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Revised analyses and their effect on the fine-mesh forecast for the Fastnet storm

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Summary

A particular combined analysis and forecast computation of the Meteorological Office fine-mesh numerical weather prediction model has been studied to discover why the 'Fastnet low' was not well predicted. The forecast was rerun several times, each run starting with a slightly changed and 'improved' analysis. It was found that a depression was predicted when the analysis was changed, and that this forecast depression could be deepened by increasing the number of analysed levels that were 'improved'. With four levels of the original analysis changed a significant depression was forecast. The position of this depression was, however, some 200 n mile in error.

Introduction

On 13 August 1979 a depression over the North Atlantic deepened quickly and moved to the south-west of Ireland. At 00 GMT on 14 August the depression was situated near Valentia with a central pressure of about 978 mb (Fig. 1). This depression had deepened by about 20 mb in 12 hours, which is very rapid for the time of year, and it was also associated with storm-force winds. It was this weather system that caused the chaos amongst competitors in the Fastnet Race of the Royal Ocean Racing Club, in which many lives were lost.

The Meteorological Office operational 10-level numerical forecast model was unsuccessful in predicting the intensity of the depression: the various operational forecasts based on observations up to 12 GMT on 13 August all failed to indicate the vigour of the system. The fine-mesh (rectangle) version of the numerical forecast starting with data for 00 GMT on 13 August was particularly inaccurate, with the 24-hour forecast of mean-sea-level (m.s.l.) pressure verifying at 00 GMT on 14 August predicting a trough of 1008 mb over Ireland. The actual m.s.l. pressure of the depression centre at this time was about 30 mb lower. An investigation, confined to this worst operational run, was carried out to ascertain whether the forecast model was unable to cope with the development or whether an inaccurate objective analysis was the cause of the poor numerical forecast.

The investigation took the form of a series of experiments.

The experiments

The experiments consisted of a rerunning of the analysis and forecast programs several times. Each run started with data additional to those used by the operational analysis thereby creating a modified analysis. These new data consisted of artificial, or 'bogus', observations of the geopotential of a number of standard levels together with a corresponding wind, for several positions over the North Atlantic. This technique, known as bogusing, is used operationally in the Central Forecasting Office (CFO) by upper-air forecasters to force the objective analysis program to produce a more acceptable analysis in data-sparse areas. No bogus observations had been used in the operational rectangle analysis on this occasion.

For the experiments carried out during this investigation the bogus pressure-level geopotential and wind data were obtained from subjectively analysed charts of the pressure levels concerned. Four levels of the objective analysis were changed in this manner in order to bring them closer to the equivalent subjectively analysed levels.

