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Estimates of surface gust speeds using radar observations of showers

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Summary

The speed of travel of shallow showers during the 1979 Fastnet Yacht Race, and on other occasions of strong wind, has been found to give a good indication of the peak surface gusts at exposed coastal locations. An objective echo-tracking procedure is capable of determining the speed of travel of the showers provided that the radar data are available with a resolution of at least 5 km and 5 min.

1. Introduction

Small, fast-moving precipitation echoes are sometimes observed by radar. If it were possible to relate such observations to the occurrence and magnitude of strong surface winds this would suggest a useful practical application of weather radar in addition to its more usual role in the measurement of precipitation distribution and intensity. It is now more than 25 years since Ligda and Mayhew (1954) reviewed radar studies of the motion of small precipitation areas (SPAs). They concluded that such radar measurements (so-called spawinds) are not very helpful for estimating winds because of difficulties in determining the steering level of the precipitation areas. Frequently these areas travel at the velocity of the winds far above the surface. Areas of locally heavier rain in frontal regions, for example, are often found to travel at the speed of convective generating cells embedded within the middle-tropospheric flow. The high speed of such areas (sometimes as high as 130 km h^{-1}) does not necessarily bear any relation to the speed of the winds at the surface. Nevertheless, there are occasions when the precipitation echoes can be shown to be due to showers confined to a shallow layer in the lower troposphere, and the purpose of this note is to consider whether the radar echo movements in these circumstances can be used to make worthwhile inferences about the surface winds.

In this paper we present radar observations obtained as part of the Short Period Weather Forecasting Pilot Project (Browning 1980) on the occasion of the 1979 Fastnet Yacht Race (14 August 1979) when storm-force winds occurred in sea areas Fastnet and Lundy. The radar, located at Camborne, Cornwall, observed numbers of short-lived showers over the sea during the period of the gales. The showers were light and only just above the threshold of radar detectability; they were also very shallow with tops

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mostly in the range 2 ± ½ km above sea level. Similar observations were obtained on 7 and 8 December 1979 when once again the South-west Approaches were exposed to strong winds located in the cold air to the south of a depression, although on this occasion the winds were not as strong as on 14 August. Results to be presented in this paper show that, in both cases, the showers travelled rapidly, at speeds similar to those of the peak gusts reported at the surface. A computerized cell-tracking procedure, capable of evaluating these velocities from the radar data almost in real time, has been used, and the results are compared with those derived subjectively.

2. The synoptic setting

A deep depression travelled eastwards across southern Ireland in the early hours of 14 August and behind the cold front a strong, fairly dry west-south-westerly flow covered the South-west Approaches. Reports from competitors indicate that the strongest winds over the area occurred between 0200 and 0600 GMT. Fig. 1 shows the surface analysis superimposed on the pattern of cloud-top height derived from the Meteosat infra-red imagery at 0600; at this time the strongest surface winds were in a narrow zone just to the north-west of the radar at Camborne (C). The cloud tops in the area near Camborne are seen to have been in the range 1·3 to 2·7 km. The locations of individual showers detected by the radar at 0600 are indicated in the figure by triangles. Although operational compromises dictate that only low-elevation radar data are available in real time, data from higher elevations are tape-recorded for off-line analysis and these data confirmed the satellite indications that the showers were confined below 2·7 km.

Fig. 2 is a vertical cross-section along the line VXCBrB in Fig. 1. It shows the 0600 winds at Valentia (V), Camborne (C) and Brest (Br) and also the 1030 ascent at Aberporth displaced to the position in relation to the synoptic system that it would have occupied at 0600 (position X). The strongest surface winds occurred between X and C, at little to the south-east of the main upper tropospheric jet which reached 77 m s^{-1} at 300 mb. The small cumulus turrets drawn in Fig. 2 between X and C indicate the vertical extent of the showers which occurred in this region.

Fig. 3 shows a vertical sounding representative of the airstream generating the showers. It is actually the 09 Larkhill sounding but its position relative to the synoptic pattern at 06 puts it on the boundary of the area of interest (see Z in Fig. 1). The sounding indicates that the showers were within a boundary layer capped by very dry air above 750 mb, the dry air probably having had a recent history of subsidence. Other soundings representative of the same general airstream showed a similar thermodynamic structure; however, those made from stations exposed to a flow coming directly from the sea exhibited a more nearly constant θ_w in the boundary layer, indicating that the boundary layer over the sea was convectively well mixed. Surface temperatures representative of sea-surface conditions have been used to construct the line of parcel ascent on the sounding shown in Fig. 3.

3. Velocities of shower echoes compared with surface gusts

The area over which showers 2½ km deep could be detected by the Camborne radar is indicated by the dashed line in Fig. 1. The average velocity of each of the shower echoes within this area has been evaluated over half-hour periods using data at 5 min intervals. The resulting velocities have been compared with records from anemometers in the vicinity.

The successive half-hourly positions of a line of shower echoes that crossed the Isles of Scilly soon after 0000 GMT on 14 August are shown in Fig. 4. The tracks of the individual shower cells are marked in the diagram together with their velocities, which ranged from 23 ± 3 m s^{-1} to 28 ± 3 m s^{-1}. This line of showers, which could also be tracked as a cloud band on the Meteosat infra-red imagery, produced a well-defined gust at exposed stations in south-west England and Wales. The anemograph

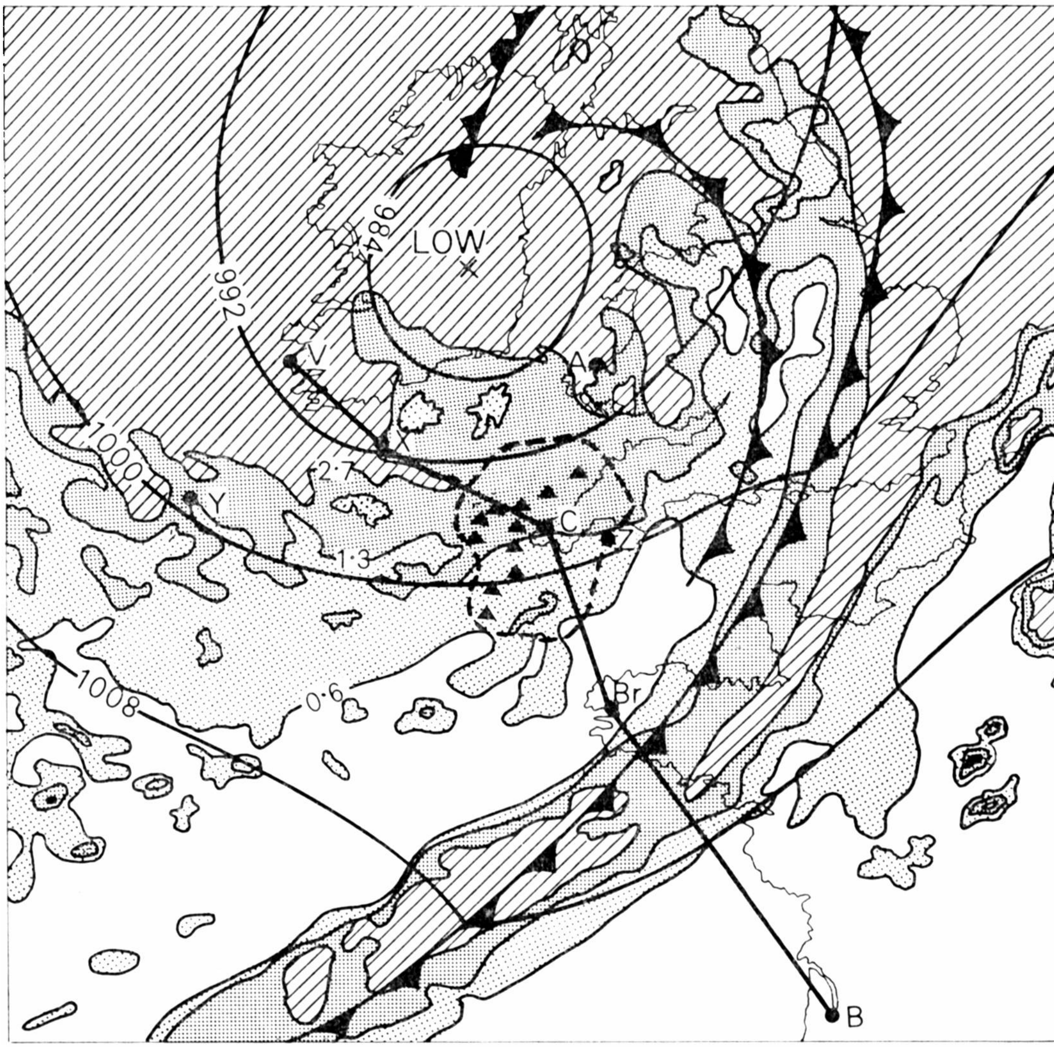

Figure 1. 14 August 1979, 06 GMT: smoothed contours of the height of the cloud tops (km) from Meteosat infra-red imagery with surface isobaric (8 mb intervals) and frontal analysis superimposed. Triangles mark the positions of showers observed on the Camborne radar at 0600 and the heavy dashed line indicates the limit of radar observations. Circles mark the positions of vertical soundings relative to the synoptic system at 0600; Valentia 0600 (V), Aberporth 0600 (A), Aberporth 1030 (X), Camborne 0600 (C), Camborne 1200 (Y), Larkhill 0900 (Z), Brest 0600 (Br) and Bordeaux 0600 (B).

record at Scilly, for example, which is shown in Fig. 5, illustrates a peak gust of 24 m s^{-1} (47 kn) at 0008 GMT. The corresponding peak gusts during the passage of this line of showers through Gwennap Head, Lizard and Hartland Point were 23, 21 and 27 m s^{-1} respectively. These values are plotted in Fig. 4. The peak gusts at these exposed stations were evidently within $\pm$ 5 m s^{-1} of the nearest shower echoes.

