Robert Bucher

Robert Bucher, a Swiss national, born in Lucerne on 11 June 1950, joined the Centre on 1 January 1988, as a Translator/Reviser in the Administration Department. Robert was of German mother tongue with fluency in English, French and Italian. He qualified as a translator and interpreter and prior to joining ECMWF in 1988, worked as a French Translator/Interpreter for the Kreditanstalt für Wiederaufbau in Frankfurt since 1979.

Robert's duties at ECMWF included all translations of the Centre's documents into both French and German for all official meetings as well as vacancy notices, annual reports and also published documents that the Centre issued. He also acted as a German interpreter at official meetings held at ECMWF. Robert was always keen to keep up with the latest developments and would try and incorporate them into his work and more recently, he established himself as a focal point of assistance for all kinds of PC applications.

Robert's performance, in all aspects of his work was exceptional and he was a highly organised and competent individual with a vast knowledge of expertise in his field of work. He maintained excellent relations with all his in-house colleagues and friends as well as with all the outside interpreters, providing them with all the technical glossaries that contributed to the smooth running of the meetings.

Robert died on Friday 14 February 2003 at the age of 52, following a serious road accident whilst on his way to work. Robert's sudden departure has left a huge void at the Centre and is greatly missed by so many.

Robert is survived by his wife Maddalena and by their four children, Francesca, Ottavia, Fabrizio and Stefano.

Helen Brimacombe

Helen Brimacombe, a UK national born in Purley, Surrey on 30 August 1940, joined the Centre from the UK Meteorological Office on 11 February 1985 as a Receptionist. Her former post was Clerical Assistant/Receptionist at the UK Meteorological College.

In 1988, Helen was re-assigned to the General Services Section as a Clerical Assistant/Typist where she assisted the Head of General Services in all aspects of the job. She always showed total dedication and versatility in all duties assigned to her. Her performance and judgement was excellent, and Helen was promoted to Administrative Assistant on 1 January 2001.

In recent years, despite suffering from ill health, she continued to give 100% to her job and kept the General Services Section running smoothly during some difficult times. She was a warm, charming and kind-hearted person with so much to give. Helen maintained excellent relations with all her colleagues and friends and her cheerful presence will be greatly missed.

Helen died in the evening of 21 November 2002 at the age of 62, after a long fight in the Intensive Care Unit at the Royal Berkshire Hospital.

Helen is survived by her two children, Simon and Laura, and by four grandchildren.

In this issue

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Front Cover

The new IBM high-performance computing system, the successful achievement of its acceptance tests, establishment of a full user service and the migration of the Integrated Forecasting System (IFS) from the Fujitsu VPP5000 are covered in this issue.

Editorial

On page 2 Frantisek Sopko describes problems that arose in forecasting the severe flooding that afflicted the Czech Republic in August 2002. He points out that the availability of output from the ECMWF model (together with predictions by models from other centres) greatly helped, but that even the best models available today are sometimes unable to provide the degree of precision several days ahead that forecasters would like to have.

The next generation of satellite-borne remote-sensing instruments will provide a substantial increase in the number, the accuracy and the resolution of observational data. On page 6 Jean-Noël Thépaut and Erik Andersson give a survey of the techniques used at ECMWF for processing current satellite observations and they discuss the potential offered by new instruments for providing data on temperature, humidity, clouds, rainfall and winds.

On page 12 Erik Andersson, Anton Beljaars, Jean Bidlot, Martin Miller, Adrian Simmons and Jean-Noël Thépaut give details of the latest cycle of the Integrated Forecasting System, covering improved methods of assimilating satellite data, improved wave data assimilation and changes to the cloud and convection schemes. The changes have led to one of the largest positive impacts on the quality of the forecasts seen in recent years.

On page 20 Deborah Salmond, John Hennessy and Neil Storer describe the installation of the new IBM high-performance computing system, the successful achievement of its acceptance tests, the establishment of a full user service and the migration of the Integrated Forecasting System from the Fujitsu VPP5000. The ECMWF and IBM staff that were involved deserve congratulations for completing this extensive body of work on schedule.

Peter White

Changes to the Operational Forecasting System

AIRS radiances have been passively monitored since 19 February 2003

On 4 March 2003 all the operational forecast suites were switched to run on the new IBM high-performance computing system using cycle CY25r5; this major technical upgrade went smoothly, both from the internal and external users' points of view. See also, the articles on pages 12 and 20 in this issue of the Newsletter, the article on page 11 of Newsletter 93 (Spring 2002) and:
http://www.ecmwf.int/services/computing/overview/ibm_cluster.html.

Since 25 March 2003, the ECMWF medium-range operational forecasts (T511L60 deterministic and T255L40 EPS) have been run twice per day from base times 00 and 12 UTC. However, the data-assimilation cycle has remained unchanged. The 00 UTC products are archived in MARS and are available for dissemination

On 31 March 2003, the Fujitsu computers were decommissioned. As a result (and according to plans) the old version of the seasonal-forecast suite (System 1) has also been discontinued.

François Lalaurette

Model predictions of the floods in the Czech Republic during August 2002: The forecasters' perspective

In August 2002 disastrous floods hit central Europe (see also *Grazzini and van der Grijn*, pp. 18–28, ECMWF Newsletter 96 – Winter 2002/03). This was one year after the cooperation agreement between the Czech Republic and ECMWF came into force. According to this agreement the Czech Hydrometeorological Institute, as well as the Czech Military Weather Service, receives full access to all products of the ECMWF forecasting models. Therefore, we would like to assess the use of ECMWF products and other models in the forecasting and warning service of the Czech Republic, and to investigate the skill of forecasts of the heavy rain that was responsible for the floods.

The floods were caused by intensive rain from two deep cyclones and two frontal systems that moved one after another across the central Europe over a period of a few days. Both cyclones hit the territory of the Czech Republic with their most rainy sectors situated to the west or northwest of their centres. Both moved slowly, but only the second one was exceptionally developed. The warm sector had high temperatures that contributed to the formation of precipitation clouds linked with the occluded front.

The floods proceeded in two waves. The first period of rainfall mainly hit the area near the border between Bohemia and Austria. Precipitation amounts of 150 to 250 mm were measured in the area of the Novohradske mountains during two days from 6 to 7 August, and 70–150 mm were measured in southern Bohemia. Extreme precipitation was also measured in Austria.

After three days of low precipitation the second rainfall wave arrived during 11 to 13 August. At first the precipitation hit southern Bohemia, mainly in the Sǔmava mountains. Afterwards it extended to the whole territory of the Czech Republic and ended from southwest during 13 August. The highest precipitation (between 90 to 200 mm) during this three-day period was measured in southern Bohemia, and 60 to 120 mm were recorded in west and central Bohemia. Due to the previous saturation of rivers and soil, water levels in the rivers rose quickly during the second precipitation period. Water levels in some rivers significantly exceeded the return period of 100 years, and a 500-year flood discharge was measured on the Vltava River in Prague on 14 August.

Verification of pressure fields of the medium-range numerical models

The ECMWF model (run from 12 UTC), the German global model GME (run from 00 UTC) and the American model NCEP (run from 00 UTC) are used for medium-range weather forecasts in the Czech Republic. At first we verified the forecasts of atmospheric circulation, principally the two cyclones mentioned above. The actual positions of the cyclones at mean-sea-level pressure and the 500 hPa charts for the days with largest precipitation (12 UTC 7 August and 12 UTC 12 August) were compared with model forecasts.

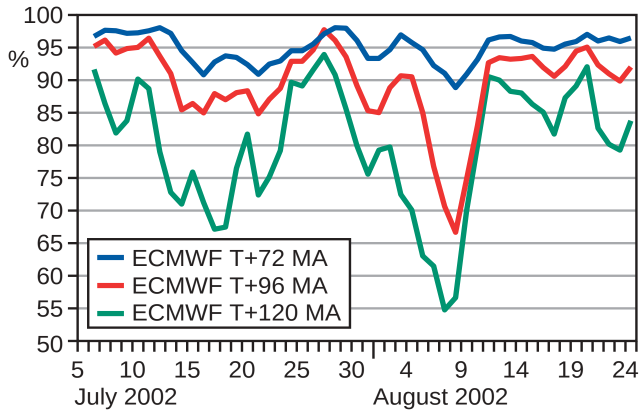

Figure 1 Anomaly correlation of the T + 72, T + 96 and T + 120 forecasts of the 500 hPa geopotential over Europe during July and August 2002.

Two criteria were used for comparison. The first was the number of model forecasts (from one to five days ahead) in which the cyclone was predicted. The number of successful forecasts for both flood waves was 14 (ECMWF), 15 (NCEP) and 16 (GME). The second criterion was the distance between centres of forecast and actual cyclones. If we take into account the forecasts from one to three days ahead, the average distance was 200 km (ECMWF), 160 km (NCEP) and 230 km (GME).

In the case of the first rainfall wave, the heavy rain was linked with a cyclone that formed, together with a frontal boundary, only about 36 hours before the beginning of the rain in Bohemia. In the case of the second rainfall wave, it was possible to follow the movement and evolution of the frontal system, together with the cyclone, for more days ahead before the beginning of intensive rain in Bohemia. This difference shows up in the differing successes of the numerical models in forecasting both rainfall waves. The success of the forecasts was significantly lower during the first wave. The ECMWF and GME models predicted the cyclone formation two days ahead, and the NCEP model three days ahead. In the case of the second rainfall wave, the numerical models predicted the cyclone better (especially the ECMWF and NCEP models) three days ahead. As we can be seen below, this was also linked with the skill of the precipitation forecasts. It is interesting that during the period of the floods, the anomaly correlations of the 500 hPa geopotential at T+72, T+96 and T+120 of ECMWF (Figure 1) (as well as EPS spread) were lower over Europe than during the periods before and after the intense rainfall event.

Verification of precipitation products of ECMWF and GME models

We verified the 24-hour forecasts of precipitation by the ECMWF operational model and two products of the Ensemble Prediction System (EPS): the probability of precipitation

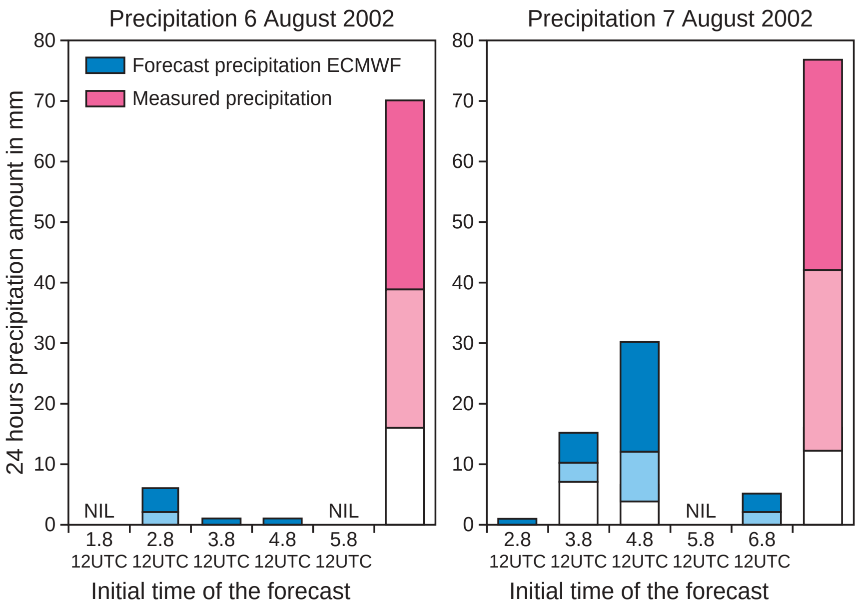

Figure 2 Comparison of 24-hour precipitation amounts forecast by the ECMWF model with measured precipitation in the area of southern and western Bohemia for both days of the first rainfall wave. The white parts indicate the minimum values within the area considered, the pale sections show the amounts below the average and the dark sections the amounts above the average.

being greater than 20 mm/day and the Extreme Forecast Index (EFI) for precipitation. The forecasts from 12 UTC from one to five days ahead were examined in the area of southern and western Bohemia, where precipitation totals were the highest. In addition the one to three-day precipitation forecasts by the GME model (from 00 UTC) were verified, but we were not able to obtain precipitation forecasts from the NCEP model. The precipitation ranges and the averages predicted by models were compared with ranges of 5% and 95% percentiles (due to elimination of extreme values) and with the averages of measured precipitation in the area mentioned.

Precipitation forecasts for the first rainfall wave

The ECMWF model first predicted significant precipitation in southern Bohemia (up to 30 mm for the 24-hour period from 06 UTC 7 August) with the run starting at 12 UTC 4 August. However, the following model run from 5 August did not forecast substantial precipitation, and intensive rain was not even forecast from the 6 August run (Figure 2). Probabilities of precipitation greater than 20 mm/day were less than 20% from the earliest EPS run time, 30% from 5 August, and 70% from 6 August. However, the forecasters received this last model run the following morning after the beginning of heavy rain in southern Bohemia. The precipitation EFI was very low (only up to 10%) for the forecasts for 3 to 5 days ahead.

The precipitation was also under-forecast by the GME model. The runs from 5 and 6 August predicted up to 40 mm/day (Figure 3), but the highest precipitation was forecast at the very southern part of Bohemia.

Both models underestimated forecasts of precipitation for the first flood wave in southern Bohemia, but the GME model was more successful. The forecasters gained the first signal dealing with precipitation up to 30 mm in the morning of 5 August (GME model). This was approximately 30 hours before of the start of the intense rainfall. However, both models managed to forecast extreme precipitation of about 100 mm/day over Austria, not too far from southern Bohemia. Considering the limitations of the models in defining the precise location of precipitation, these forecasts of heavy rain could herald the possibility of the occurrence intense precipitation to the north of the predicted area, in southern Bohemia. However, the probability of precipitation greater than 20 mm/day that was forecast by the EPS was only 30% for southern Bohemia, and values of the EFI were low as well. As a result, a warning was issued at a time when intensive rainfall had already begun.

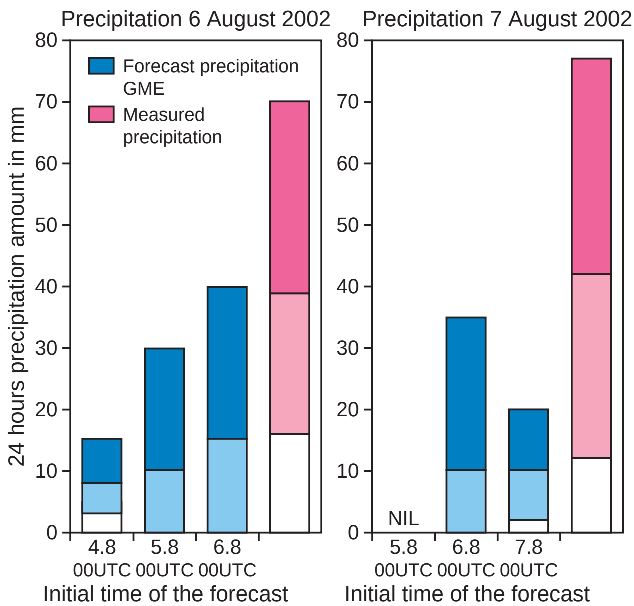

Figure 3 Comparison of 24-hour precipitation amounts forecast by the GME model with measured precipitation in the area of southern and western Bohemia for both days of the first rainfall wave.

