TECHNICAL MEMORANDUM

42

A case study of an overintensified cyclone development in the ECMWF

H. Sävijärvi and O. Åkesson

Research Department

October 1982

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen

1. INTRODUCTION

The over-intensification of northern mid-latitude cyclones is a not uncommon feature in ECMWF short and medium-range forecasts. The problem is particularly severe over the main user area (Europe) and contributes strongly to the systematic error pattern in the forecasts. The reasons for the over-development are not clear and many approaches may be needed to solve the problem.

In this paper a single case was selected for a thorough cross-examination. The over-development chosen was rapid and intense, making two day forecasts useless in northern Europe. The growth occurred in south westerly flow over central Europe, where both the initial state and forecast can be checked against plenty of observations.

The synoptic description of the development in reality and as forecast by the ECMWF operational model is described in Chapter 2. The initial state inaccuracy in mass and humidity analysis is also discussed. The possible role of the parameterization of subgrid scale effects in the overdevelopment is discussed in Chapter 3 and results of some alternative forecast experiments with varied parameterization schemes are described in Chapter 4. Our conclusions for the reasons of the overdevelopment are then summarized. Excessive latent heating together with inaccuracy in the boundary layer initial state seem to be the major agents in this case.

2. SYNOPTIC DESCRIPTION AND INITIAL STATE ACCURACY

On 2nd July 1981 12Z a shallow surface low of 1007 mb was observed just west of Lyon (Fig. 1). At 500 mb a sharp trough just west of Ireland was observed (Fig. 2). The surface moved in a NNE direction and was found over Denmark 24 hours later having deepened to around 999 mb. The ECMWF forecast from the 2nd July showed a much more developed low after 24 hours of 993 mb and positioned around 300 km SSE of the true position (Fig. 3). On the 4th July the 48 hour forecast low had deepened to 982 mb, positioned between Oslo and Stockholm, whereas the real low of 1000 mb was still about 300 km away to the NNE (Fig. 3). The operational D + 1 forecast from 3rd July also showed a deeper centre of the low in its 24 hr forecast, but with a correct position (Fig. 4). The D + 3 forecast from 1st July did not exaggerate the development of the low, however, but showed remarkable skill both in position and intensity of the feature (Fig. 4). This underlines the sporadic non-systematic behaviour of the ECMWF model and that analysis errors cannot be ruled out as possible reasons for overdevelopment even in data-rich areas.

A summary for surface parameter verification is given in Fig. 6 in the form of meteograms for Hamburg and Paris, where the right panel is the observed weather and the left panel is interpolated from the four nearest grid points following the forecast from 2nd July. Note the more moist and colder initial state and increase of (surface) humidity during the forecast. The forecast precipitation is higher than observed, particularly for Hamburg.

Fig. 7 shows the observed (balloon soundings) and +12 hour forecast relative humidity values at 850 mb at 3rd July 1981 00 GMT. The observed values are significantly lower over the cyclone development area in middle France. Fig. 8 shows the verifying observed (6Z-6Z) and model produced (12Z--12Z) rainfall over Europe for the 0-24 hour forecast (left) and 24-48 hour forecast (right) from 2nd July. The forecast rainfall is concentrated into the warm sector along the track of the developing cyclone and is also intense over the Alps. Only modest amounts of rain were observed in the neighbourhood of the cyclone centre discussed, so the excessive latent heating in the forecast might be one reason for overintensification.

2.1 Observed and analyzed initial state over Europe

Figures 1a and 1b indicate that the initial position of the surface low was not exactly the same in the subjective surface analysis (based on surface pressure and pressure change observations) and in the objective analysis, where the shallow low is about 200 km further to the southwest. The 12Z observed low is located over the Massif Central and at 6Z, 6 hours earlier, was observed near the analyzed position at 12Z over Bordeaux. Consequently, an analysis error at 12Z of about 200 km in the position of the low is evident. Assuming correct upper analyses this would lead to weaker westward vertical tilting of the trough axis than in reality.

At 500 mb the height and temperature analyses are in good agreement with the observations (Fig. 2). Also compared to the 6 hour forecast from 06Z and 24 hour forecast, there are only minor differences.

Fig. 5 shows the analyzed and observed 2m (surface) temperatures at 12Z on 2nd July 1981. For most areas the analyzed values are within reasonable limits from the observations. The largest differences are found in the Alp region, southern France and northern Italy, the analyzed values being 3-5°C colder than observed. Given a correct absolute humidity analysis this would lead to too high relative humidity near the surface through the temperature dependence of the saturation mixing ratio.

