A new Head of Research for ECMWF

Philippe Bougeault

At its December 2002 session, the ECMWF Council approved the appointment of Dr Philippe Bougeault as Head of Research following the retirement of Tony Hollingsworth on 6 July 2003.

Currently, Philippe works for Météo-France where he is Head of the Mesoscale Meteorology Group (Toulouse). He is a 'founder' participant in the Mesoscale Alpine Project (MAP) and has made major contributions to the project organization and was a co-Scientific Director for the field experiment phase. He is chairman of the MAP Scientific Steering Group. In addition, he has taught at the Ecole National de la Météorologie (Toulouse) and the Ecole Polytechnique (Paris).

He serves on a number of French national research committees and he is a member of the following international committees:

– The Scientific Steering Committee of the World Weather Research Programme (WMO/CAS);
– The JRC/CAS Working Group on Numerical Experimentation (WGNE);
– Chairman of the Scientific Steering Committee of MAP (Mesoscale Alpine Programme);
– The ECMWF Scientific Advisory Committee.

Philippe's speciality is the parametrization of physical processes, fine-scale modelling and the organization and management of field experiments. He has authored or co-authored papers or reports on a wide range of subjects including contributions to:

– The physics and modelling of the planetary boundary layer;
– The practice of Large Eddy Simulation (LES);
– Methods of treating the upper boundary condition in numerical models
– The parametrization of deep convection;
– The modelling of land-surface exchanges;
– Fine-scale modelling of alpine valleys;
– Non-hydrostatic modelling.

I take this opportunity to congratulate Philippe on his appointment and to welcome him to the Centre's management team.

David Burridge (Director)

In this issue

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Front Cover

The breakdown of the winter polar vortex in the Southern Hemisphere stratosphere that occurred in September 2002 is covered in the article on page 2.

Editorial

This issue of the Newsletter contains information concerning three important items that were approved by Council at its 57th session in December 2002. Firstly, Philippe Bougeault was approved as the new Head of Research to succeed Tony Hollingsworth on his retirement; a short résumé of his career by the Director, David Burridge, is printed opposite. The second is the acceptance of Serbia and Montenegro as a Co-operating State; this brings the total number of European States supporting the Centre to 24. The third item is the approval of the Centre's four-year programme of activities covering the period 2003-2006; details are outlined in the article on page 36.

On page 2 Adrian Simmons, Mariano Hortal, Agathe Untch and Sakari Uppala describe the breakdown of the winter polar vortex in the Southern Hemisphere stratosphere that occurred in September 2002; similar phenomena have been noted before in the Northern Hemisphere, but this is the first time it has been observed in the Southern Hemisphere. In their discussion they emphasise the success of the ECMWF operational model in predicting the event a week in advance, and draw attention to the usefulness of the ERA-40 reanalysis data for monitoring the behaviour of the stratosphere over several years.

Two articles, one on page 10 by François Lalaurette and Gerald van der Grijn and the other on page 18 by Federico Grazzini and Gerald van der Grijn, are concerned with the prediction of extreme weather. The first introduces the concept of an Extreme-Forecast Index designed to give a measure of the extent to which ensemble forecasts differ significantly from the local model climatology, thereby indicating the likelihood of extreme weather occurring; examples are given of its application in forecasts of severe gales, rainfall and tropical cyclones. The second article is concerned with the floods that afflicted several countries in central Europe during August 2002. The authors discuss both the medium-range and the monthly forecasts of the event, and they point out that the forecast sensitivity of the occasion may have been related to details of the analysis some days earlier over the Great Lakes region of North America.

On page 28 Matteo Dell'Acqua, Laurent Gougeon and Dieter Niebel give a step-by-step description of the software package known as ECaccess that enables registered users to access the ECMWF computing and archiving facilities. Further information can be obtained from the ECMWF web site.

Peter White

Changes to the Operational Forecasting System

On 29 October 2002, radiances from the new NOAA-17 satellite were activated in the data assimilation. As a result, radiances from three polar orbiting sounders (ATOVS from NOAA-15, 16 and 17) are currently assimilated for the first time.

A new cycle of ECMWF model, Cy25r4, has been implemented on 14 January 2003. This version includes changes to many aspects of the data assimilation and forecasting system:

- Revised multi-incremental (T95/T159) 4D-Var algorithm, including interpolation of high to low-resolution trajectory
- Omega-equation and non-linear balance, and statistics from ensemble of 4D-Var assimilations, in the J_b (background error cost function)
- Revised, more selective to gravity waves J_c (digital filter cost function)
- Assimilation of GOES WV radiances, MODIS winds, more HIRS channels and SAR ocean-wave data
- Direct assimilation of SSM/I radiances in 4D-Var
- Improved cloud-scheme numerics, cleaner code, and bug fixes; Revised cloud physics
- Revised convection scheme with new type and cloud top/base algorithms; checks all levels up to 700hPa for initiation of deep convection

In addition the RNORM parameter scaling EPS initial perturbations was reduced from 2.0 to 1.6 as a consequence of the data assimilation statistics retuning. This has the effect of keeping the EPS spread at the same level as in the current operational version.

The impact of these changes has been found to be meteorologically positive during the test period over a wide range of areas and parameters. Tests conducted during the summer have shown a clear reduction of forecast errors generated over North America and advected towards Europe at this time of the year. The new model version removes convective instability more effectively and realistically, as was found in several case studies. Stratosphere forecasts have also been improved.

This version is being run in parallel on the Fujitsu VPP5000 and IBM HPCF, and is planned to be the one to be migrated to the new computer later this year.

François Lalaurette

Serbia and Montenegro becomes a Co-operating State

A co-operation agreement was concluded between ECMWF and the Federal Republic of Yugoslavia, since renamed 'Serbia and Montenegro', coming into force on 1 January 2003.

Dr David Burridge, Director of ECMWF, said: "We are looking forwards to closer collaboration with the Federal Hydrometeorological Institute in extending the use of our medium-range and seasonal weather forecasts for the benefit of the people of Yugoslavia".

Mr Mimcilo Zivkovic, Director of the Federal Hydrometeorological Institute, said: "After a long period and with much effort we have succeeded in concluding this agreement. The work of the European Centre will be vital for improving the quality of our forecasting, and for our warning services in advance of extreme weather. We will be striving to extend the lead-time of our forecasts as far as possible, based on the world-beating output from the Centre. Our meteorological staff will benefit from contacts with their colleagues at the European Centre. We heartily welcome this agreement."

A total of twenty-four States now support the Centre, eighteen Member States and six Co-operating States.

Breakdown of the stratospheric winter polar vortex

Towards the end of September 2002, the cold polar vortex in the Southern Hemisphere stratosphere elongated and split into two in a manner seen every few years in the northern hemisphere, but never before observed in the Southern Hemisphere. Despite its rarity, the event was predicted accurately about a week in advance by the ECMWF forecasting system. The unusual flow conditions nevertheless exposed a weakness in the numerical stability of the Centre's model. In this article we illustrate the performance of the forecasting system for this particular event, and show how the availability of analyses from the ERA-40 project (see http:// www.ecmwf.int/research/era) helps put the event in context.

Analyses and forecasts of sudden warmings of the Northern Hemisphere stratosphere

Fifty years prior to this September's remarkable event, *Scherhag* (1952) reported an equally remarkable and never-before observed warming of more than 40 K over two days measured at heights above 30 km by radiosondes launched late in February from Berlin. Originally dubbed 'The Berlin Phenomenon', it subsequently became clear that such 'sudden warmings' are by no means rare in the northern hemisphere winter stratosphere, and can be associated with substantial changes in the large-scale circulation pattern. On occasions, these changes comprise simply distortion, growth or decay, or a spatial shift of the principal features of the wintertime stratospheric circulation, the cold polar vortex and the Aleutian anticyclone. Once every few years, however, the vortex elongates and splits substantially or completely into two, often accompanied by development of a second strong anticyclone.

Two examples of such vortex splitting are presented in Figure 1. They are drawn from the extensive range of ERA-40 analyses, from August 1957 until the end of 2001, the production of which by ECMWF is close to completion. The first, shown in the left-hand panels, is from January 1958. *Scherhag* (1960) referred to this case as a recurrence of the Berlin Phenomenon after the passing of six years. The 10 hPa height map for 19 January shows a substantial cyclonic vortex centred well off the pole between northern Norway and Greenland, accompanied by a quite strong Aleutian anticyclone. Five days later, the planetary-wave pattern has rotated eastward, the vortex has assumed a more elongated and bowed shape and high pressure has built over southern and eastern Europe. By 29 January, the vortex has split completely into two portions centred over Canada and Russia, with anticyclones located over the Bering Strait and southwest of Ireland. The evolution depicted in these 10 hPa ERA-40 analyses matches well that seen in 25 hPa analyses reported at the time by *Teweles and Finger* (1958) and *Scherhag* (1960).

The second example in Figure 1 is for the event that occurred in February 1979. Although there are differences in the size and orientation of the polar vortex on 11 and 16

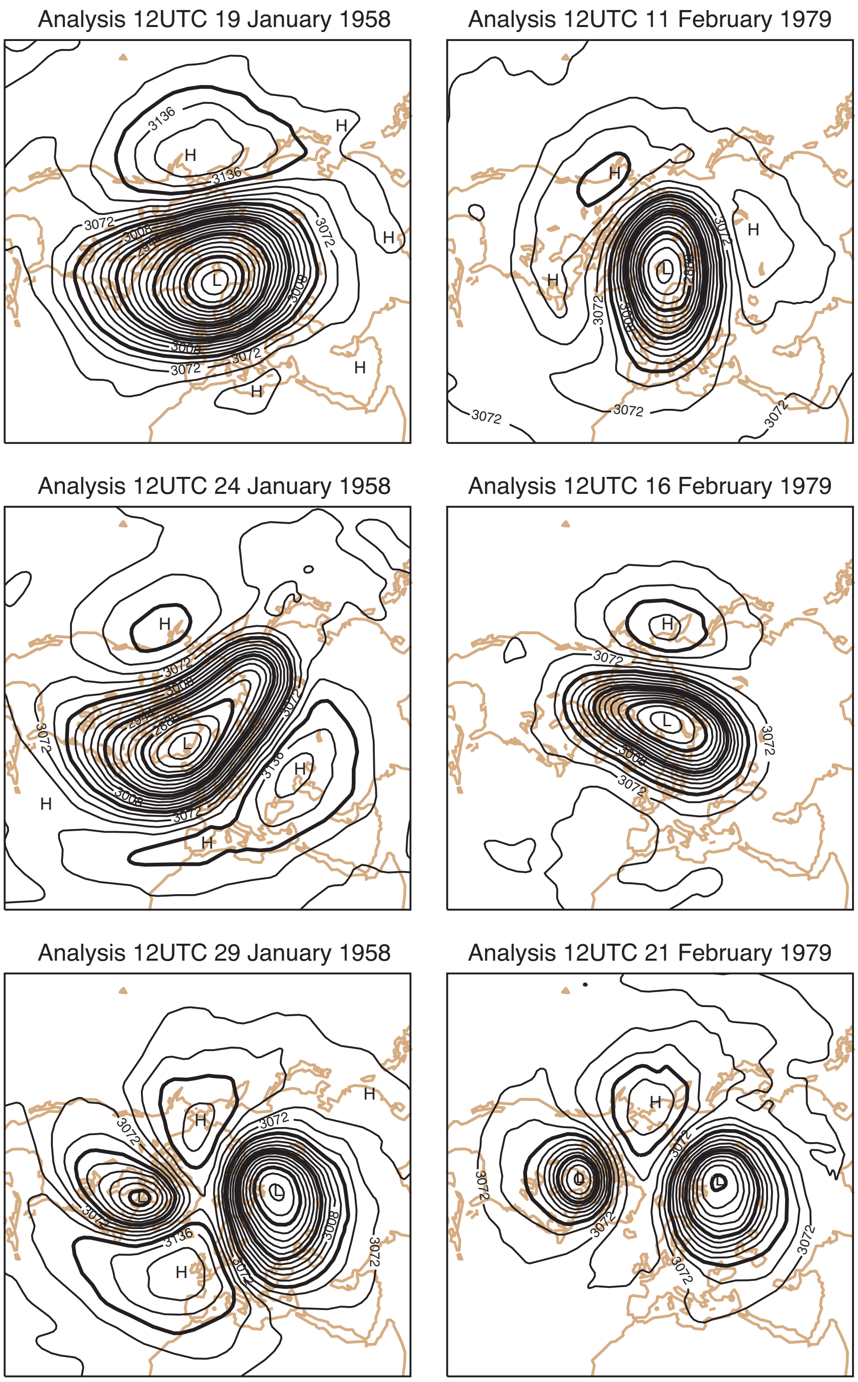

Figure 1 The 12 UTC ERA-40 10hPa Northern Hemisphere height analyses for 19, 24 and 29 January 1958 (left) and 11, 16 and 21 February 1979 (contour interval 16 dam).

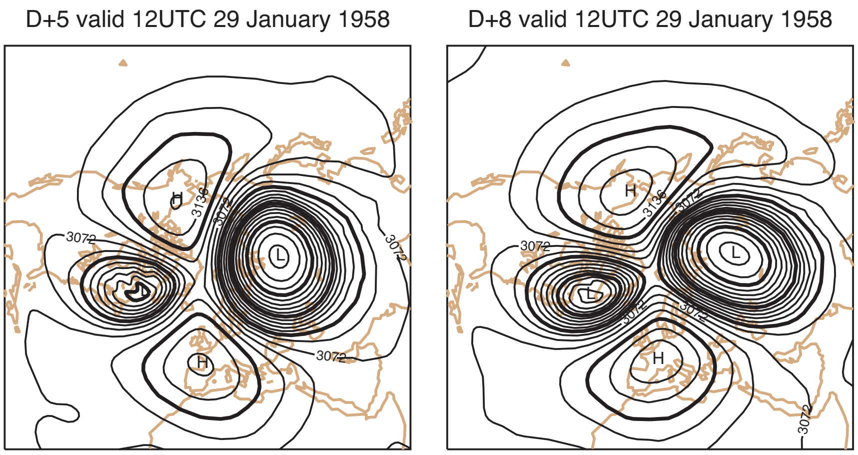

Figure 2 The five- and eight-day 10 hPa height forecasts valid at 12 UTC 29 January 1958, run from the ERA-40 analyses using the ERA-40 forecast model (contour interval 16 dam).

February 1979 compared with 19 and 24 January 1958, the subsequent vortex split results in a pattern on 21 February 1979 similar to that of 29 January 1958. ECMWF first produced analyses for the winter of 1979 as part of its contribution to the First Global Atmospheric Research Programme (GARP) Global Experiment (FGGE), and forecasts run from the FGGE analyses by *Bengtsson et al.* (1982) and *Simmons and Strüfing* (1983) provided highly accurate depictions not only of the February vortex split but also of the major circulation changes that occurred in preceding weeks. This was the first time such forecast skill had been demonstrated for stratospheric warming events. These and other studies of the well-observed 1979 warmings capped a decade or so of research following the first mechanistic sudden-warming simulation by *Matsuno* (1971). A picture emerged of the fundamental dynamical nature of the phenomenon, involving strong planetary-scale forcing from the troposphere, the upward propagation and amplification of the forced planetary waves, and the non-linear interaction of these waves with the stratospheric flow in which they propagate. A review by *McIntyre* (1982) documents the extent of understanding at the time.

Since then, ECMWF's operational forecasts have proved generally successful at predicting major warming events, for up to a week or so ahead. Moreover, a number of recent changes to the forecasting system have brought further significant improvements in operational stratospheric analyses and forecasts. The most notable of the changes was the introduction of increased stratospheric resolution in March 1999, discussed by *Untch and Simmons* (1999) in an earlier edition of this Newsletter. The ERA-40 analyses benefit from all but the latest of these developments.

We can, in fact, go right back to the 1958 case to provide an example of the considerable skill that exists in forecasting warming events in the northern hemisphere. Ten-day forecasts have been carried out from each of the 00 and 12 UTC ERA-40 analyses for the year, employing the same T159-resolution model as used for the ERA-40 data assimilation. Figure 2 shows five- and eight-day 10 hPa height forecasts valid at 12 UTC 29 January 1958. The five-day forecast is clearly successful in capturing the vortex split, the principal error being a slight eastward shift of the overall pattern. The eight-day forecast also displays the vortex split, although in this case the break is not quite complete in that the closed 3056 and 3072 dam contours encompass both of the low centres. All forecasts out to day six show complete splitting of the vortex, and failure to form a second vortex occurs only at the range of nine and ten days. The radiosonde measurements (which include soundings from fixed ocean weather ships) and conventional surface observations made in 1958 are clearly sufficient to enable remarkably good forecasts of this major stratospheric warming when processed by a skilful modern data-assimilation system.

September 2002 in the Southern Hemisphere stratosphere

The left-hand panels of Figure 3 show operational 10 hPa height analyses over the southern hemisphere for 20, 25 and 30 September 2002. On 20 September, the cold vortex was centred close to the South Pole, with an anticyclone centred south of Western Australia. Major change occurred over the next five days. The vortex split into two, the anticyclone south of Australia intensified considerably and a smaller anticyclone developed over the South Atlantic. In the course of the following five days, one of the two resulting cyclonic vortices, that over the South Pacific, weakened considerably and moved slightly westward. The other cyclone and dominant anticyclone moved eastward and poleward, the anticyclone continuing to build while the cyclone decayed.

This dramatic evolution of the southern stratospheric circulation was captured extremely well by the ten-day operational forecast made on 20 September.

The two right-hand panels of Figure 3 show the five- and ten-day 10 hPa height forecasts valid on 25 and 30 September, respectively. The five-day forecast is in almost perfect agreement with the analysis. Moreover, the essence of the change from day five to day ten is described, although errors of positioning and intensity do become evident by the end of the forecast range.

Seven- and ten-day operational forecasts valid on 25 September are shown in Figure 4. The seven-day forecast is

Results are presented here only from the deterministic operational forecast made with 60-level vertical resolution extending to 0.1 hPa. Corresponding EPS forecasts were made with 40-level vertical resolution extending only to 10 hPa. 40-level EPS control forecasts of 10 hPa height were generally poorer than the 60-level operational forecasts.

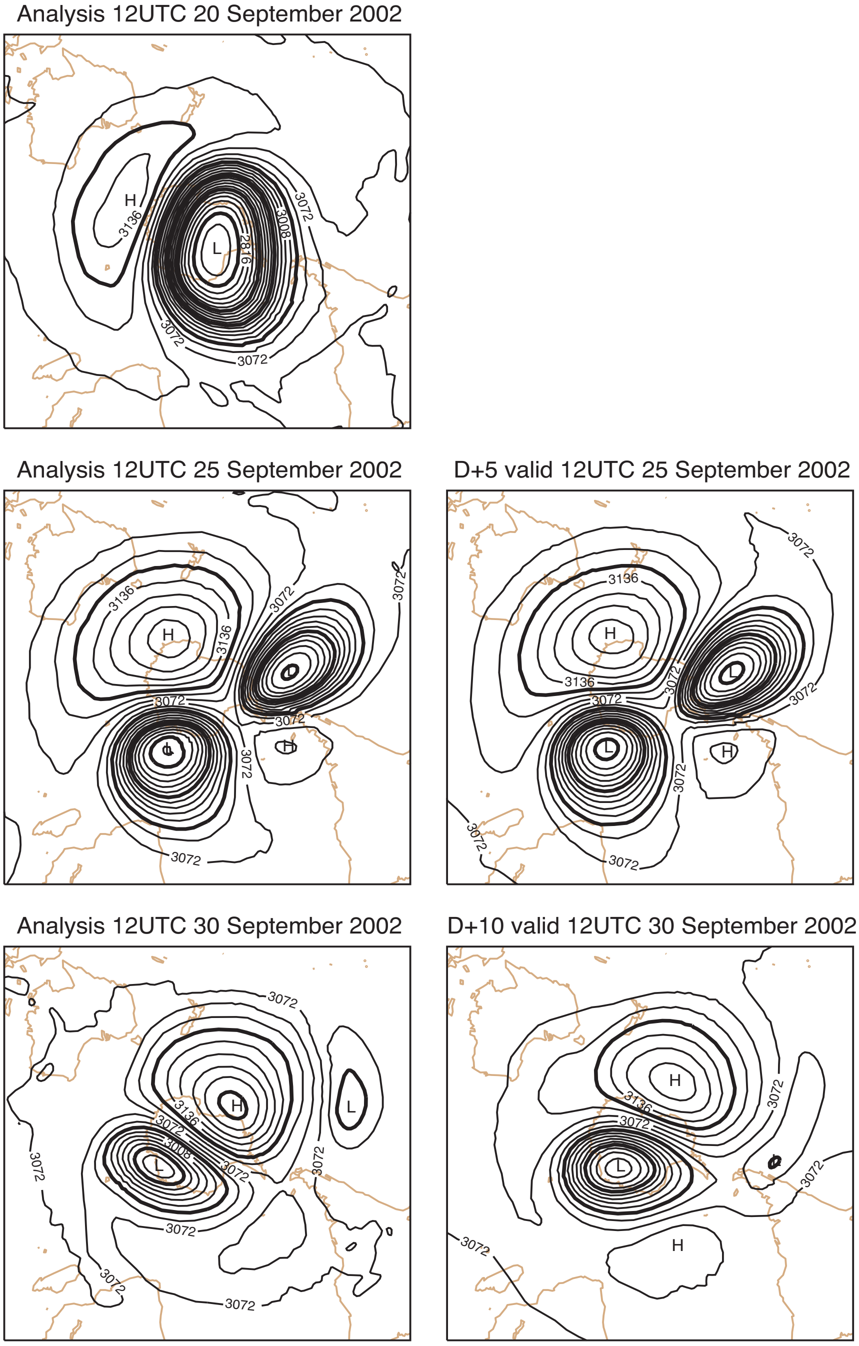

Figure 3 The operational 10 hPa Southern Hemisphere height analyses (left) for 12 UTC 20, 25 and 30 September 2002, and the five- and ten-day forecasts (right) from 12 UTC 20 September 2002 (contour interval 16 dam).

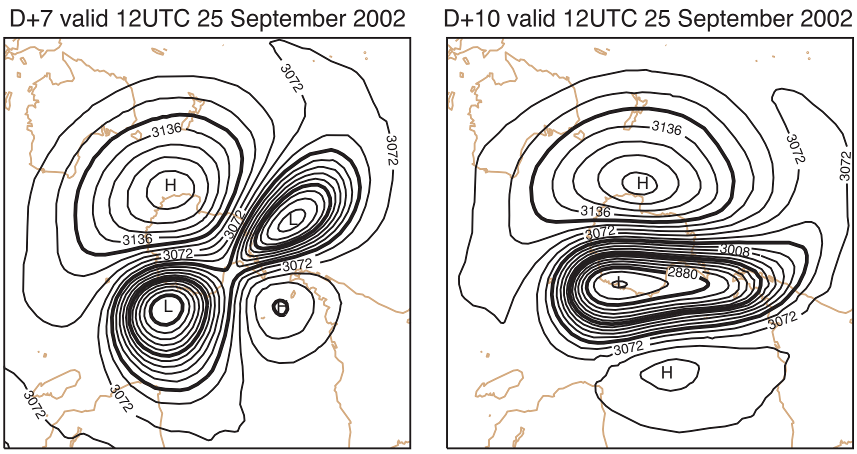

Figure 4 The operational seven- and ten-day 10 hPa height forecasts valid at 12 UTC 25 September 2002 (contour interval 16 dam).

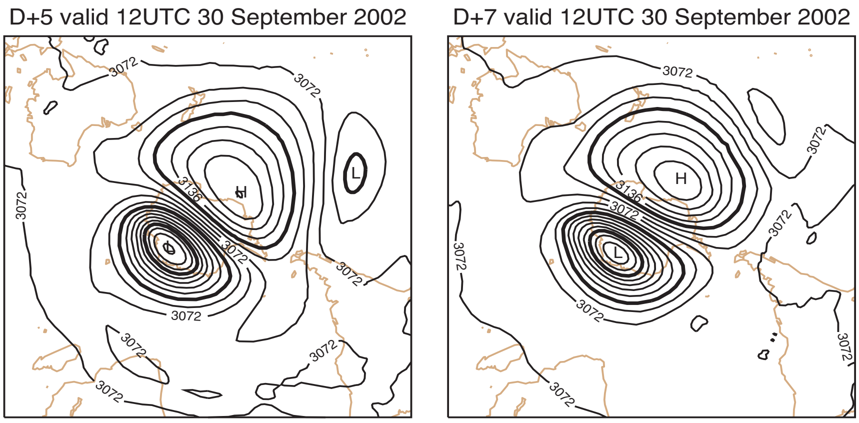

Figure 5 The operational five- and seven-day 10 hPa height forecasts valid 12 UTC 30 September 2002 (contour interval 16 dam).

largely successful; at the time illustrated, the vortex splitting is not quite complete but this is due to a slight delay in timing rather than a failure to capture the split fully. The vortex elongates but does not split in the ten-day forecast. Forecasts from 16 and 17 September show the formation of two cyclonic centres, but no complete split of the vortex. Complete vortex splitting occurs in all forecasts from 18 September onwards.

Figure 5 shows the five- and seven-day forecasts valid on 30 September. An improvement can be seen in the location and orientation of the main cyclone and anticyclone from day ten (Figure 3) to day seven. The remnant of the second cyclone is too weak, and too far to the west at day seven, rather than too far to the east as it is at day ten. This feature is depicted well at the five-day range.

It is beyond the scope of this article to investigate the mechanism of the vortex split and why it was not until this year that such an event should be observed in the southern hemisphere. The analyses produced by ECMWF and other forecasting centres are, however, important resources that may be deployed in such investigations. The horizontal resolution of the assimilating forecast model used at ECMWF was increased to T511 in November 2000, and the September 2002 event provides an opportunity to illustrate the level of detail that can be produced by such a comprehensive, high-resolution numerical model. Figure 6 presents maps of the distributions of potential vorticity and water vapour on the 850 K isentropic surface derived from the analyses for 20, 25 and 30 September 2002. The vortex at this level is characterized not only by large negative values of potential vorticity but also by relatively high values of water vapour arising from the modelled descent of air moistened by methane oxidation near the stratopause. In the ECMWF data-assimilation system, background stratospheric values of potential vorticity are changed (predominantly on medium to large scales) by the 4D-Var analysis of radiosonde and satellite data, whereas background stratospheric humidity is unchanged by the analysis.

The principal features of the potential vorticity (PV) and humidity fields are very similar over the period shown, both changing primarily due to advection by the distribution of winds on the isentropic surface. Figure 6 shows clearly the split of the vortex into two seen in the height-field maps of Figure 3. It also shows multiple extended streamers of small-PV/dry air (light-shaded bands) drawn in from low latitudes and of large-PV/moist air (darker-shaded bands) extruded from the vortex or vortices. There is particularly strong extrusion from both vortices after the split on 25 September, especially from that over the South Pacific, consistent with the weakening of the vortices seen in height fields.

