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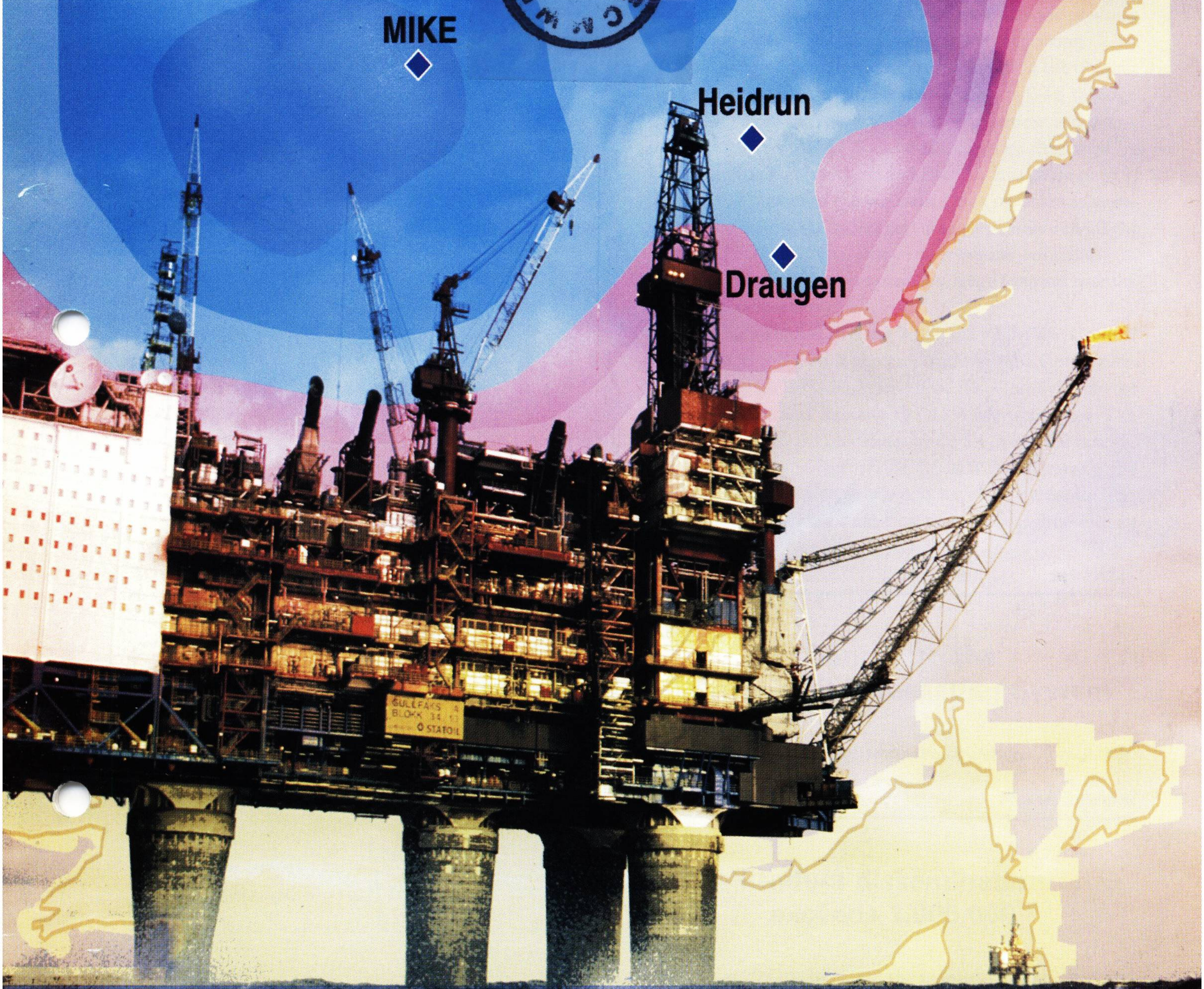

- Probabilistic forecasts for ocean waves
- Assimilation of meteorological data from commercial aircraft
- ECMWF external policy

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen terme

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METEOROLOGICAL

GENERAL

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Front Cover

The GULLFAKS oil rig – the article on page 2 discusses probabilistic ocean-wave forecasts for oil rigs and other marine applications.
(Photograph: Øyvind Hagen, Statoil).

Editorial

On page 2 Øyvind Saetra and Jean-Raymond Bidlot discuss the application of ensemble prediction of waves for forecasting hazardous conditions during delicate operations by oil rigs and other marine vessels. The results are encouraging and indicate that there is potential for developing EPS wave products to become more effective tools in marine forecasting.

The benefits arising from the large increase in the number of aircraft observations now available on the GTS through the deployment of automated data acquisition and transmission systems (ACARS and AMDAR) are described by Carla Cardinali, Lars Isaksen and Erik Andersson on page 9. Tests of the impact of the additional data obtained as vertical profiles during the ascent and descent phases of the flight paths indicate that the extra observations contribute to significant improvements in medium-range forecasts over the northern hemisphere.

At its 56th session in June 2002, the ECMWF Council voted that, as foreseen in the preparation of the Convention establishing the ECMWF in 1974, the Grand Duchy of Luxembourg could become the 18th Member State. The Council also adopted guidelines, and a list of specific actions, for the external policy of the ECMWF concerning the Centre's responsibility in relation to WMO requests. The external policy is reproduced on page 14, together with an introduction by Dominique Marbouty.

Peter White

Changes to the Operational Forecasting System

There have been no changes to the operational forecasting system.

François Lalaurette

Product dissemination exceeds 1,000,000

On 25 October 2002, the number of products generated for dissemination exceeded one million for the first time ever; the exact number is 1,100,324. This was mainly triggered by the addition of model-level products from the EPS. It is interesting to note that the number of products reached 100,000 on 22 May 1996

Dragan Jokic

Probabilistic forecasts for ocean waves

In June 1998, the Ensemble Prediction System (EPS) at ECMWF was coupled to the ocean-wave model. From then on, daily ensemble wave forecasts have been available. Although the positive impact on both the atmospheric and the wave forecasts was the main reason for the introduction of the coupling (*Janssen et al.* 2001), probabilistic forecasts of ocean waves derived from the EPS are also potentially very valuable products. For the offshore and shipping industry, such a forecasting tool could have numerous applications, such as ship routeing and the planning of high-risk operations. In many activities out at sea, the most critical environmental parameter is ocean waves. Oil rigs in the ocean are designed to withstand almost any possible wind condition, but extreme waves may, in some cases, result in serious damage to a platform. A common oil rig design criterion requires that the 100-year maximum wave must not touch the platform deck. It is not necessarily feared that the rig itself might topple, but rather that many of the light installations on the platform deck, such as walking bridges and fences, are not designed to withstand the forces from waves. When hazardous or delicate operations are to be performed, ensemble forecasts could be used to estimate the probabilities of weather events that are considered dangerous. Particularly if such activities need to be planned days ahead, probabilistic forecasts of dangerous weather and sea-states can provide important information. Examples may be the towing and installation of oil rigs or the salvage of wrecked vessels. During operations like these, it is vital that certain weather and sea-states are avoided. If not, both the risk to human life and the potential economic loss may be enormous. Since this type of probabilistic information is not available from traditional deterministic models, forecasting systems that are able to predict reliably, even small probabilities of such hazardous events, would be very useful.

In marine forecasting, some sort of floating object is often involved. This may be anything from small barges and ramps, to huge vessels. A common feature for all floating objects is that their response to ocean waves is strongly sensitive to the wave frequency, with a maximum response near the resonance frequency of the structure in question. If this situation occurs, the structure might be subject to violent oscillations even for wave heights that would generally be regarded as relatively small. During the construction of a floating bridge in Salhusfjorden in Norway, the bridge modules were transported from The Netherlands to Norway across the North Sea on barges. During one of these transports, one module was lost when it fell off due to strong oscillations of the barge. Very much to the surprise of the skipper of the barge, the wave height was rather small when this happened. It is likely that the resonant periodic motion of the barge due to ocean waves was the cause of this incident (Johannes Guddal, personal communication). The wave EPS makes it possible to provide forecasts of the response probability, though this type of service would need to be tailored for individual users (for example, to take account of the characteristics of a particular container vessel). Using information on the response properties of the vessel and the local sea-state, any motion of freedom, such as the pitch and heave, can in principle be estimated. If certain threshold values for these motions are to be avoided, the EPS could be used to issue maps where areas with a significant probability of these thresholds occurring are highlighted. The point to be stressed is that, for many applications, the important forecast parameter is not necessarily the wave height alone, but rather the joint probability of wave height and period, or perhaps some other parameter characterising the wave-energy distribution.

One of the objectives of the EU-funded research project SEAROUTES is to investigate the possible usefulness of ensemble predictions for ship routeing. As a first step towards such a goal, the forecast system itself needs to be tested against observations. Validation of the system is, of course, necessary to enable all end-users to take full advantage of probability forecasts. A decision-maker who has to decide whether or not to take action when the forecast threshold probability of a given event is exceeded, or has to decide which path to follow during an Atlantic crossing, must be confident that the forecast probabilities reflect the true risk that a certain event will take place.

The 10–11 November 2001 storm in the Norwegian Sea

On the night of 10–11 November 2001, extreme wave conditions were experienced in the Norwegian Sea. At two oil platforms, Heidrun (65.30°N, 7.30°E) and Draugen (64.30°, 7.80°E), significant wave heights in excess of 15 m were observed, the highest individual wave being of the order of 25 m. Draugen has been in operation since 1994 and Heidrun since 1996 (in the vicinity Heidrun's present position, a buoy was deployed between 1980 and 1988). The waves observed in November 2001 were the largest ever recorded at these two locations. Also, at the weather ship Polarfront (MIKE 60°N, 2°E) positioned further out at sea, a maximum significant wave height of 15.5 m was measured during this storm. The Polarfront has measured waves regularly since the late 1970s, and had only recorded wave height of this magnitude earlier on two occasions.

ECMWF issues global forecasts of the probability of significant wave heights above thresholds of 2, 4, 6, and 8 m on a daily basis, based on the EPS. Looking at the probability forecast five days ahead of this event for this area, it is obvious that something dramatic was about to take place. Figure 1 shows the day-5 probabilities of waves exceeding 8 m. The positions of the weather ship and the two oil platforms are marked with their respective station names in this plot. In the area where the weather ship was positioned, the EPS predicted that the probability of the occurrence of waves greater than 8 m high was more than 50%. For both Heidrun and Draugen, the forecast probabilities of waves above 8 m were between 40% and 45%. Taking into account the fact that the ECMWF wave model tends to under estimate extremes (*Bidlot et al.* 2002), it is obvious that the ensemble forecast provided an early warning five days ahead of this extreme situation.

