DIABATIC FORCING AND CYCLONE DEVELOPMENTS IN A LIMITED AREA MODEL

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1. INTRODUCTION

The aim of this study is to investigate the role of diabatic forcing in cyclone developments in the limited area model of the U.K. Meteorological Office. Two cases have been selected for which the operational model forecasts successfully predicted the explosive deepening of the cyclones. The sensitivity of the forecasts to the inclusion of diabatic processes is examined and the influence of penetrative convection on the developments shown.

2. THE MODEL

The (fine-mesh) limited area model covers the region 80° W to 40° E and 30° N to 80° N. It runs on a latitude-longitude grid of resolution 0.75° x 0.9875° (approximately 75 km at mid-latitudes) and 15 levels in the vertical. It is run routinely twice a day for guidance up to 36 hours ahead (Bell and Dickinson,1987). Diabatic forcing comes through an interactive radiation and cloud scheme, large-scale precipitation which removes supersaturation, a penetrative convection scheme, and a boundary layer and surface exchange parameterization.

3. THE CASES AND EXPERIMENTS

The cases selected were both of rapidly deepening cyclones. <u>Case 1</u> is for the 14/15 December 1986 which saw the generation of the deepest depression analysed over the North Atlantic (Burt,1987). The central pressure fell by 54 mb in the 24 hours up to 00Z on the 15th when the central pressure reached its lowest value of 916 mb. This was then followed by a comparably rapid decay with the central pressure rising by 44mb over the next 36 hours.

Case 2 is another case of rapid development which occurred during 26/27 March 1987 and resulted in a deep depression of 958 mb over southern Scotland at 12Z on the 27th. The rate of deepening over the previous 24 hours was 23mb.

Both these cases were well forecast by the operational version of the model and so were considered to be good candidates for investigating the influence of diabatic forcing on the model forecasts. In both there was heavy precipitation, mostly produced by the large-scale routine although there was much convective activity in the cold air. The effects of latent heat release are likely to be the dominant diabatic forcing. There have been several studies of the influence of latent heating on the development of extra-tropical cyclones (Tracton, 1973; Chang et al,1982; Chen et al, 1983; Hoskins, 1980). The study here is restricted to a few simple sensitivity experiments.

A simple procedure was used to remove all diabatic forcing from the model by eliminating all the physical parameterizations apart from a simple friction scheme in the bottom layers of the model (up to 900mb approximately). The frictional deceleration was given up to 900mb by

$$-g \, \partial\tau/\partial p \text{ with } \tau \; \alpha \; \Delta p^{2}$$

where τ is the stress and $\Delta p = (p-900)$, p is pressure, and with the usual bulk expression for the surface stress.

A second set of experiments allowed all the physical parameterizations to operate except the deep convection scheme. This means that convective instability eventually has to be removed by explicit convection on the grid scale. This will tend to be shallower and is unlikely to reach the upper levels during the short period of the forecasts (up to 36 hours). The diabatic heating is therefore likely to be at a lower level than with the penetrative convective scheme.

For the December case the control forecast used a version of the model with a constant roughness length (0.1mm) over the sea. A formulation in which the roughness length depends upon wind-speed (Charnock,1955; Wu,1982) is found to change the surface fluxes and development of the system. For the March case the wind-speed dependence was included in the control forecasts.

4. RESULTS

4.1 14/15 December 1986 case

The 24-hour control forecast verifying at 00Z on the 15th (Figure 1) deepened the low by 71mb and forecast a central pressure of 901 mb. The verifying analysis placed the centre about 5° further west with a pressure of 916 mb. The most rapid stage in the deepening was observed between 06 and 12Z when the developing wave absorbed another depression into its circulation (Burt,1987) and the fall was 26 mb. The model forecast a smaller fall of 22mb for this period and a fall of 27 mb for the subsequent 6 hours. The total precipitation accumulated during the period 06 to 12Z (Figure 2a) reveals very high totals up to 22mm, most of which was produced by the large-scale scheme (see figure 2b for convective precipitation).

