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Operational numerical prediction of rapid cyclogenesis over the North Atlantic

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ABSTRACT

The current generation of operational numerical weather prediction models has shown considerable skill in handling cyclogenesis. This paper assesses the accuracy of forecasts of rapid cyclogenesis over the North Atlantic from the operational NWP system at Bracknell and attempts to isolate the factors relevant to successful prediction. Illustrative material is drawn in particular from the case of the record low pressure centre that developed over the North Atlantic on 14 December 1986.

1. Introduction

Rapid cyclogenesis is an extreme meteorological event and its accurate forecasting is of great practical importance. This paper presents the results of a study of forecasts of rapid cyclogenesis from the NWP system at Bracknell. The study was divided into two parts; first forecasts over a period of $2\frac{1}{2}$ years were verified to identify systematic errors in the deepening process in the models; and second a specific example of extreme cyclogenesis was studied in detail to isolate the factors relevant to successful prediction. Forecast central pressure of the low systems has been taken as a simple measure of system intensity and most verification results relate to this parameter.

Two versions of a 15-level model have been operational at Bracknell since September 1982. The global model has a grid spacing of around 150 km in mid-latitudes and the regional model, which covers the North Atlantic and Europe, has a doubled resolution with a grid spacing of around 75 km. These are the maximum horizontal resolutions that are operationally feasible on a Cyber 205 computer; the enhancements to be implemented on an ETA 10 are mentioned in Section 5 below.

The formulations of the two models are in principle identical, to the extent that they share a common computer coding. In practice though, certain refinements of the physical parameterizations have been introduced in the regional model before they have been fully proven on a global basis. These refinements are important for the prediction of specific weather elements and they can affect the details of synoptic patterns. However, the basic dynamical evolution is not usually changed by these refinements in experiments conducted to date.

Associated with each of the two models is a data assimilation scheme to establish the initial conditions for forecasts. A technique of repeated insertion of observations is used without any separate initialization. For the global model, the data assimilation is carried out in a 6-h cycle, and for the regional model, in a 3-h cycle. A new technique of continuous assimilation has been developed and introduced since the period covered by this study. The regional data assimilation is not fully independent from the global data assimilation: interpolation from global fields is performed at the beginning of each regional cycle, and is followed by 12 h of assimilation on the regional grid, leading into the regional forecast itself.

Operationally, the regional forecast with a 01.55 h data cut-off time runs before the global forecast (03.20 h data cut-off), and so the lateral boundary conditions for the regional model are provided by a global forecast from starting conditions 12 h earlier.

2. Verification of forecasts of explosive cyclogenesis

Most cases of rapid cyclogenesis in the North Atlantic occur over the western sector between 35° N and 50° N and the lows move into the eastern sector as they mature. These areas lie conveniently within the domain of the regional model. During the period January 1986 to June 1988, all cases of observed or forecast explosive cyclogenesis within the model domain were identified. Explosive cyclogenesis was defined as a fall in the central pressure in excess of 24 hPa in a 24-h period starting at either 00 GMT or 12 GMT. The analysed fields of mean-sea-level pressure used for verification were taken from the regional model data assimilation scheme, and all fields considered in this study were projected onto the same output grid to calculate the value of central pressure. In the relatively data-sparse areas such as the North Atlantic, there is an inevitable correlation between errors of short-period forecasts and the errors of analyses from numerical data assimilation systems which use forecasts in the absence of observations. It is acknowledged that the errors of the 24-h forecasts presented here may be underestimated as a result, though the magnitude of this problem is not easily quantified.

A total of 94 forecasts were verified relating to 43 different low-pressure systems and the relationship between observed and forecast change of central pressure of the low is shown in Fig. 1. In general, the magnitude of the errors is relatively small, being in most cases less than 10 hPa. There is little bias apparent in the forecasts, even where deepening as great as 50–60 hPa occurs over a 24-h period. The few occasions where errors are much larger than 10 hPa are instances of the underforecasting of the intensity of cyclonic development.