The structures seen in Figure 6 are dynamically plausible and indicate basic good behaviour of the model's semi-Lagrangian advection scheme applied at high horizontal and vertical resolution. We cannot, however, vouch for the veracity of the smaller-scale features, and it would be of interest to seek such verification as is possible using the data available from satellites such as ENVISAT. In this context, the ozone fields produced operationally are further candidates for study. Ozone analyses exhibit the principal features on the 850 K surface shown for PV and specific humidity in Figure 6 but small-scale structure is less evident, due presumably to a stronger effect of source/sink terms in the assimilating model. Specialized analyses of total ozone from the GOME

(see http://www.knmi.nl/gome_fd)

and TOMS

(see http:// www.gsfc.nasa.gov/topstory/20020926ozonehole.html)

instruments provide an alternative view of the break- up of the vortex. Total ozone from ECMWF's operational analyses provides a qualitatively similar picture, but ozone-hole depths are underestimated. The assimilating model's parametrized sink due to heterogeneous chemical processes is not strong enough, and this is not compensated by assimilation of GOME and SBUV observations due to a strict quality control applied for low solar elevations.

Exposure of a numerical instability

The extreme flow conditions in the austral stratosphere in the final week of September 2002 exposed a 'weak' small-scale computational instability of the forecast model. Here 'weak' is taken to mean that the instability was self-limiting: the operational data assimilation and forecast runs did not fail to complete. Nevertheless, considerable noise occurred in the analysis for 26 September, and noise was present to a lesser extent on the following day. This can be clearly seen in the 10 hPa height analyses for 26 and 27 September shown in Figure 7. Noise develops in regions of strong easterly flow in the two vortices, appearing first close to where the flow lies above mountainous coastal regions of Antarctica. In Figure 7 noise can be seen to have reached large amplitude in part of the Pacific vortex on 26 September and is present to a lesser extent in the other vortex over and near Queen Maud Land on 27 September. The noise is highly predictable in that it occurs also in forecasts out to as far as eight days ahead valid on these dates, indicating that it is linked to the well-predicted large-scale flow conditions. Noise can also be seen close to the vortex centre north of Queen Maud Land in the PV map for 25 September (Figure 6), but is barely noticeable in the corresponding height map (Figure 3).

Linear analysis of the stability of the model's semi-Lagrangian advection scheme (*Hortal* 2002) shows that the scheme can indeed be unstable if the change in velocity along a single-time-step trajectory is sufficiently large. In the present case it is the change in the vertical component of the velocity that has been found to be the cause of the problem. Gravity waves that are generated by flow over the Antarctic coastal mountains and that propagate upwards and amplify in regions of easterly vortex flow appear to be the source of the large change in vertical velocity along the trajectory. Using a stable, first-order scheme for the vertical part of the trajectory calculation removes the noise, but degrades large-scale forecast accuracy when applied everywhere. Given the rarity of occurrence of the instability, an acceptable practical solution appears to be to apply a check

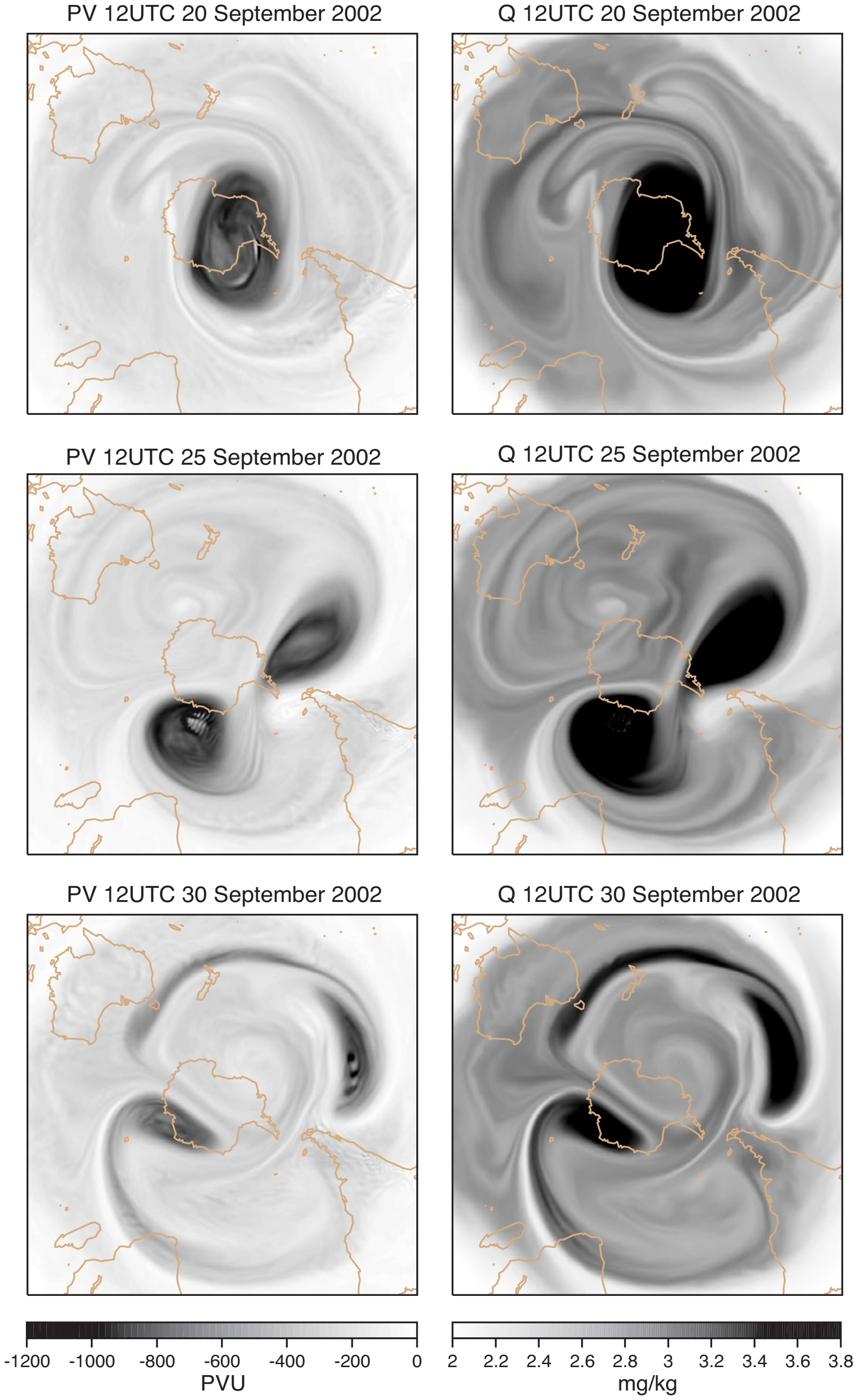

Figure 6 The operational analyses of the potential vorticity (left) and the specific humidity (right) on the 850 K isentropic surface at 12 UTC 20, 25 and 30 September 2002. For the potential vorticity, the shading covers a range from –1200 PVU (black) to 0 (white) and, for the specific humidity, it covers a range from 2 mg/kg (white) to 3.8 mg/kg (black).

(1 PVU = 10^{-6} $m^2s^{-1}K$ kg^{-1}).

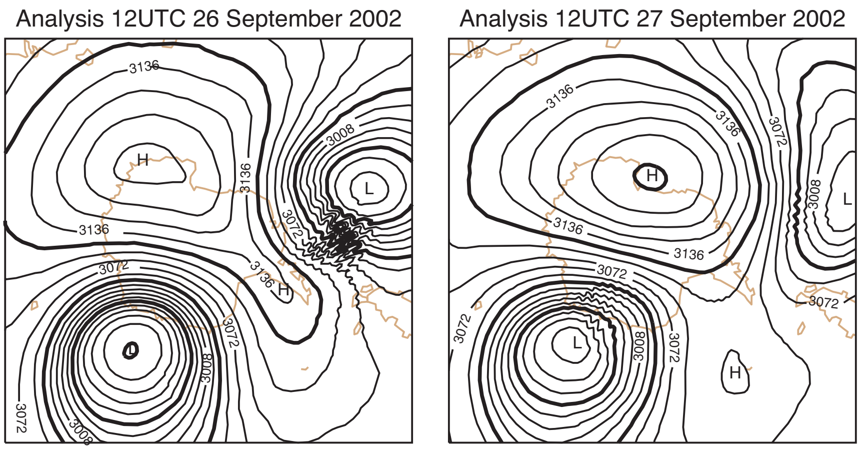

Figure 7 The operational 10 hPa height analyses at 12 UTC 26 and 27 September 2002 (contour interval 16 dam).

on the change in vertical velocity along the trajectory in the stratosphere, and to apply the first-order scheme only where a critical value is exceeded.

A reanalysis at operational resolution has been carried out for September 2002 using this more stable model formulation. It also used the improved version (cycle 25r4) of the forecasting system that became operational on 14 January 2003. This results in some modest larger-scale synoptic improvements in forecasts from the new analyses in addition to a substantial reduction in small-scale noise in analyses and forecasts. It is recommended that these reanalyses rather than the operational analyses be used in any future studies of the September vortex split. Basic analysis fields can be retrieved from MARS at six-hourly intervals from 00 UTC on 1 September to 12 UTC on 30 September by specifying CLASS=RD, EXPVER='ebfx'. Additional post-processed fields, in particular of variables on isentropic surfaces, can be accessed by specifying CLASS=RD, EXPVER='ebkh', TYPE=FC, STEP=0.

A search through the ERA archives

The splitting of the Southern Hemisphere vortex in September 2002 was thought at the time to be an event that had never before been observed. To check this, we have examined 10 hPa analyses for each day in September and October for all years for which ECMWF reanalysis data are available. This comprises the periods 1958 to 1968, 1973 to 1981 and 1986 to 2000 from ERA-40, and 1982 to 1985 from the earlier ERA-15 analysis. The year 2001 from operations has been inspected also.

In no year examined have we found an instance of pronounced vortex splitting similar to that seen in 2002. It is not uncommon to see a marked weakening of the vortex towards the end of October, and the weakening vortex may be displaced from the pole as a prelude to the establishment of summertime easterlies. There are also cases in which the vortex elongates and distorts, but does not break-up into two vortices of similar intensity.

Figure 8 presents a striking example of the latter, which serves to illustrate additional diversity in vortex dynamics. The figure shows maps of 10 hPa height and 850K PV and specific humidity for 21, 23 and 25 October 1994. On 21 October the vortex is highly elongated and bowed, and flanked by two anticyclones. The height map for two days later shows a weak low-pressure centre cut-off from the main vortex, located west of South America. There is also a hint of a second low centre in the main vortex, but this does not develop further. The cut-off low subsequently moves around the Pacific anticyclone and intensifies, reaching close to 30°S over the central Pacific by 25 October. The PV and humidity maps for this day each depict cyclonic wrapping up near the end of a band of material extruded from the main vortex. The picture is somewhat sharper for humidity, which is a prognostic model grid-point variable, than for PV, which is derived from the model's spectrally represented prognostic dynamical variables. Figure 9 presents a local map showing the distributions of relative vorticity and wind for the developing perturbation. The tilt of the system is counter to the horizontal shear of the ambient flow, indicating that barotropic instability of the local easterly flow around the Pacific anticyclone plays a role in the intensification. *Hartmann et al.* (1996) indicated the possibility of such perturbation growth by applying a singular-vector analysis to a case of extrusion of high PV air around the Aleutian anticyclone in the wintertime northern hemisphere.

Comparison with such satellite observations as are available is needed to validate the analysis of the secondary vortex development discussed above, which takes place over a region with particularly sparse coverage by in-situ measurements. Features that are directly forced at small scales by the assimilating model must also be viewed with caution. The PV map for 23 October shows U-shaped bands of low and high PV extending from the Antarctic Peninsula into the South Atlantic and then across southern South America and into the Pacific. The bands are most likely due to advection of vorticity forced persistently on 22 and 23 October in a dipole pattern over the Antarctic Peninsula by the model's parametrization of gravity-wave drag. No such feature occurs in the corresponding humidity field. The low PV band spreads to the central Pacific by 25 October, by which time a new dipole feature in PV (but not humidity) can be seen downstream of the Antarctic Peninsula.

Concluding remarks

The splitting of the austral polar vortex at 10 hPa in September 2002 was an event the like of which had not previously been observed in the southern hemisphere, yet it was predicted a week or so in advance by ECMWF's operational forecasting system. A basic capability to predict such events in the Northern Hemisphere has existed for the last twenty or more years, and has been enhanced in recent years by observational, data-assimilation and modelling improvements. Moreover, medium-range forecasts for the Southern Hemisphere troposphere have been brought to levels of accuracy similar to those reached for the Northern Hemisphere (*Simmons and Hollingsworth*, 2002). Given that flow conditions in September 2002, however unusual, were conducive to the occurrence of a major break-up of the vortex, it would have been disappointing had the forecasting system failed to predict the break-up well in advance. A more surprising aspect of fore-

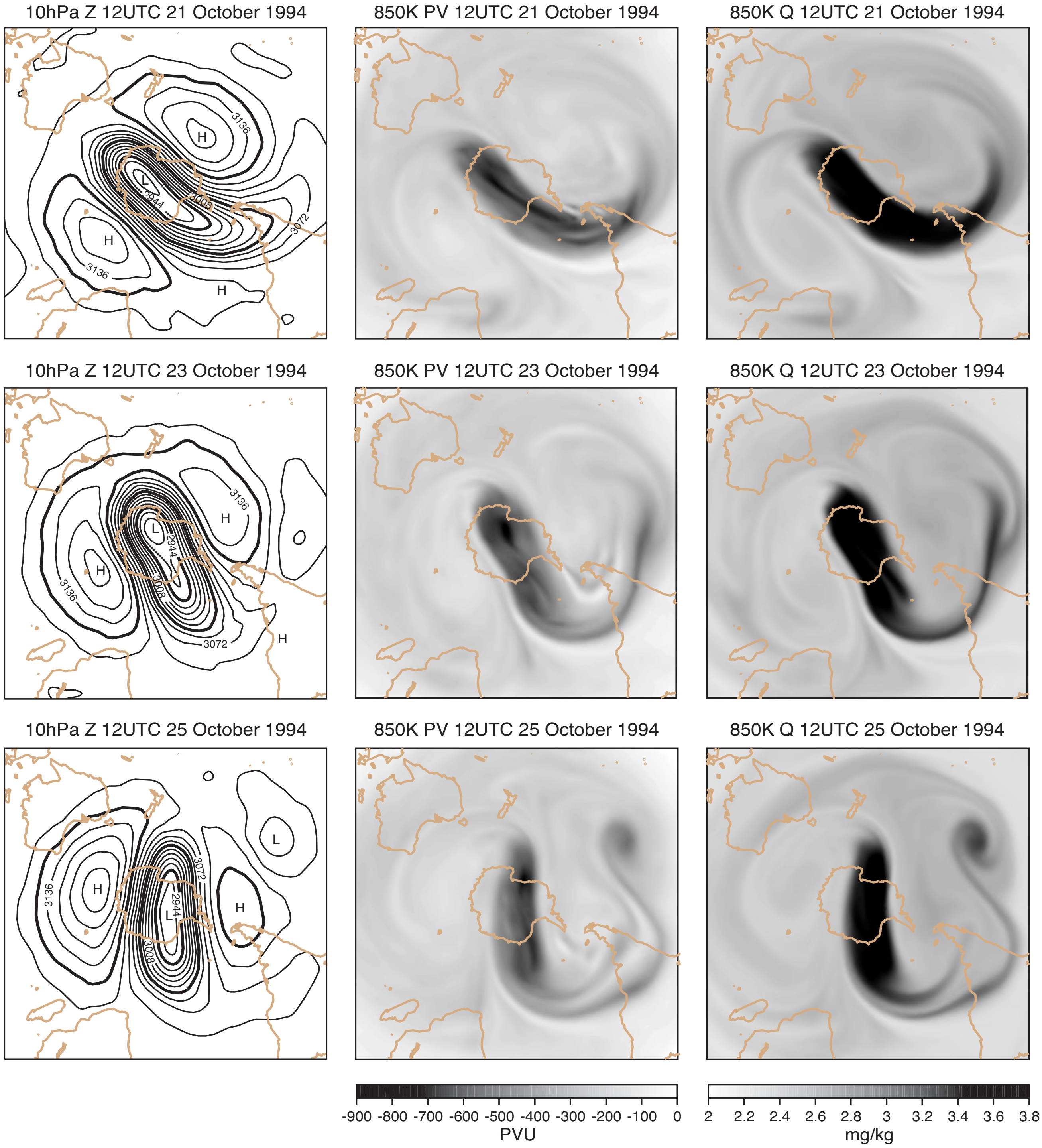

Figure 8 The ERA-40 analyses of the 10 hPa height (left), the 850 K potential vorticity (centre) and the specific humidity (right) at 12 UTC 21, 23 and 25 October 1994. The contour interval for the height is 16 dam. For the potential vorticity, the shading covers a range from -900 PVU (black) to 0 (white) and, for the specific humidity, it covers a range from 2 mg/kg (white) to 3.8 mg/kg (black) (1 PVU = 10^{-6} m^{2}s^{-1}K kg^{-1}).

cast quality during the period was the growth of significant computational noise in sectors of the split vortices. Computational instability of the model's advection scheme was known to be a theoretical possibility, but had not been seen before in either test or operational use.

The ERA-40 analyses provide a comprehensive description of the stratosphere from August 1957 onwards, and have been used here to help place the events of September 2002 in context. Although they are applicable for a wide range of studies, they should be used with care where observational data are sparse and the assimilating model is prone to systematic error. This is the case for the northern hemisphere upper stratosphere and for the southern hemisphere more generally in the period prior to the availability of radiances from satellite sounders. The ECMWF model is prone to produce too cold a springtime southern pole when run in climate-simulation mode (*Simmons et al.*, 1999), and the mean ERA-40 analyses for September for the 1959-1968 pre-satellite period are colder than those for 1989-1998 by well over 10K south of 60°S, at 10 and 30 hPa. The early analyses are thus prone to overestimate the intensity of the austral polar vortex and may not provide a reliable representation of perturbations to it. The analyses for the Northern Hemisphere in January 1958 have however been shown to be of high enough quality to enable good forecasts of the major warming that occurred late in the month. Analysis quality is significantly higher from 1979 onwards, especially in the Southern Hemisphere, due to the availability of measurements from the TOVS sounding instruments on NOAA satellites.

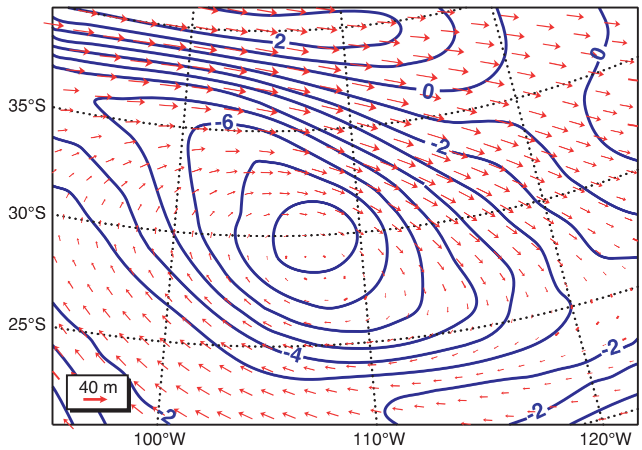

Figure 9 The ERA-40 analyses of the 850 K relative vorticity (contour interval 10^{-5} s^{-1}) and the wind at 06 UTC 24 October 1994.

Acknowledgement

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Ensemble forecasts: *Can they provide useful early warnings?*

Medium-range ensemble forecasts: why, how – and how well?

The design of ensemble methods for medium-range forecasting ten years ago was aimed mainly at addressing the problem of limited predictability of supra-synoptic weather regimes in the 6–10 days range. It has been shown since then that ensembles can deliver improved forecasts compared with purely deterministic forecasts, through improving single-value estimates by removing stochastic errors (ensemble mean) and providing reliable and sharp estimates of the probability distributions of large-scale flow patterns. Figure 1 gives the scores from different NWP models and shows that, after the first three days, the removal of realistic small-scale, but unpredictable, patterns by the use of an ensemble-mean filter is beneficial to the forecast skill. However, Figure 2 shows that the benefit of an ensemble forecast is more than a mere

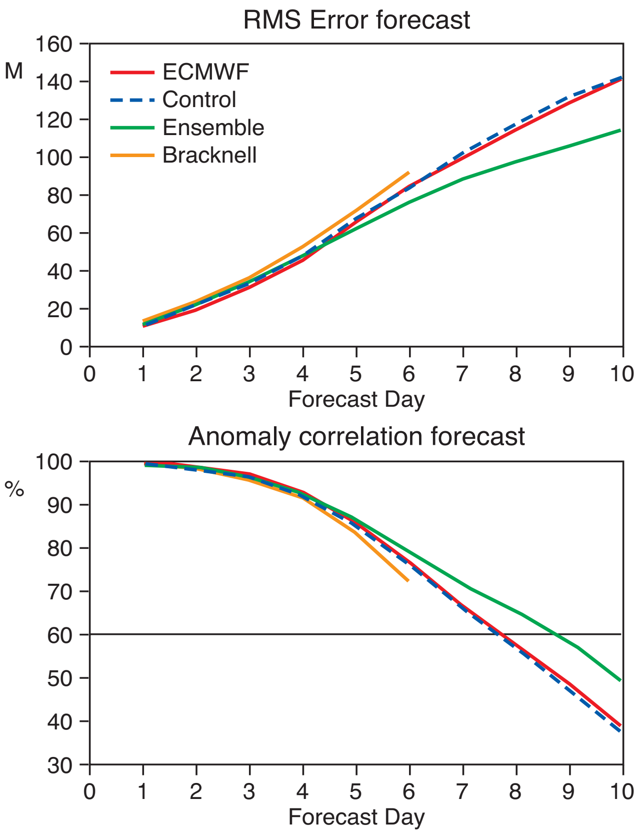

Figure 1 Verification scores for the 500 hPa height over Europe for the period 15 April to 15 October 2002: (top) the root-mean-square errors, and (bottom) the anomaly correlations. The curves shown are for the ECMWF operational deterministic forecast (red line), the EPS control forecast (blue dashed line), the ensemble-mean forecast (green line), and the Met Office forecast up to day 6 (orange line).

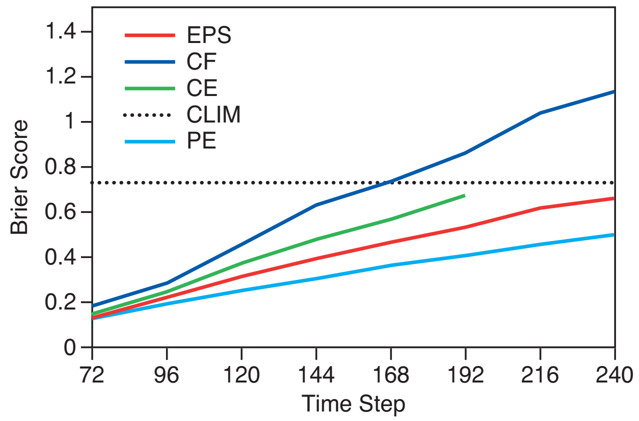

Figure 2 The Brier score (mean-square probability errors) of forecasts for North Atlantic weather regimes. The curves shown are for the EPS control forecast (blue line), the ensemble of lagged control forecasts (green line), the ensemble of perturbed forecasts (red line), and the 'perfect ensemble' forecasts (verification randomly sampled from the ensemble) (cyan line). The horizontal dotted line (CLIM) is the score reached by the probabilistic forecast based on the climate frequency of occurrence of each regime (from *Chessa and Lalaurette*, 2001).

filter applied to the high-resolution forecast; even if only the projection of the forecast onto large-scale weather regimes is looked at, the probability of occurrence of such patterns is more accurately predicted by the ensemble prediction system (EPS) than it is by the deterministic (control) forecast, or even by the ensemble of lagged deterministic forecasts valid for the same date. This allows the probabilistic forecast of weather regimes to be more skilful than a forecast of the climatological frequency of occurrence of the regime within the currently operational ten-day forecast range (when a purely deterministic forecast would usually lose its skill by day 7).

The reduction of the space of variables generated by the EPS to a projection onto a limited set of weather-regime patterns, although useful for demonstrating the level of predictability achieved by the system up to ten days ahead, is however a very restrictive approach and a long way from exploiting the potential of an ensemble of global forecasts for providing early warnings for severe weather.

Indeed, there has been only limited success so far in trying to use medium-range forecasting systems for alerting forecasters to the risk of severe weather more than a day or so in advance. On many occasions, civil security services are alerted not earlier than the day before the event, while public warnings may only be issued on the same day – however, tropical cyclone (TC) forecasts are a notable exception to this practice. The reasons usually given by forecasters as to why they do not use numerical forecasts in the early medium range are twofold:

- The global numerical models may generate nothing looking remotely like severe weather;
- If one takes signatures from the global models that are associated with severe weather, there may be no consistency in the forecasts from one day to the next, and so the rates of false alarm would be far too high for the forecasts to be useful.

However, the advances in the development of global models currently used for medium-range forecasting are such that the first of these objections is debatable. The ECMWF currently runs a deterministic forecast model having a resolution of about 40 km with 60 levels in the vertical (a resolution that, not so long ago, would have been considered appropriate for mesoscale modelling). A global model also has many advantages compared with a limited-area modelling system because it is easier to keep the forecasts under control of the global observing system without having to be concerned with lateral boundary problems.

The EPS currently runs at half the resolution of the deterministic model with a top level at 10 hPa instead of 0.1 hPa. In addition to a control run, a 50-member ensemble is run with perturbations that include:

1 Adiabatic singular vectors maximising the total energy growth in the extratropics over the next two days, as well as those (evolved) vectors that maximise the error growth over the previous two days;
2 Diabatic singular vectors targeted to maximise the total energy growth over areas where TCs have been reported (*Puri et al.*, 2001); these are scaled with a random-

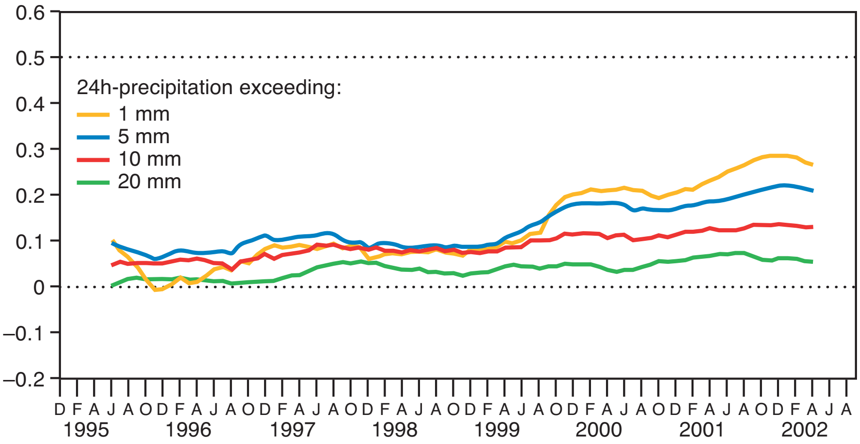

Figure 3 Evolution of the Brier skill score of EPS 96-hour forecasts of the probability of precipitation over the period 1995–2002 verified against European SYNOP reports of daily rainfall over 12 consecutive months. The thresholds are indicated in the colour-code key.

amplitude sampling of a multi-dimensional Gaussian distribution – in addition, an area (0°–25°N, 100°–60°W) is permanently kept as a target area in the Caribbean Sea;

3 Stochastic perturbations of the tendencies diagnosed by the physical parametrizations within ±50%, consistently on a vertical for all variables during six hours and over a 10° × 10° area (*Buizza et al.*, 1999).