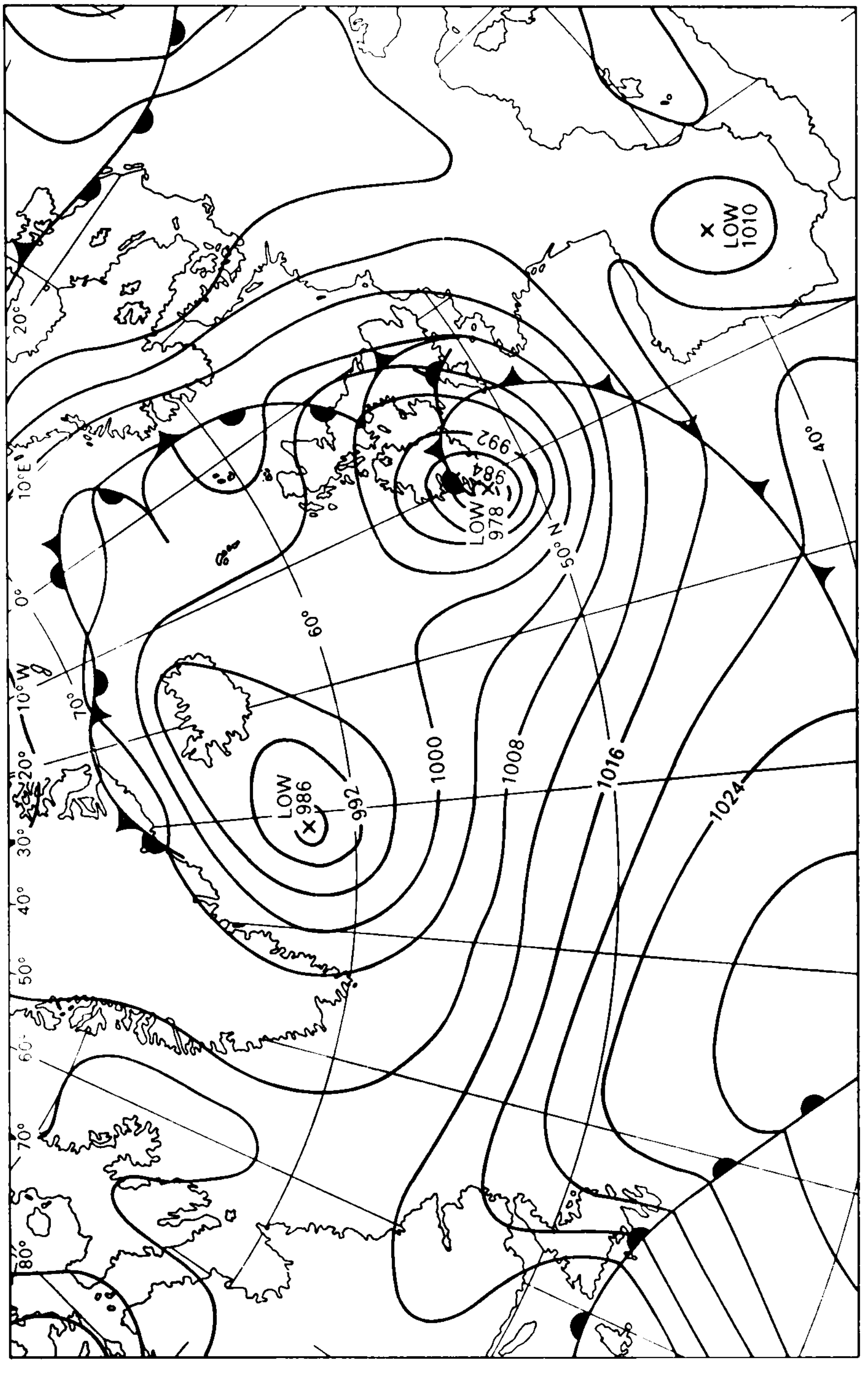

Figure 1. Subjective m.s.l. pressure analysis for 00 GMT on 14 August 1979.

The subjective and original objective analyses

There are four main levels at which the upper-air forecasters in CFO add bogus observations. These are 100 mb, 300 mb, 500 mb and m.s.l. The subjective analyses for these levels for midnight on the 13th were compared with the objective analyses to find where the major differences lay. In addition, the objective and subjective analyses for 850 mb were compared. Particular consideration was given to the region in the central North Atlantic where the depression, which became the Fastnet storm, was situated at that time. Fig. 2 shows the subjective m.s.l. pressure analysis which was drawn after the event. The central pressure of the depression, 1003 mb, is well substantiated by some late reports from ships which were not available to forecasters at the critical time. Forecasters in CFO were analysing the central pressure as about 1006 mb in the early hours of the 13th, using continuity from previous analyses.

The objective analysis scheme uses a method analogous to the continuity technique to produce a 'first-guess' analysis. This analysis is interpolated from a 12-hour coarse-mesh forecast based on data valid 12 hours prior to the current data time and is known as the background field. This background field is transformed into the objective analysis by a computer program that alters it in the light of observations made at the current data time. In regions well away from new data the background field remains as the new analysis. At 00 GMT on the 13th the background field contained a depression of insufficient depth in the area of concern. The operational analysis was made even more inaccurate by a ship correctly reporting light winds and high pressure which gave the only observation in the data-sparse area around the depression. The analysis program then interpreted this observation as representing a greater area than was actually the case, which made the final objective analysis contain a depression less deep than the background field. This depression was objectively analysed as 1014 mb, which is 11 mb higher than was eventually analysed subjectively (Fig. 2).

Fig. 3 shows the objective 300 mb analysis for 00 GMT on the 13th, together with the reports which were used for its production in the Atlantic area. Fig. 4 shows the subjectively and objectively derived isotachs from these reports although it should be pointed out that the subjective analysis used a few more aircraft reports (AIREPs) than the objective analysis; these helped to define the core of the jet stream, but only in the region 15°W to 30°W. It will be noticed that the subjective isotach chart is assigned to 250 mb. However, the same reports were used by the objective scheme at the 300 mb level. The reason for this is that the operational forecast model uses 10 levels spaced at 100 mb intervals, from 1000 to 100 mb (Burridge and Gadd 1977), and therefore it does not require an analysis at 250 mb. To make most use of the AIREPs the objective scheme assigns those within 100 mb of 300 mb to that level and the objective analysis for this level does affect those for adjacent levels (Flood 1977). The objective isotachs in Fig. 4 are those derived from the initialization process. During initialization adjustments are made to the geopotential analysis such that the fields satisfy certain requirements of the forecast model (Golding 1980). One adjustment ensures vertical static stability and may alter the various analysed geopotential fields at adjacent levels. There is also an adjustment to ensure that the wind flow is not more anticyclonic than can be allowed by the balance equation. These adjustments alter the isotachs from those deduced from the geopotential analysis. As the initialized fields are those that the forecast uses as starting data one would like these fields to be as close as possible to the real state of the atmosphere at that time.

A comparison of the two isotach fields in Fig. 4 shows that the objectively produced winds lack the strength shown by the subjective isotach analysis. Two AIREPs of 150 kn are not reflected in the objective scheme which gives speeds of 115 and 95 kn respectively in these positions. Clearly, then, the objective scheme seriously underrated the wind speeds in the jet stream above the depression. One probable reason for this inadequate analysis can be seen in Fig. 4. The grid points to which aircraft