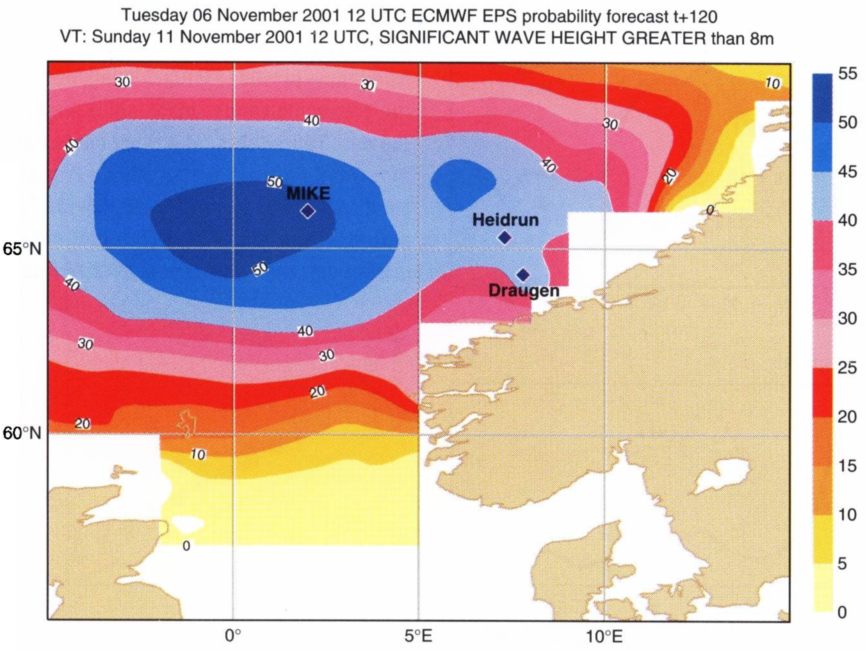


Figure 1 Day-5 probability forecast of wave height exceeding 8 m, valid at 12 UTC 11 November 2001. The three stations are marked by their respective names.

To have a closer look at the actual ensemble forecasts in this case, plume diagrams showing the forecasts from 12 UTC 6 November 2001 for Heidrun are illustrated in figure 2. The plots give the swell wave height, the wind speed and the significant wave height. Although none of the ensemble members predicted waves above 15 m, five of the members were above 12 m, and one member was slightly above 14 m. It is important to note that this plot is based on 12-hourly output, at noon and midnight; from the wave recording taken at Heidrun, the largest waves were measured between 05 and 08 UTC, though at 00 UTC and 12 UTC the measured wave heights were still about 12 m.

The performance of the EPS for ocean waves

In this study, the EPS forecasts were compared with buoy and platform observations (obtained via the Global Telecommunication System (GTS)) of wind speed, wind direction, significant wave height and peak period. Except for one platform located off the South African coast, and, one buoy on the equator near Christmas Island in the Pacific, all measurements were taken in the northern hemisphere. Since the majority of the buoys and platforms are located close to the continents, relatively few observations are obtained over the open oceans. To account for these shortcomings, the wave-height forecasts were, in addition, assessed against ERS-2 altimeter observations, and the results compared with those obtained from the buoy and platform observations. The study covered the period from 1 September 1999 to 31 March 2002, thus including three full boreal winters. Only the results for waves are shown here (for more details, refer to *Saetra and Bidlot* (2002)).

In July 2000, some changes were made to the data assimilation scheme at ECMWF but, unintentionally, the scaling used to initialise the perturbed ensemble members became too small. The problem was resolved in January 2001 but, during this six-month period, the ensemble spread was too low. The consequences of this are illustrated by our study.

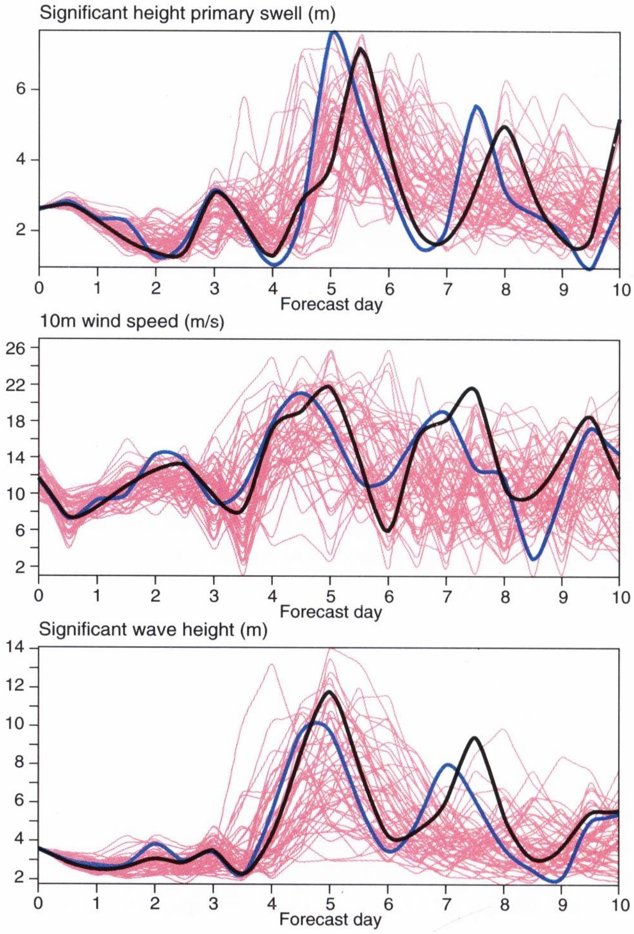


Figure 2 Plumes showing the deterministic high-resolution and ensemble forecasts for the Heidrun platform (65.30°N, 7.30°E). The deterministic high-resolution forecasts are given by the black lines, and the control forecasts by the blue lines. The magenta lines are the ensemble members. These forecasts were produced at 12 UTC 6 November 2001, and the storm is clearly seen at day 5 in this plot.

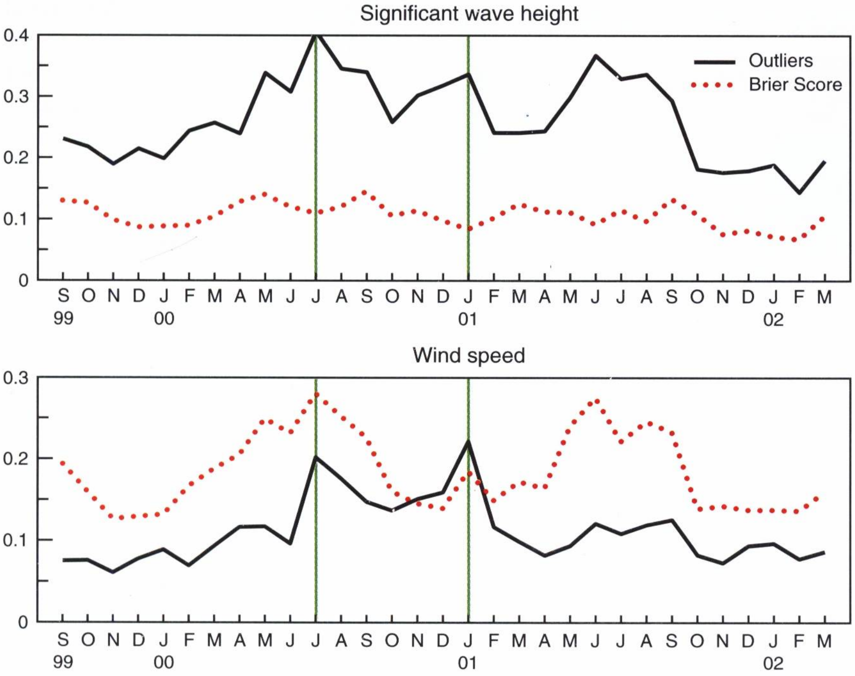


Figure 3 Monthly-mean values of the Brier score (red dotted line) and the frequency of observations lying outside the ensemble range (black solid line) for the day-3 forecasts. The Brier scores are for probabilities of waves above 2 m and wind speeds above 5 m/s, respectively. The period with a bug in the EPS initialisation is between the two vertical dashed lines.

Figure 3 shows the monthly-mean frequencies of observations lying outside the ensemble range for wave height and wind speed in the day-3 forecasts. For waves, the graph corresponds to the probability forecasts of wave heights above 2 m, and for wind speeds, the threshold value is 5 m/s. The time of introduction and removal of the error in the initialisation of the system are marked by two vertical dashed lines. For the wind speed, a sudden increase in the number of observations outside the ensemble forecasts is observed in July 2000, when the error was introduced. After January 2001, when the bug was removed, the spread returned approximately to the previous level. Changes in the ensemble spread for the wave height can also be detected during this period, but the signal is weaker for this parameter. In figure 3, the monthly-mean Brier Scores are also plotted. No particular differences in the Brier Scores are, however, detected during the period when the error was present.

As demonstrated by *Saetra and Bidlot* (2002), it is difficult to determine the ensemble spread alone because the measurements are subject to observation errors. Rank histograms are commonly used to evaluate the ensemble spread (*Anderson* 1996; *Hamill* 2001). This method is, however, very sensitive to noise. When non-negligible measurement errors are present, the method may give the false impression of too low an ensemble spread by over-populating the upper and lowermost rank. For practical purposes, however, the ensemble spread should somehow be judged in relation to the forecast skill. We would like to be able to interpret the ensemble spread as a measure of the uncertainty of the corresponding deterministic forecast in such a way that we have more confidence in the forecast when the ensemble spread is small than when it is large. Ideally, the smaller the spread, the more we should be able to trust that the deterministic forecast is good.

We expect that, for a given ensemble spread, an upper bound to the forecast errors exists. This upper bound should be an increasing function of the ensemble spread. Accordingly, the ensemble spread should be compared with something that is a measure of the upper bounds of the observed errors; for example, this can be done by using the 90-percentile of the absolute errors as a measure of a statistical error bound. For a given spread, we seek the value that separates the 10% largest errors from the rest of the data. If a situation is picked randomly from this data set, the probability is 90% that the corresponding absolute error is smaller than the value given by the 90-percentile value. In order to relate this to the ensemble spread it is necessary to divide the spread into different classes or bins, and then rank the observed errors within each class to find the value that constitutes the boundary between the 10% largest errors and the rest.

In figure 4, the 90-percentile of the absolute error for significant wave height is given as a function of the ensemble spread for the day-5 forecast range. The observations in this case are the global altimeter data, but similar results were obtained with buoy data. The ensemble spread is defined as the difference between the upper and lower quartiles of the ensemble. The absolute error is defined as the distance between the observed value and the control forecast. The black, solid line is the result when all available data are taken into account. The triangles mark the centre points of each bin for the spread. The number of cases that have been used for each bin is indicated by the histogram in the upper left corner. The 90-percentile shows a clear dependency on the ensemble spread. The data have also been divided in different areas with different characteristics, and hence different variability. Of course, the choice of percentile for the observed errors is more or less arbitrary; any other percentile gives qualitatively similar results. As an example, the 75-percentile fits roughly with the diagonal line. A very approximate rule of thumb may, therefore, be that the error in the wave forecasts is expected, with 75% probability, to be less than or equal to the interquartile range of the wave ensemble.

