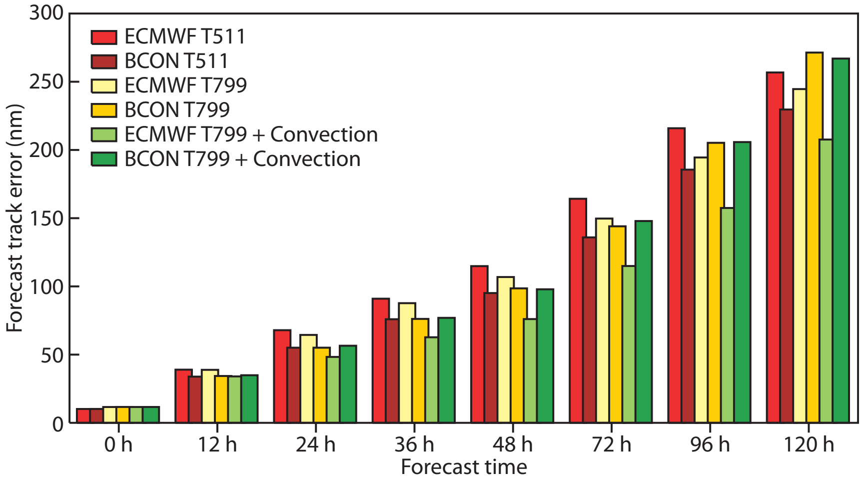

Figure 7 72-hour mean forecast error for all TCs globally for the ECMWF model and BCON for each time period for T511 (red bars), T799 (yellow bars) and T799 plus cumulus convection change (green bars).

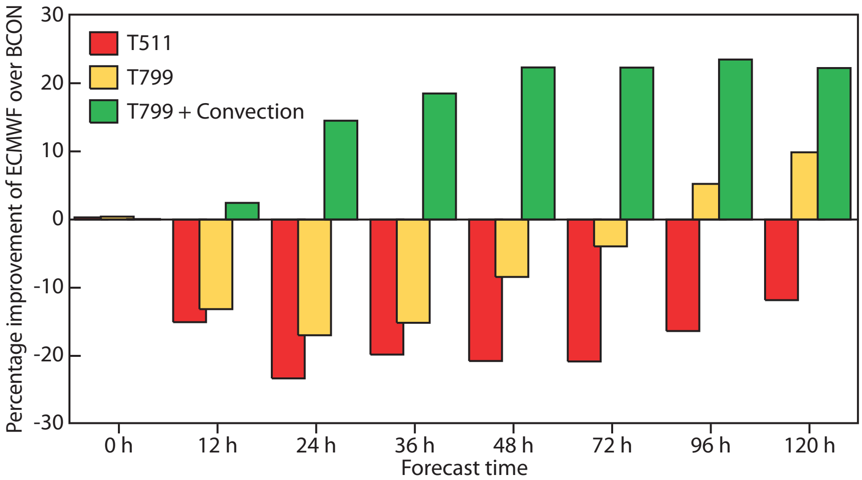

Figure 8 Percentage gain or improvement in 72-hour mean forecast error of ECMWF versus BCON for all TCs globally for T511 (red bars), T799 (yellow bars) and T799 plus cumulus convection change (green bars).

of change is similar to the global pattern of improvements at the longer forecast times with increased resolution, and the model better than consensus at all times with the physics change. However, the signal is much stronger in WPAC and even stronger in the southern hemisphere. The 20–30% gain in WPAC with the physics changes is more extreme than found globally and may be partly explained by a stronger influence of convection on the large scales in tropical WPAC.

The more muted response in the Atlantic may be a consequence of approaching an asymptote in skill as the mean 72-hour forecast error for BCON in 2008 was very low at 129 nm with the greatest-ever improvement over CLIPER at 63%. Despite these high levels of skill, the ECMWF model in 2008 achieved an even lower mean forecast error of 116 nm.

To put these statistics in perspective, consider the results from predictability studies, most notably of *Leslie et al.* (1998) where they used nonlinear systems theory and both a barotropic and baroclinic model to estimate 'inherent' predictability limits. At 72 hours all three techniques produced estimates of approximately 120 nm. There was some dependence on basin, but no more than 5%, so that the 120 nm mean forecast error is representative of a lower bound.

Leslie et al. (1998) also compared the estimates to the error of NWP models circa 1995 and found that the models were within 35–40% of the inherent limit. Clearly, this estimate is either too high or the ECMWF model is approaching the 'perfect model' as the model is performing below their limit. The weaker impact in the Atlantic is consistent with approaching a limit.

