CENTRAL FORECASTING TECHNICAL NOTE NO.6

RESULTS OF THE TRIAL OF THE SCHEME TO REPOSITION FEATURES IN A MODEL ANALYSIS BY USE OF BOGUS DATA

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1. INTRODUCTION

One of the recurrent model problems which has been identified is that of the analysis and subsequent forecasts wrongly locating the position of model features, most notably depressions, due to background errors coupled with the limited impact a small amount of data can have on a well established feature or the lack of any data at all. In many of these cases the model's structure of the feature is good, but horizontally displaced. The position of depression centres over sea areas, for example, can usually be more accurately placed by satellite imagery than by the usually small number of observations available. In cases such as these the limited amount of bogussing the Intervention Forecaster (IF) has time to perform often has only a minor impact since it is usually confined to a small area near the depression centre and often just at the surface. The results below are for a scheme which uses the model's background field (assuming it appears to have a good structure) to create a set of bogus data across a three-dimensional area around the depression and insert it back into the next model run displaced horizontally by a distance corresponding to the perceived model error.

The scheme has several advantages over traditional bogussing methods:-

a) Bogus data are generated across a far wider three-dimensional area than usually achieved by traditional methods which will increase the impact on the model analysis.

b) Since the bogus data are based on model fields which are considered to be good they are likely to be more representative and accurate than those derived from other bogussing methods where a certain amount of guess work is involved. The scheme can also maintain any asymmetric structure present in a tropical cyclone circulation or depressions elsewhere which the present automated bogussing procedure used in the tropics destroys since it assumes a symmetric circulation and a fixed vertical wind shear.

c) The time taken for the IF to enter the information required to produce such a large set of bogus data is vastly reduced allowing more time for other intervention.

2. PRINCIPLES OF THE SCHEME

The IF is supplied with an alphanumeric panel as part of the bogus menu via which the required information can be entered. This information includes the following:-

a) Latitude/longitude of the background field's position of the feature.
b) Mean sea-level pressure (MSLP) at the point above.
c) Latitude/longitude of the corrected position of the feature.
d) An indication as to whether surface, upper air or both types of bogus data are to be generated.
e) Upper and lower limits of upper air data (if required).

f) Model into which the bogus data are to be inserted (global or limited area).

g) Bogus grid size option.

This information, supplied by the IF, is passed to the observation processing programs on the Cray via the intervention dataset and intervention processing programs. The automated scheme, which is part of the observation processing system, then creates a set of bogus data based on the model's background field and inserts it back into the next model run at positions displaced by the required amount. The types and three-dimensional extent of the bogus data are discussed in sections 2.1 and 2.2 below.

2.1 Types of Data used

If surface bogus data are required the scheme will generate observations of MSLP and 10m wind speed and direction for insertion into the model. If these happen to fall over land the model quality control will flag the bogus wind data.

If upper air bogus data are required the scheme will generate temperatures and wind speeds and directions at some or all of four levels which lie between the limits specified. These levels are 850mb, 700mb, 500mb and 250mb. The option to suppress the generation of bogus data above or below particular levels was included so that the scheme can be used in cases when, for example, there is a good coverage of AIREP observations which should be assimilated into the model and complemented by bogus data at lower levels only.

At the planning stage, it was decided not to include relative humidity (RH) bogus into the scheme. Results from "A Trial of the Impact of Bogus Data in the Fine-Mesh Model" (Central Forecasting Technical Note No.4) show that RH bogus has the greatest impact of all bogus data types on the model. However, Unified Model RH fields are known to be unreliable at times and hence inserting these values at several different levels over a wide area back into the model was felt to be a potentially hazardous exercise, particularly in the case of tropical cyclones where the insertion of RH bogus data has been known to produce rapid deepening of systems in the past. During the trial, the RH fields would be closely monitored to assess the impact of this decision on the analysis and forecast.

2.2 Areal Extent of the Bogus Data

The bogus data are generated on a regular grid with a fixed distance between each bogus point. During the trial, bogus point separations of between 400km and 500km were used for the global model (200km to 250km for the limited area model (LAM)). It is important that the bogus data generated adequately cover both the areal extent of the feature in the background field and in its corrected position, but without encroaching on other nearby features which do not require repositioning. This is achieved by offering the IF a set of bogus grid area options from which to choose. The smallest grid area option available is a 2x2 grid of bogus data i.e. 400x400km for a 400km bogus point separation. The largest grid area option available for global runs is a 5x5 grid of bogus data i.e. 1600x1600km for a 400km bogus point separation. The centre of the grid of bogus data generated is positioned half way between the model's position of the feature and the corrected position so as to equally cover the areas where the feature is in the background field and where the IF feels it should be.

2.3 Safety Checks

It is likely that such a powerful tool could cause significant damage to the model as well as significant improvements if a wide range of checks are not employed to detect possible problems. Most of these checks centre around the information supplied by the IF to ensure it has been correctly entered. These checks are detailed below.

a) The analysis hour supplied by the IF is checked against the model's housekeeping file to ensure that the data are inserted into the correct model run. No bogus data are generated around the feature if the times do not match.

b) The MSLP at the model's position of the feature entered by the IF is checked against the actual background fieldsfile value at this point. If there is a discrepancy of more than 5mb no bogus data are generated around the feature. This check should help detect errors in coding hemispheric indicators N, S, E and W incorrectly provided the MSLP does not happen to be the same at the incorrect latitude and longitude as at the correct latitude and longitude.

c) As a further check for errors in the positions entered by the IF, no bogus are generated if a request to shift the feature across the equator is made.

d) It is intended that the scheme should be used to attempt relatively small shifts of features over several model runs if necessary, rather than attempt a large shift all in one model run. Consequently, a limit to the shift requested has been included and is presently set to 500km. If a shift of between 500km and 1000km is requested it is scaled down to 500km. If a shift of more than 1000km is requested, no bogus data are generated at all since background errors of this magnitude are very rare and hence it is assumed that the corrected feature position has been entered incorrectly by the IF.

e) If the bogus grid area option selected is small (i.e. one or both of its dimensions are equal to the bogus point separation) the maximum shift allowed is halved to 250km to ensure that the bogus data will cover both the area where the feature is in the background field and also the area around the corrected position.

f) For LAM runs a check is made for individual bogus points falling outside the model area or within one grid-point of its boundary. If this check is positive no attempt is made to generate bogus data at this point.

g) In line with checks on traditional bogus data, no bogus data are generated by the system at points which lie over orography greater than 1000m in height.

h) On a bogus grid of, say, 25 points it would be unsatisfactory for a significant number not to generate bogus data due to the checks in f) and g) above since this could result in a partial shift of a feature produced by the remaining bogus points. Hence, if more than 25% of a grid of bogus points are "flagged" by the checks in f) and g), no bogus data are generated at all around the feature since it is considered that a partial shift of a feature could be worse than no shift at all.

i) It is possible to use the scheme to reposition several features in the same model run. However, it is clearly undesirable for independent areas of bogus data to overlap. Hence, each separate grid of bogus data is checked against previous grids already generated and if they overlap or come within one bogus point separation of each other no bogus data are generated on the latest grid.

3. RESULTS OF THE TRIAL

A total of 9 cases have been used to test the impact of the scheme on model analyses and forecasts. Each case was identified by one of the duty IFs as having a feature (usually a depression) misplaced in the model's background field which required repositioning. This was achieved by use of satellite imagery or isolated observations. The cases were rerun by eliminating all traditional bogus and substituting bogus data supplied by the scheme. Single cycle assimilations and forecasts were run and comparisons made with parallel runs using operational bogus data only and using no bogus data at all. Since the scheme's main use is in data sparse areas, the forecasts were verified against operational analyses although it must be borne in mind that these could be biased towards the operational forecasts since the positional error present in the initial background field may still be present in the verifying analysis if there were little or no data (bogus or other) to correct the error in the intervening operational model runs.

The results from each case are detailed below. The following abbreviations will be used : COP for operational runs of the model, RBG for runs with "reposition" bogus data generated by the new scheme and NOBG for runs with no bogus data. All references to shifts achieved are relative to the background field.

3.1 Case 1

Feature	: Tropical cyclone FEFA
	: North-east Pacific Ocean
Data time	: 00Z 01.08.91
Background position	: 16.6N 117.9W
Corrected position	: 15.7N 119.5W
Bogus vertical profile	: Surface and all four levels
Bogus horizontal profile	: 800km x 800km
Bogus point separation	: 400km (Global model)

In this first test of the scheme the tropical cyclone centre was successfully shifted 1.1 degrees west and 0.9 degrees south in the MBG analysis. The COP analysis achieved a shift of less then 0.4 degrees west and south using the tropical cyclone bogussing facility presently available to the Intervention Bench. Both analyses maintained a central pressure of 1002mb. In the forecast, RBG gave a slightly better position at all times up to T+96 by which time both forecasts had erroneously dissipated the tropical cyclone. Figs.1(a) to 1(d) show the T+24 RBG, COP and NOBG forecasts and the corresponding verifying analysis. These indicate the improvement in the forecast position using the new scheme. However, it must be noted that the verifying analysis was still in error as the Tropical Cyclone Advisory position was 16.5N 122.7W at the verifying time as marked on Fig.1(d) - further south than analysed by the model. No further experiments were carried out on this case.

3.2 Case 2

Feature	:	Depression off Norwegian coast
Data time	:	06Z 03.09.91
Background position	:	70.0N 9.0E
Corrected position	:	70.0N 4.0E
Bogus vertical profile	:	Surface and all four levels
Bogus horizontal profile	:	1000km x 1000km
Bogus point separation	:	250km (LAM)

In this first test of the scheme in the LAM the depression was shifted approximately 80% of the distance required in the RBG analysis and the centre was filled by 1mb more than the NOBG analysis. The small number of operational bogus data supplied had a negligible impact on the COP analysis. The RBG forecast was better up to T+18 as it correctly held the depression centre further west than the NOBG forecast. Beyond T+18 a dual centre developed on the system and both forecasts incorrectly deepened the northernmost centre. However, the MBG forecast continued to linearly maintain the depression centre's position some 3-4 degrees further west than the NOBG forecast. Figs.2(a) to 2(c) show the T+6 RBG and NOBG forecasts and the corresponding verifying analysis, indicating the improved short-term forecast produced by the new scheme.

3.3 Case 3

Feature	:	Thickness ridge to west of
	:	Newfoundland
Data time	:	12Z 09.09.91
Background position	:	52.5N 48.0W
Corrected position	:	53.5N 44.0W
Bogus vertical profile	:	Three upper levels only
	:	(850,700,500mb)
Bogus horizontal profile	:	500km x 1500km
Bogus point separation	:	250km (LAM)

When the scheme was originally proposed, it was envisaged that it might be used to reposition not only complete depressions, but also features such as frontal systems. In order to assess the scheme's usefulness in this type of situation the following case was tested.

The duty IF felt that the limited area model's background field correctly positioned the depression centre, but the thickness ridge needed repositioning to the east-north-east on the basis of satellite imagery. In the test, this was attempted by bogussing a rectangular swathe of data across the zone of the ridge at 850, 700 and 500mb only. In the RBG analysis the result was a successful shift in the thickness ridge, but a considerable reduction of its warmth. Note the positions of the 558dam thickness isopleth in Figs.3(a) and 3(b) (the RBG and COP analyses). Despite no surface bogus being generated, the RBG analysis MSLP field still adjusted to the upper bogus producing a shift in the eastern half of the depression centre, a loss of 6mb of central pressure and the spurious accentuation of the trough to the south west of the depression. This is shown in Figs.3(c) and 3(d).

All these effects were maintained into the forecast which resulted in the COP forecast generally being better than the RBG forecast. By T+30 the RBG forecast had too shallow a depression centre and seems to have a double frontal structure brought about by the development of the spurious surface trough in the analysis. Figs.3(e) to 3(g) show the T+30 RBG and COP forecasts and corresponding verifying analysis.

A further experiment was carried out which involved inserting bogus in the thickness ridge zone as before, but also using the scheme to generate a set of surface bogus data to support the background field in the hope of maintaining the surface depression's position in the analysis. However, the result was only a marginal improvement on the earlier RBG analysis.

From this case, it would appear that the scheme cannot be used to attempt a shift of a thickness ridge only without expecting an effect at the surface since the upper-air bogus data generated by the scheme not only adjusts upper fields, but also fields at the surface during the assimilation in order to maintain the model's equilibrium.

3.4 Case 4

Feature	: Depression in Southern Ocean
Data time	: 00Z 05.09.91
Background position	: 61.0S 19.0E
Corrected position	: 57.7S 15.0E
Bogus vertical profile	: Surface and all four upper levels
Bogus horizontal profile	: RBG1 = 1500km x 1500km
	: RBG2 = 1200km x 1200km
	: RBG3 = 1600km x 1600km
Bogus point separation	: RBG1 = 500km
	: RBG2/3 = 400km (Global model)

In this first test of the scheme on a large mid-latitude depression, the opportunity was taken to investigate the impact of various bogus point separations and horizontal profiles on the scheme's performance.

Three experiments were run and will be referred to as RBG1, RBG2 and RBG3. The parameters used for these experiments are detailed above. The shift being attempted in this case was near the maximum allowed by the scheme. In the analysis, virtually the whole of this shift was achieved, but at the expense of up to 6mb in central pressure. Figs.4(a) to 4(d) show the RBG3 and NOBG MSLP and 500mb height and thickness analyses. These indicate that the scheme successfully shifted surface and upper air features alike. The RBG3 analysis was marginally better, positionally than RBG1 and RBG2, but lost 1mb more central pressure.

Unfortunately, all the forecasts were significantly in error by T+48, so verification is difficult. At T+24 the RBG3 and NOBG forecasts were fairly similar, having eliminated the 6mb difference between them present in the analysis. Although the NOBG forecast located a depression centre in the same place as the verifying analysis, the RBG3 forecast gives a better hint of the dual structure of the system (see Figs.4(e) to 4(g)). However, as mentioned at the start of this section, the verifying analysis' depression centre may still have been located too far south by the model had the error identified 24 hours earlier not been corrected operationally.

A comparison of the three RBG experiments shows minor differences between them, but the following conclusions were made. RBG3 achieved a slightly larger shift than RBG1 due to its closer bogus spacing and slightly larger areal extent, but at the expense of an extra millibar of central pressure. Since the concensus of opinion amongst the IFs is that a modest loss of central pressure is a price worth paying to achieve a shift in a depression's location and the loss of central pressure is, in fact, recovered by T+24 in this case, it was concluded that the RBG3 experiments parameters gave a better result. For the same reasons the RBG3 forecast was concluded to be better than the RBG2 forecast. This was due totally to the larger areal extent of the bogus data used by the RBG3 experiment since their bogus point separations were the same. This emphasises the need to supply the IF with a range of area options which will adequately cover large mid-latitude systems of this kind.

3.5 Case 5

Feature	: Ex-typhoon Ivy in north Pacific
	: Ocean
Data time	: 00Z 12.09.91
Background position	: 47.5N 179.0E
Corrected position	: 46.2N 178.3W
Bogus vertical profile	: Surface and all four levels
Bogus horizontal profile	: MBG1 = 1600km x 1600km
	: MBG2 = 1800km x 1800km
	: MBG3 = 2000km x 2000km
Bogus point separation	: MBG1 = 400km
	: MBG2 = 450KM
	: MBG3 = 500KM (Global model)

In this case a mature ex-typhoon required repositioning across the 180 degree longitude line in the north Pacific Ocean. This case was again used to test three different bogus point separations to establish an optimum value. All experiments involved the insertion of bogus data at 25 separate points on a 5x5 grid.

Figs.5(a) to 5(d) show that the scheme successfully shifted the surface depression and its associated upper fields as required, but, in the case of the RBG1 experiment, filled the depression by 2mb more than the NOBG analysis and also altered the shape of the centre. This shift was again maintained into the forecast and at T+24 the RBG1 and NOBG forecast positions of the depression lie either side of the verifying analysis' position (see Figs.5(e) to 5(g)). Notably, the RBG forecast has again more than recovered the central pressure lost in the analysis. Particularly of note at T+24 is the RH field. Since RH bogus are not generated by the scheme, it was a concern that the scheme may shift a depression, but leave the associated RH field in its original position. In fact, in the analysis the shift in the RH fields was minor when compared with, for example, the MSLP field. However, by T+24 the model's RH fields had adjusted to the other directly shifted fields and, as Figs.5(h) and 5(i) show, the RBG1 700mb RH field had been shifted to the south and east in the vicinity of the depression.

By T+72 both the RBG1 and NOBG forecasts gave a good prediction of the development. As Figs.5(j) to 5(l) show, the NOBG forecast gave a slightly better positional forecast of the now complex system, but the RBG1 forecast represented the relative depths of the two centres better. Overall, neither forecast can be said to be better than the other in this case.

A problem which occurred when running the RBG1 experiment was that two of the MSLP bogus observations generated were flagged by the model quality control both on the background and buddy checks. Their increments were 16 and 17mb and they were positioned in the tight gradient to the north and west of the depression centre. Clearly, in the northern hemisphere, where background errors are smaller, increments of this size are not acceptable to the quality control. No buddy checking is performed between bogus observations and there were no nearby observations which supported the bogus observations, so the final quality control decision was based on the background check alone. Experiment RBG2 was run with a 450km bogus spacing and this raised no background flags and just one buddy check flag due to conflict with a nearby observation. With a spacing of 500km (RBG3) no flags were raised at all. The RBG3 analysis shift was slightly less than RBG1 and RBG2 which were similar although RBG2 lost 1mb less central pressure than RBG1.

From the results above it was concluded that 400km was too small a spacing for bogus observations since the areas of influence of each bogus observation in the assimilation overlap sufficiently to result in the loss of more central pressure than for a larger spacing, as in the RBG1 experiment. This problem will occur particularly when there are tight gradients around the depression and adjacent bogus increments are considerably different. 500km would seem a safer separation, but in this case the shift achieved was not so large as for a 450km spacing which indicates that 450km is the optimum value to allow the maximum shift with the minimum overlap of the bogus data's area of influence in the assimilation.

3.6 Case 6

Feature	: Depression to the west of Portugal
Data time	: 00Z 06.09.91
Background position	: 39.5N 26.0W
Corrected position	: 41.0N 24.0W
Bogus vertical profile	: Surface and all four levels
Bogus horizontal profile	: 1350km x 1350km
Bogus point separation	: 225km (LAM)

In this case approximately two-thirds of the required positional shift of the depression was achieved in the RBG analysis and, unlike other cases, no central pressure was lost when compared with the NOBG analysis. The forecast development of the depression was similar in both the RBG and NOBG forecasts, but the RBG forecast maintained the depression slightly north and east of the NOBG centre. When compared with verifying analyses, the RBG forecasts were positionally marginally better at all times, but were 1mb deeper than the NOBG forecasts. The depression, in fact, filled quicker than either forecast indicated.

An example of the forecast improvement achieved can be seen at T+12. Figs.6(a) to 6(c) show the MSLP forecasts and verifying analysis. Although neither forecast picked up the strong asymmetric structure of the depression, RBG gave a better position of the centre. Other fields were examined to confirm that they reacted in a similar manner to the MSLP field. Figs.6(d) and 6(e) show the RBG and NOBG wet bulb potential temperature T+12 forecasts. These confirm that the frontal structure has been shifted along with the depression centre. On examining the RH fields it was again found that the shift in the analysis was minor due to the lack of RH bogus data, but by T+12 the fields had adjusted to the shift in the depression (see Figs.6(f) and 6(g)). Overall, this case shows a small forecast improvement as a result of using the scheme.

3.7 Case 7

Feature	: Depression to the west of southern
	: Chile
Data time	: 00Z 20.09.91
Background position	: 53.5S 82.0W
Corrected position	: 48.0S 81.0W
Bogus vertical profile	: Surface and all four levels
Bogus horizontal profile	: 1350km x 1800km
Bogus point separation	: 450km (Global model)

This depression had been misplaced for several previous model runs (by up to 10 degrees at one stage) and traditional bogus data had reduced some of the error. However, at this data time, satellite imagery showed that the model was still considerably in error. The shift required was actually larger than the 500km allowed by the scheme so it was, in fact, scaled down to 500km by the scheme. At the time of this error the IF felt that the surface observations from Chile and Argentina were good, but the portion of the depression over the sea needed repositioning. Hence, a rectangular swathe of bogus data were created over this sea area.

Due to the large shift attempted and the fairly tight pressure gradient to the south of the depression, some of the bogus increments were very large - up to 19.7mb. However, because of large background errors in this part of the globe, no flags were raised on the bogus data by the model quality control.

Despite its size, in the analysis the depression was shifted the full required distance north and a little further east than required, but with the loss of 12mb in central pressure. Figs.7(a) and 7(b) show the RBG and NOBG MSLP analyses. Other analysis fields such as heights, temperatures, wet bulb potential temperature, winds and RH were all examined and showed shifts of a similar magnitude to the MSLP field, except the RH fields which were shifted by a smaller amount. Figs.7(c) and 7(d) show how the bogus data affected the 250mb height field in the analysis.

The forecasts show considerable success for the scheme with a marked evolutionary difference in the development of the system. At T+24 NOBG maintained a depression to the west of Chile with a central pressure of 972mb whereas RBG pushed the depression across the land mass towards the Falkland Islands and notably recovered its central pressure to 979mb - just 7mb above the NOBG value (see Figs.7(e) and 7(f)). The verifying analysis (Fig.7(g)) shows clearly that RBG is a better forecast and in fact the central pressure of the system was even higher than the RBG forecast.