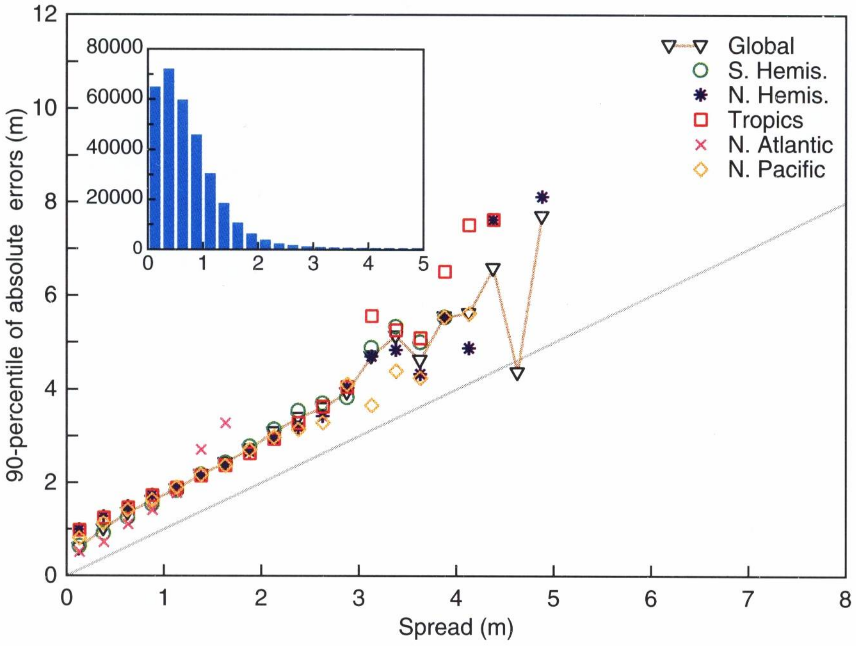
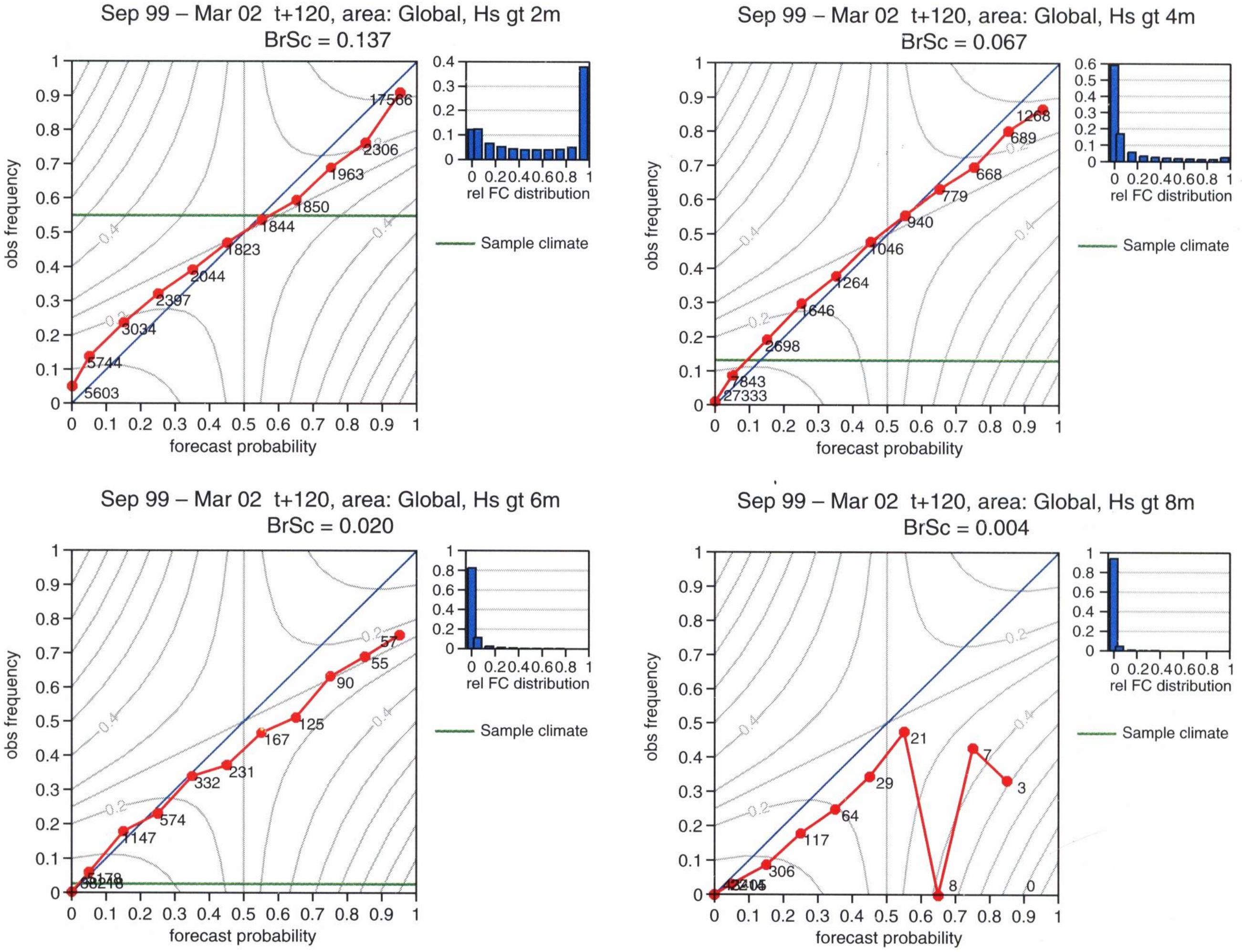


Figure 4 Day-5 forecast spread-skill based on the altimeter wave heights. The frequency in the various bins for ensemble spread are depicted in the bar diagram. The tropics are defined as the area between 20°N and 20°S.

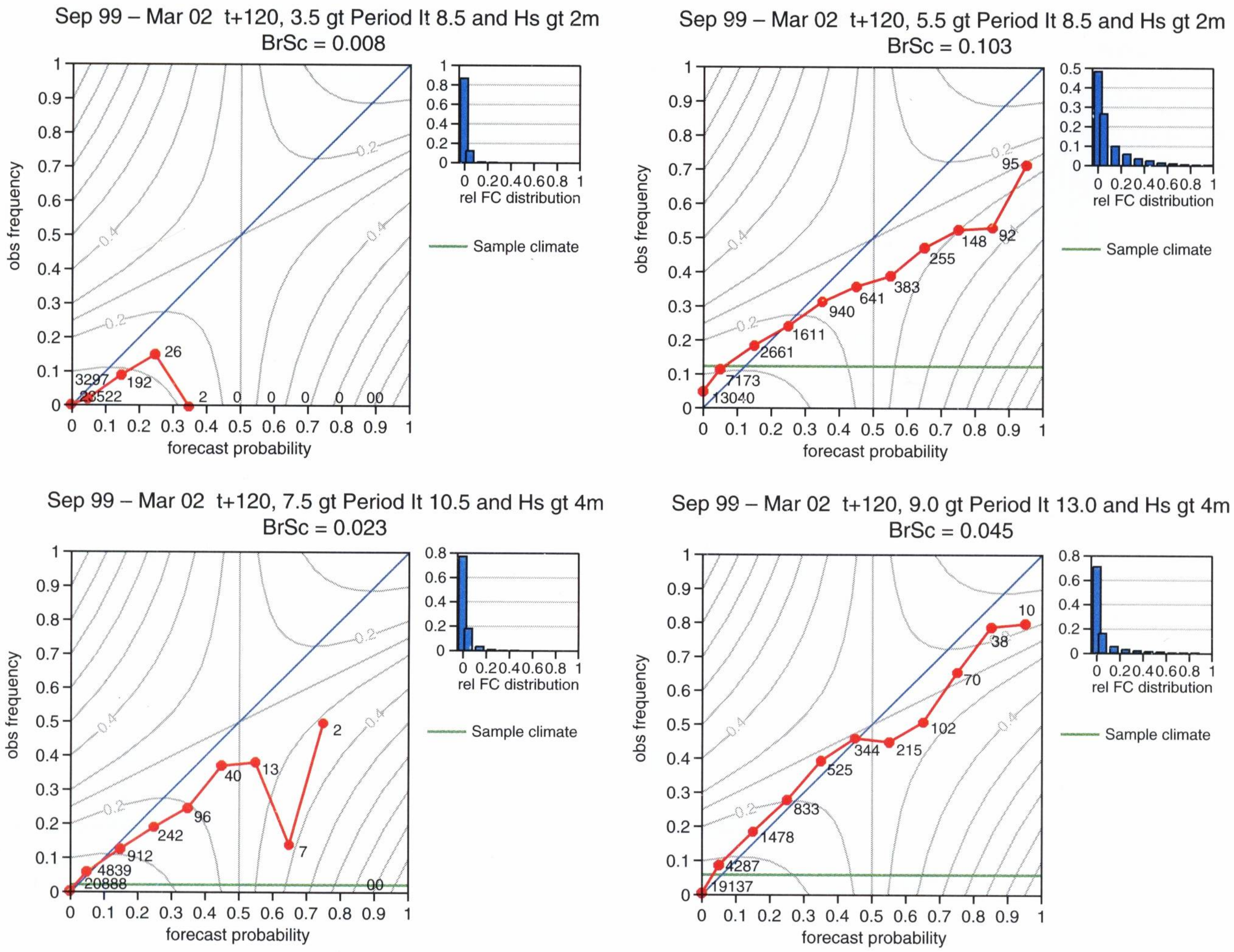

Sep 99 – Mar 02 t+120, area: Global, Hs gt 2m
BrSc = 0.137

Sep 99 – Mar 02 t+120, area: Global, Hs gt 4m
BrSc = 0.067

Sep 99 – Mar 02 t+120, area: Global, Hs gt 6m
BrSc = 0.020

Sep 99 – Mar 02 t+120, area: Global, Hs gt 8m
BrSc = 0.004

Figure 5 Day-5 reliability diagram for wave height. BrSc stands for Brier Score (see text). All buoy data were used. The panels illustrate results for thresholds of 2, 4, 6, and 8m.