The other showers that were observed during the period 0000–0900 were distributed less regularly.

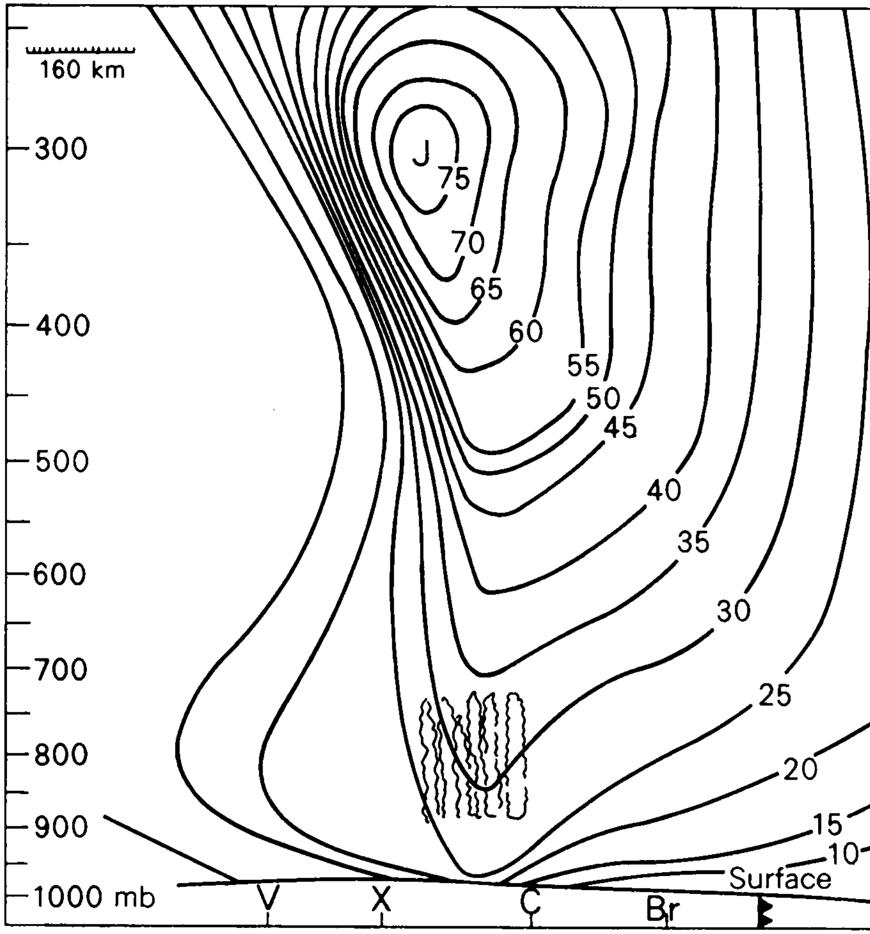

Figure 2. Vertical cross-section of the mean wind speed (m s^{-1}) along the line from Valentia to Bordeaux through X, C and Br as shown in Figure 1. The surface position of the cold front is indicated by the conventional symbol, and the vertical extent of the showers observed between X and C is represented by small cumulus turrets.

Although they could be associated with features on the satellite imagery, the time lapse of ½ h between pictures meant that individual showers could not be tracked by satellite. Individual radar echoes rarely passed directly over a surface-wind recording station and so it was difficult to relate individual showers to surface gusts in a one-to-one manner. Accordingly we have derived average velocities for clusters of showers observed to be moving with similar velocities (50–100 km across) and we have compared these with the maximum surface gusts recorded within one hour of the corresponding time. Figs 6(a) and 6(b) show the results for 0600 $\pm$ 1 h and 0800 $\pm$ 1 h. In these diagrams the velocity vectors for observations within $\pm$ 1 h of the nominal map time are plotted in positions slightly displaced from their true geographical positions so as to be in the correct location relative to the mesoscale wind system at map time. The displacements were made assuming a system velocity equal to the mean shower velocities. Figs 6(a) and 6(b) show that the maximum surface gusts at exposed sites were within $\pm$ 5 m s^{-1} of the velocities of the nearby shower echoes. This agreement is as good as that between the maximum

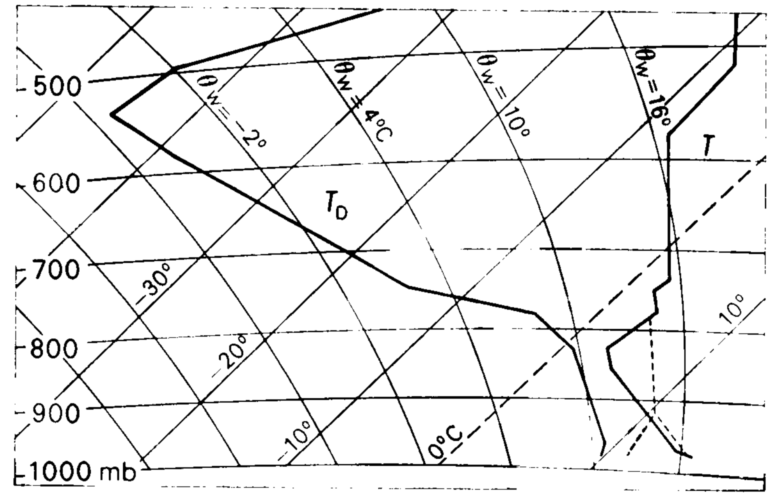

Figure 3. Vertical sounding from Larkhill at 09 GMT on 14 August 1979, representative of the airstream generating the showers. The dashed line shows the path of ascent for a parcel of air rising from the sea surface (T = 16 °C, T_d = 12 °C) through ambient conditions represented by the sounding.

gusts reported by adjacent anemometer stations and so we cannot hope to achieve verification to any greater accuracy. Comparing Fig. 4 with Fig. 6 we further note that the shower velocities reflect the trend shown by the peak surface gusts, which increased over the period 0100–0600 and then began to decrease over the period 0600–0800. Over Scilly, for example, around 0000 GMT the maximum gusts were in the range 23–26 m s^{-1}; they increased to 26–28 m s^{-1} around 0600 and then fell again to 23–26 m s^{-1} around 0800.

The above results are consistent with a model in which eddies confined within the convective boundary layer mix momentum vertically so as to produce downdraughts which over the sea and at exposed coastal locations reach the surface with a horizontal component of velocity similar to that possessed by the convective element as a whole and greater than that of the mean surface wind. The anemograph traces show that the gusts are more numerous than the precipitation echoes observed by the radar, implying that 'dry convection' is equally important and that the weak echoes observed by the radar are simply the tracers of the flow.

It was observed that maximum gusts recorded by anemometers further inland were significantly less than those from exposed coastal stations. The greater effect of friction on the surface layer over land would reduce the strength of the maximum gusts experienced at the surface (but it is also probable that their strength is underestimated owing to the failure of the anemometers to respond fully to sudden, large, short-lived increases in wind speed). Nevertheless, the shower velocities still provide an upper limit to the gusts which might be expected over land.

4. Further examples

In view of the promising results derived from the tracking of small precipitation echoes on the occasion of the Fastnet Race gales, other occasions were sought on which radar observations of shallow showers were obtained during strong winds. One such case occurred on 7 and 8 December 1979 when a depression moved north-north-west along the western coast of Ireland and strong winds occurred to

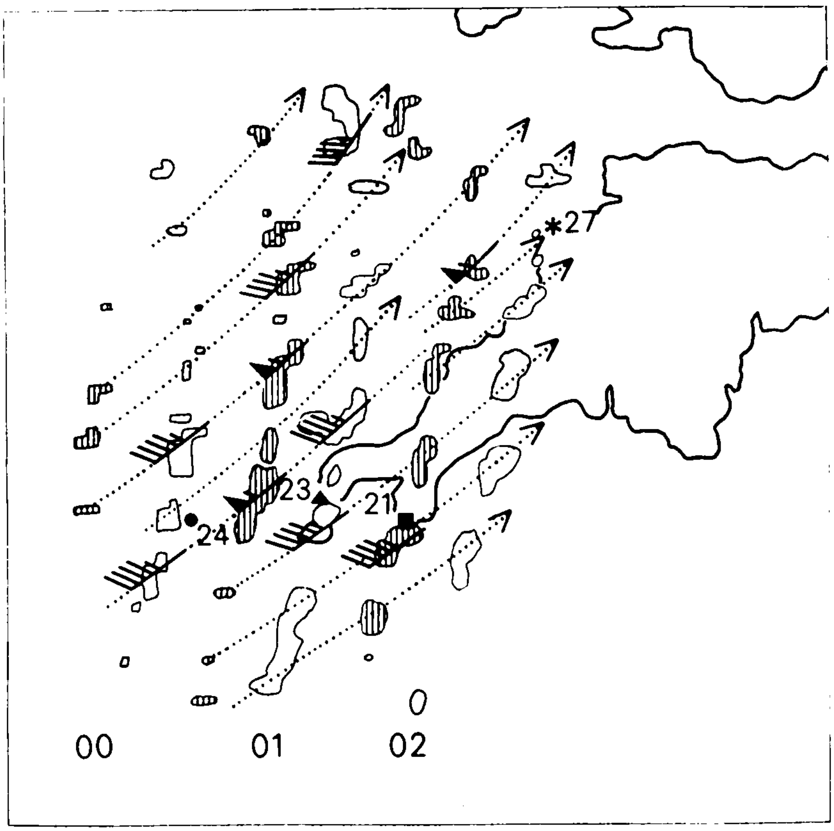

Figure 4. Successive half-hourly positions of a line of showers observed by the Camborne radar; alternate positions are shaded. The tracks of individual showers are marked by dotted lines and their average velocities over periods of half an hour are represented by wind shafts (one full feather = 10 m s^{-1}; one triangle = 25 m s^{-1}). The peak surface gusts (m s^{-1}) experienced at the passage of this line are plotted at Scilly (●), Gwennap Head (▲), Lizard (■) and Hartland Point (*).

the south of it behind the cold front. Fig. 7 shows the surface analysis for 12 GMT on the 7th. Small precipitation echoes were observed by the Camborne radar on the 7th and again on the 8th, and multi-elevation data indicated that they were confined below 3 km except for a few hours around midday on the 7th. Vertical soundings representative of the airstream maintaining the showers showed a well-mixed convective boundary layer with a general cloud-top level around 750 mb (2·4 km).