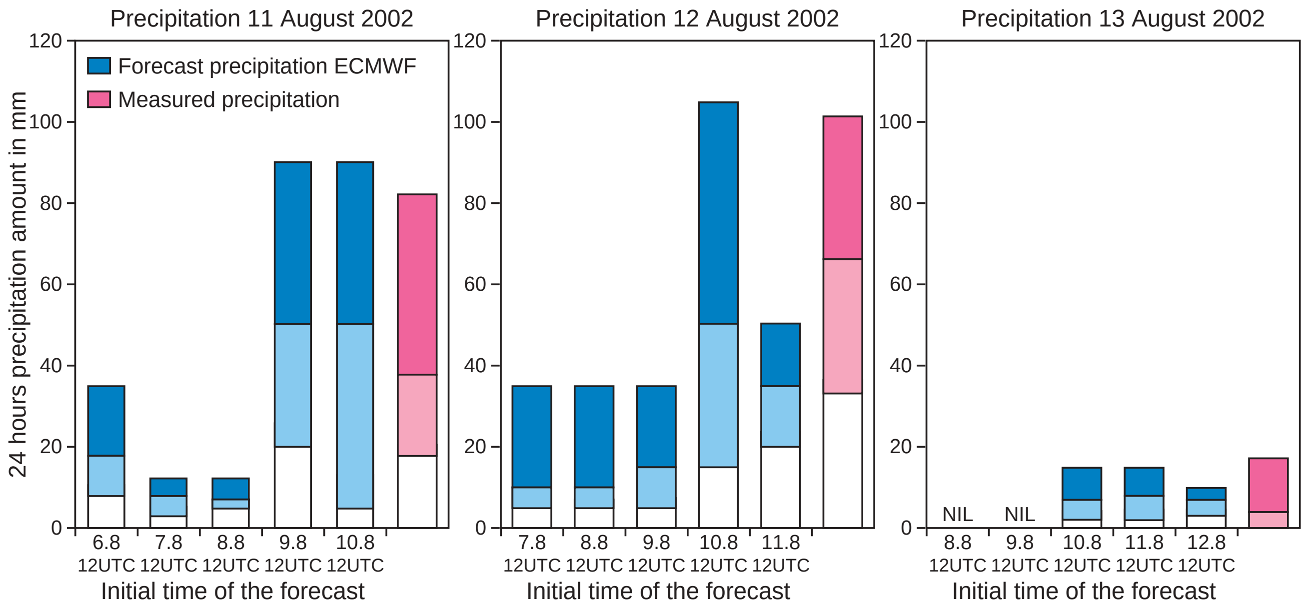

Figure 4 Comparison of 24-hour precipitation amounts forecast by the ECMWF model with measured precipitation in the area of southern and western Bohemia for the days of the second rainfall wave.

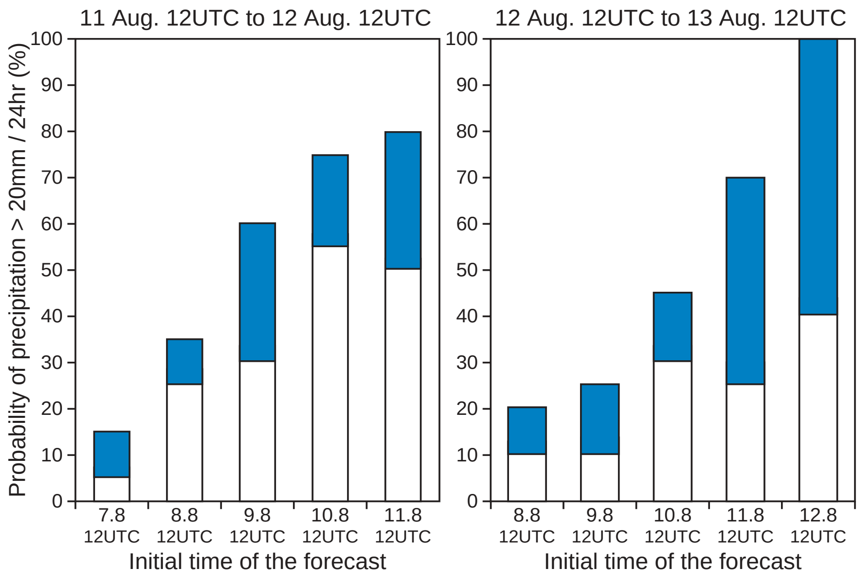

Figure 5 Probability forecast of precipitation amounts greater than 20 mm/day from the ECMWF EPS in the area of southern and western Bohemia for two days of the second rainfall wave.

Precipitation forecasts for the second rainfall wave

Four to five days ahead of the second rainfall wave (from 6 to 8 August), the ECMWF model predicted up to 35 mm/day for the area of southern and western Bohemia (Figure 4). The model from the following day (12 UTC 9 August) forecast significantly more precipitation from 20 to 90 mm for 11 August (this was a slight overestimate in comparison with the measured precipitation), and from 5 to 35 mm for 12 August. The next forecast from 12 UTC 10 August was very good. The model persisted with high precipitation values of 5 to 90 mm for 11 August and 15 to 105 mm for 12 August. But the maximum precipitation was forecast in an area situated more eastwards (over southeast Bohemia and west Moravia) than the observed. The termination of the heavy rainfall was forecast well.

As time approached towards the development of the second rainfall wave, the probability of precipitation greater than 20 mm/day also increased (Figure 5). The ECMWF forecast higher probabilities (30 to 60% for the period from 12 UTC 11 August to 12 UTC 12 August) from the EPS run from 12 UTC 9 August. The run from the following day predicted the precipitation probabilities of 55 to 75% for the same period and 30 to 45% for the next day. Similarly high probabilities (50 to 80% for the first, 25 to 70% for the second day) were also predicted the next run from 11 August.

The model run from 9 August for 12 and 13 August forecast higher, but not extreme, values of precipitation EFI (15 to 50%). Nevertheless, in southeast Moravia and Slovakia, where the precipitation was much lower, the EFI for 11 August was about 70%; this is apparent from Figure 6a) and b).

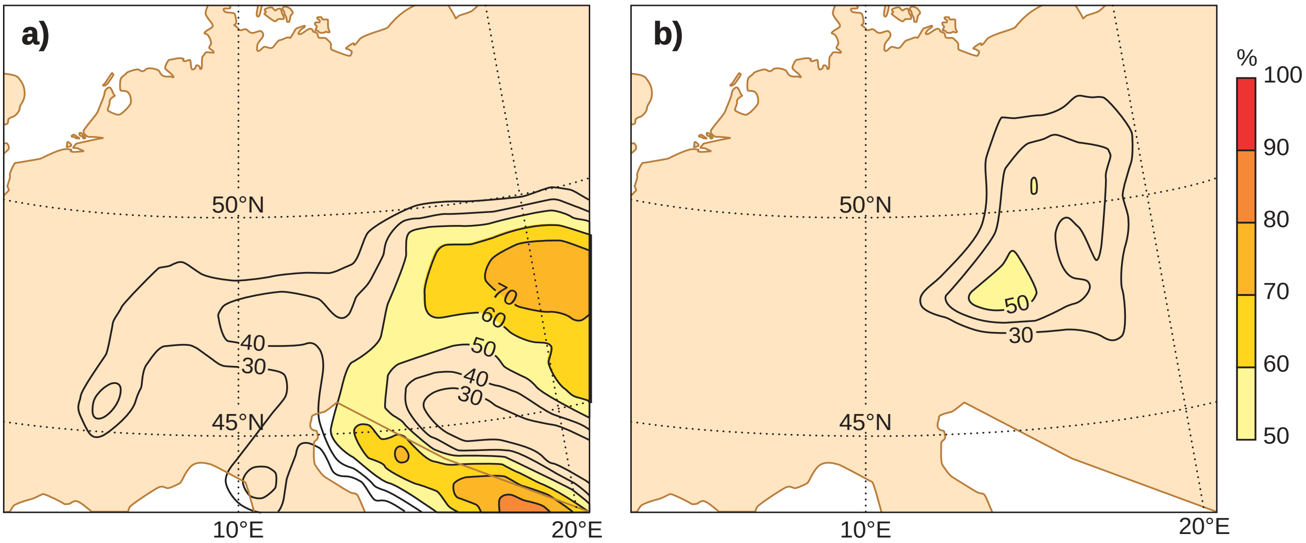

Figure 6 a) The Extreme Forecast Index for precipitation in central Europe over the last 24 hours for 06 UTC 12 August 2002 from the base 12 UTC 9 August 2002 and b) over last 24 hours for 06 UTC 13 August 2002 from the base 12 UTC 9 August 2002.

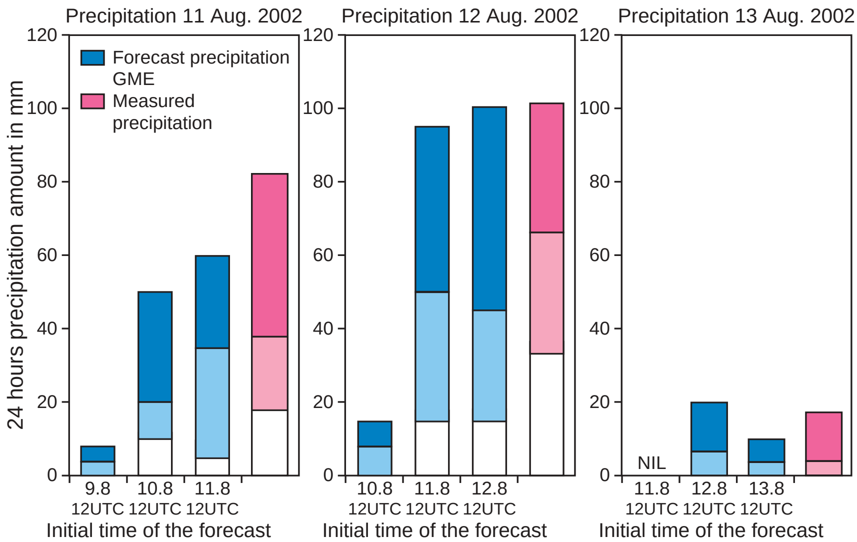

Figure 7 The comparison of the 24-hour precipitation amounts forecast by the GME model with measured precipitation in the area of southern and western Bohemia for the days of the second rainfall wave.

The German global model (GME) from 00 UTC 10 August for the same area forecast 10 to 50 mm for 11 August and up to 15 mm for 12 August (Figure 7). The run from 11 August significantly increased the precipitation totals for 11 August (up to 5 to 60 mm) and 12 August (up to 15 to 95 mm); this was about three quarters of the measured precipitation. The model also forecast the location of the precipitation and its movement northeastwards well.

The precipitation for the second flood wave was forecast significantly better than for the first wave. The ECMWF model predicted precipitation up to 30 mm/day five days ahead. The probabilities of precipitation greater than 20 mm/day increased as well. High precipitation, as well as higher probabilities of precipitation and higher values of the EFI, were forecast for the first time from the run starting from 12 UTC 9 August. At the same time, forecasters also began to use precipitation forecasts from the GME model. These slightly underestimated the rainfall while ECMWF model was good. In accordance with these model outputs, on 8 and 9 August the forecasters predicted occasional rain and showers for 11 to 13 August. The first warning that the forecasters issued was on 10 August for the second wave of intensive precipitation, and for an increase of water levels in rivers. The second warning was issued the next day for increased precipitation totals; the predicted precipitation totals in this warning were very successful. In addition, regional models continuously improved and made forecasts more accurate.

The value of numerical model output

The ECMWF products have begun to be very important material for weather forecasts in the Czech Hydrometeorological Institute and in the Military Weather Service after the start of the cooperation agreement with ECMWF. The products of the German global model (GME) and the American model (NCEP) are also useful. All were used in issuing the weather forecasts and warnings of extremely heavy rain that caused the disastrous floods in August 2002.

Despite great progress in modelling the atmosphere and in the development of numerical models, it is apparent that in some cases a forecast of a serious flooding a few days ahead can be unsuccessful. The use of three models and of ensemble products enables the Czech forecasters to consider the degree of uncertainty, or possible alternatives of weather development, and to improve the weather forecasts as a result. The ECMWF products have become an important basis, mainly for medium-range weather forecasts and forecasts of severe weather in the Czech Republic.

Frantisek Sopko (Czech Hydrometeorolical Institute)

Assimilation of high-resolution satellite data

Over the past few years, the importance of satellite data has progressively increased, to the extent that satellite systems now provide the main sources of information for assimilation in the ECMWF forecasting system. Its contribution to forecast skill in the Northern Hemisphere is now more important than that of radiosonde data. In the Southern Hemisphere forecast skill has improved very significantly over the last five years, and is now at a similar level to that of the Northern Hemisphere. This is largely due to enhanced utilization of satellite data. Over this period of time there has been a substantial enhancement of the space-based observing systems, with improved instruments providing measurements of a variety of atmospheric quantities. There have also been significant improvements in the data assimilation techniques. The main advantage of satellite observing systems is that they provide data with a fairly uniform spatial and temporal coverage of the atmosphere. On the other hand, most current satellite data have generally poor vertical resolution, and the difficulties in handling clouds, precipitation and surface effects on the data can severely limit the exploitation of the full information content of the data. Nevertheless, it is now quite clear that the extended and improved utilization of new satellite data in ECMWF's 4D-Var assimilation system has contributed significantly to improved forecast performance. Furthermore, it is expected that forthcoming satellites carrying a new generation of instruments will ensure that the positive trend continues. In particular, advanced sounding instruments, such as AIRS on the American AQUA platform and IASI on the European METOP series of satellites, will substantially improve the vertical resolution of the temperature and water vapour information. Besides, a number of missions will provide a very large amount of observations of the Earth's hydrological cycle. ECMWF is therefore currently undertaking a major development effort devoted to the assimilation of cloud and precipitation related quantities. Other current active research addresses further opportunities such as the

Spacecraft	Instru-ment	Total no. processed	No. of used data	Measurement
METEOSAT-7	Imager	235,580	38,111	Water-vapour radiances, sensitive to upper tropospheric humidity
GOES-8		754,064	26,721	
GOES-10		497,944	23,109	
NOAA-16	HIRS	1,688,264	81,867	Infrared, temperature and humidity sounding
NOAA-17		1,440,048	67,756	
NOAA-15	AMSU-A	2,046,100	178,497	Microwave radiances, temperature sounding in stratosphere and upper/mid troposphere
NOAA-16		2,368,620	246,815	
NOAA-17		2,380,560	228,327	
DMSP-13	SSMI	88,620	40,901	Microwave, tropospheric humidity
DMSP-14		87,745	33,166	
DMSP-15		88,445	39,452	
QuikSCAT	Seawinds	216,240	111,800	Near-surface winds over ocean
Total		**11,889,230**	**1,116,522**	

Table 1 List of satellite data (excluding ozone data and cloud-drift winds) used in ECMWF pre-operational tests, for 00 UTC 8 January 2003. The test system became operational on 14 January 2003.

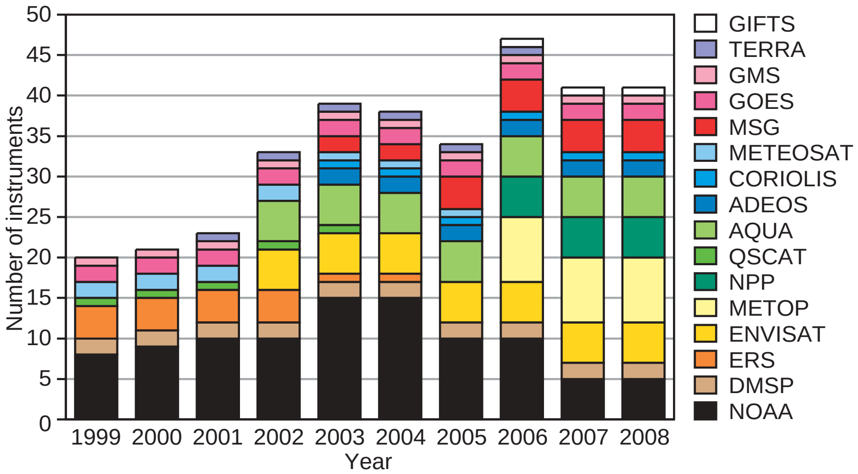

Figure 1 Number of satellite sensors available for assimilation: actual from 1999–2002 and projection until 2008 (from the 'Met Office Satellite Data Volume Plan', 25 April 2002, by Roger Saunders). The acronyms in the legend are names of satellites, or series of satellites, of the operational and research programmes of the European, American and Japanese space agencies.

assimilation of radio-occultation measurements from GPS receivers, or wind profiles from space-borne Doppler Wind Lidar.