Sep 99 – Mar 02 t+120, 3.5 gt Period lt 8.5 and Hs gt 2m
BrSc = 0.008

Sep 99 – Mar 02 t+120, 5.5 gt Period lt 8.5 and Hs gt 2m
BrSc = 0.103

Sep 99 – Mar 02 t+120, 7.5 gt Period lt 10.5 and Hs gt 4m
BrSc = 0.023

Sep 99 – Mar 02 t+120, 9.0 gt Period lt 13.0 and Hs gt 4m
BrSc = 0.045

Figure 6 Day-5 reliability for the joint probability of significant wave height and peak period. BrSc stands for Brier Score (see text). All buoy data were used. The panels illustrate results for thresholds of 2 m and periods between 3.5 and 6.5 s, 2 m and periods between 5.5 and 8.5 s, 4 m and periods between 7.5 and 10.5 s, and 4 m and periods between 9.0 and 13.0 s.

In figure 5, the reliability diagram (*Wilks* 1995) for the day-5 forecast probabilities of wave heights in excess of 2, 4, 6 and 8m are plotted. For a given event, the forecast probabilities are split into discrete bins ranging from zero to one. For each probability class, the number of times the event is observed with respect to the total number of ensemble forecasts in that class, defined as the observed frequency, is plotted against the corresponding probability class. For a perfectly reliable forecasting system, these points lie on the diagonal line. The plots also display the overall Brier score for each event. This is essentially the mean-squared error for a probability forecast with 0 for a perfect forecasting system and 1 as upper bound (*Wilks* 1995). The graphs shown here are based on buoy data from all stations. Generally, the results indicate good reliability, particularly for the 4m threshold. For threshold values of 2 and 6m, the reliability is also quite good, but there is a small tendency for the points to lie below the diagonal line, which indicates that high probabilities are forecast slightly too often. The Brier score is smaller for the two largest threshold values. This is due to the fact that for threshold values of 6 and 8m, the vast majority of both forecasts and observations are in the two lowest forecasting classes; while for 2 and 4m the EPS forecasts are more evenly spread over the range of probabilities. For the 8m threshold, the reliability curve shows the behaviour typical for situations with insufficient sample size.

In figure 6, the day-5 forecast-reliability diagram of the joint probability of wave height and period are given. Here, two relatively low-threshold values of 2 and 4m for wave height have been used. For a 2m wave height, the intervals are for periods between 3.5s and 6.5s and between 5.5s and 8.5s. The reliability diagram for the first of these is typical for rare events, but with relatively good reliability. The second case is much more common as the reliability curve also reveals. For the 4m wave-height threshold, the periods are between 7.5s and 10.5s for the first case, and between 9s and 13s for the second case. For this threshold, the first case shows the behaviour typical of rare events with relatively good reliability. The second case also shows quite good reliability, but in this case the period interval is much more common.

Economic value

It is important to assess the value of the ensemble forecasts. Obviously, the ensembles provide additional information that could not be obtained by traditional forecasting methods. In many operations involving weather-related risks, the decision on whether to carry out the operation or not must often be taken at a time when the potentially dangerous part of the operation lies several days into the future. For instance, when an oil rig is to be towed, a perilous part of the operation is the installation of the platform at the future operations site, in some cases many days after the onset of the move. In such cases, ensemble forecasts should provide valuable information.

Richardson (2000) suggested a method for estimating the relative economic value of weather forecasts, including ensemble forecasts. This method is also well suited for comparing the relative value of the ensemble forecasts with that of traditional deterministic forecasts. The method assumes a situation where a person has to decide on whether to take action to avoid a weather-related risk or not. If the probability of waves above the dangerous threshold is considered too high, action can be taken to postpone the operation in order to prevent a potential loss *L*. In this scenario, taking action involves costs *C*, associated with the delayed operation. If L_0 is the part of the potential loss that is saved by taking action, the cost-loss ratio is defined as $\alpha = C/L_0$. The relative economic value compares the expected expenses of the actual forecast with those for a perfect forecast, and with the expenses associated with the use of climatology, to make the decision. According to this, a perfect forecast will score 1 and a forecast that does not perform better than the sample climate will score 0 (for details, see *Richardson* (2000)).

In figure 7, the relative economical value of the ensemble wave forecast and a deterministic forecast, represented here by the control forecast, is given as a function of the cost-loss ratio. In addition, the EPS has been compared with the 'poor-man' ensemble (PME), which was constructed by adding normally distributed noise to the control forecasts. The standard deviation used for this is 0.96 m, which is the average root-mean-square error for the day-5 forecasts for waves when compared with buoy data. The figure shows the results for the day-5 forecast for waves above 2, 4, 6 and 8 m thresholds. In the curves for the EPS in this case, the appropriate probability level has been found by calculating the economic value for a discrete set of probabilities ranging from 0 to 1 for each cost-loss value, and choosing the one that maximises the economic value. For the largest threshold value (8 m), economical benefits of using the forecasts are only obtained for small cost-loss ratios. It is reasonable to believe that this result is due to an insufficient number of observations of wave heights in this range, as is also apparent from the reliability diagrams discussed earlier. Although the EPS performs better than the PME, the differences are not very large.

The relative economic value of the forecasts for the joint probability of wave height and period is given in figure 8. The threshold levels here correspond to the reliability diagrams shown in figure 6. The standard deviation used to create the PME for the peak period is 2.71 s, corresponding to the average root-mean-square error at day 5. Encouragingly, for all cases shown, the relative economic value of the EPS is larger

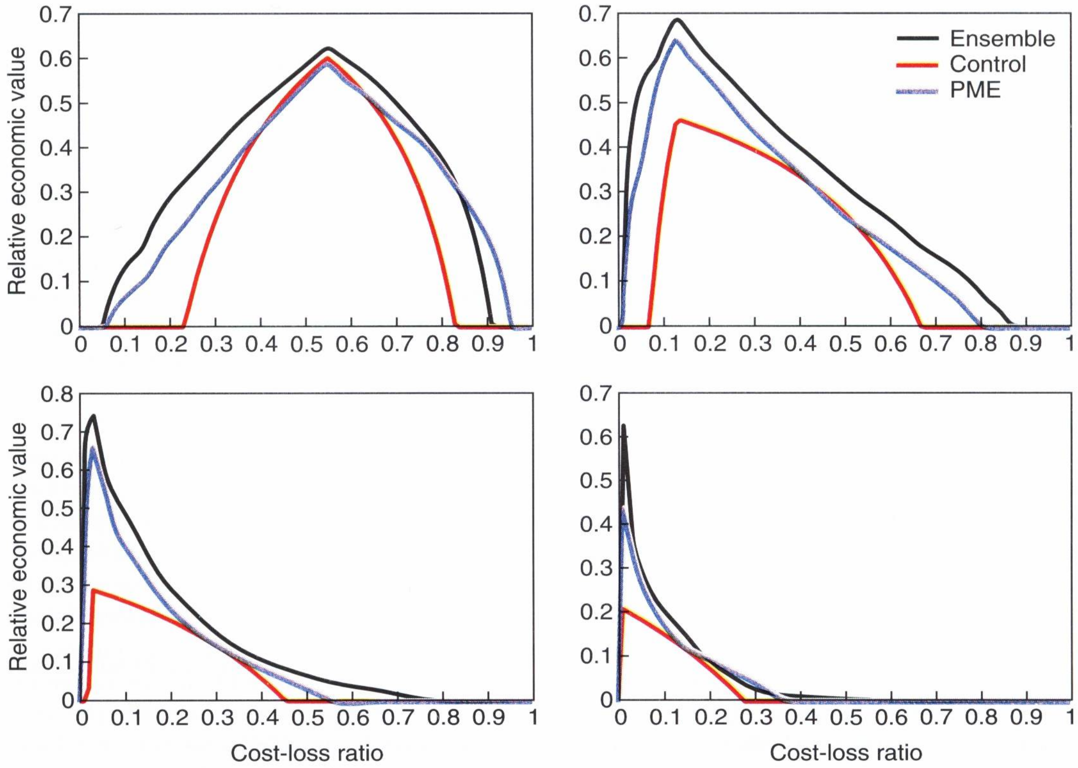


Figure 7 Relative economic value for the day-5 wave-height forecasts as function of the cost-loss ratio. The threshold values are 2, 4, 6, and 8 m, and correspond to the values used for the reliabilities in figure 5. All buoy data were used.

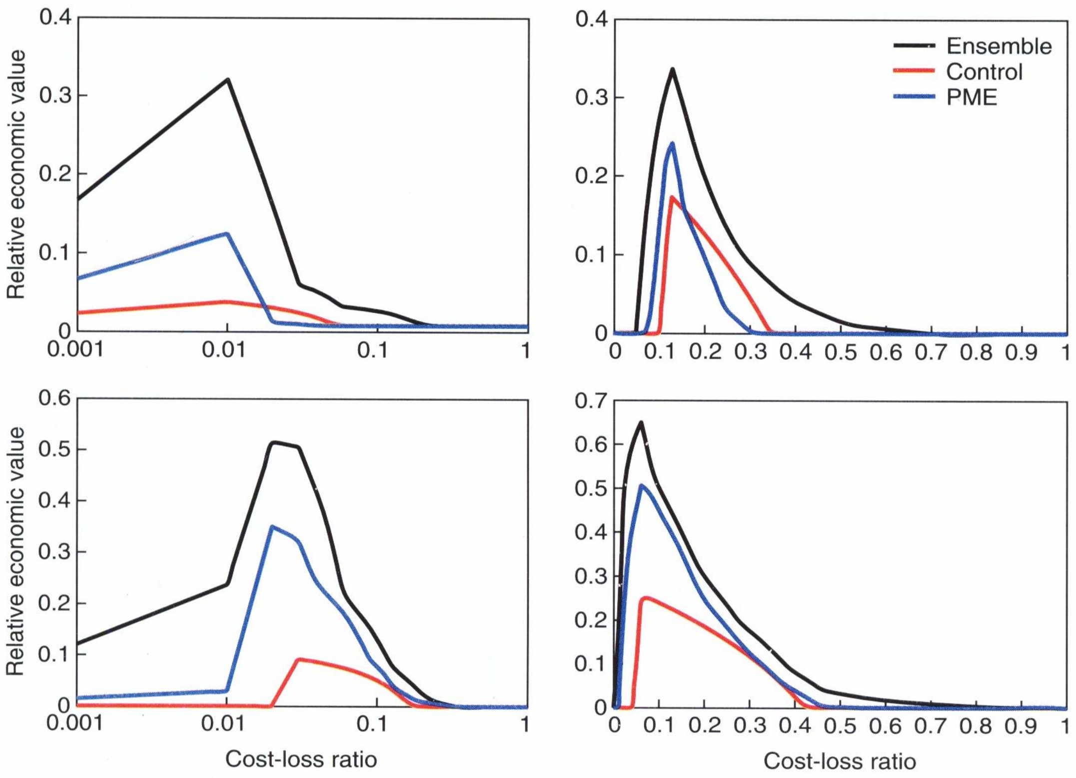


Figure 8 Relative economic value for the day-5 forecasts of the joint probability of wave height and peak period (see figure 6 for threshold values). Note that the two plots to the left-hand side represent rare combinations of wave height and period and exhibit an economic value above that of climatology only for cost-loss ratios below 0.1. To see the differences more clearly, these are plotted with a logarithmic scale along the cost-loss axis.

than the value of both the control forecast and the PME. The two cases on the left-hand side of the plot represent rare combinations of wave height and period. For these cases, relative economic values above climatology are obtained only for very low cost-loss ratios (note the logarithmic scale on the cost-loss axis). The results indicate that the relative difference between the PME and the EPS is larger for rare, or complex situations. However, it is very important to remember that this is strictly dependent on the correct choice of probability level for deciding whether or not to take action.