Summary of the results

We have examined recent trends in dynamical medium-range TC track prediction and the relative role of model resolution versus physics. The medium-range (day 3) was emphasised for two reasons: (a) any TC forecast aid must first make good track predictions before second-order properties such as maximum surface wind speed (intensity) can be considered in the official forecast (i.e. all aspects of the forecast must be physically reasonable and consistent) and (b) by 72 hours into the integration, model errors become dominant (i.e. a good analysis cannot overcome model errors).

The near halving in the mean 72-hour track forecast error for both the models and the official forecasts from ~300 nm in the mid 1990s to ~150 nm in the mid 2000s is a testament to the major advances in global NWP, especially in the modelling of the tropical general circulation.

A consensus, or simple averaging of the track forecasts from multiple, quasi-independent models, was found to have higher skill than any individual model and that the model was typically 20% worse at 72 hours than consensus. However, recent results from the ECMWF global model put this long-standing relationship into question.

In November 2007 significant changes were made to the ECMWF model physics, including the parametrization of cumulus convection. By comparing TC track forecasts before and after changes in the ECMWF model physics, we found a dramatic improvement in medium-range track skill, especially in the convectively more active, monsoon-trough TC basins of the western North Pacific and the southern hemisphere. The improvement in the Atlantic was less pronounced, possibly due to approaching an asymptote in skill as the model and consensus forecasts in 2008 had the lowest errors in history (*Franklin*, 2008) and were below predictability estimates from the 1990s. We also found that an increase in the ECMWF model resolution in February 2006 had a smaller impact.

Personal views about the implications for medium-range TC track prediction

The implication of these ECMWF model results for the future of TC track prediction and hurricane model forecast improvement are many fold and in my opinion strongly challenge conventional wisdom. The following personal views do not fully follow from the results presented, but represent my interpretation based on over 30 years of experience with TC NWP modelling.

The first notion is that high spatial resolution is a necessary or even a sufficient condition for TC prediction. For TC simulation, the inner core must be resolved, but in regards to motion, dynamical considerations (*Fiorino & Elsberry*, 1989) and the global model results indicate that the resolution of ECMWF model (~ 25 km) is adequate as this model outperformed both the higher-resolution global model (T959L60) of the Japan Meteorological Agency (*JMA*, 2008) and the limited-area models (e.g. GFDL) in 2008.

My second impression is that TC motion becomes a global problem sooner than may have been previously thought. Consequently, by 72 hours small changes in the large-scale, far from the storm, have a significant effect on track, and that global-scale information must be *accurately* communicated into a limited-area model. However, the lateral boundary conditions cannot be mathematically formulated to perform this communication accurately (*Harrison & Elsberry*, 1972). Indeed, even if it were possible, there would be still be a 'physics' barrier because of differences in the parametrizations/physics between the global and limited-area model.

The most accurate approach to high-resolution TC modelling is either a cloud-resolving global model or a two-way interactive nest inside a global model, as opposed to one-way influence of a separate global model on a different limited-area model. The forecast time at which global-scale errors significantly degrade the limited-area model solution could be as early as 48 hours, in which case running such one-way influence models past 48 hours is counter-indicated.

The consensus approach to deterministic forecasting has been very successful over the last nine years and has motivated the application of single- and multi-model ensemble systems to improve consensus by adding solutions with higher skill and greater error decorrelation. However, the ECMWF model was 20% *better* than consensus *globally* in 2008 – a staggering achievement for an NWP model. Hitherto, the models were 20% *worse*. My third suggestion is that the path to better forecasts may not lie in multi-model ensembles, and that we must better understand how the ECMWF model broke through the 1990s predictability limits to find a way forward.

Fourthly, the reasonable assumption that skill, especially for intensity, is critically dependent on the analysis of the TC vortex is debatable. ECMWF is the only operational NWP centre that makes no TC-specific adjustments to the analysis of the TC wind structure. Other modelling systems use either synthetic observations or wholesale vortex replacement. One explanation why the ECMWF 'less-is-more' approach yields better TC track forecasts is that external vortex specification distorts the larger-scale flow around the cyclone and thereby adds error, albeit small, on scales that vortex motion is sensitive. In the current era of a huge observing system and accurate models, small errors do matter, and identifying the critical aspects of the TC vortex analysis problem will be more challenging.

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Special Project computer allocations for 2009–2011

The allocations for 2009 have been approved. The figures for 2010 and 2011 indicate what has been requested.