The availability of current satellite data

The main providers of Earth-observation satellite systems and space-based observations of the atmosphere are the American (NASA and NOAA), European (EUMETSAT and ESA) and Japanese (NASDA) space agencies. Collaboration between the agencies ensures the longer-term continuity of the operational systems in polar as well as geostationary orbits. An overview of available satellite systems 1999 to 2008 and the number of instruments of interest for NWP is given in Figure 1. So far the main provider of temperature and humidity sounding data has been the NOAA-series (TOVS and ATOVS) of polar-orbiting satellites. Currently data from three NOAA satellites (15, 16 and 17), each with three main instruments (HIRS in the infrared, AMSU-A and AMSU-B in the microwave) are used in ECMWFs operational system (see Table 1), actively for HIRS and AMSU-A, passively for AMSU-B. The humidity-sensitive microwave instruments (SSMI) on the US Navy's DMSP-series of polar-orbiting satellites also provide an important source of data for assimilation. Data from three DMSP satellites (13, 14 and 15) is currently used operationally. The European METEOSAT and American GOES geostationary satellites provide frequent full-disc radiance data within about 50° north and south of the Equator. These data are predominantly sensitive to the upper-tropospheric humidity. Data are currently used from METEOSAT-7 (at 0°W) and from GOES-8 and 10 (at 75°W and 135°W, respectively). Accurate near-surface wind data over the oceans is provided by the scatterometer instruments (active microwave) on the European ERS satellite, and by the American QuikSCAT. Wind data from ERS were used operationally from 1996 to 2002. Currently (and in the past 12 months), QuikSCAT data are assimilated. Data counts of the number of processed and actively used data from each of the above-mentioned satellite systems are given in Table 1, for 00 UTC 8 January 2003. It is worth noticing that the total number of data used from these space-based observing systems (1,116,522), now far exceeds the number of used data from the terrestrial observing systems (376,097).

The rapid increase in the number of data used per assimilation cycle is shown in Figure 2. The increase has been a factor of ten, compared with 1997, when a 6-hourly 3D-Var assimilation system was operational. The increase towards the end of year 2000 was due to the change from 6-hourly to 12-hourly cycling of 4D-Var. The increases in 2002 mainly reflect the enhanced use of ATOVS radiances, and the introduction of QuikSCAT winds and water-vapour radiances from METEOSAT. The most recent increase (red bar) in January 2003 is due to the introduction of a third DMSP satellite, a third NOAA satellite, and the use of water-vapour radiances from the two GOES satellites.

How satellite data are used in the ECMWF system

A schematic of how 4D-Var works is shown in Figure 3. The observations (green) are compared to a short-range forecast

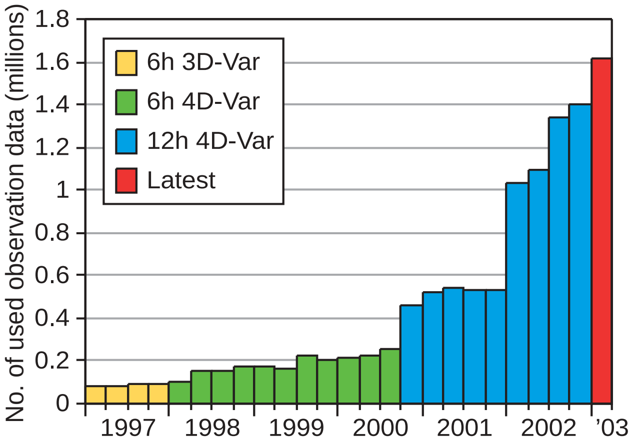

Figure 2 The number of observational data used in ECMWF's operational system per assimilation cycle: 6-hourly 3D-Var (yellow), 6-hourly 4D-Var (green), 12-hourly 4D-Var (blue), and since the latest operational change (red) implemented 14 January 2003.

(blue), at the valid times of the observations. From the differences between the model and observed values, 4D-Var then provides an analysis that gives a new forecast (red) in closer agreement with the observations over the entire 12-hour assimilation period. The 4D-Var method is particularly suited for the use of asynoptic data, and for extracting dynamical information from time series of observations. All observations are compared with the model at their correct time, to within 15 minutes in the current operational system. This enables accurate treatment of satellite data also in places where the atmosphere is changing rapidly. At high latitudes, where satellite orbits overlap, observations can be available at several times at nearly the same location – thus providing tendency information, which can be usefully assimilated by 4D-Var. The geostationary satellites provide time sequences of hourly radiance data over most parts of the tropics and the subtropics. From the temporal variations in the data it is possible with 4D-Var to deduce some information from the movement of observed features, thus contributing to the analysis of the tropical wind field, in addition to the humidity information more directly inferred from the radiances.

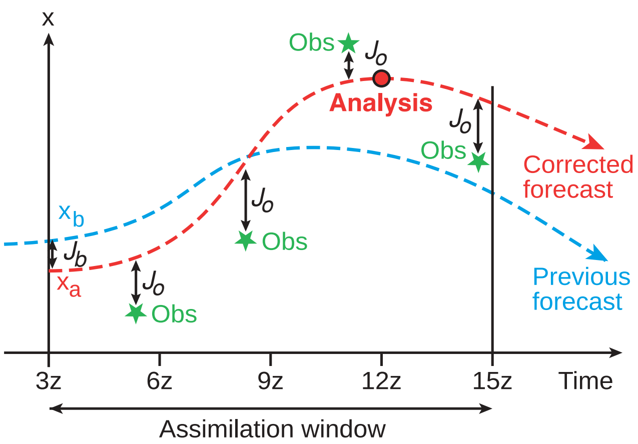

Figure 3 Schematic of 4D-Var.

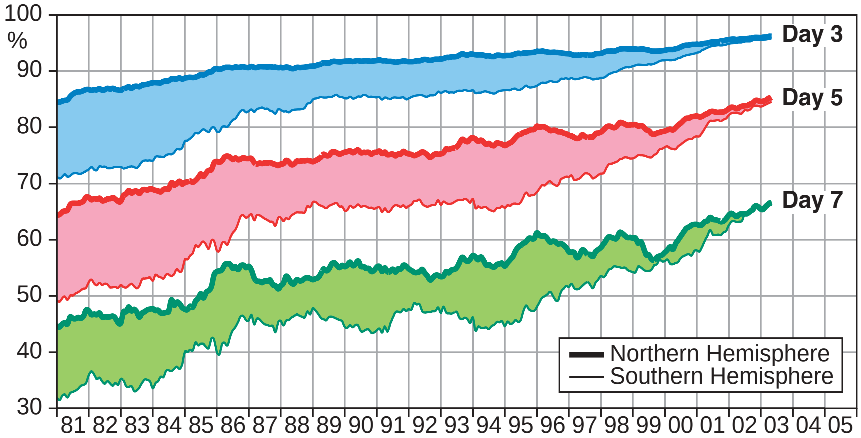

Figure 4 Anomaly correlation coefficients of 3, 5 and 7-day ECMWF 500 hPa height forecasts for the extra-tropical Northern and Southern Hemispheres, plotted in the form of annual running means of archived monthly-mean scores for the period from January 1980 to April 2003. Values plotted for a particular month are averages over that month and the 11 preceding months. The coloured shadings show the differences in scores between the two hemispheres at the forecast ranges indicated (after *Simmons and Hollingsworth*, 2002).

Several of the satellite instruments provide data at very-high horizontal resolution, in some cases far in excess of the resolution of the operational assimilation system (~120 km). The data are therefore thinned to a resolution of 125 km. The horizontal thinning is applied separately for each 30 minute time period, allowing a maximum of 24 measurements of the same type within the 12-hour assimilation period, in each 125 × 125 km thinning box. A specific quality-control procedure is applied because of the particular nature of satellite measurements.

What is specific to satellite data?

Satellite data are different from conventional observations in that the measured quantities by satellite instruments do not relate directly to geophysical quantities. Satellite instruments do not measure temperature, do not measure humidity, and do not measure wind. Satellite instruments measure essentially the radiance that reaches the top of the atmosphere at a given frequency. The radiance is related to geophysical parameters through the radiative transfer equation. By selecting radiation at different frequencies (or channels), a satellite instrument can provide information on a range of geophysical variables at various levels, depending on the peak of the so-called weighting functions of its different channels. The altitude of the peak of the weighting function depends on the strength of the atmospheric absorption for a given channel. A further distinction has to be made between passive and active instruments. Passive instruments sense radiation emitted by the surface and/or atmosphere (or the solar radiation reflected by it). Active instruments emit radiation and measure how much of it is reflected or back-scattered by the surface and/or atmosphere.

The problem of assimilating geophysical information from satellite data is not new. It is well known that the problem is generally ill-posed (i.e. an infinite number of different temperature profiles could give the same measured radiance). If one wants to utilize satellite radiances to determine the initial conditions of a NWP model, the role of data assimilation is to solve this ill-posed problem. Any technique requires the use of a priori information, the quality of which will drive the accuracy of the final retrieved product. A robust and sustained positive impact of satellite data in the ECMWF data assimilation system has been obtained with the advent of 3D and 4D-Var techniques that allow the direct assimilation of radiance observations, and therefore avoid the need for an explicit retrieval step for which the error characteristics always remain difficult to assign when the inputs and the chain of processing the retrieved products is poorly known by NWP centres. In the case of 3D or 4D-Var, the inversion is further constrained by the simultaneous assimilation of other observations. Note, in particular, that in 4D-Var the adjustments forced by radiances at different times of the assimilation window will be consistent with the forecast model physics and dynamics (as shown by *Andersson et al.* (1994), radiances can cause wind adjustments during the assimilation). Last, the characterization of observational errors in radiance space is much easier. Radiances are now used directly in the ECMWF upper-air data assimilation system for most of the instruments. The last exceptions concern atmospheric motion vectors derived from cloud tracking (because the direct assimilation of cloud information is not mature enough), and ambiguous wind products from scatterometers.

Stringent quality-control checks are in place to remove those radiance data that have been affected by precipitation or clouds, or have a strong contribution from the surface. A bias correction of the radiances is applied before they are assimilated, in order to remove some of the systematic errors present in the data and in the radiative transfer model. The bias correction varies with scan angle and air mass, through a regression relationship based on model predictors.

Impact of the satellite data on the quality of the forecasts

Figure 4 is an updated version of Figure 4 in the paper by *Simmons and Hollingsworth* (2002). This figure presents running annual-mean anomaly correlations of 500 hPa height for ECMWF's operational three-, five- and seven-day forecasts for the extratropical Northern and Southern Hemispheres for the period from January 1980 to November 2002. The first remark is the general upward trend of the curves (indicating a progressive improvement of the forecast quality over the covered period). A second striking feature is the higher rate of improvement in the forecasts in the Southern Hemisphere. In twenty-two years, the skill of medium-range weather forecasts in the Southern Hemisphere has reached a level now comparable (if not superior) to the one

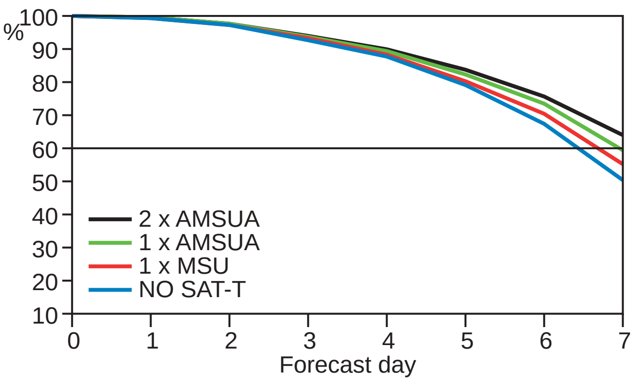

Figure 5 Forecast skill averaged over 50 cases (as measured by the 500 hPa height anomaly correlation coefficients over Europe up to day 7) when no microwave sounding data is made available to the 3D-Var analysis (blue curve), when one MSU instrument from NOAA-14 (red curve), when one AMSU-A instrument from NOAA-16 (green curve) and finally when two AMSU-A instruments from NOAA-15 and NOAA-16 are supplied to the analysis (black curve)

in the Northern Hemisphere. Bearing in mind the relatively poor data coverage provided by the conventional observing system (in particular over the oceans), this result is a strong indication of an improved usage of satellite data in the ECMWF assimilation system.

More generally, recent experiments have demonstrated that the addition of observations from new satellite instruments has systematically improved the performance of the ECMWF forecasting system. Many NWP centres now depend upon the temperature information provided by the microwave sounding instruments on board the NOAA polar orbiting spacecraft. Experiments have been carried out to measure the impact of these systems in a number of configurations. In Figure 5, the blue line shows the forecast skill averaged over 50 cases (as measured by the 500 hPa height anomaly correlation coefficients over Europe up to day 10) when no microwave sounding data is made available to the analysis (which for these experiments is a version of the ECMWF 3D-Var system similar to that being used in the reanalysis project). The other lines in Figure 5 show the increased forecast skill when radiance data from one MSU (on NOAA-14), one AMSU-A (on NOAA-16) and finally two AMSU-A instruments (NOAA-15 and NOAA-16) are supplied to the analysis. The results confirm the importance of the microwave sounding data in the ECMWF suite, and the need to maintain the best possible operational configuration (i.e. two AMSU-A instruments at that time).

Since summer 2002, three NOAA operational satellites carry AMSU-A instruments and they now provide an almost complete coverage of the Earth every four hours (see Figure 6). From this figure one can see how the third sounding mission nicely complements the NOAA-15/16 pair over the south-west Pacific and the north-east Atlantic Oceans (00UTC), the east Pacific and the south Indian Oceans (06 UTC), the South Atlantic and north-west Pacific Oceans (12 UTC) and, finally, the south-east Pacific and the north Indian Oceans (18 UTC).

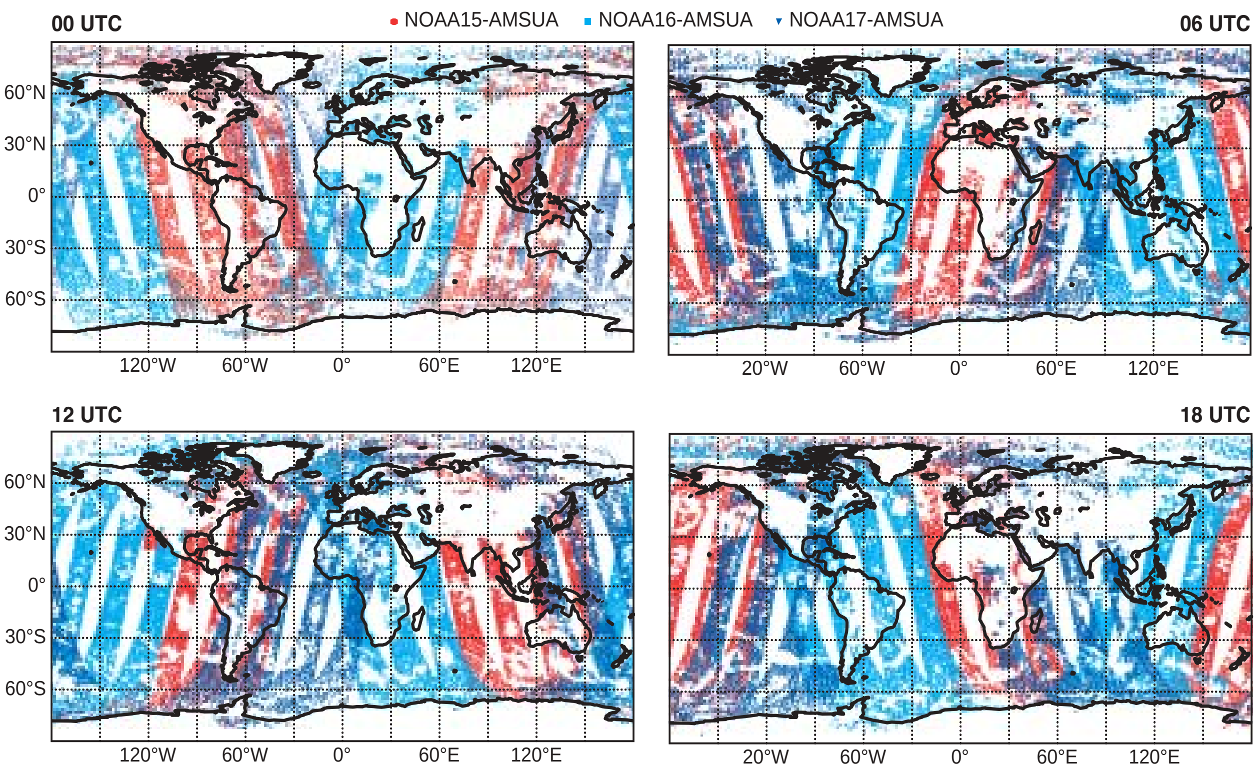

Figure 6 Data coverage for the NOAA-15 (red), NOAA-16 (cyan) and NOAA-17 (blue) AMSU-A instruments, for the four 6-hour periods centred at 00, 06, 12 and 18 UTC 12 November 2002. The plots show the data used for AMSU-A channel 5, which is a temperature-sounding channel in the mid and lower troposphere.