As in section 3 the shower velocities have been compared with the maximum surface gusts and the results are shown in Fig. 8. Fig. 8(a) is for 1000 $\pm$ 1 h on the 7th and Fig. 8(b) is for 0400 $\pm$ 1 h on the 8th. The maximum gusts at the exposed sites are within $\pm$ 5 m s^{-1} of the velocities of nearby showers. Comparing Figs 8(a) and 8(b), it is evident that the peak surface gusts decreased in the period between 1000 on the 7th and 0400 on the 8th, and the shower velocities manifest the same trend. (On this occasion the peak gusts recorded at Scilly appear low compared with those shown by the other anemometers and the shower velocities, illustrating that there is a problem in verification, probably because of the effect of the exposure to different wind directions of any anemometer situated on land.)

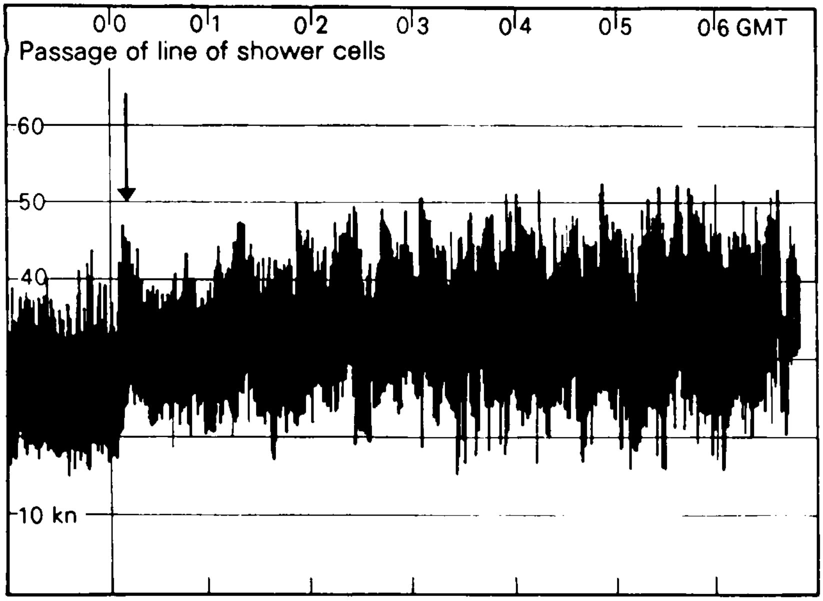

Figure 5. The anemograph record from Scilly on 14 August 1979 between 00 GMT and 06 GMT showing a maximum gust of 24 m s^{-1} (47 kn) on the passage of the line of showers, and gusts over 26 m s^{-1} (50 kn) later in the period.

Table I summarizes the results for 14 August, 7 and 8 December and for some other occasions on which radar observations of shallow showers were compared with peak surface gusts. Comparisons between the two sets of velocities are made within two zones, both zones being centred on Gwennap Head, the approximate centre of the set of anemograph locations. (On three occasions the showers were some distance from the set of anemograph locations, in which case a comparison can be made only over the larger of the two zones.) Table I shows that, with the exception of 17 December at 0000, all the cases gave agreement between the sets of velocities to within $\pm$ 5 m s^{-1} in both areas. (At 0000 on the 17th a few small precipitation echoes moving eastwards at 31 m s^{-1} were observed far to the south of the other showers.)

5. Possible operational utility

The velocities of shower echoes presented in sections 3 and 4 were derived off-line by careful subjective analysis. However, in view of the relationship that has emerged between the velocity of shallow shower echoes and the maximum surface gusts at exposed coastal station, it appears that these velocities might, on occasions, be useful in an operational context provided that they could be evaluated virtually in real time. Accordingly, an objective computerized cell-tracking procedure was applied to the Camborne radar data on 14 August 1979 and on 7–8 December 1979.

The procedure used is based upon the radar echo centroid tracking technique described by Barclay and Wilk (1970). Echo areas were defined using a single-linkage cluster technique. This is a simple form of hierarchical clustering (see, for example, Anderberg 1973) which places, in clusters, grid squares with echoes which lie within a specified number of grid squares in the west–east and north–south

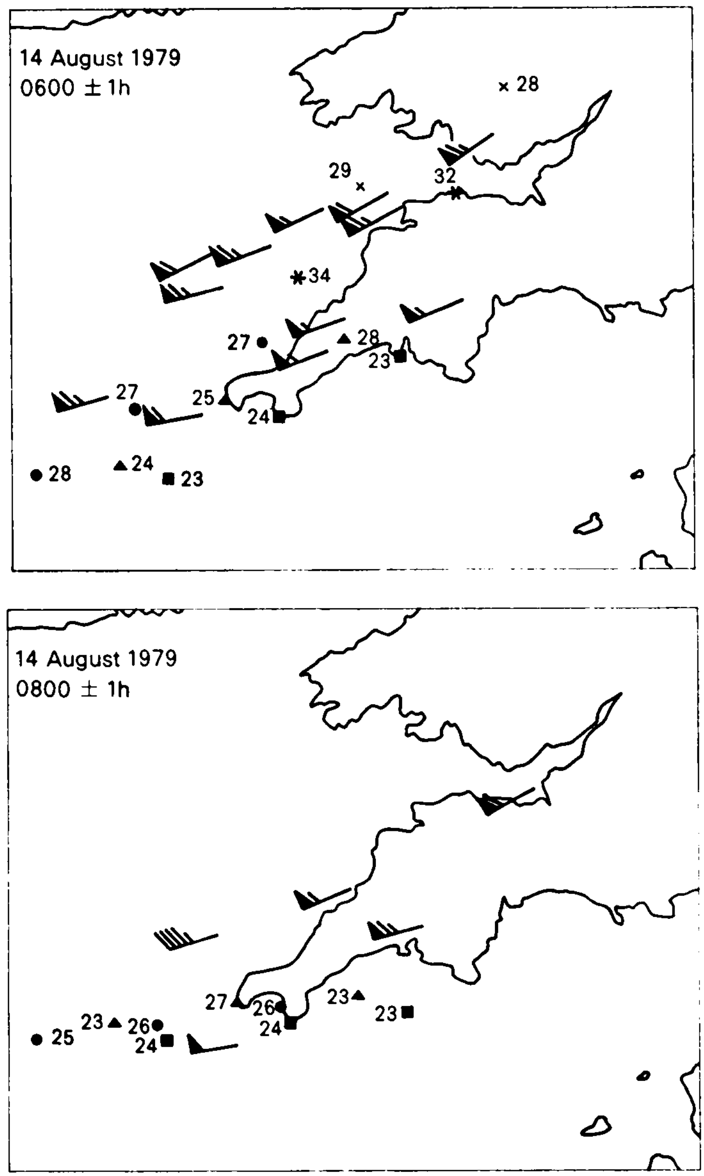

Figure 6. Shower velocity vectors for 14 August 1979 at 0600 ± 1 h and at 0800 ± 1 h. The average velocities were derived over periods of half an hour and are plotted as wind shafts, where one full feather represents 5 m s^{-1}. Peak gusts (m s^{-1}) experienced at the following exposed sites are plotted for comparison: Scilly (●), Gwennap Head (▲), Lizard (■), Hartland Point (*), Mumbles Head (X). All observations within ± 1 h of the nominal map time are plotted in positions displaced from their true geographical positions so as to be in the correct location relative to the wind system at map time.

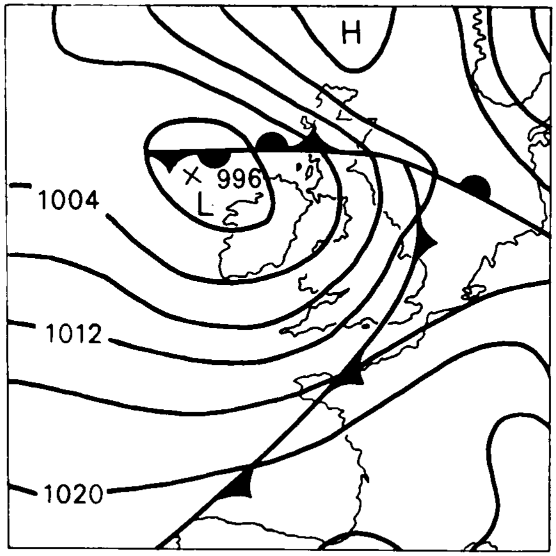

Figure 7. December 1979, 12 GMT: surface isobaric and frontal analysis as published in the *Daily Weather Report* of the Meteorological Office.

directions. (A more detailed description will be given in a paper being prepared by Browning *et al.*, entitled 'On the forecasting of frontal rain using a weather radar network'.) The basic input data used in this study were recorded on a 5 km grid at 5 min intervals.