By T+48, the differences were very marked. Another depression had developed to the west of Chile, but in the NOBG forecast the original depression was nothing but an extended trough across Tierra Del Fuego (Fig.7(h)). In complete contrast, the RBG forecast had two distinct centres, the original depression being positioned near the Falkland Islands (Fig.7(i)). Again, this compares favourably with the verifying analysis (Fig.7(j)) which had a distinct centre over the Falkland Islands and also a second centre further to the east. Figs.7(k) and 7(l) show the 500mb height and thickness patterns for the T+48 forecasts and show how the RBG forecast has a cut-off upper low compared to the NOBG forecast's extended trough. Fig.7(m) is the verifying analysis. By T+72 the NOBG forecast had developed a distinct circulation to the east of the Falkland Islands, but the RBG forecast still gave better guidance.

Throughout the forecast period RH fields were again examined and, as before, it was found that the shift in the analysis was small compared to that of other fields, but during the forecast the fields adjusted to the different development brought about by the bogus data. The COP forecast was also examined which included a relatively small number of bogus observations inserted in the vicinity of the depression. In the analysis, no shift of the depression was achieved, but simply a loss of 5mb central pressure. The forecast development was almost identical to the NOBG run, but with small differences in central pressure values.

It is a fairly widespread practice amongst IFs to insert bogus data in multiples of two, five or sometimes as much as nine at each required location and it is recognised that the IF may be tempted to use this scheme in a similar manner in an attempt to achieve the maximum impact in the data assimilation. Hence, two further experiments were run to assess the use of the scheme in this way. The RBG forecast was run again, but with two identical bogus observations at each location. The analysis and forecast evolution were found to be identical apart from the depression centre retaining 1mb more of its central pressure. A further experiment was run with five bogus observations at each location (RBG X 5) and, interestingly, the results were quite different. In the analysis the depression lost 3mb less central pressure, but the shift achieved was less than 20% of that in the RBG analysis. Consequently, the forecast showed significant differences. At T+24 the depression centre was correctly located near the Falkland Islands, but a secondary centre was maintained to the west of Chile (see Fig.7(n)). The later forecasts were also slightly poorer, since they continued to maintain the trough across Tierra Del Fuego rather than develop a col as in the RBG forecasts and verifying analyses. These results show that inserting multiple sets of bogus data cannot be guaranteed to improve the analysis or forecasts of a system. However, in this case, a single set of bogus data has been shown to make a significant improvement to the forecast evolution of a southern hemisphere depression.

3.8 Case 8

Feature	: Small wave depression in mid-North
	: Atlantic Ocean
Data time	: 00Z 11.09.91
Background position	: 37.1N 39.9W
Corrected position	: 36.0N 38.8W
Bogus vertical profile	: Surface and all four levels
Bogus horizontal profile	: 900km x 900km
Bogus point separation	: 225km (Limited area model)

In this case a relatively small shift of a wave depression was required and about two-thirds of this shift was achieved in the RBG analysis with the loss of 2mb more central pressure than the NOBG analysis (Figs.8(a) and 8(b)). Operationally, 94 bogus observations were entered to achieve this shift and the result is shown in the COP analysis in Fig.8(c). The shift was marginally less than in the RBG analysis, but 1mb less central pressure had been lost.

The forecasts showed some small differences in the development of the wave depression. Figs.8(d) to 8(g) show the T+24 RBG,NOBG and COP forecasts and the verifying analysis. Both the RBG and COP forecasts had correctly positioned the wave depression further south than the NOBG forecast, but the RBG forecast had a shallower feature which verifies better. All the forecasts miss the development of another depression further to the west, but the RBG forecast makes the best attempt at producing a circulation around it. Again, relative humidity fields show a small movement in the RBG analysis, but adjust to the shift in the other surface and upper-air fields in the forecast.

Overall, the COP and RBG forecasts gave a similar improvement when compared with the NOBG forecast. However, the COP analysis and forecast required 94 bogus records to be entered by the IF to achieve this. The RBG forecast required just one bogus record which produced 25 bogus observations. Clearly, the time saving which would have been achieved by using the scheme is immense.

3.9 Case 9

Feature	: Rapidly deepening secondary
	: depression in North Atlantic
Data time	: 06Z 30.10.91
Background position	: 49.2N 25.0W
Corrected position	: 51.7N 24.8W
Bogus vertical profile	: Surface and all four levels
Bogus horizontal profile	: 900km x 900km
Bogus point separation	: 225km (LAM)

In this case the scheme was tested on a rapidly deepening secondary depression which was identified as being positioned further north than in the background field from satellite imagery. Figs.9(a) and 9(b) are the RBG and NOBG analyses. These show that a shift north had been achieved, but at the loss of enough central pressure for the secondary depression to lose its distinct circulation. A problem encountered in this case was that 4 of the 25 MSLP bogus observations were flagged by the quality control, 3 of which were on the southern flank of the depression. This was due to large increments in an area with relatively small background errors. This would be responsible for the apparent "hangback" of the isobars south of the 50 degree line.

By T+12 the NOBG forecast of the depression centre was 2mb deeper than the verifying analysis, but the MBG forecast was 10mb shallower. Despite this, the RBG forecast positioned the depression centre correctly whereas the NOBG centre was 1.5 degrees too far south. During the remainder of the forecast the RBG run recovered much of the central pressure lost in the early stages, but became positionally worse than the NOBG forecast. Figs.9(c) to 9(e) show the T+36 RBG and NOBG forecasts and the verifying analysis. The RBG forecast's central pressure is better, but the depression centre is too far south and the troughing to the north is too severe.

Although in previous cases it has been said that the loss in central pressure is a price worth paying to obtain a correct position, in most of these cases the depressions were at a mature stage and starting to fill. In this case the depression was rapidly deepening and so the loss of central pressure caused by using the scheme was accentuated and was more important than in other cases since it had a significant impact on the forecast wind strength near the depression centre. Again, some of the central pressure lost was recovered in the later stages of the forecast, but by then RBG was not so good positionally. Hence, it must be concluded that the scheme is not ideally suited for use on rapidly deepening depressions since the loss in central pressure usually experienced could have a greater negative impact on the forecast than in cases of mature depressions, the forecasts of which are sometimes improved by the loss in central pressure.

4. SUMMARY

The following points summarise the characteristics of the scheme identified during the running of the test cases.

1. The success of the scheme in the analysis was variable; on occasions the total shift required was achieved, on others only a part, but in nearly all cases more than 50% of the required shift was achieved in the analysis.

2. All primary model fields examined were shifted in the analysis; MSLP the most and RH the least.

3. The greater the shift achieved by the scheme, the greater the loss in central pressure of the depression occurred in the analysis.

4. The central pressure lost in the analysis was often partially or wholly recovered during the forecast.

5. RH fields which showed little shift in the analysis frequently adjusted to the shift achieved in other fields during the forecast.

6. Any shift achieved in the analysis was usually linearly maintained in the forecast, although it occasionally amplified.

7. The scheme achieved most success on well established, mature depressions.

8. The scheme's worst performances were on a thermal ridge and a rapidly developing secondary depression.

9. 450km is the best bogus point separation for the global model.

10. 225km appeared to work well as a bogus point separation for the LAM. However, prior to operational implementation in the LAM tests will be carried out on a larger spacing since it is appreciated that the observational radius of influence for the LAM is not half of that for the global model, but their values are approximately in the ratio 1:1.2. Also, further cases need testing in order to examine the impact of the scheme on rainfall fields.

11. Best results were achieved using surface bogus and bogus at all four upper levels. When all levels were not used, the model fields at the unused levels still attempted to adjust to the bogus data. Levels should only be omitted when good quality observational data is present.

12. If a large shift is attempted and the depression has a tight MSLP gradient, there is a possibility of bogus observations being flagged by the quality control, particularly in the northern hemisphere.

13. Flagging of parameters other than the MSLP in the bogus observations is unlikely.

14. Conflict with observations near to the bogus data is possible which may result in quality control flags being raised. However, it must be noted that if there is a large amount of real data near the feature, the scheme should not be used. Similarly, if there is a very small amount of real data, the bogus data generated by the scheme is likely to achieve a much greater degree of success in moving the whole of the model's feature even if the real data are flagged in the process.

5. CONCLUSIONS

From the selection of cases used to test the new bogussing facility, it is clear that it can have a beneficial impact on both analyses and forecasts when used correctly. In one case a significant improvement in the forecast evolution was achieved by use of the scheme. The only cases where a negative impact occurred were when trying to shift a thermal ridge and a rapidly deepening secondary depression, so it must be concluded that the scheme's use should be restricted to established depressions only, where most success was achieved.

Although it is a fairly cumbersome value to deal with, a bogus point separation of 450km is recommended for the global model with area options ranging from 450km x 450km for small tropical cyclones to 1800km x 1800km for larger mid-latitude systems. Creating bogus data at the surface and all four levels up to 250mb was considered to work well in areas where there is no real data available for assimilation into the model.

Having looked closely at RH fields in particular, it was felt that the lack of RH bogus data did not have a detrimental impact on the forecast fields since they appeared to adjust well to the other data. However, the impact of this on LAM rainfall fields has not been examined in these first few test cases.

It was agreed to initially implement the scheme operationally with a restriction on use to systems south of 30N. This took place on 4th February 1992. This would then enable a period of monitoring to take place and also tests on LAM rainfall fields, before considering use of the scheme in all areas of the globe. Guidelines issued to Intervention Forecaters on how to use the scheme are attached in Appendix 1. A full impact experiment of intervention in general including this new bogussing facility will also be undertaken using the parallel suite.

APPENDIX 1

GUIDELINES FOR INTERVENTION FORECASTERS ON THE USE OF THE REPOSITION BOGUS SCHEME

PLEASE READ THESE GUIDELINES BEFORE ATTEMPTING TO USE THE SCHEME

1. PURPOSE OF THE SCHEME AND GENERAL GUIDELINES

This scheme is designed to reduce the time the Intervention Forecaster will need to spend when inserting bogus data in the vicinity of tropical cyclones and mid-latitude depressions which have a good structure in the model's background field, but are wrongly located. The information required as input is detailed in Section 2. Once supplied with this information the scheme will generate its own 3-dimensional profile of bogus data based on the background field, but inserted at a corrected position in the vicinity of the feature.

Tests have shown considerable success for the scheme in achieving shifts of depressions in the analysis and subsequent forecasts, but it must be noted that the shift achieved is variable and is frequently accompanied by a loss in central pressure of the depression. However, in most cases this loss is recovered in the forecast and has little detrimental impact overall when compared with the benefits of achieving a better location of the depression.

Whilst the scheme undergoes an operational trial, its use will be restricted to depressions located south of 30N. This restriction may be lifted once the impact of the scheme has been further assessed.

In order to achieve maximum benefit from the scheme and avoid potential pitfalls the following list of "DO NOTs" should be adhered to:-

A. **DO NOT** use the scheme on shallow waves, thermal ridges, rapidly moving or rapidly deepening depressions. Tests have shown the impact can be negative in these cases. Restrict use to well defined depressions or tropical cyclones which are not undergoing rapid movement or rapid deepening.

B. **DO NOT** use the scheme unless you have access to a background field valid at the next model analysis time on which to assess the model error. The scheme always uses the background fieldsfile as the source of its data.

C. **DO NOT** attempt to complement the scheme by use of traditional or "PF9" bogus data near to the depression being shifted. The precise positions and values of the bogus data generated are determined by the scheme and are likely to conflict with any bogus data entered manually. The spacing of the bogus data generated by the scheme has also been tuned for maximum impact in the analysis, so additional bogus data could reduce this impact and cause confusion in the model when assimilated.

D. **DO NOT** insert bogus data (either traditional or by use of this scheme) around a feature in a subsequent model run having used the scheme in the previous run unless the impact of the bogus data in the previous run can be assessed. For example, the 06Z run follows immediately after the 00Z Update run, so an assessment of the impact would not be possible unless the scheme was also used in the 00Z Main run. The impact of the scheme will vary - sometimes a total shift is achieved, sometimes less than half the required shift is achieved. The loss in central pressure is also variable, so the impact must be assessed in each run individually.

E. **DO NOT** attempt to use the scheme several times at the same location in an attempt to "add weight" to the bogus data generated. The first entry only will be used and tests have shown that the use of the scheme in this way is not necessarily beneficial in any case.

F. **DO NOT** use the scheme for very small shifts (fine-tuning), but also avoid very large shifts since large increments could cause the bogus data to be flagged by the quality control. The maximum shift allowed is 500km. Shifts of up to 1000km will be scaled down to 500km. Shifts greater than this will be ignored. The maximum shift is reduced to 250km for small scale features when a small grid area option is selected.

G. **DO NOT** use the scheme in areas over or near to high ground. Individual bogus observations will not be generated over land above 1000m and if more than 25% fall into this category, no bogus will be generated at all for the block.

2. INFORMATION REQUIRED AS INPUT

For each depression which requires repositioning the following information should be input through the PF8 bogus option. An example of the panel layout is attached.

2.1 Analysis Time

This must be the validity time of the background field which is in error. Asynoptic hours should not be specified.

2.2 Latitude/Longitude of Feature in Background

This will usually be the position of centre of the depression to be shifted in the background field. However, in the case of asymmetric depressions it is preferable to specify the geometric centre of the circulation which will not coincide with the point of lowest pressure. This point is used as the centre of the grid on which the bogus values are calculated.

2.3 Mean Sea-Level Pressure at the Background Position

This value is for the point specified in 2.2 above and must be supplied purely for the purpose of checking against the actual model background MSLP value at this point. This will help eliminate possible errors in coding the position of the feature. The value entered need only be accurate to the nearest 5mb.

2.4 Corrected Latitude/Longitude of Feature

This is the position where the point stated in 2.2 above **should** be located in the Forecaster's judgement. The shift implied should not exceed 500km or 250km when the smallest of the grid area options are used (see 2.8 below).

2.5 Surface/Upper Air Selection

Select both surface and upper air bogus in all cases of depression shifts as tests show the model adjusts well to a full 3-dimensional structure of bogus data.

2.6 Upper/Lower Limits

Bogus will be generated at any of the following levels which fall within the range specified (inclusive): 850mb, 700mb, 500mb, 250mb. Use the defaults of 250mb and 850mb except in circumstances when, for example, there may be a large numbers of good AIREPs, or the feature does not extend to the top of the troposphere, in which case an upper limit below 250mb should be specified to suppress the generation of bogus data at this level.

2.7 Model Run

Whilst use of the scheme is restricted to features south of 30N use the default of "G" - global model.

2.8 Grid Area Option

This determines the size of the grid of bogus data which is used by the scheme. Select an option (0-9) which will adequately cover the feature both in its background and corrected positions - see the separate list of options available. The scheme will automatically position the grid selected to cover both the area of the feature in its background and corrected positions. In the global model bogus data generated are separated by 450km.

3. REASONS FOR NO BOGUS DATA BEING GENERATED

The bogus information records processed in each model run are listed in the intervention dataset with identifier "DBR" and are also listed in the QxxxAOIN output. The actual bogus observations generated by the scheme are listed with identifier "CFOREPBG" in the QxxxAOLP listing. These data are quality controlled in the same manner as standard bogus data. If a particular record listed in the QxxxAOIN output appears not to have generated any bogus data the reason should be one of those listed below:-

A. The depression was positioned north of 30N in its background or corrected position.

B. The hour specified was not the analysis hour.

C. The background MSLP entered was more than 5mb different from the actual background MSLP at the stated location.

D. A shift across the equator was requested.

E. The shift requested was more than twice the maximum allowed by the scheme.

F. The area of bogus overlaps or comes very close to another area of bogus data previously generated for that model run.

G. More than 25% of the individual bogus observations generated within the block are over orography above 1000m or, in the case of the LAM (not applicable yet), are outside the model boundaries. Note, if less than 25% fall into these categories only individual observations are not generated as opposed to the whole block.

If the reason does not appear to be any of the above, or you have any other queries concerning the scheme please contact me during the day or leave a note in the intervention book at night or at weekends.

Julian Heming CF5
Room 212b Ext.4494

GLOBAL GRID AREA OPTIONS

Points at which bogus data are created are denoted by * and are separated by 450km in the north-south and east-west directions. This is equivalent to approximately 4 degrees of latitude.

Option 0
1800km x 1800km

```
*   *   *   *   *

*   *   *   *   *

*   *   *   *   *

*   *   *   *   *

*   *   *   *   *
```

Option 1
1350km x 1350km

```
*   *   *   *

*   *   *   *

*   *   *   *

*   *   *   *
```

Option 2
900km x 900km

```
*   *   *

*   *   *

*   *   *
```

Option 3
450km x 450km

```
*   *

*   *
```

Option 4
1800km x 1350km

```
*   *   *   *   *

*   *   *   *   *

*   *   *   *   *

*   *   *   *   *
```

Option 5
1350km x 900km

```
*   *   *   *

*   *   *   *

*   *   *   *
```

Option 6
900km x 450km

```
*   *   *

*   *   *
```

Option 7
1350km x 1800km

```
*   *   *   *

*   *   *   *

*   *   *   *

*   *   *   *

*   *   *   *
```

Option 8
900km x 1350km

```
*   *   *

*   *   *

*   *   *

*   *   *
```

Option 9
450km x 900km

```
*   *

*   *

*   *
```

The maximum shift allowed is reduced to 250km when options 3, 6 or 9 are selected.

Please ensure that the option selected adequately covers the depression in its background position **and** in its corrected position. It is preferable to select an option which is too large rather than one which is too small since the latter may result in an elongated or troughed depression.

APPENDIX 2

SUMMARY OF FIGURES

All figures are of mean sea-level pressure fields unless otherwise indicated. "RBG" indicates rerun with reposition bogus included, "NOBG" indicates rerun with no bogus included, "COP" indicates operational run.

Figure 1(a) : RBG T+24 forecast. DT 0000 GMT 01.08.91

(b) : COP T+24 forecast. DT 0000 GMT 01.08.91

(c) : NOBG T+24 forecast. DT 0000 GMT 01.08.91

(d) : Verifying analysis. DT 0000 GMT 02.08.91

Figure 2(a) : RBG T+6 forecast. DT 0600 GMT 03.09.91

(b) : NOBG T+6 forecast. DT 0600 GMT 03.09.91

(c) : Verifying analysis. DT 1200 GMT 03.09.91

Figure 3(a) : RBG analysis. DT 1200 GMT 09.09.91
500mb height and 1000-500mb thickness

(b) : NOBG analysis. DT 1200 GMT 09.09.91
500mb height and 1000-500mb thickness

(c) : RBG analysis. DT 1200 GMT 09.09.91

(d) : NOBG analysis. DT 1200 GMT 09.09.91

(e) : RBG T+30 forecast. DT 1200 GMT 09.09.91

(f) : NOBG T+30 forecast. DT 1200 GMT 09.09.91

(g) : Verifying analysis. DT 1800 GMT 10.09.91

Figure 4(a) : RBG3 analysis. DT 0000 GMT 05.09.91

(b) : RBG3 analysis. DT 0000 GMT 05.09.91
500mb height and 1000-500mb thickness

(c) : NOBG analysis. DT 0000 GMT 05.09.91

(d) : NOBG analysis. DT 0000 GMT 05.09.91
500mb height and 1000-500mb thickness

(e) : RBG3 T+24 forecast. DT 0000 GMT 05.09.91

(f) : NOBG T+24 forecast. DT 0000 GMT 05.09.91

(g) : Verifying analysis. DT 0000 GMT 06.09.91

Figure 5(a) : RBG1 analysis. DT 0000 GMT 12.09.91

(b) : RBG1 analysis. DT 0000 GMT 12.09.91
500mb height and 1000-500mb thickness

(c) : NOBG analysis. DT 0000 GMT 12.09.91

(d) : NOBG analysis. DT 0000 GMT 12.09.91
500mb height and 1000-500mb thickness

(e) : RBG1 T+24 forecast. DT 0000 GMT 12.09.91

(f) : NOBG T+24 forecast. DT 0000 GMT 12.09.91

(g) : Verifying analysis. DT 0000 GMT 13.09.91

(h) : RBG1 T+24 forecast. DT 0000 GMT 12.09.91
700mb relative humidity

(i) : NOBG T+24 forecast. DT 0000 GMT 12.09.91
700mb relative humidity

(j) : RBG1 T+72 forecast. DT 0000 GMT 12.09.91

(k) : NOBG T+72 forecast. DT 0000 GMT 12.09.91

(l) : Verifying analysis. DT 0000 GMT 15.09.91

Figure 6(a) : RBG T+12 forecast. DT 0000 GMT 06.09.91

(b) : NOBG T+12 forecast. DT 0000 GMT 06.09.91

(c) : Verifying analysis. DT 1200 GMT 06.09.91

(d) : RBG T+12 forecast. DT 0000 GMT 06.09.91
850mb wet bulb potential temperature

(e) : NOBG T+12 forecast. DT 0000 GMT 06.09.91
850mb wet bulb potential temperature

(f) : RBG T+12 forecast. DT 0000 GMT 06.09.91
850mb relative humidity

(g) : NOBG T+12 forecast. DT 0000 GMT 06.09.91
850mb relative humidity

Figure 7(a) : RBG analysis. DT 0000 GMT 20.09.91

(b) : NOBG analysis. DT 0000 GMT 20.09.91

(c) : RBG analysis. DT 0000 GMT 20.09.91
250mb height

(d) : NOBG analysis. DT 0000 GMT 20.09.91
250mb height

(e) : RBG T+24 forecast. DT 0000 GMT 20.09.91

(f) : NOBG T+24 forecast. DT 0000 GMT 20.09.91

(g) : Verifying analysis. DT 0000 GMT 21.09.91

(h) : NOBG T+48 forecast. DT 0000 GMT 20.09.91

(i) : RBG T+48 forecast. DT 0000 GMT 20.09.91

(j) : Verifying analysis. DT 0000 GMT 22.09.91

(k) : NOBG T+48 forecast. DT 0000 GMT 20.09.91
500mb height and 1000-500mb thickness

(l) : RBG T+48 forecast. DT 0000 GMT 20.09.91
500mb height and 1000-500mb thickness

(m) : Verifying analysis. DT 0000 GMT 22.09.91
500mb height and 1000-500mb thickness