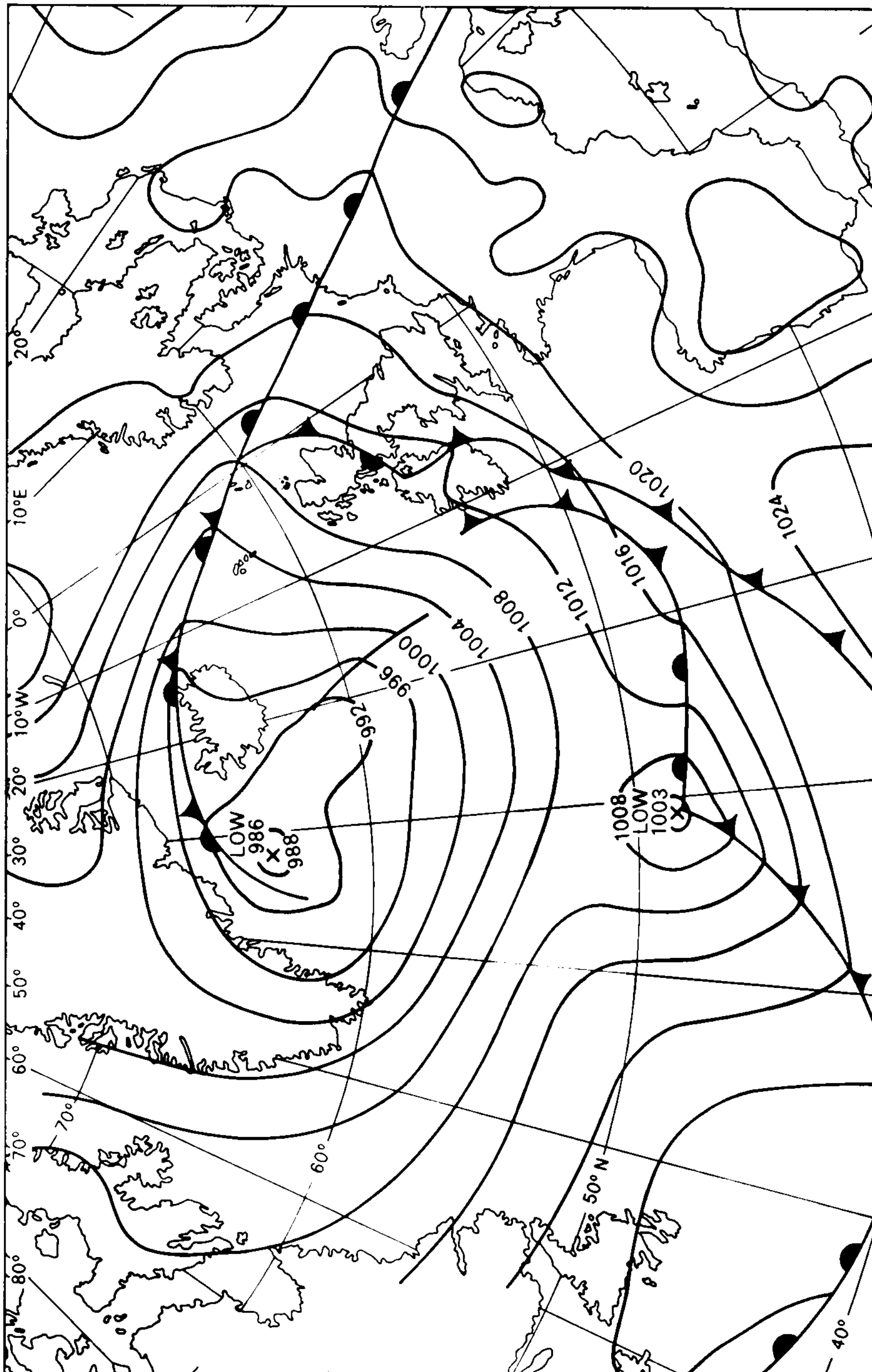

Figure 2. Subjective m.s.l. pressure analysis for 00 GMT on 13 August 1979.