Member State		Institute	Project title	2009		2010		2011	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Continuation Projects									
Austria	1	Univ. Graz (Kirchengast)	Climate monitoring by advanced spaceborne sounding and atmospheric modelling	30,000	300	30,000	300	30,000	300
	2	Univ. of Natural Resources and Applied Life Sciences, Vienna (Seibert)	Modelling of Tracer Transport (MoTT)	30,000	100	30,000	100	30,000	100
	3	Univ. Vienna (Steinacker)	MESOCLIM – Mesoscale alpine climatology	4,960	16	4,960	16	4,960	16
Belgium	4	MUMM (Ponsar)	Data assimilation in high-resolution hydrodynamic and ecological forecasts of the North Sea	120,000	700	120,000	700	120,000	700
Denmark	5	DMI (Amstrup)	Data impact studies in HIRLAM	900,000	6,000	900,000	6,000	500,000	5,000
France	6	CNRM/GMAP, Météo-France (Fischer)	Investigation of coupling the ALADIN and AROME models to boundary conditions from ECMWF and ERA model data	30,000	800	30,000	800	30,000	800
	7	CERFACS (Rogel)	Seasonal to inter-annual predictability of a coupled ocean-atmosphere model	10,000	150	10,000	150	10,000	150
	8	CERFACS (Weaver)	Variational data assimilation with the OPA OGCM	150,000	2,000	150,000	2,000	150,000	2,000
Germany	9	MPI, Mainz (Baumgärtner)	Solar effects in an Earth-System-Model simulation for 1960–2006	1,200,000	1,500	1,200,000	1,500	1,200,000	1,500
	10	MPI, Hamburg (Bengtsson)	Numerical experimentation with a coupled ocean/atmosphere model	304,000	800	350,000	850	400,000	900
	11	Univ. Frankfurt (Casanova, Ahrens)	Combination of seasonal forecasts by BMA	500	200	500	200	x	x
	12	FU Berlin (Cubasch, Kirchner)	Investigation of systematic tendency changes and their influence on the general circulation simulated with climate models	20,000	1,500	20,000	2,000	20,000	2,000
	13	ISET (Czisch)	Evaluation of the global potential of energy towers	100	20	100	20	100	20
	14	DLR (Dörnbrack)	Influence of non-hydrostatic gravity waves on the stratospheric flow field above Scandinavia	150,000	80	150,000	80	150,000	80
	15	DLR (Dörnbrack)	Support tool for HALO missions	50,000	80	50,000	80	50,000	80

Member State		Institute	Project title	2009		2010		2011	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Germany	16	Univ. Munich (Egger)	Landsurface-atmosphere interaction	150	10	150	10	150	10
	17	Univ. Cologne (Elbern)	GEMS: work package WP_RAQ_2	1,700,000	10,000	2,200,000	10,000	2,200,000	10,000
	18	DLR & MPI Chemistry, Mainz (Eyring, Steil)	Impact of anthropogenic emissions on tropospheric chemistry with a special focus on ship emissions	400,000	4,000	400,000	4,000	400,000	4,000
	19	MPI, Hamburg (Feichter)	Climate impact of specific economic sectors	350,000	1,200	X	X	X	X
	20	Univ. Köln (Fink)	Interpretation and calculation of energy budgets	120	15	120	15	150	20
	21	DLR (Gierens)	Ice-supersaturation and cirrus clouds	200,000	100	200,000	100	200,000	100
	22	MPI, Hamburg (Hagemann)	Regional downscaling of ERA-40 data and validation of the hydrological cycle	580,000	4,600	660,000	5,400	740,000	6,200
	23	DLR (Hoinka)	Climatology of the global tropopause	500	10	500	10	500	10
	24	MPI, Hamburg (Jacob)	Regional ensemble prediction	84,000	6,500	92,000	7,500	104,000	8,500
	25	Univ. Karlsruhe (Jones)	The impact of tropical cyclones on extratropical predictability	300,000	400	300,000	400	300,000	400
	26	MPI, Hamburg (Jungclaus)	Community simulations of the last millennium (COMSIMM)	600,000	3,000	600,000	3,000	x	x
	27	DLR (Keil, Craig)	Ensemble modelling for the improvement of short range quantitative precipitation forecasts	120,000	150	120,000	150	120,000	150
	28	Univ. Karlsruhe (Kottmeier)	Mesoscale modelling using the DWD Lokal-Modell	10,000	0	10,000	0	10,000	0
	29	FU Berlin (Langematz)	Chemistry-climate model simulations for WMO ozone assessment	830,000	4,000	10,000	1,000	10,000	1,000
	30	Leibniz-Institut, Univ. Kiel (Latif)	Seasonal to decadal forecasting with coupled ocean-atmosphere general circulation models	1,070,000	7,000	1,000,000	7,000	1,000,000	7,000
	31	IMK-IFU (Laux)	Statistical analysis of the onset of the rainy season in the Volta Basin (West Africa)	0	10	0	10	0	10
	32	DLR (Mayer)	Remote sensing of water and ice clouds with Meteosat second generation	20,000	20	20,000	20	20,000	20
	33	Ruhr-University Bochum (Pahlow)	Optimisation of water management by using ensemble forecasts	30,000	3	25,000	3	X	X
	34	Alfred Wegener Institute, Potsdam (Rex)	Ozone and water vapour transport with the residual circulation	200	200	200	200	X	X
	35	Alfred Wegener Institute, Potsdam (Rinke)	Sensitivity of HIRLAM	100	10	100	10	100	10
	36	FZ Jülich (Schultz)	Global atmospheric chemistry modelling	500,000	9,000	600,000	10,000	700,000	11,000
	37	FU Berlin (Ulbrich, Leckebusch)	Investigations of storms in forecasts, hindcasts and climate model simulations on daily to seasonal and climatological timescales	5,000	1,500	5,000	2,000	5,000	2,000