The analysis of humidity is done in the following way: the integrated water content of a column, e.g. P_s-850 mb (or 1000-850 mb if $P_s > 1000$ mb) is analyzed using a correction method and the difference from the first guess is then used to calculate the difference in the relative humidity $(q/q_s(T))$, where q_s is based on the analyzed temperature. This difference is added to the first guess relative humidity, where q_s is now based on first guess temperature, and converted back to absolute humidity for the model, q_s again being based on analyzed temperature. As the analyzed surface temperatures were lower than observed by 3-5°C over the Alps (Fig. 5), and the first guess temperatures are even lower at 12Z (because the 6-hour forecast starting from 06Z data and used as first guess does not include the daily cycle), this conversion between absolute and relative humidity with inconsistent temperatures can cause errors near the ground. These errors may be expected to be largest over high ground where the water content of column P_s-850 mb is dominated by ground effects.

The absolute humidity of the first guess and 12Z analysis for 2nd July 1981 are shown in Fig. 9 at the lowest model layer, which is about 30 m above the ground. Also the relative humidity is shown, based on the appropriate temperature field. The relative humidity is reduced only slightly in the updating of the first guess fields. In both cases it is nearer to night time than day time observed surface relative humidities. The absolute humidity is, however, higher in the analysis than in the first guess over the Alps by 2-3 g/kg (20-30%) which in turn is higher than the observed surface humidity by roughly the same amount in the same region, implying even lower first-guess temperatures over the Alp region for 12Z.

The quasi-conservation of relative humidity and variation of the absolute humidity, as featured above, through the 4 analysis per day cycle, is the opposite from what is observed and could be cured by either improving the first guess fields by inclusion of a daily cycle, or by having proper temperature fields (first guess) in the conversion between relative and absolute humidity or by analyzing and interpolating full humidity fields instead of increments. The problem is most severe near the ground but through vertical correlations in the analysis scheme, the 850 mb absolute humidities are also slightly enhanced. This extra moisture, especially over the rough terrain, is likely to be transported to the free atmosphere by mechanical turbulence in the model. Since it also increases the initial conditional instability of the lowest layers, convective turbulence may contribute as well.

If the initial moisture field near the ground was at all important for the cyclone development, the above discussion may help to explain the inconsistencies in the present, previous and following day forecast behaviour (Fig. 4).

The development was very intense from 2nd July data where the area near the initiating cyclone was over (model) high terrain. The development was slightly too intense from 3rd July data when the area near the growing cyclone was over flat land, and less intense from 1st July data when the development took place in the model over land but presumably after the initial moisture field had already been adjusted dynamically to the model.

3. CYCLONE GROWTH AND THE GRID SCALE PARAMETERIZATION

Comparisons between ECMWF grid point and spectral models with the same parameterization scheme (Girard and Jarraud, 1981) show that the systematic error patterns are very similar in the two models and the over-intensification of cyclones is a common and similar feature in both of them. This suggests that the adiabatic part of the model is not the major factor in over-intensifications. Consequently, we will discuss here the possible role of the sub-grid scale effects in the present cyclone case, following Hoskins' (1980) treatment.

3.1 Destabilization and baroclinic wave growth

The diabatic heat sources can act directly on the development of transient phenomena by forcing vertical motions; through the omega equation localized heating maximum forces rising motion and localized cooling forces sinking motion. However, systematic heat sources can also change the gross vertical static stability, which is one of the factors controlling wave growth in baroclinically unstable conditions. The static stability has a damping effect on short baroclinic waves. For the Green problem, Hoskins (1980) demonstrated that by halving the static stability for an unstable wave at wavenumber 12 in typical mid-latitude conditions, the e-folding time decreased from 3 days to 22.5 hours. Thus destabilization of the model atmosphere through systematic cooling in middle and upper atmosphere and heating near the surface can lead to intensified cyclone development. The observed mid-tropospheric cooling and over-intensification of cyclones in the ECMWF model may be coupled dynamically in this way.

Energetically the baroclinic disturbances are driven by rising of warm air and sinking of cold air, thereby releasing eddy available potential energy (EAPE) to eddy kinetic energy (EKE). The generation of available potential energy (APE) may be written as $G = \{N.Q\}$ (Lorenz, 1967) where Q is heating, { } is global average and N is an efficiency factor which represents the effectiveness of heating at any point in producing APE. Lorenz' hypothetical distribution of N shows that the generation is very effective if strong cooling occurs in high and middle latitude upper troposphere.