Summary and discussion

According to *Strauss and Lanzinger* (1996), the EPS spread should be sufficient to cover the uncertainties in the forecast. However, it seems difficult to test this criterion objectively when looking at the ensemble spread alone. One suggested method is to use rank histograms, where the frequency of the observations for each rank is illustrated as a histogram. A problem with this method is that, by simply counting the number of observations outside the ensemble range, one does not distinguish between very large and very small errors. As demonstrated by *Saetra and Bidlot* (2002), interpretation of the rank histograms as to whether the spread is sufficient or not, demands perfect observations. Even small observation errors may cause the rank histograms to give the false impression of too low an ensemble spread. This can be to some extent compensated for by adding the same amount of error to the ensemble members. However, good knowledge of the error statistics is needed for this method to be conclusive.

When viewing the spread in relation to the skill of the deterministic forecast, a relatively strong correlation is demonstrated. From a forecaster's point of view, the ensemble spread should be a measure of how much confidence he or she can have in a particular weather prediction. Small spread equals strong confidence, and visa versa. By sorting the ensemble spread into different bins and calculating the percentiles of the absolute errors for each bin, an upper bound to the expected forecast error is found. By applying this method, an apparent correlation between spread and skill can be demonstrated. For waves, the slope of the curve is more or less parallel to the diagonal line, indicating that the forecast error of the deterministic model could be expected to bounded by the inter-quartile range of the ensemble spread.

The reliability of the probability forecasts seems to be very good indeed, although the buoy and platform observations indicate a small tendency for over-confidence in forecasting wave heights above 6 and 8 m. The reason for this is not clear to us at the moment. Generally, the wave model is known to underestimate high waves but, when looking at individual time series for cases with very high waves, we can see that, in most cases, a number of the ensemble members have predicted wave heights that are well above the observed values. The reason seems to be that these members have been forced by sufficiently strong wind speeds, resulting in too large probabilities being forecast for the larger waves classes. One explanation for this may be related to he the stochastic physics in the atmospheric component of the EPS. On the other hand, for the two lowest threshold levels, the plotted points of observed frequency versus forecast probability are very close to the diagonal line.

The reliability of forecasts of combinations of wave height and wave period is rather good. Even for the most atypical combination, the points on the reliability diagram are located relatively close to the diagonal. However, again for the joint probabilities, there is a general tendency for slightly too confident probability forecasts.

Tests of the value of the EPS forecasting system for decision-making indicate that a 'poor-man' ensemble performs relatively well, even though the real ensemble, in almost all situations, outperforms it. For more complex forecasting parameters, the benefit of using the real ensemble, rather than a 'poor-man' ensemble becomes even more apparent. This encouraging result should, hopefully, serve as an inspiration for the development of more interesting products based on the EPS, leading to an ability to exploit fully the potential of wave ensembles as a marine forecasting tool.

Further reading

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Øyvind Saetra and Jean-Raymond Bidlot

Assimilation of meteorological data from commercial aircraft

Meteorological observations of wind and temperature are automatically recorded by instruments onboard commercial aircraft, both at cruise-level and during ascent and descent at airports. The data are collected by means of aeronautical telecommunications networks and distributed to weather centres around the world via the WMO Global Telecommunications System (GTS). The aircraft data have increased in numbers and coverage very substantially in recent years, with co-ordination provided by WMO (World Meteorological Organisation) and EUCOS (European Composite Observing System) programmes. At ECMWF, (European Centre for Medium-Range Weather Forecasts) we now receive around 130,000 aircraft reports in any 24-hour period. The data are used within the 4D-Var assimilation system improving the analyses of jet-streams and of the vertical distribution of temperature and wind in the vicinity of many airports. A significant positive impact on forecast performance has been demonstrated. For a more detailed report, see ECMWF Tech. Memo. 371 (*Cardinali et al.*, 2002).

The availability of aircraft data

Over the past few years the number and the coverage of automated aircraft data has increased very significantly - in particular the ACARS (Aircraft Communication Addressing and Reporting System) and AMDAR (Aircraft Meteorological Data Relay) systems (*WMO 1996*). The WMO AMDAR programme seeks to make the aircraft-based observing system more cost effective by reducing the number of redundant data at the main airports and in heavily trafficked air-routes, while improving the reporting in regions with less air traffic. Due to this effort, more aircraft observations become available in otherwise data sparse areas. The number of airports at which aircraft provide wind and temperature profiles during ascent and descent, has thereby increased substantially. For Europe, these activities are co-ordinated through the E-AMDAR programme (part of EUCOS): Data 'Optimisation' Systems have been developed to significantly reduce the quantity of redundant data over Europe. These are now being enhanced to enable AMDAR reporting to be automatically activated on high priority long haul flights when available. The dramatic improvement in data coverage in recent years, for the European AMDAR, is demonstrated by the statistics shown in Table 1. The main participating airlines are KLM, British Airways, Air France, SAS and Lufthansa.

Date	No. of observations	No. of profiles at airports	No. of airports observed	No. of reporting aircraft
14 Oct 1999	5,504	226	49	36
21 Jan 2002	25,684	748	109	201

Table 1 European AMDAR data coverage for two selected dates. From the EUMETNET annual report 2001 (*Bruce Truscott, Met Office*).

AMDAR reports are often produced at the specified frequency of one report per seven minutes at cruise level, with additional reports at wind maxima. During ascent, reporting is typically at 10 hPa intervals vertically for the first 100 hPa in the lower part of the profile and every 50 hPa above that layer to top of climb (near 20,000 feet) with the reverse applying during the descent phase. The AMDAR system thus provides data at altitude roughly every 70-100 km along the flight path as well as detailed profiles in the near vicinity of airports. The telecommunications cost to collect the data in real-time can be as low as 1 US cent per observation in some countries, and up to 50 US cents over some oceans, with a global median value of 5 US cents (Stickland, 2001).

The resulting global coverage of aircraft data as received at ECMWF on 1 September 2002 is shown in Figure 1. The plot shows AIREP data in red (28,038), AMDAR in blue (26,673) and ACARS in green (78,187), with a total of 132,898 reports. Of these 79,259 were used in the 4D-Var data assimilation system, 562 were rejected in automated quality control checks, and the remainder were classified as redundant due to duplication or very dense reporting. The long-term evolution of the aircraft observing system can be seen in Figure 2, which shows the number of data available (black) and used (red) in ECMWF's 40-year re-analysis of meteorological data, from 1957 onwards.

How the data are used

The ECMWF data assimilation system is a 4D-Var scheme. One of the strengths of 4D-Var is its ability to assimilate frequent and irregularly spaced data. All available observations within a 12-hour period are used in one global estimation-problem. The observations are compared with a short-range forecast on a half-hourly basis. The differences between observations and a short-range forecast are analysed to obtain a corrected model state (the analysis), which evolves during the 12-hour assimilation period in better agreement with the observations. The short-range (12-hour) forecast and the comparison with observations is carried out at full resolution, currently T511 spectral truncation (40 km), whereas the analysis increments are evaluated at T159 (120 km).

Aircraft provide automated reports of wind and temperature measurements with accuracy comparable to that of radiosondes: 1-2 m/s for wind and 0.7-1.2 K for temperature. The AMDAR and ACARS measurements are of higher quality than the traditional AIREP measurements. At ECMWF, many data types are thinned before use to avoid potential imbalances between data types with very different densities. For aircraft data the observation error correlation is thought to be very small, enabling the data to be used at a resolution similar to that of the assimilating model. Given that the resolution of the 4D-Var assimilation system has increased significantly in recent years it has been possible to increase the number of data used. Aircraft data are now (since January 2002) thinned along-track only if their separation is less than 60 km, considering one flight at a time. Where there are several flights in an area, the data from different flights are used as mutually independent measurements. During ascent and descent, aircraft data are thinned only where there is more than one observation per flight per model level. The resulting density of used data is illustrated in Figure 3, for Europe and parts of North America, at jet-level and in the mid-troposphere. The density is very high at jet-level over parts of North America, and near the busiest airports in the lower and mid-troposphere, in both Europe and North America.

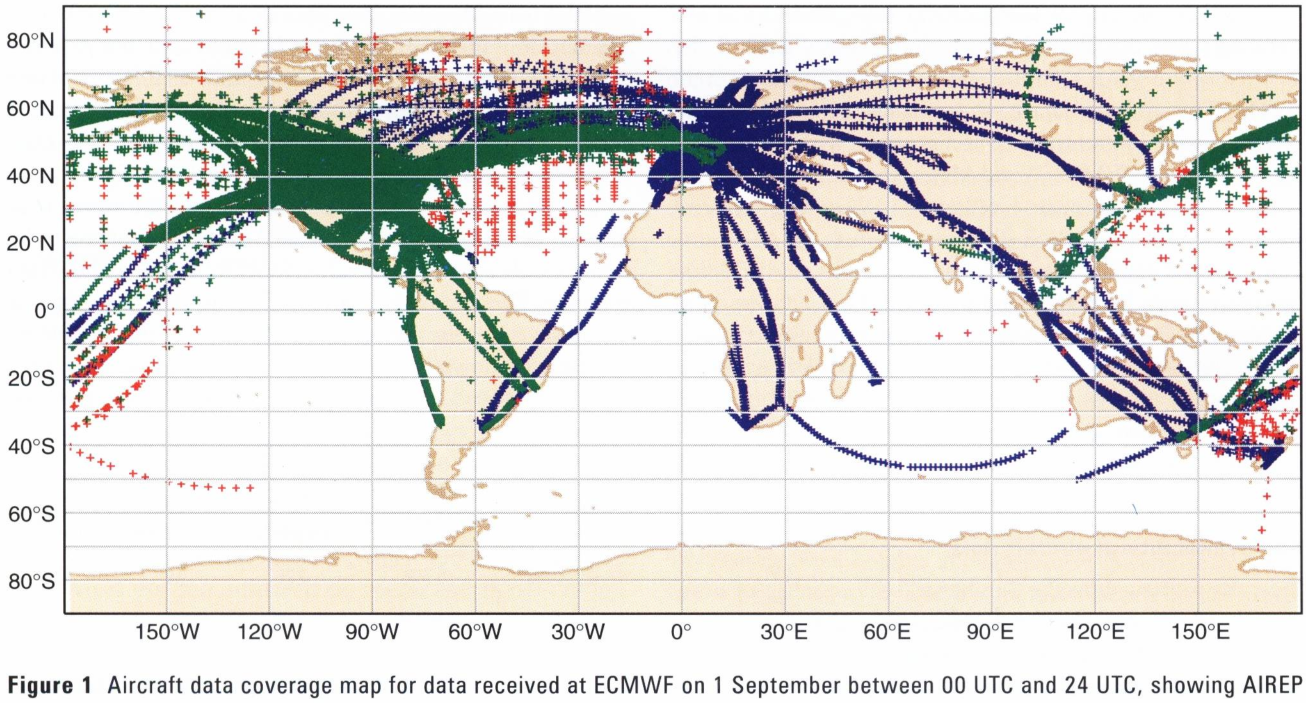

Figure 1 Aircraft data coverage map for data received at ECMWF on 1 September between 00 UTC and 24 UTC, showing AIREP (red), AMDAR (blue) and ACARS (green). Up-to-date maps of this kind for the most recent 6-hour periods are available on the ECMWF web site (www.ecmwf.int/products).