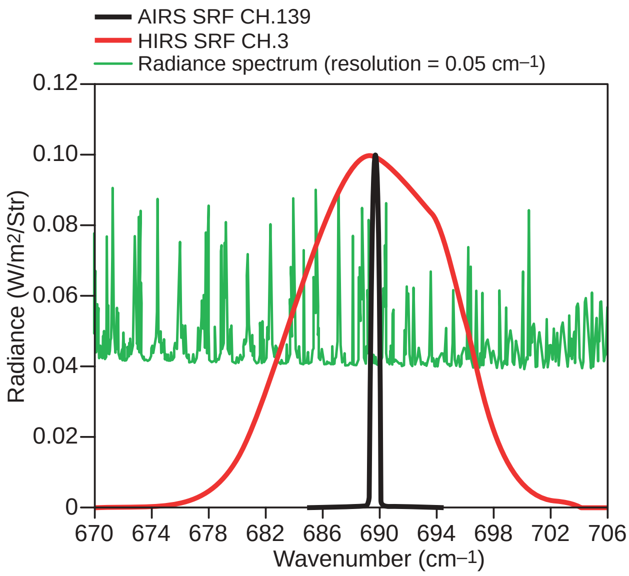

Figure 7 Spectral Response Functions (SRF) of HIRS channel 3 and AIRS channel 139 (long-wave CO_2 band) superimposed with a radiance spectrum at a resolution of 0.05cm^{-1}.

Impact studies have been performed to demonstrate the benefit of a third sounding mission in the ECMWF data assimilation system. Forecast skill scores averaged over 40 cases (mixing results from impact over operations and over the e-suite at that time) of the current baseline including NOAA-15 and NOAA-16, and of the new baseline including also NOAA-17 have been computed. A small but significant positive impact has been found for most of the geographical areas. This positive impact led to the operational introduction of NOAA-17 data in the ECMWF data assimilation system on 29 October 2002.

Further challenges for the assimilation of satellite data

If satellite observations are already playing an essential role in improving numerical forecasts today, the combination of increased model resolution and improved physics, enhanced data assimilation techniques, together with advances in satellite instruments over the next decade, offers the potential for further improvements in data assimilation at NWP centres.

Assimilation of advanced sounders

In parallel with model and data assimilation improvements, the evolution of the current and future satellite observing systems clearly promises a massively increased spectral resolution in the infrared instruments firstly on board polar orbiters, such as AIRS (Advanced Infrared Sounder) on board AQUA launched in May 2002, IASI (Infrared Atmospheric Sounding Interferometer) on board METOP to be launched in 2005, and later on, possibly, geostationary platforms, such as GIFTS (Geostationary Imaging Fourier Transform Spectrometer) to be launched in 2007. As illustrated in Figure 7, those instruments measure radiation in many thousands of different channels, and therefore provide atmospheric temperature and composition information at a much higher accuracy and vertical resolution than can be achieved with the current generation of instruments such as HIRS on NOAA platforms.

Active preparation is under way to exploit AIRS data operationally at ECMWF, and to achieve this a number of key issues are being considered. A particular effort is being dedicated to the design of new monitoring facilities able to check out simultaneously hundreds of channels, for which departures are now computed operationally on a daily basis. The monitoring statistics also provide the input to the bias corrections that have to be applied and to the characterizations of the observational errors. A comprehensive and consistent bias-handling system is a key element for current and future exploitation of advanced sounders. In particular, the extraction from advanced sounders of new quantities (such as trace gases) with low signal-to-noise ratios will only be possible if different bias sources in temperature and water vapour are thoroughly understood and controlled. This requires a capability for disentangling systematic errors inherent in instruments, and radiative transfer and NWP model deficiencies.

A procedure for channel selection has to be designed for efficiently assimilating the maximum amount of information from the original thousands of channels. The challenge is to find a set of channels that is small enough to be assimilated efficiently in a global NWP system (with operational time constraints), but which is still large enough to capture the important atmospheric variability. A particular effort has been undertaken by the AIRS Science Team to provide the NWP community with a near-real-time channel subset that fulfils the NWP requirements. More sophisticated channel selection strategies are also under investigation (*Rabier et al*. 2002).

A key issue for the successful exploitation of advanced infrared sounders is the detection of clouds since they have a significant impact on the radiance measurements. Given that important atmospheric structures occur in cloudy areas, it is of utmost importance to take into account the effect of clouds when present, and so cloud detection is therefore needed to interpret the data correctly. A failure to detect the presence of clouds can result in a (possibly large) signal being wrongly interpreted by the assimilation system, which might force erroneous adjustments to the temperature and humidity fields. However, an over-stringent cloud-detection system can lead to very little data reaching the assimilation, thus reducing the impact of the new high-resolution instrument. *McNally and Watts* (2003) have designed a cloud-detection technique that can be used to identify which radiances at a particular location are free of cloud and which are not. In the longer term, cloud-affected radiances could be exploited, as they can, in principle, provide unique high-resolution information about the temperature structure near the cloud top. In that respect, advanced sounders may indeed be able to determine the cloud top and cloud amount accurately.

Lastly, advanced sounders offer new environment opportunities since they will also provide information about minor constituents of the atmosphere (ozone, N_2O, CO, CH_4). It is also hoped that CO_2 information (at least total column) can be extracted from high-resolution sounders and ECMWF is actively involved in a research initiative to address this issue.

Thanks to many efforts engaged in the various domains covered above, the first assimilation experiments of AIRS radiances are very encouraging. It is, therefore, believed reasonable to expect a first 'day-1' operational implementation of AIRS satellite radiances some time during 2003.

Assimilation of cloud and rain information

New sources of information on clouds and precipitation are becoming available to the NWP community. Satellite imagery is already providing a lot of information on cloud fields, and rain information can be retrieved from microwave imagers. New missions such as Cloudsat-Calipso (to be flown together with AQUA) and Earthcare will enhance the validation of the cloud parametrizations in NWP models by providing, for the first time, information on cloud profiles thanks to the use of 'active' instruments penetrating atmospheric hydrometeors. Global information on rain will be available for NWP with missions such as the Global Precipitation Mission (GPM) and its European component (E-GPM). A particular effort is already taking place at ECMWF to assimilate rain information from the TRMM (Tropical Rainfall Measuring Mission) Microwave Imager (TMI) and the Special Sensor Microwave Imager (SSMI). The degree of agreement between the model and the observations is now considered sufficiently good for us to be convinced that assimilation of such quantities is feasible. An assimilation strategy has been designed at ECMWF for assimilating rain information in two steps: the first step consists of a 1D-Var analysis of surface rain rates, or of the brightness temperatures that generate retrieved total-column water-vapour information, that can then be fed into the 4D-Var system. Figure 8 displays the TMI surface rain-rate product (top right) derived from the PATER algorithm (*Bauer* 2001), the equivalent short-range forecast quantity (top left), the resulting 1D-Var analysis of TMI brightness temperatures (bottom left) and surface rain rates (bottom right) for the case of a tropical cyclone ZOE located east of Indonesia at 12 UTC 26 December 2002. Both approaches manage to capture the cyclone horizontal structure fairly well. The 1D-Var assimilation of brightness temperatures has the advantage that observational error statistics are easier to handle and that, because of the sensitivity of radiances to moisture, rain can be generated from the procedure even if the model background is dry.

Early results indicate that the induced modifications of the humidity field persist in the forecast and improve the cyclone-track forecast. If these encouraging results are confirmed, a real breakthrough will have been achieved in terms of exploitation of satellite data in NWP. Indeed, this approach would have the advantage of providing an optimal coherent treatment of satellite observations under clear, cloudy and rainy conditions.

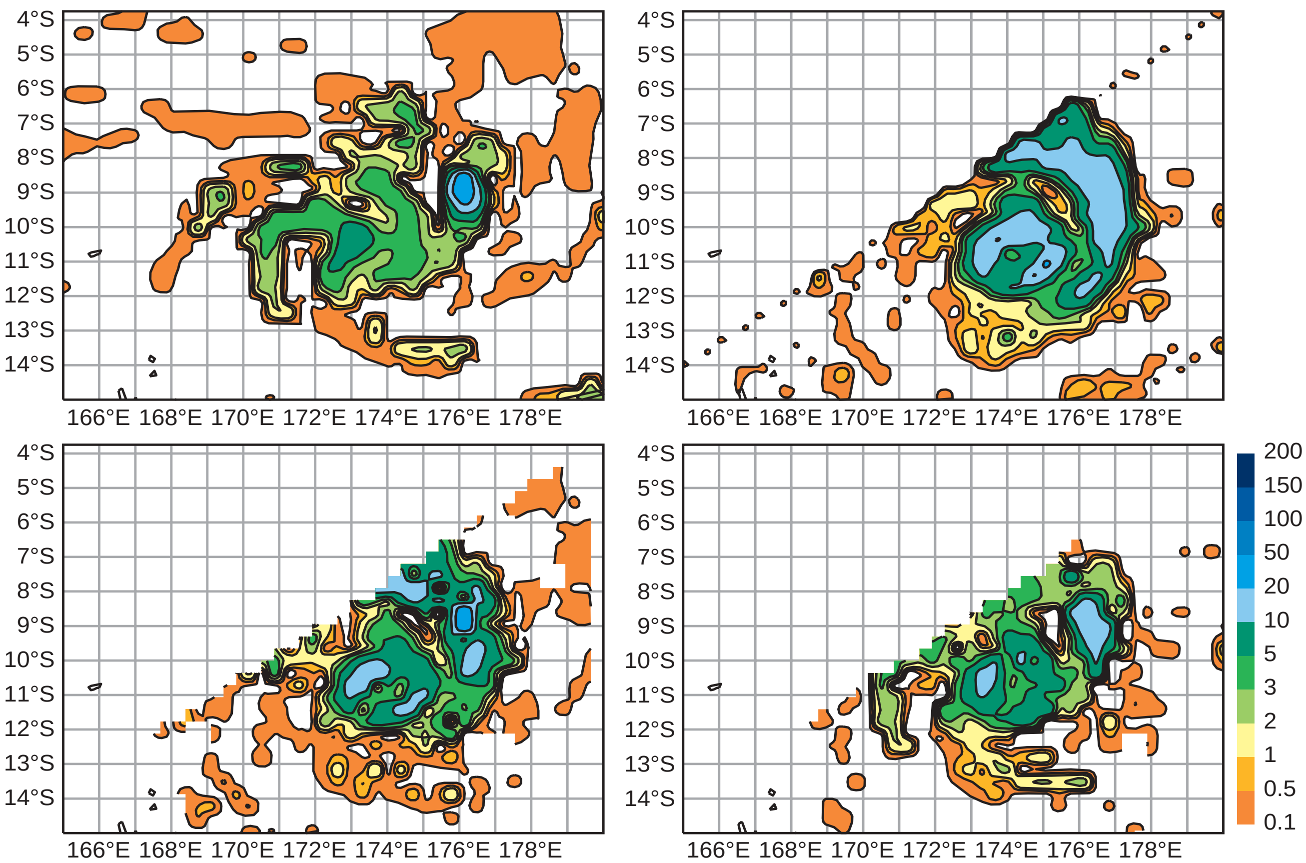

Figure 8 Model background surface rain rate (top left panel), TMI surface rain rate PATER product (top right panel), 1D-Var surface rain rate analysis using TMI brightness temperatures (bottom left panel) and 1D-Var surface rain rate analysis using rain rate products (bottom right panel). Case of cyclone ZOE, 12 UTC 26 December 2002 (after *Moreau and Lopez*, personal communication)

Radio-occultation techniques using the GPS (Global Positioning System)

These techniques exploit an opportunity to derive meteorological information from the already-existing GPS constellation (originally designed for other applications). GPS receivers (such as the GRAS instrument on board METOP) measure the Doppler shift of a GPS signal refracted along the atmospheric limb path. This refraction is proportional to (among other parameters) the density of the atmosphere (and therefore indirectly to temperature and humidity profiles). Provided a sufficient number of receivers are installed on LEO (low earth orbiting) satellites, this technique could offer high vertical resolution (but a somewhat coarse horizontal resolution of ~200-300 km) self-calibrated 'all weather' observations of atmospheric temperature and humidity. Exploiting this new technique in the 4D-Var data assimilation system is a challenge that ECMWF has started to address.

Wind profiling from space with a Doppler wind Lidar

The European Space Agency is currently developing a space-based Doppler wind Lidar (DWL) for launch in 2007, the so-called Atmospheric Dynamics Mission (ADM). This new concept will, for the first time, provide wind-profile measurements from space. The accuracy is predicted to be similar to that of radiosonde wind data. The ADM DWL is an active instrument, which fires pulses of 355 nm wavelength laser light towards the atmosphere. In the return signal, backscattered light from molecules and particles at different levels in the atmosphere is collected and the sequences of measured Doppler frequency shifts allow the determination of velocity profiles of the wind-component parallel with the instrument's line-of-sight. The vertical resolution is 500 m below 2 km, 1000 m up to 16 km, and 2000 m in the two layers between 16 and 20 km altitude. ECMWF is preparing for the future use of ADM data in NWP in a two-year study funded by ESA. The yield and accuracy of the data is simulated, given realistic cloud and aerosol distributions. The ADM contribution to analysis accuracy with respect to jet streams and the tropical circulation will be assessed.

Acknowledgements

The ECMWF Data Assimilation and Satellite Sections are warmly acknowledged for providing a lot of material for this paper. The input from Adrian Simmons and Philippe Lopez has also been invaluable.

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Jean-Noël Thépaut and Erik Andersson.

A major new cycle of the IFS: Cycle 25r4

The forecasting system at ECMWF is regularly upgraded (at least once per year) to incorporate new or improved assimilation techniques, numerical methods, physical parametrizations, and data usage. There are also frequent coding revisions to improve the efficiency of the codes and to adapt to new hardware etc. Often a new cycle contains one or more of these changes, but occasionally a cycle comprises changes to almost all components of the forecasting system, and CY25r4 was one of these. Furthermore, a new IFS (Integrated Forecasting System) cycle often has relatively modest meteorological impacts, but CY25r4 gave one of the largest positive impacts seen in the testing of cycle changes in recent years. The extent of the changes and revisions is such that this article concentrates on describing only the principal changes to the system, their motivation and main meteorological impacts. Overall assessment of the cycle in terms of the combined impact of all changes on objective verifications is also briefly discussed. Several of the changes are, or will be, described in more detail in Technical Memoranda or other publications. This cycle was implemented operationally on 14 January 2003.

Data Assimilation changes

An important trend in the development of the 4D-Var data assimilation system is the rapid increase in the use of satellite data. The additional data contribute significantly towards improved analysis accuracy. However, very dense or very frequent observations can reduce the rate of convergence of the iterative solution algorithm, adding substantial computational load to 4D-Var, or requiring limited accuracy of the solution. In 4D-Var, the main computational expense is related to minimizing an objective cost function. This is currently done at T159 resolution having first compared the observations against T511 model fields.