Potential temperature cross sections through the cyclone centre along 50°N in the present case (Fig. 10) show that the model atmosphere, at day 1, is actually statically more stable than the verifying analysis, so that the intense growth was not due to low vertical (dry) stability of the model atmosphere.

3.2 Convective and large scale latent heat release

The initial state for the present case (Fig. 1 and 2) was favourable for cyclone development and thus it may not be possible to extract the role of the parameterization scheme in initiating it. However, once the cyclone was formed there was strong convective precipitation in the model , in, mainly, the warm sector area, while large scale precipitation was negligible. The total rainfall for 24 and 48 hour forecasts is shown in Fig. 8. The surface observations did not report much rain at all (Fig. 8).

The latent heat release in the model presumably took place in the low and middle troposphere and enhanced the upward vertical motion, low level trough and upper ridge in the warm sector area of the cyclone, as discussed in Hoskins (1980). The vertical motion for day 1 is shown in Fig. 11b as a west-east cross section through the cyclone centre along 50^{O}N; the verifying vertical velocity ω from the initialized analysis is in Fig. 11a. The upward motions are enhanced in the forecast in the warm section area, thereby both driving the cyclone energetically (rising of warm air releasing EAPE to EKE) and lifting more moist air up.

3.3 Radiation

Fig. 12 gives the cloud cover cross section for day 1 forecast and for the verifying analysis. The cloudiness (a function of relative humidity) extends high up in the forecast; a typical feature in the ECMWF model. The radiative heating from the parameterization scheme for day 1 is in Fig. 12c.

The top layer of the thick forecast cloud deck is cooling by long wave radiation at a rate of 5^{O}C/day, and below the cloud deck there is weak heating at 2^{O}C/day. The cloud top cooling rate is relatively high; Webster and Stephens (1980) report substantial heating below the cloud deck and only weak cooling from the top. However, their calculations were for tropical conditions. The radiation is calculated in the ECMWF forecast every 12 hours and is kept constant during the interval so strong radiative heating/cooling can have a considerable cumulative effect during the 12 hour interval.

The radiative heating pattern in Fig. 12 is destabilizing the model atmosphere in the cyclone centre. The cloud top cooling may also have a feedback effect on condensation: in the cooling upper atmosphere the saturation mixing ratio q_s decreases and thus relative humidity q/q_s may increase. It can be shown that at the 500mb level a 3^{O}K decrease in temperature lifts relative humidity from 80%

to 100% if absolute humidity remains the same. The strong, systematic and continuous radiative cooling at the model cloud top may thus increase cloud heights and induce condensation both by enforced vertical motions in the destabilized lower atmosphere and by feedback to the increasing relative humidity. Cross sections of relative humidity have indicated that the ECMWF model typically has too large humidity values too high up with strong contrasts between moist and dry regions.

3.4 Boundary layer effects

The development discussed here occurred over land in summer conditions and thus the heat exchange with the surface was probably not important. Fig. 13 displays the weak surface heat flux and boundary layer dissipation in the model as the time mean between day 0 and day 1. The PBL dissipation map indicates maximum frictional drag in the cyclone centre area, which may help to set up latent heat release by forcing the initially rather moist boundary layer air up to the free atmosphere by Ekman pumping. The model boundary layer was, however, statically more stable than the analysis in the cyclone centre, which may reduce this effect. On the other hand, the initial state humidity analysis near the surface was more moist (by 30%) than surface observations in the cyclone development area over France and the Alps, so that even weak Ekman pumping may help to transfer the extra moisture up. The too moist analyzed surface layer and too much model precipitation in the first forecast days over the mountainous areas are systematic features in the present ECMWF system.

4. ALTERNATIVE FORECAST EXPERIMENTS

For testing the role of the parameterization scheme in the present case, three experiments were made. In the first experiment (I) the radiation scheme and convective processes (the Kuo scheme) north 20°N were switched off. In the second experiment (II), the parameterization includes only dry adiabatic adjustment and simple frictional drag at the surface; this "minimum physics" version is described in Burridge and Haseler (1977). The experiment (III) is "dry"; all latent heating is switched off. This version is the same as in Hoskins (1980). Fig. 14 gives the day 1 and day 2 surface maps for the three experiments, all started from the 12Z initialized analyses at 2nd July 1981. They may be compared to Fig. 3 for verification and the operational forecast.