The forecast with simple friction only (Figure 3) only predicts a low of 932 mb positioned about 2° further east and with a retarded frontal trough compared to the control. Since the surface drag formulation is similar, the most likely cause of the relative lack of development is the absence of latent heating. A similar sensitivity to latent heat release is shown by the forecasts reported by Hoskins (1980). The forecast with latent heating leads to an amplification of the upper ridge (Figure 4) and a decrease in relative vorticity (see Figure 5 of the vector wind difference). There is a relative upper high and outflow compared to the simple friction forecast and the vertical velocity differences at 700mb (Figure 6) show the change in the position of the frontal zone and centre.

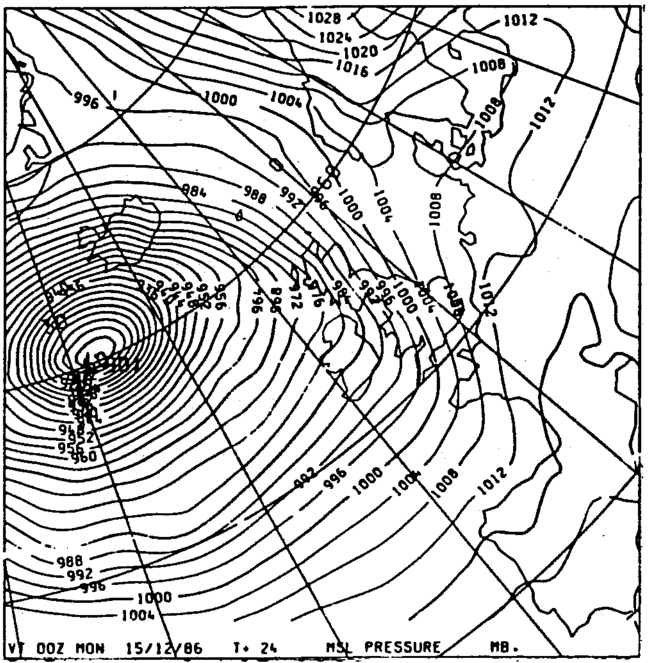

Fig. 1 24-hour control forecast of mean sea-level pressure valid at 00Z 15/12/86

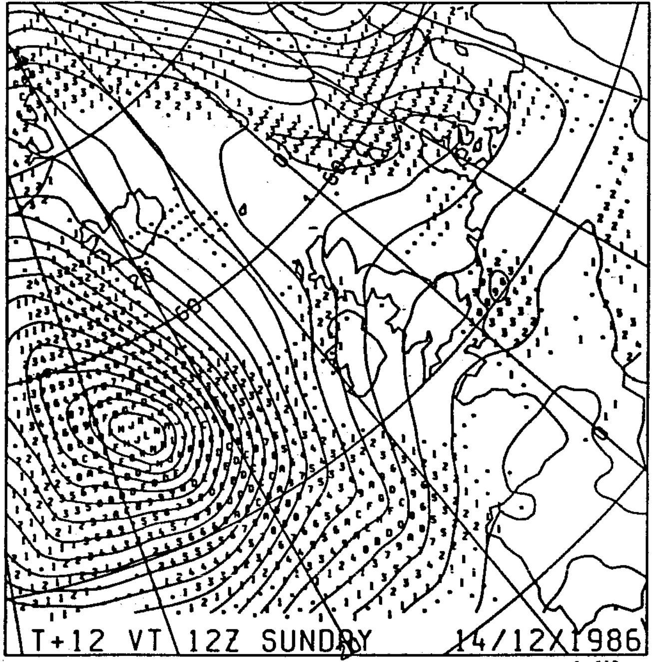

Fig. 2a Total precipitation in mm accumulated by the control forecast between 06Z and 12Z 14/12/86. Letters refer to values above 10 e.g. A=10, B=11,...L=20,..N=22 etc.