(n) : RBG X 5 T+24 forecast. DT 0000 GMT 20.09.91

Figure 8(a) : RBG analysis. DT 0000 GMT 11.09.91

(b) : NOBG analysis. DT 0000 GMT 11.09.91

(c) : COP analysis. DT 0000 GMT 11.09.91

(d) : RBG T+24 forecast. DT 0000 GMT 11.09.91

(e) : NOBG T+24 forecast. DT 0000 GMT 11.09.91

(f) : COP T+24 forecast. DT 0000 GMT 11.09.91

(g) : Verifying analysis. DT 0000 GMT 12.09.91

Figure 9(a) : RBG analysis. DT 0600 GMT 30.10.91

(b) : NOBG analysis. DT 0600 GMT 30.10.91

(c) : RBG T+36 forecast. DT 0600 GMT 30.10.91

(d) : NOBG T+36 forecast. DT 0600 GMT 30.10.91

(e) : Verifying analysis. DT 1800 GMT 31.10.91

DT 00Z THUR 1/ 8/91 VT 00Z FRI 2/ 8/91

T+ 24

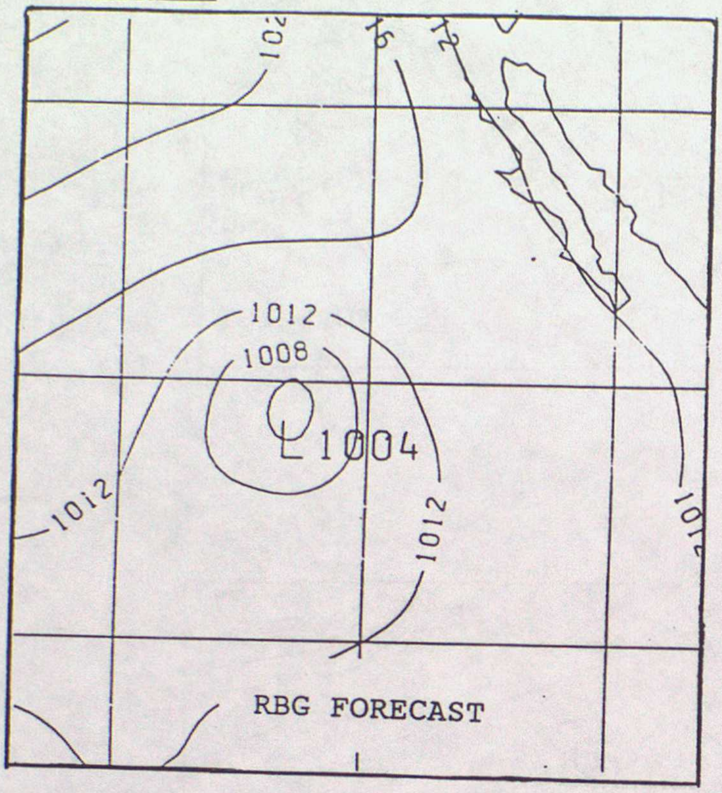

FIGURE 1(a)

T+ 24

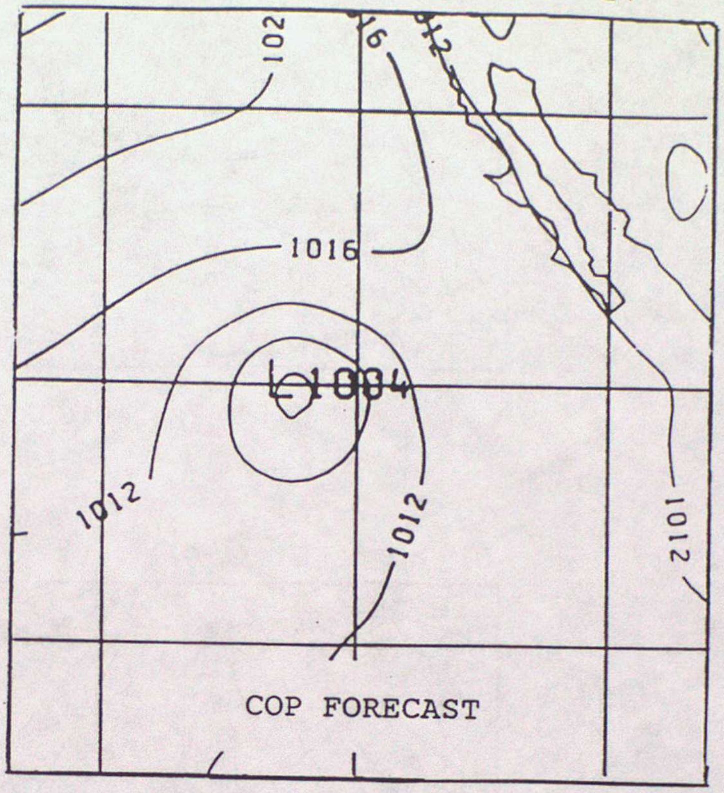

FIGURE 1(b)

DT 00Z THUR 1/ 8/91 VT 00Z FRI 2/ 8/91

T+ 24

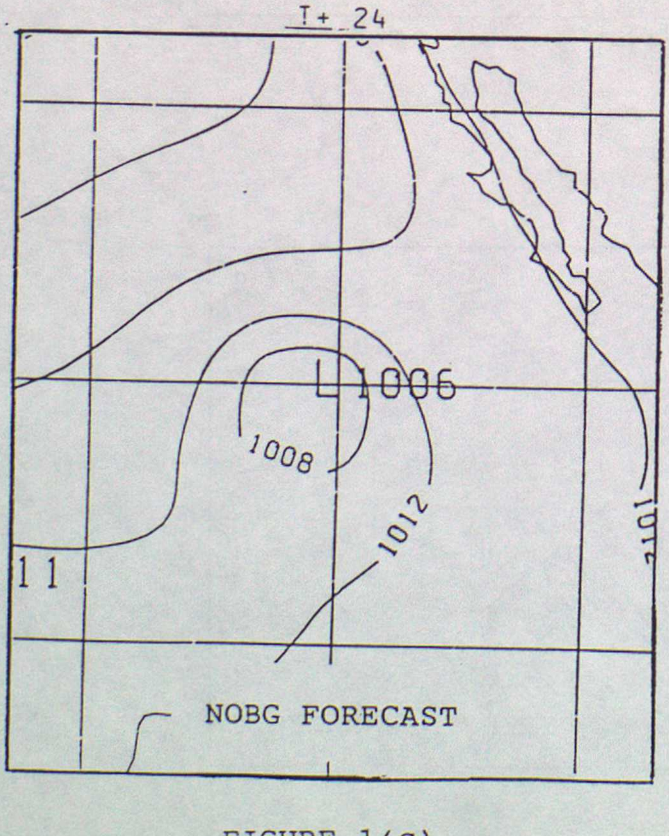

FIGURE 1(c)

DT 00Z FRI 2/ 8/91

T+ 0

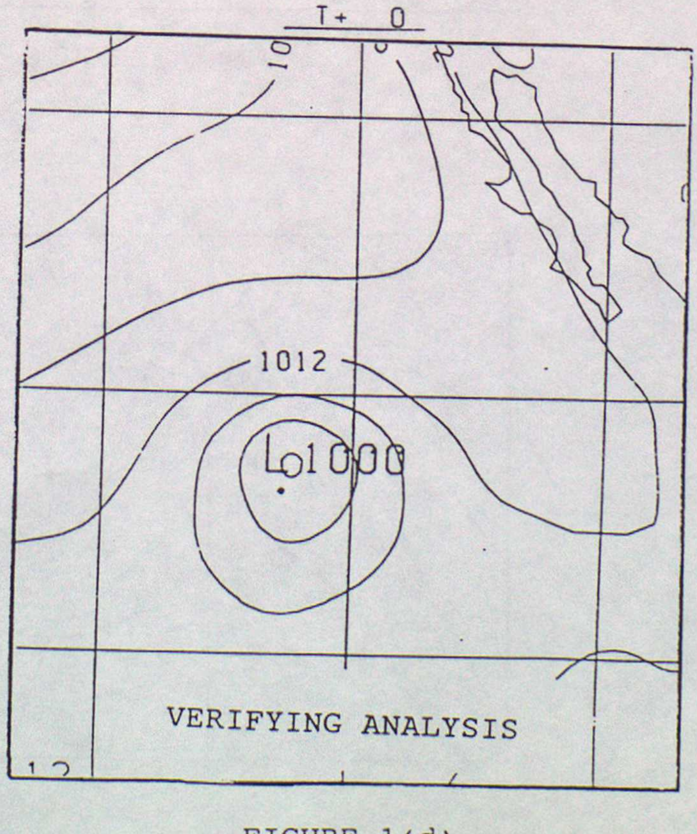

FIGURE 1(d)

DT 06Z TUES 3/ 9/91 VT 12Z TUES 3/ 9/91 T+ 6

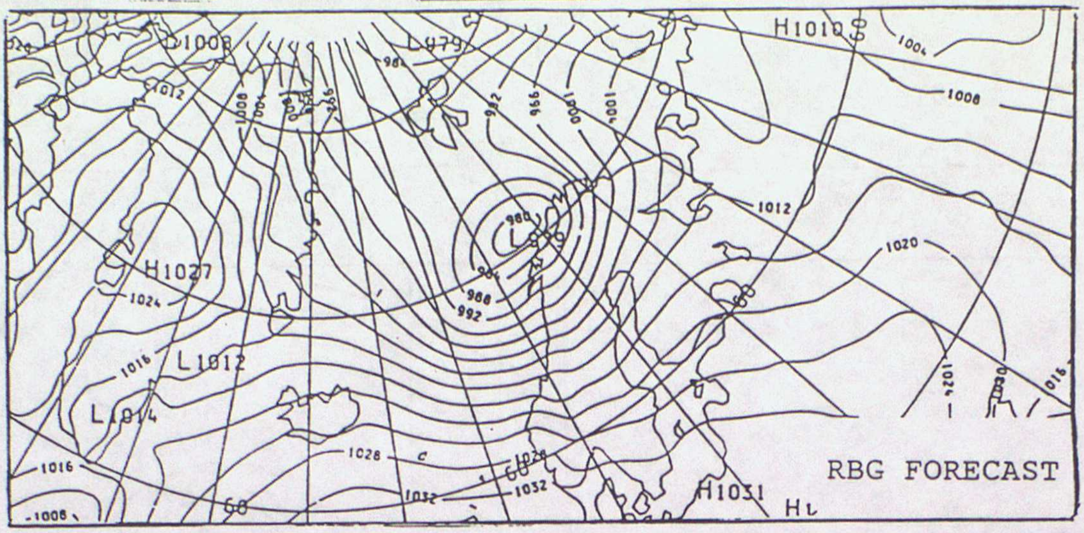

FIGURE 2(a)

DT 06Z TUES 3/ 9/91 VT 12Z TUES 3/ 9/91 T+ 6

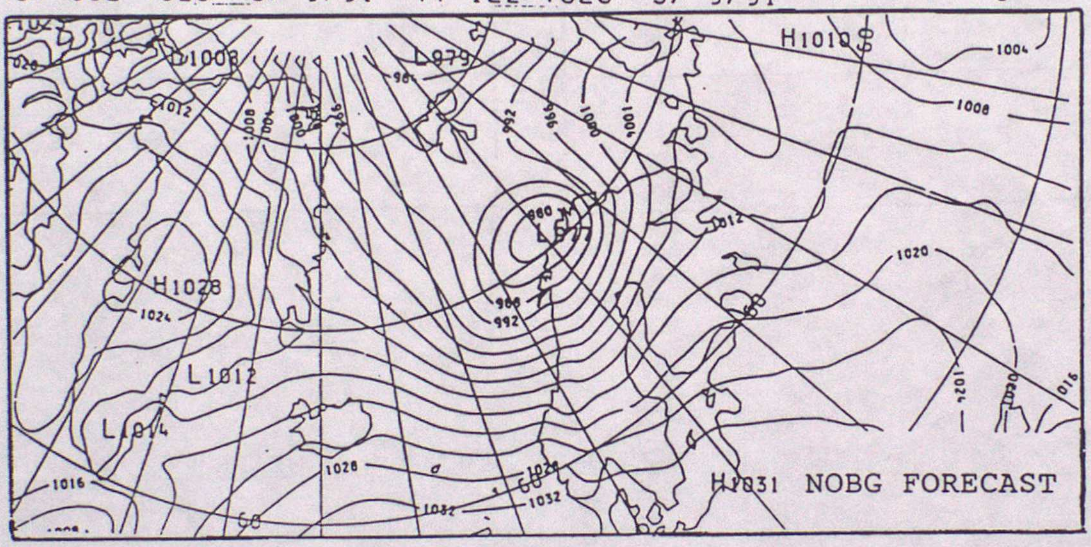

FIGURE 2(b)

DT 12Z TUES 3/ 9/91 T+ 0

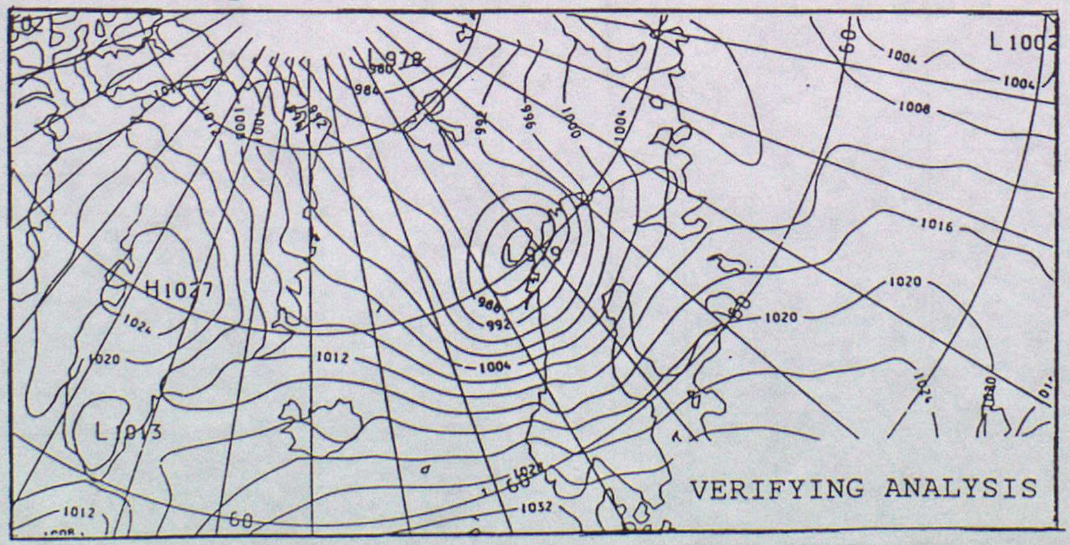

FIGURE 2(c)

T+ 0 DT 12Z MON 9/ 9/91 VT 12Z MON 9/ 9/91 T+ 0

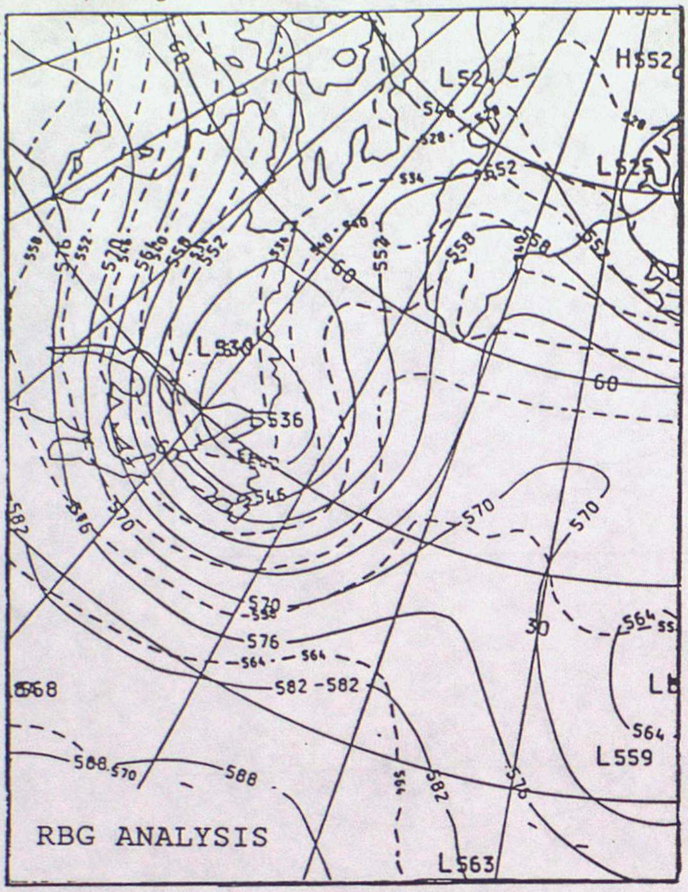

FIGURE 3(a)

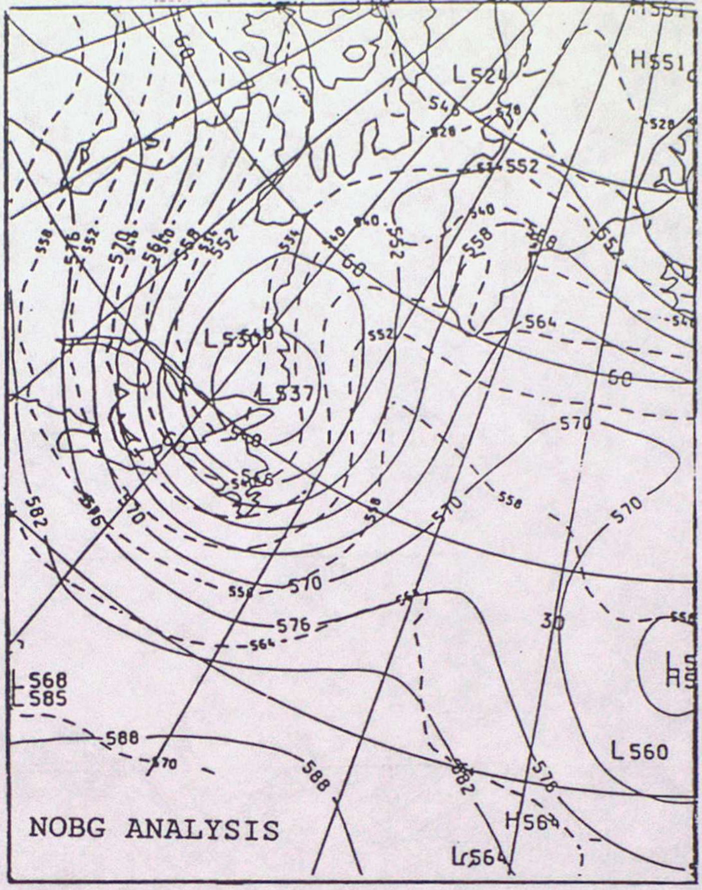

FIGURE 3(b)

T+ 0 DT 12Z MON 9/ 9/91 VT 12Z MON 9/ 9/91 T+ 0

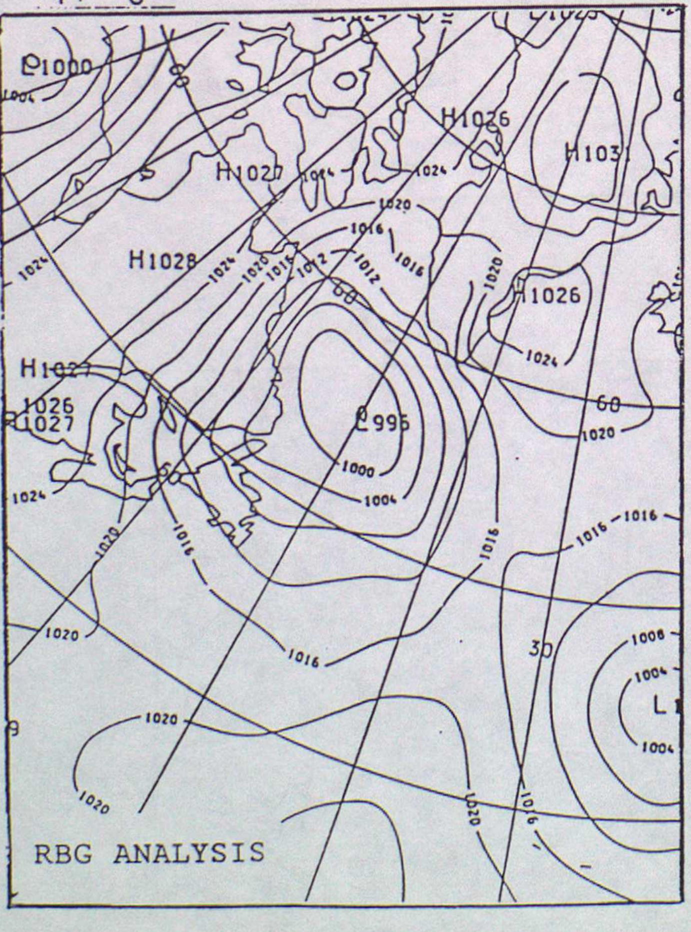

FIGURE 3(c)