The cyclone development in Experiment I is rather similar to the operational forecast, the cyclone centre over Sweden being only 3 mb less deep at day 2. The reason is that the large-scale precipitation in Experiment I is almost identical to the convective precipitation in the operational forecast; and the net latent heating (the total rainfall) is consequently rather similar in these two forecasts, although its vertical distribution may be different: convective condensation tends to occur at higher levels than large-scale condensation. Thus, removing both radiation (cooling of cloud top levels) and convection (heating of cloud top levels) did not have a major effect in the development; the net heating presumably remained essentially similar to the operational forecast.

The cyclone development in Experiment II is slow in the beginning. At day 1 there is no closed low yet over Denmark and the forecast is quite good except that the 850 mb level east-west thermal contrasts are strong. From day 1 to day 2 the cyclone intensified in Experiment II at the same rate as in the other two forecasts so that the surface pressure in the low centre over Sweden at day 2 was 992 mb in Experiment II, while it was 986 mb in Experiment I, 983 mb in the operational forecast and 1000 mb in the verifying analysis. The gradients are, however, too strong because the ridge east of the cyclone has intensified too much. With the simple surface friction used in Experiment II, the surface system intensity depends critically on the drag coefficient chosen.

Experiment III, where the latent heat release was removed, did not overdevelop the cyclone (Fig. 14), although its northward movement is underestimated as in Experiment II. The weak vertical velocities in the cyclone area of Experiment III at day 1 are shown in Fig. 11c. It thus seems that the overintensification was largely caused by the strong latent heat release in the operational forecast and in Experiment I. Another example where latent heat release was crucial in one system (but not in others) was reported in Hoskins (1980).

The 500 mb forecasts are quite good (up to day 2) in the two "dry" experiments (II and III). The upper air wave growth related to the surface cyclone is too intense with strong temperature gradients in the two forecasts (operational and Experiment I), which included moist processes.

5. CONCLUDING REMARKS

We have taken a close look at a case where the ECMWF model developed an intense small scale cyclone over Europe where only a weak low was observed. Our aim was to choose a typical case and identify the causes of the overintensification in it.

The case chosen was a weak summer cyclone development in the south westerly flow over southern France. The ECMWF model intensified the surface low to 983 mb in two days while 1000 mb was observed in the low centre. By checking various diagnostics, verifying the initial state against observations, and making alternative experiments with varying complexity of the physics of the model, we suggest the following. The initialised analysis in the region of the cyclogenesis was rather good in the free atmosphere, but the surface low was displaced by about 200 km towards the west so the tilting of the unstable baroclinic wave was initially not accurate (Fig. 1). Also the humidity analysis was too moist in the lowest layers compared to surface observations in the Alp region (Fig. 9) due to inconsistencies in the conversion between relative and absolute humidity and lack of daily cycle in the first-guess field.

After 12 hours into the forecast the 850 mb level is too moist in the model in the cyclone area (Fig. 7). This may result from vertical transport from the (too) moist surface layer by Ekman pumping and from enhanced vertical motions and adiabatic cooling caused by excessive latent heat release in the warm front section (Fig. 11 and 8). The rainfall was mainly convective in the operational forecast; switching off convective processes did not improve the situation as large-scale condensation then simply reproduced the excessive precipitation.

Because the observed rainfall during the cyclone development was only modest, it may not come as a surprise that switching off the latent heat release in the model produced a good forecast without overintensification (Fig. 14). The vertical velocities near the cyclone area are then reduced by a factor of 3-4, and are close to the analyzed values (Fig. 11). This illustrates the strong feedback between vertical motion and latent heating in the ECMWF model. This strong feedback implies that the initial state, including humidity, may be quite important in rapid onsetting of both convective and largescale condensation, especially with high humidity over mountains, such as occurred in the initial development of the present cyclone case. The inconsistencies between previous, the presently discussed and later forecasts (Fig. 4) indicate the same.

We cannot state how typical the present overdevelopment was. Experiments in several cases, preferably with variable initial conditions, are needed.

REFERENCES

Girard, C. and Jarraud, M. 1981 Short and medium range forecast differences between a spectral and a grid point model. An extensive quasi-operational comparison. ECMWF Technical Report, in preparation.

Hoskins, B.J. 1980 Effect of diabatic processes on transient mid-latitude waves. Workshop on Diagnostics of diabatic processes, ECMWF, pp.85-100.

Lorenz, E.N. 1967 The nature and theory of the general circulation of the atmosphere. WMO, Geneva, Switzerland, No.218, TP.115, 161p.