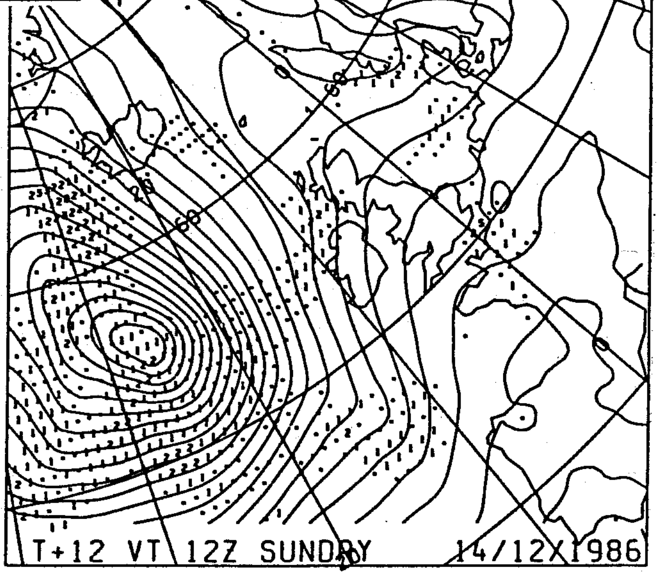

Fig. 2b Convective precipitation in mm accumulated by the control forecast between 06Z and 12Z 14/12/86.

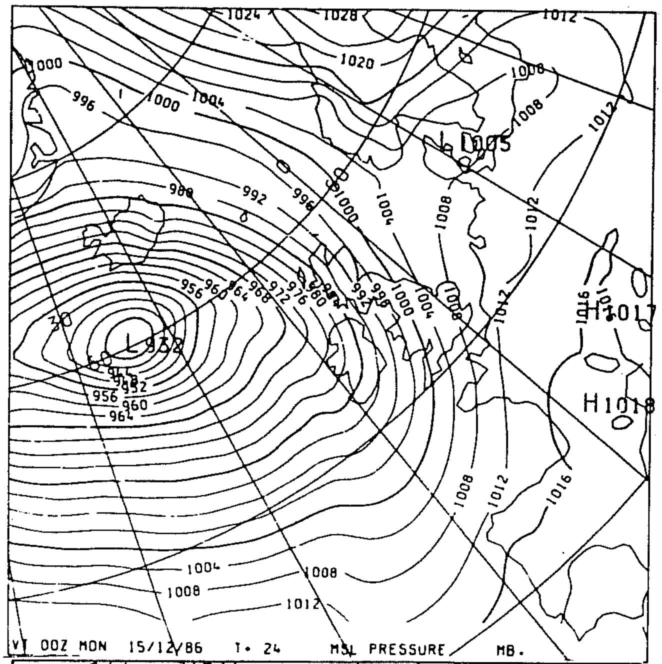

Fig. 3 24-hour forecast of mean sea-level pressure made with simple friction , valid at 00Z 15/12/86