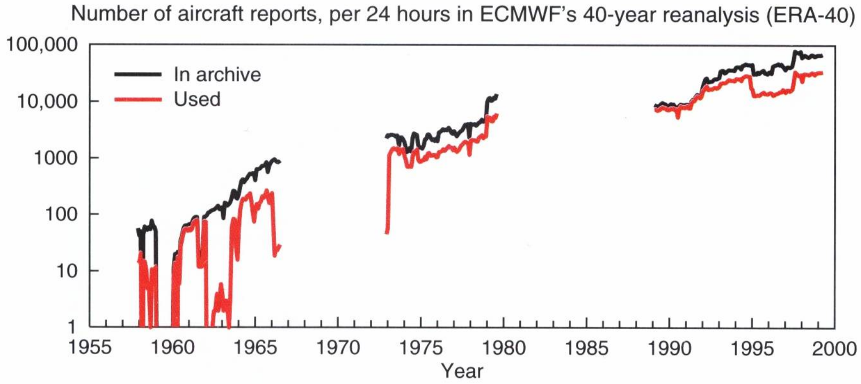

Figure 2 Number of aircraft reports, per 24-hours, in ECMWF's 40-year re-analysis of meteorological data, on a logarithmic scale. The ERA-40 processing is carried out in three concurrent streams, which when complete will provide a continuous record of the atmosphere from 1957 onwards. *(Data provided by Per Kållberg)*.

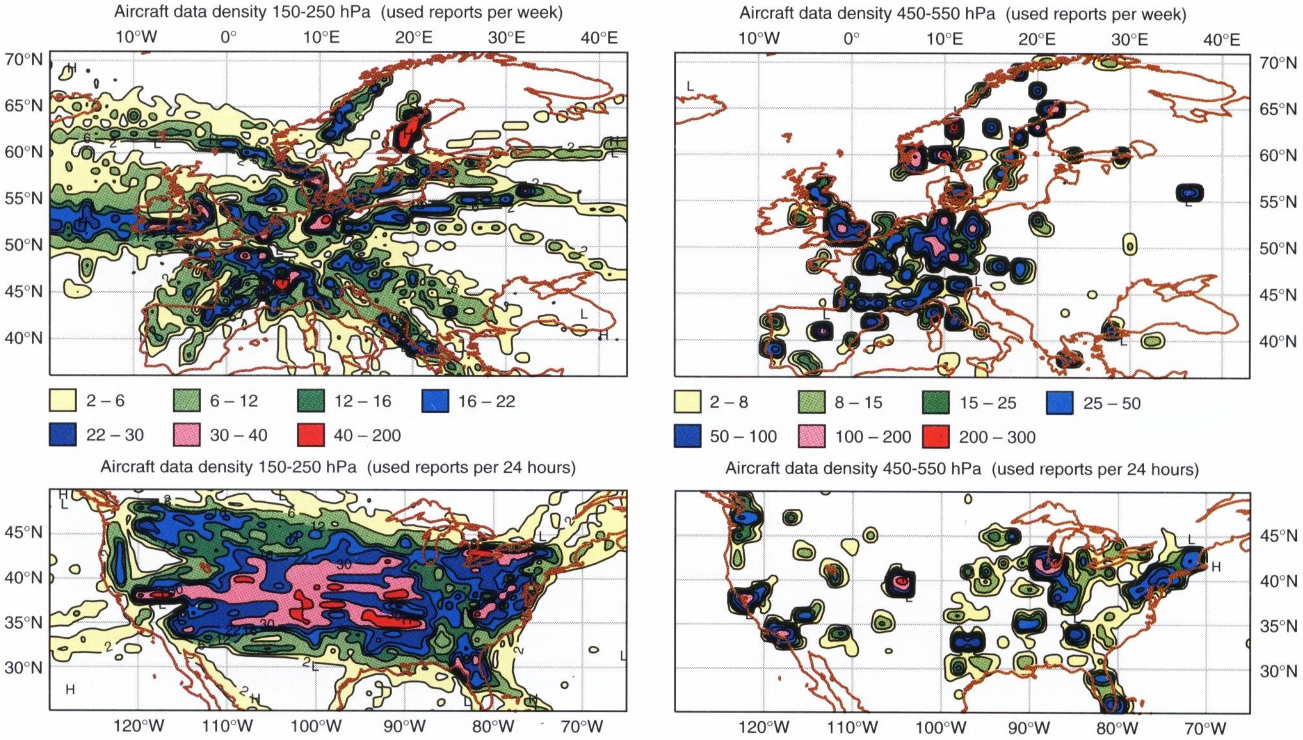

Figure 3 Density of used aircraft data between 1 August 2002 and 7 August 2002 in the mid-troposphere (right) and at cruise level (left) over parts of North America per 24 hours (top) and Europe per week (lower panels), see legend. The density is given in terms of number of data used by 4D-Var, per 1° × 1° box, within the vertical range and time-period indicated in the legend.

It has turned out necessary to apply a consistency check on the reported flight track for each aircraft. We check that it is physically possible for the aircraft to have travelled the distance between consecutive reported locations. We assume that a normal aircraft has a flight speed not exceeding 1200 km/hour (and a supersonic flight not exceeding 2400 km/hour). The check thus rejects those locations that imply unrealistic flight speeds. If more than half of the locations are suspect, the whole flight is rejected. The most typical reason for rejection of this type is that an aircraft incorrectly reports the same time during the whole flight.

Impact of profiling data from ascending/descending aircraft

The impact in 4D-Var of profiles from American and European automated aircraft in ascending and descending phase has been tested in a data denial impact study. It is of interest to test if 4D-Var extracts significant information from the aircraft data, which are irregularly distributed in space and time, given that in these areas there is good coverage of PILOTs, radiosondes and wind profilers. This study is one of several recommended by the WMO/CBS Expert Team on Data Requirements and the Redesign of the Global Observing System. The data denial experiment was run for two one-month periods: January and July 2001. All aircraft data below 350 hPa were removed over North America (25°–60°N, 120°–75°W) and Europe (35°–75°N, 12.5°W –42.5°E). This resulted in approximately 13,000 fewer data (temperature, u and v wind components) being used in the experiment, per 12-hour data assimilation cycle.

Analysis impact

One aspect of the analysis impact is illustrated in Figure 4. It shows the difference in rms (root-mean-square), between the data denial experiment and the control experiment, of

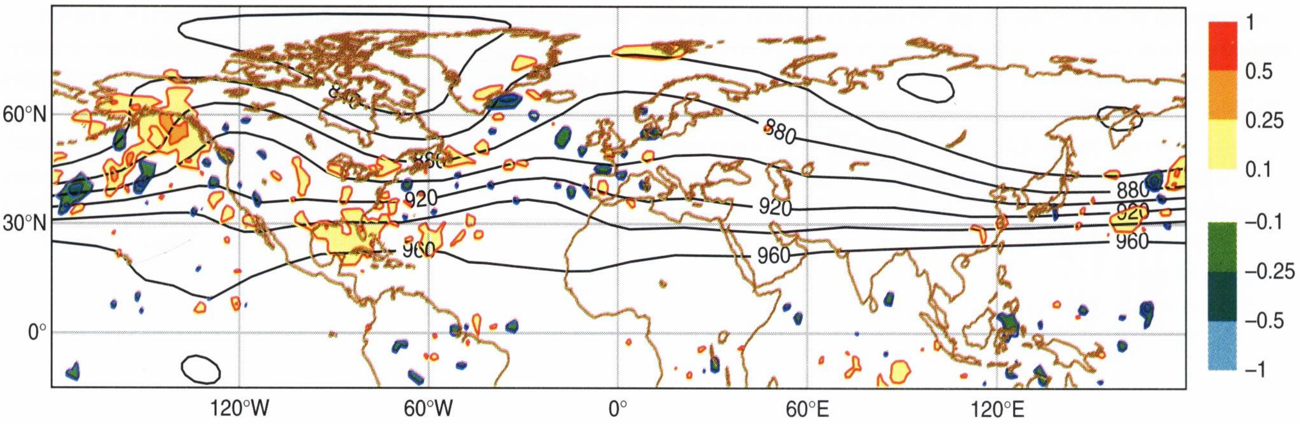

Figure 4 Difference in root-mean-square of analysis increments between the data denial experiment and the control, for 300 hPa geopotential height at 12 UTC over the period 2–31 January 2001. The shading starts at ±0.1 dm, with yellow (positive) shading indicating larger analysis increments in the data denial experiment. Area integrated values are: Europe 0.0 m, North Atlantic 0.11 m, North America 0.33 m and the Northern Hemisphere extra tropics 0.15 m. The mean 300 hPa geopotential height analysis is contoured with an interval of 20 decametres.