Member State		Institute	Project title	2009		2010		2011	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Germany	38	Univ. Bremen (Weber)	Chemical and dynamical influences on decadal ozone change (CANDIDOZ)	20	20	20	20	20	20
Germany	39	Univ. Mainz (Wirth)	Water vapour in the upper troposphere	1,000	20	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)	300,000	1,500	300,000	1,500	300,000	1,500
Ireland	41	Met Éireann (Wang)	Changes in the North Atlantic climate and impacts for Ireland	50,000	1,000	50,000	2,000	50,000	3,000
Italy	42	CNMCA (Bonavita, Torrisi)	Limited area ensemble Kalman filter	1,200,000	500	1,400,000	500	1,800,000	500
Italy	44	CNMCA (Bonavita, Torrisi, Marcucci)	EUCOS observing system experiment (EUCOS-OSE)	700,000	500	700,000	500	700,000	500
Italy	44	ISMAR-CNR (Cavaleri)	Evaluation of the performance of the ECMWF meteorological model at high resolution	250,000	200	250,000	200	X	X
Italy	45	ARPA-SIM (Di Giuseppe, Marsigli)	Flow dependent error statistic for satellite data assimilation in regional model (FEAR)	1,000,000	150	1,000,000	150	1,000,000	150
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	4,000	30	4,000	30	4,000	30
Italy	47	ISAC-CNR (Maurizi)	GEMS: BOLCHEM	90,000	120	X	X	X	X
Italy	48	ARPA-SMR Emilia Romagna, & UK Met Office (Montani, Mylne)	Limited area ensemble forecasts of windstorms over Northern Europe	900,000	120	920,000	140	950,000	160
Italy	49	ARPA-SMR Emilia Romagna & MeteoSwiss (Montani, Walser)	Improvements of COSMO limited area ensemble forecasts	720,000	450	750,000	500	800,000	550
Italy	50	ARPA-SMR Emilia Romagna & Italian Met. Service (Paccagnella, Montani, Ferri)	Limited area model targeted ensemble prediction system (LAM-TEPS)	710,000	700	800,000	800	900,000	900
Italy	51	Univ. Genova (Parodi)	High resolution numerical modelling of intense convective rain cells	50,000	200	50,000	200	50,000	200
Italy	52	ARPA-SMR Emilia Romagna & UCEA (Pavan, Esposito)	Seasonal prediction for Italian agriculture (SPIA)	10	100	10	100	10	100
Italy	53	CNMCA (Zauli, Torrisi)	Tuning COSMO-ME to H-SAF requirements	1,200	700	1,400	800	1,600	900
Netherlands	54	KNMI (Haarsma)	Storm tracks in a warmer climate	300,000	500	300,000	500	300,000	500
Netherlands	55	KNMI (Hazeleger)	Patterns of climate change: coupled modelling activities	400,000	500	400,000	500	1,000,000	500
Netherlands	56	KNMI (Hazeleger)	EC-Earth: developing a European earth system model based on ECMWF modelling systems	5,000,000	15,000	5,000,000	20,000	5,000,000	25,000