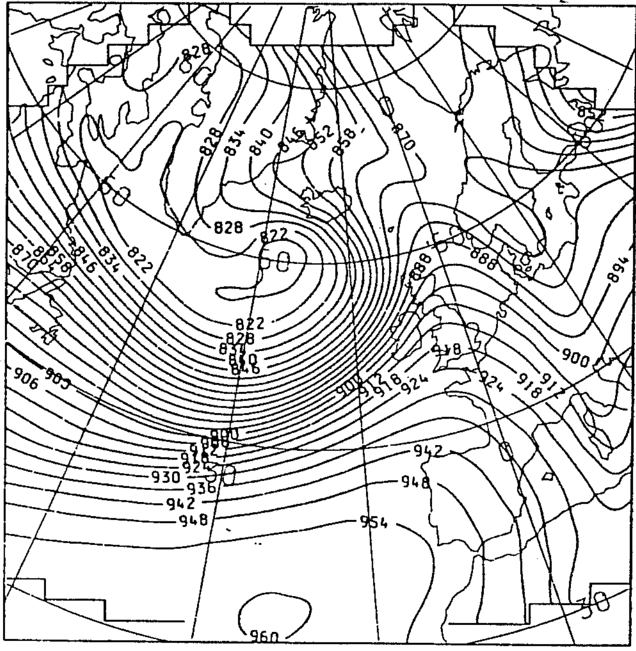

Fig. 4a 24-hour control forecast for 300mb height , valid at 00Z 15/12/86

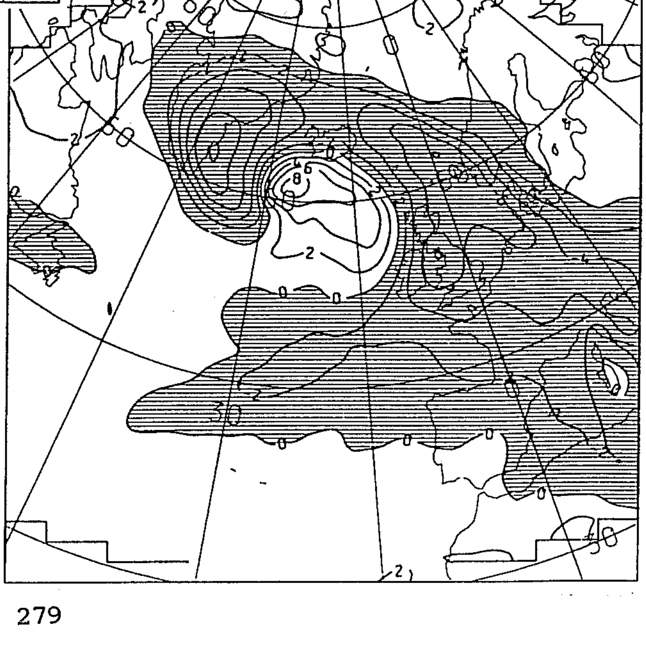

Fig. 4b 24-hour forecast for difference in 300mb height (simple friction-control), valid at 00Z 15/12/86

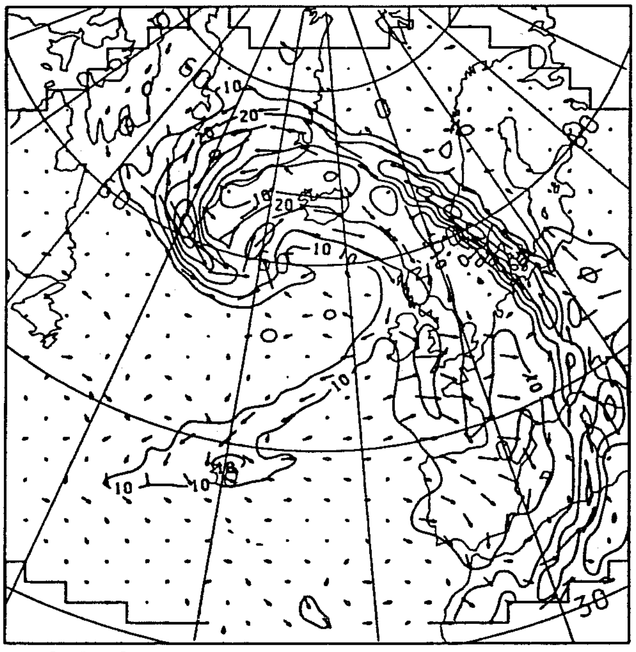

Fig. 5 24-hour forecast for difference in 300mb winds (simple friction-control), valid at 00Z 15/12/86

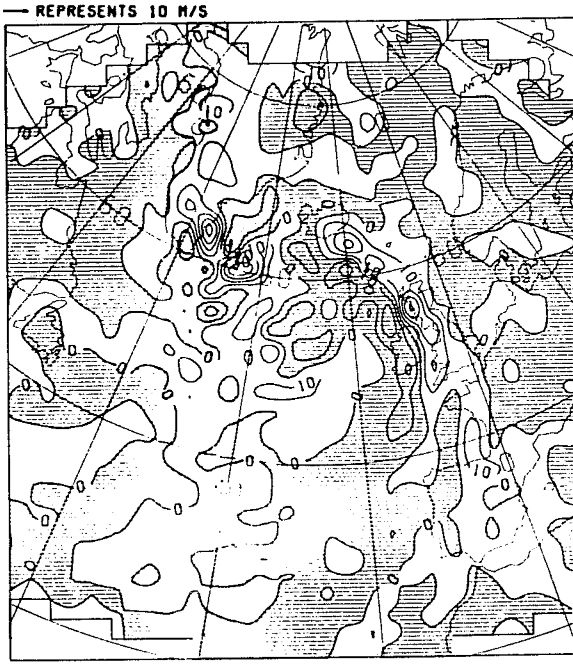

Fig. 6 24-hour forecast for difference in 700mb vertical velocity in mb h^{-1} (simple friction-control), valid at 00Z 15/12/86