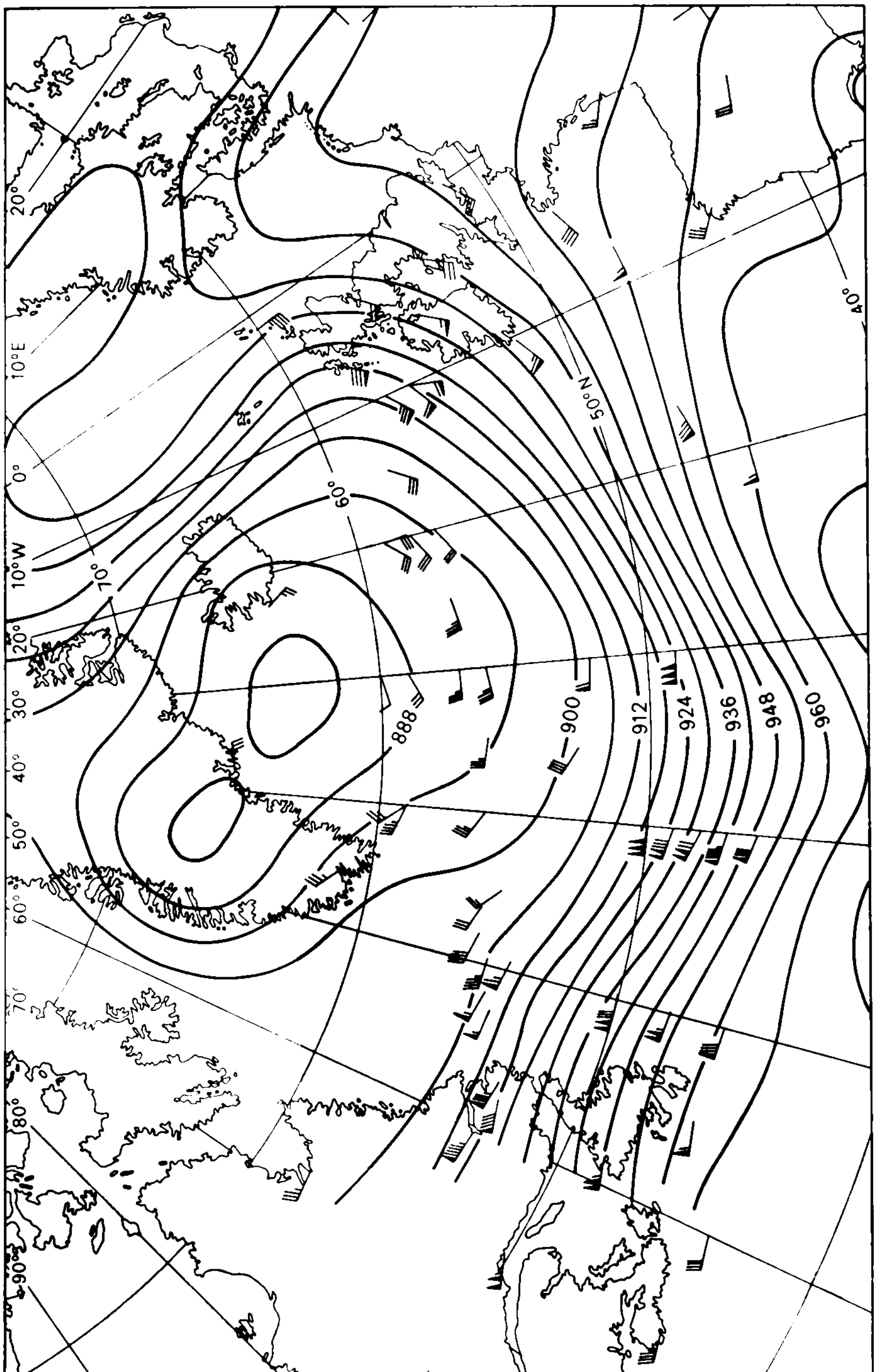

Figure 3. Original objective **300** mb analysis for **00** GMT on 13 August 1979, showing the aircraft and radiosonde reports used.

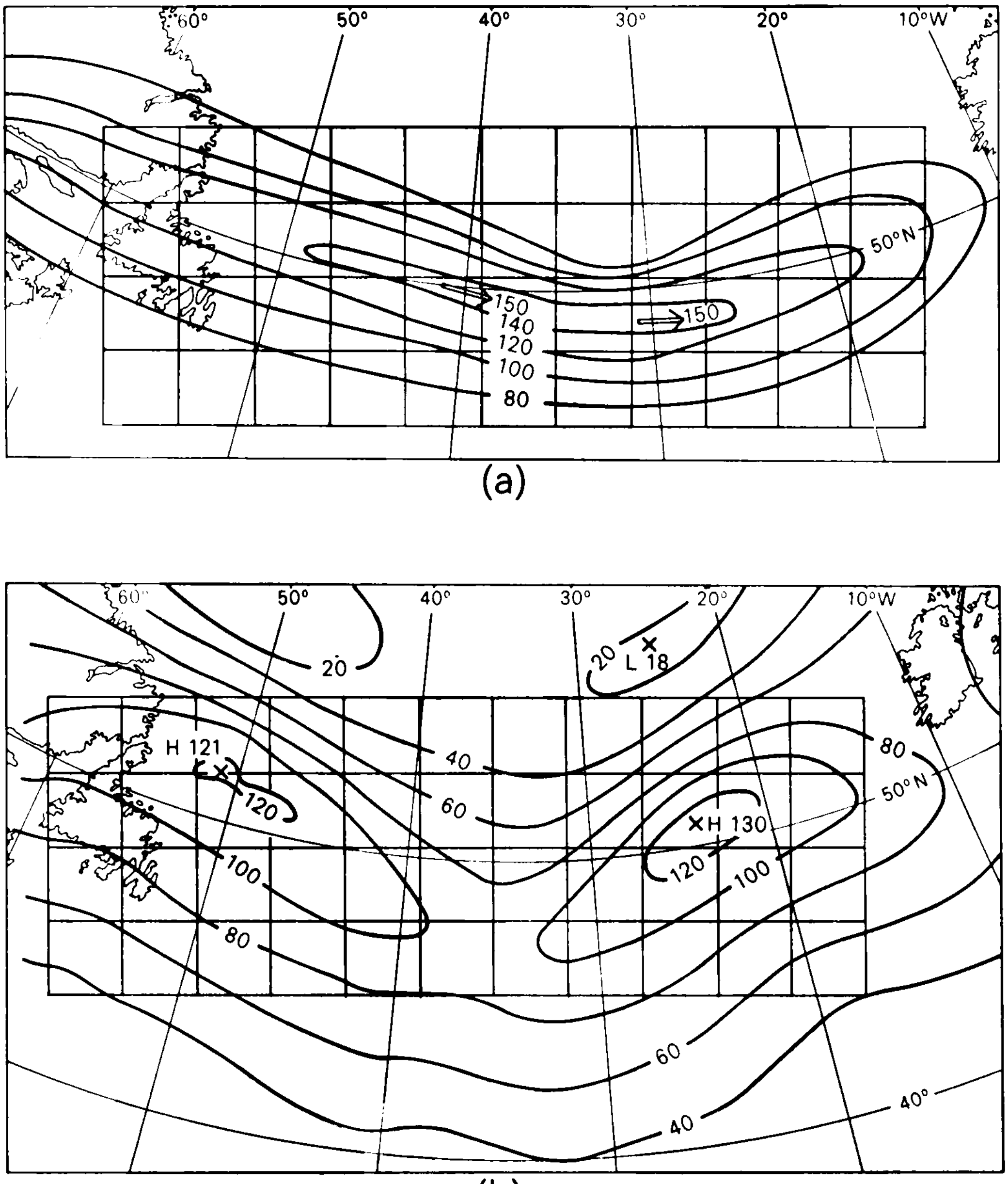

Figure 4. Isotachs for 00 GMT on 13 August 1979, in knots, showing part of the analysis grid: (a) subjectively produced from aircraft and radiosonde reports for approximately 250 mb, and (b) objectively produced from the initialized 300 mb field.