In CY25r4, with the increasing data volumes in mind, the 4D-Var-solution algorithm was comprehensively revised to improve its accuracy and efficiency. Future increases in analysis resolution (to T255 or higher) should be possible with the new algorithm. Following an approach implemented at Météo-France, the new solution algorithm first solves the 4D-Var problem approximately at low resolution (T95). This provides an accurate preliminary analysis for subsequent calculations at full analysis resolution (T159), thereby reducing the number of computationally expensive iterations that must be performed at full resolution. In addition, information gleaned during the T95 step about the 'shape' of the analysis cost function is used to accelerate ("precondition") the T159 minimization. The iterations are carried out until an objective stopping-criterion is reached, ensuring that the solution is reached to within similar error bounds from day to day in the operational suite. The scheme was further modified to take advantage of the Conjugate Gradient algorithm, the most efficient of available minimizers for this type of application. The revised 4D-Var furthermore generates its estimate of analysis error simultaneously with the actual analysis (rather than in a separate calculation), which also contributes to the efficiency gains of the new cycle.

Figure 1 shows an example of analysis increments calculated at T95 (Figure 1(a)) and the update calculated at T159 (Figure 1(b)). The example is for temperature at model level 50. It shows that most of the increment is formed at T95, with finer-scale and smaller additions or corrections obtained from the T159 iterations.

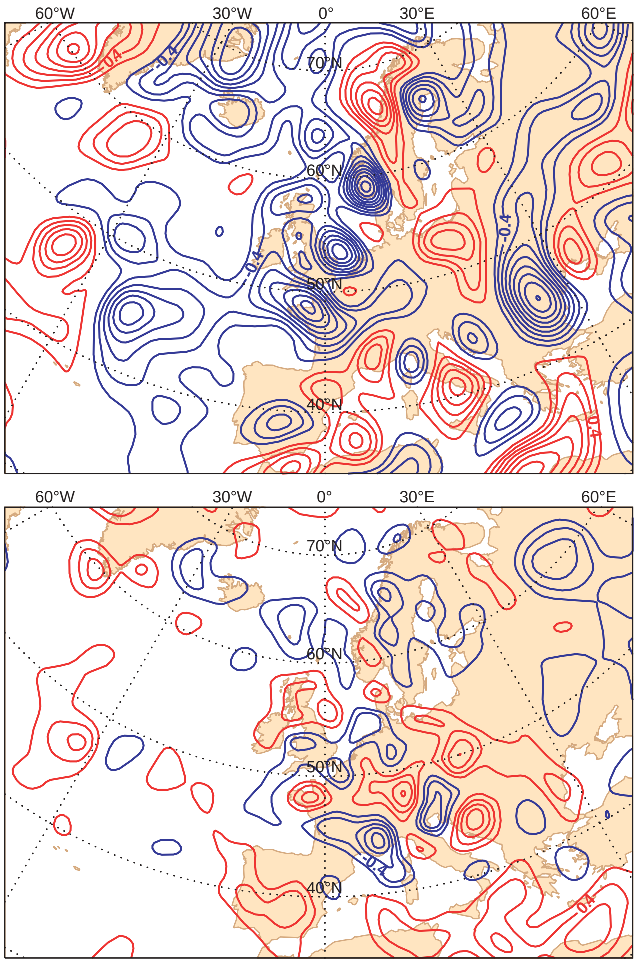

Figure 1 Analysis increments for temperature (0.2 K contours, positive in red and negative in blue) at model level 50 (~880 hPa), at 00 UTC 25 September 2002, produced by (a) the T95 and (b) the T159 iterations of the revised 4D-Var solution algorithm (*L. Isaksen, Y. Trémolet and M. Fisher*, personal communication). The total analysis increment is the sum of the two. Most of the increment is formed at the lower resolution with smaller additions and corrections obtained at the higher resolution.

Analysis changes were also made with more direct meteorological impacts. These were:

1. A new set of background-error statistics, based on an ensemble of 4D-Var assimilations. The new statistics have smaller amplitude reflecting the improved accuracy of the assimilation system, especially in the stratosphere, and the error structures described are generally sharper in both the horizontal and the vertical.
2. The low-resolution (T95 and T159) model fields and their evolution over the 12-hour assimilation period are now generated through interpolation of a high-resolution (T511) forecast for improved consistency – a full description of this modification is given in ECMWF Technical Memorandum 399 (*Trémolet*, 2003).
3. The dynamical balance between wind and mass analysis increments was improved to account for the effects described by the non-linear balance equation and the quasi-geostrophic omega equation. This is likely to be of particular importance in ageostrophic flows near jet streams (Figure 2) and in the tropics.
4. The control of gravity-wave noise in the analysis was made more selective by applying the 'digital filter' technique on divergence only, rather than for all dynamical fields.

Use of satellite data

Improvement of the use of SSM/I data

For better scientific consistency and a more efficient data handling in the assimilation system, the SSM/I data assimilation strategy has been changed. The operational 1D-Var retrieval of total-column water vapour and near-surface wind speed has been replaced by the direct assimilation of radiances, bringing the use of SSM/I radiances in line with use of HIRS, METEOSAT and AMSU-A radiances. This entailed introducing use of the same fast radiative-transfer model, RTTOV, for SSM/I as for the other radiances. In addition, an improved surface emissivity model has been activated for both the SSM/I and the AMSU-A microwave sensors. Test assimilation experiments demonstrated improved performance from the use of RTTOV for SSM/I, evidenced by strongly reduced biases and distribution widths. Simulations of the AMSU-A radiances were also improved.

Assimilation of polar winds from MODIS

New satellite-derived wind products over the Polar Regions are derived at the University of Wisconsin (Madison, USA) by tracking structures in consecutive swaths from the Moderate-resolution Imaging Spectroradiometer (MODIS) onboard the NASA-Terra satellite. This new product provides unprecedented coverage of the polar wind field, poorly observed otherwise. Several assimilation experiments have been performed to assess the impact of these data on the quality of the ECMWF analyses and forecasts.

Early 3D-Var trial experiments showed a large positive impact of the MODIS winds in the Northern Hemisphere and a small positive impact in the Southern Hemisphere. Recent 4D-Var experiments confirmed the positive impact

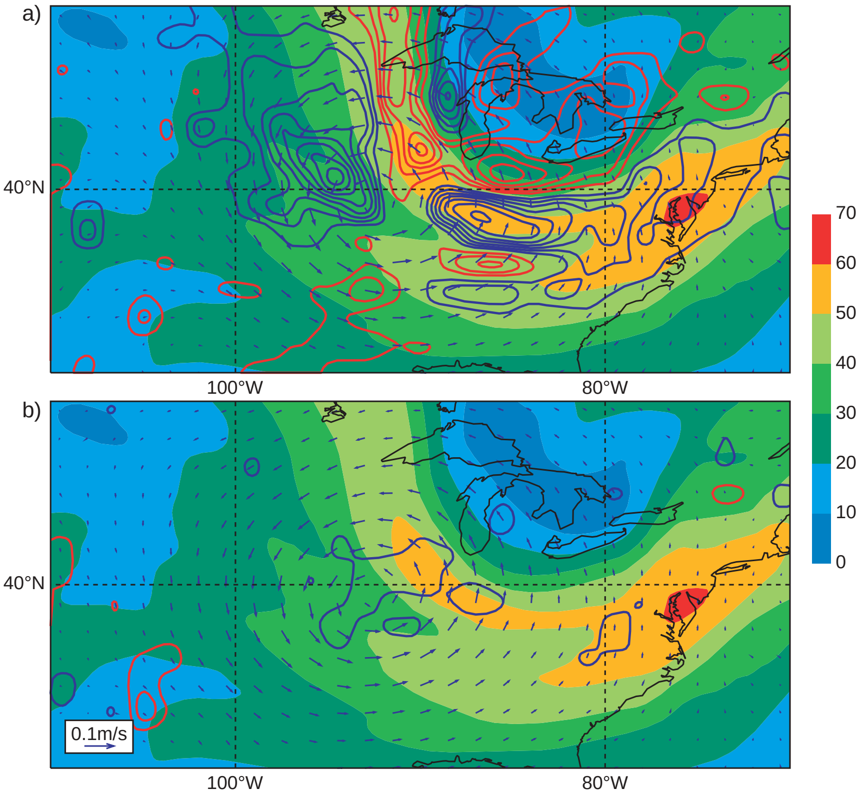

Figure 2 Analysis increments due to a single height observation at 300 hPa near the jet entrance at 09 UTC 14 May 2002 for (a) the revised 4D-Var and (b) the previous version (*M. Fisher*, personal communication). The wind speed is colour shaded in 10 m/s bands according to the legend. The wind increments are shown as arrows and the contours indicate their divergence (red) and convergence (blue). In this case, the single height observation lowers the geopotential (not shown) at the jet entrance resulting in cyclonic wind increments. The revised 4D-Var produces a convergence/divergence pattern consistent with the secondary circulation expected in the region of a jet-entrance, in contrast to the previous version.

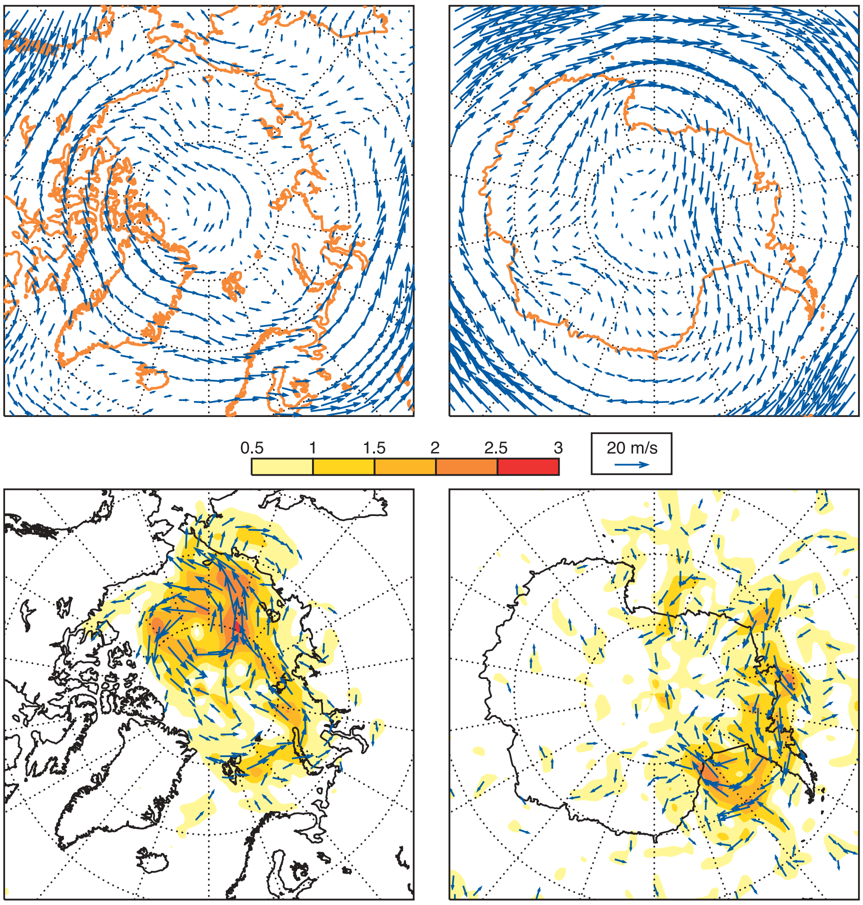

Figure 3 Mean polar-wind analyses at 400 hPa for the CTL (No MODIS) experiment for 5 March – 3 April 2001 (upper row). The difference between the mean wind analysis for the MODIS and the CTL experiment for the same period is shown in the lower panel. Shading indicates the magnitude of the difference vector (m/s).

of these wind products. Several synoptic examples have revealed how Northern-Hemisphere forecasts are sensitive to analysis perturbations over the Polar Regions and how the assimilation of MODIS winds could reduce key analysis errors in these areas, subsequently leading to improved forecasts. The assimilation of MODIS winds can significantly alter the mean polar wind analysis, as illustrated in Figure 3 where the mean 400-hPa polar wind fields are displayed for the current 4D-Var configuration (CTL) and for the North Pole and South Pole. The difference between the mean wind analysis for the MODIS and the CTL experiment is shown in the lower panel. Differences are largest over the Arctic sea ice, where MODIS winds act to strengthen the cyclonic circulation. It was verified that the changes to the mean-wind analyses are indeed supported by the rest of the observing network.

Following the first operational implementation of MODIS winds in the CY25r4 version of the assimilation system, several improvements have been identified. Quality-control decisions have been very conservative thus far, with no assimilation of low-level winds. The tuning of observational errors (variance and correlations) has been copied from that of the atmospheric motion vectors from geostationary satellites. Also, similar products from the AQUA platform are now available at ECMWF, but are only passively monitored for the time being. Addressing these issues will further enhance the impact of this new source of observations.

Introduction of data from more HIRS channels

Since 1999, when data from the first AMSU-A instrument on board NOAA-15 began to be assimilated operationally, the HIRS instruments on NOAA platforms have only been used in a very limited way. Only channel HIRS-12, a channel sensitive to upper-tropospheric water vapour, has been used from the NOAA-14 satellite. It was felt that the quality of temperature information provided by AMSU-A together with the difficult issue of cloud contamination of infrared sounders did not make it worthwhile assimilating HIRS temperature channels. Recently, a new quality-control method has been developed for cloud detection. This approach makes use of the long-wave sounding channels, with appropriate thresholds on observation departures to identify the first channel (going downward from the top of the atmosphere to the surface) affected by clouds, and with channels peaking below being considered cloudy. Several trial experiments showed a significant positive impact of these data on the forecast skill, and their use was thus included in CY25r4.

Assimilation of GOES clear-sky water-vapour radiances

The first operational implementation of clear-sky water-vapour radiances from a geostationary platform was in April 2002, with the assimilation of radiance products from the EUMETSAT METEOSAT-7 satellite. This implementation showed good local improvements in the quality of the upper-tropospheric humidity (UTH), estimated via the comparison of the model field with independent sources of observation (HIRS and AMSU-B from NOAA platforms). Similar products have been made available from the American GOES West and East satellites since Spring 2002. These products are of better quality than those from METEOSAT in terms of bias, and are of similar nature in terms of noise. The assimilation of the GOES radiances has revealed an impact very comparable to that of METEOSAT. In particular, a drying of the intertropical convergence zone (ITCZ) and the south Pacific convergence zone (SPCZ), together with a moistening of adjacent regions, was seen, clearly contributing towards corrections of model deficiencies. Forecast scores showed small but positive improvements, especially for upper-tropospheric wind and geopotential fields. Following the introduction of these data in CY25r4, tests of the assimilation of METEOSAT-5 radiance products (which have recently improved in quality) are being planned to extend the radiance coverage to the Indian Ocean. Complete tropical and subtropical UTH coverage will then be achieved when GOES-9 is relocated over the western Pacific (as displayed in Figure 4).