Fig. 2 presents these results relative to the evolution of the low-pressure system. For each of the lows for which observed or forecast explosive cyclogenesis occurred, the time (H), marking the start of the 12-h period of most rapid deepening, was identified and was used to define a common time scale for all forecasts. The mean central pressure over the period $H-24$ to $H+36$ h is displayed in the figure (solid line) together with the mean forecasts from the regional model runs (dashed line) with initial data times (a) $H-24$, (b) $H-12$, and (c) H. The standard deviations of the forecast errors are indicated by the error bars. It is clear that slight underforecasting of deepening at longer lead times is compensated by slight overforecasting at short lead times. In particular, it is apparent that the onset of the filling process that begins after $H+24$ is not predicted in the model. It is also interesting to note that runs beginning at time H, the time of onset of rapid deepening, have negligible systematic errors in the initial 12-h deepening rate; it seems that any spin-up effects in the model due to the data assimilation do not influence the deepening process. For runs with data time $H-12$, the mean forecasts from the global model (dotted line) are also shown and the systematic errors are much larger. There is consistent underforecasting

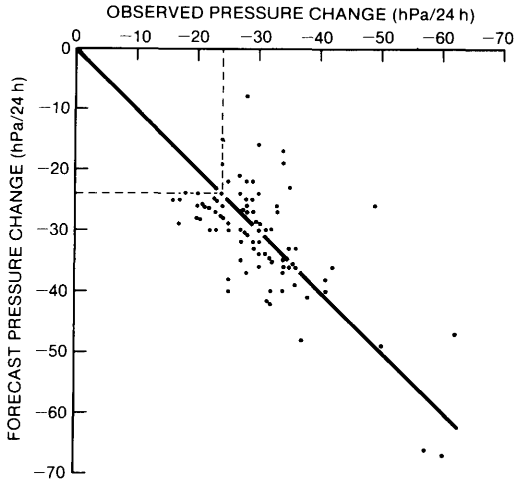

Fig. 1. Observed 24-h change in central pressure of rapidly deepening lows in the North Atlantic against values forecast by the regional model during the period January 1986 to June 1988. Only cases where the observed or forecast pressure change is less than −24 hPa have been plotted.

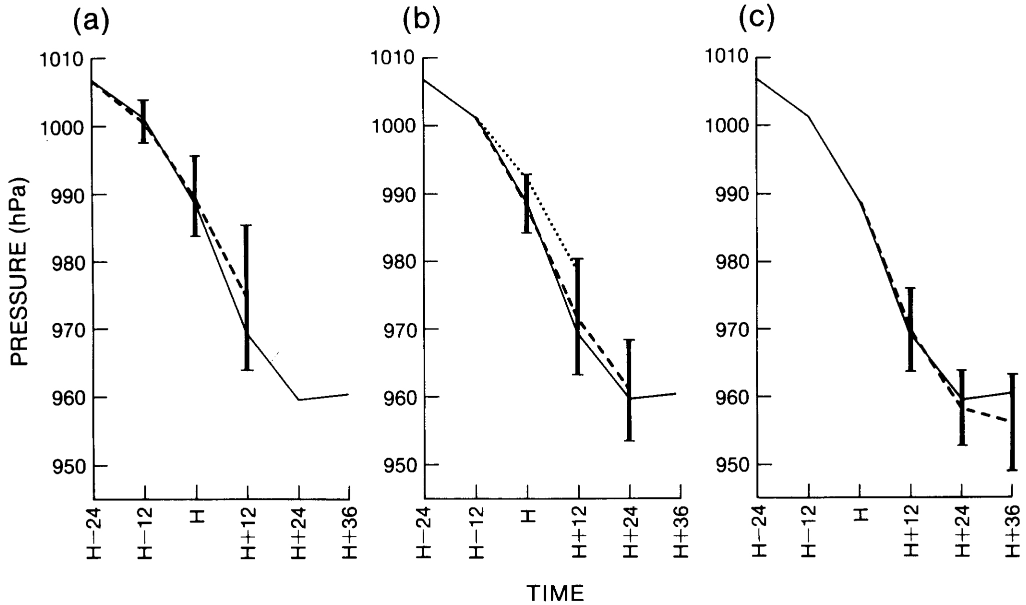

Fig. 2. Mean central pressure oberved (solid line) and forecast by the regional model (dashed line) for all rapidly deepening lows in the North Atlantic between January 1986 and June 1988. The time scale has been adjusted so that the maximum observed deepening occurs between H and $H + 12$. Values are shown for forecast runs starting at data time (a) $H - 24$, (b) $H - 12$ and (c) H. In case (b), mean central pressure forecast by the global model (dotted line) is also shown. The error bars indicate the standard deviation of the forecast errors of the regional model.

of the deepening process and errors of the 24-h forecasts average +8 hPa, some 6 hPa larger than in the case of the regional model.