reports are interpolated are 300 km apart; the analysis fits orthogonal polynomials on these grid-point values and evaluates the polynomials on a 100 km grid. The 300 km separation of the analysis grid points clearly cannot represent the strong wind shear associated with this jet stream, most of the core of which lies between grid points. The grid-point spacing used for the objective analysis is 300 km rather than 100 km because although the fine-mesh forecast grid length is 100 km it has not been proved that a finer-mesh analysis would improve the numerical forecast enough to justify the increased computer time.

The objective geopotential analysis at 300 mb (Fig. 3) showed a marked trough at 35°W that was not really indicated by the AIREPs. The subjective analysis was drawn with a much smoother flow and also with a tighter gradient in the region of the stronger wind speeds.

The 500 mb charts were analysed with no data over the central North Atlantic apart from two weather ships. Neither of these ships provided much help in deciding what the state of the atmosphere was above the surface depression.

In the Atlantic area the subjective analysis used the standard gridding technique of adding the analysed thickness to the surface (1000 mb) analysis. The resulting analysis was then refined further, using the 300 mb analysis as a guide. The dubious accuracy of the subjective analysis at this level and, indeed, at other levels away from 1000 mb and 300 mb should be borne in mind. The major differences between the subjective and objective analyses at 500 mb were similar to the differences between the corresponding 300 mb charts. The flow was much weaker in the objective analysis and it also had a much more marked trough at 35°W.

The objective chart for 850 mb was also examined and, although there were no data for the critical area, it was considered likely that a closed circulation would have occurred above the surface depression. This was not present in the objective analysis; indeed, this analysis was probably some 6 decageopotential metres too high in the area of concern, as judged from 1000–850 mb thickness considerations.

Attempts to improve the objective analysis

The analysis programs were rerun several times using the same data that were used operationally plus bogus observations. The bogus data were added for one or more of the levels 1000 mb, 850 mb, 500 mb and 300 mb. Fig. 5 shows the objective m.s.l. pressure analysis after bogusing and Fig. 6 shows the 300 mb isotachs after bogusing. The values chosen for the bogus geopotentials near the centre of the low at 850 mb were estimated by adding thicknesses deduced from Ocean Weather Stations 'C' and 'R' to the 1000 mb geopotential derived from the subjective m.s.l. pressure analysis.

There are two ways in which the upper-air forecasters in CFO can intervene in the objective analysis. The bogusing technique has been described earlier. The second technique is the alteration of the background field via a computer terminal. If the background field does not agree with the forecaster's idea of what the analysis is likely to be at the appropriate time then the contours may be displayed on the screen of the terminal and can be modified with a light-pen. The forecaster can see the direct results of intervening in the background field because the new background field is displayed on the screen. However, this new background field is not the new objective analysis but only the first stage. Unfortunately, on 13 August a problem with the computer program did not permit intervention to be carried out in this way.

Any bogus observations that are introduced are used by the analysis program after the background field has been introduced and carry more weight in the analysis (Flood 1977). Unfortunately, it is not possible operationally to see the results of bogusing before the resulting objective analysis is used by the forecast model, so the field cannot be inspected and refined further. However, during the running of these experiments there was enough time to produce an acceptable analysis by introducing bogus data