A comparison of the objectively derived echo velocities with those derived subjectively is shown in Fig. 9. Altogether the computerized procedure recognized 19 clusters of shower echoes on 14 August and 20 on 7–8 December. Most of the objectively derived velocities are seen to be within $\pm$ 5 m s^{-1} of the subjectively derived values, thereby indicating the potential of the objective procedure. An investigation of the individual echo clusters identified objectively showed that all except one of them corresponded to actual groups of showers. The sole exception, identified by brackets in Fig. 9, suffered from confusion with sea clutter. When the objective procedure was rerun using data at 15 min instead of 5 min intervals and on a 20 km instead of 5 km grid, this led to far fewer showers being tracked and it produced erroneous velocities for up to half of the remaining tracks.

Considerably more effort has been put by the meteorological community into the use of sequences of geostationary satellite cloud images for wind determination than has been put into the use of radar sequences. Individual cumulus clouds and stratus elements are normally used for the measurement of low-level winds on the mesoscale. The only clouds which are good tracers of the mesoscale wind field at low levels, however, are very small ($\approx$ 2 km) and short-lived ($\approx$ 10 min) (Fujita *et al.* 1975) and, just as we have found in the present study that 5 min radar data are needed to give reliable velocities, so too it has been found by other workers that 5 min satellite imagery is needed in order to give reliable results (Rodgers *et al.* 1979).

6. Conclusions

The speeds of weak shower echoes observed during the 1979 Fastnet Yacht Race and on other occasions have been shown to be of comparable magnitude to those of the peak surface gusts at exposed coastal locations. Objective procedures can be applied virtually in real time and these have been shown

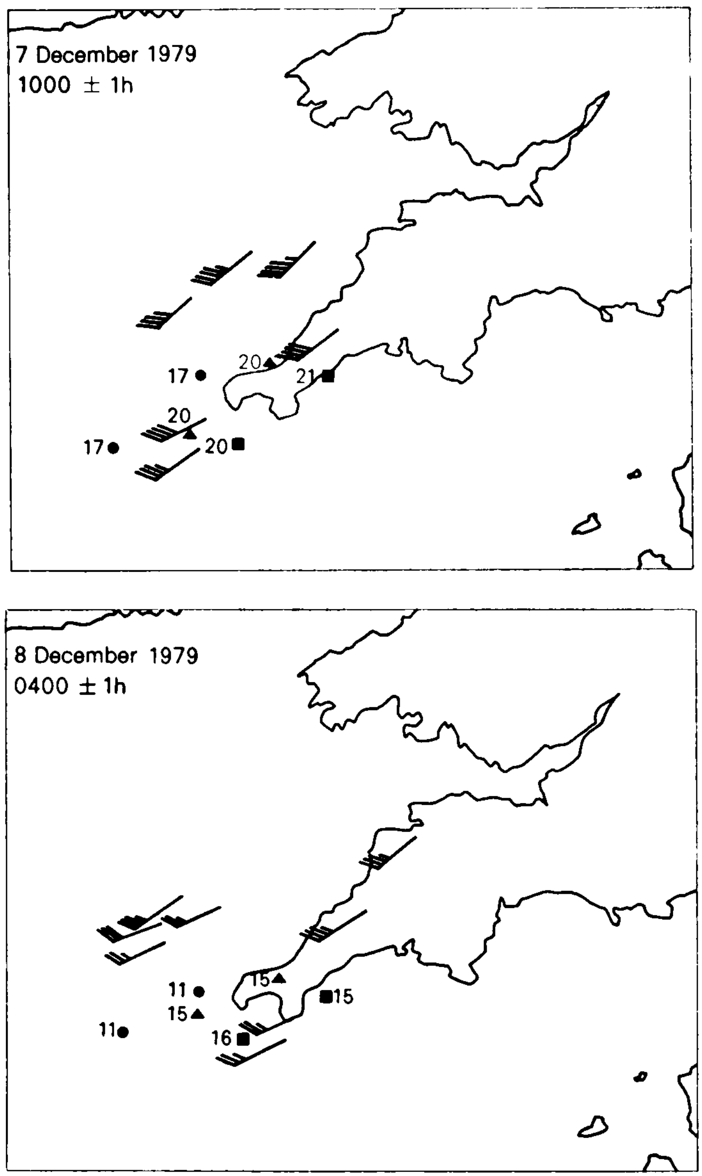

Figure 8. Shower velocity vectors and peak gusts at exposed sites, plotted similarly to Figure 6 for 7 December 1979 at 1000 ± 1 h and 8 December 1979 at 0400 ± 1 h.

Table I. *Comparison between shower velocities and peak surface gusts on* 10 *occasions when shallow showers were observed by the radar.*

Date	Time GMT	Maximum possible height of showers km	Range of shower speeds within 50 km of Gwennap Head m s^{-1}	Range of peak gusts within 50 km of Gwennap Head m s^{-1}	Range of shower speeds within 100 km of Gwennap Head m s^{-1}	Range of peak gusts within 100 km of Gwennap Head m s^{-1}
29 Sept. 1978	0400	3·1	19–20	20–25	19–22	20–25
14 Aug. 1979	0600*	2·7	29	24–28	26–33	24–34
14 Aug. 1979	0800*	2·7	22–25	24–27	22–27	23–27
30 Nov. 1979	1900	2·7	17	15–18	17–21	15–18
30 Nov. 1979	2230	2·7	None	16–20	15–18	14–21
7 Dec. 1979	1000*	2·5	20	17–20	18–22	17–21
7 Dec. 1979	1630	3·1	17	15–17	16–20	15–18
8 Dec. 1979	0200	2·9	None	13–17	14–16	12–17
8 Dec. 1979	0400*	2·9	13–14	11–16	13–16	11–16
8 Dec. 1979	0600	2·9	None	9–14	11–16	9–14
16 Dec. 1979	2200	3·1	19	18–22	19–22	18–22
17 Dec. 1979	0000	3·1	21–24	15–21	19–31	15–21

* These four cases are shown in Figs 6 and 8.

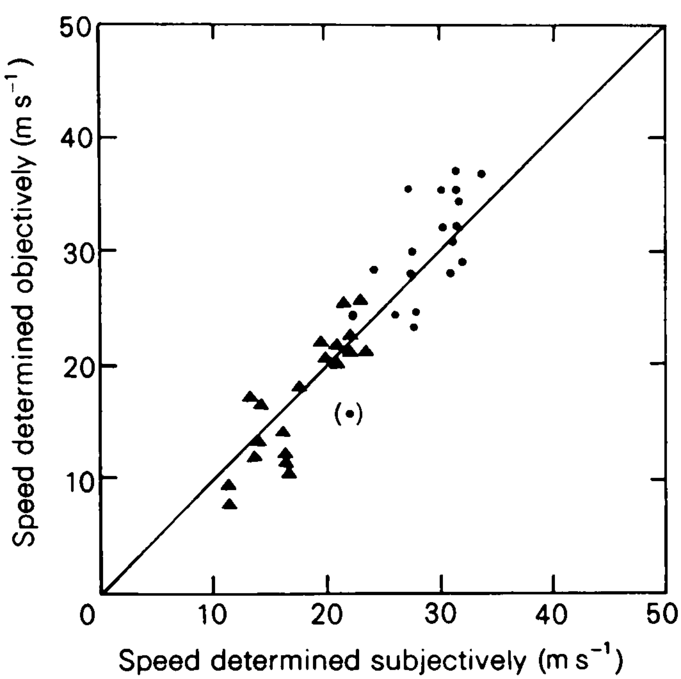

Figure 9. A comparison of shower velocities (m s^{-1}) derived from the computerized cell-tracking procedure with those derived subjectively. Results for 14 August 1979 are shown as circles, and those for 7–8 December as triangles. The bracketed symbol represents an echo cluster which suffered from confusion with sea clutter.

to be capable of measuring the echo velocities provided that the radar data are available in digital format with a resolution of at least 5 km and 5 min. In general, for the showers to provide an indication of the low-level flow, they need to be restricted to a fairly shallow ($\leqslant$ 3 km) well-mixed boundary layer. Therefore it is necessary to investigate the three-dimensional structure of the radar echoes or to combine the radar data with satellite and other information to determine whether the showers are indeed shallow. In operational terms, it is unlikely that the method of determing the upper limit to surface gusts described in this paper will be applicable on large numbers of occasions; however, the possibility is worth keeping in mind since, in an eventual operational system for the short-period forecasting of precipitation patterns, it is likely that an objective cell-tracking procedure will be carried out in any case. Thus, the ability in certain circumstances to assess the maximum likely surface gust and to determine the meso-scale structure of strong low-level winds should be regarded as a useful by-product of a future weather radar network.

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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 prod uce 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.