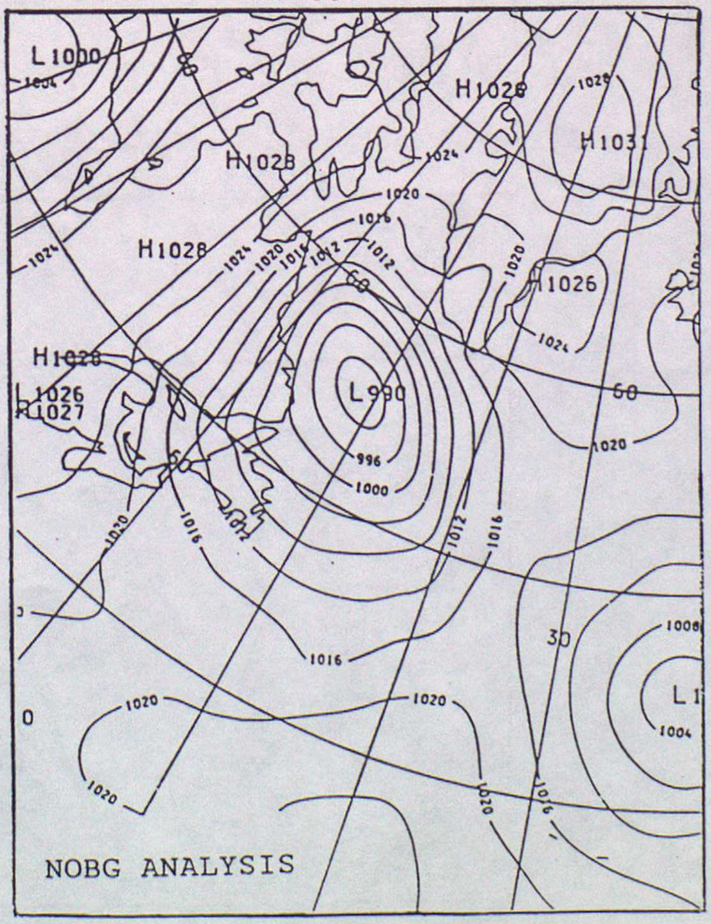

FIGURE 3(d)

DT 12Z MON 9/ 9/91 VT 18Z TUES 10/ 9/91 T+ 30

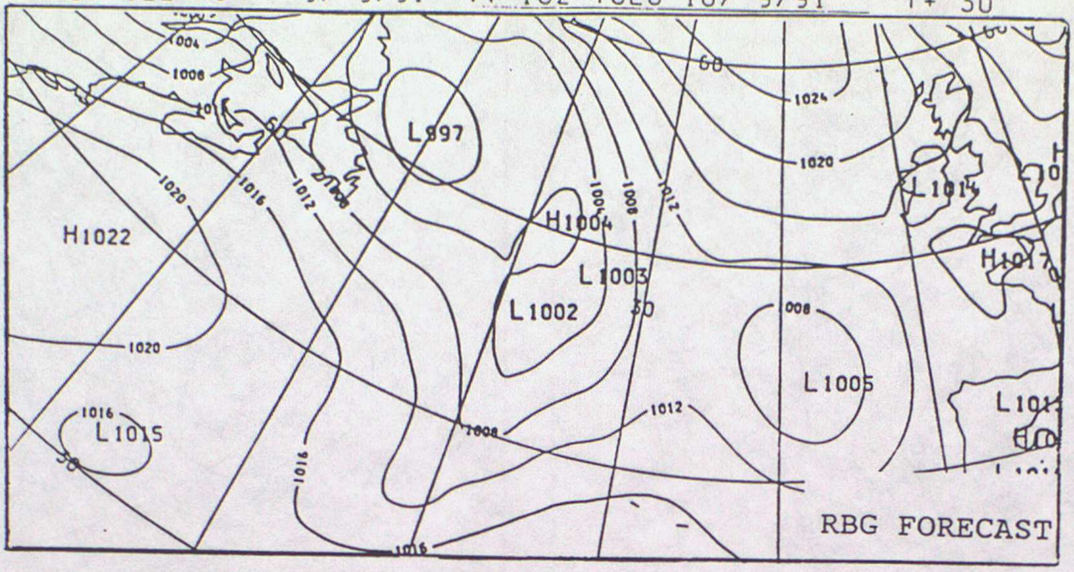

FIGURE 3(e)

DT 12Z MON 9/ 9/91 VT 18Z TUES 10/ 9/91 T+ 30

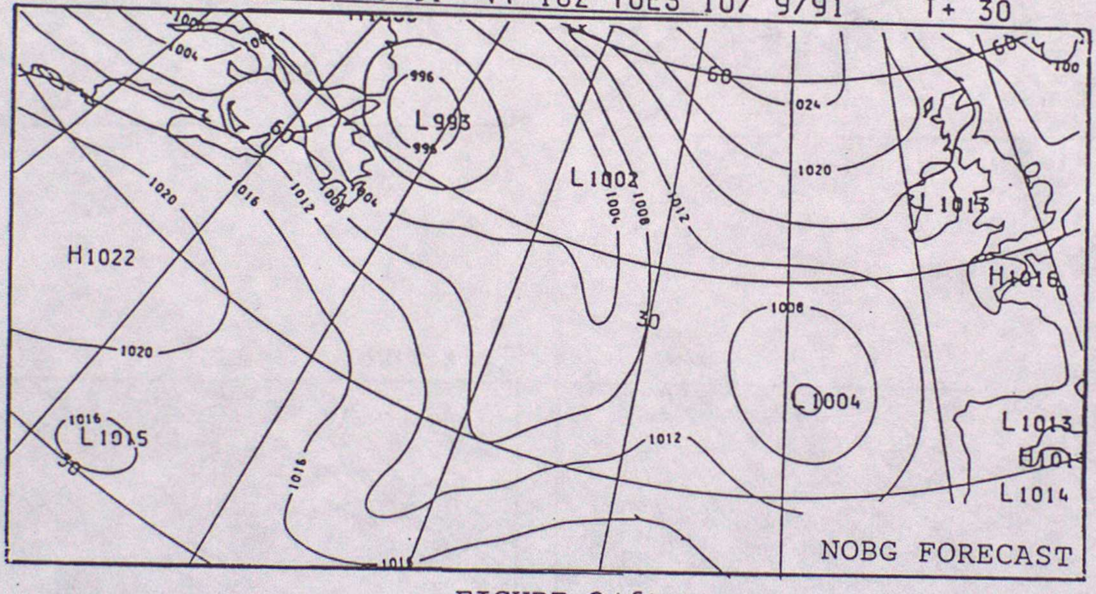

FIGURE 3(f)

DT 18Z TUES 10/ 9/91 T+ 0

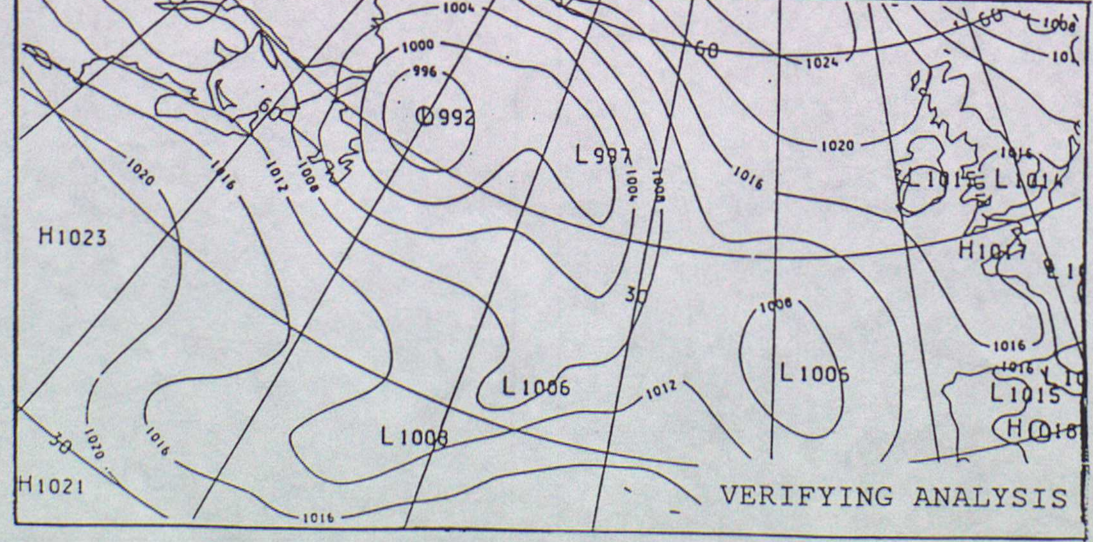

FIGURE 3(g)

T+ 0 DT 00Z THUR 5/ 9/91 T+ 0

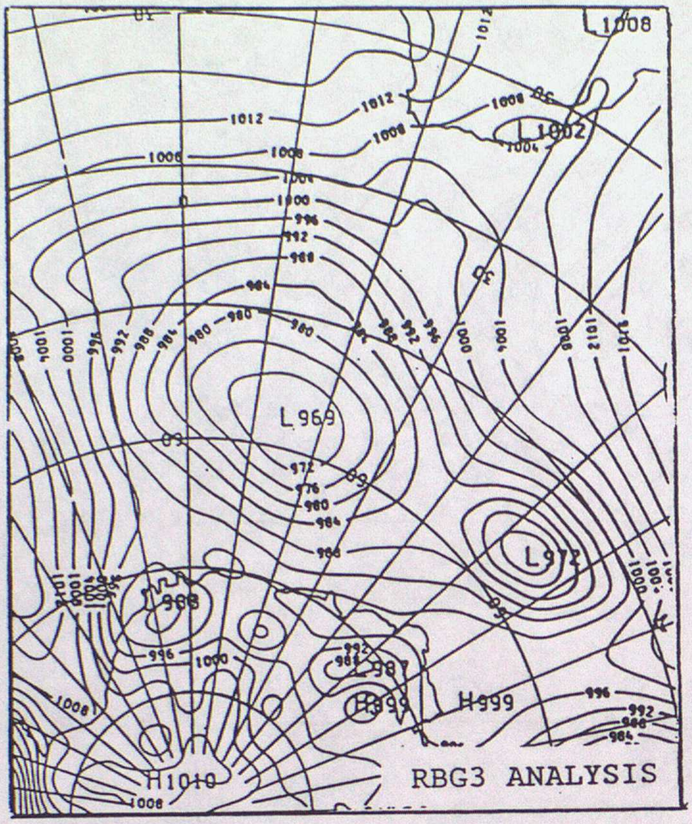

FIGURE 4(a)

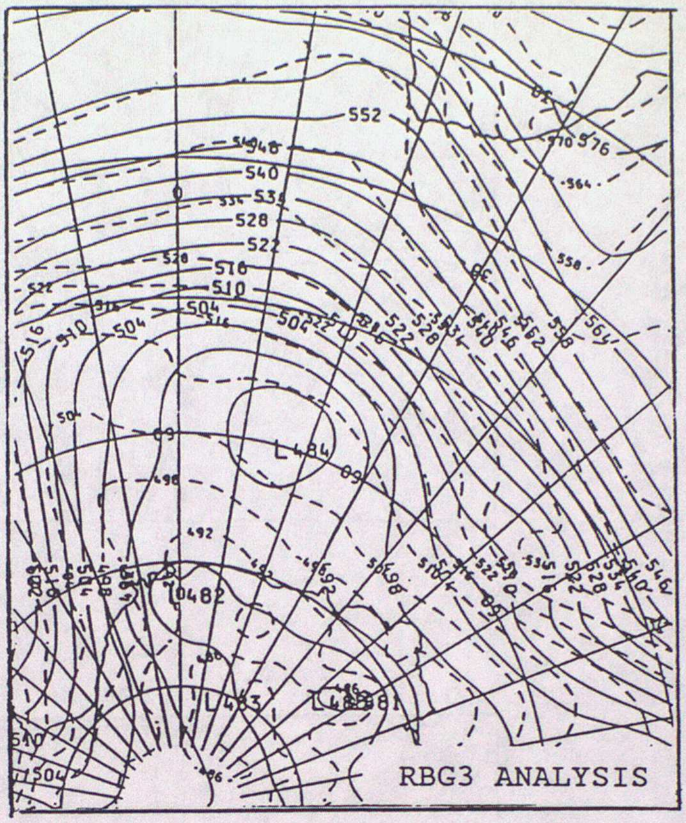

FIGURE 4(b)

T+ 0 DT 00Z THUR 5/ 9/91 T+ 0

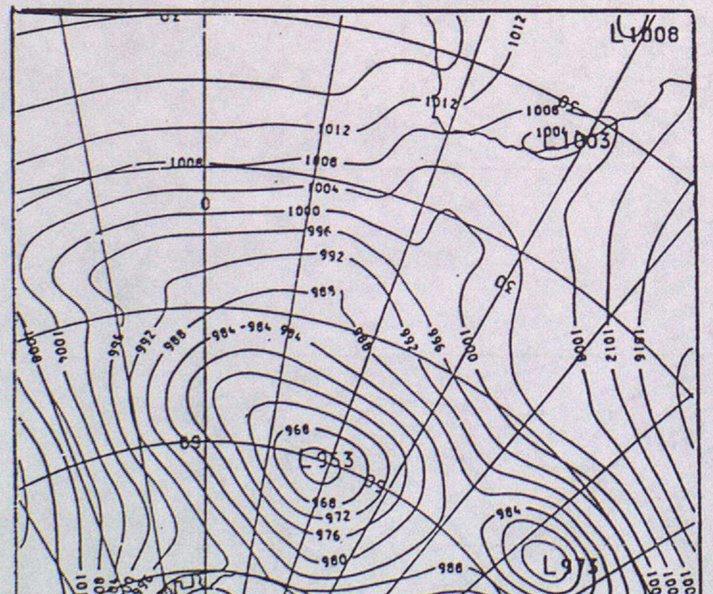

FIGURE 4(c)

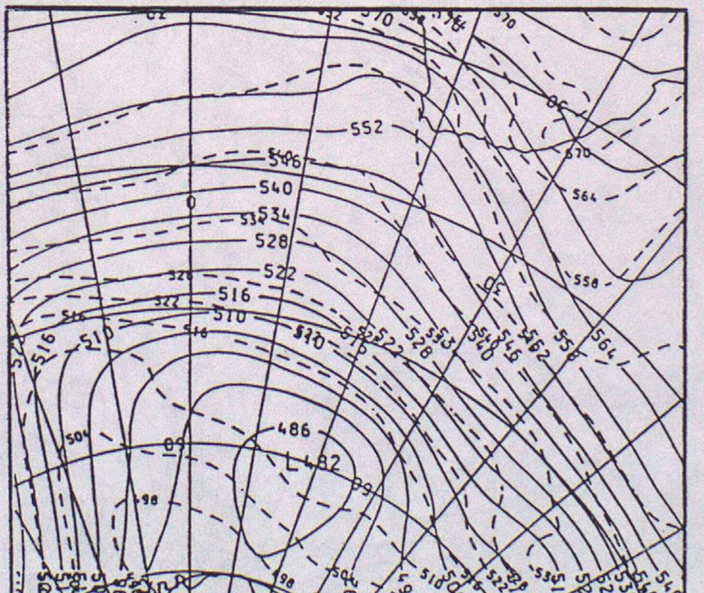

FIGURE 4(d)

DT 00Z THUR 5/ 9/91 VT 00Z FRI 6/ 9/91 T+ 24

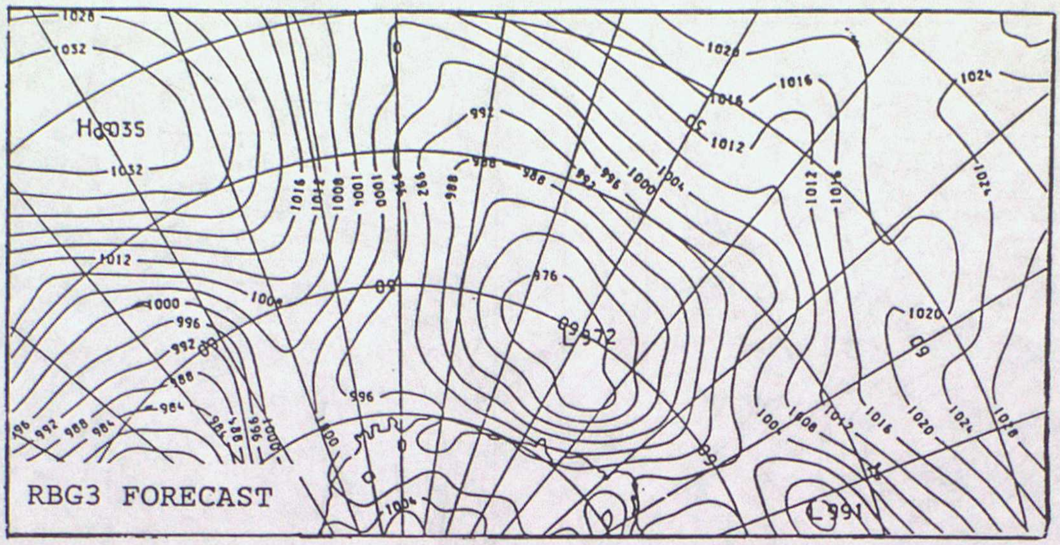

FIGURE 4(e)

DT 00Z THUR 5/ 9/91 VT 00Z FRI 6/ 9/91 T+ 24

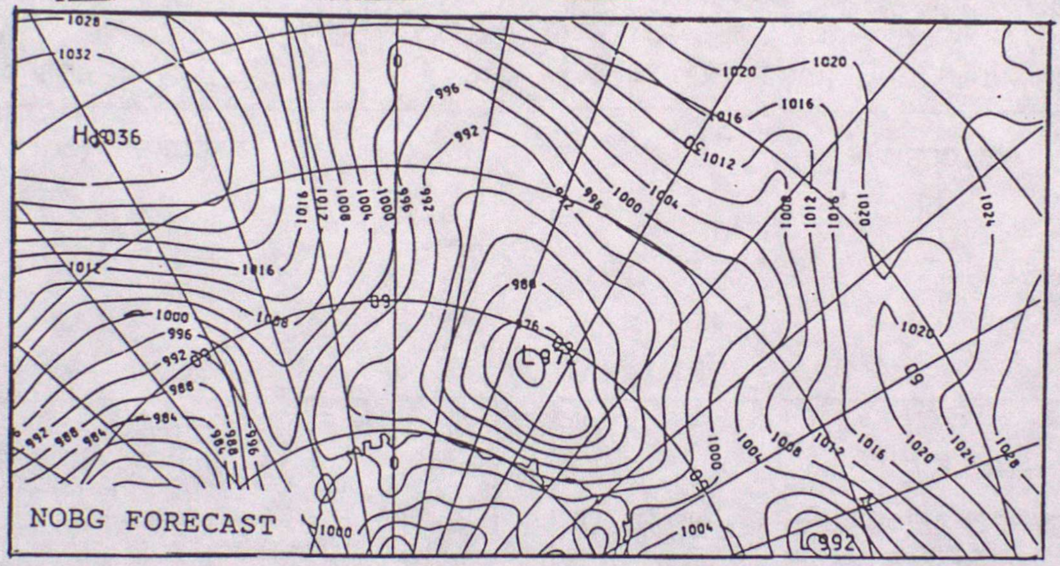

FIGURE 4(f)

DT 00Z FRI 6/ 9/91 T+ 0

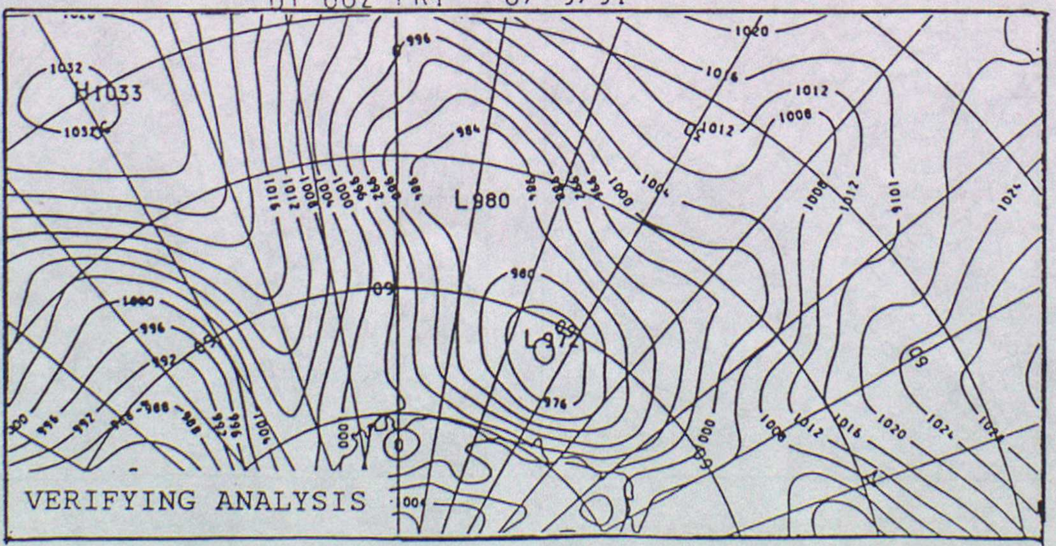

FIGURE 4(g)

T+ 0 DT 00Z THUR 12/ 9/91 T+ 0

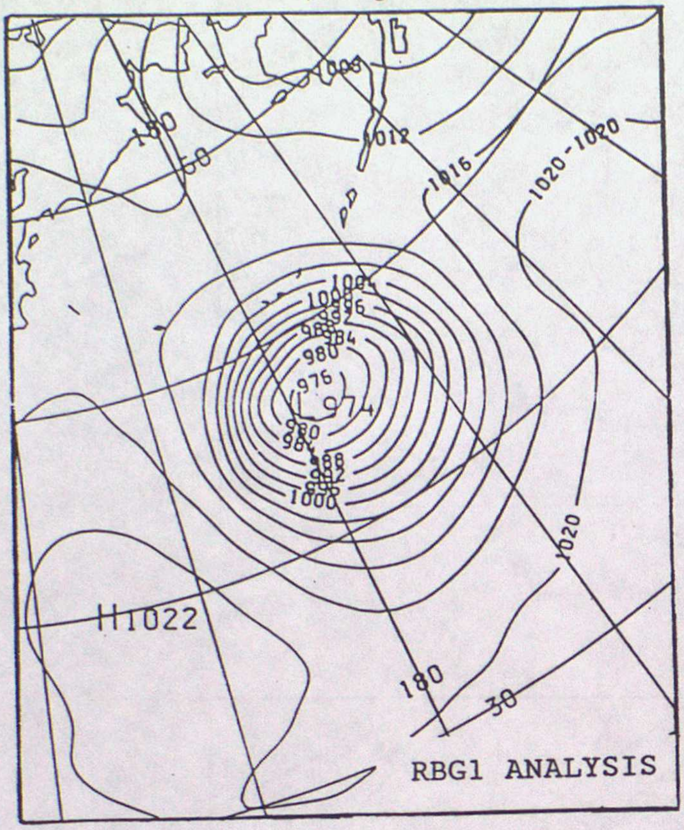

FIGURE 5(a)