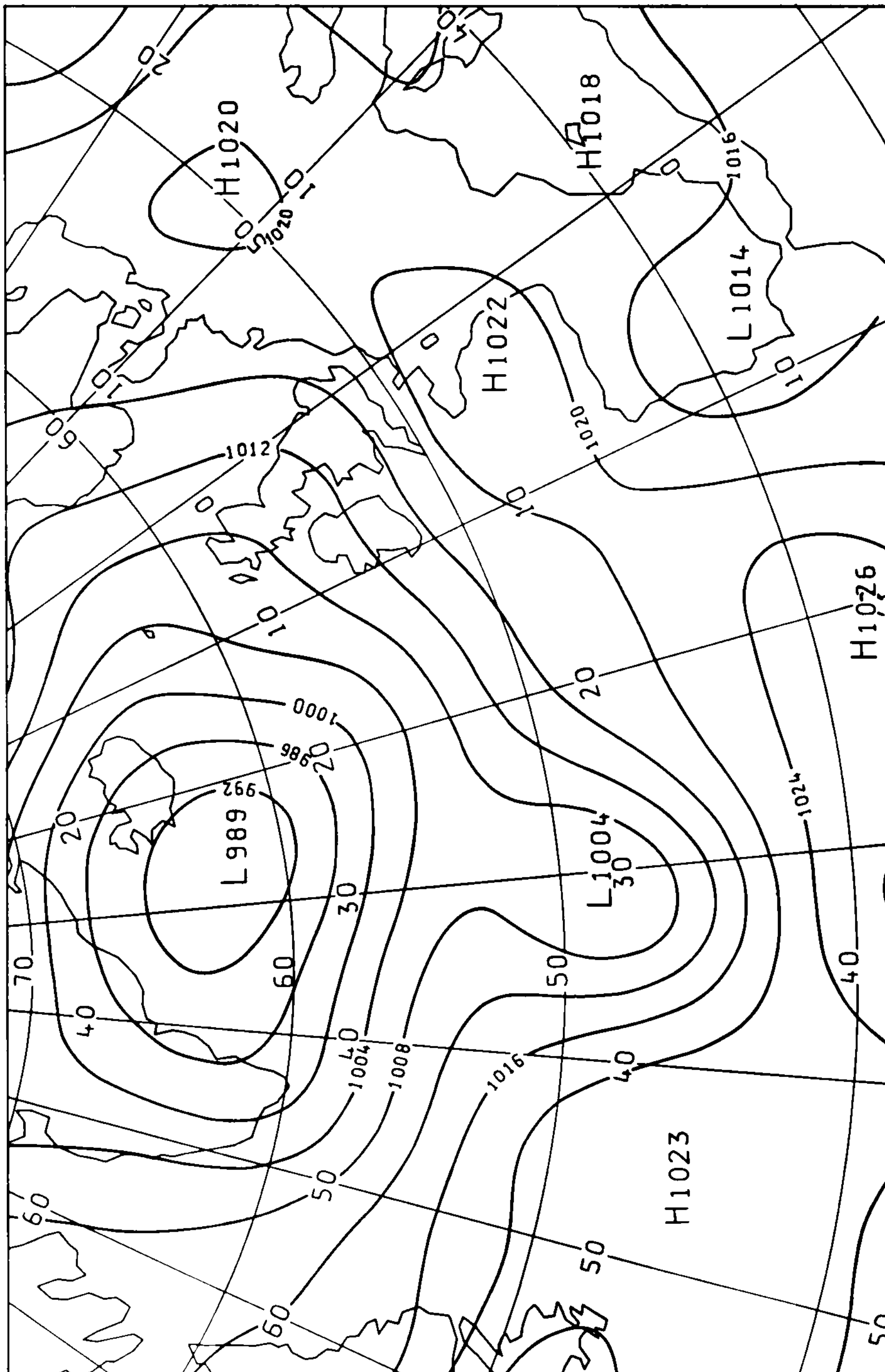

Figure 5. Objective m.s.l. pressure analysis for 00 GMT on 13 August 1979 after bogusing (as used in case 7).