Member State		Institute	Project title	2009		2010		2011	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
Netherlands	57	KNMI (Onvlee)	The Hirlam-A project	1,000,000	8,500	1,250,000	8,500	1,500,000	8,500
	58	KNMI (Selten)	Climate change studies using the IFS system	225,000	500	225,000	500	X	X
	59	KNMI (Siebesma)	Rain in cumulus	250,000	250	275,000	250	300,000	250
	60	KNMI (van Meijgaard)	Multi-annual integrations with the KNMI regional climate model RACMO2	500,000	2,500	X	X	X	X
	61	KNM (van Meijgaard)	Regional modelling of the Greenland surface mass balance for key episodes in the past and the future	500,000	1,500	500,000	1,500	X	X
	62	KNMI (John de Vries)	Data assimilation over the North Atlantic (DANA)	65,000	1,000	65,000	1,000	X	X
	63	KNMI (van Weele)	Global chemistry-transport modelling of natural reactive greenhouse gases	100,000	100	100,000	100	100,000	100
	64	KNMI (van den Hurk)	Participation in GLACE-2	100,000	580	50,000	580	50,000	580
Norway	65	DNMI (Benestad)	Seasonal predictability over the Artic region – exploring the role of boundary conditions	160,000	1,000	215,000	1,000	X	X
	66	Univ. Oslo (Isaksen)	Ozone as a climate gas	50,000	5	50,000	5	50,000	5
	67	DNMI (Iversen)	GLAMEPS – Grand limited area model ensemble prediction system	1,500,000	10,000	2,000,000	10,000	2,000,000	10,000
	68	DNMI (Iversen, Kristiansen)	REGCLIM: optimal forcing perturbations for the atmosphere	400,000	1,000	600,000	1,000	X	X
Portugal	69	Univ. Lisbon (Soares)	HIPOCAS-SPEC	0	10	0	10	0	10
Spain	70	Univ. Illes Balears (Cuxart)	Study of the stably stratified atmospheric boundary layer through large-eddy simulations and high resolution mesoscale modelling	96,000	200	96,000	200	96,000	200
	71	Univ. de Castilla-La Mancha (Gärtner)	Analysis of land surface-atmosphere interactions through mesoscale simulations	700,000	1,000	700,000	1,000	700,000	1,000
	72	Univ. Basque Country (Saenz)	Mesoscale meteorological reanalysis over the Iberian Peninsula	50,000	2,000	50,000	2,000	X	X
Sweden	73	SMHI (Robertson)	GEMS/MACC – Global and regional earth-system monitor using satellite and in situ data	145,000	6	145,000	6	145,000	6
Switzerland	74	Institute for Atmospheric and Climate Science, ETH Zurich (Lohmann)	Cloud aerosol interactions	250,000	200	300,000	200	300,000	200
United Kingdom	75	ESSC, Univ. Reading (Bengtsson)	Predictability studies with emphasis on extra-tropical and tropical storm-tracks and their dependence on the global observing systems	300,000	300	300,000	300	300,000	300
	76	Univ. Reading (Ehrendorfer)	The TIGGE Data Base: atmospheric predictability and Bayesian decision making	9,000	30	9,000	30	X	X
	77	Univ. Reading (Haines)	Using data assimilation in a high-resolution ocean model to determine the thermohaline circulation	1,000,000	7,000	460,000	7,000	X	X

Member State		Institute	Project title	2009		2010		2011	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
United Kingdom	78	Univ. Oxford (Hanlon)	Attribution of changes in extreme weather risk using large ensembles of climate model simulations	25,000	150	X	X	X	X
	79	Univ. Reading (Hoskins)	Moist singular vectors and African easterly waves	75,000	150	X	X	X	X
	80	Manchester Metropolitan Univ. (Lee)	Determining the relative roles of NO_x and CO_2 emissions from aviation in climate change	80,000	500	45,000	400	X	X
	81	DARC, Univ. Reading (Migliorini)	Assimilation of geostationary ozone measurements for global ozone monitoring	150,000	1,000	X	X	X	X
	82	DARC, Univ. Reading (Migliorini)	GlobModel	150,000	1,000	150,000	1,000	X	X
	83	Univ. Reading (O'Neill)	Assimilation of retrieved products from EOS MLS	900,000	3,000	900,000	3,000	300,000	3,000
	84	DARC, Univ. Reading (O'Neill)	How good are simulated water vapour distributions in the UTLS region?	70,000	250	X	X	X	X
	85	Keele Univ. (Shrira)	Direct numerical simulations of 2-D freak waves	100,000	100	X	X	X	X
	86	BAS, Cambridge (Turner)	Assessment of ECMWF forecasts over the high latitude areas of the southern hemisphere	0	1	0	1	0	1
ICTP	87	ICTP (Kucharski)	Dynamical downscaling of seasonal predictions with a regional climate model	500,000	2,000	500,000	2,000	500,000	2,000
	88	ICTP (Kucharski)	Decadal interactions between the tropical Indo-Pacific Ocean and extratropical modes of variability in an intermediate coupled model	100,000	600	100,000	600	100,000	600
JRC	89	JRC-IES (Dentener)	The linkage of climate and air pollution: simulations with the global 2-way nested model TM5	120,000	160	150,000	180	200,000	200
	90	JRC-IES (Dosio)	Coupling a regional climate model to a biogeochemical land-surface model in the study of climate change impacts on the European ecosystem	200,000	100	200,000	100	X	X
New Projects									
Austria	1	Univ. Vienna (Haimberger)	Bias estimation of historic in situ upper air data	5,000	200	5,000	500	10,000	1,000
Denmark	2	DMI (May)	Numerical experimentation with the EC-Earth system with special focus on the Mediterranean region	600,000	5,000	300,000	2,500	X	X
	3	DMI (Yang)	Decadal climate change experiments of EC-Earth at high resolution and with top atmosphere	200,000	1,000	200,000	2,000	X	X
Netherlands	4	KNMI (Huijnen)	Global reactive gases modelling in GEMS and MACC: towards an operational assimilation and forecasting system for tropospheric reactive gases	100,000	250	100,000	250	100,000	250