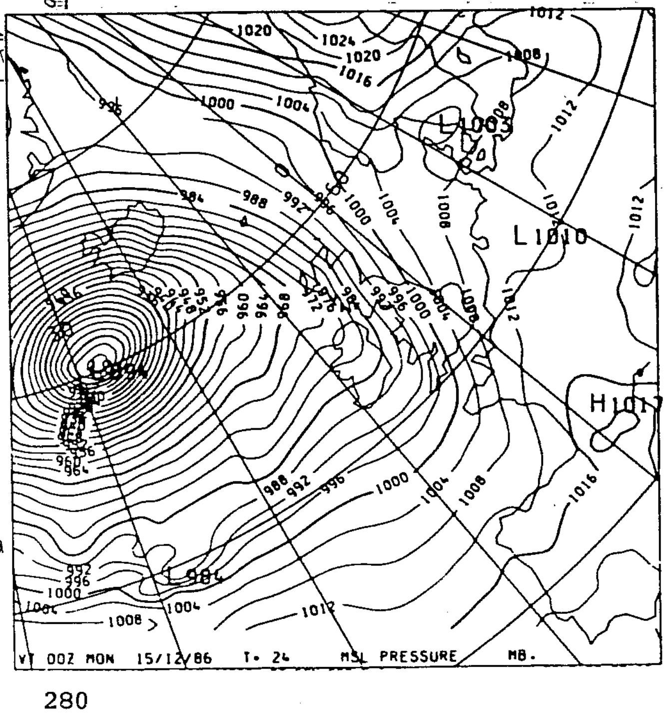

Fig. 7 24-hour forecast of mean sea level pressure made without deep convection , valid at 00Z 15/12/86

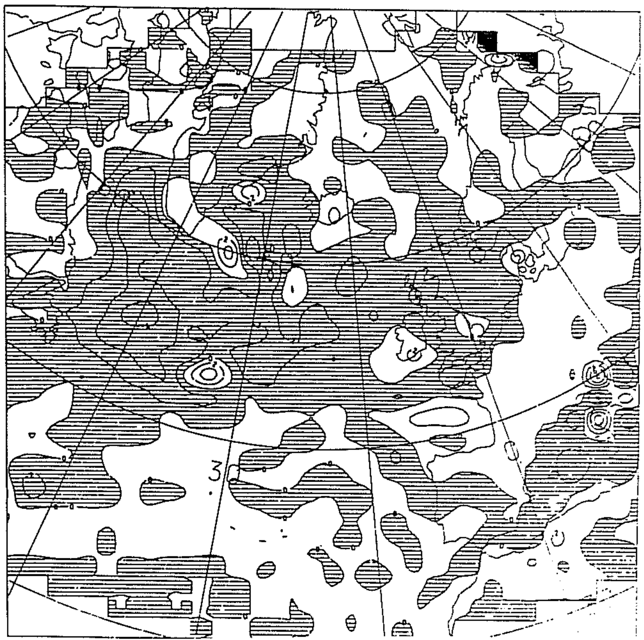

Fig. 8 Difference in total precipitation accumulated during 24-hours to 00Z 15/12/86 (no convection-control).