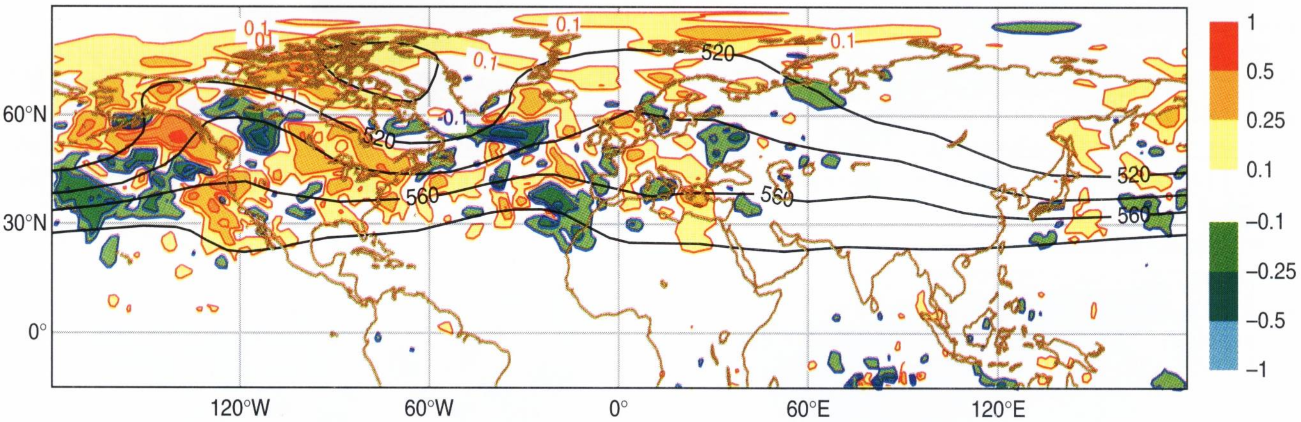

Figure 5 Difference in root-mean-square of 48-hour forecast error, between the data denial experiment and the control, for 500 hPa geopotential height at 12 UTC over the period 2 - 31 January 2001. Otherwise like figure 6. Area integrated values are: Europe 0.20 m, North Atlantic -0.02 m, North America 0.89 m and the Northern Hemisphere extra tropics 0.30 m.

analysis increments of 300 hPa geopotential height, for the winter period (January 2001). Yellow (green) shading indicates larger (smaller) analysis increments in the experiment without profiling aircraft data. We show 300 hPa here because at levels above 350 hPa similar numbers of data have been used in both experiment and control. It may at first seem counter-intuitive that the increments are larger in the assimilation that uses less data. The explanation is that the exclusion of accurate and useful data can make the errors in the short-range forecasts larger. When a less accurate 12-hour forecast is used as background in the next assimilation cycle, observation minus background departures are larger, resulting in larger analysis increments. We can conclude from Figure 4 that the denial of profiling aircraft data has had a detrimental effect on the assimilation over the Eastern United States extending into the Western parts of the North Atlantic storm track region.

Forecast impact

The deterioration at analysis time amplifies rapidly during the early stages of the forecasts in this experiment. Figure 5 shows the difference in rms of 48-hour forecast error, at 500hPa. We can see that the deterioration due to the denial of the profiling aircraft data has amplified during the first two days of the forecasts, and spread to Northern Canada and parts of the Arctic. The impact over Europe and its surroundings is also negative on average, with large variations.

The impact remains significant also in the medium-range, as seen in Figure 6. The impact has shifted predominantly down stream from North America, and to higher latitudes. There is a clear deterioration in the denial experiment, for the forecast performance in the northern parts of the North Atlantic, the British Isles, parts of Scandinavia and the Arctic. The precise location of the areas of forecast impact is likely to depend strongly on the synoptic situation during the test period.

The forecast verification anomaly correlation scores for the Northern Hemisphere (Figure 7) shows a clear deterioration from day-4 onwards in winter, and from day-6 onwards in summer, due to the removal of data from ascending and descending aircraft.

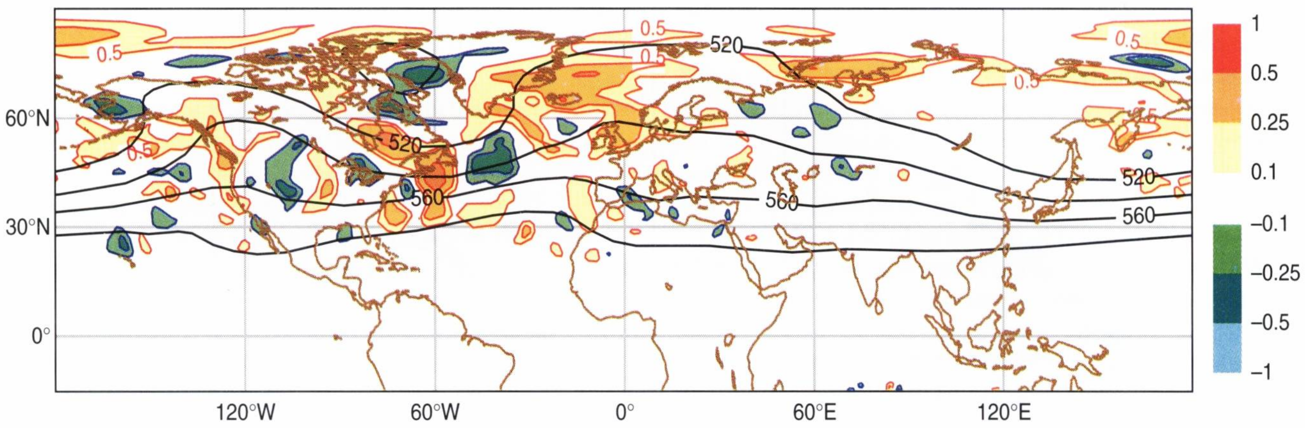

Figure 6 Difference in rms of 120-hour forecast error, between the data denial experiment and the control, for 500 hPa geopotential height at 12 UTC over the period 2–31 January 2001. Otherwise like figure 6. Area integrated values are: Europe 3.02 m, North Atlantic 2.90 m, North America 0.31 m and the Northern Hemisphere extra tropics 1.35 m.

The significance of the forecast impact is shown more clearly in scatter diagrams, such as those shown in Figure 8, for the Northern Hemisphere (left) and Europe (right), for the two experiment periods. In the diagram for the Northern Hemisphere a majority of cases fall below the 45° line, indicating consistent positive forecast impact when profiling aircraft data is used. A t-test on the statistical significance of the results gives 98 % for the Northern Hemisphere. For Europe the impact is essentially neutral over all, as most of the day-5 forecast impact appeared over the North Atlantic, the North Pacific and the Arctic.

The total impact of aircraft data, including that of the data at cruise-level, was tested and compared with other elements of the global observing system, in a study by *Bouttier and Kelly* (2001). They reported a substantial positive short-range forecast impact over Europe and North America, qualitatively in agreement with the results presented here.

Acknowledgements

We are grateful to Jeff Stickland and Bruce Truscott (Met Office) for detailed information on the WMO and EUCOS AMDAR programmes, and for their comments on the manuscript. We thank Milan Dragosavac for the operational acquisition of aircraft data, and Per Kållberg (ERA-40) for the data in Figure 2.

Further reading

Bouttier, F. and **G. Kelly**. Observing-system experiments in the ECMWF 4D-Var data assimilation system. *Q.J. Royal Meteorological Society*, **127**, 1469-1488.

Cardinali. C., L. Isaksen and **E. Andersson**, 2002: Use and impact of automated aircraft data in 4D-Var. ECMWF Technical Memorandum, 371, pp 17. Submitted to *Monthly Weather Review*

Stickland, J., 2001: Aircraft data for NWP. *Proceedings of 8th ECMWF Workshop on 'Meteorological Operational Systems'*, Reading, 12-16 November 2001.

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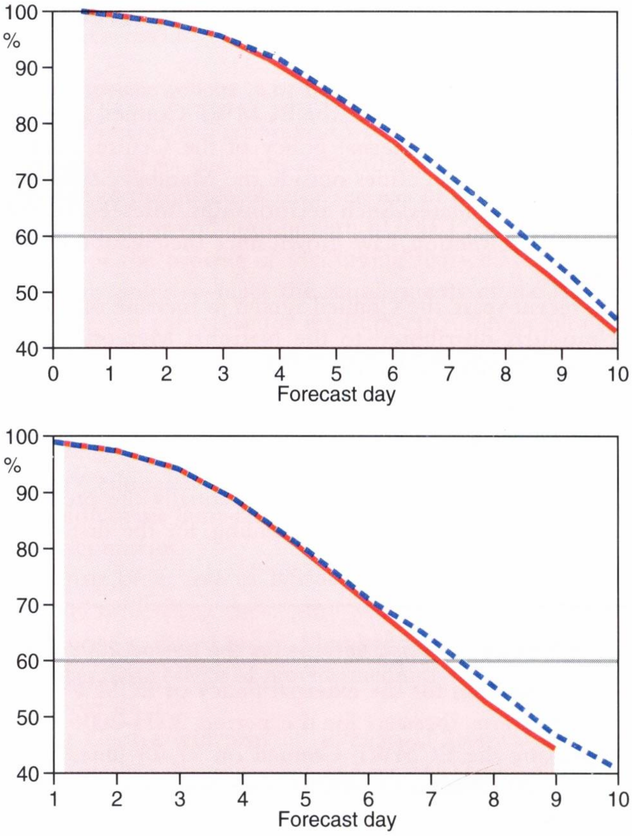

Figure 7 Northern Hemisphere anomaly correlation (%) of 500 hPa forecast error verified against operational analyses, each averaged over 31 cases, January 2001 (left) and July 2001 (right), 12 UTC. The data denial experiment is shown in red and the control is the blue dashed line.

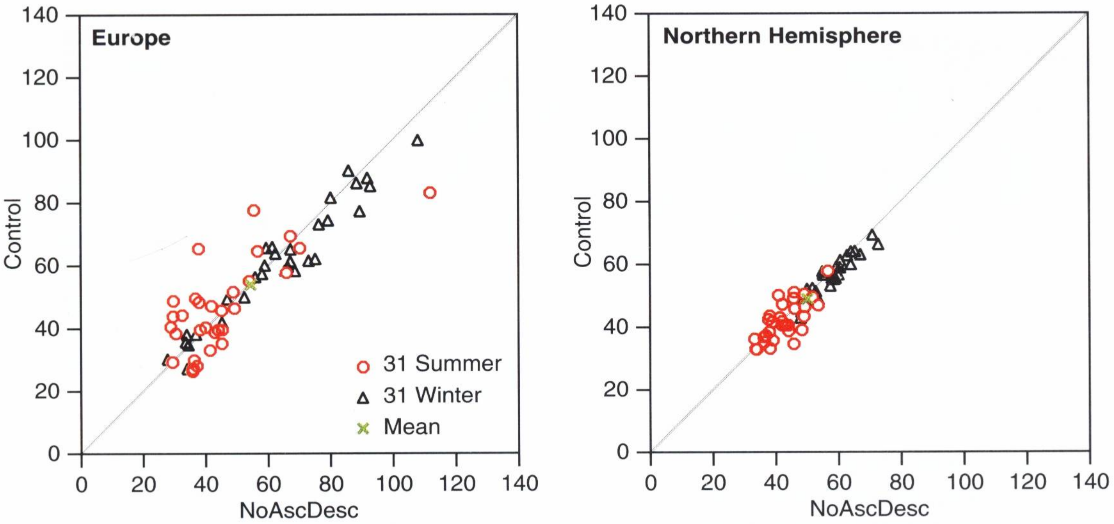

Figure 8 Scatter plot of the rms of 120-hour forecast error (m) for 500 hPa geopotential height. Each marker represents one day in the January period 2001 (black triangles) and July 2001 (red circles), for Europe (left) and the Northern Hemisphere extra-tropics (right). The error in the forecast from the denial experiment is plotted along the x-axis and that of the control along the y-axis. The average forecast error is shown by the green x-marker. Markers plotted below the diagonal indicate larger error in the data denial experiment than in the control.