As an example of the skill that the EPS now achieves in forecasting weather events such as rainfall, Figure 3 shows the evolution of the Brier skill scores of predictions of the probability of precipitation (PoP) for the 12 UTC EPS forecasts since 1995 (the Brier skill score measures the reduction in the rate of bad forecasts compared with climatology). Since March 2001, the EPS has also been run experimentally from 00 UTC.

The following sections aim at providing evidence, not only that global NWP models nowadays generate severe-weather signatures, but also that there is some signal to be detected up to a range of three to five days ahead using the improved signal-detection capability offered by running an ensemble of forecasts.

Severe weather in medium-range forecast models

The ability of the model to generate severe storms has improved in recent years, although the direct comparison of model wind speed over land with observations shows a fairly large negative bias. Among the reasons why this occurs is that, when designing boundary-layer parametrizations, modellers have tended to concentrate on the need to have a good momentum budget rather than on the objective of optimising on-site validation of local effects. A step towards improved post-processing of maximum wind-gust values based both on explicitly predicted model winds and on the subgrid-scale representation of turbulent fluxes was, however, taken in the year 2000 at ECMWF, resulting in a better correspondence between model predictions and observations. An example of signatures now to be found for a typical small-scale storm over Western Europe is given in Figure 4, where a good agreement between the short-range forecast and observations can be seen.

Recognition of the ability of models to generate severe-weather signatures is only one side of the story, of course, because it tells us nothing about the rate of success and failure with which the model generates them three to four days in advance. The models do usually not see severe weather as the most likely scenario at these ranges however. Forecasters have expressed an interest in using even small probabilities of severe-weather occurrence as useful early warnings to help them focus their monitoring of the situation as the severe weather comes closer. The definition of thresholds on which to base such probabilities is difficult because it is very dependant on the local climate. In fact, it could be argued that in any populated area, indigenous populations have adapted their activities remarkably well to the local climate; what is considered a severe cold outbreak in Montreal is not likely to be the same in Cairo, and the same could probably be said for severe storms in Reykjavik and Berlin. In order to generate maps where all locations are a priori equally likely to be hit by an unusual event, it has been proposed to map the severity of events with respect to the local climate distribution (*Lalaurette*, 2002). In this way, provided that we use the model to represent the local climate, orographic or land-sea effects should be handled consistently in both the climate and the model forecast, making the measure of departures more meaningful. The method is described in the next session.

An extreme-forecast index

Although the models currently generate severe-weather systems consistently throughout the medium-range, their forecast skill quickly declines over the first few days. In the case of the Halloween storm (Figure 4), this resulted in errors in both the location and the intensity of the storm (Figure 5), although the model correctly predicted the large-scale rapid perturbed flow that was to affect the area. Such errors in the smaller scales are to be expected for unstable systems in which small errors in the analysis quickly amplify. It is, therefore, of interest to see whether the EPS is able to tackle these uncertainties in a probabilistic way.

The ensemble distribution of 90-hour wind forecasts for Dover based on 12 UTC 26 October 2000 can be found in Figure 6. Although far from values that were observed (25 m/s winds with gusts up to 37 m/s), some of the members did indicate that the situation was deviating from normal. This is easier to see when the climate distribution based on EPS forecasts valid for this time of the year and this location are also reported, as is the case here. For example, although the value of 15 m/s that is exceeded by 33 members out of 50

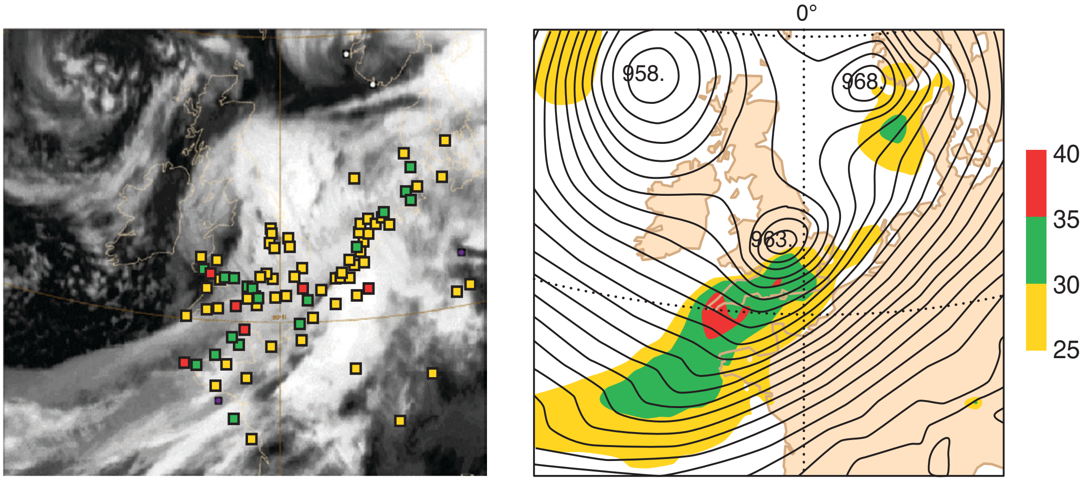

Figure 4 The 'Halloween' storm over the British Isles at 06 UTC 30 October 2000. **Left** The Meteosat7 infrared picture with superimposed SYNOP wind gust reports shown as coloured squares. **Right** The mean-sea-level pressure and wind gusts forecast from initial data at 12 UTC 29 October 2000. The colour key applies to both panels and is in m/s.

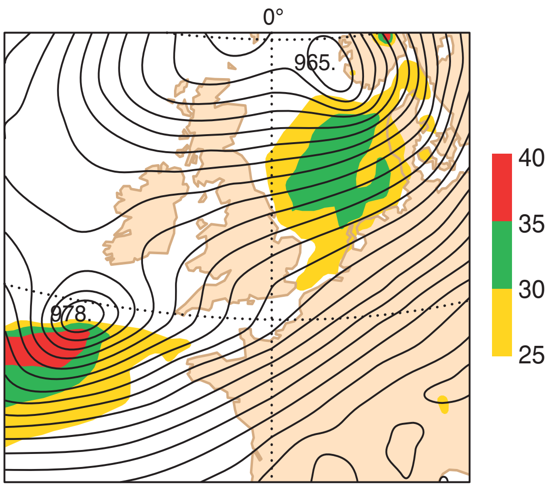

Figure 5 As Figure 4 (Right), but for the 90-hour forecast of the 'Halloween' storm valid at 06 UTC 30 October 2000.

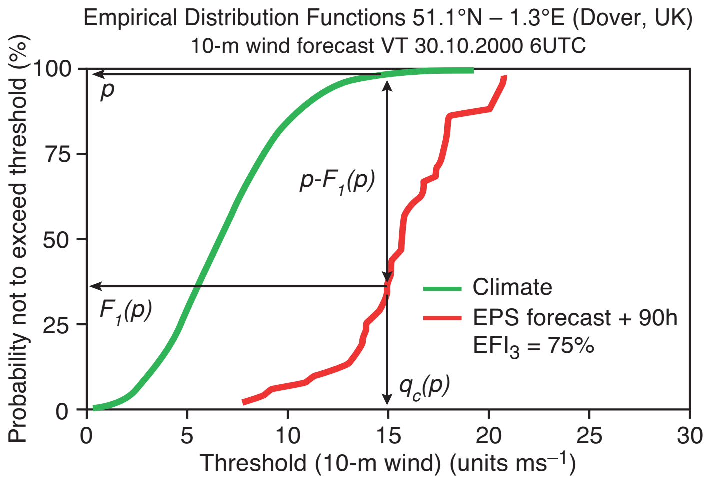

Figure 6 Distributions of the wind at Dover for the model climatology and for the 90-hour forecast of the 'Halloween' storm valid at 06 UTC 30 October 2000.

here would not be considered as a severe-weather event in Dover, it is to be found only in slightly more than 1% of the EPS records at this time of the year and at this location.

The inspection of such local, empirical EPS distributions of parameters (such as wind, temperature or rainfall) is, however, not something that could easily become part of the routine work of any forecaster; the amount of information that would be needed before an assessment of the situation could be made would be far too large to be achievable in time for the forecast to be of any use. As has been the case each time a practical use of ensemble forecasts has been considered, some aggregation of the available information has to be made. Early attempts have mostly aimed at clustering large-scale scenarios on the basis of their similarity over subcontinental areas. Such an approach, although helpful in describing the large-scale evolution of the weather, is unlikely to provide useful information for severe-weather events because scenarios that can look similar on the large scale can generate very different kinds of local events. It is rather proposed here to scale the EPS distributions with respect to the climate.

To each proportion p of the climate records is attached a value $q_c(p)$ known as a *quantile* (*Wilks*, 1995). How much a given EPS forecast deviates from the climate could, therefore, be measured by $p - F_f(p)$ (see Figure 6), where $F_f(p)$ is the proportion of EPS members that lie below $q_c(p)$. These differences are then integrated in probability space to provide an *Extreme-Forecast Index* (EFI) of order n (*Lalaurette*, 2002):

$$EFI_n = (n+1)\int_0^1 \left(p - F_f(p)\right)^n dp$$

If n is even and $\int_0^1 F_f(p)dp > 1/2$, then

$$EFI_n = -(n+1)\int_0^1 \left(p - F_f(p)\right)^n dp$$

The result of such a procedure is that differences between the climate and forecast probability distributions functions (PDFs) are scaled between –1 and +1 (–1 if the PDF in the forecast is entirely shifted below the minimum climate record, +1 if it is entirely shifted beyond the maximum). If the PDF from the forecast is the same as from the climate, then *EFI* = 0.

An example of an EFI_3 field generated from 90-hour forecast EPS distributions based on 12 UTC 26 October 2000 is indicated in Figure 7. It shows that, although the deterministic forecast misplaced the event, enough EPS members did predict it at the right location for the EFI_3 to reach high values where the event happened (see Figure 4). Indeed the EFI_3 value at Dover reached +75%, clearly indicating a well-above-normal level of risk for gale-force winds four days in advance.

One of the benefits of using an index that scales the departures of the forecast distribution from the climate globally, rather being based on reaching a given threshold, is that it improves the robustness of the signal. Figure 8, for example, shows the time-series of probabilities and EFI values as the forecast range became shorter during one of the dramatic rainfall events that flooded large parts of Central Europe during August 2002. Although probabilities of precipitation greater than the thresholds of 50 mm and 20 mm were indeed showing unusual values as far as six days in advance, the signal was very inconsistent with time. By comparison, the integrated values from the EFI gave a much smoother signal although, in this case, the signal did not show up before two to three days prior to the event.

Maps of the type shown in Figure 7 have been posted on the Web server for the ECMWF Member States since April 2002. Several case studies have been looked at, and forecasters have expressed a keen interest for this type of product. It is not intended, of course, as an automated warning system – rather as a *warning light* that makes sure a potentially dangerous event does not go unnoticed by the forecaster. From this point, more detailed investigations of the full probability distributions, either locally (Figure 7) or by isolating *worst-case* synoptic scenarios should help in detecting dynamical signatures from future observations and in making well-informed decisions for issuing public warnings.

Another area in which the EFI can be useful, however, is to explore the predictability of severe weather. Case studies may provide biased estimators of severe-weather forecast performance; there is always some kind of signal that the forecaster should, in retrospect, have been aware of. Also, conducting a verification study using forecasters expertise in real time or in delayed mode is both costly in terms of human resources and is biased in its own way by the forecaster's perspective. It must be recognised, moreover, that D+3 to D+5 forecasts are hardly ever examined in the context of severe weather. Strategies to explore the potential benefit that is to be gained from using such forecasts should, therefore, be explored first, before considering whether extending the range of warnings by one or two days would bring more benefit than frustration.

As a first step in this direction, 6 to 30-hour model forecasts have been used as a proxy for daily precipitation analyses – a reasonable choice in the absence of a comprehensive verification network (*Rubel and Rudolf*, 2001). The events targeted were those with daily rainfall exceeding 95% of the model climate records, and the verification period was December 2001 to April 2002. Results in terms of hit rates and false-alarm rates are shown for Europe in Figure 9 for different values of the EFI, both for the EPS and the control deterministic forecast. Results in terms of the ROC curves look rather positive, with a large portion of the curve lying well above the zero-skill diagonal. The longer the forecast range, the larger the benefit from using an ensemble becomes – indeed at the 6 to 30-hour range, the verification used here is biased in such a way that the control forecast is perfect, while the ensemble still generates some false alarms and misses some events.

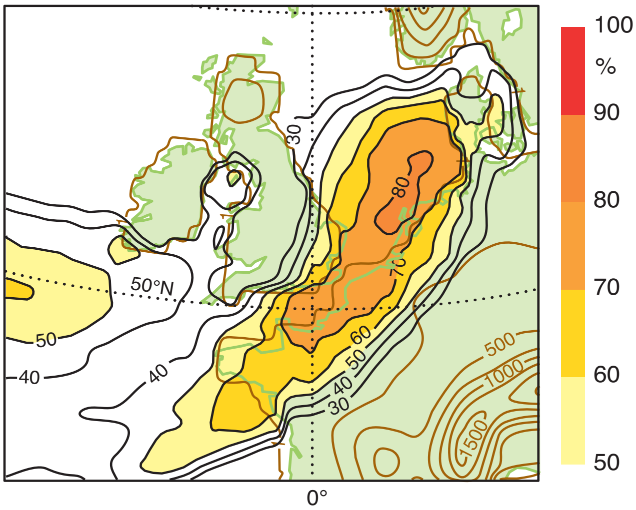

Figure 7 The extreme-forecast index (EFI) for the 90-hour forecast of the 'Halloween' storm valid at 06 UTC 30 October 2000 (see colour key for details of the contouring).

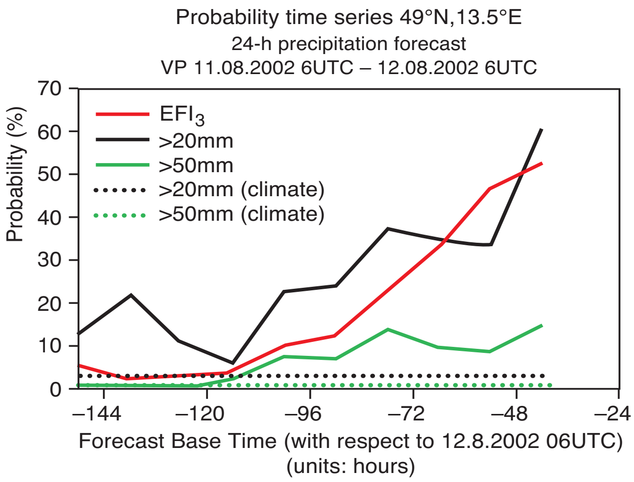

Figure 8 Time-series of the probability of precipitation exceeding 20 and 50 mm/day (see colour key) and the extreme-forecast index (EFI_3) for forecasts verifying on 11–12 August 2002 upstream of Prague before the occurrence of major floods. The model climate values are also shown.

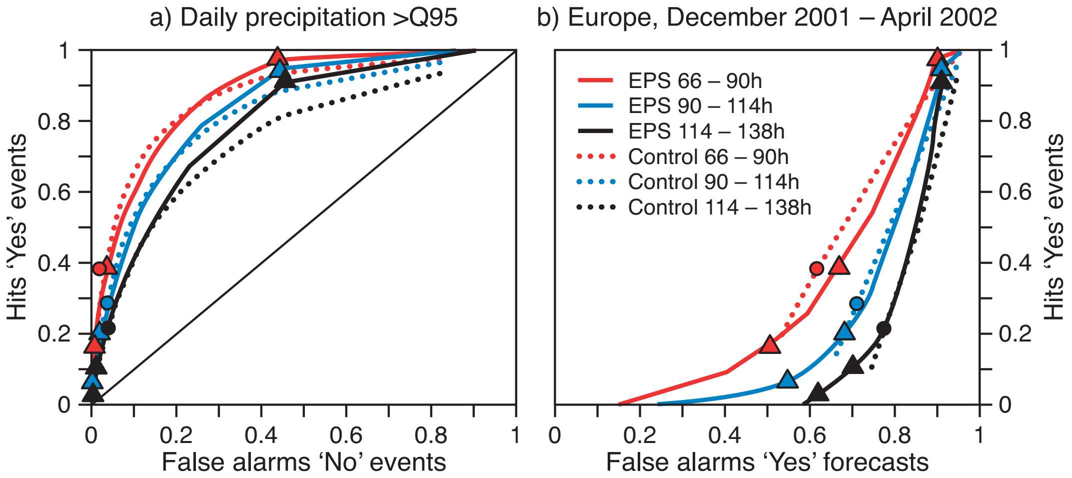

Figure 9 Verification of the EPS and control forecasts that daily rainfall would exceed 95% of the model climate records (Q95). **a)** The ROC curves, and **b)** the same as (a) but false alarms are scaled with respect to the total number of forecast occurrences; each point corresponds to a different extreme-forecast-index threshold (the triangles are for 50%, 30% and 0%, respectively, and the circles are for the control forecast predicting the Q95 value exactly).

Although these results indicate without doubt that there is skill in the early medium range in forecasting moderately severe weather events, it should be realised that to achieve large hit rates a significant number of false alarms will be generated as well. This fact is, in a way, hindered by the rarity of the event on the ROC curves. If, instead of the false-alarm rate per number of non-occurring events, the curves are shown with respect to the number of warnings issued, it can be seen in Figure 9 that, in order to achieve a hit rate of 50%, about 60% to 80% of the warnings would be wrong. Whether or not this is an acceptable result is certainly user dependent. It must be emphasised, in any case, that the decision to use early warnings of severe weather has to be carefully balanced. There is certainly more than pure randomness in the skill achieved, as a no-skill rate of false alarms per warning issued should be 95% for forecasts of an event occurring only in 5% of the cases. The rate of hits / false alarms generated by using such an early-warning system would however be very far from what could be obtained by waiting until a few hours before the event occurs. Because there are protection measures that cannot wait until the last minute to be taken (releasing water from reservoirs to avoid floods, evacuating populations in the paths of TCs, interrupting air and rail traffic for major storm events, for example) there may be some value attached to such early-warning procedures.

Tracking tropical cyclones in the forecast

In a recent (January 2002) change to the operational EPS, tropical perturbations were added to the initial perturbations. *Barkmeijer et al.* (2001) and *Puri et al.* (2001) found that, to benefit from singular-vector (SV) perturbations in TC ensemble forecasting, it was necessary to define target areas in the vicinity of TC locations (rather than only using the entire tropical region) and to ignore perturbation growth above 500 hPa in a diabatic SV computation. A more recent study regarding the impact of these so-called targeted tropical singular vectors on ensemble TC tracks has been presented by *Palmer et al.* (2001). In order to validate TC forecasts, a TC tracker has been developed at ECMWF in line with developments at other centres (*van der Grijn*, 2002). No TC genesis is handled at present – the tracking is restricted to only those TCs that have been reported by the World Meteorological Organization's Regional Special Meteorological Centres (RSMCs) with responsibility for TCs. The algorithm currently uses model data on a 0.5°×0.5° latitude-longitude grid. Starting from the analysis, TCs are tracked for 120 hours every 12 hours in the EPS forecasts and every six hours in the operational deterministic forecast. The tracking algorithm is based on a weighted average of extrapolation and mid-troposphere steering to calculate the first-guess position of the next tracking point (the method is adapted from that of *Sinclair* (1994)). A search is then made in the vicinity of this first-guess position for a local pressure minimum. This location, the minimum pressure value and the maximum 10 m wind speed are stored in the TC forecast database for the deterministic forecast, the EPS control forecast and all 50 EPS members. The tracker stops if either the TC goes extratropical (beyond latitudes ± 45°), is too weak ($p > 1010$ hPa or vorticity $<5\times10^{-5}\ s^{-1}$) or loses its warm core for two consecutive time steps.

The skill of the deterministic TC forecasts has been assessed for February to May 2002. The results are shown in Figure 10. Scores are given for the high-resolution operational model and lower-resolution EPS control model. The sample size decreases rapidly with increasing forecast step due to all TCs not surviving for the five-day period considered in the verification; this happens partly because of observed behaviour (some TCs die during this period) and partly because of model failure to maintain the TC activity. The forecast error in core pressure is always positive; i.e. the TCs in the analyses and forecasts are, on average, weaker than observed (this is especially the case for the control forecast). However, this

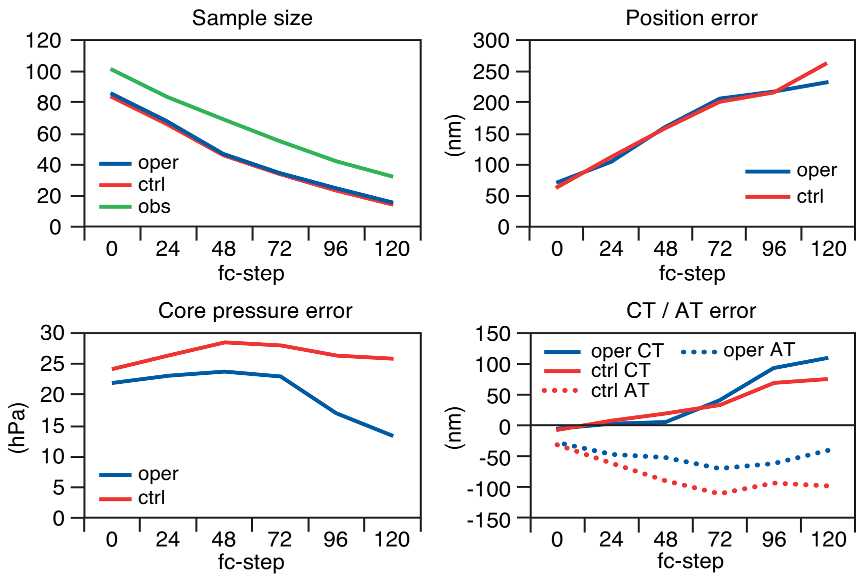

Figure 10 Position errors, core pressure errors and cross-track (CT) and along-track (AT) errors for predictions of tropical cyclones during February to May 2002 from the operational deterministic forecasts (blue lines) and the EPS control forecasts (red lines). The left-hand panel shows the forecast sample size compared with the observed sample size (green line). (*van der Grijn*, 2002)

positive bias in core pressure seems to decrease, or at least to saturate, later in the forecast. Apparently the model is more capable of developing TCs with a realistic core pressure in the forecast than of analysing them in the initial conditions, a feature that may be related to the limited resolution of both the structure (background) functions and of the incremental 4D-var inner loops.

Of particular importance for practical applications is the distance error in tracking TCs. It is, on average, 60 nm in the analyses, and it increases almost linearly to around 250 nm at D+5. Model resolution does not seem to have much impact on this error. The right-hand panel of Figure 10 shows that, at both resolutions, the forecasts have a slow bias and a right-hand off-track bias. From the analysis until the D+3 forecast, the along-track error for the control forecast is almost twice as large as for the operational forecast, while having a comparable cross-track error.

'Strike probability' and probabilistic verification of TC forecasts

Conventional probability maps are useful in assessing the likelihood of a certain event at a specific location. However, a drawback of such a probability map is that probability values do not always 'add up'. In theory, probability values can be very low even when all EPS members support a specific event (e.g. the 10m wind speed exceeding 25m/s). This can happen when the EPS members predict the event, but at different locations for a given time step. To enhance the signal for severe weather one must think of a different type of probability; a forecaster is often more interested in whether a TC will affect a certain area than when it will hit a specific location. The exact location of the TC is of less importance, within a certain margin, since the TC is likely to be equally (or even more) devastating if its centre passes close to the forecast track, or with a slight time delay.

The concept of *strike probability* originates from this idea. The strike probability is defined as 'the probability that a TC will pass within a 65 nm radius from a given location at any time during the next 120 hours'. The strike probability is based on the number of members that predict this event, each member having an equal weight. The actual value of 65 nm corresponds roughly with the value that is in use at the National Hurricane Center in Miami, USA.

One of the advantages of a strike-probability map is the elimination of the time dimension and, therefore, its simplicity (see Figure 11). It allows the forecaster to make a quick assessment of the high-risk areas regardless of the exact timing of the event. Another feature of a strike-probability map is that it gives the forecaster an estimate of the skill that can be expected from the control forecast. This is because, on average, the control model's track error should be equal to the ensemble track spread. In other words, the width of the probability plume is a direct measure of the spread in the EPS and would ideally be a good indicator of the expected error in the control forecast. *Elsberry and Carr* (2000) also found that a small spread in TC tracks from five different models is often indicative of a small consensus track error. In the case shown in Figure 12 though, rather than the spread of the EPS tracks, it is their bimodal mode that is more remarkable – although the track in the operational deterministic forecast missed the recurvature of the typhoon, the EPS gave an early indication of the likelihood of such a recurvature that might have been a useful indication for a forecaster in Korea.

The strike probability can be used to assess the skill of the EPS with respect to TC forecasting. Figure 12 illustrates this both in terms of reliability and signal detection (ROC). A clear improvement in reliability can be seen from the pre-operational testing of cycle CY24r3 of the ECMWF forecasting system introduced in January 2002. However, the system is over-confident in the high probability range. A 95% probability forecast only verifies in 60% of the cases. This might be an indication that the spread is still too low in the early forecast steps. Just like the reliability diagram (Figure 12(a)), a clear improvement of cycle CY24r3 over the earlier cycle CY23r4 can be seen. It must be noted that, despite the small values of the false-alarm rate, the actual number of false alarms is quite large, as has already been mentioned earlier

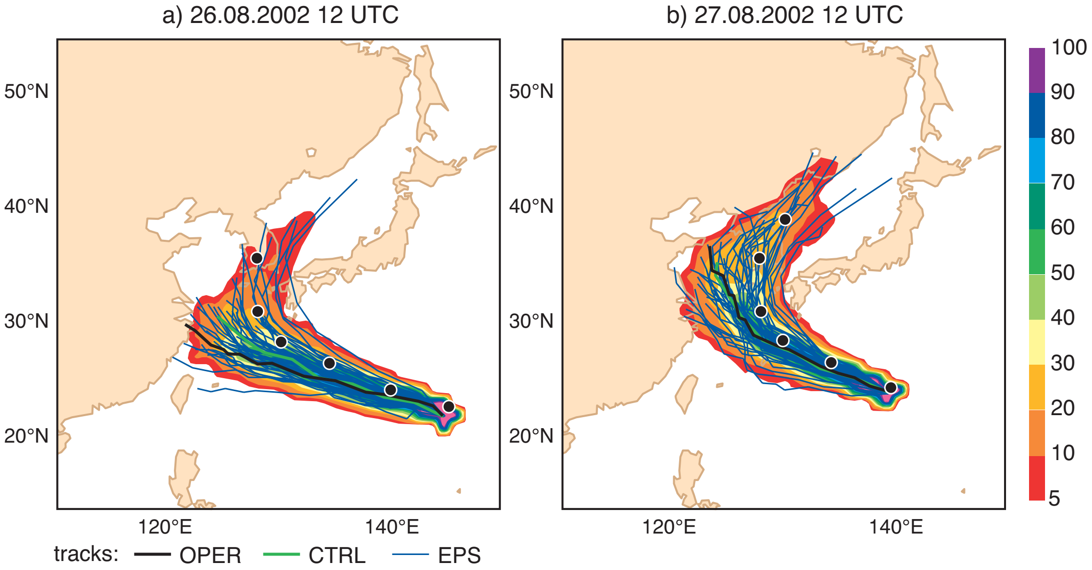

Figure 11 The strike-probability map of tropical cyclone 23W (Rusa) showing the probability that the cyclone will pass within a 65 nm radius during the next 120 hours. The colour shading (see key) represents the probabilities based on 51 tracks from the EPS forecasts (blue tracks). The EPS control forecast is shown in green and the operational deterministic forecast in black with black circles. (a) The 0 to 120-hour forecast starting at 12 UTC 26 August 2002, and (b) the same as (a) but starting at 12 UTC 27 August 2002.