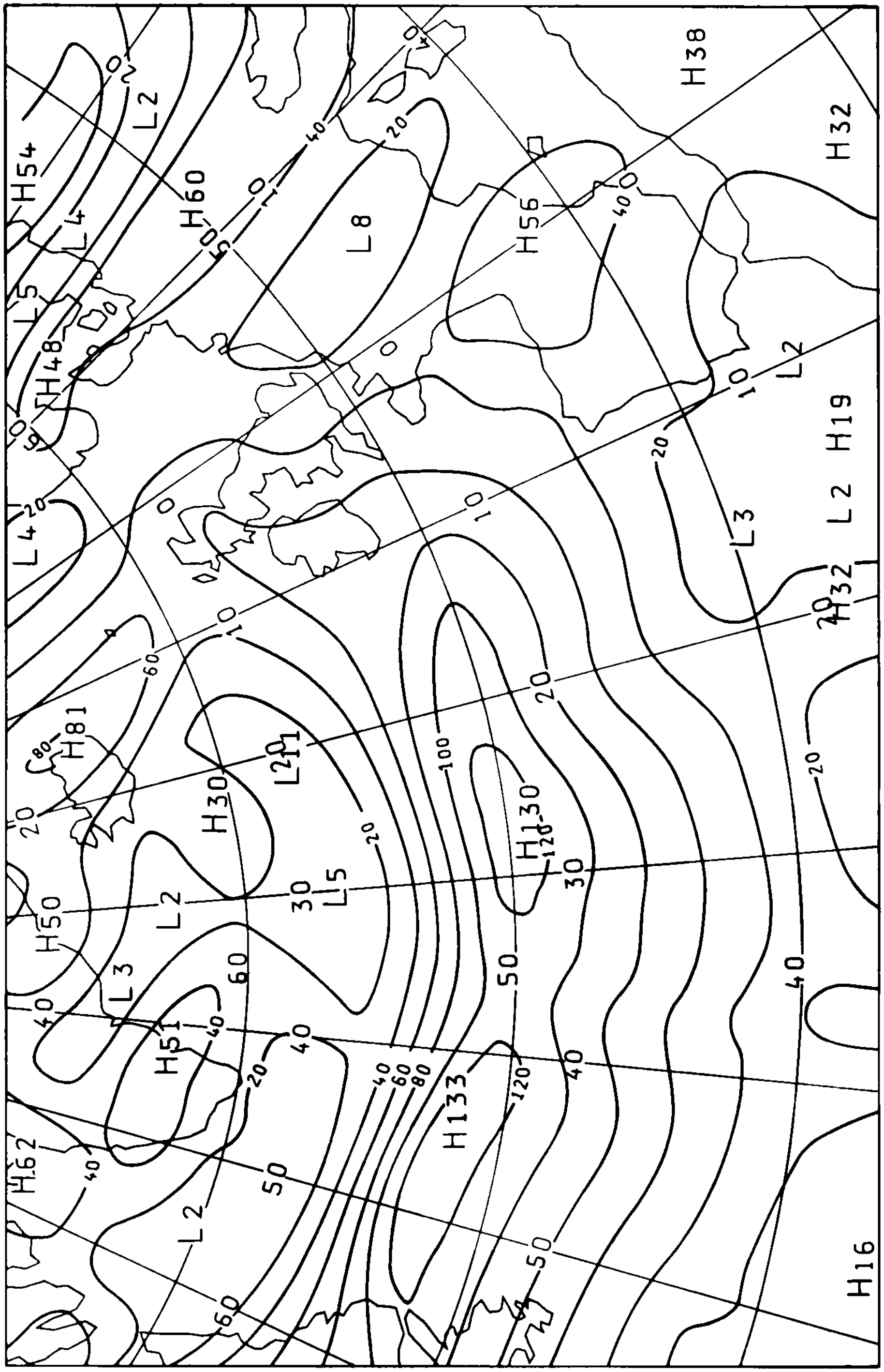

Figure 6. Initialized isotachs for 300 mb at 00 GMT on 13 August 1979 after bogusing (as used in case 7).

on a trial basis and then running the analysis program. If the fields were not acceptable the bogus data were altered and the process was repeated until an acceptable analysis was created. It can be seen that the objective m.s.l. pressure analysis produced in this way (Fig. 5) is a fair representation of the subjective analysis (Fig. 2). This technique was not very successful, however, when an attempt was made to improve the 300 mb analysis. The coarse 300 km grid would not allow the required tight gradient to be created. The isotachs in Fig. 6 show the best field produced for this level, although the wind speeds are still too light. The main improvement made to the original objective 300 mb field was an increase in gradient upstream of the surface-low position. There is still a serious lack of wind strength above the surface low at 31°W. The difficulty encountered in improving the 300 mb analysis is indicated by the fact that 17 bogus observations were used at this level. The 500 mb analysis after bogusing was probably a fair representation of the field at this level. The wind strength was increased successfully in the Atlantic region when compared with the original objective analysis.

The effect of the changed analyses on the forecast depression

The forecast was rerun seven times using a different analysis each time. The results are given in Table I and are presented in order of increasing depth of the forecast depression. Case 1 is the operational forecast. It can be seen that when the objective m.s.l. pressure analysis is acceptable, i.e. in the cases numbered from 2 to 8, bogusing at 850 mb was more effective at producing a deeper depression than bogusing at both 500 mb and 300 mb. As was explained earlier the 300 mb analysis could not be improved satisfactorily because of the coarse grid, so one cannot tell whether a good 300 mb analysis would have resulted in as much improvement in forecasting the depth of the depression as was achieved by modifying the 850 mb field. However, bogusing just the 300 mb field was more effective at producing stronger winds in the Fastnet area, probably a more important consideration for the forecaster. The position of the depression in the 24-hour forecast was most accurate when just the 1000 mb analysis level was modified. For most cases (see Table II) addition of 850 mb bogus data decreased the positional accuracy but increased the accuracy of the central pressure of the forecast depression.

Although cases 5–7 used more surface bogus observations than the other cases it is probably fair to compare all the cases 2–8 as if the surface bogusing was the same. This is supported by comparing cases 7 and 8 which differ only in the number of surface bogus observations and yet produce very similar results.

Cases 5 and 6 differ only in the objective analysis of the 850 mb level. These differences were quite small and yet produced quite a large difference in forecast position of the depression (70 n mile difference). This result indicates the sensitivity of the forecast model to the analysis at this level in the development area. There are, however, no facilities for intervening at 850 mb in CFO.

Also shown in Table II are the geostrophic wind speeds. Any of the forecasts after intervention, particularly cases 3–8, predicted more realistic wind speeds over the Fastnet area. The original operational forecast predicted a geostrophic wind of only 23 kn, whereas the forecasts from the experiments predicted geostrophic winds ranging from 35 kn to 65 kn. The actual geostrophic wind was near 100 kn over a smaller area near the centre of the low and about 60 kn for the area over which the objective wind speed was measured. The winds near the surface over the Fastnet area at this time were up to force 10. The trough that crossed the Fastnet area between midnight and 06 GMT on the 14th was well forecast. It is thought (Watts 1979) that this trough, with the associated change in wind direction and speed, was responsible for the unusually short period, very large waves. Fig. 7 shows that the original forecast gave no indication of a depression or strong winds near the Fastnet sea area. The other three forecasts portrayed indicate that gale-force winds would be likely in the area and that a vigorous depression would have formed. The trough-line mentioned is indicated on all the forecasts.

Table I. *Forecast values of the central pressure of the depression for different analyses. The actual value was* 978 *mb (see Fig.* 1).