3. The case of 14–15 December 1986

A new extratropical North Atlantic low-pressure record was set by a depression that deepened explosively during 14 December 1986. By 00 GMT 15 December, the depression was situated between Iceland and Greenland, and the central pressure was analysed at 916 hPa by analysts in the Meteorological Office's Central Forecasting Office and perhaps 3 or 4 hPa lower by staff at the Deutscher Wetterdienst (see Burt, 1987). Sanders (1987) reported an estimate by Bosart of 908 hPa for the central pressure at this time. The change in central pressure between 00 GMT 14 December and 12 GMT 15 December as analysed manually and by the two operational data assimilation schemes is shown in Fig. 3. Clearly, the true value of the central pressure is uncertain to within several hPa. The analyses also suggest that the position may be uncertain to within a few degrees of longitude.

The sequence of numerical guidance available operationally at Bracknell and relating to this explosive development was of a high quality. For example, the 72-h forecast from the global model valid at 00 GMT 15 December showed a low centre of 931 hPa that was positioned correctly near 60° N but probably 3–6° too far east. The 36-h forecast from the regional model (Fig. 4) valid at the same time showed a 907 hPa centre, again near 60° N, probably 0–3° too far east.

This case provides a more extreme example of the general characteristic noted in Section 2; forecasts of central pressure are significantly higher in the global model than in the regional model. The possible factors contributing to these differences may be listed as follows.

(i) Horizontal resolution in the forecast (150 km versus 75 km).

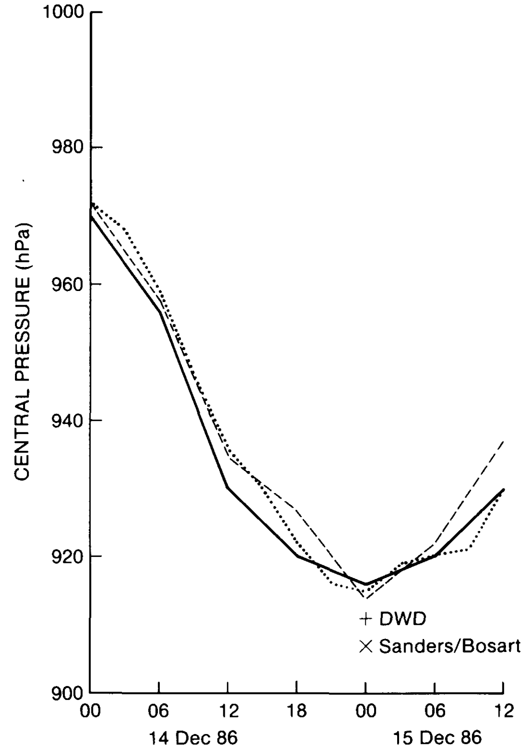

Fig. 3. Central pressure between 00 GMT 14 December and 12 GMT 15 December 1986 of an explosively deepening low in the North Atlantic as analysed by the Central Forecasting Office at Bracknell (solid line), the global model (dashed line) and the regional model (dotted line). Estimates of the central pressure by Deutscher Wetterdienst and Bosart are also shown.

(ii) Horizontal and temporal resolution in the data assimilation (150 km and 6 h versus 75 km and 3 h).

(iii) The effects of additional observations (those arriving at Bracknell between 01.55 and 03.20 h after the 00 and 12 GMT analysis times).

(iv) The impact of the lateral boundary conditions supplied to a regional model.

(v) The effects of differences in the parameterizations of the physical processes in the two models.

Factors (i), (ii), (iv) and (v) are considered below for various runs from 00 GMT 14 December 1986. Factor (iv) has also been investigated by Carter (1988). Factor (iii) can on occasion be crucial, as in the case of the great storm of 15–16 October 1987 (Lorenc et al., 1988), but has not been investigated here.

A set of 36-h forecasts from data time 00 GMT 14 December has been assembled to assess the factors (i), (ii), (iv) and (v) listed above. In the initial conditions for these runs, the low centre in question was analysed at around 970 hPa.

The runs were as follows.

Run A: Operational global model forecast.

Run B: Operational regional model forecast.