Member State		Institute	Project title	2009		2010		2011	
				HPCF units	Data storage	HPCF units	Data storage	HPCF units	Data storage
New Projects									
Netherlands	5	KNMI (van Noije)	Global atmospheric chemistry modelling with EC-Earth: understanding past and predicting future tropospheric ozone in a changing climate	300,000	500	300,000	500	300,000	500
	6	KNMI (Weber)	Modelling past greenhouse worlds with EC-Earth: understanding past and predicting future response to high greenhouse gas levels	400,000	200	400,000	200	400,000	200
Norway	7	NILU (Eckhardt)	FLEXPART transport simulations for the International Polar Year and further model development	150,000	150	150,000	150	150,000	150
	8	DNMI (Frogner)	TEPS – Targeted EPS for Europe	500,000	500	500,000	500	500,000	500
	9	DNMI (Randriamampianina)	Tuning of HARMONIE assimilation and forecast systems	500,000	2,000	500,000	2,000	X	X
Sweden	10	Stockholm University (Magnusson)	New methods for an ensemble prediction system	200,000	1,020	X	X	X	X
Switzerland	11	Institute for Atmospheric and Climate Science, ETH Zurich (Storelvmo)	Aerosol influence on clouds, precipitation and climate in EC-Earth	250,000	200	250,000	200	250,000	200
Total requested				**34,550,860**	**146,000**	**33,355,060**	**145,346**	**29,712,590**	**128,358**

Special Projects finishing in 2008

Member State		Institute	Project title
Austria	1	Univ. Vienna (Haimberger)	Homogenization of the global radiosonde temperature and wind dataset
	2	Univ. Vienna (Hantel)	Convective fluxes diagnosed from gridscale ECMWF analyses
	3	Univ. Vienna (Steinacker)	4D OMEGA FORM – 4 dimensional objective mesogamma analysis of Föhn in the Rhine Valley during MAP
Ireland	4	Met Éireann (McGrath)	Community Climate Change Consortium for Ireland (C4I)
Italy	5	INGV, Bologna (Manzini)	Middle atmosphere modelling
Netherlands	6	KNMI (van Velthoven)	Chemical reanalyses and sensitivity studies with the chemistry-transport model TM4
Norway	7	DNMI (Frogner)	NORLAMEPS: Limited Area Ensemble Prediction System for Norway
	8	DNMI (Tveter)	Optimisation of operational NWP at met.no

Member State computer allocations for 2009

Member State	HPCF (kunits)	Data Storage (Gbytes)
Belgium	22,682	67,202
Denmark	19,344	57,314
Germany	92,283	273,420
Spain	43,538	128,998
France	73,412	217,509
Greece	18,817	55,753
Ireland	16,783	49,726
Italy	62,292	184,561
Luxembourg	12,805	37,939
Netherlands	30,245	89,610
Norway	20,388	60,406

Member State	HPCF (kunits)	Data Storage (Gbytes)
Austria	20,506	60,755
Portugal	17,050	50,517
Switzerland	23,410	69,360
Finland	17,554	52,008
Sweden	22,483	66,615
Turkey	21,384	63,358
United Kingdom	77,273	228,949
Allocated to Special Projects	34,551	146,000
Reserved for Special Projects	13,200	40,000
Total	**660,000**	**2,000,000**

Responsibilities of Representatives and Contact Points

THERE are a variety of Representatives and Contact Points within ECMWF's Member States and Co-operating States who liaise with staff at ECMWF. The role of these Representatives and Contact Points is given below. Note that:

- The purpose of the Technical Advisory Committee (TAC) is covered on page 36 in the item about "*ECMWF Council and its committees*".
- A list of TAC Representatives, Computing Representatives and Meteorological Contact Points is given in the table on page 34.