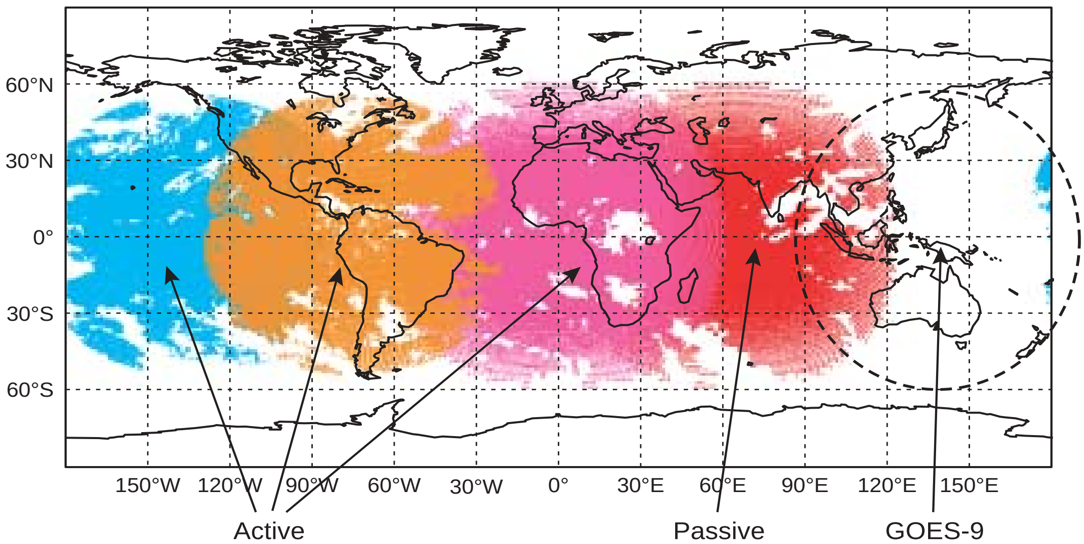

Figure 4 Data coverage provided by the GOES satellites (cyan and orange) and the METEOSAT satellites (magenta and red) for 00 UTC 10 May 2003. The total number of observations was 266,878.

SAR wave data assimilation

Until CY25r4, altimeter data were the only data source in the wave-model assimilation. The altimeter data give wave heights and wind speeds over a small footprint. A more accurate description of the sea state requires the two-dimensional wave-energy spectrum. Such observations, albeit neither necessarily fully comprehensive nor independent, are available from the synthetic-aperture radar (SAR).

ERS-2 SAR wave mode 'imagette' spectra are processed operationally to retrieve ocean-wave spectra using an inversion scheme based on the work done by *Hasselmann et al.* (1996). The inversion scheme relies on a model first guess to resolve the directional ambiguity and to provide first-guess information on the high-frequency part of the wave spectrum. Note that the SAR images only part of the total wave spectrum. Waves with wavelength shorter than an observation-dependent cut-off wavelength are not detected or are heavily distorted.

In CY25r4, the method originally developed by *Hasselmann et al.* (1997) was implemented. This is based on the assimilation of wave systems as derived from a spectral-partitioning scheme that works on the principle of the inverted catchment area. The different wave systems are characterized through their mean energy, frequency and direction. The mean parameters are assimilated using an optimal interpolation scheme, and the analysed spectra are reconstructed by resizing and reshaping them based on the mean parameters obtained from the scheme.

Most of the experiments were carried out with the uncoupled or stand-alone version of WAM in which operational six-hourly wind-field analyses are used to force the model. SAR data are expected to have the largest impact on the low-frequency part of the wave spectra, which has the least impact on the atmospheric coupling. Nevertheless, the final implementation was tested with the coupled system.

Hindcasts for December 2000 and May 2001 were run without any data assimilation (no data), using only SAR data, only altimeter data, and with both SAR and altimeter data. Figure 5 shows that, for May 2001, using either set of satellite data improves the global statistics. Altimeter data have a larger beneficial effect on the wave-height statistics, whereas adding SAR to altimeter data produced further benefit, especially for the peak period. Data assimilation for December 2000 resulted in the reduction of the systematic biases without any impact on the random error.

Hindcasts for other months, both with the coupled and with stand-alone model, confirmed the small beneficial impact of SAR data on top of altimeter data for spring and summer in the Northern Hemisphere (where independent buoy observations are available).

Forecast model changes

The model changes in CY25r4 comprise two main components: (i) A major revision of the cloud scheme and its numerics, and (ii) a substantial change to the convection scheme, mainly in the convection-activation and type-selection algorithms.

Cloud scheme

The ECMWF prognostic cloud scheme has been operational since April 1995, but over the years many changes and adjustments have been made, resulting in a code that has become increasingly difficult to work with and to improve. Furthermore, the numerics of the cloud equations were not

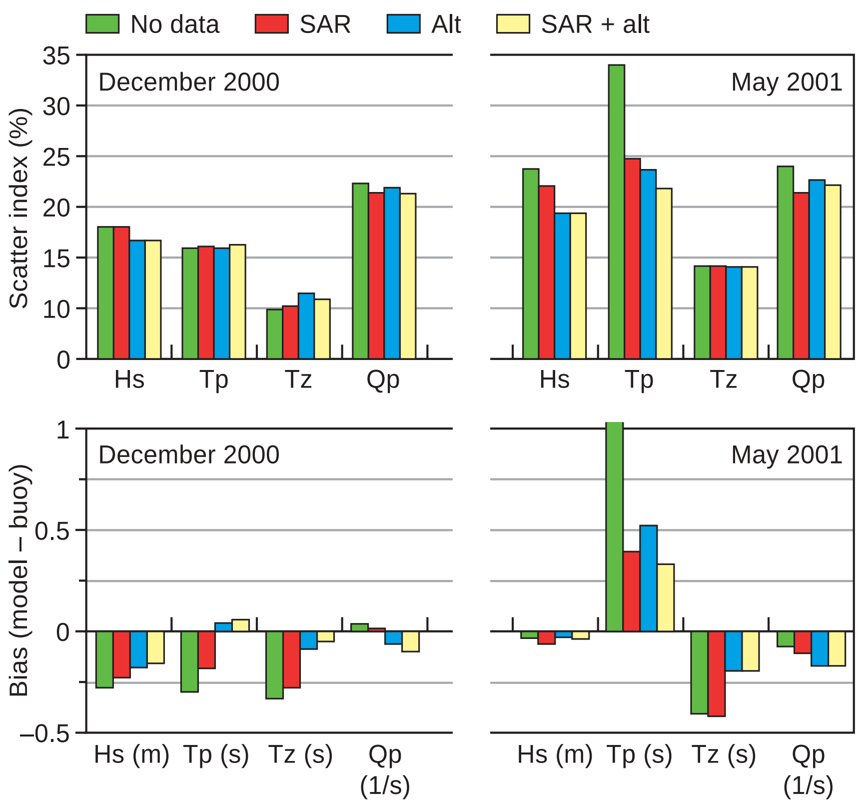

Figure 5 Comparison between wave-model hindcasts in stand-alone mode and buoy and platform data for December 2000 and May 2001. Significant wave height (Hs), peak wave period (Tp), zero mean crossing wave period (Tz) and peakiness factor (Qp) are compared for runs without any data assimilation (no data), with only SAR data assimilation (SAR), with only altimeter (alt) assimilation and with both SAR and altimeter (SAR + alt) assimilation. The scatter index is defined as the standard deviation of the difference normalized by the observation mean value.

compatible with the currently used 'second-order' integration of the physics processes. Therefore, a considerable effort has been made to rewrite the cloud scheme, removing as many of the switches and limiters as possible without any negative impact on the scheme's performance. Although the emphasis has been on the numerics, scientific changes were made as well. The ice fall-out formulation was not functioning as intended due to numerical inaccuracies, with the small particles settling faster than the large particles. A new formulation has been introduced to correct this unphysical behaviour, with the Heymsfield and Donner formulation being used for the large particles and a constant velocity specified for the small particles. The revised code treats nearly all processes impartially, conserves total condensate amount, and is over 30% faster than the original code.

A new algorithm for the activation of convection and the computation of cloud base and cloud top

From operational monitoring it had become evident that, in some situations (mainly in summer), unrealistically high precipitation was produced by the model over land, particularly over the USA. In these cases model precipitation was dominated by large-scale condensation accompanied by strong ascent (~1 m/s) over a small number of grid points. When this occurs during the first-guess computation, it is harmful to data assimilation as the resolved ascending motion creates large divergent flows in the upper troposphere which do not fit the observations.

Further diagnosis revealed that the convection scheme failed to be sufficiently active in night-time situations. This was traced back to the lack of convection activation when the lower levels are stable. In the former version of the convection scheme, activation of deep convection is only possible from the lowest model level, otherwise the so-called 'mid-level' convection should take over, but mid-level convection is rather weak with the current closure. When the parametrized convection is not strong enough, the resolved motion results in overly strong precipitation events.

To alleviate these problems, the convection-activation algorithm has been redesigned. Prior to the changes, the cumulus parametrization starts with a decision on the occurrence of cumulus convection and its type: shallow, deep or mid-level. Additionally, cloud-base values need to be specified. The original scheme switches on if an undiluted parcel

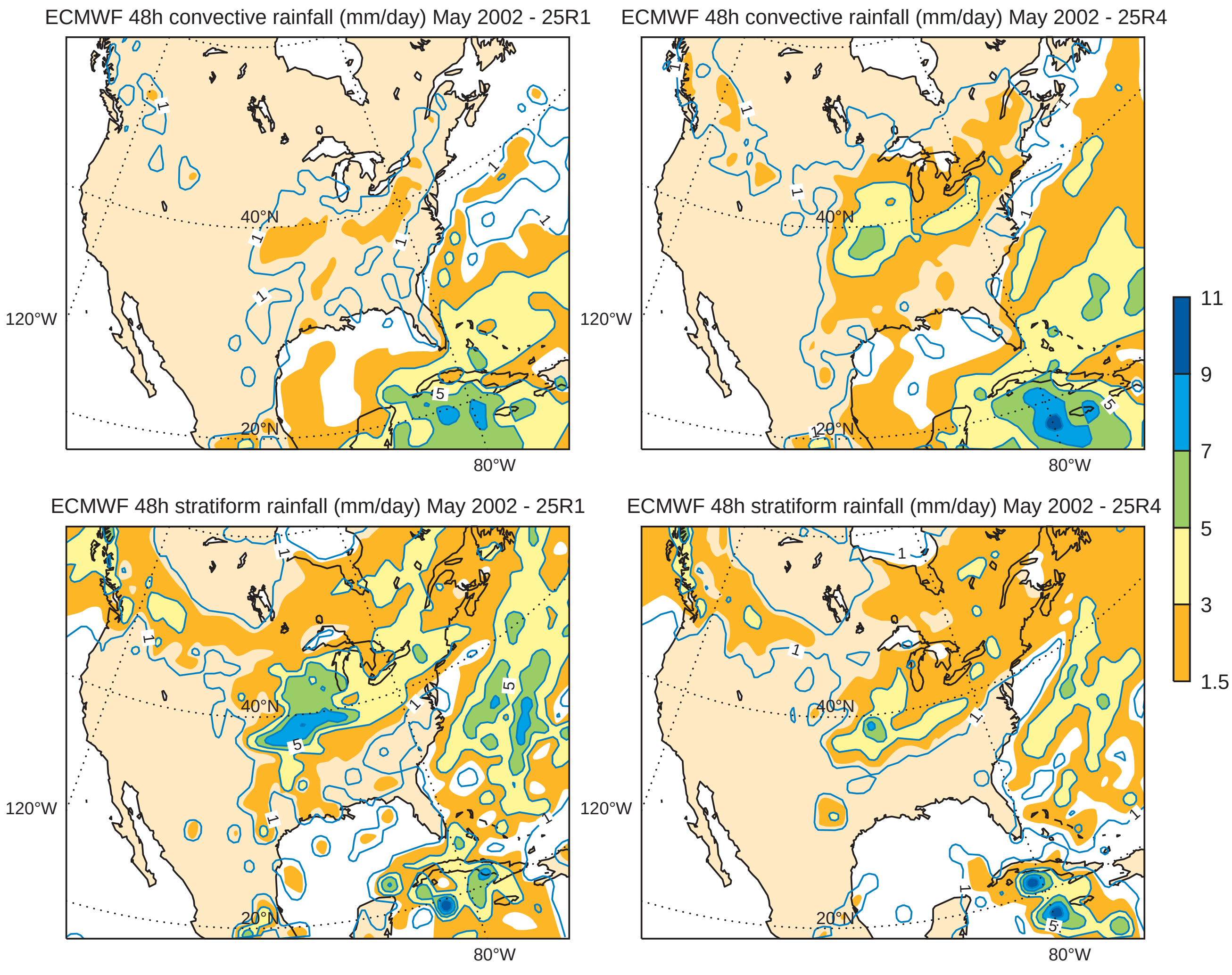

Figure 6 The May 2002 monthly-mean convective precipitation (top) and stratiform precipitation (bottom) from daily 24- to 48-hour forecasts with CY25r1 (left) and CY25r4 (right). The colour key is in mm/day.

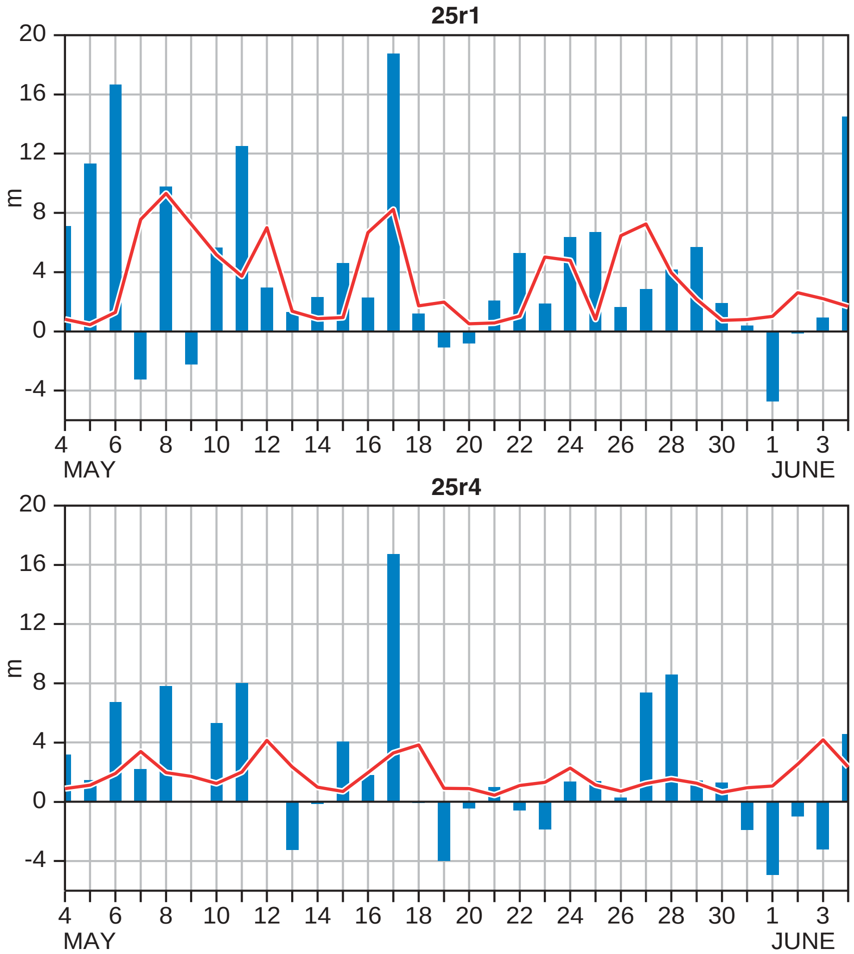

Figure 7 Time-series of the mean 200 hPa height increments (m) (blue bars), and the maximum divergence (10^{-4} s^{-1}) (red line), for the month of May over North America (30–50°N, 50–80°W). The upper panel shows results from diagnostics produced using CY25r1 and indicating systematic positive increments at 200 hPa and extreme divergence values associated with excessive precipitation. The lower panel shows the same parameters using CY25r4.

exceeds a negative buoyancy of 0.5 K at cloud base. The undiluted parcel ascent is also used for the type decision according to an estimate of cloud depth. Furthermore only the lowest level is tested in this manner.

The new formulation starts with an entraining plume from the lowest model level to test for shallow or deep convection depending on cloud depth, with deep convection requiring a minimum cloud depth of 200 hPa. For shallow convection the parcel is initialized with thermodynamic excess properties and a vertical velocity according to surface-layer similarity. Then, mixed-layer parcels (averaged over 30 hPa) are lifted with an entraining plume model (constant entrainment) from any level up to 300 hPa above the surface to test for deep convection thus enabling deep convection when the lower layers are stable. The discrete cloud base is now set to the closest model level instead of the level below cloud base. Convection activity has also been increased by decreasing the water loading in the updraught. Furthermore, precipitation efficiency in the updraughts has been increased, leading to less detrainment of condensate to the stratiform clouds.