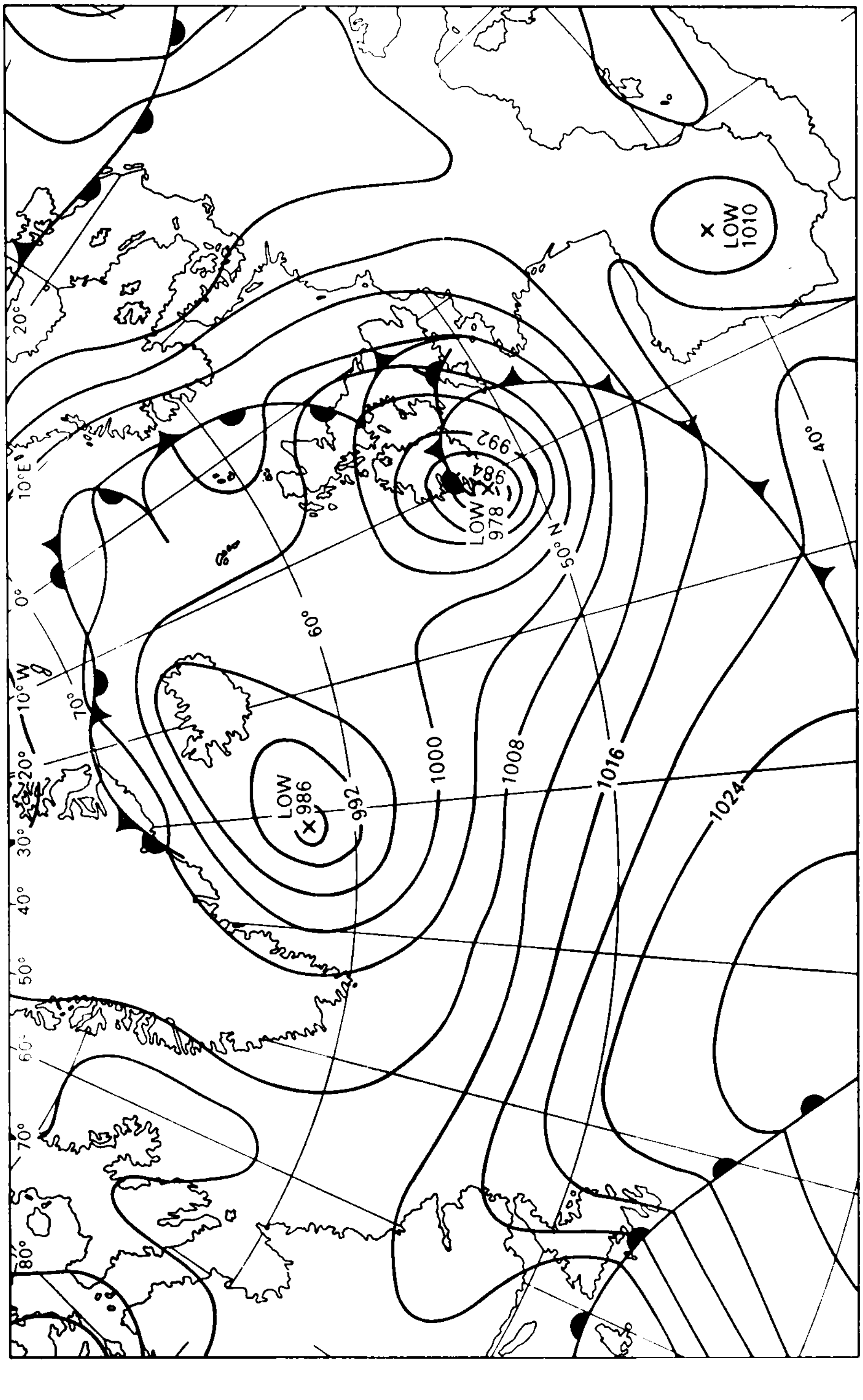


Figure 1. Subjective m.s.l. pressure analysis for 00 GMT on 14 August 1979.

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

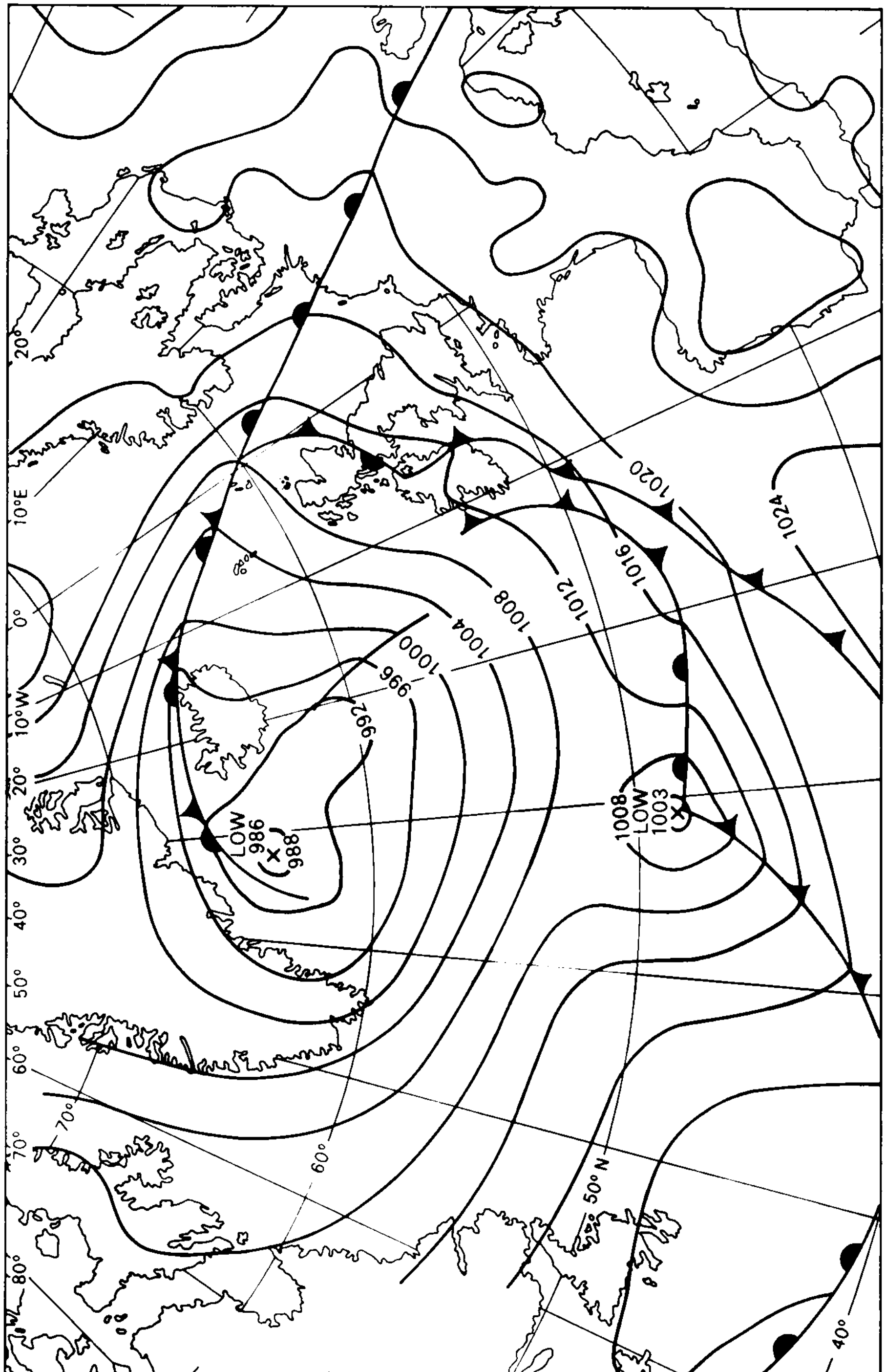


Figure 2. Subjective m.s.l. pressure analysis for 00 GMT on 13 August 1979.