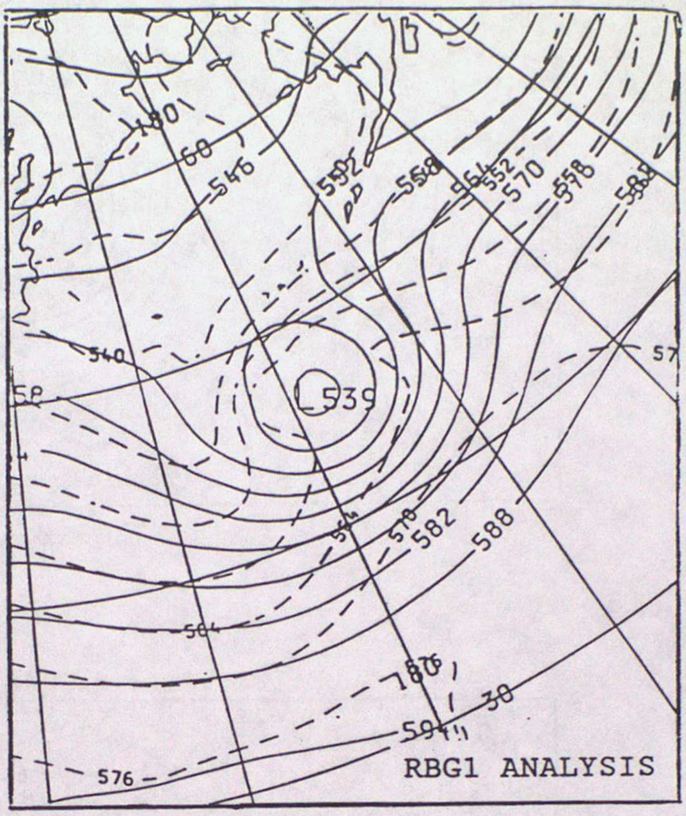

FIGURE 5(b)

T+ 0 DT 00Z THUR 12/ 9/91 T+ 0

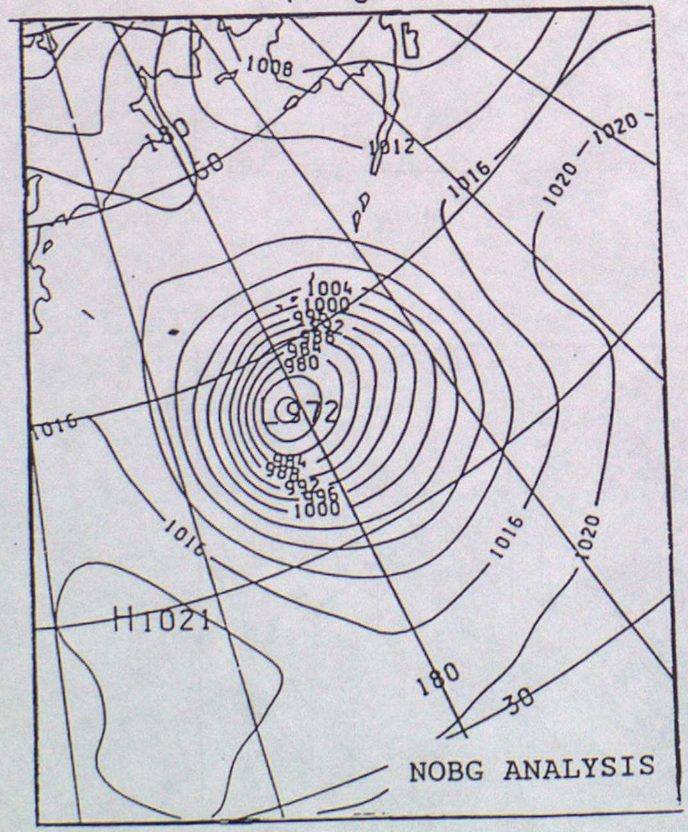

FIGURE 5(c)

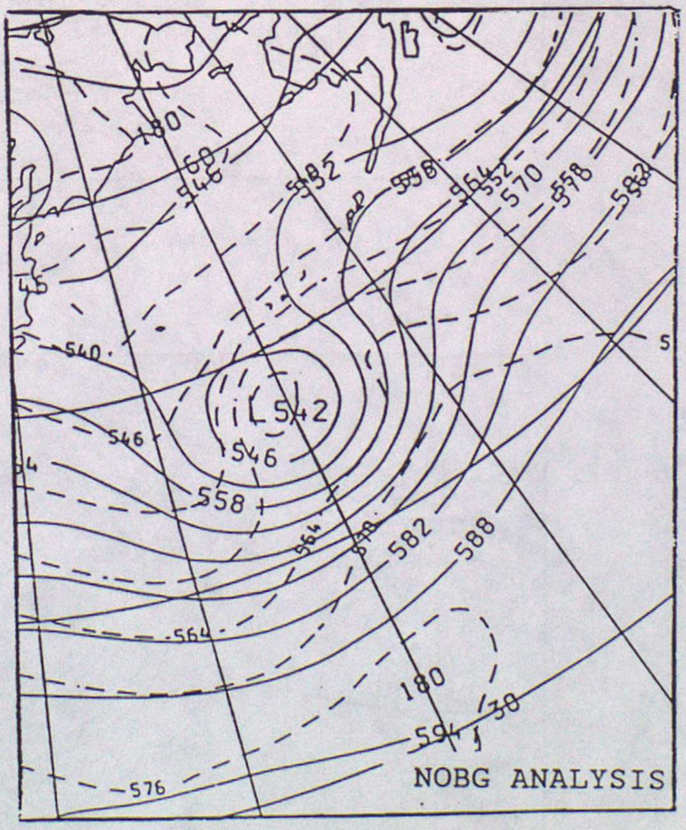

FIGURE 5(d)

DT 00Z THUR 12/ 9/91 VT 00Z FRI 13/ 9/91 T+ 24

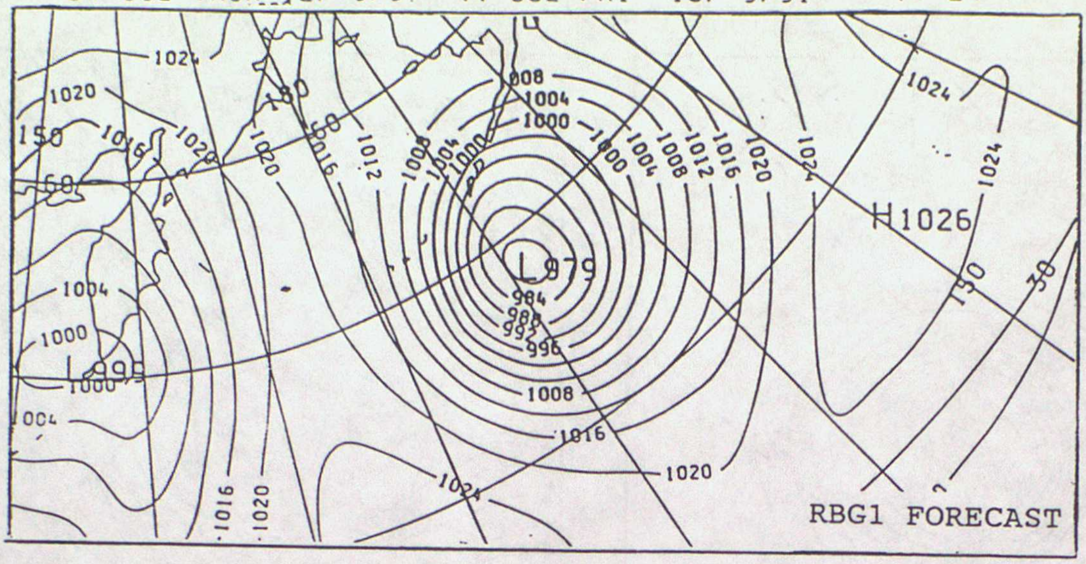

FIGURE 5(e)

DT 00Z THUR 12/ 9/91 VT 00Z FRI 13/ 9/91 T+ 24

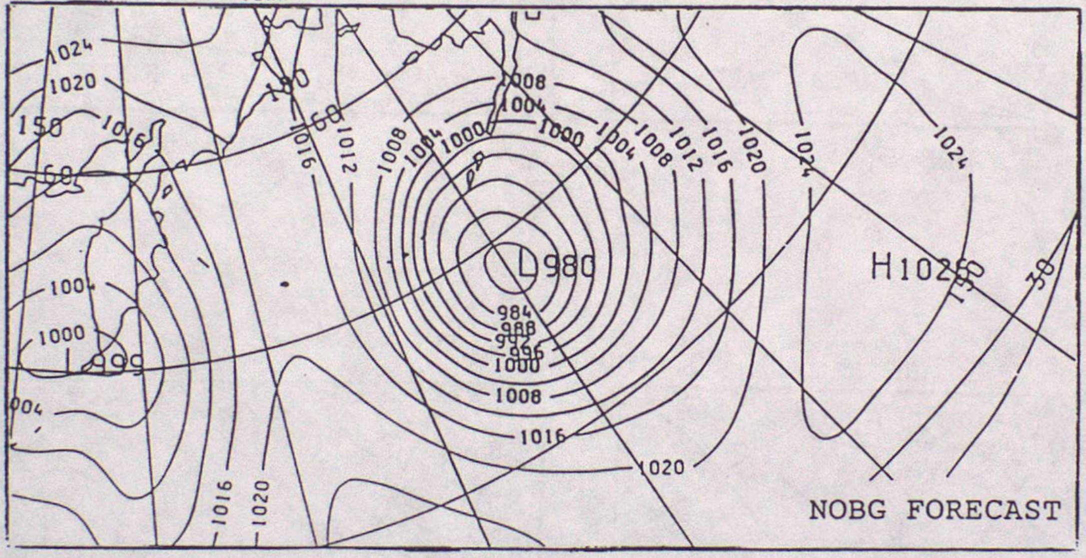

FIGURE 5(f)

DT 00Z FRI 13/ 9/91 T+ 0

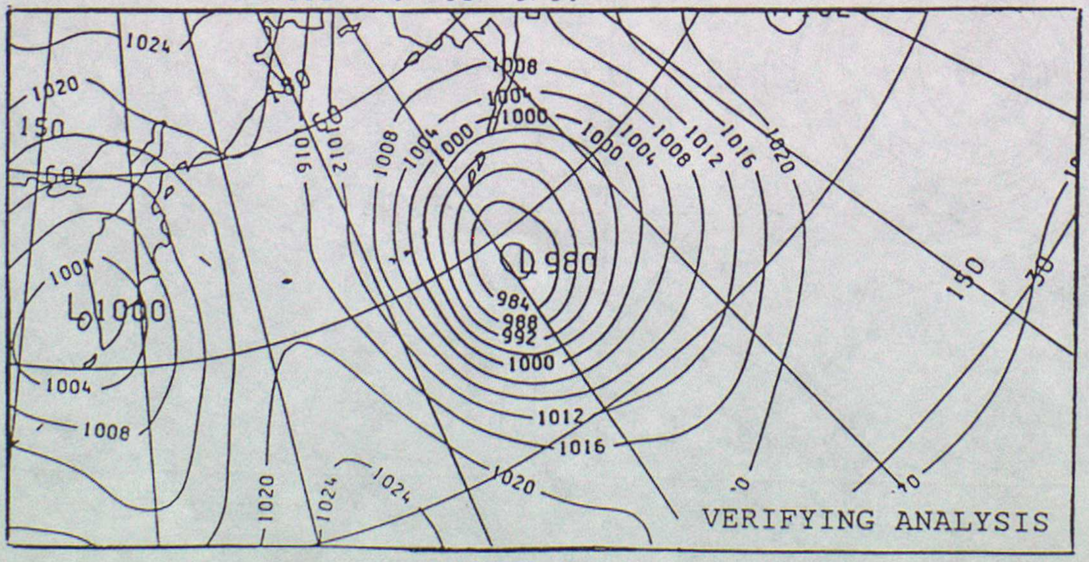

FIGURE 5(g)

DT 00Z THUR 12/ 9/91 VT 00Z FRI 13/ 9/91 T+ 24

700MB REL. HUMIDITY %

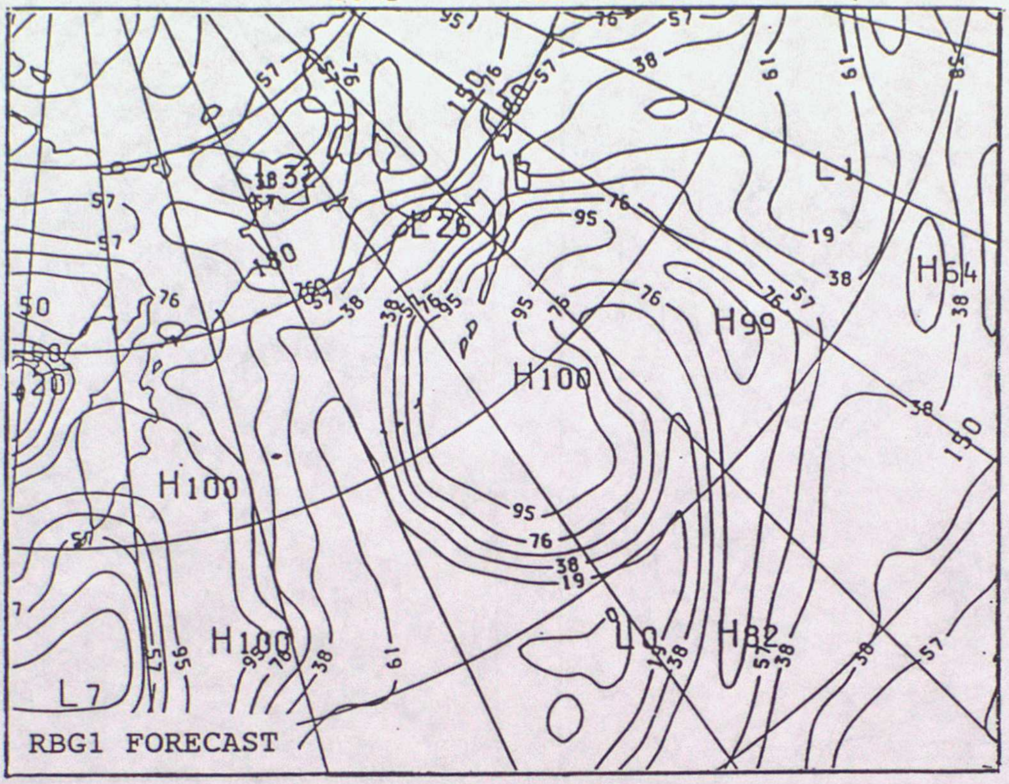

FIGURE 5(h)

DT 00Z THUR 12/ 9/91 VT 00Z FRI 13/ 9/91 T+ 24

700MB REL. HUMIDITY %

FIGURE 5(i)

T+ 72 DT 00Z THUR 12/ 9/91 VT 00Z SUN 15/ 9/91 T+ 72

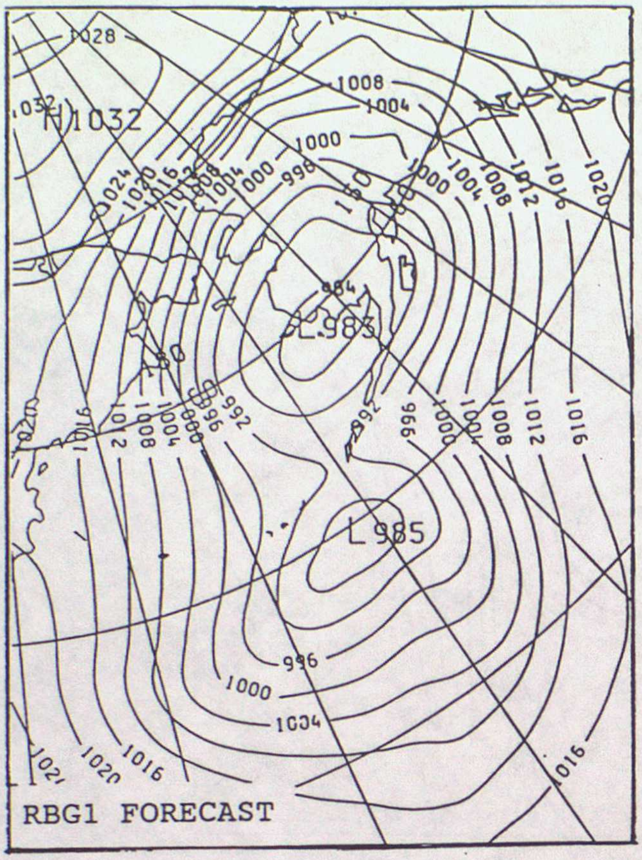

FIGURE 5(j)

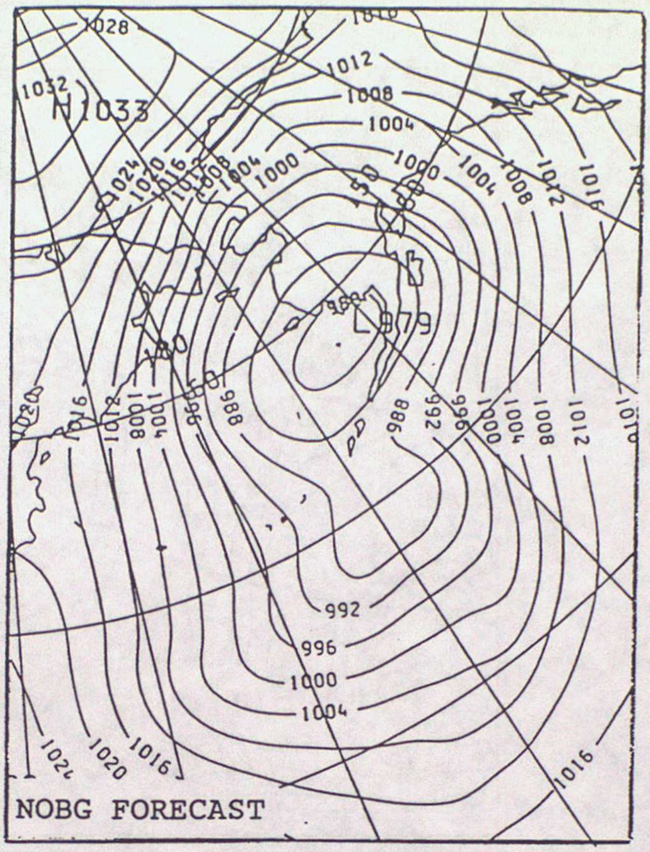

FIGURE 5(k)

DT 00Z SUN 15/ 9/91 T+ 0

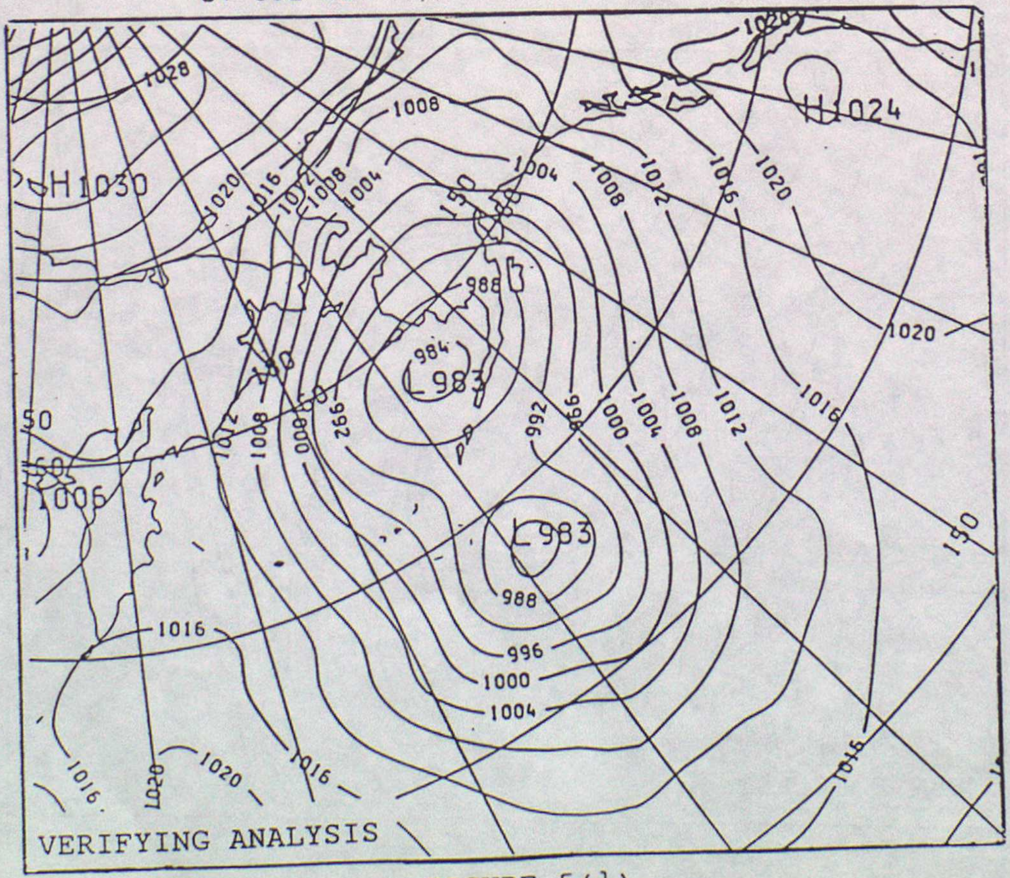

FIGURE 5(l)