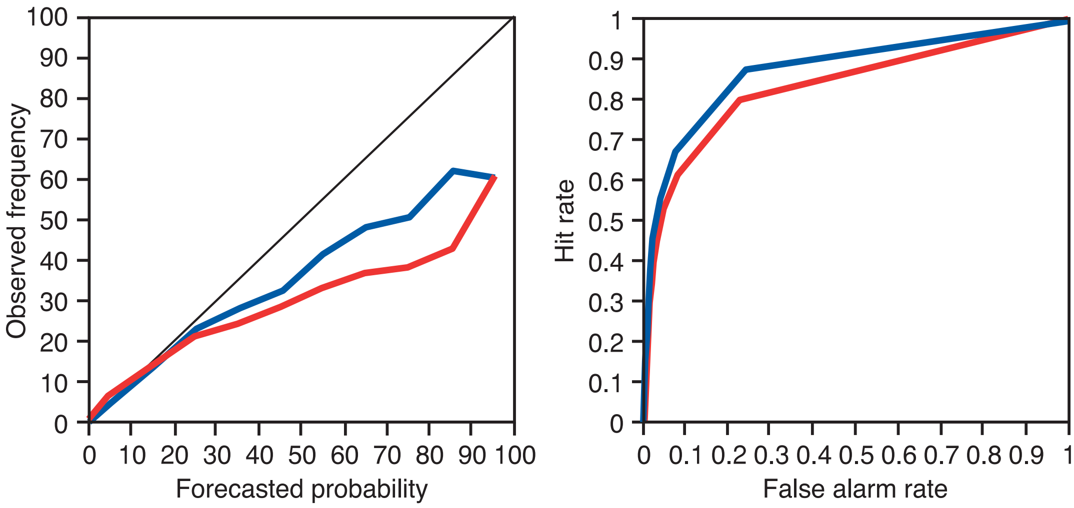

Figure 12 **Left** The reliability diagram, and **Right** the ROC curves for the forecast probability that a tropical cyclone will pass within 65 nm any time during the first 120 hours of the forecast. The curves shown are for forecasts using cycle CY23r4 with no tropical-cyclone targeting (blue lines) and using cycle CY24r3 with tropical-cyclone targeting (from *van der Grijn*, 2002).

(Figure 10). However, taking the severity of the event into account and the loss involved, it is likely that most users would favour a forecast system that is designed to reduce the number of misses at the expense of a higher amount of false alarms

Although a probabilistic approach is likely to be desirable in order to be able to extract the signal from the numerical forecasts in a way that can be tailored to the users' needs, the quality of the product ultimately relies on the quality of the numerical model itself; from this view point, the forecast quality has improved quite significantly in recent years, and this is what makes it possible to think of extending the range of warnings for severe weather into the early medium range. Developments of the EPS system are also of paramount importance if one expects to sample properly the tails of the forecast distributions, i.e. those that matter in the early medium range when severe weather is only a possible, but low probability, scenario.

Signal detection of severe-weather events in the early medium range is likely to be difficult, although one can find some comfort in the fact that the preliminary results shown here for TCs and large precipitation events indicate high rates of successful forecasts. Nevertheless, it cannot be disputed that the success is only achieved provided that preliminary action is taken on the basis of very small probabilities (which inevitably lead to very high false-alarm rates). The skill achieved by the EPS system in this context is, however, not negligible; it has been shown that the false alarms can be reduced significantly compared with a random forecast system, or even compared with a deterministic forecast system (such as the EPS control forecast, Figure 10). It still will remain, however, some time before users are likely to be convinced that they can make valuable decisions based on such products.

Finally, the status of these products is still very experimental. Operational production is, however, planned, and this will involve both archiving the forecasts in MARS and disseminating the products in real time to Member States and to RMSCs for tropical cyclones.

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François Lalaurette and Gerald van der Grijn

Central European floods during summer 2002

The summer of 2002 will long be remembered for the floods that devastated many parts of central Europe. Many countries experienced one of the wettest summers in decades. The driving force behind the large rainfall amounts can be found in the rather anomalous large-scale circulation. In particular July was characterized by a stronger than normal zonal flow over the Atlantic with many transient waves passing across western and central Europe. In August the mean flow was more blocked with a dominating high pressure over northern Europe. However the most active period, in terms of cyclonic activity, occurred between the 15 July and the 15 August 2002. During this period, several Atlantic systems passed across Europe initiating at least four major occurrences of cyclogenesis over the Mediterranean Sea. Since Mediterranean depressions are one the major sources of precipitation for southern and eastern European countries, an enhanced cyclonic activity can have important effects on the hydrological balance. This is particularly true for eastern countries that are far away from the Atlantic or from other regions of cyclogenesis (*Martyn*, 1992). The increase in cyclonic activity over the Mediterranean during July and August 2002 can clearly be seen in Figure 1, as depicted by a negative geopotential anomaly.

Among many severe precipitation events affecting various parts of Europe, one event stands out above all the others: the flood that hit central Europe in August. Figure 2 shows a time-series of accumulated precipitation in central Europe compared with the ERA-15 climate during July and August 2002. Three wet periods can be distinguished: mid July, 6–8 August and 11–13 August. At the onset of the second wet period in August, the soil was already close to saturation due to previous rainfall. Combined with unusually perturbed meteorological conditions, the ideal conditions were set for extensive floods in central Europe.

The social impact of the floods was enormous. As well as Germany and the Czech Republic, the countries that were most severely affected, the floods hit communities in Austria, Slovakia and Romania. The damage caused by the floods was very severe and widespread, affecting around two million people. The economic losses have been estimated at around 30 billion Euro. As a reference, these losses are comparable with the losses suffered by the USA in 1992 due to the infamous hurricane Andrew (see the web page of National Climatic Data Center NOAA for further details).

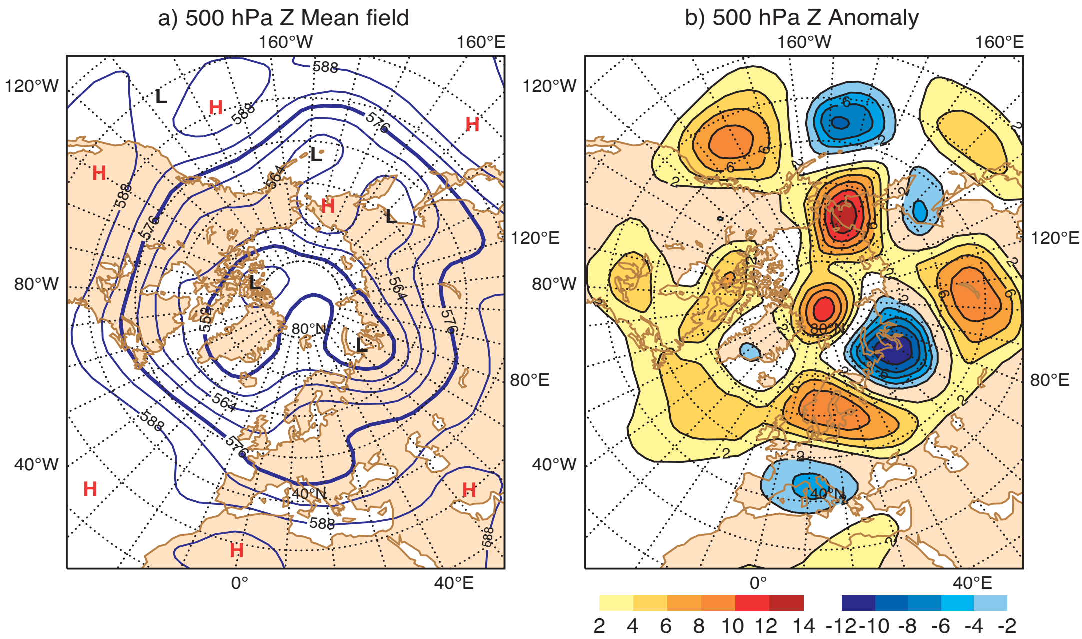

Figure 1 The 500 hPa geopotential (dam) (a) mean field and (b) anomaly during the period 15 July–15 August 2002. The anomaly refers to ERA-15 (1979–1994) climate for the same period.

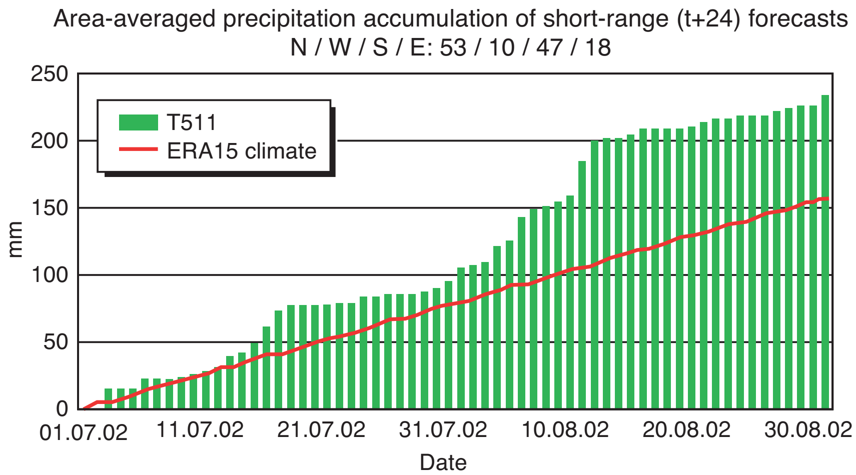

Figure 2 The daily accumulated precipitation averaged over a large area in central Europe for the months of July and August. The values are derived from t+24 forecasts as a proxy for observed precipitation. The red line is the climatological daily rate estimated from the ERA-15 dataset. Note how the 'observed' precipitation rate was steadily higher than the climate from mid-July.

This article focuses on the two major precipitation events during the first half of August. The first event (6–7 August) affected mainly Austria while the second event (11–13 August) had the largest impact in Germany and the Czech Republic.

The chronology of the flood

Figure 3 shows the synoptic situation during 3-14 August. On 3 August a low pressure area was situated over western Europe, advecting unstable air towards the Alpine region. In the following days the upper-air low propagated gradually eastwards into continental Europe. On 6 and 7 August the low dominated over central Europe, leading to torrential rainfall on the northern and eastern edges of the Alps.

After a relatively dry spell that lasted no more than two days, a sharp trough over the British Isles developed into a 'cut-off' upper-air low on 10 August. This set the stage for the second rain event. The upper-level cut-off triggered surface cyclogenesis over the Mediterranean that produced strong thunderstorms over Italy. On 11 and 12 August the cut-off moved slowly north-eastward advecting warm and moist Mediterranean air with a south-easterly flow into central Europe. Enhanced instability due to convergence of this air, together with colder maritime air advancing from the west, reinvigorated the surface low as it moved north-eastward. This process was further enhanced due to orographic lifting on the various mountain ridges that are present in central Europe. It should be noted that this type of cyclogenesis and cyclone track is rather unusual during the summer months, being more frequent during the winter and spring seasons (*Martyn*, 1992).

On 6 and 7 August heavy precipitation, coinciding with already wet soil conditions, led to the first high river levels in central Europe. Several synoptic stations reported 48-hour

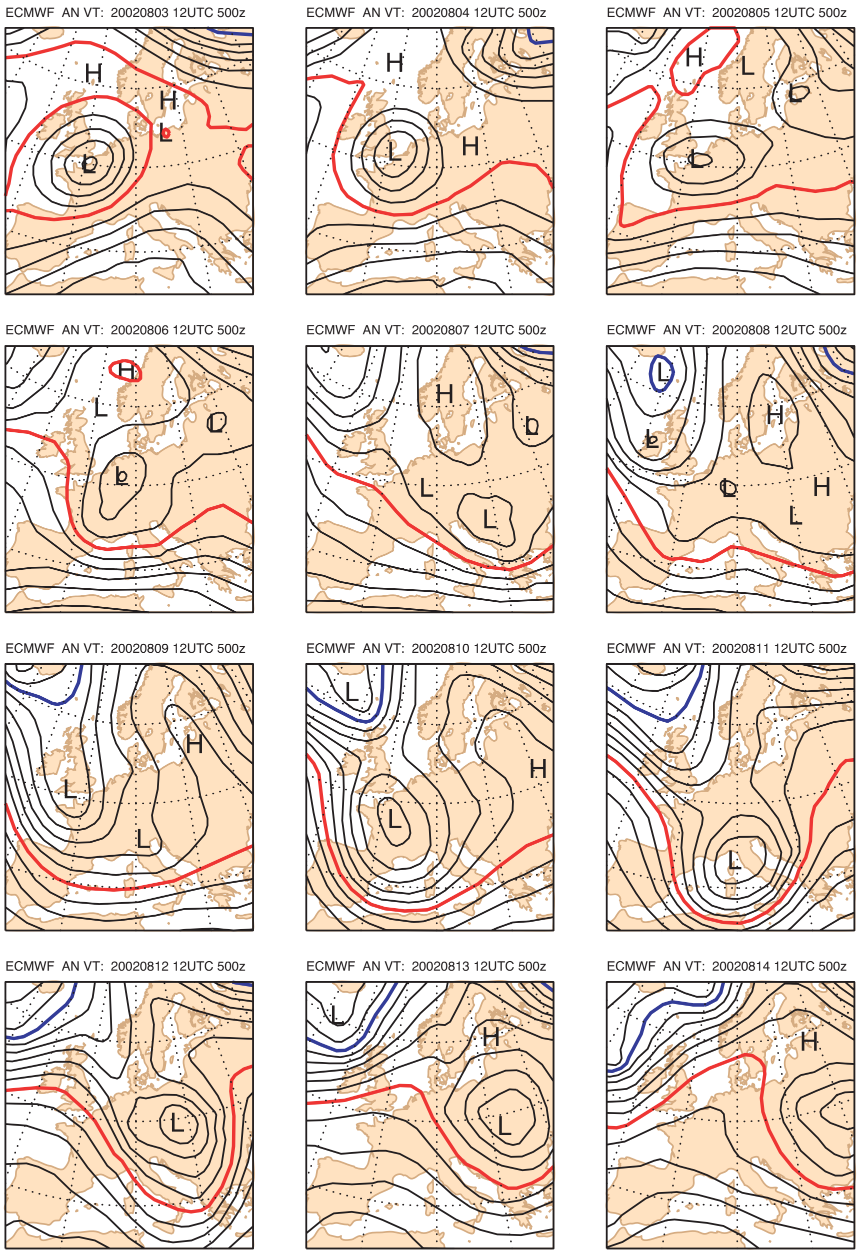

Figure 3 The evolution of the 500 hPa geopotential field over Europe during 3-14 August 2002.

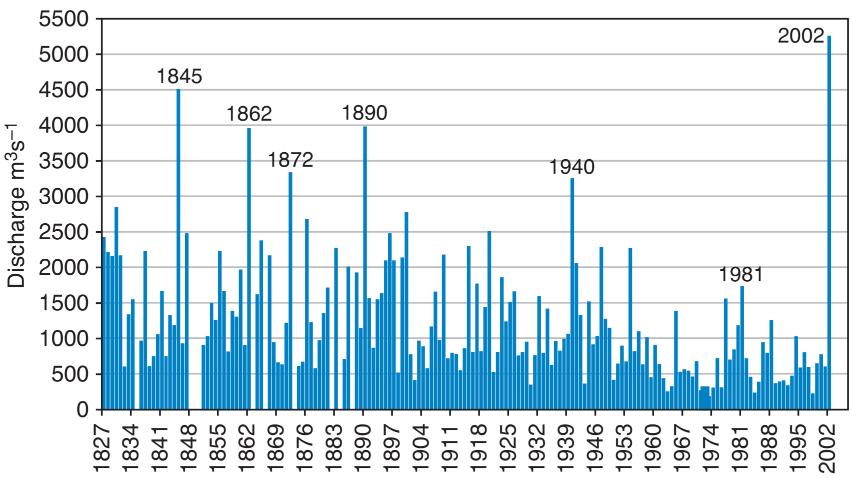

Figure 4 The time-series of maximum discharge levels of the Vltava at Prague (diagram reproduced courtesy of Czech Hydrometeorological Service) over the period 1827–2002.

accumulated precipitation amounts of more than 100 mm (e.g. Linz 149 mm, Wendelstein 150 mm). This first wave of precipitation caused localized flooding of the northern tributaries of the Danube in Austria and the Czech Republic but was not sufficient to trigger further flooding downstream.

The second wave of precipitation started on 10 August. This event affected a larger catchment area and persisted over a longer time period. At several synoptic stations the 72-hour accumulated precipitation exceeded 150 mm. Some stations reported record-breaking values for 24-hour accumulated precipitation. For example, at Zinnwald-Georgenfeld south of Dresden, 312 mm was measured which is an absolute record for the daily precipitation ever recorded in Germany. Such precipitation values, on such a spatial scale, are extraordinary for this region.

At the onset of the second event, the soil in the catchments areas of the Danube, Elbe and Vltava were still close to saturation. As a result, the river catchments were unable to absorb any extra water when the second wave of precipitation started on 10 August. Water levels began to rise quickly, and flooding of the smaller and medium sized rivers occurred almost immediately. As the rainfall continued on 12-13 August, flooding occurred also on the Danube, Elbe and Vltava.

Figure 4 shows a time-series of the maximum discharge levels of the Vltava at Prague during the past 175 years. On 14 August 2002 a peak discharge of 5300 m^3/s was measured in Prague. It can be clearly seen that this was well above the highest discharge level ever measured. In a preliminary assessment the Czech Hydrometeorological Service has estimated this flood to have a 500-year return time.

ECMWF medium-range forecast performance: synoptic-scale prediction

In this section we look more closely at the medium-range forecast for the floods. The performance of both the deterministic model (T511, 40 km) and the Ensemble Prediction System (EPS) (T255, 80 km) is assessed. As already mentioned in section 2, the floods were related to two waves of precipitation.

6–8 August 2002

Figure 5 shows the analysis of the 500 hPa geopotential field for 12 UTC 6 August, compared with forecasts from different initialization times. The forecasts from 5, 4 and 3 August show good correspondence with the analysis. The position of the cut-off is well predicted resulting in a south to south-westerly flow into central Europe. However, earlier forecasts show a displaced low and, therefore, a different flow into central Europe with respect to the verifying analysis.

The observed precipitation compared with different precipitation forecasts is shown in Figure 6. Though not at the correct location, it can be seen that the forecasts did show very large amounts of 48-hour accumulated precipitation over central Europe. The forecast from 12 UTC 2 August, i.e. four days before the start of the event, shows very large amounts of precipitation south-east of the Alps. Subsequent forecasts

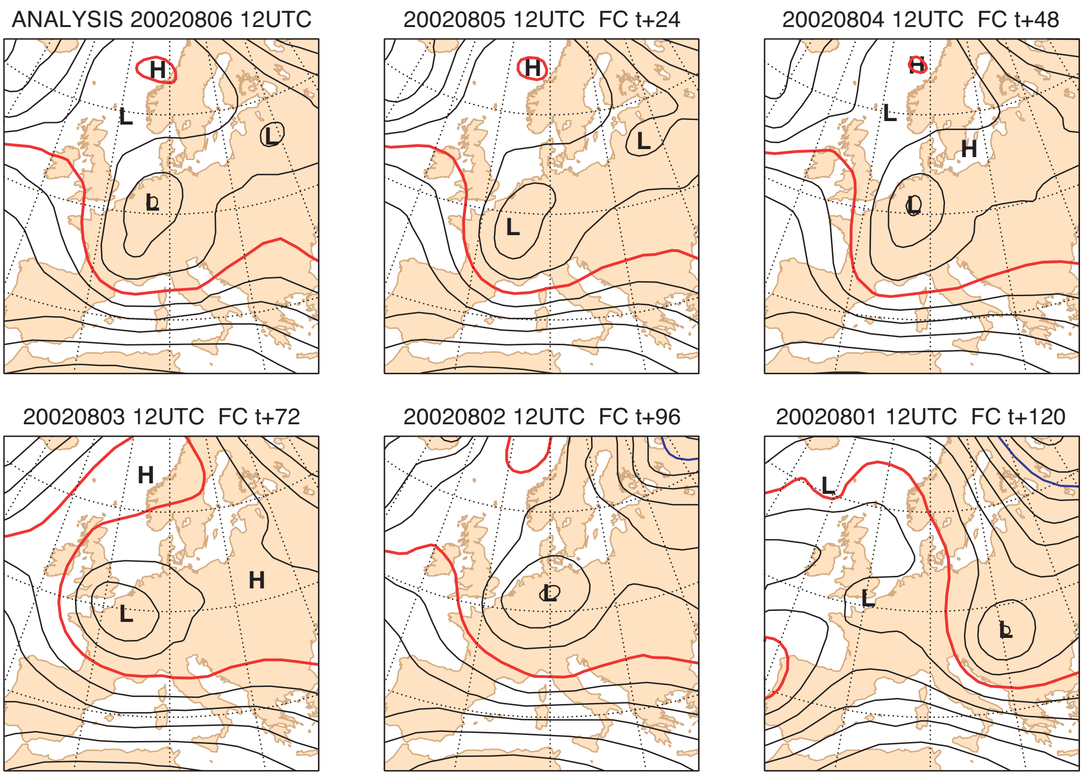

Figure 5 The analysis of the 500 hPa geopotential compared with forecasts from different starting dates. All the plots are valid for 12 UTC 6 August. From top left to bottom right: the analysis, the forecasts starting from 12 UTC 5 August, 4 August, 3 August, 2 August and 1 August. The contour interval is 40 m and the red isoline corresponds to 5760 m

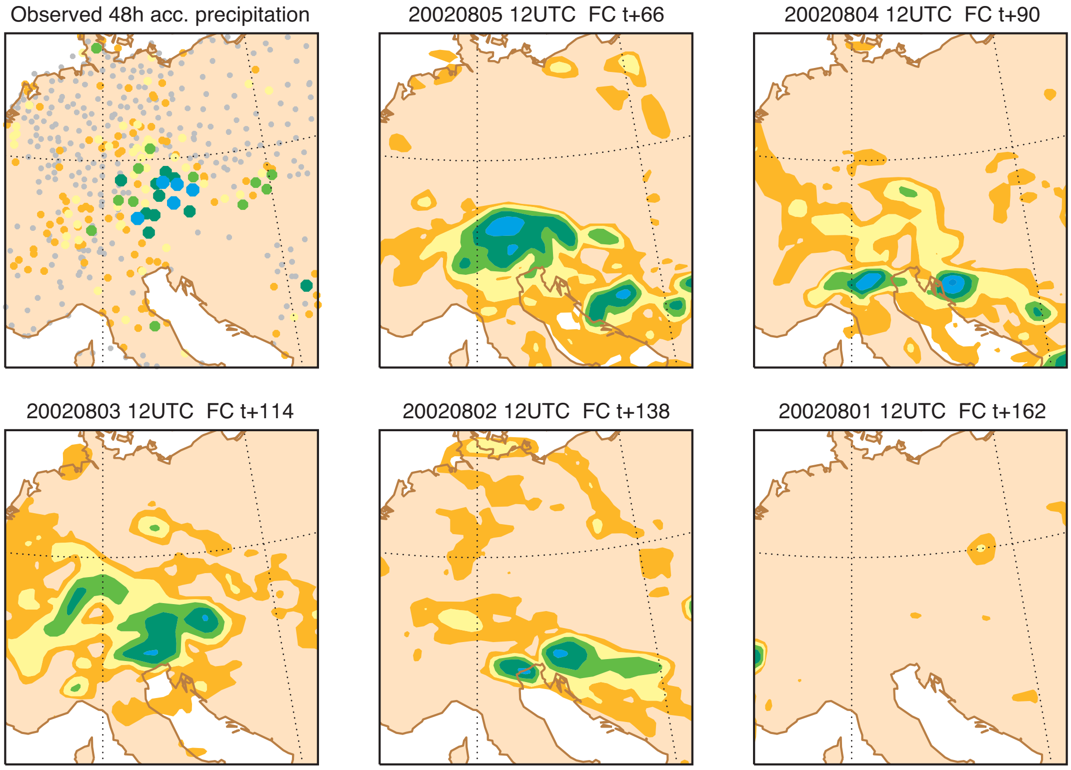

Figure 6 The observed precipitation at SYNOP stations (upper left) compared with different forecasts all valid for the same time. The observed and forecast precipitation values have been accumulated over 48 hours from 06 UTC 6 August to 06 UTC 8 August. The forecast ranges indicated in the plots refer to the end of the accumulation period. The colour code is the same for observations and forecasts: 10-20 mm (orange), 20-40 mm (yellow), 40–70 mm (green), 70–125 mm (dark green), 125–200 mm (cyan), 200–300 mm (blue), and 300–500 mm (dark blue). SYNOP stations reporting less than 10 mm/48 h are indicated with a grey dot.

also indicate heavy rainfall, but only the forecast from 5 August comes reasonably close to the observations, though still misplaced.

A probabilistic approach shows a reduced inconsistency for this event. Probability maps from the EPS for more than 100 mm in 48 hours are shown in Figure 7. In contrast to the T511 forecast, which predicted the event too far south, the EPS was more successful in predicting the area of the event, showing a consistent signal more to the north and being, thus, closer to the event. One may argue that the absolute values of the probabilities in Figure 7 are not very significant. However, the climatic probability for the EPS to forecast more than 50 mm in 24 hours over central Europe in summer is around 1%–2%. The climatic probability for more than 100 mm in 48 hours is likely to be even smaller. Therefore, probability values in the order of 5%–12%, as in Figure 7, deserve closer attention, and even more if the signal is consistent in several consecutive forecasts.

Despite some signal in the EPS, the Extreme Forecast Index [(EFI), see article on page 10 in this issue)] did not give any indication of abnormally wet conditions anywhere in central Europe.

11–13 August 2002

Only two days after the end of the first heavy precipitation event, a new stronger and deeper trough reached the Mediterranean region on 10 August 2002. Figure 8 shows the analysis of the 500 hPa geopotential field for 12 UTC 11 August, compared with forecasts from different initialization times. A common feature in the forecasts, even beyond D+5, is the presence of a deep trough and a cut-off low over Europe. However, the position of the trough is not correctly forecast earlier than three days before the event. As a consequence, the precipitation forecast does show large amounts in the medium-range, but the positioning is inconsistent showing large maxima but mostly on the southern side of the Alps (Figure 9). The forecast from 12 UTC 8 August shows a significant improvement and the subsequent forecasts gradually become closer to the observed precipitation pattern. However, it must be noted that even the forecast from 12 UTC 10 August, one day before the start of the event, does not adequately forecast the local maximum over Germany.