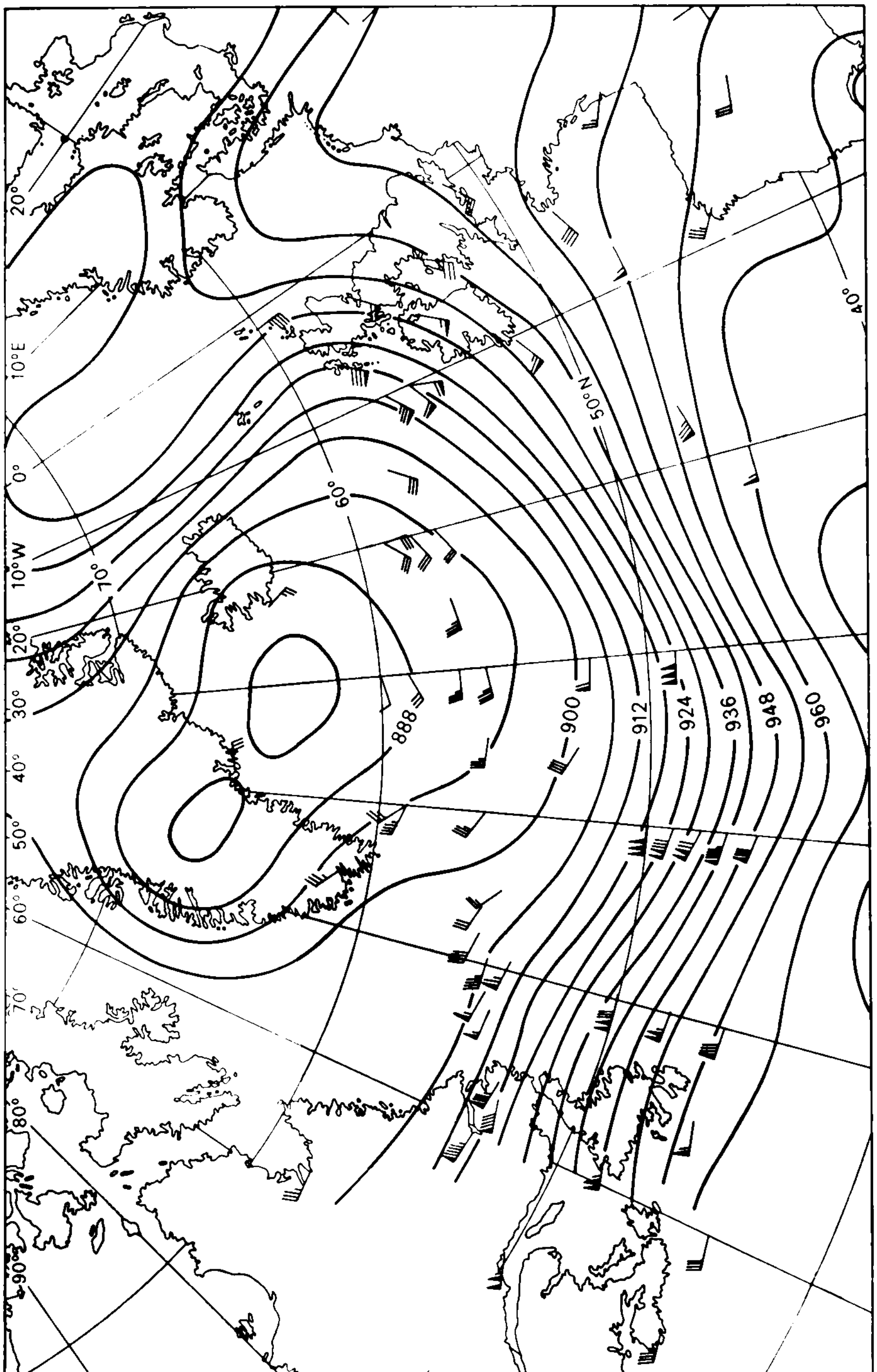


Figure 3. Original objective **300** mb analysis for **00** GMT on 13 August 1979, showing the aircraft and radiosonde reports used.

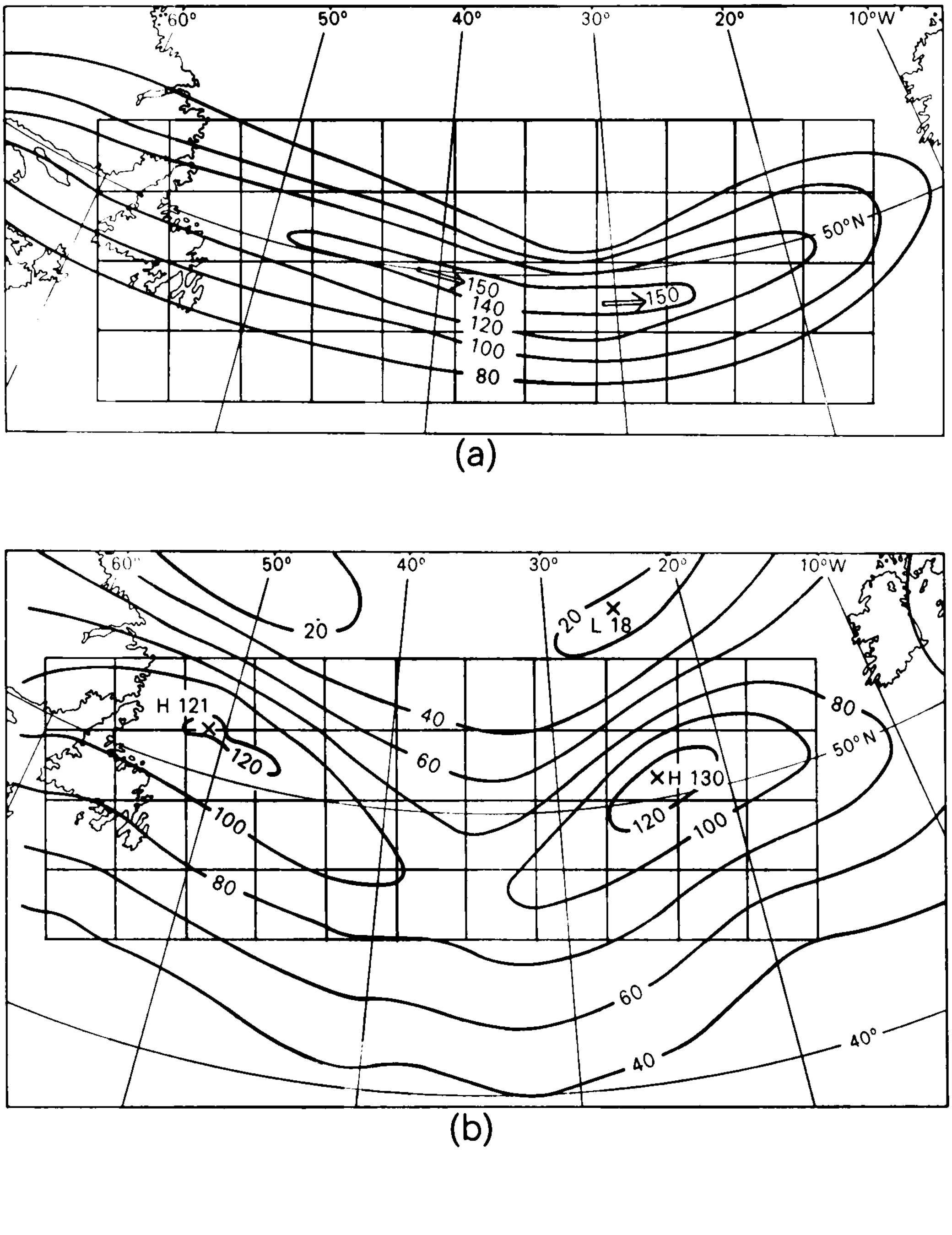


Figure 4. Isotachs for 00 GMT on 13 August 1979, in knots, showing part of the analysis grid: (a) subjectively produced from aircraft and radiosonde reports for approximately 250 mb, and (b) objectively produced from the initialized 300 mb field.

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

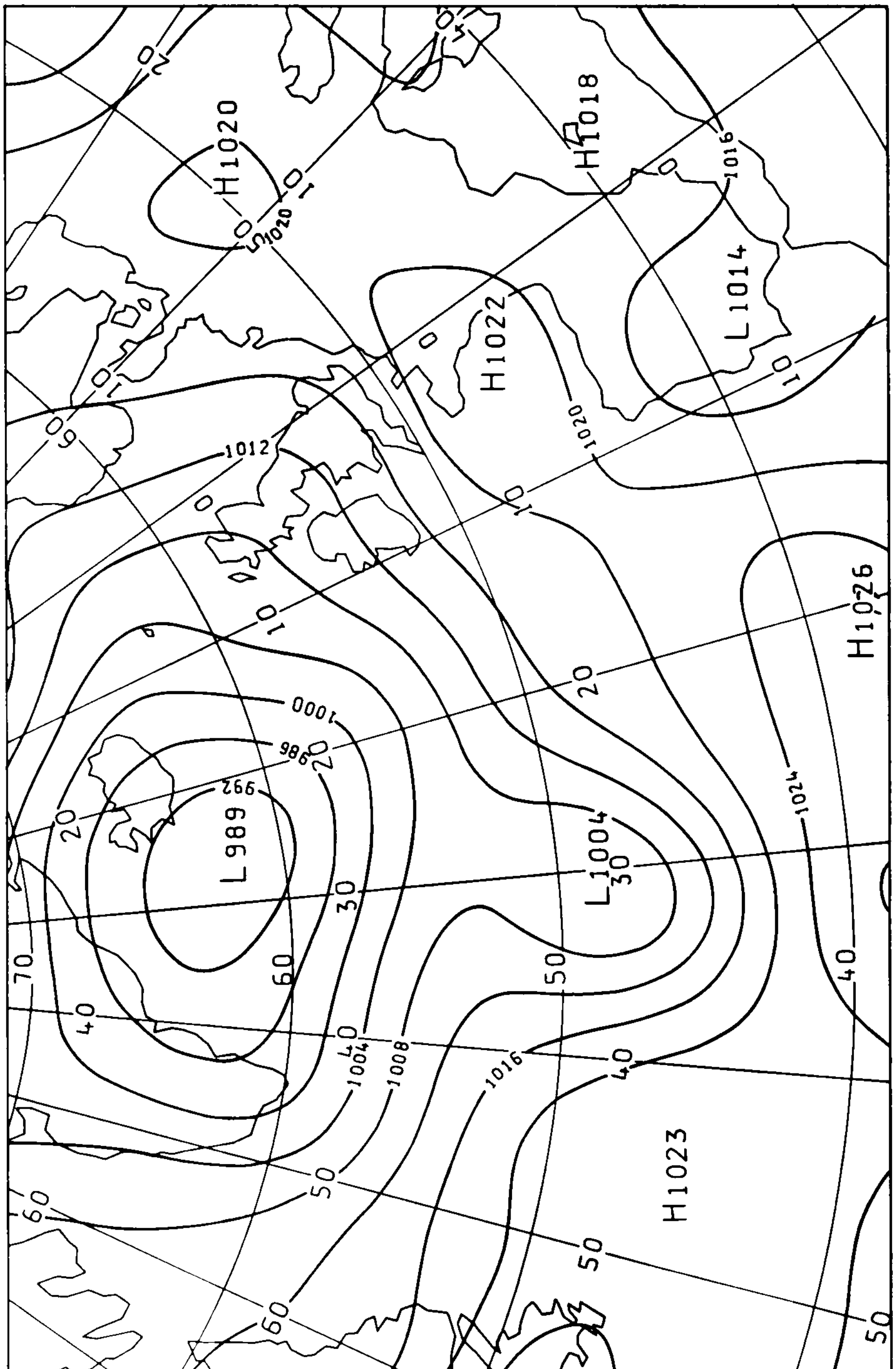


Figure 5. Objective m.s.l. pressure analysis for 00 GMT on 13 August 1979 after bogusing (as used in case 7).