Computing Representatives

Computing Representatives co-ordinate the registration of users of ECMWF computing services, and represent their organisation in matters relating to the use of ECMWF computing facilities and the attendance to the Computer User Training Course. They play a very important role in improving the information flow and facilitating various administrative transactions between ECMWF and countries that have access to ECMWF's computing services. They liaise with the Head of Computer Division and User Support at ECMWF. Meetings of the Computing Representatives are held at ECMWF annually. For more information on these meetings see:

www.ecmwf.int/newsevents/meetings/computing_representatives/

Meteorological Contact Points

Meteorological Contact Points receive information from ECMWF about the meteorological aspects of the operational forecasting system, including the high-resolution deterministic model, ensemble forecast system, seasonal forecasts and the "Boundary Conditions for Limited Area Modelling" optional project. They are encouraged to provide feedback concerning the performance of the forecasting system to ECMWF. In addition they may refer to the Head of Meteorological Operations Section or any of the Meteorological Analysts at ECMWF if they wish to discuss aspects of the daily model output.

Security Representatives

Security Representatives represent their organisation in matters relating to computer and network security, and receive information about ECMWF's security arrangements. They liaise with the Security Officer at ECMWF. Meetings of the Security Representatives are held at ECMWF annually. For more information on these meetings see:

www.ecmwf.int/newsevents/meetings/security_representatives/

Telecommunication Technical Contacts

Telecommunication Technical Contacts deal with day-to-day matters concerning the Regional Meteorological Data Communication Network (RMDCN). They liaise with the Head of the Networking and Computer Security Section and Computer Operators at ECMWF. A list of contacts is available at:

rmdcn.ecmwf.int/About_RMDCN/Contact_Names/

Catalogue Contact Points

Catalogue Contact Points are the primary contact for external organisations wishing to receive real-time ECMWF products via one of the ECMWF Member States or Co-operating States. A list of contacts is available at:

www.ecmwf.int/products/catalogue/delivery.html

The Catalogue of ECMWF real-time products is available at:

www.ecmwf.int/products/catalogue/

TAC Representatives, Computing Representatives and Meteorological Contact Points

Member States	TAC Representatives	Computing 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	Dr D. Schröder	Dr E. Krenzien	Mr T. Schumann
Greece	Lt Col A. Anthis	Mr A. Emmanouil	Mr D Ziakopoulos, Mr M. Manoussakis, Mr P. Fragkouli
Spain	Mr E. Monreal	Mr R. Corredor	Mr A. Alcazar
France	Mr B. Strauss	Mrs M. Pithon	Mr J. Clochard
Ireland	Mr P. Halton	Mr P. Halton	Mr M. Walsh
Italy	Dr S. Pasquini	Dr C. Gambuzza	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	Mr C. Fernandes	Mr N. M. Moreira
Switzerland	Dr S. Sandmeier	Mr P. Roth	Mr E. Müller
Finland	Dr Juhani Damski	Mr K. Niemelä	Mr P. Nurmi
Sweden	Mr M. Hellgren	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	Ms A. Trojakova	Mr K. Ostatnický	Mr F. Sopko
Estonia	Mr T. Kaldma	Mr T. Kaldma	Mrs M. Merilain, Mrs T. Paljak
Hungary	Dr L. Bozó	Mr I. Ihász	Mr I. Ihász
Iceland	Mr H. Björnsson	Mr V. Gislason	Mrs S. Karlsdottir
Latvia	Mr A. Bukšs	Mr A. Bukšs	Mr A. Bukšs
Lithuania	Mrs V Auguliene	Mr M. Kazlauskas	Mrs. V. Raliene
Montenegro	Mr A. Berber	Mr A. Marčev	Ms M. Ivanov
Morocco	Mr H. Haddouch	Mr M. Jidane	Mr K. Lahlal
Romania	Dr I. Pescaru	Mr R. Cotariu	Mrs T. Cumpanasu
Serbia	Ms L. Dekic	Mr V. Dimitrijević	Mr B. Bijelic
Slovakia	Mr J. Vivoda	Mr O. Španiel	Dr M. Benko
Slovenia	Mr J. Jerman	Mr P. Hitij	Mr B. Gregorčič
Observers			
EUMETSAT	Mr M. Rattenborg	Dr S. Elliott	
WMO	Mr M. Jarraud		

ECMWF Council and its committees

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

http://www.ecmwf.int/about/committees

Council

The Council adopts measures to implement the ECMWF Convention; the responsibilities include admission of new members, authorising the Director 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: Dr Fritz Neuwirth (*Austria*)

Vice Chair: Ms Maria Ågren (*Sweden*)

Finance Committee (FC)

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

Chair: Ms Monika Köhler (*Austria*)

Vice Chair: Mr Sergio Pasquini (*Italy*)

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: Dr Heikki Järvinen (*Finnish Meteorological Institute*)

Technical Advisory Committee (TAC)

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

Chair: Dr Alan Dickinson (*United Kingdom*)

Vice Chair: Mr Bernard Strauss (*France*)