To obtain further insight in the temporal evolution of the observed and forecast precipitation, Figure 10 shows a time series of the areal-average accumulated precipitation over an area including central and southern parts of Germany, Austria and the Czech Republic. After a 48-hour period, ending at 06 UTC 13 August, almost 70 mm of precipitation had occurred. Given the size of the area and the large number of synoptic stations from which this value is derived (212), one realizes the scale of this event. An increase in forecast skill can be seen, with the forecasts from 9 and 10 August being much closer to the observed values than the two previous ones. However, the overall amount is still underestimated.

Improved consistency can be seen in the EPS probability maps (Figure 11), that show the probability of exceeding 100 mm in 48 hours, as predicted by four consecutive forecasts from different base dates but valid for the same period. Starting from rather low but significant values four days before the event, the signal gradually increases in later forecasts. Just as in the deterministic forecast, the precipitation over Germany is largely missed.

The EFI from 8 August showed a remarkable signal for 24-hour accumulated precipitation for 11 August (not shown). However, the signal was concentrated over the Italian side of the Alps and the Balkans and, therefore, was not correctly positioned. Figure 12 shows the EFI from the following two base dates, 9 and 10 August. A moderate EFI signal can be seen correctly positioned over Austria but less extended than the actual area affected by heavy rainfall.

Apart from the absolute value of a probability forecast, the evolution of that signal with different base dates is important to provide credibility in the forecast. Figure 13 shows, for different base dates, the empirical distribution function of the 24-hour accumulated precipitation for a given point 'R1' (chosen close to the main observed precipitation maximum, see Figure 12). It can be seen that a remarkable departure in the EPS distribution from the climate occurred in the forecast from 00 UTC 10 August (t+78, dotted blue line). From this time onwards the EPS distribution steadily moved away from the climate distribution. Some members, at different lead times, forecast up to 80 mm in 24 hours.

Though it is outside the scope of this article to investigate fully the reason behind the 'modest' performance of the deterministic forecast, it is of interest to discuss the enhanced forecast inconsistency observed during early August.

In the week preceding the heavy precipitation events, meteorological analysts at ECMWF reported enhanced and rather unusual forecast inconsistencies over Europe. As often happens, the source of forecast consistency over Europe has to be found further upstream to the west. In this case, various investigations traced back the differences to a trough over the North American east coast. This particular trough proved to be very sensitive to initial conditions. This was also reflected in the size of the initial EPS perturbations that were particularly large in that area. In the same region large analysis increments were observed on the cyclonic side of the trough. The increments were mainly due to aircraft data indicating a stronger wind speed at jet level than the model background.

This particular coincidence of persistent analysis increments over a rather unstable and active meteorological system is very favourable for large error-growth and therefore is likely to have triggered large inconsistency over Europe.

The Research Department is conducting sensitivities experiments on this case study and preliminary results seem to confirm a rather strong sensitivity to initial conditions over the USA Atlantic coast. In addition a rerun of the case with new model version, currently under pre-operational test (at the moment of writing), is also showing positive results with reduced analysis increments over USA and reduced forecast inconsistency over Europe.

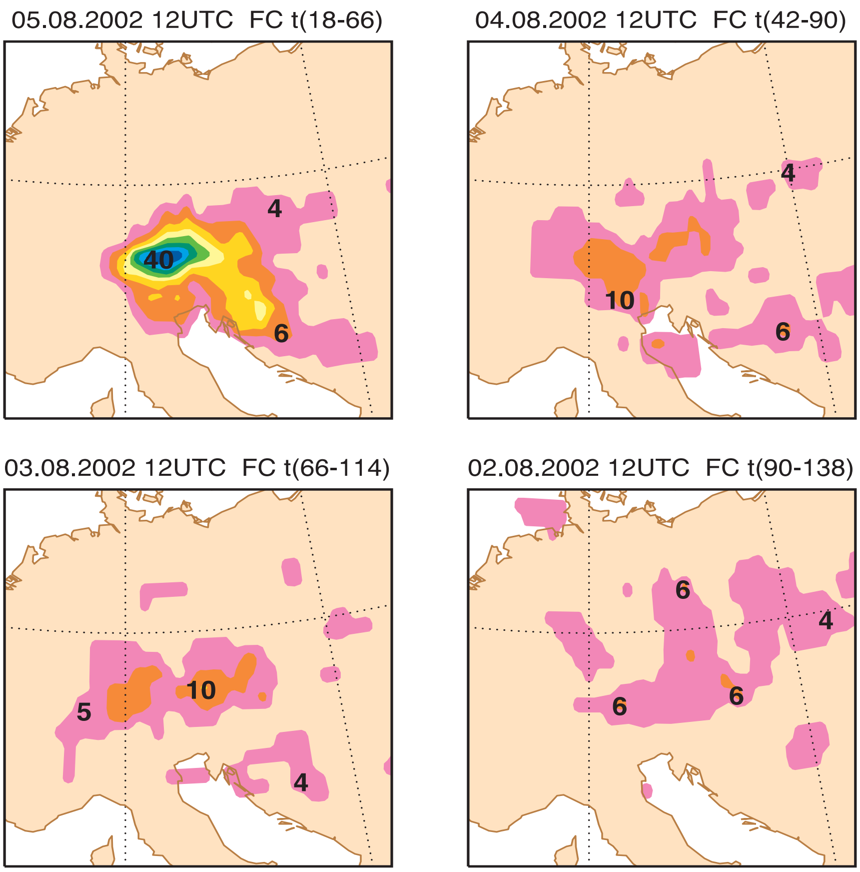

Figure 7 The EPS probability for precipitation exceeding 100 mm for forecasts from different starting dates valid for the 48-hour period from 06 UTC 6 August until 06 UTC 8 August. The shading intervals are 1%, 5%, 10%, 15% etc.

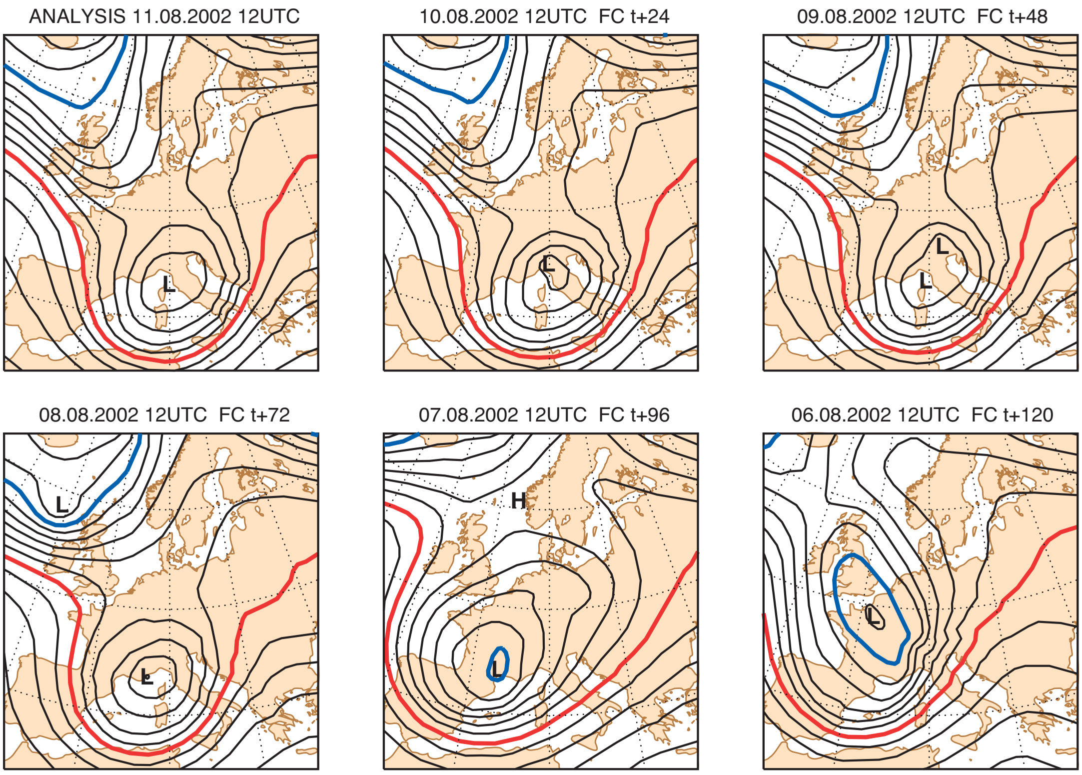

Figure 8 The analysis of the 500 hPa geopotential compared with forecasts from different starting dates. All the plots are valid for 12 UTC 11 August. From top left to bottom right: analysis, forecast from 12 UTC 10 August, 12 UTC 9 August, 12 UTC 8 August etc. The contour interval is 40 m, blue and red isoline correspond to 5520 m and 5760 m respectively.

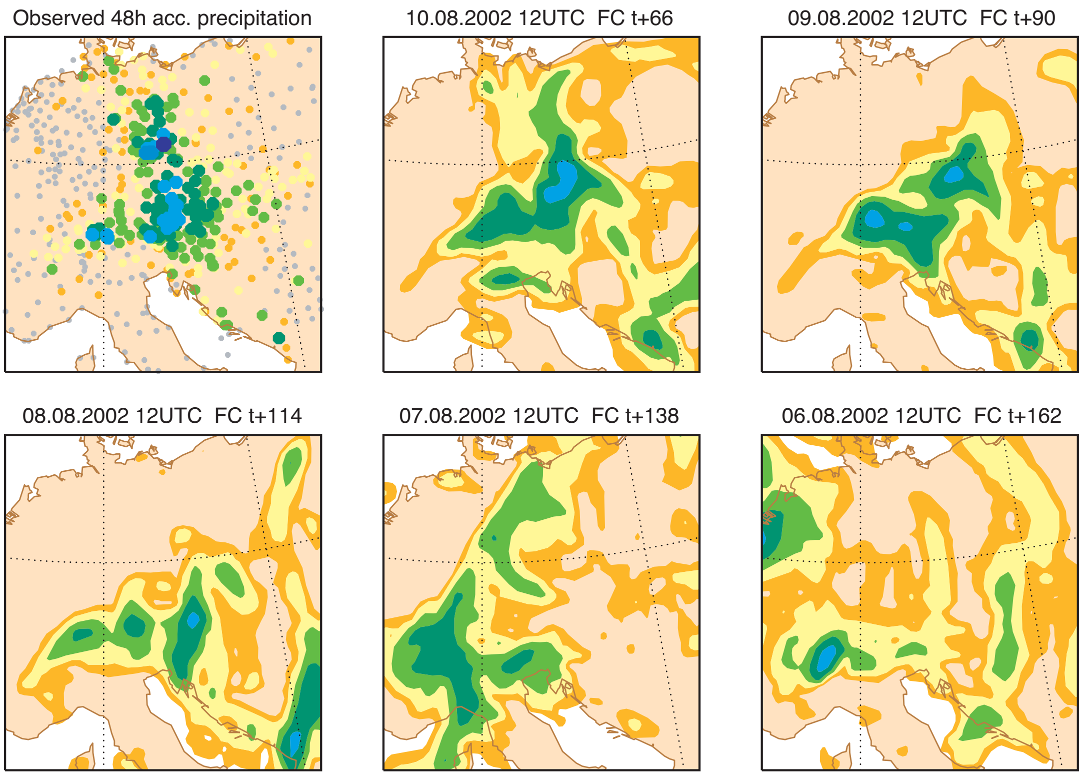

Figure 9 As Figure 6, but valid for the 48-hour period from 06 UTC 11 August until 06 UTC 13 August.

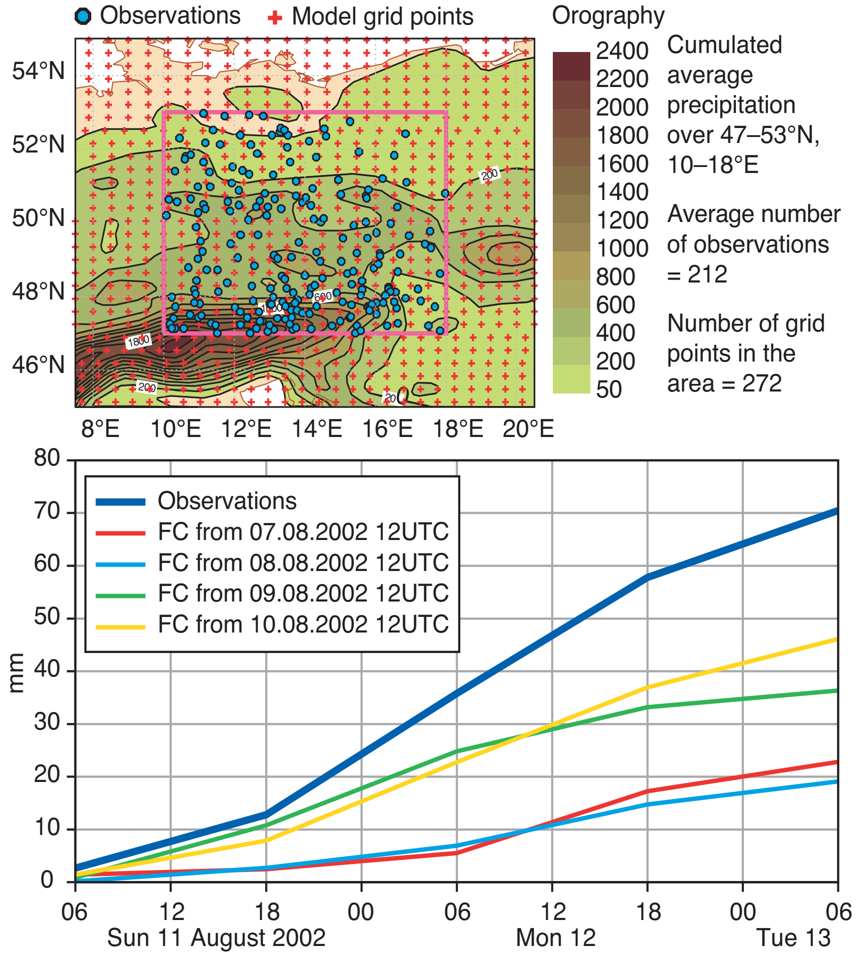

Figure 10 The evolution of the areal-average accumulated precipitation over a large area in Central-Europe. The solid blue line represents the areal averaged accumulation of observed precipitation. The dashed lines represent the same but for different forecasts from different base dates: yellow–10 August, green–9 August, cyan–8 August, red–7 August. The upper panel shows the area for which the averages are computed enclosed by a magenta box. The cyan dots are the SYNOP stations and the red crosses the model grid used in the calculation. In addition, the model orography is shaded.

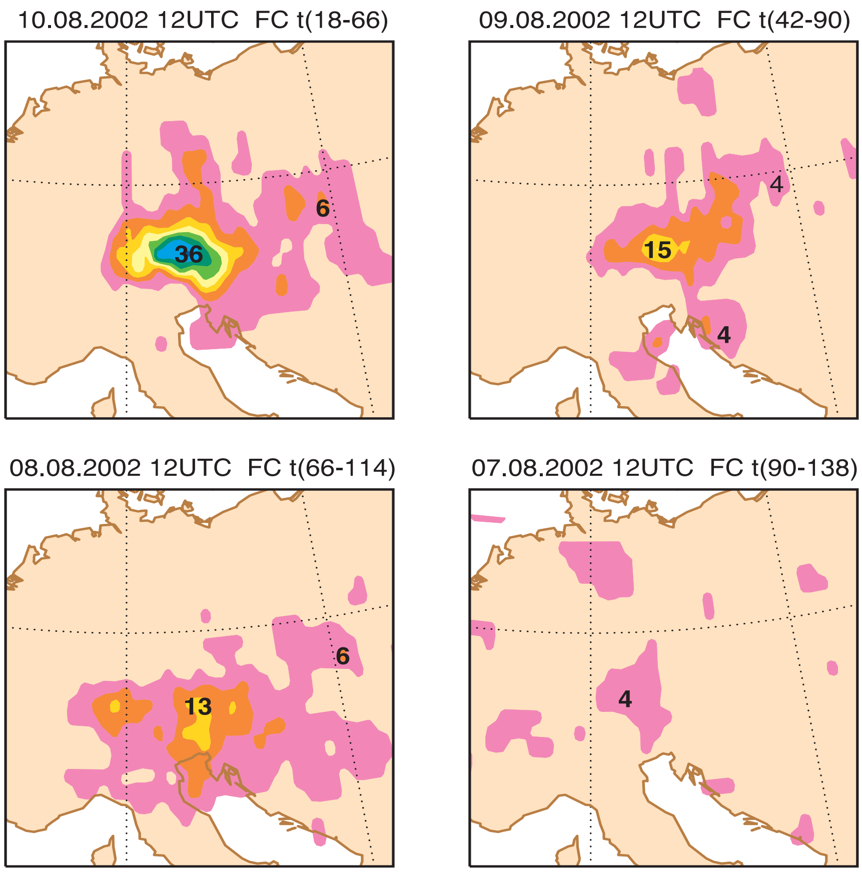

Figure 11 As figure 7, but valid for the 48 hour period from 06 UTC 11 August until 06 UTC 13 August

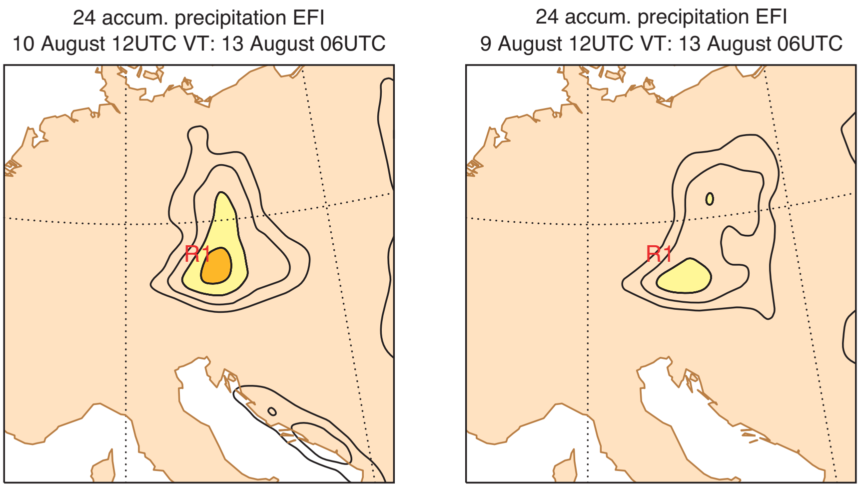

Figure 12 The EFI maps from two forecast valid for the same time. They are referring to 24-hour accumulated precipitation between 06 UTC 12 August and 06 UTC 13 August.

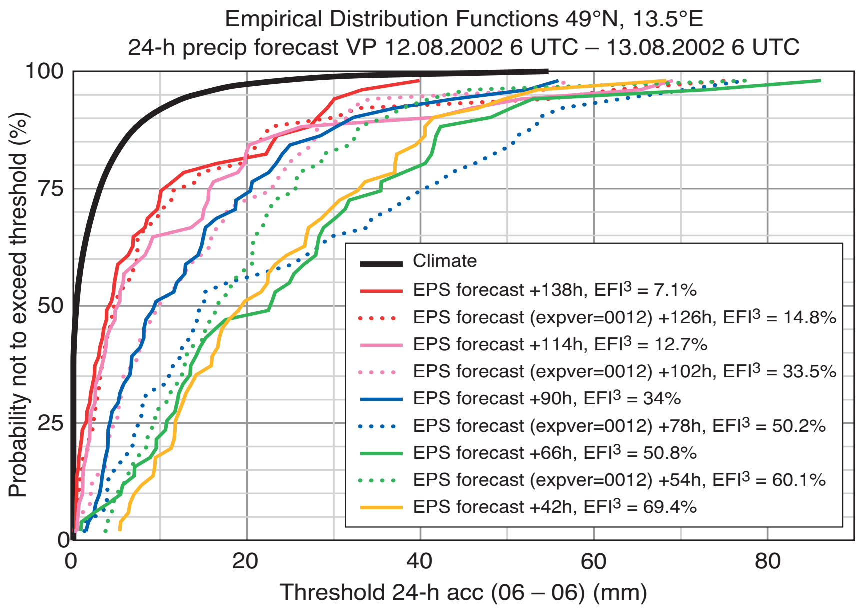

Figure 13 The empirical distribution function from EPS 24-hour accumulated precipitation at (49°N, 13.5°E). The colours indicate different forecast base dates, the solid curves are the EPS forecast from 12 UTC while the dashed curves indicate the EPS forecast from 00 UTC.

Monthly forecast: large-scale flow prediction

Since 27 March 2002 a monthly forecast (MF) suite has been run routinely at ECMWF. The suite runs twice per month providing a 32-day probabilistic forecast (*Vitart*, 2002). Figure 14 shows the MF precipitation anomaly for the four-week period starting at 17 July 2002.

The precipitation events occurred in week 3 and week 4 of this MF. The forecast anomalies Figure 14 (left) correspond roughly with the analysed anomalies Figure 14 (right), with dry anomalies over large parts of northern Europe and wet anomalies over central Europe and the Mediterranean. It is interesting to note that such persistent precipitation anomalies in week 3 and 4 are rather unusual, as the MF tends to drift strongly towards climatology at this forecast range.

This rather unusual persistence of the signal may suggest an increased predictability for this type of situation. Further investigations, stimulated also by discussion with Mel Shapiro (NOAA/OAR), revealed that the second trough that moved over Europe was part of an intriguing Rossby-wave train. Figure 15 (right panel) shows a Hovmöller diagram of the 500 hPa geopotential anomaly 'observed' during the period covered by the MF from 17 July.

During the first fifteen days of August an unusually long-lived wave train is clearly visible propagating around the whole northern hemisphere. This is the unmistakable signature that a major downstream development was taking place. The origin of this long wave train can traced back to 1 August somewhere over eastern Asia. However, it is not clear yet what processes excited such strong downstream development.

Despite the inconsistencies in the medium-range forecast, the operational medium-range forecast suite was able to forecast correctly this peculiar wave-packet propagation. Surprisingly, the monthly forecast from 17 July was also able to produce the same circulation regime with a wave train similar in wavelength to that observed (Figure 15 (left)). Even though a clear phase shift is evident, indicating a possible zonal wind speed bias in the forecast, this can be regarded as a very encouraging result indicating that this event was linked to a large-scale circulation regime that the monthly forecast system was able to predict, even at extended range. Nevertheless, further research is needed to understand fully the relation between flow patterns and predictability and, in particular, to what extent the predictability increases due to the contribution of such large (in time and space) wave propagation modality.

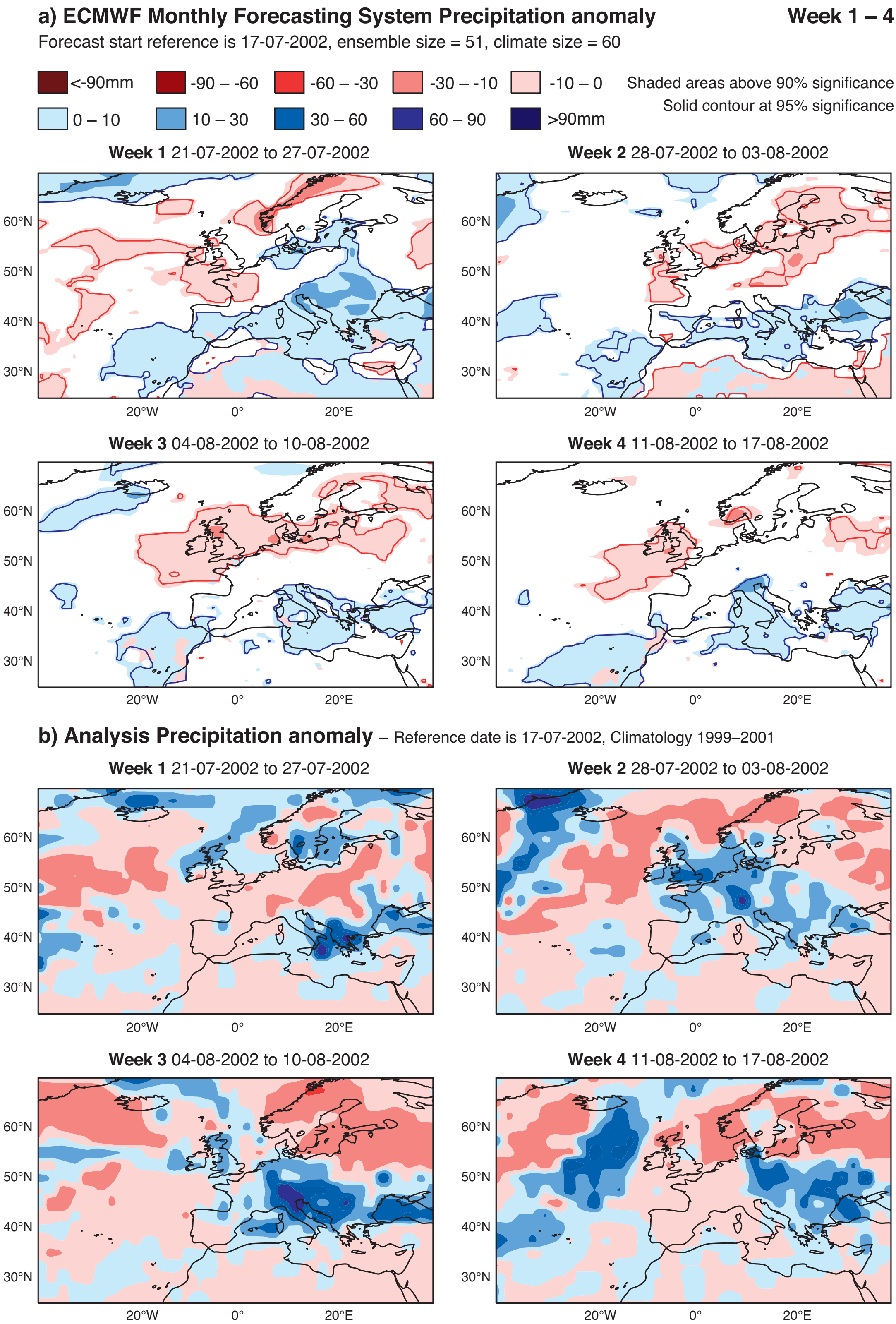

Figure 14 The precipitation anomaly derived from the monthly forecast from 17 August 2002. The left panel shows the forecast anomaly from the climate. The right panel shows the analysed anomaly from the climate compared with the observed anomalies (b). The blue areas are wet anomalies while the red areas represent dry anomalies.