DT 00Z FRI 6/ 9/91 VT 12Z FRI 6/ 9/91 T+ 12

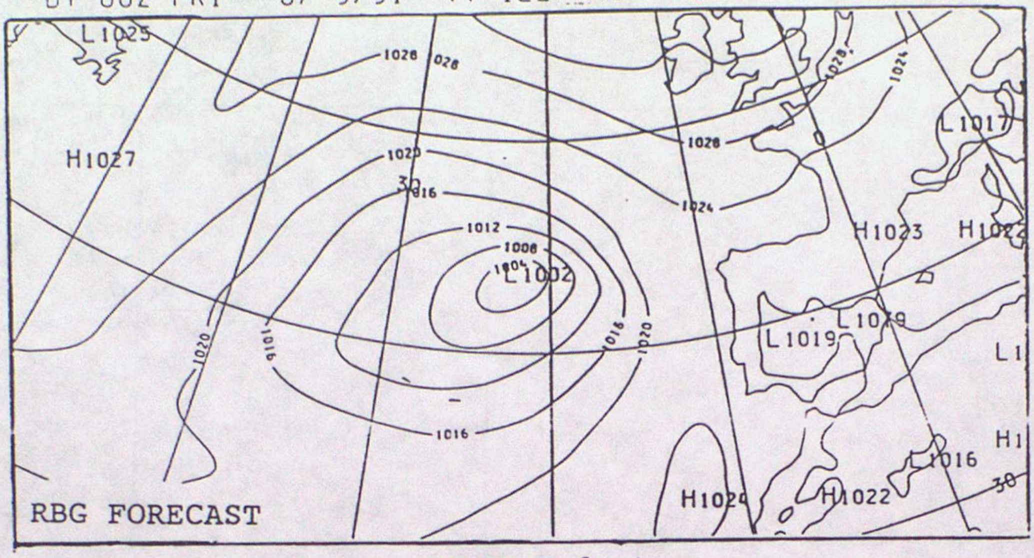

FIGURE 6(a)

DT 00Z FRI 6/ 9/91 VT 12Z FRI 6/ 9/91 T+ 12

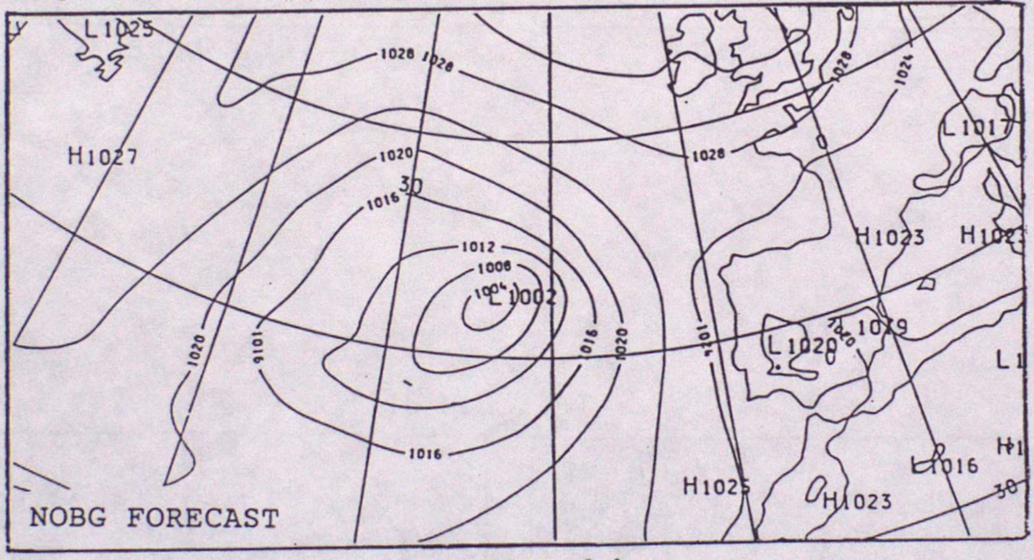

FIGURE 6(b)

DT 12Z FRI 6/ 9/91 T+ 0

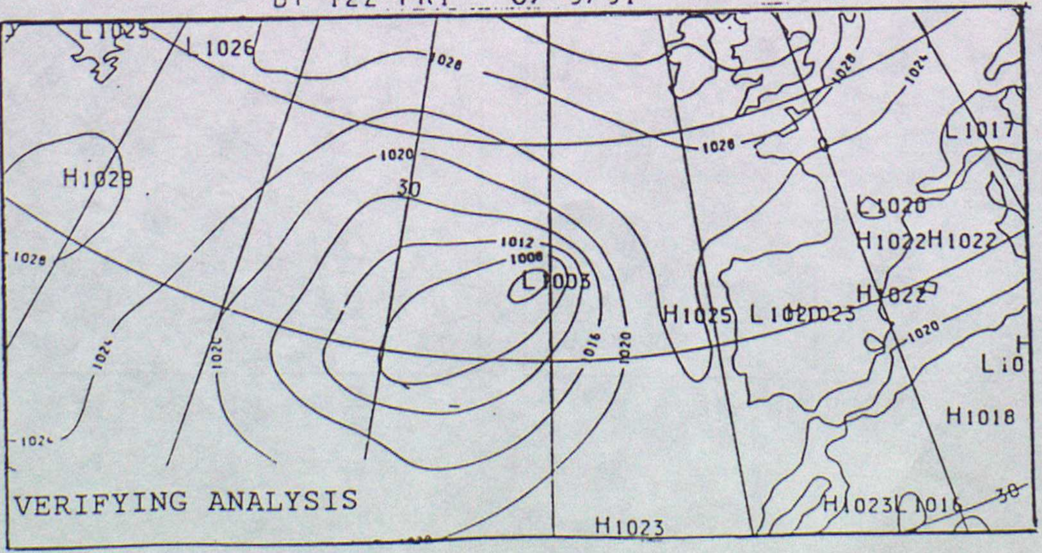

FIGURE 6(c)

DT 00Z FRI 6/ 9/91 VT 12Z FRI 6/ 9/91

T+ 12 850MB W.B.P.TEMP. DEG C. T+ 12

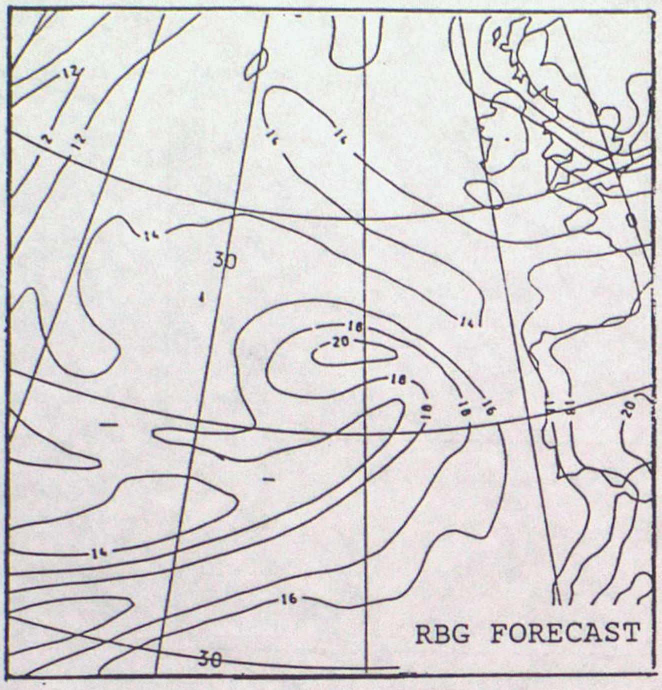

FIGURE 6(d)

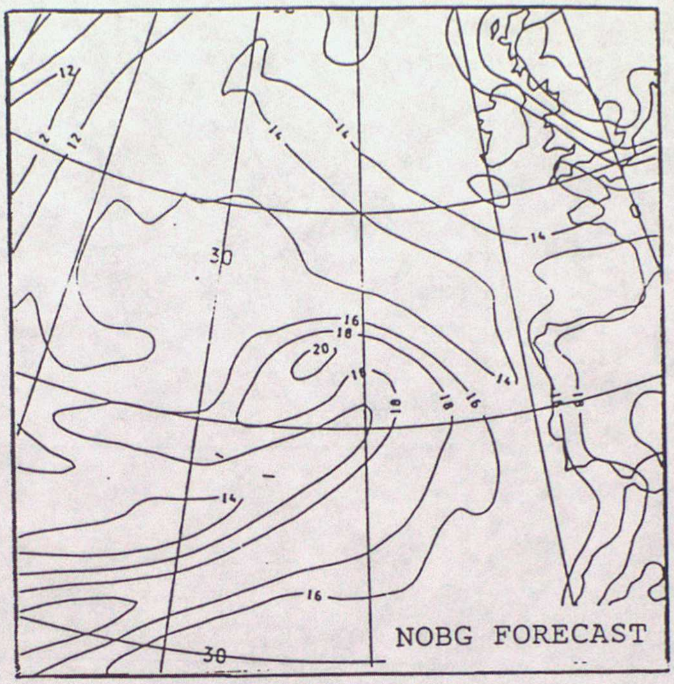

FIGURE 6(e)

DT 00Z FRI 6/ 9/91 VT 12Z FRI 6/ 9/91

T+ 12 850MB REL. HUMIDITY % T+ 12

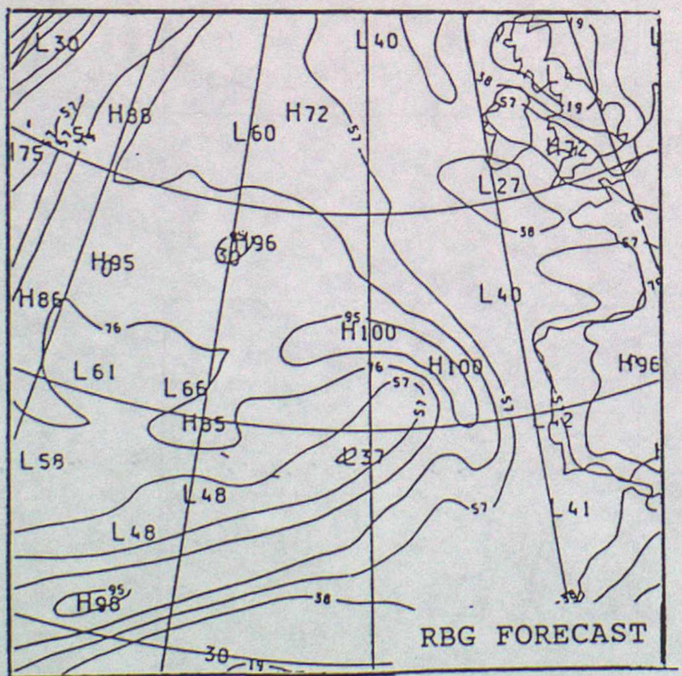

FIGURE 6(f)

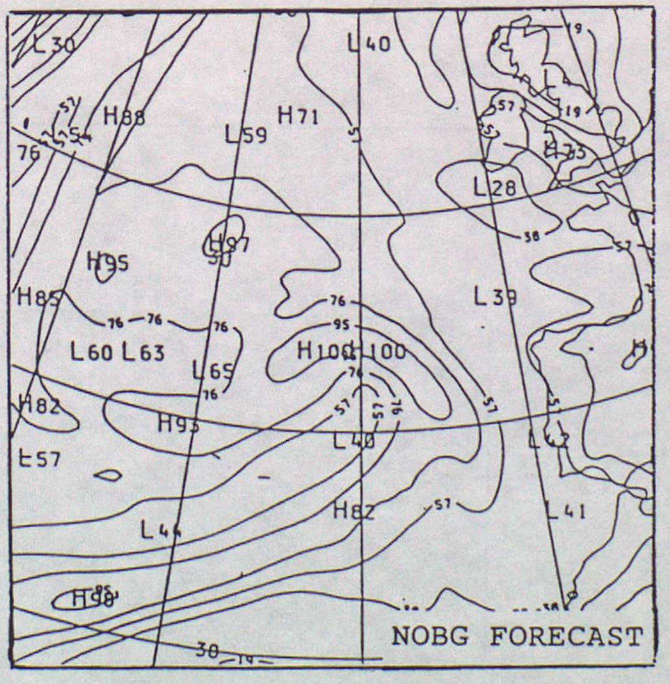

FIGURE 6(g)

DT 00Z FRI 20/ 9/91 T+ 0

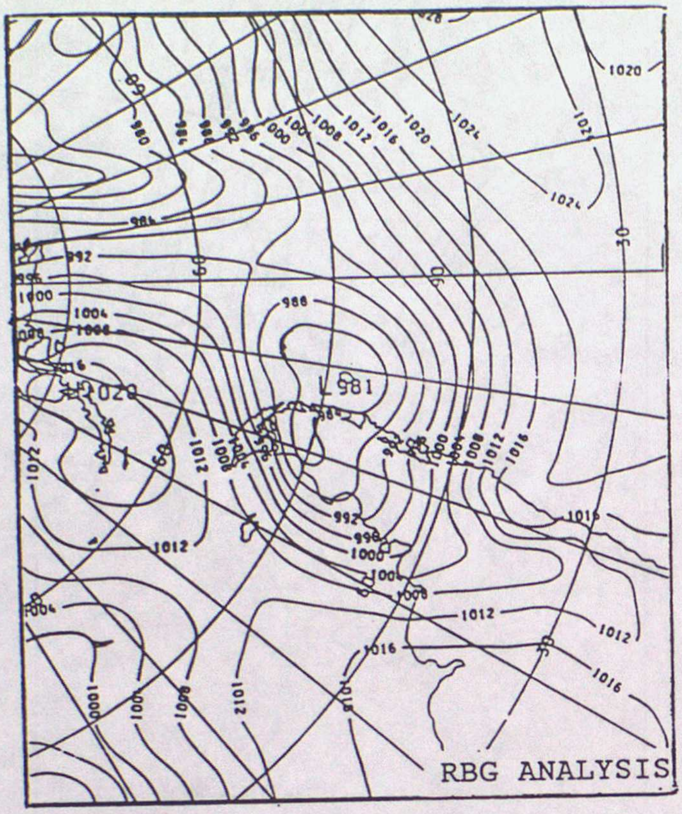

FIGURE 7(a)

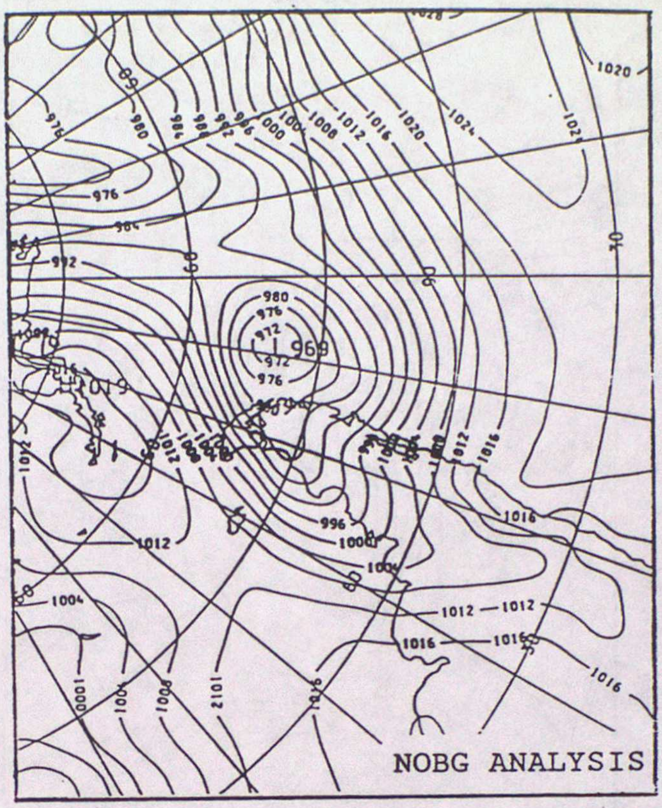

FIGURE 7(b)

DT 00Z FRI 20/ 9/91 T+ 0

250MB HEIGHT DM.

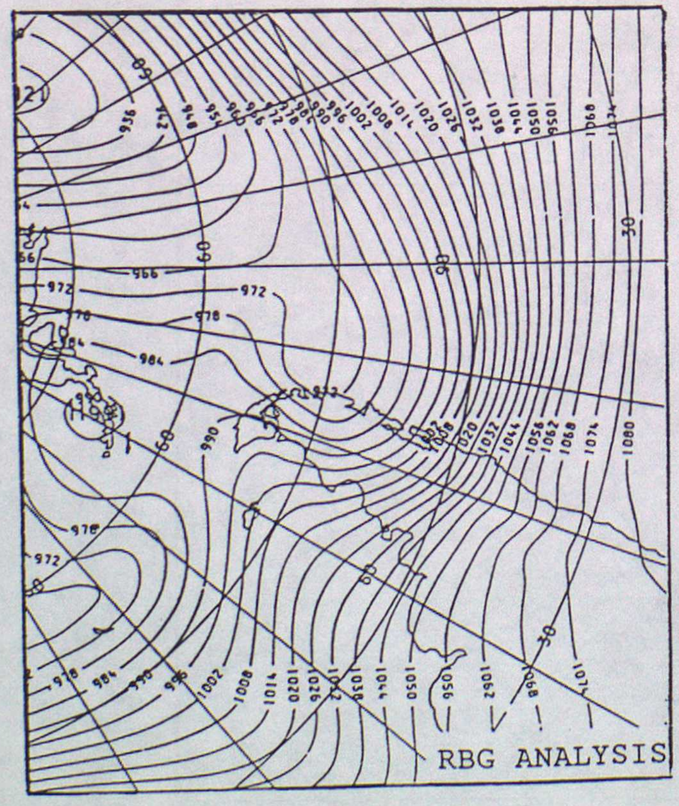

FIGURE 7(c)

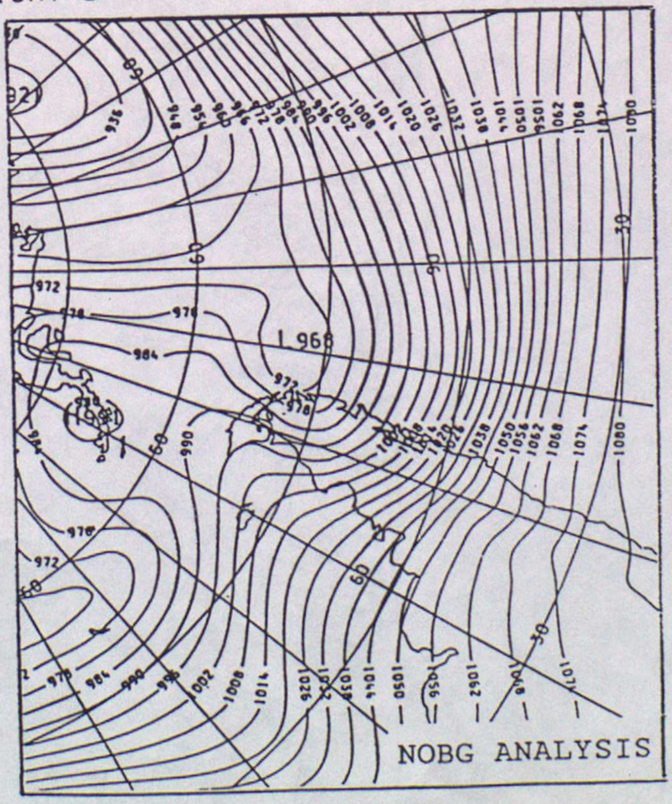

FIGURE 7(d)

DT 00Z FRI 20/ 9/91 VT 00Z SAT 21/ 9/91 T+ 24

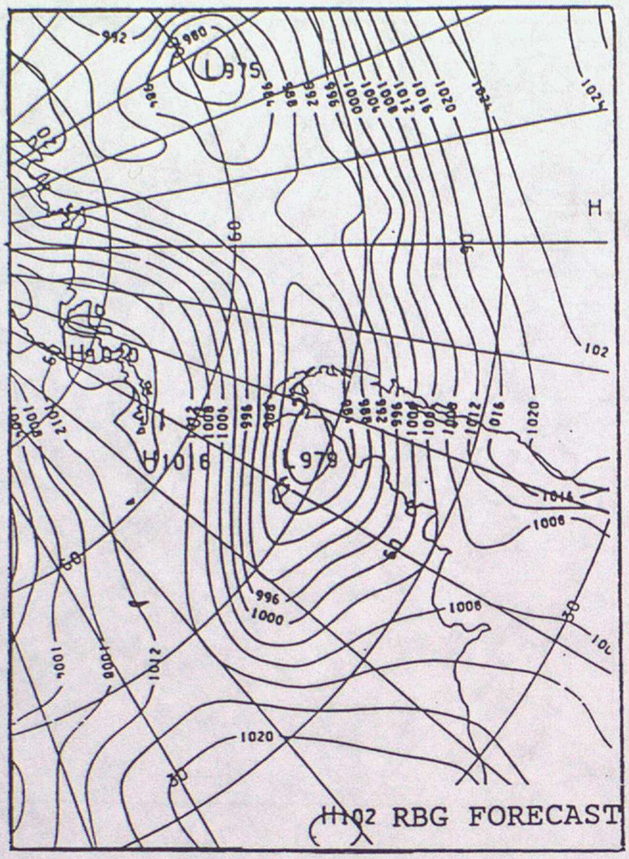

FIGURE 7(e)