Carla Cardinali, Lars Isaksen and Erik Andersson

ECMWF external policy

Introduction

At its session in June 2002, the ECMWF Council adopted guidelines for the external policy of the Centre, i.e. the relationships with entities outside the Member States and Co-operating States. Such relationships, foreseen in the Centre's Convention, have grown since the creation of the Centre.

In recent years, the Council agreed to increase the range of products distributed to the National Meteorological Services of WMO, both on the GTS and on the Centre's web site, in particular to support the prediction of severe weather:

- December 1999: to provide seasonal forecast products in graphical form on the web.
- November 2000: to increase substantially the products disseminated on the GTS including, for the first time, products from the EPS.

Following these decisions, the Council felt it necessary to define guidelines for the Centre's external policy for the future. It is an important text, where Council commits itself to supporting the wider meteorological community in general, and in particular developing countries, particularly by making available medium-range warnings of severe weather, including tropical cyclone forecasts.

This text will be included in the Four-year Programme of Activities of the Centre and will be reviewed annually. In particular, two specific aspects will be developed:

- The contribution to the global exchange of meteorological data with the development of the RMDCN outside WMO Region VI, the management of which is provided by ECMWF.
- The co-operation of the Centre with the worldwide research community.

Dominique Marbouty

Guidelines and specific actions for the period 2003-2006

These guidelines for the external policy of ECMWF and specific actions foreseen for the period 2003-2006 were adopted by the ECMWF Council on 27-28 June 2002.

Article 2(1)(g) of the ECMWF Convention states: *"The objectives of the Centre shall be . . . (g) to assist in implementing programmes of the World Meteorological Organization"*. Therefore, it was clearly recognised from the beginning that ECMWF would play an international role and thereby increase Europe's visibility in the world meteorological community. A cooperation agreement with WMO came into force in November 1975.

During the first years of activity, the Centre became a world leading Numerical Weather Prediction centre, building upon the existing experience within its Member States and with significant scientific and technical cooperation with non-Member States. The Centre started disseminating global medium-range forecast products on the GTS in November 1980. In 1988 ECMWF became a Regional/Specialised Meteorological Centre of WMO, specialising in global medium-range weather forecasts. Relevant ECMWF products are made available to ACMAD, via MDD, through a cooperation agreement with ACMAD.

Since then, ECMWF has developed

(i) the first operational 4D-Var assimilation system, allowing a fully developed use of the rapidly-increasing fleet of meteorological satellites,

(ii) an Ensemble Prediction System, which remains almost unchallenged, with its 51 members at 80 km resolution, and

(iii) a new seasonal forecasting system which has become one of the world's most appreciated systems. Seasonal forecast products have been made available to WMO members since December 1997.

In addition, ECMWF has developed over the years the largest NWP archive in the world. This is a major asset for research in seasonal forecasting, climates, observing systems, etc. Council agreed to allow access to this archive to the research community.

Today, Europe is clearly recognised as a world leader in meteorology. Because of its excellence and its visibility in the science of NWP, ECMWF plays a key rôle to the benefit of its Member States and Co-operating States.

Such a rôle implies some duties to the wider meteorological community in general, and especially toward developing countries. It necessitates the development of a policy on external relationships for ECMWF to assist in responding properly for example to the recent WMO request for an increase of the GTS dissemination from ECMWF.

Guidelines for external policy

The Convention provides that ECMWF will assist in implementing WMO programmes. In particular, ECMWF will continue to act as the Regional/Specialised Meteorological Centre (RSMC) of the WMO, specialising in global medium-range weather forecasts. The Secretariat will regularly review the products distributed on the GTS to ensure that the products meet with the requirement of providing numerical guidance to WMO Member States in the medium range. The Director will propose, if appropriate, relevant updates to Council.

In line with the guidelines developed by the WMO CBS, the support provided by ECMWF should include the provision of global medium-range warning of severe weather, e.g. severe extra-tropical storms, flooding and drought. Medium-range prediction products for tropical cyclones should be developed and made available to RSMCs with responsibility for tropical cyclones.

The Centre will review within the products developed for its Member States those that could be made available to developing countries at an affordable level, particularly by use of available dissemination systems.

When developing its international activities, ECMWF will take into account the desire of its Member States to improve the visibility of Europe and of its Member States within the world meteorological community.

The European Aspect

ECMWF and its Member States will continue to encourage those states of Central and Eastern Europe that fulfil the factors to be taken into account in relation to co-operation agreements to conclude such co-operation agreements.

Extending membership of the Centre to some other European States will continue to be an objective of the Council.

Despite being initiated as a COST action, ECMWF has little contact with the EU apart from research programmes. The Centre should develop such relations, participate in actions of the EU and contribute to the objectives of the EU and the Commission. The Centre will keep under consideration the possibility of inviting the EU to sessions of the Council as observer.

Despite the value of its archive, this asset is not fully used by the European research community. The Centre will consider all possibilities to improve and facilitate such use.

Definitions used in this document

External policy:	Policy on relationships with entities outside the Member States and Co-operating States
The Centre:	The entity made up of the Council, its Committees, the Director and the Secretariat
ECMWF:	Identical to the Centre
The Council:	The ruling body, with the powers and duties laid down in Article 6 of the Convention
The Director:	The chief executive officer of the Centre, responsible to Council, with powers and duties laid down in Article 9 of the Convention
The Secretariat:	The staff of the Centre

Annex: specific actions to be taken during the period 2003–06

The Director will report yearly to Council on the implementation of its decisions concerning the distribution of products to the meteorological services of WMO Members.

The Director will consult with EUMETSAT and WMO as part of the process of identifying replacements of the MDD in order to meet the requirements of the African countries, in particular for medium-range severe weather guidance. The Council will review the ACMAD co-operation agreement at its autumn session in 2003.

The Centre will develop a proposal with a view to ECMWF becoming an RSMC for global seasonal prediction.

The Centre will assess the possibilities and costs of specific provision of medium-range products directed towards developing countries.

As part of its role of RSMC for global medium-range weather forecasting, the Centre will make available specific products developed for its Member States to enable non-Member State NMSs to provide medium-range warnings of severe weather.

The Centre will provide EPS-based Tropical Cyclone track forecasts developed for its Member States to Tropical Cyclone RSMCs.

The Centre will be proactive in the GMES program and will propose running major projects in co-operation with Member States National Meteorological Services and institutions involved in this area.

The Centre will assess the possibilities and costs for providing encoding/decoding software for GRIB and BUFR in different computer environments.

The Centre will ensure a wide and easy availability of the ERA-40 archive for research.

The Centre will assess the possibilities and costs with a view to developing specific training activities directed towards the use of the Centre's medium-range products.

The Director will make appropriate proposals to Council in relation to external policy.

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

Technical Memoranda

371 **C. Cardinali**, **L. Isaksen** and **E. Andersson**: Use and impact of automated aircraft data in 4D-Var. *June 2002*

372 **E. Andersson**, **A. Garcia-Mendez**: Assessment of European wind profiler data, in an NWP context. *June 2002*

373 **F. Lalaurette**. Early detection of abnormal weather using a probabilistic extreme forecast index. *July 2002*

374 **D. Gustafsson**, **E. Lewan**, **B.J.J.M. van den Hurk**, **P. Viterbo**, **A. Grelle**, **A. Lindroth**, **E. Cienciala**, **M. Mölder**, **S. Halldin**, **L-C. Lundin**: Boreal-forest surface parametrization in the ECMWF model-1D test with NOPEX long-term data. *July 2002*

376 **P. Prior** (Compiler): Report on the fourteenth meeting of Computing Representatives, 27–28 May 2002. *August 2002*

Workshops

Eighth workshop on Meteorological Operational Systems 12–16 November 2001

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Nov 13–15	**Workshop** – *Role of the upper ocean in medium- and extended-range forecasting*	
Nov 18–22	**Computer Users Training Course** – *Use of ECMWF supercomputing resources*	
Dec 2–3	**Council**	*57th*

2003

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Mar 25	**Advisory Committee on Data Policy**	*3rd*
Apr 7-8	**Policy Advisory Committee**	*18th*
Jun 3-4	**Finance Committee**	*70th*
Jun 11-12	**Council** (Copenhagen)	*58th*
Oct 6-8	**Scientific Advisory Committee**	*32nd*
Oct 8-10	**Technical Advisory Committee**	*33rd*
Oct 13-14	**Finance Committee**	*71st*
Oct 15-16	**Policy Advisory Committee**	*19th*
Oct 16-17	**Advisory Committee on Data Policy**	*4th*
Oct 20	**Advisory Committee of Co-operating States**	*10th*

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Useful names and telephone numbers within ECMWF

Telephone number of an individual at the Centre is:

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

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

E-mail

The e-mail address of an individual at the Centre is:
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e.g. the Director's address is: D.Burridge@ecmwf.int

Internet web site

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

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Deputy Director and Head of Research Department	
Anthony Hollingsworth	005
Head of Administration Department	
Gerd Schultes	007
Head of Operations Department	
Dominique Marbouty	003

ECMWF switchboard	000

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Computer Operations Section Head (Acting)	
Graham Holt	301
Networking and Computer Security Section Head	
Matteo Dell'Acqua	356
Servers and Desktops Section Head	
Richard Fisker	355
Systems Software Section Head	
Neil Storer	353
User Support Section Head	
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User Support Staff	
John Greenaway	385
Norbert Kreitz	381
Dominique Lucas	386
Carsten Maaß	389
Pam Prior	384

Computer Operations

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Console - Shift Leaders	803
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Console email: ops@ecmwf.int	
Fault reporting - Call Desk	303
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Els Kooij-Connally	751

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Meteorological Analysts	
Antonio Garcia Mendez	424
Anna Ghelli	425
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Erik Anderson	627
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Jean-Nöel Thépaut	621
Reanalysis Project (ERA)	
Saki Uppala	366

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Acting Division Head	
Tim Palmer	600
Seasonal Forecasting Head	
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Mariano Hortal	147
Physical Aspects Section Head	
Anton Beljaars	035
Ocean Waves Section Head	
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Computer Co-ordinator	
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Education & Training

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