Testing of the cloud and convection changes

The combination of cloud and convection changes has been tested extensively in long integrations and data assimilation. After some re-tuning of the cloud scheme, an improved model climate was obtained with better tropical winds. The latter is obviously important for seasonal forecasting. The main experimentation was in combination with the data assimilation and satellite changes forming CY25r4. The modifications to the convection scheme result in a systematic increase of the convective precipitation at the expense of large-scale precipitation (Figure 6). Because of the increased activity of the convection scheme, the atmosphere is stabilized and the number of cases with extreme precipitation is substantially reduced. This is particularly noticeable in the first-guess divergence and the 200-hPa height increments over North America at 12 UTC (Figure 7). The operational system with CY25r1 showed many night-time events with strong vertical motion (up to 1 m/s), strong precipitation and excessive divergent flow in the upper troposphere. The resulting wind field was not supported by the observations, resulting in rejection of data and non-optimal performance of the data assimilation system. The new cycle reduces the extreme events by stabilizing the atmosphere through more active parametrized convection (see bottom panel of Figure 7). The improved analysis is reflected in smaller wind errors over North America in the 24-hour range and a downstream effect of improved medium-range forecasts over the Atlantic and Europe.

Overall performance

Development and testing of CY25r4 was greatly aided by a rapid migration of the forecasting system to ECMWF's new

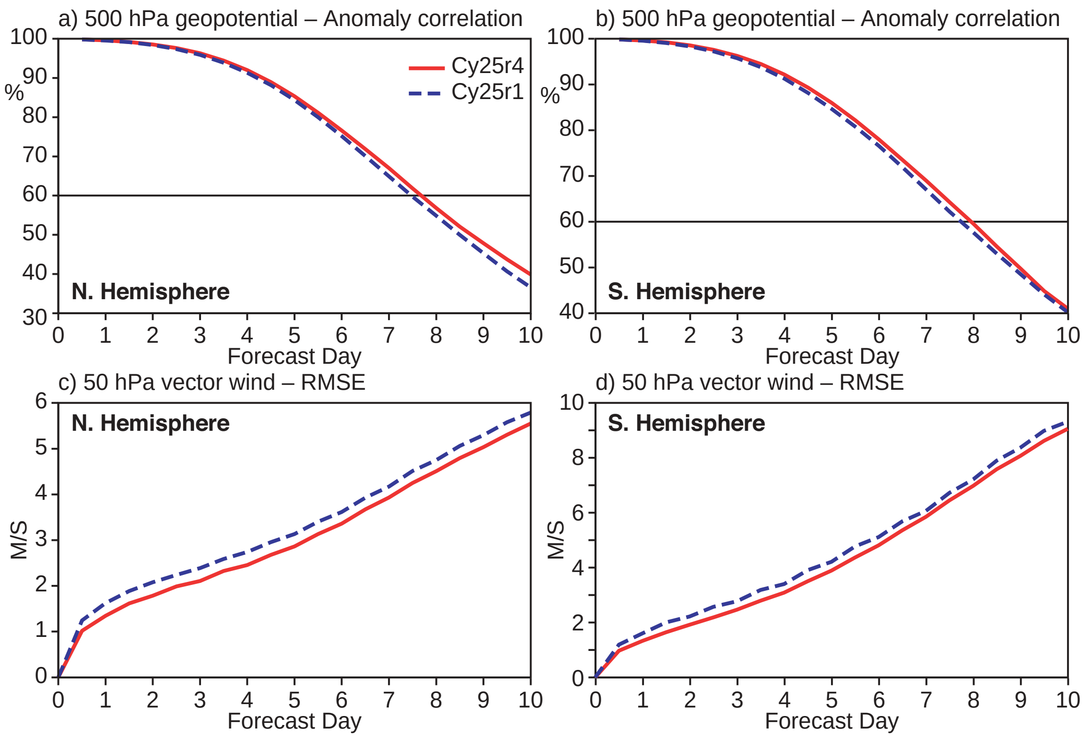

Figure 8 Anomaly correlation of 500 hPa height (upper panels) and root-mean-square 50 hPa vector-wind error (lower panels) for the extratropical Northern Hemisphere (left-hand panels) and Southern Hemisphere (right-hand panels). Mean scores for the period from 4 May 2002 to 13 January 2003 are shown for 12 UTC forecasts from cycle CY25r4 (red solid) and cycle CY25r1 (blue dashed) verified against analyses.

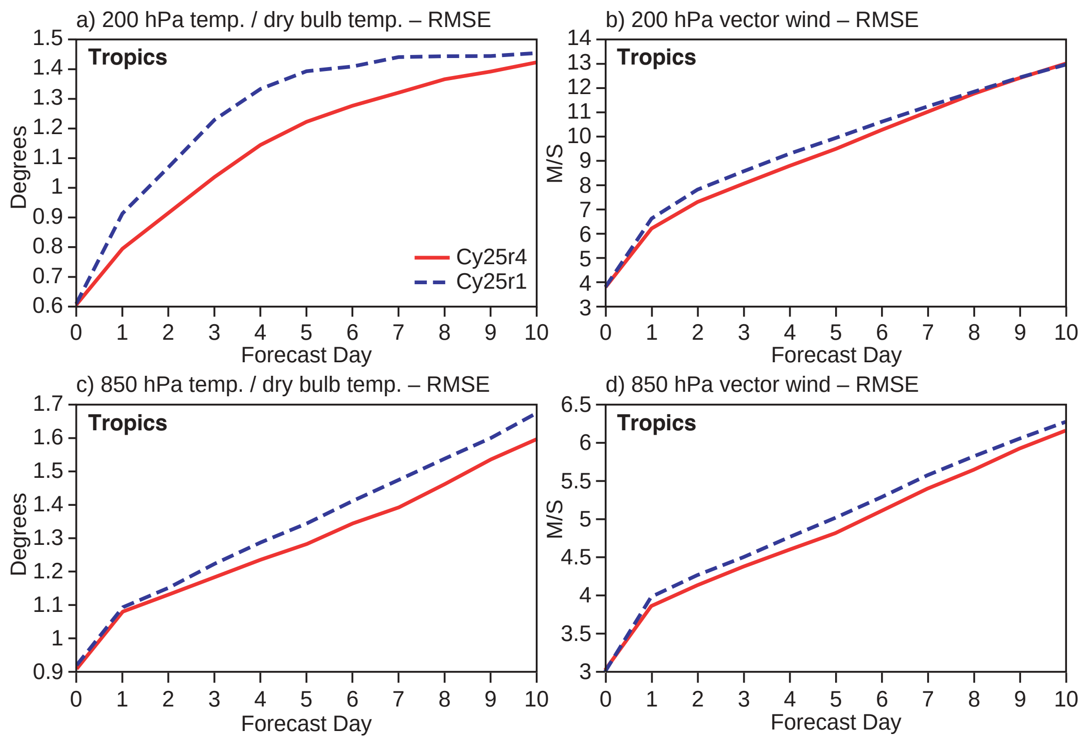

Figure 9 Root-mean-square 200 hPa (upper panels) and 850 hPa (lower panels) root-mean-square errors of temperature (left-hand panels) and vector wind (right-hand panels) for cycle CY25r4 (red solid) and cycle CY25r1 (blue dashed) averaged over 12 UTC forecasts from 4 May 2002 to 13 January 2003 verified against tropical 12 UTC radiosondes.

IBM high-performance computing system. This enabled an unprecedented number of days of assimilation and forecasts to be run in research mode prior to, and then in parallel with, near-real-time running of the new cycle both on the IBM system and on the then-operational Fujitsu VPP5000 system. In total, forecasts from 12 UTC for each day from 4 May 2002 to 13 January 2003 were run using CY25r4 on the IBM system. Comparisons of these forecasts with the operational forecasts for the period produced using CY25r1 on the VPP5000 provided confidence in the technical migration of the forecasting system in addition to confidence in the meteorological changes introduced in CY25r4.

Objective verification showed improvement of CY25r4 over CY25r1 for virtually all levels, areas, variables and time ranges, and for verification against analyses and against radiosondes. Figure 8 shows 500 hPa height anomaly correlations and 50 hPa root-mean-square vector-wind errors for the extratropical northern and Southern Hemispheres, averaged over all forecasts. Forecasts from a particular cycle were verified against the analyses from the same cycle to the extent possible, and against operational analyses (i.e. analyses from the other cycle) for the small percentage of cases for which this was not possible. The conclusion that the CY25r4 forecasts are better than the CY25r1 forecasts is statistically significant at the 0.1% confidence level out to day 7 for a t-test applied to the score differences, assuming them to be temporally uncorrelated. The 60% level for the mean Northern Hemisphere 500 hPa height anomaly correlation is crossed some 4.5 hours later with CY25r4 than with CY25r1. The corresponding figure for the European domain (not shown) is 6 hours, although the much larger scatter of results for this domain renders the improvement of CY25r4 over CY25r1 of lower statistical significance than for the hemisphere as a whole. ECMWF's current ten-year strategy aims at a net improvement of one day in these measures of forecast skill, equivalent to an average improvement of just under 2.5 hours per year.

Figure 9 shows verification statistics for the tropics. Root-mean-square errors of 850 and 200 hPa temperature and vector wind are shown. In this example the verifications are against radiosonde data. A substantial improvement of CY25r4 over CY25r1 is again seen.

Concluding remarks

The preceding sections have described a major new IFS cycle with large and extensive impacts on the meteorology, and with outstanding improvements in objective scores. Operational implementation was not achieved without several 'false starts' during testing, and the success of the cycle owes much to the existence of a flexible and efficient computing environment for running research forecasts and pre-operational ('e-suite') trials. The new cycle contained very extensive technical revisions to enable efficient performance of the IFS on the IBM supercomputers. The successful implementation of the cycle also depended crucially on this work.

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Hasselmann S., **C. Brüning**, **K. Hasselmann**, and **P. Heimbach**, 1996: An improved algorithm for the retrieval of ocean wave spectra from SAR image spectra. *J. Geophys. Res.*, **101**, C7, 16615- 16629.

Hasselmann S., **P. Lionello**, and **K. Hasselmann**, 1997: An optimal interpolation scheme for the assimilation of spectral data. *J. Geophys. Res.*, **102**, C7, 15823-15836.

Erik Andersson, Anton Beljaars, Jean Bidlot, Martin Miller, Adrian Simmons and Jean-Noël Thépaut

Migration of the high-performance computing service to the new IBM supercomputers

On 18 December 2001, the Director of ECMWF signed a contract with IBM to replace ECMWF's Fujitsu VPP systems by a succession of systems based on IBM servers in a Cluster 1600 architecture, each phase of the contract to comprise two identical clusters (see *Dent et al*. pp 11-14 ECMWF Newsletter 93 - Spring 2002). The first phase, where each cluster has 30 IBM p690 servers with four Nighthawk-II nodes acting as I/O servers, was installed the following year.

A migration task force was set up. This comprised a small number of staff, from various sections within ECMWF, who would establish what needed to be done in order to ensure that the Centre would continue to provide a full high-performance computing service to its users once the service on the Fujitsu systems was terminated. The task force members were not necessarily the people who would perform the work needed to ensure a smooth transition of service from the Fujitsu to the IBM system. They were the ones charged primarily with understanding and specifying the requirements, the resources needed, both in computing terms and in manpower, and the timetable for the migration. The group was also responsible for monitoring the progress of the migration.

The number of p690 servers was not fixed at the time the contract was signed, since the contract called for the provision of a certain amount of sustained computing power. Because of this, there were uncertainties in the power and cooling requirements of the equipment needed for the initial phase of the contract. This, coupled with the flexibility of options open to IBM in the equipment it can install in order to fulfil the performance requirements of later phases, meant that it was difficult to plan the exact location where the hardware was to be installed. There were several possibilities, one of which would have required installing one of the clusters in the area designated as the 'tape library'. This option, however, could have necessitated making alterations to the Fujitsu VPP700 system that was located there. In the end it was decided that the equipment could be installed in

Figure 1 The 2 Cluster 1600 systems in the main computer hall.

the main computer hall, though it was somewhat of a tight fit, as can be seen from the photograph (Figure 1).

In January 2002 a small test system was installed in the machine room. This comprised four Nighthawk-II nodes, one 32-CPU p690 server, a small dual-plane 'colony' switch and about half a terabyte of disk space. At that time the Parallel Support System Program (PSSP) software did not support connecting the p690 server to the switch. This was achieved in May, when the server was logically partitioned into four nodes (LPARs), each of which was connected to the two planes of the switch. This test system was used extensively to port codes and utilities from the Fujitsu VPP system and to test out GPFS, the General Parallel Filesystem and LoadLeveler, the batch subsystem that is used on the IBM system. Up until then ECMWF had always used NQS as the batch subsystem on its supercomputers and moving to LoadLeveler was a significant departure from this, requiring a lot of experimentation.

By the time that the first of the two large clusters arrived in June 2002, a large proportion of the migration was complete. Also, by gaining early experience with the test system, it was possible to configure this cluster and provide a user service in a much shorter length of time than would otherwise have been the case. Because the disk subsystem on the cluster, based on fibre-channel disks, was considerably different from that on the test system, based on Serial System Architecture (SSA) disks, that part of the migration effort related to I/O performance had been postponed until the arrival of the first cluster. This could now get underway, as could experiments on the scalability of application codes with respect to the number of nodes they use. Work could also start at this time on setting up the various suites of jobs that are run each day to produce the operational forecast. More information about these aspects of the migration is given later.

When the second cluster arrived in August even less time was needed to get it into service, thanks in part to some of the systems administration tools that the HPC section had migrated from the Fujitsu VPP system. At this time however it was becoming apparent that there were some serious problems that had to be resolved before the formal acceptance process could proceed. IBM put a lot of effort into analysing and fixing these problems, most of which were eventually traced to p690 and switch adapter microcode and to 'bugs' in the code which attempts to recover from various hardware failures. Acceptance of the system was delayed until these problems were fixed.

The system passed its 'operational acceptance' test on 8 December 2002 and ECMWF was able to offer a full user service from 4 January 2003, exactly on schedule. On 7 February this year the system passed its 'reliability acceptance' test, with an availability of 99.1% and on 4 March ECMWF switched the dissemination of products from the operational forecast that was run on the Fujitsu systems to that which is run on the IBM system. Finally on 31 March the user service on the Fujitsu VPP system was terminated.

Migration of IFS from the Fujitsu VPP5000 to the IBM p690

ECMWF's Integrated Forecasting System (IFS) software is developed jointly with Météo-France, who will continue to run it operationally on their Fujitsu VPP5000 system.

The migration of the IFS to the IBM system involved two overlapping stages. One stage was needed to get the code to run correctly, while the purpose of the other was to enhance its performance.

Correctness

It was discovered very early on that trapping errors on the IBM system was quite different from the way errors were trapped on the Fujitsu system. By default, codes which run on the IBM system do not abort when they hit a floating-point error, they continue to execute, producing meaningless results. After some investigation a method was found of producing a signal when floating-point errors occurred that could be used with little or no penalty in performance, which meant it could be used in production runs of IFS as well as in debugging runs. This signal could then be trapped by the software to provide a trace-back of the routine calling sequence.

Bit-reproducibility is an essential requirement for the IFS code. This means that when the code is run several times with the same data, it produces exactly (down to the least significant bit) the same results, even if subsequent runs use different numbers of processors and nodes. The IBM compiler has a very useful option that enables this feature, the '-qstrict' option. Using this option guarantees bit-reproducibility, it also has the advantage of assisting debugging, by ensuring that results obtained by code compiled with compiler optimisation switched off are identical to code where optimisation is switched on.

Once these two requirements were satisfied it was then much easier to debug the IFS code and to identify errors in IBM's compiler and libraries.