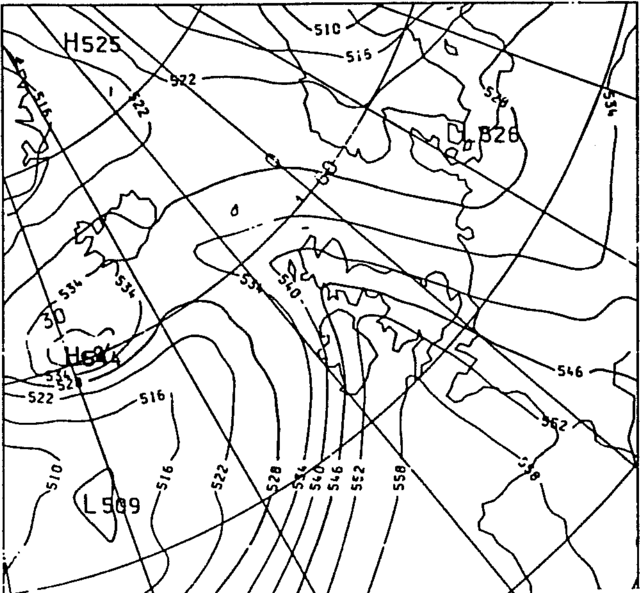

Fig. 9a 24-hour control forecast of 500-1000mb thickness , valid at 00Z 15/12/86

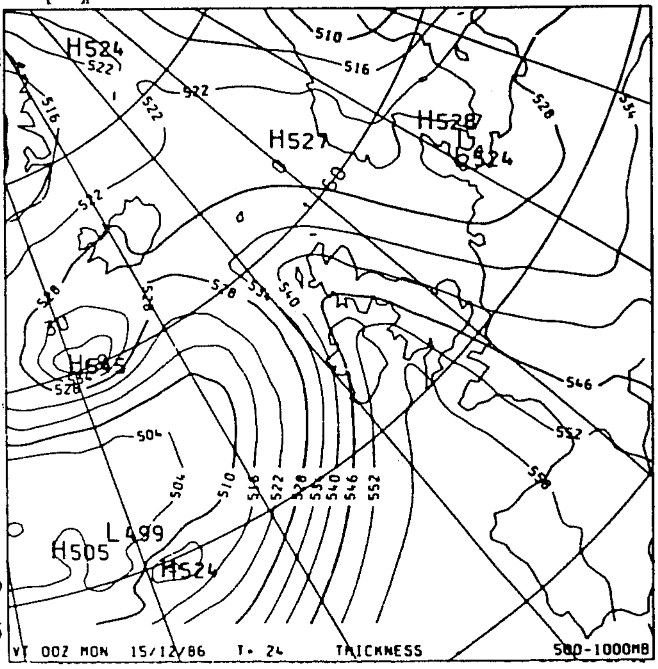

Fig. 9b 24-hour forecast of 500-1000mb thickness made without deep convection , valid at 00Z 15/12/86

Removing the deep convection scheme resulted in a slightly greater depth for the depression (Figure 7) The change in total precipitation during the forecast (Figure 8) shows that although the large-scale process has partly compensated for the lack of a convection scheme there is an overall decrease in the cold air. There is a decrease of 12 dam in 500-1000mb thickness pattern (Figure 9) in the cold air. Penetrative convection in this region is likely to act to damp the growth of the depression by reducing thermal contrast.

For the decay stage of the depression the control forecast did not capture the rapid filling. The centre was almost stationary south-west of Iceland and only filled to 938 mb in the 36 hours from the initial analysis at 00Z on the 15th. Removing the deep convection scheme had a similar effect to the earlier forecast with the filling 8 mb less.

It is likely that part of the reason for the slow decay is the use of a constant roughness length (0.1 mm) over the sea. Replacing this by a wind-speed dependent length resulted in a forecast for the central pressure of 945 mb. Over the 36 hours of the forecast the mean latent and sensible heat fluxes from the surface (Figure 10) increased by up to 150 Wm^{-2} (40%) and 50 Wm^{-2} (25%) respectively over the region to the south with the strongest winds. Much of the extra latent heating was released to the atmosphere in this area and increased the 500-1000mb thickness by 6 dam. In both these experiments the filling of the depression depends upon the flux of latent heating from the surface to the atmosphere although in the latter increased surface friction no doubt plays a part.