Advisory Committee for Data Policy (ACDP)

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

Chair: Mr Colin Cuthbert (*United Kingdom*)

Vice Chair: Mr Klaus Haderlein (*Germany*)

Advisory Committee of Co-operating States (ACCS)

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

Chair: Mr Ivan Čačić (*Croatia*)

Vice Chair: Mr Laszlo Bozo (*Hungary*)

ECMWF Calendar 2009

Mar 9–13	Training Course – Use and interpretation of ECMWF products
Mar 16–May 21	Training Course – Numerical Weather Prediction
Mar 16–25	*Predictability, diagnostics and seasonal forecasting*
Mar 30–Apr 3	*Numerical methods and adiabatic formulation of models*
Apr 20–29	*Data assimilation and use of satellite data*
May 11–21	*Parametrization of diabatic processes*
Apr 27–28	Advisory Committee on Data Policy (*10th Session*)
Apr 28–29	Finance Committee (*82nd Session*)
Apr 29–30	Policy Advisory Committee (*27th Session*)
May 6–8	Workshop on “Assimilation of IASI in NWP”
May 11–12	Security Representatives’ Meeting
May 12–14	Computer Representatives’ Meeting
Jun 1–5	Training Course – Use and interpretation of ECMWF products
Jun 10–12	Forecast Products – Users’ Meeting
Jun 15–17	Workshop on “Diagnostics of Data Assimilation System Performance”
Jun 25–26	Council (*71st Session*)
Sep 7–10	Seminar on “Diagnosis of Forecasting and Data Assimilation Systems”
Sep 30–Oct 2	Scientific Advisory Committee (*38th Session*)
Oct 5–7	Technical Advisory Committee (*40th Session*)
Oct 12–16	Training Course – Use and interpretation of ECMWF products for WMO Members
Oct 12–13	Finance Committee (*83rd Session*)
Oct 13–14	Policy Advisory Committee (*28th Session*)
Oct 19	Advisory Committee of Co-operating States (*15th Session*)
Nov 2–6	12th Workshop on “Meteorological Operational Systems”
To be decided	Workshop on “Non-hydrostatic Modelling”
Nov 23–26	MACC Scientific and Technical Training Workshop
Dec 8–9	Council (*72nd Session*)

ECMWF publications

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

Technical Memoranda

579 **Janssen, P.A.E.M.**: On some consequences of the canonical transformation in the Hamiltonian theory of water waves. *November 2008*

578 **Richardson, D.S., J. Bidlot, L. Ferranti, A. Ghelli, M. Janousek, M. Leutbecher, F. Prates, F. Vitart** & **E. Zsoter**: Verification statistics and evaluations of ECMWF forecasts in 2007-2008. *October 2008*

577 **Morcrette, J.-J., A. Beljaars, A. Benedetti, L. Jones** & **O. Boucher**: Gustiness as predictor for lifting sea-salt and dust aerosols in the ECMWF IFS. *October 2008*

576 **Drusch, M., K. Scipal, P. de Rosnay, G. Balsamo, E. Andersson, P. Bougeault** & **P. Viterbo**: Exploitation of satellite data in the surface analysis. *October 2008*

575 **Dee, D.** & **S. Uppala**: Variational bias correction in ERA-Interim. *October 2008*

574 **Cloke, H.L.** & **F. Pappenberger**: Operational flood forecasting: a review of ensemble techniques. *October 2008*

567 **Rodwell, M.J.** and **T. Jung**: Understanding the local and global impacts of model physics changes: an aerosol example. December 2008 (published in *Q. J. R. Meteorol. Soc.*, 2008, **134**, 1479–1497).

560 **Doblas-Reyes, F.J., A. Weisheimer, M. Déqué, N. Keenlyside, M. McVean, J.M. Murphy, P. Rogel, D. Smith** & **T.N. Palmer**: Addressing model uncertainty in seasonal and annual dynamical ensemble forecasts. *November 2008*

558 **Pappenberger, F.** & **R. Buizza**: The skill of ECMWF precipitation and temperature predictions in the Danube basin as forcings of hydrological models. *December 2008* (submitted to *Weather and Forecasting*)

Proceedings

GRAS SAF Workshop on Applications of GPS Radio Occultation Measurements, *16–18 June 2008*

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 website – www.ecmwf.int/publications/newsletter/index.html

Useful names and telephone numbers within ECMWF

Telephone

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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Philippe Bougeault	005
Head of Operations Department	
Walter Zwieflhofer	003
Head of Administration Department	
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Survey of readers

To complete the short questionnaire about the *ECMWF Newsletter* please go to:

www.ecmwf.int/publications/newsletters/

and follow the links. See the article on page 4 for more details about the questionnaire.