Performance

Over the years, IFS has been adapted to run well on such diverse systems as those with vector processors, scalar processors, distributed memory and shared memory. Maintaining this capability is very important. Primarily, the IBM Cluster 1600 system at ECMWF is computationally different from the Fujitsu VPP5000 in the following respects:

- It has an order of magnitude more processors;
- Each processor is an order of magnitude less powerful (in sustained performance of the IFS code);
- It has scalar processors rather than vector ones;
- It has shared memory nodes.

The MPI message-passing paradigm has been used in the IFS model for many years. The code's two-dimensional processor decomposition in grid-point and spectral space allows it to scale well to hundreds of MPI tasks. It has been found that message-passing communication on the IBM system currently performs better when it is not overlapped with buffer packing or with computation An option to exploit this was introduced into the message passing routines. Removing message mailbox buffering in the IFS code, by creating long messages, has also been found to improve the communications on the IBM system. The semi-Lagrangian communication has been greatly reduced by using an "on-demand" scheme, in which only the data that is strictly needed to perform interpolations is transferred.

With the multi-processor nature of the p690 servers it has been possible to exploit a new programming paradigm - that of SMP (Shared Memory Processing) as provided via the OpenMP standard. This has been introduced into the model where it reduces the number of MPI tasks and various overheads that are associated with them. IFS is now a hybrid model, using both MPI and OpenMP. It has been found that on the 8-CPU nodes created by logically partitioning the p690 servers, four MPI tasks, each with two OpenMP threads give better performance than using eight MPI tasks, while two MPI tasks, each with four OpenMP threads give even better performance. This is demonstrated in Figure 2.

The high-level outer-loop blocking scheme designed into IFS can give good performance on a scalar processor with cache, by choosing the inner-loop length (NPROMA) to be small (between 10 and 40), while on a vector processor good performance can be obtained by choosing NPROMA to be large (greater than 1000). This parameterisation of the blocking scheme within the code is very flexible. This means that the choice can be made at run-time, rather than compile-time, allowing IFS to be easily tuned to suit the architecture of the system on which it is running.

Another IFS optimisation that was found to be important for a cache-based processor was minimising memory accesses, e.g. by reducing copying and eliminating unnecessary zeroing of arrays. It was also found that performance could be enhanced by introducing intrinsic vector functions from the IBM vector MASS library into a few key subroutines and functions.

Most of these design features, which enable IFS to give good performance on a range of different computer architectures, had already been included in the IFS benchmark. A feel for the cumulative effect on the IBM system of the individual performance improvements resulting from these features can be shown by disabling them all and then re-enabling them, one by one. This test is summarised in Figure 3.

Migration of the operational suites of jobs from the Fujitsu VPP5000 to the IBM p690

The migration of the codes for which the Meteorological Applications Section is responsible began prior to the delivery of the test system. ECMWF's general-purpose servers,

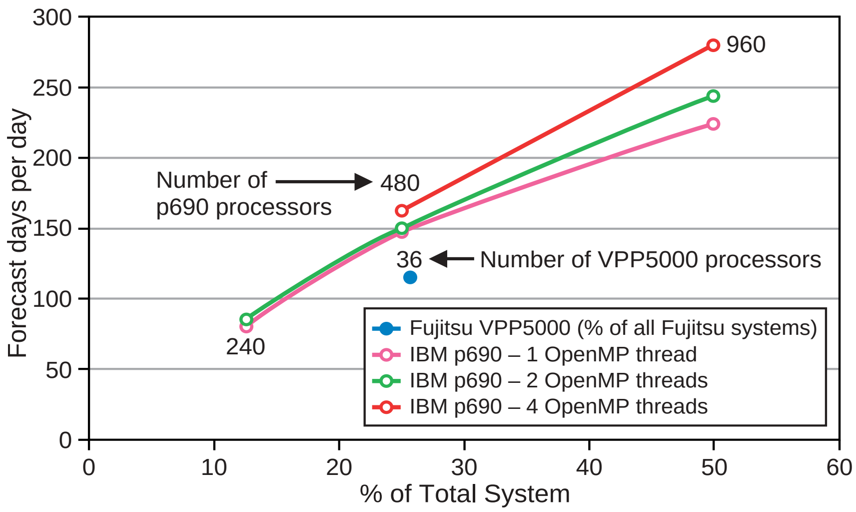

Figure 2 Scalability of a high-resolution forecast using different numbers of OpenMP threads: T799/L90.

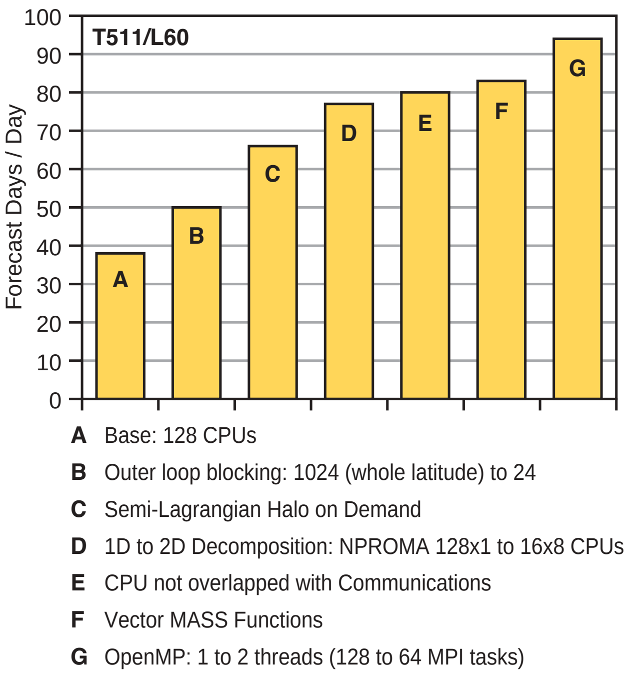

Figure 3 Impact of different features of IFS

two IBM Nighthawk nodes called "leda" and "metis" were used and later on the test system, with the aim of providing on the p690-based systems, as soon as possible the full functionality of:

- EMOSLIB (GRIB, BUFR, interpolation and file handling software);
- the Fields Data Base (FDB) software;
- the Meteorological Archival and Retrieval System (MARS);

These software packages are vital components for the running of both operational and research work at ECMWF. Basic versions of these were up and running on the test system within a week of its being configured.

Further development of the FDB software included changes to support any new attribute data types that may be created. The specification of configuration settings is now extremely flexible and the database architecture is a fully open one. By this we mean that it allows attributes to be added or changed without applications having to be modified to take this into account. Attributes themselves are not limited to intrinsic data types, such as integers, they can even be represented by phrases or sentences. The software now supports multi-threaded environments. A parallel overwriting technique enables a parallel application that is rerun to use the FDB more efficiently. A new configuration mode was developed, which utilises new buffering techniques and shared memory when used by parallel applications.

Optimisations were made to the handling of interpolation coefficients and features such as OpenMP, threads and memory-mapped files were investigated and introduced where they improved performance. Tests were performed to achieve the most efficient results with the IBM's compiler options. 64-bit versions of file handling routines were adopted to allow for files that are larger than two gigabytes. All of these various software packages were integrated into the jobs of the operational suites.

There are well over 500 scripts in the various operational suites and all of these needed to be modified in order to get them to run under the AIX. Changes were also necessary to use the LoadLeveler batch job subsystem, instead of NQS. Again, the two IBM general-purpose servers were used to gain initial experience.

By September 2002, all of the main operational suites were running on the new supercomputer, using an IBM version of IFS (model cycle 25r1). Initially they ran without product generation but this was soon added. Modifications were made to the product generation code in support of the new FDB structure as well as changes in the area of message passing. These suites were run on the IBM system during its operational acceptance test phase.

In November all of the main operational suites were running on the new supercomputer, this time using a new IFS (model cycle 25r3). The Multi-analysis and Sensitivity suites were added later.

In January 2003 the latest IFS (model cycle 25r4) was introduced and test suites using this were run to gain experience with LoadLeveler class structures, job submission and scheduling. These suites were frozen (no more changes made) early in February and they then ran in parallel with the operational suites on the VPP5000.

On 4 March 2003 the ECMWF operational forecast production was moved to the IBM supercomputer. The suites which were switched to the IBM HPCF on that day were:

- The main deterministic 10-day forecast suite;
- The Ensemble Prediction System (EPS) suite;
- The Boundary Conditions suite;
- The European wave model suite;
- The Multi-analysis suite;
- The Sensitivity suite.

The first operational Seasonal forecast suite on the IBM was run the following week on 13 March 2003.

Final comments

Considering its scope and the amount of effort and co-ordination required, this migration from the tightly coupled vector-CPU based Fujitsu VPP system to the more general-purpose scalar-CPU based IBM Cluster 1600 system was performed in a short period of time. The fact that ECMWF's own staff and staff from IBM put in a lot of effort and worked very well together contributed much towards this successful outcome. All of those involved can be justly proud of this achievement.

Neil Storer, John Hennessy and Deborah Salmond

ECMWF Workshops 2003

11–13 March 2003 – GEWEX workshop on Objective analysis of precipitation.

The primary goal of the workshop was to improve our understanding of the issues involved in the objective analysis of precipitation using the many sources of information available (e.g. gauges, satellite-derived estimates, radar observations and model output data) and to make recommendations for the Global Precipitation Climatology Project (GPCP) to advance its efforts to provide global analyses of precipitation.

While the current GPCP precipitation analyses, as well as others that have been constructed, have proved useful for many purposes, it has become clear that efforts to improve their accuracy and consistency are required. This is partly because of the desire for higher spatial and temporal resolution, which necessitates extracting more information from the available data, and partly because the methods currently in use were developed 5–10 years ago and the state of the science has advanced. The workshop was aimed at bringing together members of the GPCP community with experts in the theory and practice of objective analysis including, in particular, members of the numerical weather prediction (NWP) community, with the aim of describing the current state of the science and of making recommendations to the GPCP.

23-26 June 2003 – Modelling and assimilation for the stratosphere and tropopause

The ECMWF model currently has a top level at 0.1 hPa with about 25 levels above the tropopause. It is planned to increase the vertical resolution, particularly in the vicinity of the tropopause. The workshop will discuss recent studies and plans for the future. General issues to be considered will include the diagnosis and improvement of analyses and forecasts and of the associated transports, and the impact of the vertical resolution on the upper boundary condition. Studies of the assimilation of new data from recent satellites, the potential of future satellites, and the assimilation and monitoring of H_2O, O_3, CO_2, CH_4, N_2O and aerosols will also be reviewed.

18–19 September 2003 – First workshop on ECMWF high-performance networking

The objective of this workshop will be to bring together European users and vendors of high-performance networking technologies and to share thoughts on the technology deployments, high-performance trends and future directions. The workshop will continue in the direction set by the High-Performance Networking Forum - Europe whose last meeting was hosted by ECMWF on 11 October 2002.

3–6 November 2003 – Simulation and prediction of intra-seasonal variability

Details to be announced later.

10–14 November 2003 – Ninth workshop on meteorological operational systems

The objective of the workshop is to review the state of the art of meteorological operational systems and to address future trends in analysis. It is expected that the workshop will be organised under the following main headings:

- The use and interpretation of medium-range forecast guidance,
- Operational data-management systems.
- Meteorological visualisation applications.
- A special session on satellite data requirements and timely delivery will be organised.

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Technical Memoranda

391 **B.J.J.M. van den Hurk**, **P. Viterbo** & **S.O. Los**. Impact of leaf area index seasonality on the annual land surface evaporation in a global circulation model. *October 2002*

392 **B.J.J.M. van den Hurk** & **P. Viterbo**: The Torne-Kalix PILPS2E experiment as a test bed for modifications to the ECMWF land surface scheme. *October 2002*

393 **Ø. Saetra**, **J.-R. Bidlot**, **H. Hersbach** & **D. Richardson**. Effects of observation errors on the statistics for ensemble spread and reliability. *December 2002*

394 **J.W. Taylor** & **R. Buizza**: A comparison of temperature density forecasts from GARCH and atmospheric models. *January 2003*

395 **H. Hersbach**. CMOD5 – An improved geophysical model function for ERS C-Band scatterometry. *January 2003*

396 **A.M. Lubrano**, **G. Masiello**, **M. Matricardi** & **C. Serio**. Retrieving N2O from nadir viewing infrared spectrometers. *January 2003*

397 **M. Fisher**. Estimation of entropy-reduction and degrees of freedom for signal for large variational analysis systems. *January 2003*

399 **Y. Trémolet**. Diagnostics of linear and incremental approximations in 4D-Var. *February 2003*

400 **C. Cardinali** and **R. Buizza**. Forecast skill of targeted observations: a singular vector based diagnostic. *February 2003*

402 **P. A.E.M. Janssen**, **S. Abdalla**, and **H.Hersbach.** Error estimation of buoy, satellite and model wave height data. *March 2003*

403 **G. Seuffert**, **H. Wilker**, **P. Viterbo**, **J.-F. Mahfouf**, **J.-C. Calvet**. Soil moisture analysis combining screen-level parameters and microwave brightness temperature: A test with field data. *March 2003*

ERA Project Report Series

No. 3 Workshop on Re-Analysis. *5–9 November 2001*

ECMWF calendar 2003

Meteorological Training Course

Jun 2–6	**Use & interpretation of ECMWF products**	
Jun 3–4	**Finance Committee**	*70th*
Jun 11–12	**COUNCIL**	*58th*
Jun 16–17	**Users' Meeting–Medium-range forecasts**	
Jun 18–19	**Users' Meeting–Seasonal forecasts**	
Jul 23–26	**Workshop** – *Modelling and assimilation for the stratosphere and tropopause*	
Sep 8–12	**Seminar** – *Recent developments in data assimilation for atmosphere and ocean*	
Oct 6–8	**Scientific Advisory Committee**	*32nd*
Oct 8–10	**Technical Advisory Committee**	*33rd*
Oct 13–14	**Finance Committee**	*71st*

Meteorological Training Course for WMO members

Oct 13–17	**Use & interpretation of ECMWF products**	
Oct 15	**Advisory Committee on Data Policy**	*4th*
Oct 20	**Advisory Committee of Co-op. States**	*10th*
Oct 21–22	**Policy Advisory Committee**	*19th*
Nov 3–6	**Workshop** – *Simulation and prediction of intra-seasonal variability*	
Nov 10–14	**Workshop** – *Meteorological operational systems*	*9th*
Dec 2–3	**COUNCIL**	*59th*

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METEOROLOGY

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Internet web site

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

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Networking and Computer Security Section Head	
Matteo Dell'Acqua	356
Servers and Desktops Section Head	
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Systems Software Section Head	
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Console - Shift Leaders	803
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Applications Section Head	
John Hennessy	400
Graphics Section Head	
Jens Daabeck	375
Operations Section Head	
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Acting Division Head	
Tim Palmer	600
Seasonal Forecasting Head	
David Anderson	706
Model Division	
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Physical Aspects Section Head	
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Peter Janssen	116
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New products on the ECMWF web site

ECMWF Newsletters

ECMWF Newsletters (published quarterly and containing articles describing details of new developments in the Centre) are now available on-line in pdf format.

http://www.ecmwf.int/publications/newsletters/

Research Data Server

The ECMWF Data Server provides free access to publicly released data from the DEMETER and ERA-15 (Reanalysis) projects. In the future other project data will be made available (ERA-40, ENACT).

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

Data Services on-line ordering

ECMWF, from its operational and research activities, has collected a unique set of global numerical weather-prediction data in its archives. To enable these data, assembled as a result of ECMWF operations, to be accessible to all possible users, Data Services now provides a powerful on-line ordering service that can be used to query, select, estimate costs and submit orders for data.

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

Computing Systems

An overview of all aspects of ECMWF's computer facilities is given, including a history of ECMWF supercomputers and descriptions of the main components to our computing environment: the IBM supercomputer; data-handling system; disaster recovery system; general-purpose servers; highly available servers; desktop systems; local-area network and wide-area network.

http://www.ecmwf.int/services/computing/overview/

Andy Brady