4.2 26/27 March 1987 case

The control 36-hour forecast for 12Z on the 26th has a low of 960 mb, slightly greater than the 958 mb observed and with the centre slightly too far south-west over Northern Ireland (Figure 11). As with the December case the forecast made with simple friction failed to develop as much with the depth 11mb higher (Figure 12) whilst the absence of a deep convection scheme resulted in a forecast low of 958 mb. The 300mb

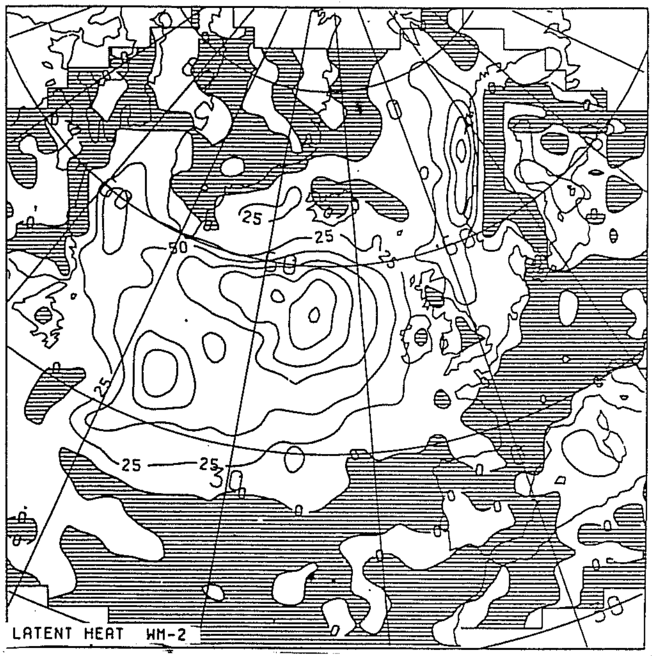

Fig. 10 Difference in surface latent heat flux meaned over 36-hour forecast for (wind-speed dependent roughness minus constant roughness over sea), valid at 12z 16/12/86.

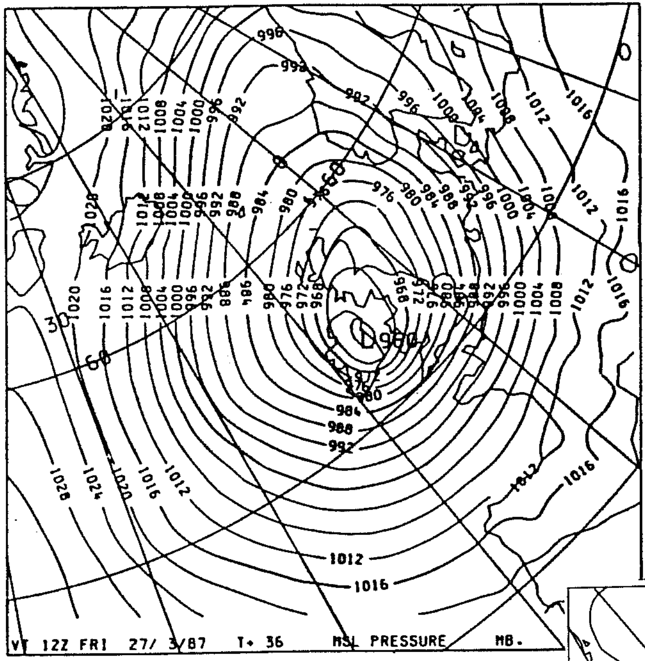

Fig. 11 36-hour control forecast of mean sea-level pressure valid at 12Z 26/03/87

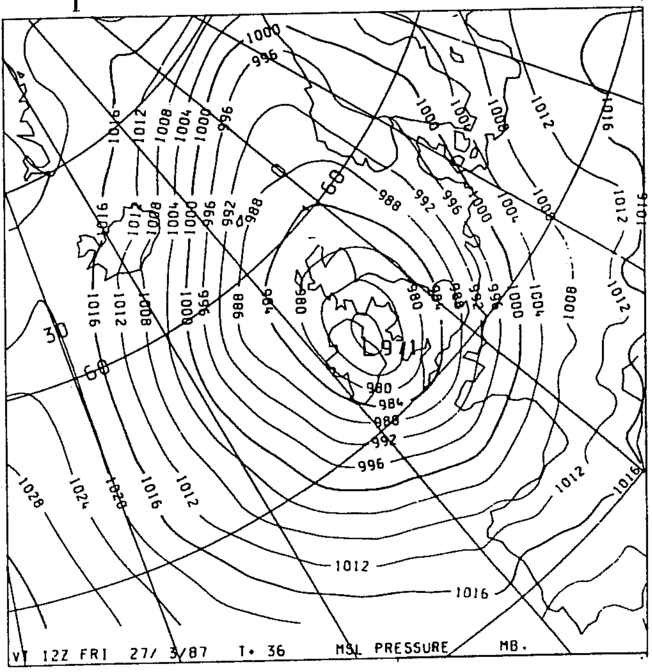

Fig. 12 36-hour forecast of mean sea-level pressure made with simple friction , valid at 12Z 26/03/87