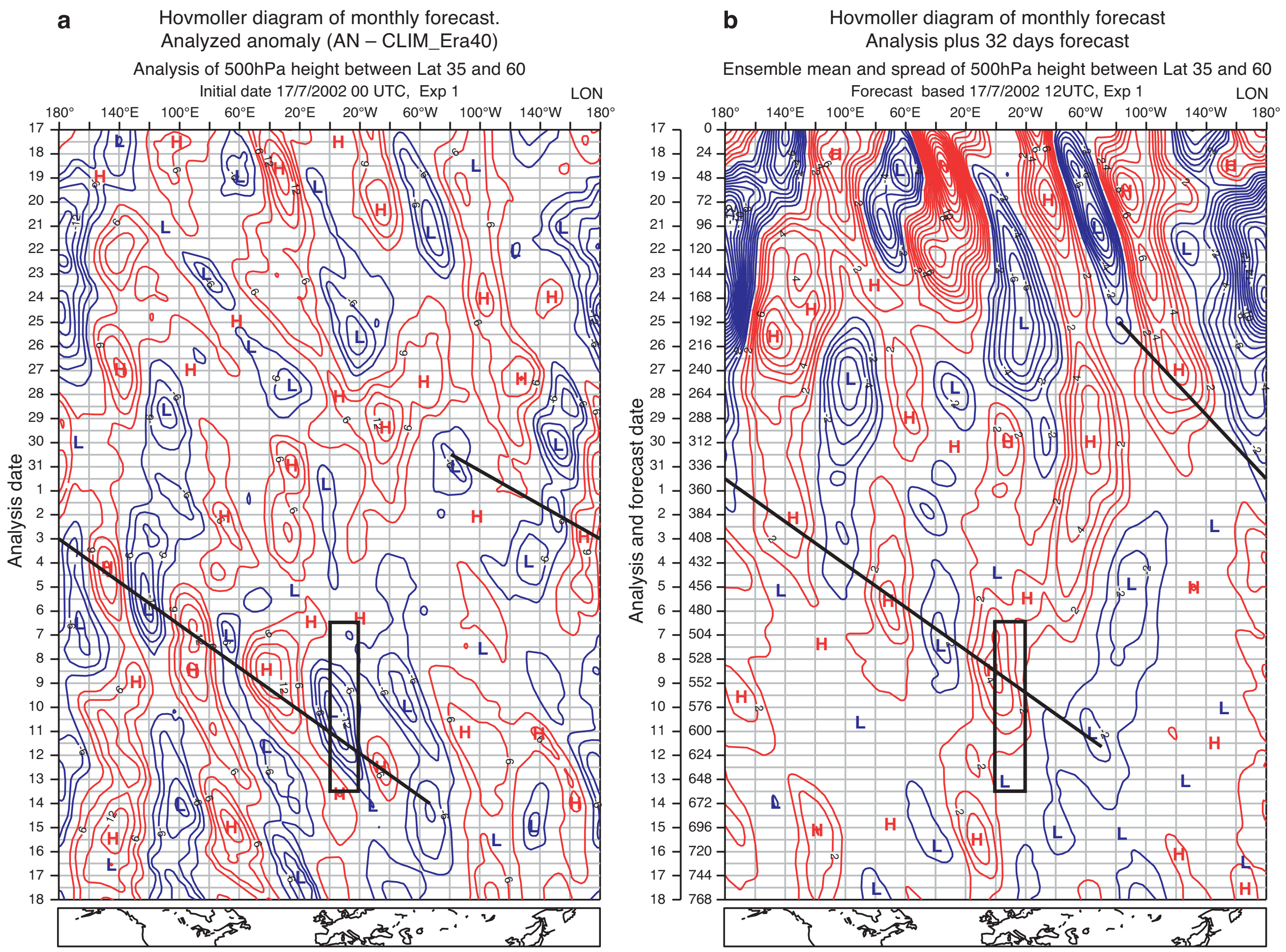

Figure 15 The Hovmöller diagram of 500 hPa geopotential anomaly of the analysis (left) and the monthly forecast (right) initialized at 00 UTC 17 July 2002. (a) The analysed geopotential anomaly with respect to ERA40 climate (1989-2001) (contour interval 3 dam, with red and blue representing positive and negative anomalies, respectively), and (b) the MF ensemble-mean anomaly with respect to the model climate (1989–2001) is shown (contouring interval 1 dam). The black rectangles in both plots highlight the space / time window in which the flood occurred. The solid black lines highlight the wave-train propagation.

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Federico Grazzini and Gerald van der Grijn

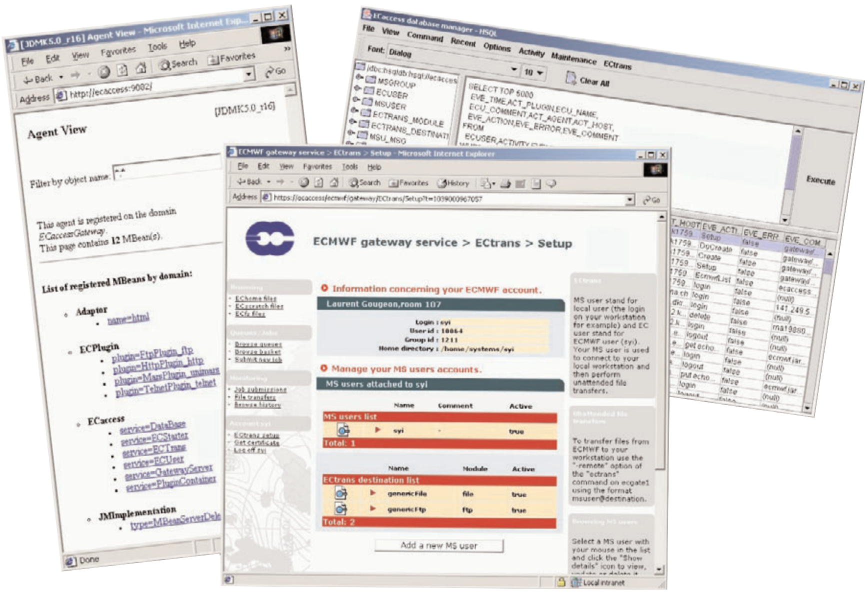
ECaccess: A portal to ECMWF

Soon after ECMWF became operational, access to the computing facilities for remote users became an important issue. Software was made available to all remote users to enable such access via the dedicated leased lines.

By the middle of the 1980s, the New Telecommunication System (NTS) software was running on the VAX servers, allowing remote users to submit and manage batch jobs from external sites to ECMWF and to transfer files between external sites and ECMWF.

In the early 1990s, UNIX and TCP/IP became the standards of choice and Telnet, FTP and X11 access for remote users became possible via the new UNIX-based servers. To secure that access, authentication became based on SecurID software. The equivalent of the NTS software was created in the UNIX-and-TCP/IP-based ECBATCH software package, consisting of the ECcopy and the ECcmd software and suitable for unattended access. ECmars software was created for direct access to part of the MARS system.

The Internet soon offered the possibility of access to all users, not only the Member State sites but also from anywhere in the world. A firewall with Telnet, FTP and X11 Gateways and extensions to the ECBATCH software package securely expanded the access range into the Internet.



Nevertheless, over time, the limitations of these methods became apparent: users need to be very knowledgeable; the user interfaces are disparate and not always easy to use; there are many different transport mechanisms involved, so problems with access are sometimes difficult to resolve. It also became necessary to offer facilities to interact with ECFS and to simplify the access method for users to avoid the double authentication process. In conclusion, to amalgamate all the different access methods to ECMWF services in a single package, ECaccess was created.

What does ECaccess do?

The new ECaccess software package provides a portal for registered users to access the ECMWF computing and archiving facilities with single step authentication from anywhere on the Internet. Authentication is performed in a uniform way, using SecurID cards and standard X509 certificates.

ECaccess allows registered users to connect to Ecgate1 and open X11 windows, to transfer files, archive and retrieve data in ECFS and submit jobs from any Unix workstation or Microsoft Windows PC. Jobs can currently be submitted to Ecgate1 and the VPPs. Submission to the IBM HPC will be offered early in 2003. Users can monitor and control submitted jobs through a Web interface. Job output data can be transferred to user workstations or PCs via the 'ectrans' command.

ECaccess replaces the current Ecbatch/Eccopy service and the Telnet, FTP and X11 specific Gateways (tn-gw.ecmwf.int, ftp-gw.ecmwf.int, x-gw.ecmwf.int).

ECaccess architecture

The ECaccess Gateway is the interface between the client and the ECaccess server. The Gateway can be located within the protected Local Area Network (LAN) or in a DeMilitarised Zone (DMZ). If located outside the protected area, the firewall must be configured to permit legitimate traffic between the clients and the Gateway and between the Gateway and the ECaccess server.

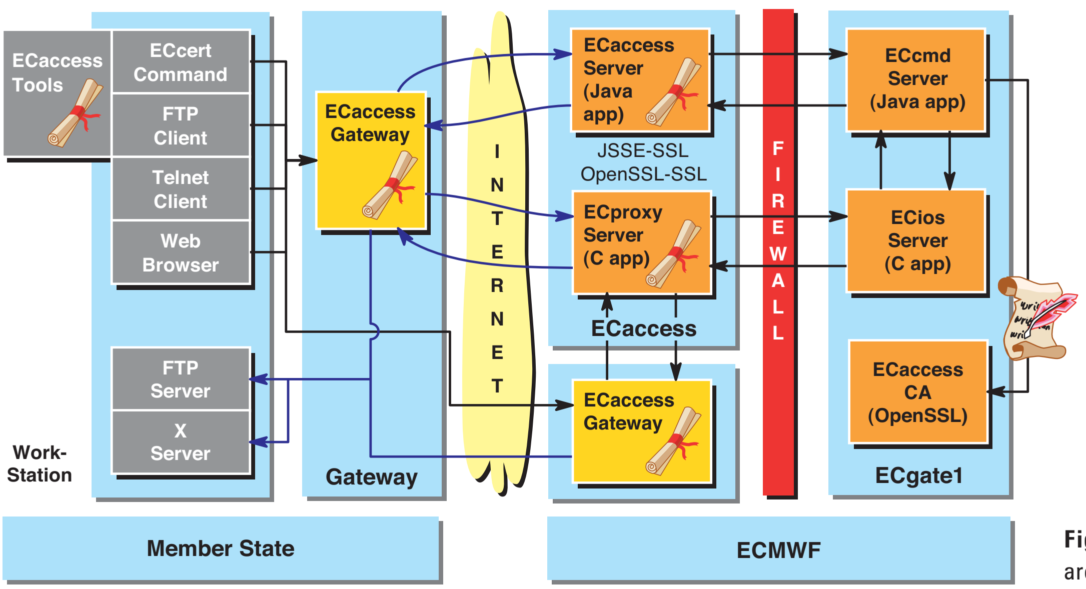


Figure 1 The ECaccess architecture.

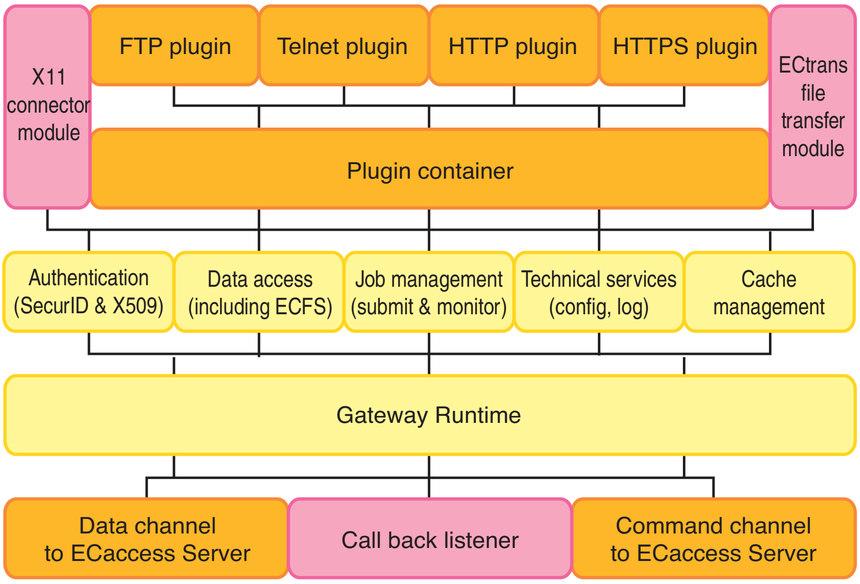


Figure 2 The ECaccess Gateway internal architecture.

The ECaccess Gateway has been developed using Java[tm] object oriented programming technology, and can be run on almost any platform. This is done to avoid the usual porting issues existing with other languages such as C/C++.

The ECaccess tools, installed on the remote user's workstation or PC, offer high-level commands allowing users to manage their files and jobs from within batch scripts. The ECaccess tools are provided for several target operating systems and C sources are included to allow easy porting to most popular programming environments.

Finally, the ECaccess Server provides technical and high-level services to the Gateways, allowing generic access to computing and archiving facilities at ECMWF through Ecgate1. Two types of connections are maintained between the ECaccess Server and the ECaccess Gateways, one dedicated to data transfer and one dedicated to job and file management. The ECproxy Server carries out data transfer. It is a pure C, multithreaded application allowing fast transfer rates. The ECaccess Server, based on Enterprise Java Bean (EJB) technology, part of the Java2 Enterprise Edition (J2EE) framework, carries out the jobs and files management. Figure 1 gives a general overview of the ECaccess architecture:

Full ECaccess functionality requires a Gateway to be installed on the remote site. A Gateway is available at ECMWF for individual users, but secure file transfers from ECMWF to remote sites can be performed only if a Gateway is installed on the remote site.

Security

ECaccess addresses security at two levels: user authentication is performed using SecurID cards; batch requests (job submissions, file transfers, etc.) and Gateways are authenticated with X509 certificates.

A public-key infrastructure has been set-up by ECMWF to deliver:

- X509 certificates (valid for seven days) to authenticate users batch requests: users can request a certificate through a SecurID login process.
- X509 certificates (valid for two years) to authenticate ECaccess Gateways: administrators can register and get a certificate for their Gateway on the ECMWF Web site at http://www.ecmwf.int/services/ecaccess.

SSL is used to guarantee the integrity of the application data and the confidentiality of the transferred jobs and the monitoring information.

ECaccess Gateway

Figure 2 represents the internal organisation of the ECaccess Gateway.

The Gateway includes built-in mechanisms to maintain a secure connection with the ECaccess Server, to authenticate users and manage their requests, to transfer data and submit jobs.

The Gateway includes a model for the management of 'plug-in' services. A plug-in is a piece of code that handles requests/responses flowing through the Gateway. Currently, there are plug-ins for incoming FTP, HTTP/S, X and Telnet requests to ECMWF. Other plug-ins will be added in the future.

Plug-ins

- The FTP plug-in lets users submit jobs and transfer files between their own workstation or PC and the ECMWF file systems. This extended FTP server can be used for access to ECMWF computing and archiving facilities in interactive mode with a standard FTP client (or an FTP browser) or in batch mode from within shell scripts.
- The HTTP and HTTPS plug-ins let users manage and monitor their jobs and transfer files. They offer the same functionalities as the FTP plug-in from an HTTP browser.
- The Telnet plug-in provides access to Ecgate1 with a single-sign-on login process. Communication and authentication is established through the Gateway. The login process is secure and overcome the limitation of the current Telnet specific Gateway.

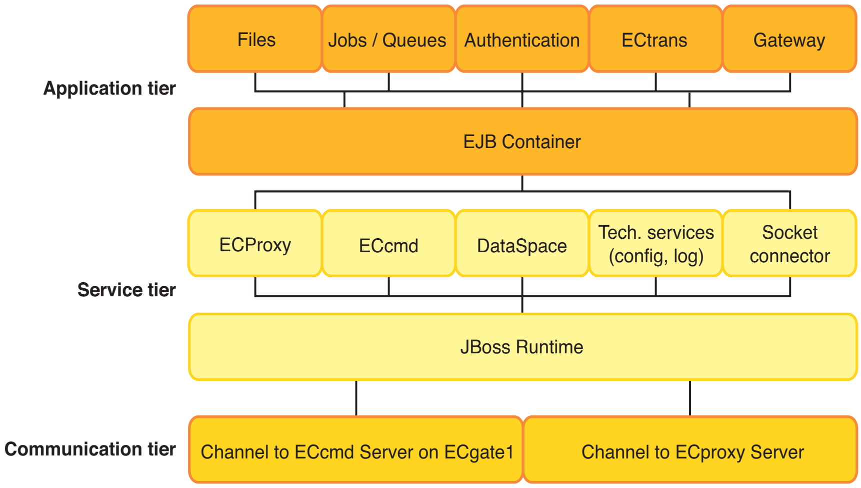


Figure 3 The ECaccess Server internal architecture.

Call back

The Call back listener receives notifications from the ECaccess Server and activates either the ECtrans file transfer module to transfer data to a remote user's workstation, or the X11 connector module to open connections to a remote user's X11 server.

ECaccess Server

The ECaccess Server runs on the ECMWF side. Figure 3 represents the internal architecture of the ECaccess Server.

The ECaccess Server includes built-in mechanisms, such as the Java Authentication and Authorization Service (JAAS) and the SSL protocol, to authenticate the Gateways and provide a secure framework for remote access to ECMWF services.

The application tier provides public services to the Gateways. The Enterprise Java Bean (EJB) container relies on the services tier, which provides internal services to the EJB components (Files, etc.). The communication tier manages communications between the Gateways and the ECproxy Server, for the data transfers, and between the ECaccess Server and the ECcmd daemon.

Why do I need ECaccess?

With ECaccess, scientists from institutions anywhere in Europe can access the complex computer environment at ECMWF via the Internet using any standard FTP, Telnet or HTTP client. Jobs can be prepared and submitted remotely. Data produced by the jobs or MARS retrievals can be transferred back to the remote user's workstation or PC. Debugging or monitoring a suite of jobs can be done interactively starting the X11 applications via a Telnet connection.

ECaccess offers remote users uniform access to ECMWF services in both interactive and batch mode. In particular, ECaccess enables remote users to:

- Connect directly to Ecgate1 via Telnet.
- Open X11 windows on Ecgate1, the VPPs and the HPCs.
- Transfer and manage HOME, SCRATCH, ECFS or MARS files.
- Submit and monitor jobs from any desktop.
- Automate file transfers from ECMWF to any workstation or PC using ECtrans.

How do I use ECaccess?

In order to use ECaccess, an account at ECMWF is required. Authentication is performed using SecurID cards to use the ECaccess services in interactive mode, or by creating a seven-day X509 certificate for batch access. Users connect to an ECaccess Gateway and go through an authentication procedure. The Gateway authenticates external users and contacts the ECaccess server, which in turn manages access to ECMWF services. Connections to the ECaccess Gateway can be made interactively via standard Telnet, FTP and HTTP clients or in batch mode via the ECaccess tools (a set of UNIX commands which can be called from batch scripts).

Managing files

Files can be managed interactively via FTP and HTTP or in batch mode via the ECaccess tools.

The root directory of the FTP server (Figure 4) contains the ECaccess domains: ECFS and ECTMP (the user's ECFS permanent and temporary directories); ECHOME (the user's home directory on Ecgate1); ECSCRATCH (the scratch directory) and ECJOBS (the queue directory).

Simply use drag and drop to transfer files between a local folder and any of the target ECaccess domains.

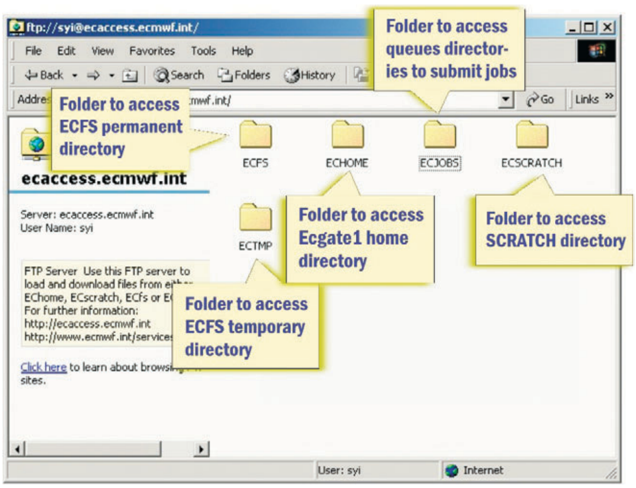


Figure 4 The root directory of the ECaccess FTP server.

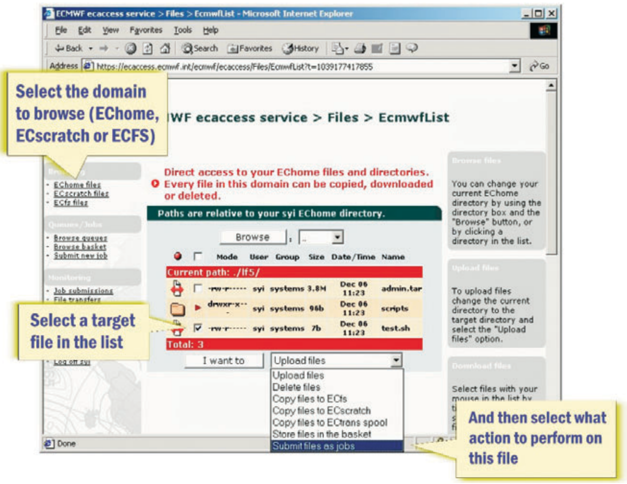


Figure 5 Access to the ECaccess domains.

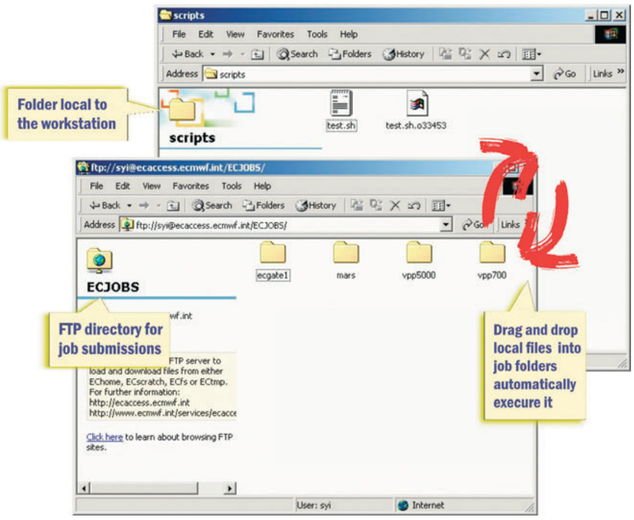


Figure 6 Jobs submissions using an FTP browser.

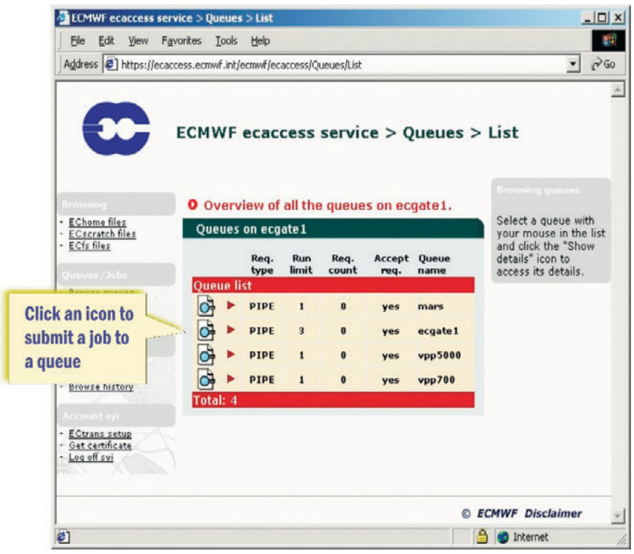


Figure 7 Selection of a target queue for a job submission.

With an HTTP browser, the ECaccess domains can be selected using the 'Browsing' menu of the ECaccess Web interface (Figure 5). Within the selected domain, users can transfer or delete files, submit jobs and browse directories:

With the ECaccess tools, remote users can select a target domain by setting the environment variable ECDOMAIN, and then manage or transfer files to and from this domain.

For example, to manage ECFS files, a remote user will set ECDOMAIN to ECFS and use the following commands:

- 'ecls' or 'ecdir': to print the list of ECFS files.
- 'ecget' or 'ecreget': to retrieve an ECFS file.
- 'ecput': to store a local file in ECFS.
- 'ecmkdir' or 'ecrmdir': to create or remove ECFS directories.
- 'ecdelete' or 'ecchmod': to delete or change permissions of an ECFS file.

Managing jobs

Jobs can be managed interactively via FTP and HTTP or in batch mode via the ECaccess tools.

The ECaccess FTP server can also be used to submit jobs. To submit a job from an FTP browser, click on the ECJOBS folder of the ECaccess root directory. Each ECJOBS subfolder is a target queue for job submissions (Figure 6).

A script dragged and dropped into an ECJOBS subfolder is automatically submitted as a new job. Once executed, the job input file is renamed to include the job identifier and the job output file is created. All the files associated with the job can later be inspected or dragged and dropped into a directory local to the user's workstation or PC.

A user can also use an HTTP browser to submit jobs step-by-step using the 'Browse queues' menu of the ECaccess WEB interface (Figure 7).

The list of available queues is displayed in a table with an icon for each queue. A target queue can be selected by clicking the appropriate icon. After having checked the details of the selected queue, click the 'Submit a job to this queue' button to include the job into the specified queue (Figure 8).

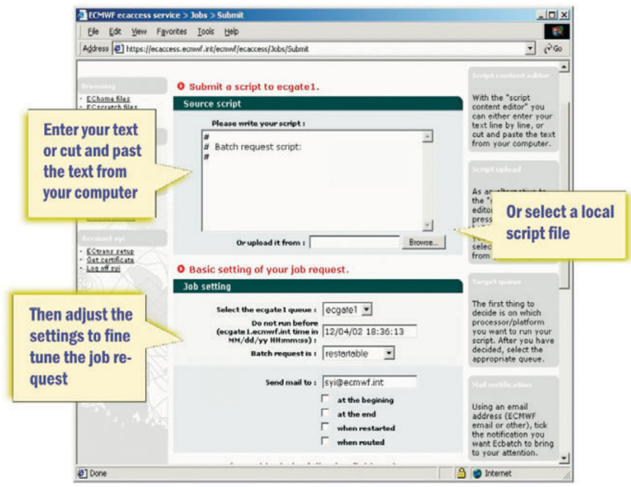


Figure 8 Batch request settings.

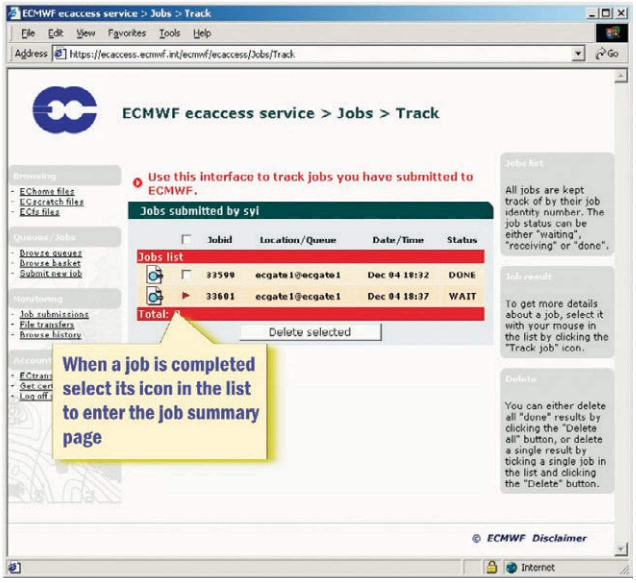


Figure 9 Batch request monitoring.