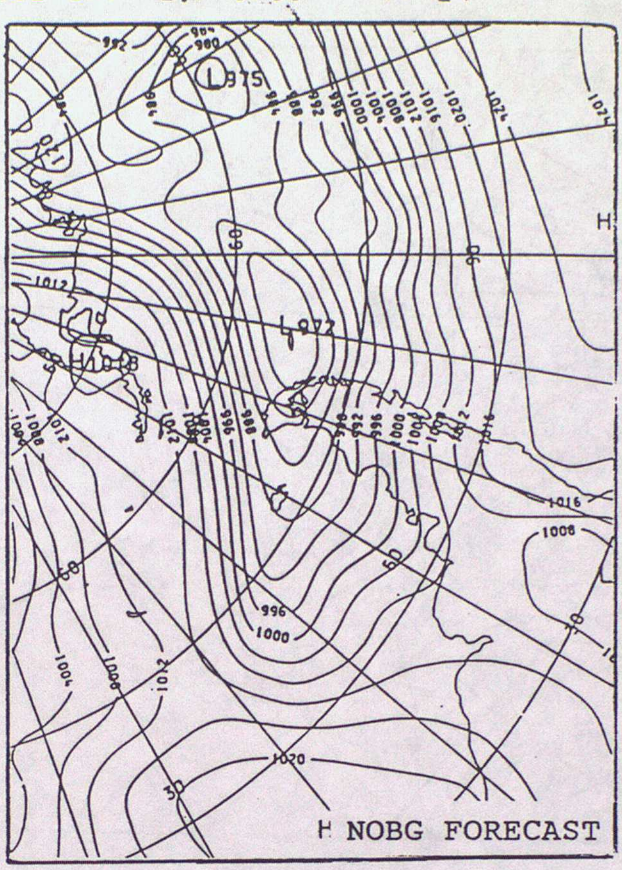

FIGURE 7(f)

DT 00Z SAT 21/ 9/91 T+ 0

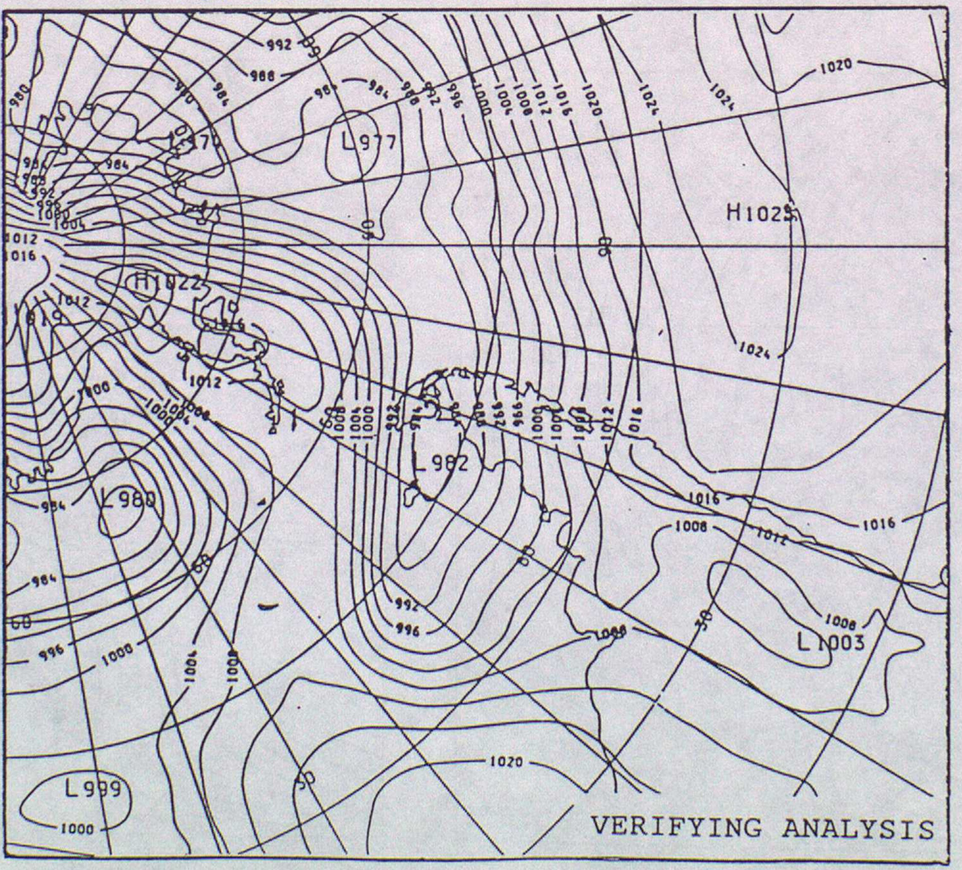

FIGURE 7(g)

DT 00Z FRI 20/ 9/91 VT 00Z SUN 22/ 9/91 T+ 48

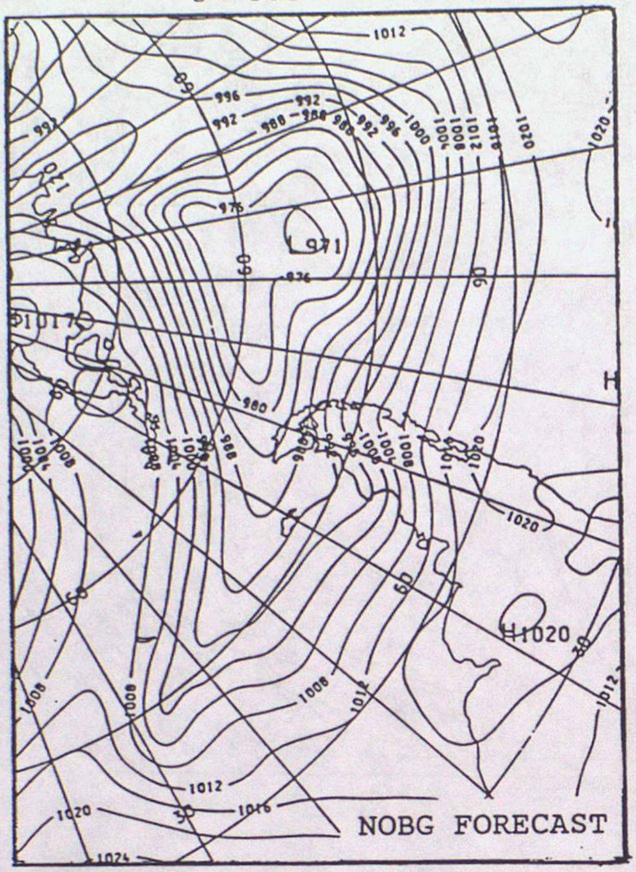

FIGURE 7(h)

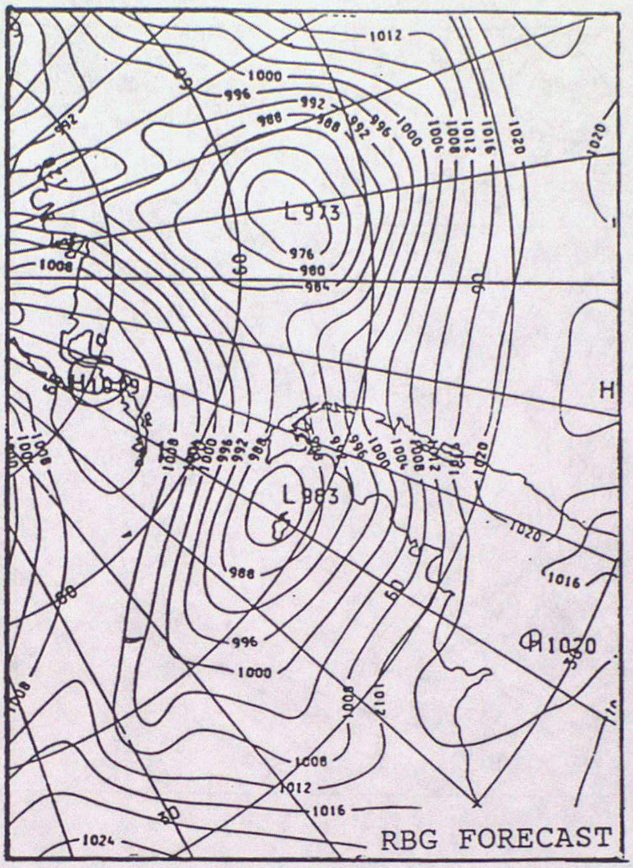

FIGURE 7(i)

DT 00Z SUN 22/ 9/91 T+ 0

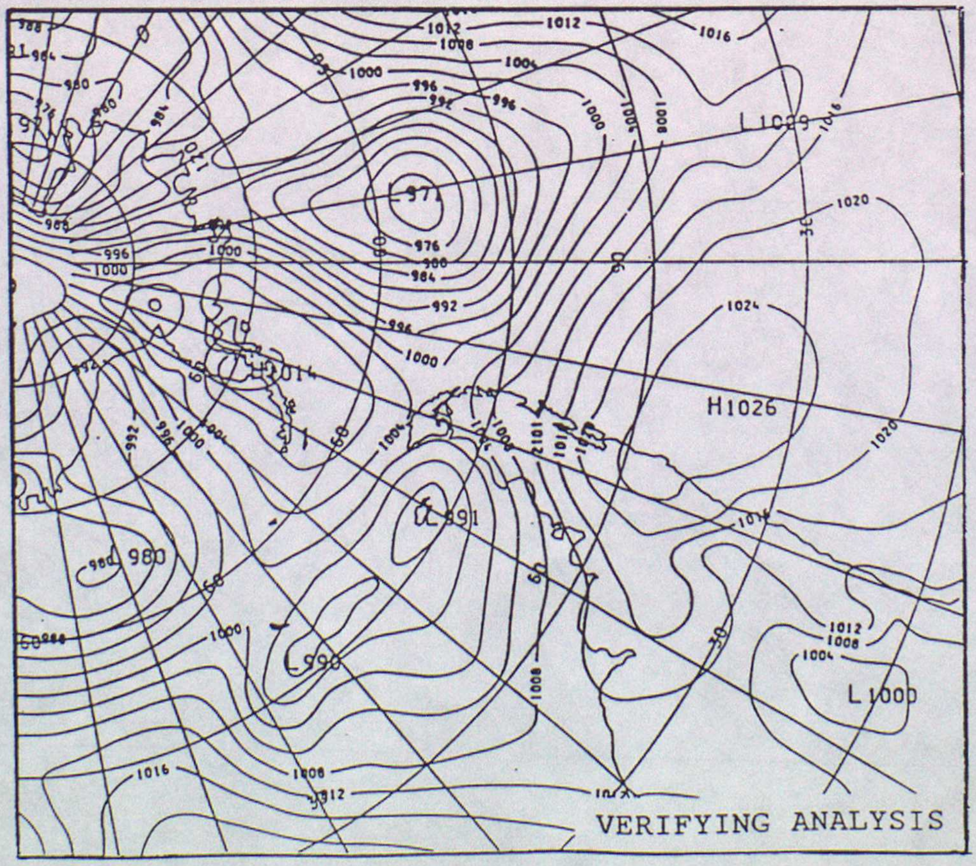

FIGURE 7(j)

DT 00Z FRI 20/ 9/91 VT 00Z SUN 22/ 9/91 T+ 48

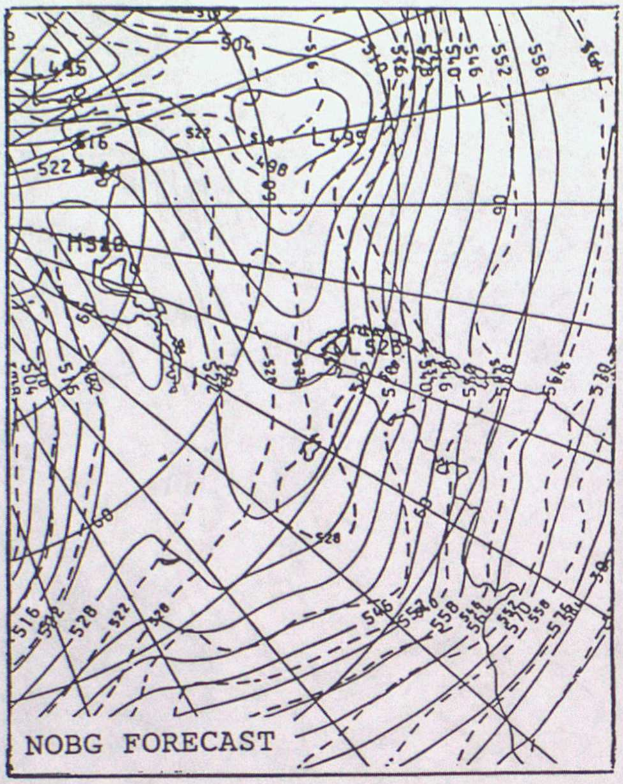

FIGURE 7(k)

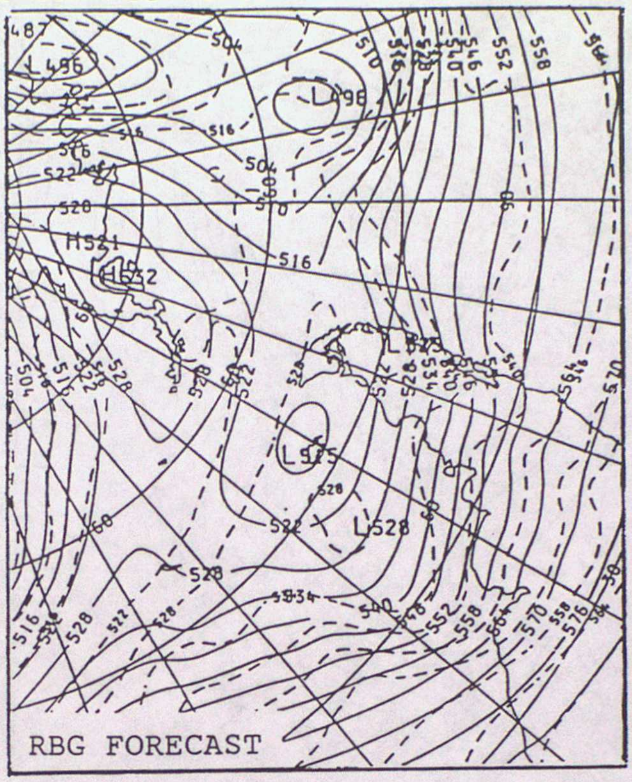

FIGURE 7(l)

DT 00Z FRI 20/ 9/91 VT 00Z SAT 21/ 9/91

DT 00Z SUN 22/ 9/91 T+ 0

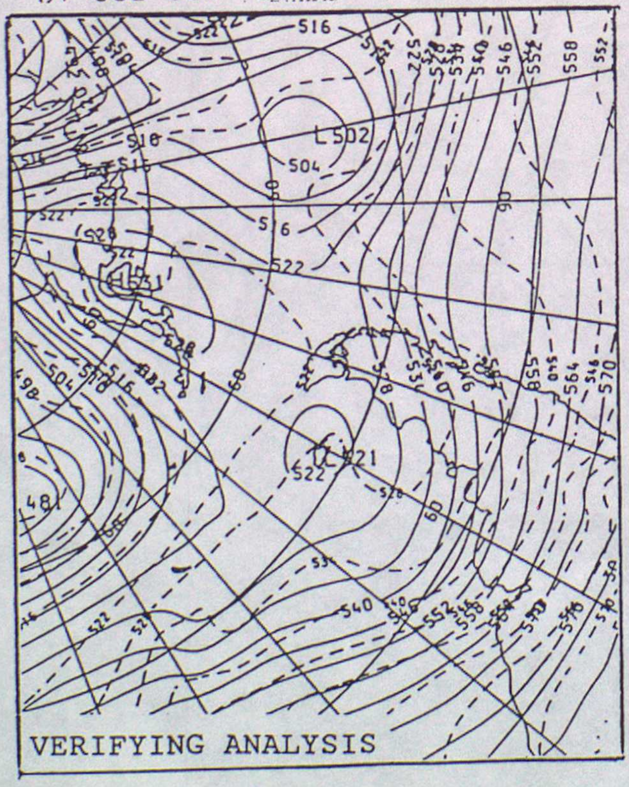

FIGURE 7(m)

T+ 24

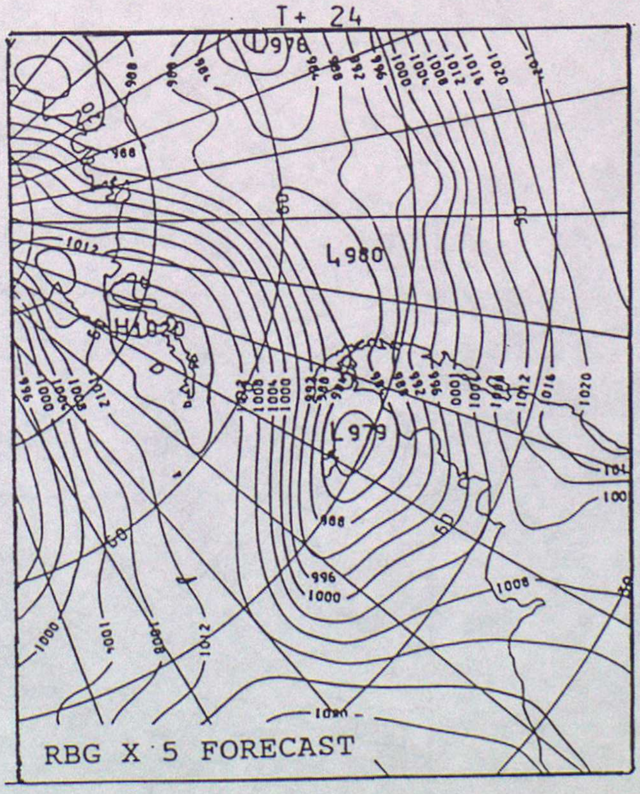

FIGURE 7(n)

DT 00Z WED 11/ 9/91 T+ 0

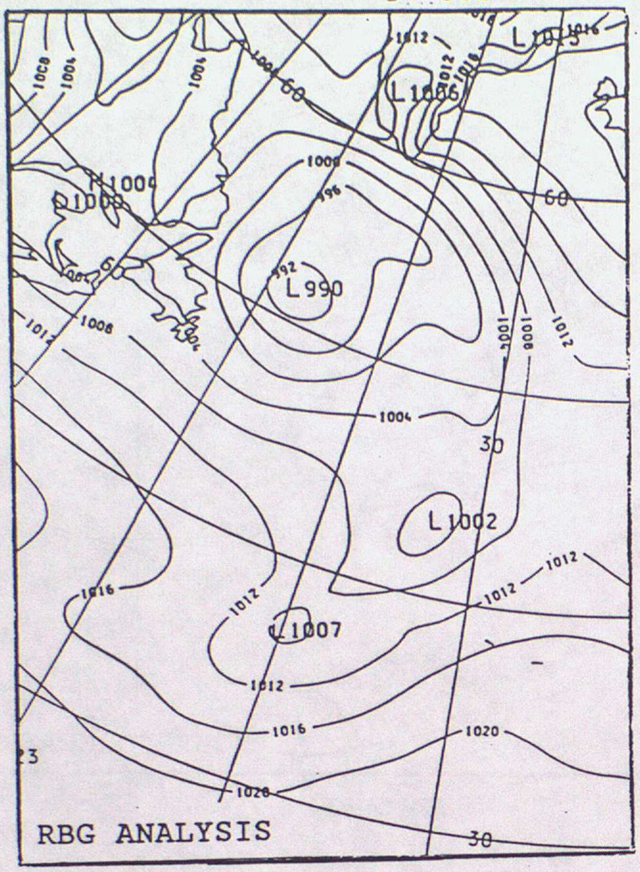

FIGURE 8(a)

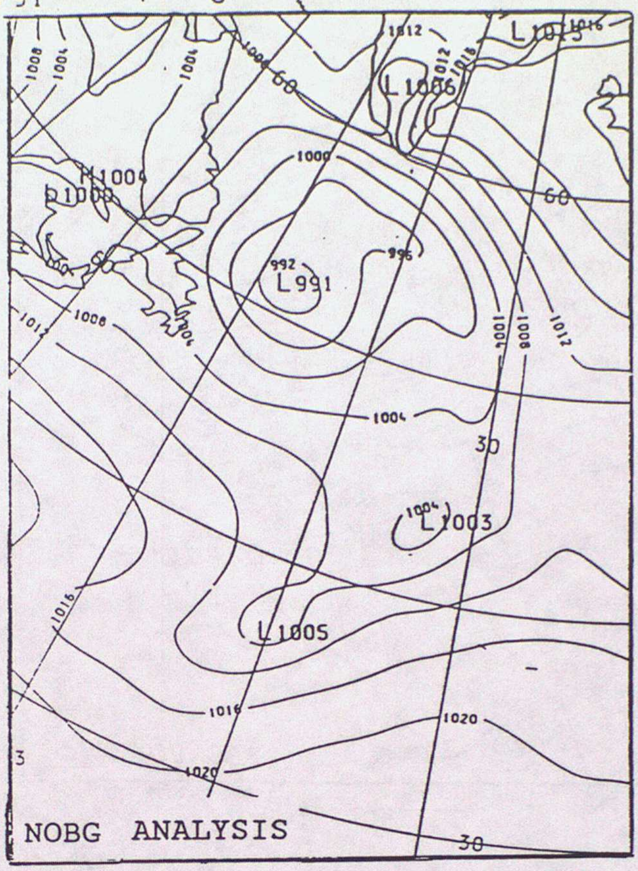

FIGURE 8(b)