Case number	Number and level of bogus observations 1000 mb	850 mb	500 mb	300 mb	m.s.l. pressure of the depression centre in the 24-hour forecast	m.s.l. pressure of the depression in the analysis at start time
					millibars	
1	—	—	—	—	1007	1015
2	3	—	—	—	1000	1005
3	3	—	—	17	996	1005
4	3	—	10	17	994	1005
5	5	5	—	—	993	1004
6	5	6	—	—	991	1004
7	5	5	10	17	988	1004
8	3	5	10	17	987	1005

Table II. *Positional error of the forecast depression, and the geostrophic wind speed for the 24-hour forecasts shown in Table I.*

Case number	Positional error (n mile)	Geostrophic wind speed over Fastnet area (kn)
1	No depression forecast	23
2	80	35
3	160	55
4	110	45
5	130	40
6	200	45
7	200	65
8	230	60

Conclusions

The following conclusions relate specifically to the combined analysis and forecast run of the fine-mesh forecast model from midnight data on 13 August 1979. However, some generalizations have been tentatively made:

(1) An inadequate analysis was a major reason why the forecast model did not predict the vigorous depression that crossed Ireland on 14 August.

(2) Alteration of the lowest levels of the analysis had a greater effect on the forecast of the depression centre than did alteration of higher levels. Specifically, the greatest effect was achieved by altering the 850 mb analysis.

(3) If the forecast started with a good 1000 mb analysis but no other levels were improved there was an unrealistic vertical temperature profile, the 1000–850 mb thickness being too high. However, the forecast was improved if it ran with these initial conditions.

(4) The 850 mb level is not an 'intervention' level in CFO although conclusions (2) and (3) indicate it might usefully be made one, especially if the analysis itself could be modified, as opposed to the background field. However, it is unlikely that the forecasters will have enough time to do anything to this level before the fine-mesh forecast is run at HH + 2 h 20 min.

(5) The jet stream at higher levels could not be adequately analysed because of the large distance (300 km) between the analysis grid points. Thus, the effect of a good 300 mb analysis on the forecast could not be evaluated.

Acknowledgements

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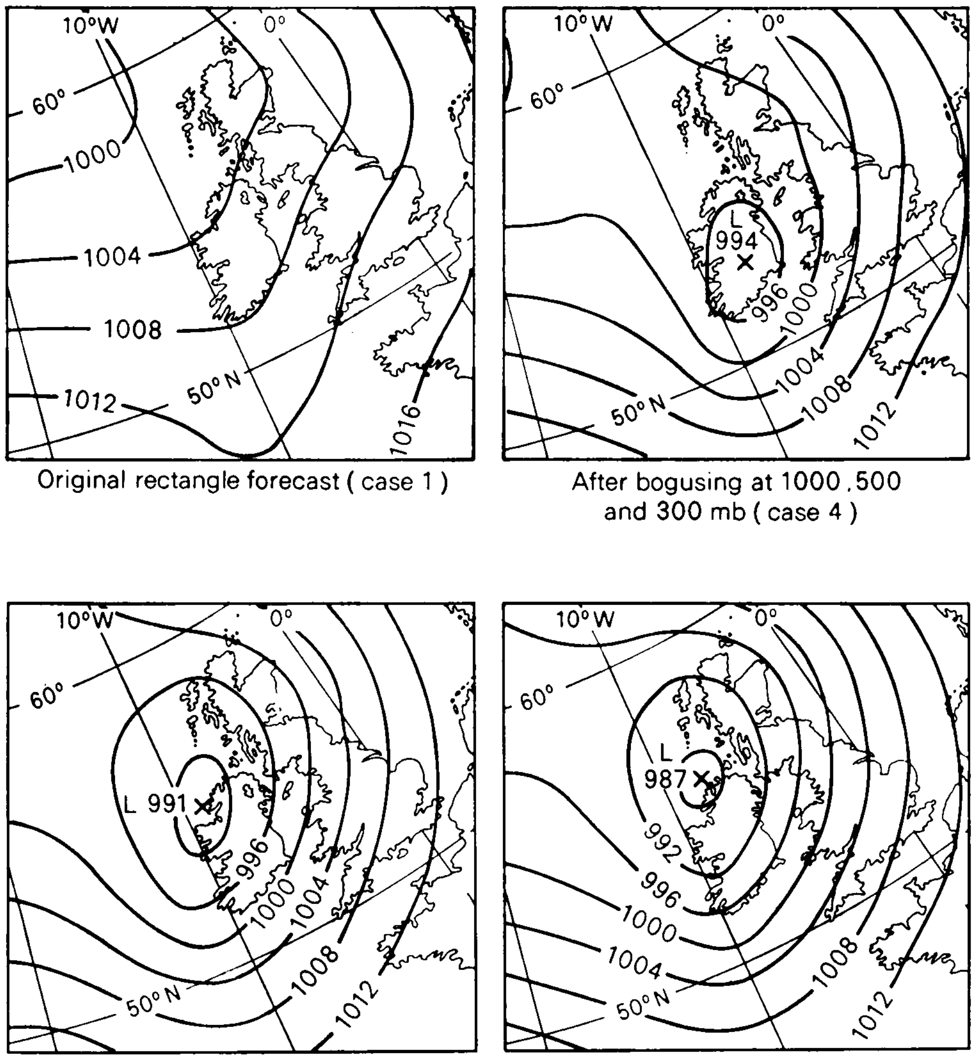

Original rectangle forecast (case 1)

After bogusing at 1000, 500 and 300 mb (case 4)

After bogusing at 1000, 850 500 and 300 mb (case 6)

After bogusing at 1000 and 850 mb (case 8)

Figure 7. Some forecasts for verification time 00 GMT on 14 August 1979 (T + 24 h).

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