Once the source script is provided (either from a local file or from a text entered in the job input text area) and the settings have been checked, click the 'Submit job' button.

Once submitted, jobs can be monitored using the job track interface. The monitoring interface provides remote users with information on the job requests referenced by the job identifier number. To access it, click the 'Job submissions' link in the 'Monitoring' menu (Figure 9).

Jobs submitted via the Web interface or via the ECtools commands will appear in the list of jobs.

Once the job has completed (status is DONE), its outputs can be managed (Figure 10).

The output, input and error files associated to the selected job can be transferred to an ECaccess domain or directly edited using the job editor of the Web interface.

With the ECaccess tools, remote users can prepare batch scripts, transfer them to ECMWF, submit them and retrieve the results. The status of submitted jobs can be interactively monitored.

To submit a job, a user will execute the 'ecjput' command, specifying the name of the queue where the job is to start, and the name of the file located on the remote user's workstation or PC ('ecjreq' can be used if the file is located at ECMWF). Optionally, an email address to receive a notification when the job is started or completed can be provided. Then the following commands are available to monitor and manage the job requests:

- 'ecjget': to get the job output files.
- 'ecjdel': to delete and cancel a job request.
- 'ecjls': to list the submitted job requests.

Unattended file transfers

The ECtrans command is provided for batch script running at ECMWF, on ECMWF user accounts. Its purpose is to automate files transfers from the VPPs, Ecgate1 or the HPCs using the secure file transfer feature of the ECaccess Server (Figure 11).

Managing users and hosts

An external user makes a file transfer request from ECMWF, providing a remote user identifier and a remote destination. The destination is either a target file on the ECaccess Gateway host, or an FTP destination on a remote server or remote user's workstation or PC. The connecting parameters to these remote destinations (remote user identifier and passwords) are held in the ECaccess Gateway database.

Via his HTTP browser a user can define the mapping between his ECMWF user identifier and his local user identifiers. He can also check his available destinations by clicking the 'ECtrans setup' link in the 'Account' menu (Figure 12).

Local users (MS users) can be created, updated or deleted. The parameters attached to a local user are a hostname (e.g. the remote workstation or PC for FTP access), a user identifier and a password (e.g. the login parameters of the FTP account). Details on local users and destinations can be viewed by clicking on the appropriate icon.

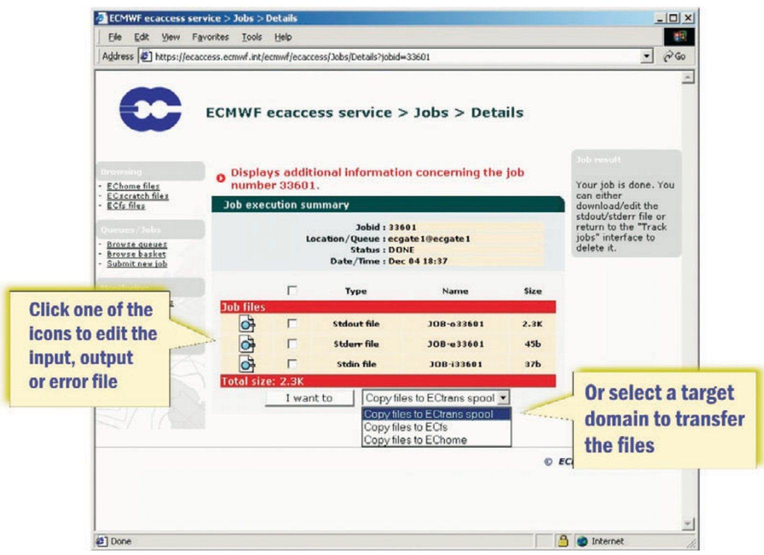


Figure 10 Outputs of a batch request.

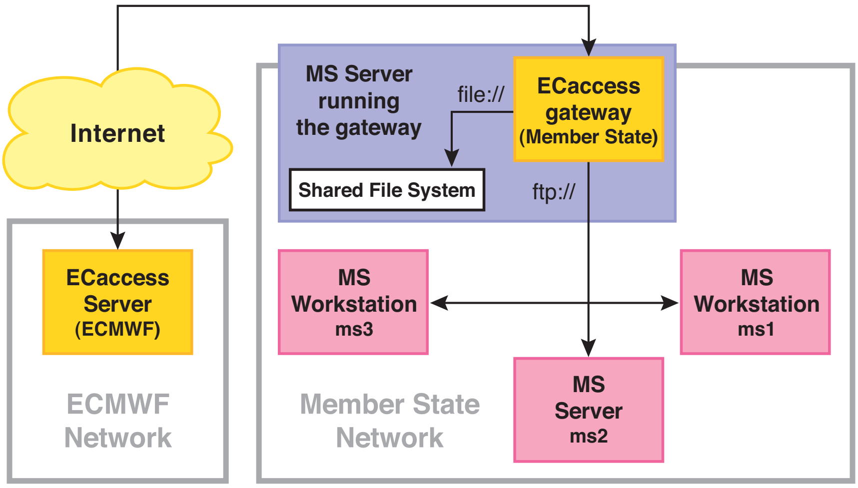


Figure 11 ECtrans mechanism.

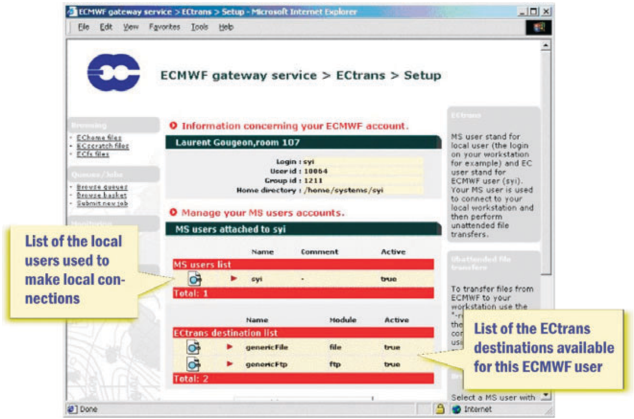


Figure 12 ECtrans setup.

Sending files

Figure 13 shows the usage of the ECtrans command.

Flags can be used to specify the action to perform in case of an existing target file, to request notification in case of a successful and/or a failed transfer and to specify whether the transfer is from ECMWF to a remote site or the other way. When transfers are performed from ECMWF to a remote site, files are transferred to the ECtrans spool. A transfer identifier is returned for each spooled request. This identifier can later be used to monitor the transfer.

With an HTTP browser, a user can monitor the ECtrans spool, by clicking the 'File transfers' link in the 'Monitoring' menu. The list of the spooled requests is then displayed. To get details for a specific request, click the appropriate icon in the list (Figure 14).

The transfer status is either INIT (spooling of the source file is still in progress), COPY (the transfer of the spooled file to the target destination is still in progress), DONE (the transfer was successful) or STOP (the transfer has failed). When the transfer is completed (successful or not) the user can restart it if necessary, providing new transfer parameters.

Similar transfer management can be performed using the ECaccess tools. For example, to initiate a file transfer from the ECaccess domain ECSCRATCH, the user will set ECDOMAIN to ECSCRATCH and use the 'ectreq' command. The following commands are also available:

- 'ectls': to list the transfers carried out by ECTrans.
- 'ectret': to retry a failed transfer.
- 'ectdel': to cancel a transfer and remove its file from the spool.
- 'ectinfo': to display the target destination of a transfer request.

Telnet

The ECaccess Telnet server allows remote users to log into their shell account at ECMWF and execute commands on

```
Command Prompt - telnet ecaccess
ecgate1% ectrans -help
usage: ectrans [-gateway name] -remote msuser@[destination] \
        [-get] -source filename [args ...] (*)
      ectrans -check requestID              (*)

 -gateway (arg) - access gateway name   (default (**): ecaccess.ecmwf.int)
 -remote  (arg) - access method         (default (**): *none*)
 -source  (arg) - source file name
 -target  (arg) - target file name      (default: same as -source)
 -mailto  (arg) - target email address (default: current user)
 -get           - pull (rather than push) file
 -onsuccess     - mail sent on successful transfer
 -onfailure     - mail sent when transfer has failed
 -keep          - keep the request in the spool
 -reject        - if existing target file (default)
 -append        - if existing target file
 -resume        - if existing target file
 -overwrite     - if existing target file
 -verbose       - verbose mode on
 -version       - print version number
 -help          - this message

(*)  If successful, a requestID is returned, which can be used in
     check requests.
(**) The default values depend on the GATEWAY or REMOTE environment
     variables.
ecgate1%
```

Figure 13 Usage of the 'ectrans' command.

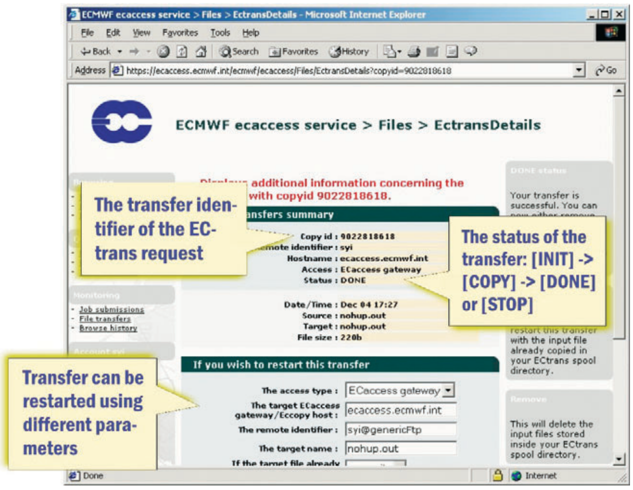


Figure 14 ECtrans monitoring.

Ecgate1. The ECaccess Telnet server comes with a dedicated UNIX command, available on Ecgate1, called 'ecxterm'. Started from an ECaccess Telnet session, this command allows the opening of X applications from any host at ECMWF to any target remote user's workstation or PC.

X11

The ECaccess X11 plug-in allows remote users who have an X server running on their workstation or PC to log into their shell account at ECMWF and start X applications on any ECMWF host.

On ECgate1, a user can open xterm windows with the 'ecxterm' command. To open xterm windows on a different ECMWF system, the 'hostname' option of 'ecxterm' can be used.

The 'ecxterm' command is also part of the ECaccess tools. Remote users can start an 'xterm' on Ecgate1 running the 'ecxterm' command from their local desktop.

ECaccess administration

The ECaccess administration package provides tools to manage and monitor the ECaccess Gateway. The package includes a database and a log manager. Through graphic interfaces, administrators can interrogate the ECaccess database and monitor the log created by the Gateway activity. Using an HTTP browser, administrators can manage and monitor the services of the Gateway (e.g. start and stop the FTP, HTTP, Telnet or ECtrans service).

Next steps

There currently is only a single ECMWF ECaccess Gateway, for access via the Internet. In the near future, a second ECMWF ECaccess Gateway will be made available for access via RMDCN. Also, ECaccess will continue to be enhanced and adapted to facilitate the life of remote users and allow access to the new ECMWF resources.

If you wish to use ECaccess or make it available to your users, further information regarding ECaccess installation, administration and usage can be found at the ECMWF Web site: http://www.ecmwf.int/services/ecaccess. Also, you may wish to contact ecaccess@ecmwf.int.

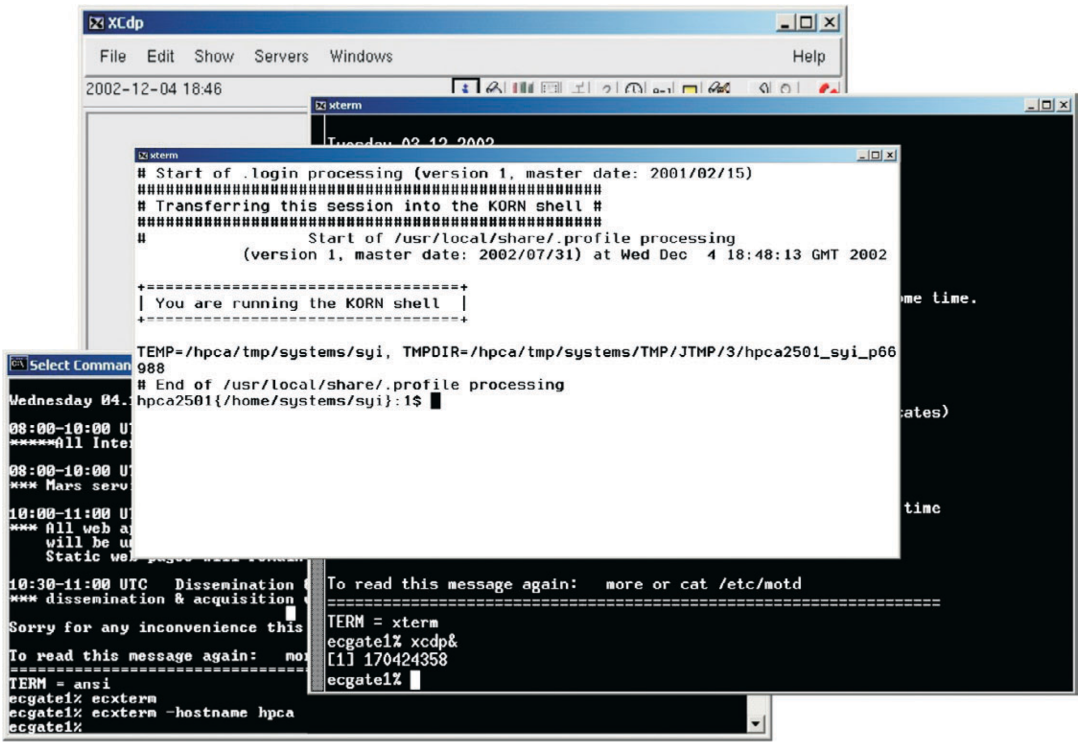


Figure 15 In the following example, once logged on Ecgate1 with a Telnet client, the user has opened an 'xterm' window and used this window to start an 'xcdp' session. An 'xterm' window has also been opened on the HPCA using the command 'ecxterm -hostname hpca'.

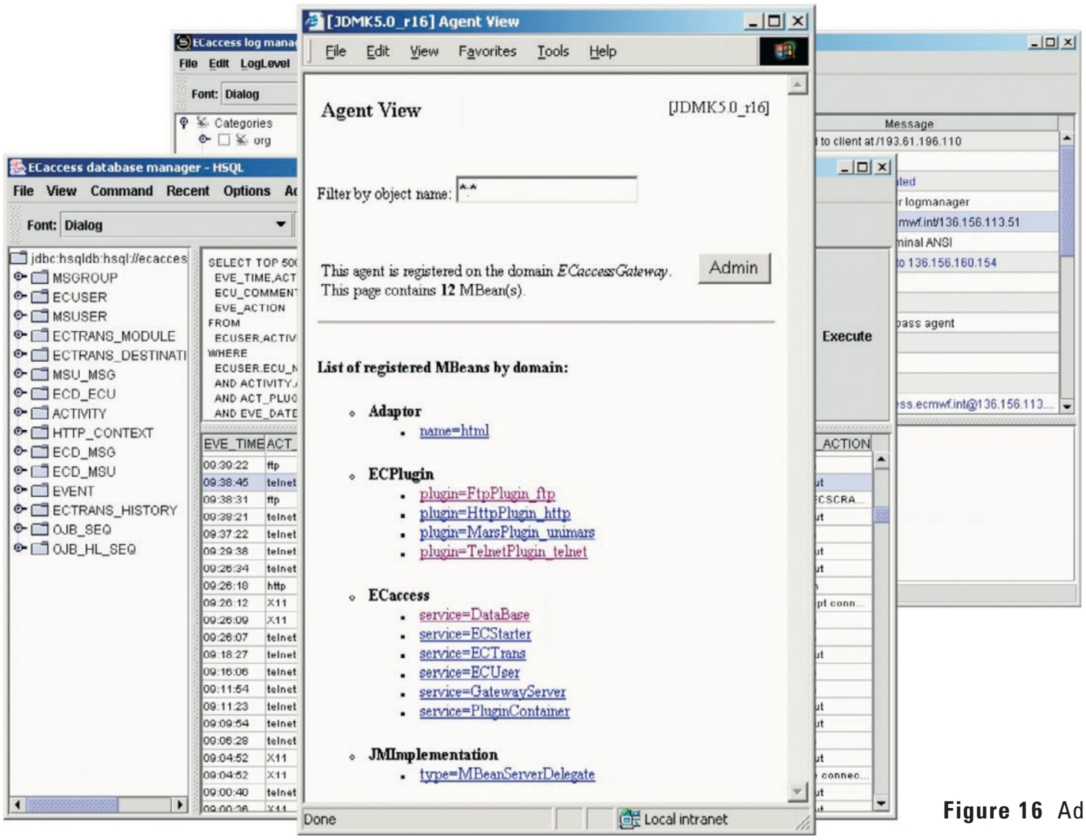


Figure 16 Administration tools

Matteo Dell'Acqua, Laurent Gougeon and Dieter Niebel

ECMWF programme of activities 2003 to 2006

The Director presented the Centre's programme of activities for the years 2003 to 2006 to Council in December 2002. The Committees had examined the scientific, technical, administrative and policy aspects of the programme in detail during the autumn, and the Committee Chairmen reported to Council on the generally supportive views of their Committees.

Council delegates expressed support and enthusiasm for the programme during a detailed and lengthy discussion; it was clear that the Member States' and Co-operating States' National Meteorological Services all have a great interest in the Centre and its progress.

During the four-year period, the Centre's Computer Hall will be substantially enlarged, and new office accommodation will be constructed.

Introduction and executive summary

Our mission is to deliver operational forecasts of increasingly high quality and scope from a few days to a few seasons ahead. Our targets for this four-year programme (2003–2006) are to:

- continue extension of the skill of medium-range forecasts, both deterministic and probabilistic, (from three days to ten days ahead) at the rate of one day per decade
- prepare by 2003/4 an assessment of seasonal forecast skill over the last 40 years;
- continually improve the timeliness and reliability of product dissemination, and availability of the computer facilities to the Member States [1];
- extend the range of reliable forecasts of severe weather over land and sea towards day 4 and day 5.

The research and operational activities necessary to achieve these targets flow naturally from our responsibilities, capabilities and opportunities, and entail:

- Development of a suitably comprehensive earth-system data assimilation capability to make best use of all available data (especially satellite data) to provide analyses, together with estimates of the uncertainty of the analyses;
- Development of a suitably comprehensive and integrated high-resolution earth-system model, using efficient and economical numerical methods with a comprehensive and extensively-validated physical parametrization packages together with estimates of uncertainty in these packages;
- Development of the methodology of ensemble forecasting for medium-range, extended-range and seasonal forecasting, with an emphasis on forecasting severe weather;
- Operational delivery of an enhanced range of meteorological and associated products;

[1] Throughout this document, where appropriate, the term 'Member State' is taken to include Co-operating State.

- Maintenance and extension of our scientific and technical collaboration with scientific and technical institutes in the Member States.

For the period 2003–2006, the research and operational programme to achieve these targets are set out below and in the accompanying Detailed Research Programme. A central component of the Research Programme is the use of the most advanced models and assimilation systems to exploit major satellite programmes thoroughly, including the METOP satellites which will carry the advanced sounder IASI, and which represent a major European investment.

The projected improvements in forecast accuracy and forecast products will bring substantial benefits to European economies and civil society. These benefits will be realized by drawing on extensive collaboration across Europe in which the National Meteorological Services and the Centre will play prominent roles. An important element in fostering such collaboration will be continuation of the policy of actively encouraging the circulation of staff between the Centre and the Member States' National Meteorological Services. Supplementary man-power support from interested outside agencies will be required, in particular for observing system studies, for reanalyses, and for research into ensuring optimal use of data from new satellite instruments.

The EU and ESA are developing collaborative programmes (referred to as Global Monitoring for Environment and Security (GMES) in EU documents, and Earth Watch in ESA documents) to address issues of monitoring the global environment for treaty verification purposes, and for coping with natural hazards.

ECMWF and the European weather services can play a central support rôle in the GMES and related initiatives, by working with European science networks to develop operationally useful products for GMES. Development of our existing global data assimilation system would enable us to assess the distribution, sources and sinks of greenhouse gases, reactive gases and aerosols and also monitor the land-surface and the upper ocean. In partnership with the European meteorological community we are developing a substantial proposal (GEMS - Global Earth-system Monitoring using Satellite and in-situ data) to the EU's 6th Framework programme. For each area, there will be a GEMS sub-project led by a Member States institution. The Centre will provide overall coordination and execution of a sub-project on system integration and reanalysis. In addition, we plan to participate in an EU 6th Framework project to develop multi-model ensemble techniques for risk assessment on seasonal and inter-annual timescales.

This European-wide collaboration will act to catalyse substantial European investments in fundamental science, operational forecasting systems and satellites and ensure practical deliverables. Vital support will be given to European climate and environmental research. In addition, we will develop our international activities along the guidelines outlined in the External Policy adopted by Council in June 2002.

Development of the operational prediction systems and the research programme

By the beginning of 2003 we will be producing a wide range of atmospheric and marine forecasts:

- Atmospheric global ten-day forecasts will be based on a T_L511 (40 km horizontal resolution) deterministic model and an Ensemble Prediction System (EPS) employing a T_L255 (80 km horizontal resolution) models.
- Ten-day wave forecasts for the world's oceans will be produced at a 55 km horizontal resolution.
- Five-day wave forecasts for European waters will be produced at a 27.5 km horizontal resolution.
- Seasonal forecasts will be based on coupled atmosphere-ocean models (200 km horizontal resolution).

At the start of 2003, our primary data assimilation system for producing initial values for global atmospheric forecasts will employ a 4D-Var configuration with 12-hour period, inner loops at up to T_L159 (120 km) resolution, and T_L511 (40 km) resolution outer loops.

The Centre and the UK Met Office will continue to undertake joint research and operational activities in multi-model seasonal forecasting with the ECMWF and Met Office coupled model systems. Operational and research output from the Met Office system will be made available to both the Member States and the Co-operating States.

These systems will be supplemented by a weekly 30-day experimental EPS system based on a TL159L40 system, coupled to the HOPE-E global ocean model. The initial ensemble for the 30-day EPS will be derived from the ten-day EPS. Stochastic physics will be used, in addition to the SST and ocean forcing perturbations used in the seasonal forecast system.

In 2003 we will implement an operational system to provide improved warnings of severe weather. As a result of research and extensive experimentation this will be based on two runs of the medium-range forecast suite, one from 12 UTC and one from 00 UTC. The additional run, from 00 UTC, will meet the Member States' requirements for more continuity in the forecasts, for early warnings of severe weather and for a more timely delivery of the products.

An extension of the daily medium-range forecasts to 15 days will be considered for both the deterministic model and the EPS.

In addition to our core operational programme summarized above, there is one Optional Project – 'Boundary Conditions for Limited Area Modelling', providing boundary conditions four times per day

A considerable improvement in the accuracy of forecasts has been achieved in the last ten years. The improvement amounts to about a one-day gain in skill of mean sea-level pressure and 500 hPa height over the last decade in the Northern Hemisphere, with a similar gain over the last three years in the Southern Hemisphere. Detailed analysis shows that identifiable improvements in data assimilation, models and the observing system have increased the accuracy of both short- and medium-range forecasts. The variational assimilation of radiance data from satellites, increases in horizontal and vertical resolution and improvements in the parametrization of physical processes have all contributed to the increase in accuracy. We will continue these lines of development that have brought this considerable success over the past ten years.

The development of our Earth-system forecast and assimilation facility will aim to make full use of data from the AIRS, MSG and IASI instruments, and to provide an accurate and consistent assimilation of information on dynamical and physical processes including cloud and precipitation. This will require continued development of the 4D-Var algorithm, of the reduced-rank Kalman filter, of new observation operators, and of the tangent and adjoint versions of the model physics.

To attain our goal of providing increasingly good deterministic and probabilistic medium-range forecasts, particularly for extreme weather events, the horizontal and vertical resolution will be increased. It is planned to increase the vertical resolution from 60 to 90 levels in late 2003, particularly in the vicinity of the tropopause, and to prepare in 2004–2005 for an upgrade in horizontal resolution in 2005. The horizontal resolution options to be studied are:

- Deterministic forecast and outer loops of 4D-Var $T_L719 - T_L799$
- Ensemble prediction system $T_L319 - T_L399$
- Inner loops of 4D-Var $T_L255 - T_L359$
- Seasonal forecasting $T_L95 - T_L159$

The treatment of the land surface, the boundary layer and the hydrological cycle will be refined further to provide better assimilation of remotely sensed data, to improve local forecasts, and to exploit the seasonal predictability implied by snow-cover and soil moisture anomalies. In order to improve the prediction of extreme ocean conditions, new theoretical developments will provide estimates of the probability of so-called freak ocean waves.

The research and operational milestones for 2003 to 2006 are summarized in Table 1 below. The operational options chosen for 2003 and 2005 optimize the use of human resources over the four-year period 2003–2006 and invest approximately equal computational resources in data assimilation and the EPS.

Further increases in horizontal and vertical resolution will be needed beyond the planning period to attain our goal of extending deterministic predictability by one day in the coming decade and to continue to improve the prediction of severe weather. The long-term goal is to increase the horizontal resolution of the assimilation system and deterministic forecasting system to 10km and the resolution of the model used in the EPS to 20km with consistent increases in vertical resolution. This would require a computer capable of delivering a sustained computational rate of 50 teraflops, which could be affordable soon after 2010.

2003	Twice-daily running of the medium-range forecast suite, once from 12 UTC and once from 00 UTC
	Multi-model seasonal forecast system
	Revised humidity analysis
	New formulation of the planetary boundary layer parametrization
	Enhanced adjoints for parametrized processes
	Increased vertical resolution particularly in the vicinity of the tropopause
	Validation of MSG data
	Assimilation of MSG, ENVISAT, SSMI/S & SeaWinds data
	Validation and then assimilation of AIRS data
	Preparation of an assessment of seasonal forecast skill over the last 40 years
2004	Further upgrade to the adjoints of parametrized process and the assimilation of cloud/rain information
	Introduction of a reduced-rank Kalman Filter
	Weekly running of the monthly forecast system
	Preparation of the 2005 upgrades in the resolution of the forecast system. The options to be studied are: – Deterministic Forecast and outer loops of 4D-Var (T719 – T799) – EPS (T319 – T399) – Inner Loops of 4D-Var (T255 – T359)
2005	Finalize validation and implement the 2005 upgrades in the resolution of the forecast system
	Validate and assimilate AURA/OMI data
	Continued preparations for METOP data
2006	24 hourly cycling of 4D-Var
	Monitor and then assimilate IASI and other METOP data

Table 1 Research and Operational Milestones for 2003 to 2006.

Service provision

Development of the current services

The provision, maintenance and improvement of the current services will remain primary tasks. It is our intention to achieve a high degree of timeliness and reliability in the production and delivery of the output from the operational forecasting systems. To attain this we will focus efforts on:

- further development and enhancement of the data acquisition system to accommodate the expected substantial increase in the data volumes, in particular satellite data;
- development and adaptation of the various components of the forecasting system to the evolving hardware and software systems in order to optimise the utilisation of the available computer resources;
- development and adaptation of the applications used by the Centre and the Member States which include MARS, SMS, Metview and MAGICS; MAGICS will be rewritten in C and/or C++;
- further extension of the range of services, products and documentation available from our web site.