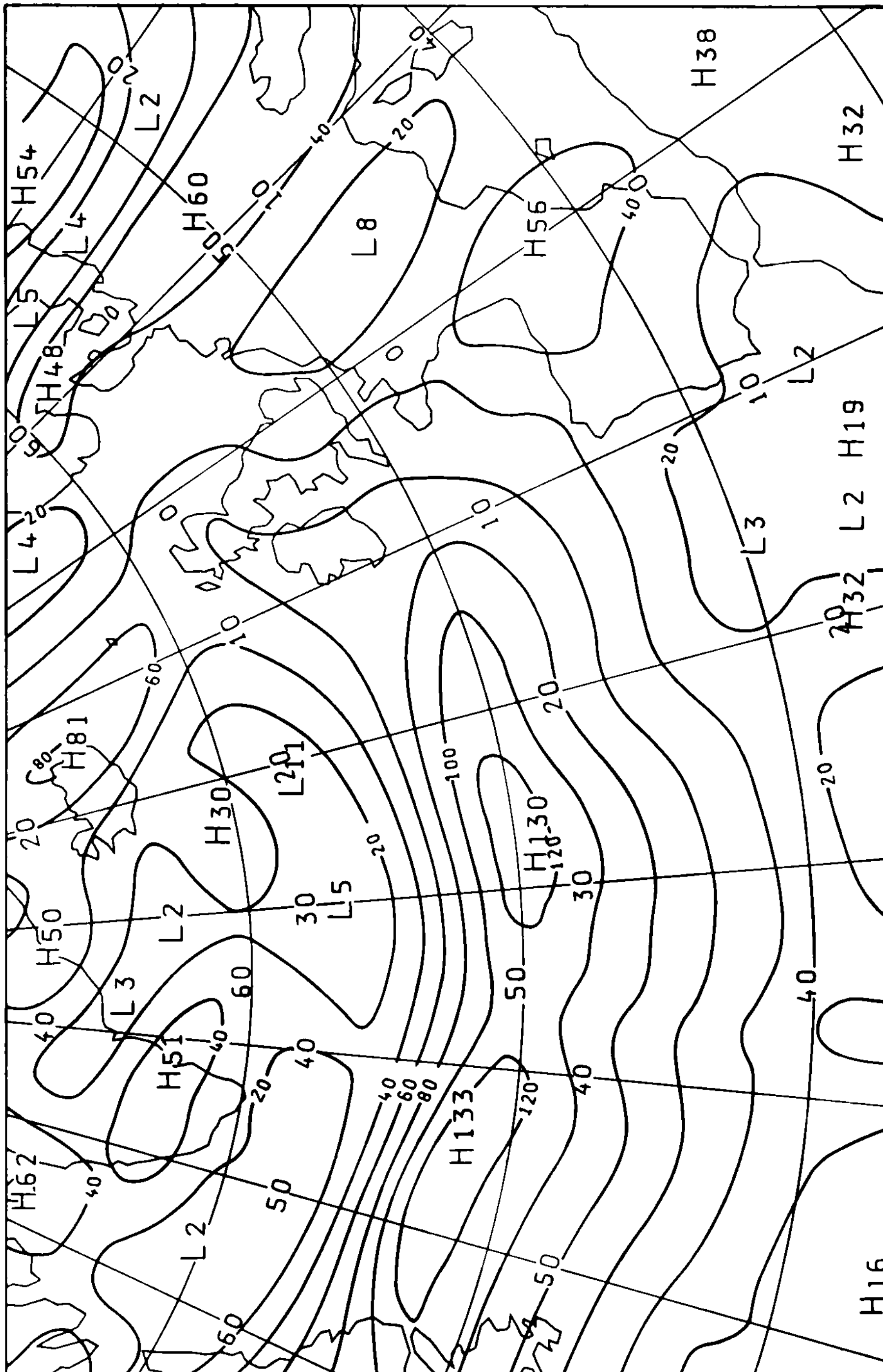


Figure 6. Initialized isotachs for 300 mb at 00 GMT on 13 August 1979 after bogusing (as used in case 7).

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.

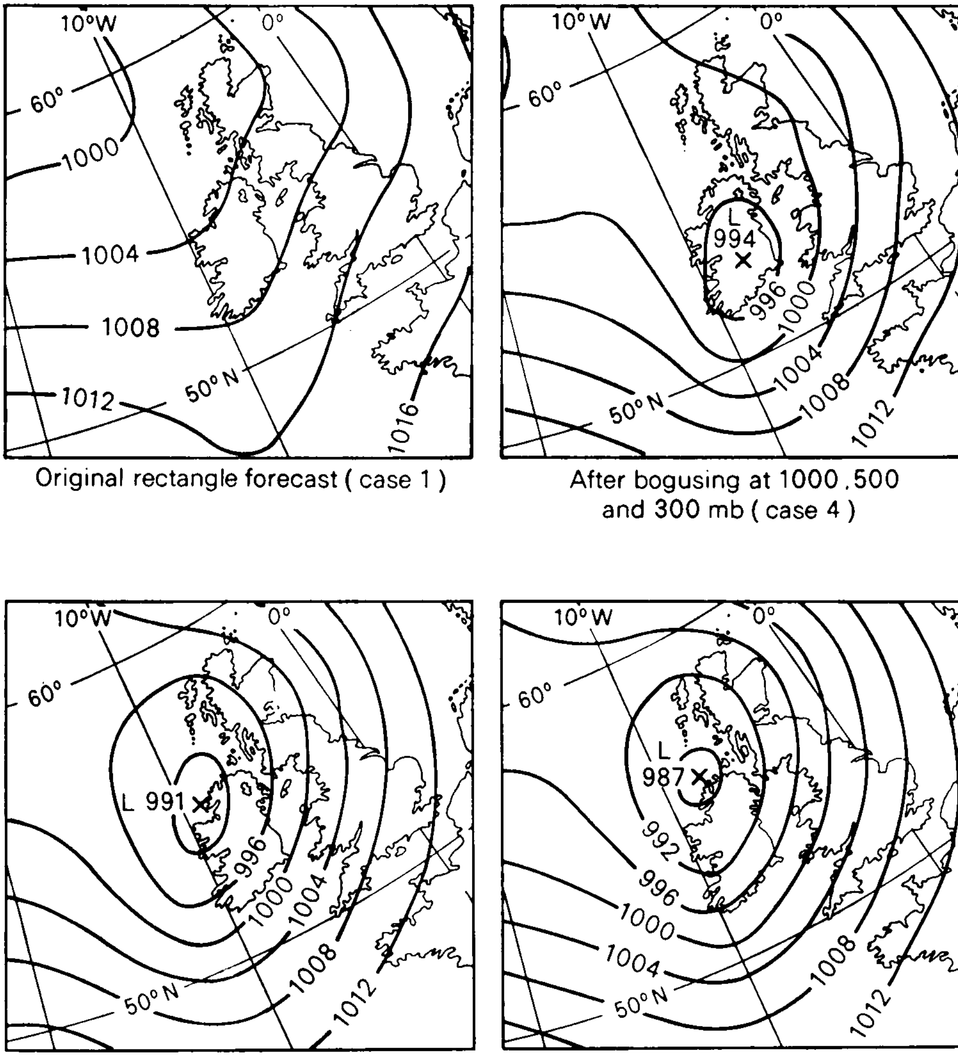
(3) If the forecast started with a good 1000 mb analysis but no other levels were improved there was an unrealistic vertical temperature profile, the 1000–850 mb thickness being too high. However, the forecast was improved if it ran with these initial conditions.

(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

Many thanks are due to my colleagues in Met O 2b for their help and advice in running the computer programs and to Bruce Painting of the Central Forecasting Office for his comments on the synoptic details of the case.



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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The WMO Symposium on Probabilistic and Statistical Methods in Weather Forecasting, Nice, 8–12 September 1980

By R. H. Maryon

(Meteorological Office, Bracknell)

The Symposium was well attended with around 70 papers being read. It was co-sponsored by the Société Météorologique de France and the program committee was chaired ably and energetically by Dr A. H. Murphy of Oregon State University.

The Symposium coincided with an interesting phase in the relationship between statistical and dynamical methods of weather forecasting. Each method in isolation now has fairly well-defined limitations, so that a rapprochement between the two schools is becoming a matter of some urgency. It was apposite, then, that two of the most distinguished speakers, Professors Lorenz and Leith, should refer respectively to the invocation of assistance from dynamical methods to supplement statistical modelling and to the different ways in which statistics might be used to aid numerical predictions. Lorenz hoped that meteorological statistics would extricate itself from the strait-jacket of linear additive models. Some escape from linearity may be possible either by introducing the results of dynamical prediction into the formulae or by allowing for realization of some of the non-linear processes going on in the atmosphere by means of analogue selection at an early stage of analysis. Brier (USA) recommended research into multiplicative, as opposed to additive, statistical models.

Professor Leith reviewed methods of stochastic–dynamical prediction. He concluded that Monte Carlo techniques, in which forward integrations are made from different members of an ensemble of initial states, have promise. However, model imperfections contribute strongly to error growth, so research should also focus on the statistical properties of model prediction error. The Meteorological Office has been active in this field and R. Dixon gave an introduction to the GMDH (group method of data handling) extrapolation technique and, in particular, its use in modifying systematic numerical forecast error. He pointed out that in a given regression sample a particular combination of predictors may be highly correlated with the predictand even though they are uncorrelated in the population. In the GMDH the regression data are split into two sequences. An algorithm determines best-fitting polynomials from the 'training' set which are evaluated against the 'checking' set. The best are re-combined for further cycling and evaluation. Tests on 72-hour 500 mb grid-point forecasts have yielded encouraging results although problems remain to be solved. A. Hollingsworth (European Centre for Medium Range Weather Forecasts) described an inconclusive experiment in Monte Carlo numerical prediction, where difficulties were encountered at the initialization stage. It must be concluded that at present a practicable combined statistico–dynamical methodology is awaited.