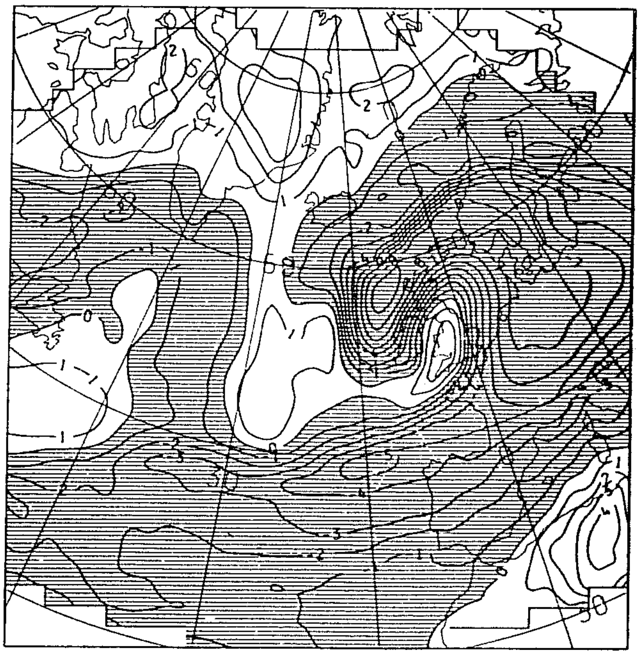

Fig. 13 36-hour forecast for difference in 300mb height (simple friction-control), valid at 12Z 26/03/87

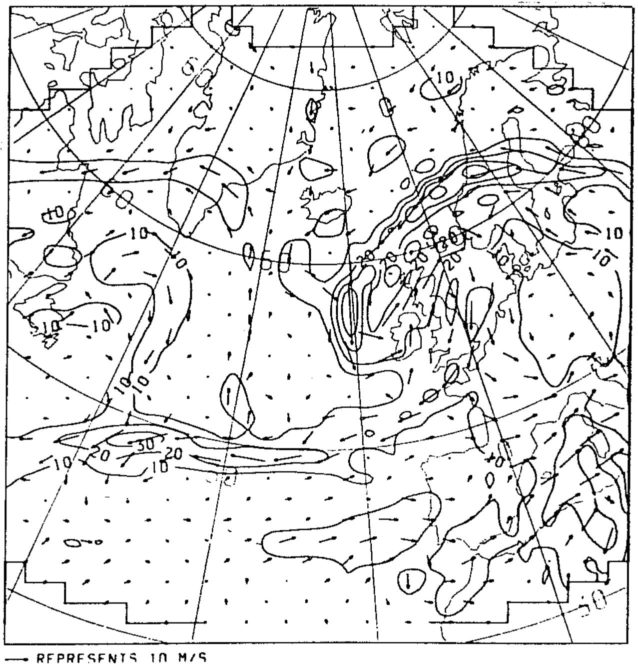

Fig. 14 36-hour forecast for difference in 300mb winds (simple friction-control), valid at 12Z 26/03/87 height (Figure 13) and wind differences (Figure 14) for the simple friction minus control show the same pattern as before with latent heating leading to a strengthening of the upper ridge ahead of the trough and relative outflow.

The decay over the next 36 hours was again inadequate in all the forecasts over this period including the control which only filled by 2mb (the observed increase was 14mb). Omitting deep convection resulted in little change to the central pressure.

5. DISCUSSION

From these brief studies of explosive events it appears that up to half of the rapid deepening is related to the diabatic forcing through latent heat release, especially from the large-scale precipitation. Omitting the deep convection scheme leads to a sligthly greater depth of the depressions. In the filling stage deep convection provides a greater damping. The filling over the sea is greater if a wind-speed dependent roughness length is used.

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