Run C: Forecast using the May 1988 version of the regional model in which the aerodynamic roughness of the sea surface is dependent on surface stress. The Charnock formulation used is described in Wilson (1988).

Run D: As run C, but lateral boundary

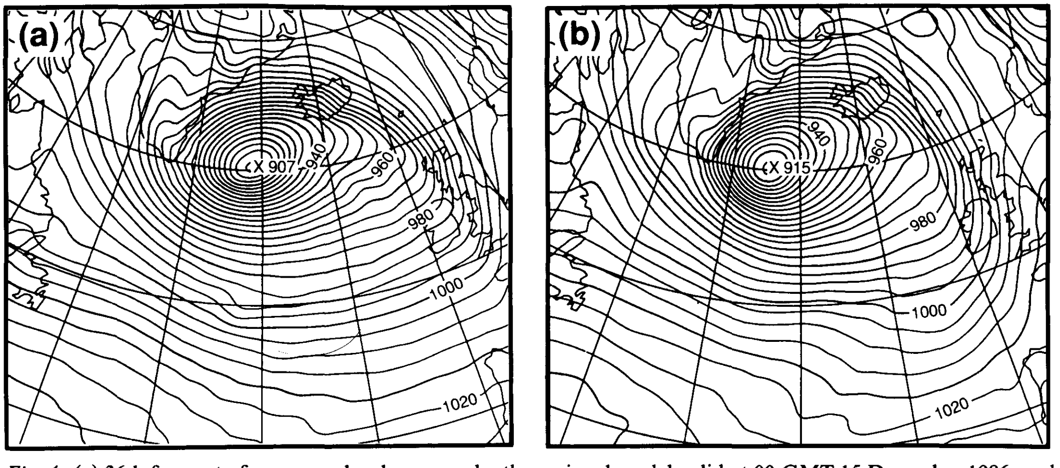

Fig. 4. (a) 36-h forecast of mean-sea-level pressure by the regional model valid at 00 GMT 15 December 1986, and (b) the verifying analysis.

conditions from a contemporary assimilation and forecast (using the "test" system described by Carter, 1988).

Run E: As run D, but initial conditions interpolated from the global model analysis.

All of the runs were successful in producing an explosive deepening of 40 hPa or more during the 24-h forecast. The positioning of the low centre at the end of the 24-h period did not vary greatly among the runs.

The values of central pressure forecast for the 5 runs are shown in Figs. 5 and 6. It may be seen that the 19 hPa difference in the intensity of the low in the operational global and regional 24-h forecasts is reduced to 15 hPa when the variable sea surface roughness is used in the regional model. The lateral boundary conditions from an earlier run explain 5 hPa of the difference. Of the remaining 10 hPa, 7 are accounted for by the regional (as distinct from the global) data assimilation. The effect of the doubled horizontal resolution in the forecast itself is probably in the range 3 to 7 hPa, depending on the exact impact of the variable sea surface roughness in the global assimilation and forecast (this has not yet been tested).

After 00 GMT 15 December, the low began to fill, the central pressure rising from 916 hPa to around 930 hPa by 12 GMT according to the manual analyses produced at Bracknell. The analysed filling of 14 hPa in the 12 h between 00 GMT 15 December and 12 GMT 15 December compares with 2 hPa filling in run A, a 5 hPa filling in run D, and a further 2 hPa deepening in run E. The underestimation of the filling process noted in Section 2 is also evident in this case.

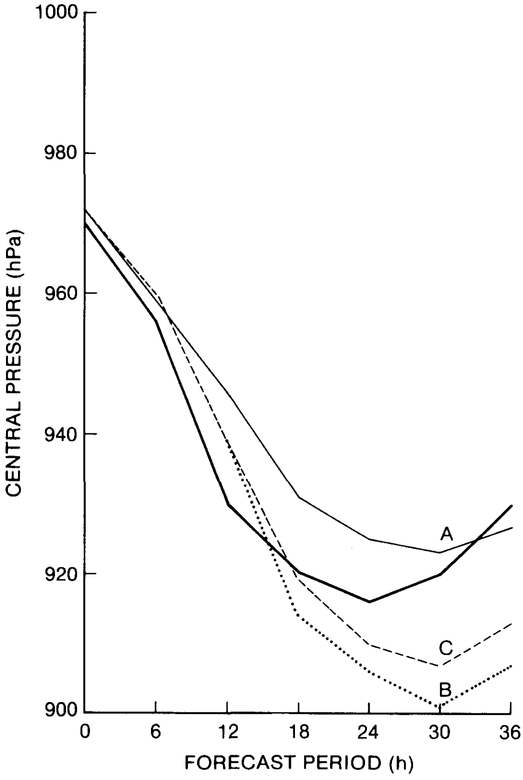

Fig. 5. Central pressure between 00 GMT 14 December and 12 GMT 15 December 1986 as analysed by the Central Forecasting Office at Bracknell (solid line) and forecast by the global model (run A) and the regional model (runs B and C).