Many papers were devoted to the topic of model output statistics (MOS) and interpretation. Considerable effort has been put into MOS in France and the USA using regression and related techniques. Klein and Dallavalle (USA) compared MOS favourably with the so-called 'perfect prog.' method. These use model output and observed historical data respectively in the regressions. They also concluded that MOS regressions for daily maximum and minimum temperatures based upon 3-month seasons were better than those based upon longer periods and that forecast error increased linearly with time. The average error for a 48-hour forecast is now comparable with the 24-hour error of a decade ago. Woodcock (Australia) suggested that analogues be sought to help in the preparation of forecasts from model output and that regression formulae were best 'stratified' with reference to synoptic type. The choosing and sifting of predictors is a perennial regression problem and Meg Brady Carr (USA) described some new techniques in this field. Ulla Hammarstrand (Sweden) presented some interesting work on the prediction of the probability of convective precipitation from model output. Speculation arose, during discussion, as to what extent the mental processes of the local forecaster might eventually be duplicated by computer—a concept which no doubt prompted one or two wry smiles.

An important topic at the Symposium was that of verification and evaluation of forecasts. Ideas were clarified by Silvert (Canada) who gave mathematical formality to concepts such as the 'effectiveness' and 'strength' of a forecast. Mason (Australia) extended the topic into the cost–loss situation and decision theory. Considerable ingenuity is often devoted to the definition and analysis of skill scores and papers by Rousseau (France) and Preisendorfer (USA) were not lacking in this respect. Murphy strongly advocated probabilistic as opposed to categorical wording, even for routine short-term forecasts for the general public. Certainly the probabilistic format is particularly well suited for input to decision-making machinery. Winkler (USA) gave a useful introduction to the allied subject of Bayesian strategy.

No great optimism surrounded the topic of long-range forecasting although a plea for its interment was rather premature bearing in mind the range of material and methods as yet untried. A number of papers were read in which discriminant analysis and other multivariate techniques featured. Juien (China) reported some success in forecasting monthly mean temperature anomalies using a combination of dynamical parametrization and factor analysis, while good results were obtained by Kung and Sharif (USA) in regressing the onset of the Indian summer monsoon upon upper-air parameters. One or two workers had used ARMA (autoregressive–moving average) models of time series in attempts to project forward time-averaged fields. The Russians Gruza and Rankova submitted a paper on the evaluation of hemispherical analogue methods. They concluded that a combination of several analogues was superior to a single best match, but that the statistical record was insufficient for any noticeable improvement over climatology. Indeed, with underlying irregular long-period oscillations apparent in many meteorological time series and forcing mechanisms, one can only speculate on what might constitute an adequate data base for analogue techniques, even ignoring the additional complications stemming from man's activities. Predictability *per se* and methods in the frequency domain received relatively little airing. The writer presented an unscheduled paper in which a method of compensating for the Slutzky–Yule effect in the autocorrelation of filtered time series was developed and the result applied in investigating atmospheric coherency on certain time scales.

With the advent of statistical computer packages, cluster, canonical and discriminant analysis are becoming increasingly widely used. Discriminant methods have now been applied to the prediction of tropical storm formation and tracking with some success (Lowe, USA; Li and Yao, China). Two non-meteorological statisticians addressed the Symposium: C. W. Granger (USA, formerly UK) discussed new developments in time-series modelling, while I. Jolliffe (University of Kent) gave a review of multivariate methods. In pointing out that the last eigenvector of a joint predictor–predictand domain can be used for forecasting, Jolliffe provided an unexpected topic for discussion.

In a final session it was decided to recommend to the WMO that a standard set of guidelines for the verification of forecasts be prepared and published. It was also considered desirable that further research should be undertaken in specific areas in which statistical methods are most likely to prove useful, for example the quantification of uncertainty in forecasts.

Despite the congestion of papers, most of which cannot be mentioned in this brief synopsis, not all the time was spent in the conference room. The organizers laid on an outing to Monaco along the beautiful coastal corniche and contrived an odoriferous if potentially expensive halt at a perfumery. The Casino visit did not find those statisticians most preoccupied with Monte Carlo methods particularly anxious to test their convictions against the Bank. Memories will linger of the balmy September evenings of the Côte d'Azur.

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Dendroclimatology Workshop

By D. E. Parker
(Meteorological Office, Bracknell)

The Second International Global Dendroclimatology Workshop was held at the Climatic Research Unit, University of East Anglia, Norwich, from 7 to 11 July 1980. The presence of scientists from the Academia Sinica, Peking, along with others from North and South America, Australasia, southern Africa, west and east Europe and the eastern Mediterranean was noteworthy.

Participants discussed two main areas of concern: the availability of adequate data, and the development and global dissemination of satisfactory methods of analysis and interpretation.

The best existing networks of dendroclimatological data are for western North America and for limited areas elsewhere, mainly in America, Europe and Australasia. Serious gaps exist in Europe, Asia and the Arctic and there is an almost total absence of data from the tropics where tree rings may not be annual. The southern hemisphere, being mostly ocean, can never be adequately covered. There are plans to acquire more data for some of the gaps in mid-latitudes, but rapid progress is unlikely owing to the lack of finance, difficulties of access, and the need for representative sampling in locations where climate is a major limiting factor on tree growth. Problems of systematic data archival at Tucson, Arizona, were discussed at length.

The interpretation of dendrochronologies is an even greater problem than the acquisition of data. Difficulties include elimination of poorly understood biological factors which may affect a whole area, such as pests, diseases, human activities and ageing of stands of coeval trees. Statistical methods of removing slow 'biological' trends, even from multi-sample chronologies, may contaminate any record of actual climatic change. Furthermore, the influence of climate on trees may be limited to particular seasons, so that the climatic record is incomplete. Even X-ray densitometry, which appears to isolate a stronger climatic signal than ring-width measurement, appears to show the influence of only certain seasons. The benefits of isotopic studies of tree wood have yet to be proven.

Dendroclimatologists have become more aware of the need for verification of results using independent climatic data, and have urged that more early instrumental meteorological data be made available for this purpose. The need was stressed for adequate testing of the statistical significance of results, and also for a realization of the need for practical appreciation of the meaning of 'significance'. For instance, a correlation of 0·3 is significant at the 5% level for 46 or more pairs of data, but only 9% of the variance is thereby shown to be common between the two sets of values. It is often difficult to assess the statistical significance of results of highly complex operations such as the production of eigenvectors of the surface-pressure field from eigenvectors of the spatial network of tree-growth, and it is here that verification using independent data is vital.

The Workshop was supported by the World Meteorological Organization, the United Nations Environment Programme, the Scientific Affairs Division of NATO and the United States National Science Foundation. The Workshop was organized by Dr M. K. Hughes of Liverpool Polytechnic, Dr P. M. Kelly of the Climatic Research Unit and Dr J. Pilcher of Queen's University, Belfast.

Letter to the Editor

Civil Defence—meteorological advisers to local authorities

Your readers will be aware of the current concern over the very inadequate level of Civil Defence arrangements at present provided in the United Kingdom. The recent statement made by the Home Secretary, the Rt Hon. W. Whitelaw, on the higher priority to be given to county council emergency planning teams, encouraged the use of volunteers.

One category of volunteers that already exists has, for many years, included a number of meteorological officers. I refer to the scientific adviser groups that all county councils maintain. These volunteers, drawn from a wide spectrum of scientific disciplines, can be an important source of expert advice for local authority chief executives in a major civil disaster, or in the event of war as a result of a nuclear strike against this county.

There is an obvious relevance of meteorological conditions to the development of many major civil disasters, e.g. Flixborough and the recent Canadian rail disaster at Missasauga. The prediction of fall-out deposition patterns and the dispersal of toxic gas clouds are of vital importance to local authorities.

Many serving meteorological officers have a war role in the event of an outbreak of hostilities. It is therefore difficult for county emergency planning officers to recruit this important category of volunteer, even if there is a meteorological station in the county.

I would therefore like to appeal through your columns to meteorological officers about to retire, or those who have recently retired, to contact either myself or the county emergency planning officer of their county council. Most counties have a very talented and interesting group of scientific adviser volunteers who undertake training which is jointly sponsored by the Home Office and county councils. The commitment is not a heavy one but one of vital importance.

J. P. Whittaker
(County Emergency Planning Officer)

Royal County of Berkshire,
Department of Emergency Planning,
Shire Hall, Reading.

Obituary

We record with regret the death on 9 April 1980 of Mr J. C. McDougall, Senior Scientific Officer, of the Synoptic Climatology Branch. Jack McDougall joined the Office in 1964 as an Assistant Experimental Officer in the High Atmosphere Branch. After some forecasting training and experience he was detached from the Office in November 1968 for two years to assist Professor R. C. Sutcliffe (formerly Director of Research in the Meteorological Office) at the University of Reading. In the next ten years he served in a number of posts both at outstations and Headquarters, including Lossiemouth, Meteorological Office College (as an instructor) and Forecasting Research. From 1971 to 1975 he studied for a degree in mathematics with the Open University and was awarded First Class Honours in January 1976—the first member of the Meteorological Office to graduate in the Open University. He and his wife Valerie—who had herself at one time been an Experimental Officer in the Office and who graduated in the Open University at the same time as her husband—were keen members of the Bridge Club and played together as partners in the First Team.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

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