DT 00Z WED 11/ 9/91 T+ 0

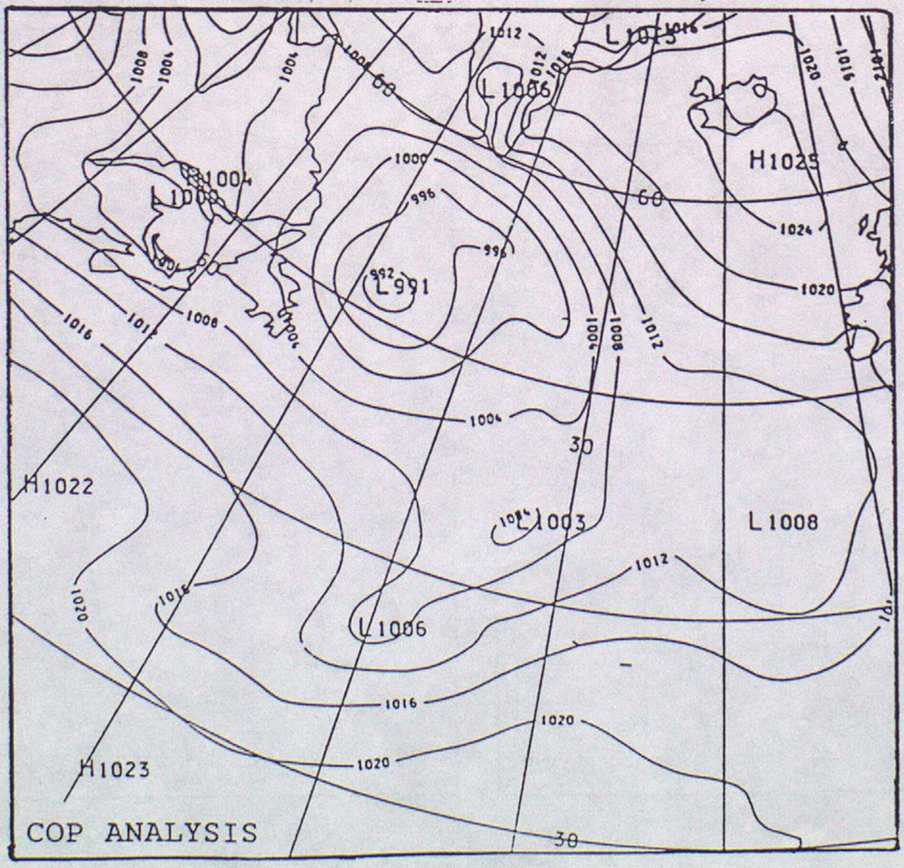

FIGURE 8(c)

DT 00Z WED 11/ 9/91 VT 00Z THUR 12/ 9/91 T+ 24

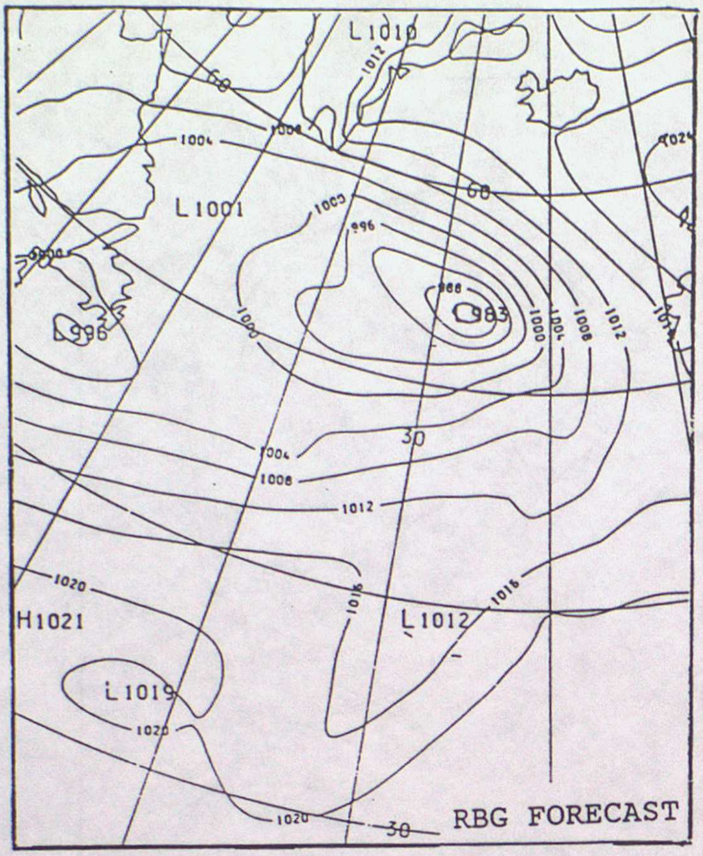

FIGURE 8(d)

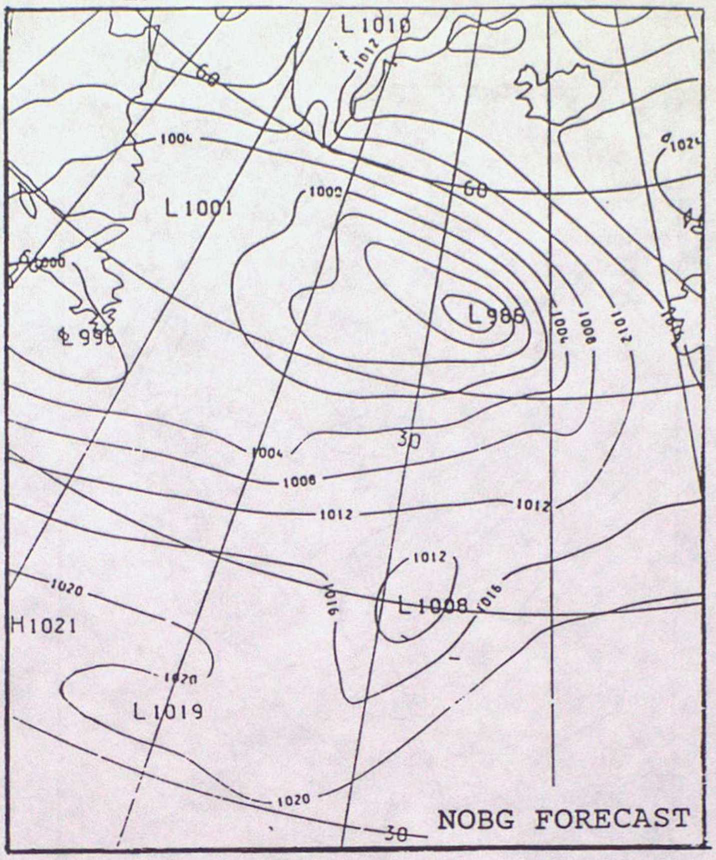

FIGURE 8(e)

DT 00Z WED 11/ 9/91

VT 00Z THUR 12/ 9/91 T+ 24

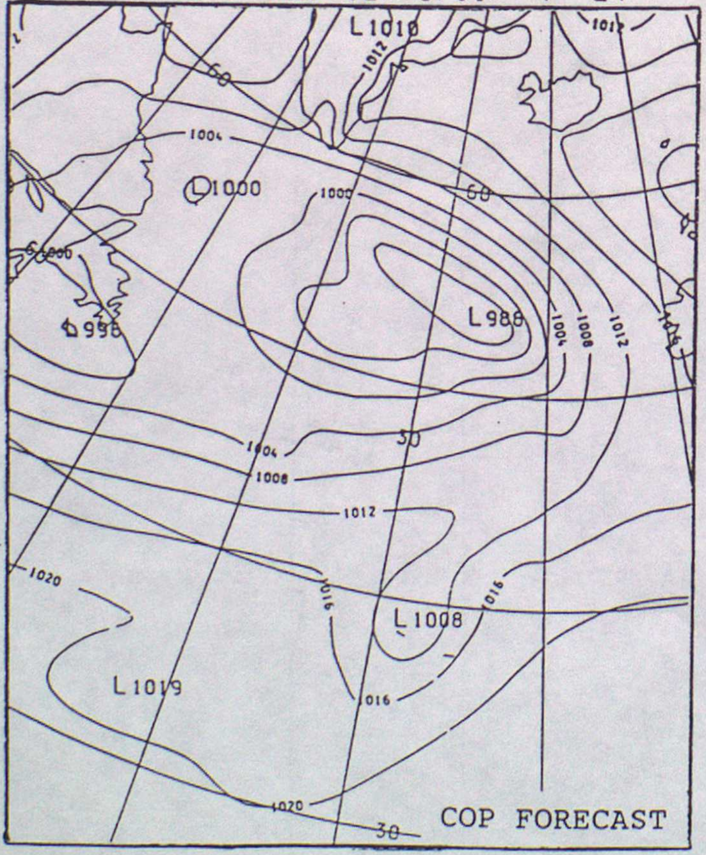

FIGURE 8(f)

DT 00Z THUR 12/ 9/91 T+ 0

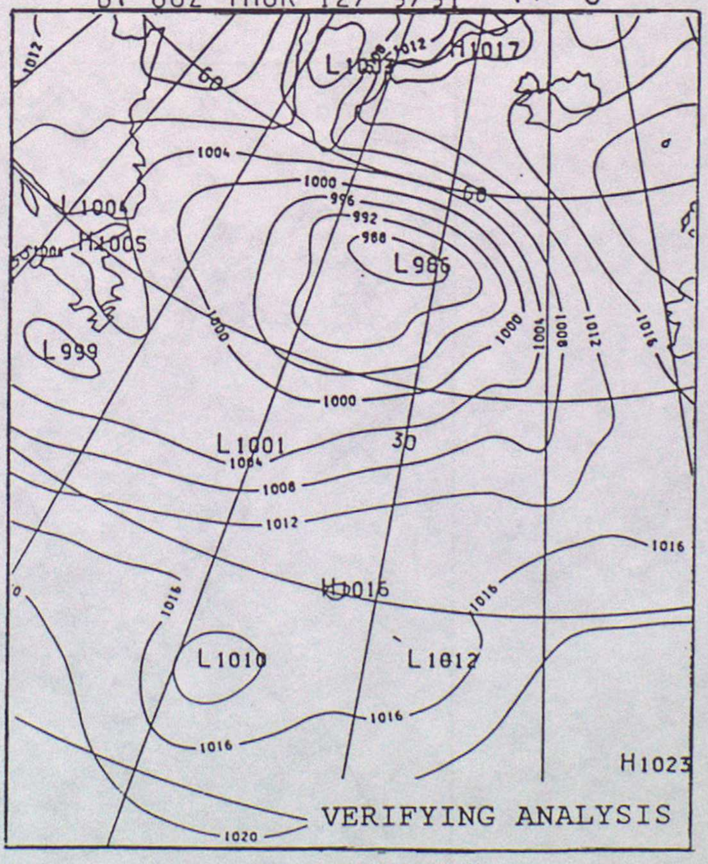

FIGURE 8(g)

DT 06Z WED 30/10/91 T+ 0

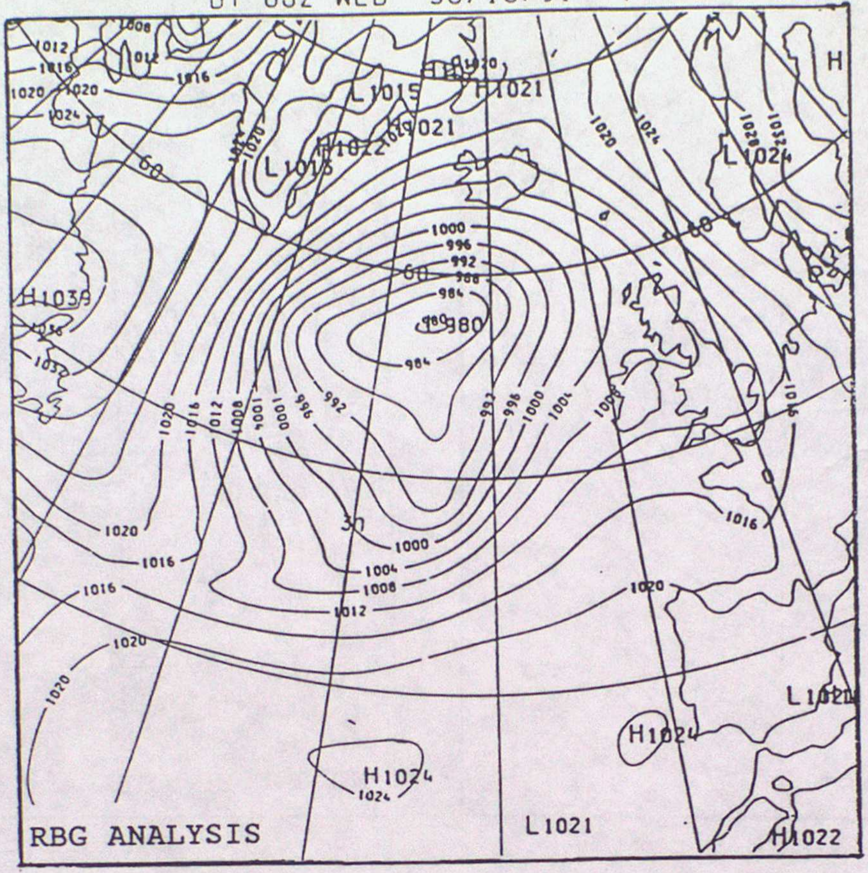

FIGURE 9(a)

DT 06Z WED 30/10/91 T+ 0

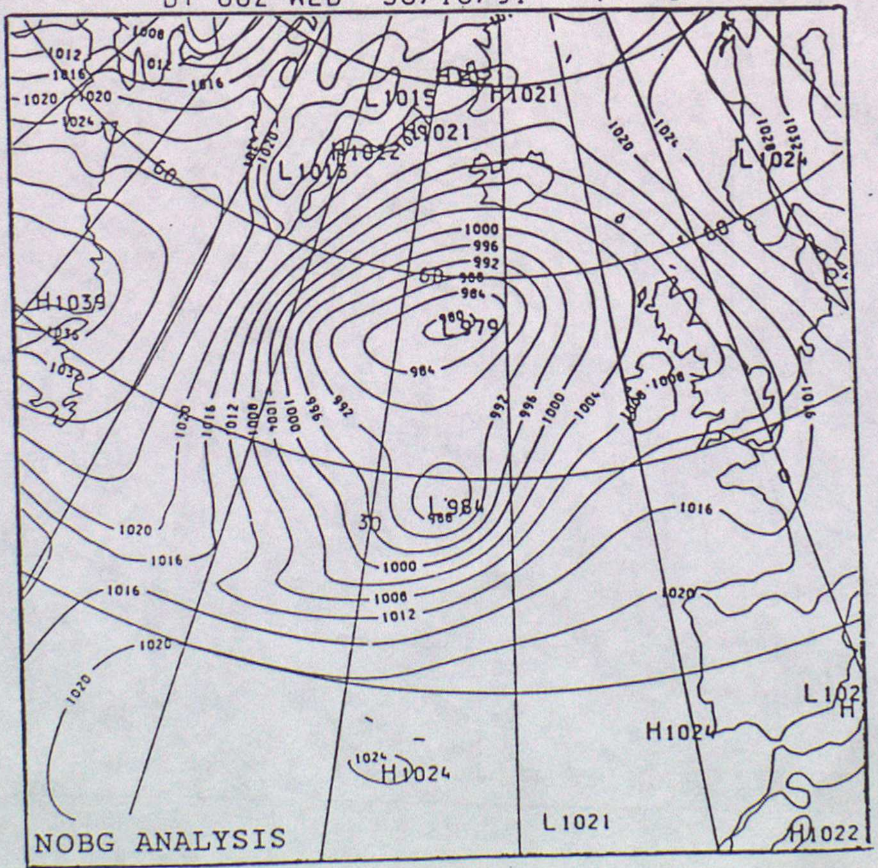

FIGURE 9(b)

DT 06Z WED 30/10/91 VT 18Z THUR 31/10/91 T+ 36

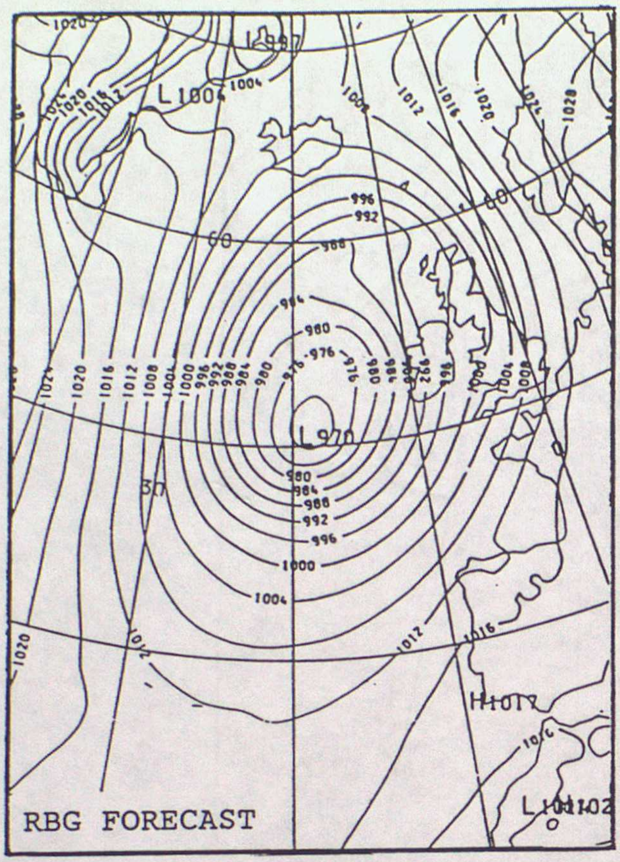

FIGURE 9(c)

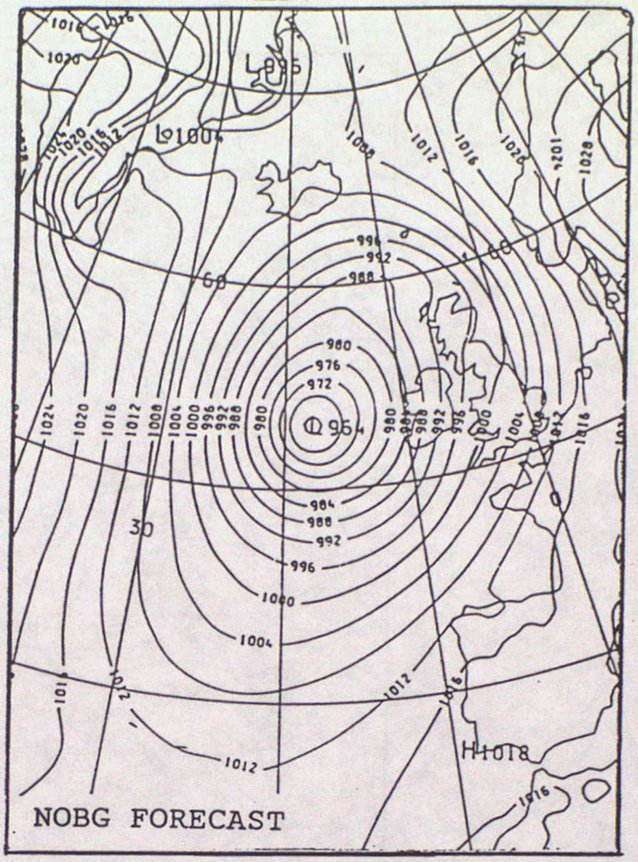

FIGURE 9(d)

DT 18Z THUR 31/10/91 T+ 0

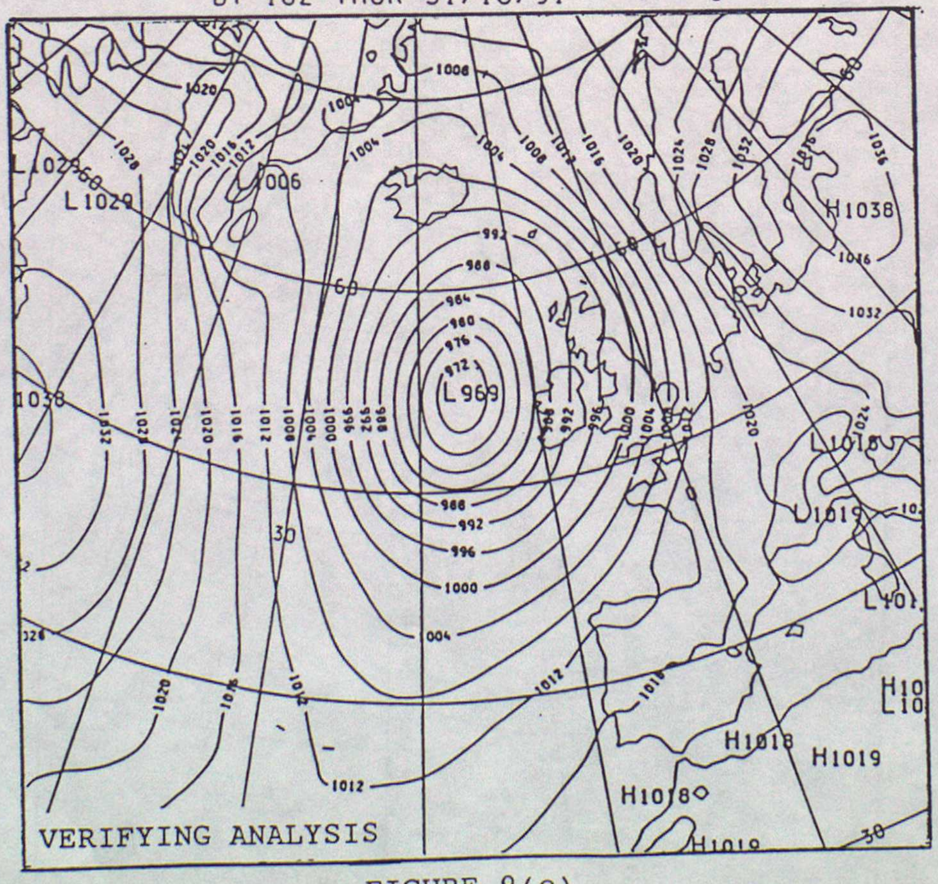

FIGURE 9(e)