Severe weather forecasting and product development

In 2003 we will implement an operational system to provide improved warnings of severe weather which will be based on two runs of the medium range forecast suite once from 12 UTC and once from 00 UTC. The EPS output from both runs will be suitable to provide ensemble boundary conditions for Member States and Co-operating States limited-area-model ensembles.

In close liaison with the users in the Member States, we will develop a range of products suited to operational needs for severe weather warnings. These developments will be guided by our experience with the currently available experimental products, such as the extreme forecast indices, tropical storm strike probabilities and probability charts of other defined weather events. As part of this programme we intend developing a range of products, which are less sensitive to effects of model changes, to identify intense cyclogenesis and potentially unstable flow configurations over the Atlantic and Europe.

Develop new ways for the product dissemination

In order to meet the States' requirements for timely production and delivery of the products, the operational production and dissemination schedule will be reviewed critically and optimised in the light of experience with the new high-performance computing facility (HPCF) resources. Member States will be given more flexibility to manage their dissemination priorities to suit their individual requirements.

The possibility of using alternative dissemination channels will be reviewed, in particular consideration will be given to using:

- additional Internet channels for data dissemination;
- existing broadcasting systems, in particular as part of the GISC development within WMO;
- Internet servers for the dissemination of limited sets of graphical products, in particular new test products.

Evaluation of and support for the observing system

The monitoring of the observing system will continue to be a key element of our operational activities. Incoming observations will be monitored carefully and the appropriate quality control checks will be essential in the preparation of the data input for the analysis. Long-term statistics of the data monitoring will provide the basis for the evaluation of the performance of the Global Observing System, the GUAN and the EUCOS in particular, and will be available to the managers of the observing systems for network design and development.

We will continue to fulfil our function as the WMO/CBS appointed lead centre for upper air data monitoring. Our data monitoring will be complemented by suitable and appropriate data impact studies to evaluate the information content of the various components of the observing systems and to decide on the use of new data. Since the FASTEX studies, there is an increasing interest in the use of targeted observations for numerical weather prediction. A major experiment (THORPEX) is being planned to test the targeted observation concept. We are well placed to contribute towards such activities, including experiments and studies and to provide the support for the operational implementation of observation targeting.

Data services

As a result of Council's revision of the Rules governing the provision of data and products, the adoption of comprehensive Catalogues and the implementation of new tariffs, our data and software services have developed substantially in recent years.

To improve our provision of archived data we will continue to develop the tools for accessing the data service information, on-line ordering and data delivery through the web. Special efforts will be made to make available specific data sets for research – the ERA-40 analyses and the multi-model seasonal predictions arising from the DEMETER project for example.

We will support Member States' commercial activity in providing data from the Catalogue of Real-time Products.

Optional project

The Optional Project Boundary Conditions for Limited Area Modelling will continue to provide boundary condition products to the participating States. It is expected that during the planning period the Project will be reviewed, in particular concerning the use of the most appropriate assimilation system, the implementation of performance monitoring and additional post-processing requirements.

Education Programme and Scientific Meetings

We will continue to organise a broad range of courses and meetings, including:

- modular training courses on the theoretical basis, implementation and operational aspects of numerical weather and wave forecasting systems;
- training courses on the use of the computer system;
- an annual seminar on topical subjects in numerical weather prediction;
- workshops on specialised topics in numerical weather prediction, computer science and operational meteorology.

The training course and the annual seminar are part of our formal education programme and are primarily for young scientists within the Member States and Co-operating States. The aim of the workshop programme is to provide us with up-to-date reviews on subjects in meteorology and computing and provide useful input for our work. Some workshops - predictability, meteorological operational systems and multi-processing on large computers - are regular features and take place biennially. The aim of the users' meetings is to foster discussions between forecasters and potential Member States' customers on the use of our products. We will publish proceedings of seminars and workshops, lecture notes and meteorological and computer bulletins as usual.

Computational resources and requirements

The computer systems will continue to be upgraded or replaced as needed to fulfil the requirements of the meteorological research and operational programme.

High-performance Computing

The contract with IBM covers the supply of high-performance computing resources until March 2007. The resources will be installed in phases, with the final phase delivering a committed performance of five times that of the current Fujitsu VPP systems in 2004. The Fujitsu VPP service will be terminated at the end of March 2003.

As in the past, emphasis will be placed on providing a good user service while maintaining a high level of utilisation. During 2003, considerable effort will be spent on re-structuring the operational workload to exploit the degree of resiliency offered by a dual cluster solution. The introduction of a new switch fabric and new clustering software in early 2004 will have a major impact on system management aspects but should not require any significant migration efforts by end-users.

For the supply of resources beyond March 2007, an Invitation to Tender (ITT) will be issued in 2005 or the contract with IBM will have to be extended. In either case, to ensure that best value for money can be obtained, our major codes must be kept suitable for most prevailing HPC architectures and our infrastructure must have sufficient capacity to allow the installation of these architectures.

Data handling system (DHS)

The implementation of the HPSS-based DHS system is progressing well and the migration from the existing system to the new system is due to complete by early 2005. Every effort is being made to keep the migration as transparent as possible to the end-users, while at the same time trying to minimise the period of overlap between the old and the new systems.

The scalability of the HPSS software should enable it to fulfil ECMWF's requirements well beyond the four-year planning period. Hardware will be added annually to increase the capacity of the system, enabling it to cope with the growing storage demands.

The Disaster Recovery System will be modified to allow it to support the new DHS.

Servers and desktop systems

The replacement of the SGI Origin servers by IBM servers will be completed in the first half of the planning period and will include the replacement of the Member State server ecgate1. Member State users will be provided with several months of parallel service for their migration from ecgate1 to the replacement system.

By early 2003, all SGI workstations will have been replaced by PCs running Linux. The PC/Linux based approach to providing desktop services will be maintained for the foreseeable future. The Call-Off contract with IBM for the supply of general-purpose servers and PCs will expire in mid-2004. ITTs to cover the supply of these types of equipment beyond mid-2004 will be issued.

The increases in satellite data and dissemination products will increase the load on the HP systems handling data acquisition, pre-processing and product dissemination. A major upgrade /replacement of these systems is planned for 2004.

Local Area Network (LAN)

The amounts of data to be transferred between the new HPCF and the DHS will require local area network bandwidths that are beyond the capabilities of the currently installed high-performance network. We plan to address this by installing a 10 Gigabit Ethernet network during the second half of 2003. The acquisition of such a high-performance local area network will require the issue of an ITT.

RMDCN

The number of sites connected to the RMDCN is likely to grow. Further WMO RA VI members are expected to join and in future parts of the GTS main trunk network may use the services provided by the RMDCN.

The contract with Equant is for eight years of service from 15 March 2000, with termination possible after five years of service at our option. A decision on whether to continue for the full eight-year period or whether to procure a new provider is required by early 2003. A possible migration from the current Frame Relay technology to a native IP network is being investigated.

Other activities

Over the past years, new types of users, for example web users and archive-only users, have been registered. The Centre's user registration and authentication system will be changed to cope better with the various types of new users.

Our Internet link provides high-bandwidth access to the computer systems for Member State users, supports the web services offered and can be used as backup for the operational RMDCN links. During the planning period, a further upgrade of the Internet link is likely to be required.

Over the next few years, Storage Area Networks (SANs) for heterogeneous computing environments may become available. The introduction of a SAN that is accessible by all our major systems would optimise the usage of the disk storage, leading at the same time to fundamental changes in the flow of data through the systems. We will carefully monitor developments in this area and install pilot equipment once products are sufficiently advanced.

We use contract labour for the maintenance of our electrical and mechanical installation. In 2003, an ITT will be issued for the provision of these services from 2004 onwards.

ECMWF Education and Training Programme 2003

The ECMWF has an extensive education and training programme to assist Member States and Co-operating States in the training of scientists in numerical weather forecasting, and in making use of the ECMWF computer facilities. The training courses consist of modules that can be attended separately. A student may decide to attend the different modules in different years.

The programme for 2003 is as follows:

Computer Users Training Course

This consists of a three-week course in February-March on the use of ECMWF computer facilities consisting of five modules of varying length. The objective of the Computer Users Training Course is to introduce users of ECMWF's computing and archive systems to the Centre's facilities, and to explain how to use them. The course is divided into five separate modules (students can attend any or all of these modules). Each module will consist of some lectures and some practical sessions. All the lectures will be given in English. A workbook will be provided for each module, together with basic manuals and other relevant documentation as required.

COM-SMS	*17–18 February*	SMS/XCdp
COM-INTRO	*3–7 March*	Introduction for new users/MARS
COM-MAG	*10–11 March*	MAGICS
COM-MV	*12–14 March*	Metview
COM-HPCF	*17–21 March*	Use of supercomputing resources

Students attending any part of the course are assumed to have experience of a computer system elsewhere, to be familiar with ANSI Fortran 77 or 90, to know basic UNIX commands, and to be able to use the vi editor. Details of the content of the modules can be obtained from http://www.ecmwf.int/newsevents/training/2003/computer/contents.html . Files in pdf format containing additional information on the lectures (including copies of the slides) can be downloaded from http://www.ecmwf.int/services/computing/training/material_2002/index.html .

Meteorological Training Course

This course on numerical weather prediction and the use of ECMWF products consists of five modules. Four of the five modules emphasise scientific training and one module is aimed more at forecasters or people with forecasting experience. The objective of the Meteorological Training Course is to assist Member States in advanced training in the field of numerical weather forecasting. The course is divided into five modules; outlines of the content of the modules can be obtained from http://www.ecmwf.int/newsevents/training/2003/meteorological/index.html.

ECMWF Products

MET OP-I Use and interpretation of ECMWF products
31 March–4 April

MET OP-II Use and interpretation of ECMWF products
2–6 June

MET OP-III Use and interpretation of ECMWF products for WMO members
13–17 October

Numerical Weather Prediction

MET PR Predictability, diagnostics and seasonal forecasting
24–28 March

MET DA Data assimilation and use of satellite data
7–16 April

MET NM Numerical methods, adiabatic formulation of models
29 April–9 May

MET PA Parametrization of diabatic processes
12–22 May

Students attending the course should have a good meteorological and mathematical background, and are expected to be familiar with the contents of standard meteorological and mathematical textbooks. Some practical experience in numerical weather prediction is an advantage. All the lectures will be given in English. A set of Lecture Notes will be provided for the modules on Numerical Weather Prediction. The Lecture Notes and copies of the slides used in the lectures can also be accessed from http://www.ecmwf.int/newsevents/training/ .

Recommended textbooks

Holton, J.R. (1992) An introduction to dynamic meteorology. **3rd ed.** *Ac. Press.*

Wallace, J.M. & **P.V. Hobbs** (1977) Atmospheric science. An introductory survey. *Ac. Press.*

Haltiner, G.J. & **R.T. Williams** (1980) Numerical prediction and dynamic meteorology. **2nd ed.** *Wiley.*

Annual Seminar

A one-week series of lectures dedicated to one specific topic, is given at the beginning of September. The subject is different every year. In the year 2003 it is on 'Recent developments in atmospheric and ocean data assimilation'. The seminar will start on Monday 8 September at 9.00 and finish Friday 12 September at 13.00.

Three dimensional variational assimilation (3D-Var) methods have been widely adopted for operational use, and there is widening operational adoption of four-dimensional variational assimilation (4D-Var) methods.

The purpose of the seminar is to give a pedagogical overview of recent developments in atmospheric and ocean data assimilation, and to outline the likely lines of development in the next 5–10 years, including the use of reduced rank Kalman filters and ensemble Kalman filters, and the implementation of more complete physical representations in 4D-Var.

Recent developments in data assimilation of relevance to ensemble forecasting will be presented. In addition there will be a discussion on modelling and assimilating data on variations in atmospheric composition due to trace gases and aerosol.

Recent ECMWF workshops

HNF Europe Workshop 2002

On 11 October 2002, ECMWF hosted the meeting of the High-performance Networking Forum Europe.

The objective of the HNF Europe meetings is to bring together European users and vendors of high-performance networking technologies and share thoughts on the technology deployments, trends and future directions. The meeting focused on Networking technologies in the morning sessions and Network storage technologies in the afternoon. It concluded with a round-table discussion on 10GbE, Infiniband and Gigabyte System networks.

For historical information, see http://hsi.web.cern.ch/HSI/HNF-Europe

Details of the workshop are available in ppt and pdf format files from http://www.ecmwf.int/newsevents/meetings/workshops/HNF_Europe/

Tenth ECMWF Workshop on the use of high-performance computing in meteorology – Realizing TeraComputing

The tenth workshop on high-performance computing in meteorology was held at ECMWF from 4 to 8 November 2002. This workshop has developed into a well-established and well-attended biennial event. This time around 140 externals from meteorological services, research establishments and computer industry participated, once again comprising a worldwide forum of experts in this field. The programme consisted of some 50 presentations including contributions by ECMWF staff. A one-day RAPS (Real Applications on Parallel Systems) workshop has become a regular part of the event, as well as the final discussion forum on the last day.

The presentation material from most of the talks has been made publicly available on the following web page (click on 'Presentations'):

http://www.ecmwf.int/newsevents/meetings/workshops/high_performance_computing

It is planned to publish the proceedings of the workshop later in 2003.

Workshop on the rôle of the upper ocean in medium- and extended-range forecasting

A workshop on the role of the upper ocean in medium- and extended-range forecasting was held at ECMWF on 13 to 15 November 2002.

The ocean plays an important role in seasonal forecasting. The best-known process is the El Niño, with its origins in the tropical Pacific where air-sea interaction is strong, but there is evidence emerging of partly predictable phenomena in the Atlantic and Indian oceans also. At shorter timescales, ocean-atmosphere interaction may be important in, for example, tropical storm prediction and the intraseasonal oscillation. With developments in the ocean observation system, and in data assimilation and modelling, the potential for making and using upper-ocean forecasts has improved substantially.

This meeting covered four main themes:

- Discussion of significant phenomena that involve air-sea coupling on the timescales from hours to months.
- The use of ocean forecasts on these timescales.
- New methods of observing the ocean, and challenges in assimilating data in ocean models.
- Recent advances in ocean and ice modelling and requirements for further progress.

A report of the workshop will be published by ECMWF and details of the workshop are available from

http://www.ecmwf.int/newsevents/meetings/workshops/role_of_the_upper_ocean/

ECMWF publications

A full list of ECMWF publications is available at

http://www.ecmwf.int/publications/library/ecpublications/

and recently published Technical Memoranda can be downloaded in pdf format from

http://www.ecmwf.int/publications/library/ecpublications/techmemos/tm00.html

Technical Memoranda

369 **O. Alves**, **M. Alonso Balmaseda**, **D. Anderson** and **T. Stockdale**. Sensitivity of dynamical seasonal forecasts to ocean initial conditions. *September 2002*

370 **M. Alonso Balmaseda**, **F. Vitart**, **L. Ferranti** and **D. Anderson**. Westerly wind events and the 1997 El Niño event in the ECMWF seasonal forecasting system: a case study. *September 2002*

377 **A. Dethof**. ERA-40: 1991–1996. *July 2002*

383 **E. Hólm**, **E. Andersson**, **A. Beljaars**, **P. Lopez**, **J-F. Mahfouf**, **A. Simmons** and **J-N. Thépaut**. Assimilation and modelling of the hydrological cycle: ECMWF's status and plans. *September 2002* (SAC paper)

384 **M. Leutbecher**. A reduced rank estimate of forecast error variance changes due to intermittent modifications of the observing network. *September 2002*

385 **P. Prior**. Report on the tenth Security Representatives' Meeting 23-24 May 2002. *September 2002*

386 **G. van de Grijn**. Tropical cyclone forecasting at ECMWF: new products and validation. *September 2002*

387 **F. Vitart**, **D. Anderson** and **T. Stockdale**. Seasonal forecasting of tropical cyclone landfall over Mozambique using coupled GCM integrations. *October 2002*

388 **Ø. Saetra** and **J.-R. Bidlot**. Assessment of the ECMWF ensemble prediction system for waves and marine winds. *October 2002*

389 **R. Buizza, D. S. Richardson** and **T. N. Palmer**. Benefits of increased resolution in the ECMWF ensemble system and comparison with poor-man's ensembles. *October 2002*

390 **N. Fourrié** and **J.-N. Thépaut**. Validation of the NESDIS Near Real Time AIRS channel selection. *October 2002*

Member State computer resource allocations 2003

Member State	Basic allocation	**Fujitsu (kunits)** Deduction for optional boundary condition project	Net allocation	**Data (Gbytes)**
Belgium	683	227	456	4463
Denmark	575	191	384	3755
Germany	3040	0	3040	19865
Spain	1118	371	747	7308
France	2222	0	2222	14518
Greece	516	171	345	3373
Ireland	459	152	307	3002
Italy	1864	619	1245	12182
Luxembourg	378	126	252	2469
Netherlands	866	287	579	5655
Norway	556	184	372	3633
Austria	619	205	414	4046
Portugal	498	165	333	3255
Switzerland	718	238	480	4689
Finland	517	172	345	3382
Sweden	664	220	444	4339
Turkey	615	204	411	4021
United Kingdom	2272	0	2272	14845
Special projects	2020	0	2020	13200
Total	**20200**	**3532**	**16668**	**132000**

Special Project allocations 2003-2004

Member State		**Institution**	**Project title**	**Priority**	**2003 HPCF units**	**2003 Data storage**	**2004 HPCF units**	**2005 HPCF units**
Continuation Projects								
Austria	1	Univ. Innsbruck (Ehrendorfer)	Singular Vector-based Multivariate Normal Sampling in Ensemble Prediction	P1	9000	6	X	X
	2	Univ. Vienna (Haimberger)	Atmospheric General Circulation statistics from ERA-40 data	P1	2000	200	X	X
	3	Univ. Graz (Kirchengast)	Climate Monitoring by Advanced Spaceborne Sounding and Atmospheric Modelling	P2	1000	150	1000	1000
	4	Universitat fur Bodenkultur, Vienna (Kromp-Kolb)	Modelling of Tracer Transport (MoTT)	P2	500	5	500	500
	5	Univ. Vienna (Steinacker)	Mesoscale Alpine Climatology (VERACLIM)	P1	100	5	100	X
Belgium	6	Univ. Louvain (van Ypersele, Fichefet)	Modelling the climate and its evolution at the global and regional scales	P2	20000	600	20000	20000
Denmark	7	DMI (Sattler)	Heavy rain in Europe	P1	50000	200	50000	5000
	8	DMI (Yang, Machenhauer)	Detection of Changing Radiative Forcing over the Recent Decades (DETECT)	P2	62000	650	X	X
France	9	L.A.M.P. (Cautenet)	Chemistry, cloud and radiation interactions in a meteorological model	P2	100	2	100	100
	10	CERFACS (Piacentini)	Universal software for data assimilation	P1	10000	200	10000	10000

France	11	CERFACS (Rogel)	Seasonal to interannual predictability of a coupled ocean-atmosphere model	P1	10000	150	10000	10000
	12	CERFACS (Siefridt)	MERCATOR	P1	250000	2500	250000	250000
	13	Univ. Nice, UNAM (Vernin, Masciadri)	Forecasting of the optical turbulence for Astronomy applications with the MesoNH mesoscale model coupled with ECMWF products	P2	4000	30	4000	4000
Germany	14	MPI, Hamburg (Bengtsson)	Numerical experimentation with a coupled ocean/ atmosphere model	P1	120000	600	175000	215000
	15	MPI, Hamburg (Bengtsson)	Simulation and validation of the hydrological cycle	P1	140000	600	190000	265000
	16	ISET (Czisch)	Evaluation of the Global Potential of Energy Towers	P2	100	50	100	X
	17	D.L.R. (Doernbrack)	Influence of non-hydrostatic gravity waves on the stratospheric flow for field above Scandinavia	P1	35000	80	40000	40000
	18	Univ. Munich (Egger)	Landsurface – Atmosphere interaction	P1	15000	100	15000	15000
	19	D.L.R. (Hoinka)	Climatology of the global tropopause	P2	5000	10	5000	5000
	20	MPI, Jena (Knorr)	Biochemical feedbacks in the Climate System	P2	60000	1000	60000	X
	21	MPI, Hamburg (Manzini)	Middle atmosphere modelling	P1	120000	950	170000	200000
	22	Alfred Wegener Institute (Rinke)	Sensitivity of HIRHAM	P1	10000	100	10000	10000
	23	MPI, Hamburg (Schultz)	Global Atmospheric Chemistry Modelling	P1	10000	800	10000	10000
	24	Univ. Koln (Speth)	Interpretation and calculation of energy budgets	P2	100	6	100	100
	25	Univ. Munich (Stohl, James)	Validation of trajectory calculations	P2	1000	80	1000	1000
	26	Univ. Mainz (Wirth)	Water vapour in the upper troposphere	P2	1000	20	1000	X
Italy	27	ICTP, Trieste (Molteni)	Nonlinear aspects of the systematic error of the ECMWF coupled model	P1	25000	120	25000	25000
	28	ARPA-SMR, Emilia Romagna & Italian Met. Service (Paccagnella/ Montani/Ferri)	Limited area model targeted ensemble prediction system (LAM-TEPS)	P1	40000	40	45000	47000
Netherlands	29	KNMI (Drijfhout)	Agulhas	P2	20000	0	20000	20000
	30	KNMI (Siebesma)	Large Eddy Simulation (LES) of boundary layer clouds	P1	25000	30	30000	35000
Norway	31	DNMI (Debernard, Haugen)	REGCLIM	P2	100000	500	100000	100000
	32	Univ. Oslo (Isaaksen)	Ozone as a climate gas	P1	15000	5	15000	15000
Portugal	33	Univ. Lisbon (Soares)	HIPOCAS-SPEC	P2	0	10	0	0
Spain	34	Univ. Illes Balears (Cuxart)	Study of the Stably stratified Atmospheric Boundary Layer through Large-Eddy simulations and high resolution mesoscale modelling	P1	60000	100	60000	60000
Sweden	35	SMHI (Undén)	The Hirlam 5 project	P1	180000	1200	250000	500000
United Kingdom	36	ESSC, Univ. Reading (Bengtsson)	Determination of the global water cycle by different observing systems	P1	180000	200	240000	360000
	37	Univ. Reading (Hoskins)	Routine back trajectories	P1	5000	4	5000	5000
	38	Univ. Reading (Hoskins)	Moist singular vectors	P1	10000	15	X	X
	39	BAS, Cambridge (Turner)	Assessment of ECMWF forecasts over the high-latitude areas of the Southern Hemisphere	P1	0	2	0	0
New Projects								
France	1	CERFACS (Ricci)	Variational data assimilation: background error covariance matrix	P1	10000	150	10000	10000
Ireland	2	Met Éireann (Lynch)	Community Climate Change Consortium for Ireland (C4I)	P1	20000	1000	30000	50000
	3	Univ. College Cork, Met Éireann (Moehrlen, McGrath, Joergensen)	Verification of Ensemble Prediction Systems for a new market: Wind Energy	P1	7000	8	7000	X

Italy	4	ISDGM-CNR (Cavaleri)	Evaluation of the performance of the ECMWF meteorological model at high resolution	P1	10000	80	10000	10000
Netherlands	5	KNMI (van Oldenborgh, Burgers)	Advanced ocean data assimilation	P1	50000	100	50000	50000
Spain/Ireland/ Denmark	6	INM, UCC, DMI (Gracia Moya, Moehrlen, Joergensen)	HONEYMOON – A high-resolution numerical wind energy model for on and offshore forecasting using ensemble predictions	P1	10000	10	10000	X
United Kingdom	7	DARC, Univ. Reading (O'Neill)	Reanalysis for the 1990s using UARS data	P1	60000	1000	X	X
Total requested					**1,762,900**	**13,668**	**1,929,900**	**2,348,700**

ECMWF calendar 2002/3

Computer User Training Course

Feb 17–18	**Introduction to SMS/XCDP**	
Feb 24–25	**PAC**	*Extraordinary session*

Computer User Training Course

Mar 3–7	**Introduction for new users/MARS**	
Mar 10–11	**MAGICS**	
Mar 12–14	**METVIEW**	
Mar 17–21	**Use of supercomputing resources**	
Mar 11–13	**Workshop** – *GWEX-GCIP Workshop on precipitation analysis*	

Meteorological Training Course

Mar 24–28	**Predictability, diagnostics & seasonal forecasting**	
Mar 31– Apr 4	**Use & interpretation of ECMWF products**	
Apr 7–16	**Data assimilation & use of satellite data**	
Apr 29– May 9	**Numerical methods, adiabatic formulation of models**	
May 12–22	**Parametrization of diabatic processes**	
Mar 24	**Workshop** – *Catalogue Contact Points*	*3rd*
Mar 25	**Advisory Committee on Data Policy**	*3rd*
Apr 7–8	**Policy Advisory Committee**	*18th*
May 15–16	**Security Representatives meeting** *to be confirmed*	
May 19–20	**Computer Representatives meeting** *to be confirmed*	

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 atmospheric and ocean data assimilation*	
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 15–16	**Policy Advisory Committee**	*19th*
Oct 16–17	**Advisory Committee on Data Policy**	*4th*
Oct 20	**Advisory Committee of Co-op. States**	*10th*
Nov 3–6	**Workshop** – *Simulation and prediction of intra-seasonal variability*	
Nov 10–14	**Workshop** – *Meteorological operational systems*	*9th*
Dec 2–3	**COUNCIL**	*59th*

Index of past newsletter articles

This is a list of recent articles published in the ECMWF Newsletter series. Articles are arranged in date order within each subject category. Articles in red can be accessed on the ECMWF public web site http://www.ecmwf.int/pressroom/newsletter/index.html

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New products on the ECMWF web site

www.ecmwf.int/about/special_projects/

Pages listing all registered Special Projects, their contact details, a description of each project and a copy of each project's report.

www.ecmwf.int/research/era/data_services/

Description of the availability of ERA-40 and some aspects of the quality of the ERA-40 analyses. There are more and more ERA-40 plots. In addition ERA-40 plots are now part of the Catalogue application which means that they can be put in 'Your room' if you (can) have one.

www.ecmwf.int/products/forecasts/d/charts/monitoring/coverage/dcover

Data coverage plots now include ozone and geostationary radiances (grad).

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

A lot of new products in seasonal forecast verification were introduced.

www.ecmwf.int/products/forecasts/d/charts/verification/special/

Weekly operational scores are available to Member States and Co-operating States real-time users. They are updated on Mondays.

www.ecmwf.int/services/archive/d/changes

Describes the changes in the archive such as the addition or suppression of fields.

www.ecmwf.int/services/ecaccess/

Describes a new interface available to all registered users for accessing the ECMWF computing and archiving facilities from anywhere on the Internet.

www.ecmwf.int/services/computing/hpcf/

Contains initial guidelines on the use of the new IBM High Performance Computing Facility, job examples, training course material and manuals (access to this page is restricted to registered users).

A new documentation describing the seasonal forecasting System 2 is now available at:

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