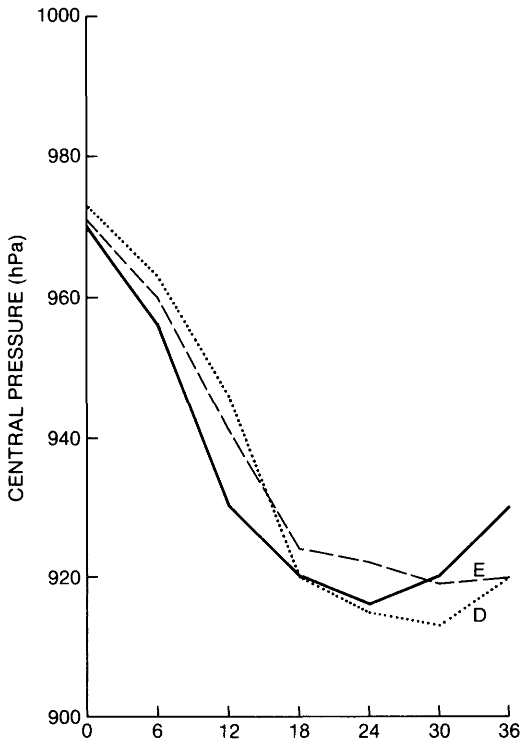

Fig. 6. As Fig. 5, but showing the central pressure forecast by runs D and E of the regional model.

4. Other cases

Operational experience with other cases shows that the superiority of the regional model in forecasting cyclogenesis extends over a wide range of deepening rates. The additional skill of the regional model can be particularly significant for relatively shallow and small-scale lows. For example, the depression that deepened from 998 to 972 hPa over the eastern North Atlantic during 10 October 1985 was forecast at an insignificant 995 hPa by the global model but at 975 hPa by the regional model (24-h forecasts valid at 00 GMT 11 October 1985).

In other cases, the regional model provides a more modest improvement in accuracy compared with a basically successful global model forecast. The storm that affected the UK on 9 February 1988, and that had deepened from 994 to 947 hPa in the 36 h up to 12 GMT on that day, was forecast to deepen to 960 hPa by the global model and to 950 hPa by the regional model.

5. Conclusions

The regional model at Bracknell is capable of realistically representing the process of rapid cyclogenesis and provides forecasts of overall high accuracy which display small systematic errors. In contrast, the global model with lower resolution significantly underestimates the deepening process. Judging by the case study reported above, the advantage held by the regional model results in approximately equal measure from the doubled horizontal resolution during the forecast and from the more accurate data assimilation.

In the statistical results of Section 2, the regional model was rather less successful in representing the subsequent filling of the low. Although, in the case studied, it still had the edge over the global model, the advantage now appeared to come solely from the regional data assimilation, the higher resolution in the forecast making matters slightly worse when running from an interpolated global analysis.

Work is in progress to enhance the operational NWP system at Bracknell to exploit the newly acquired ETA10 computer. A global grid of 0.833° by 1.25° is expected to replace the present 1.5° by 1.875°. As a consequence, a level of performance approaching that currently achieved by the regional model for the North Atlantic and Europe should become attainable elsewhere. The impact on tropical cyclones will be of particular interest.

A regional model will be retained in the enhanced operational system, with twice the horizontal resolution of the new global model. On the present evidence, it is perhaps unlikely that the new regional model will continue to give an advantage over the new global model in the forecasting of rapid cyclogenesis, but it will be needed for more detailed guidance on specific weather elements, including precipitation and surface winds.

It is suggested that given adequate observational data, an assimilation and forecast system based on a numerical model with 75 km grid spacing is capable of representing even the most extreme examples of rapid cyclogenesis over the North Atlantic. The performance in representing the subsequent filling of deep lows requires further investigation.

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