Webster, P.S. and Stephens, G.L. 1980 Tropical upper tropospheric extended clouds: Inferences from Winter MONEX. J. Atm. Sci., 37, 1521-1541.

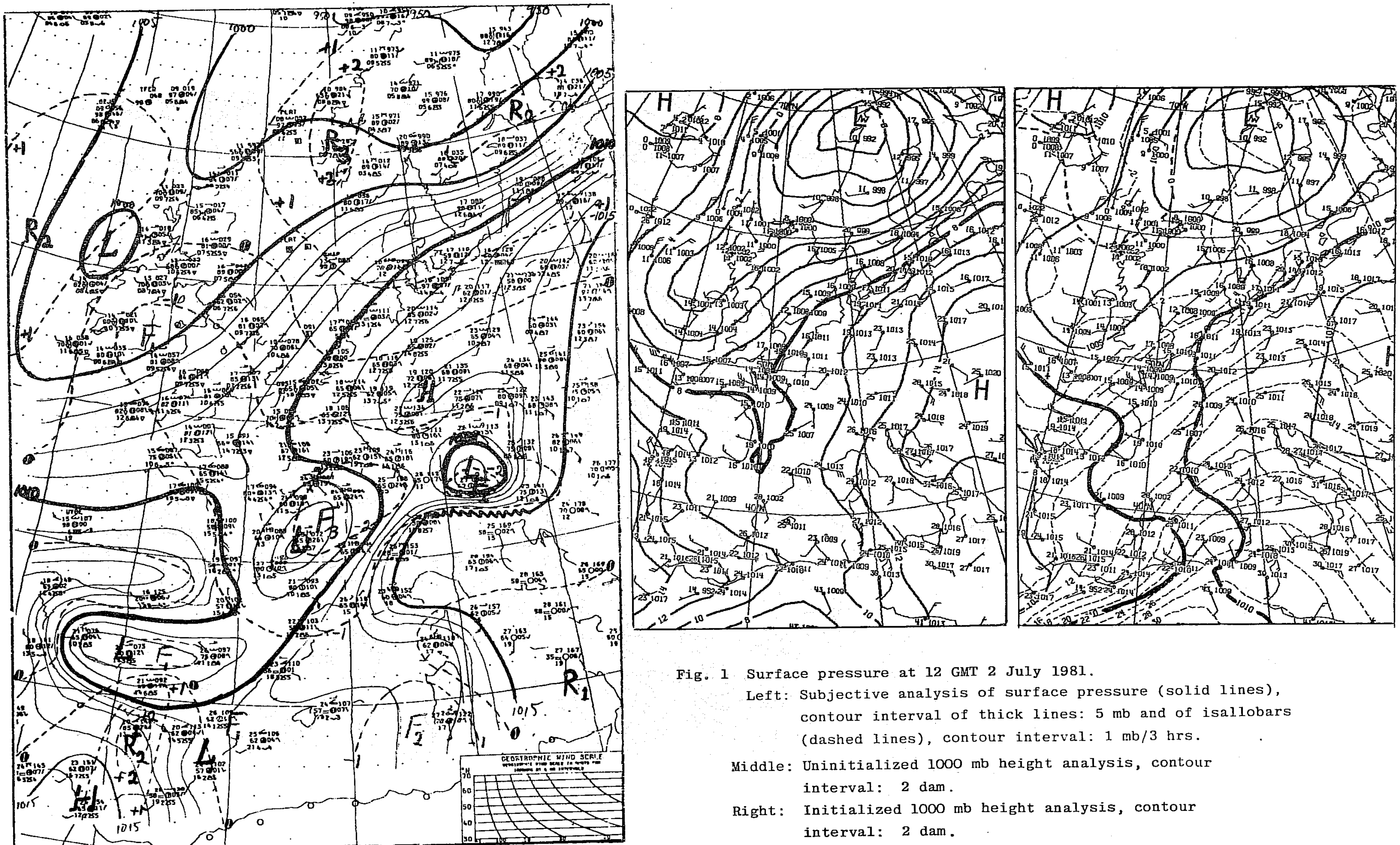


Fig. 1 Surface pressure at 12 GMT 2 July 1981.

Left: Subjective analysis of surface pressure (solid lines), contour interval of thick lines: 5 mb and of isallobars (dashed lines), contour interval: 1 mb/3 hrs.

Middle: Uninitialized 1000 mb height analysis, contour interval: 2 dam.

Right: Initialized 1000 mb height analysis, contour interval: 2 dam.

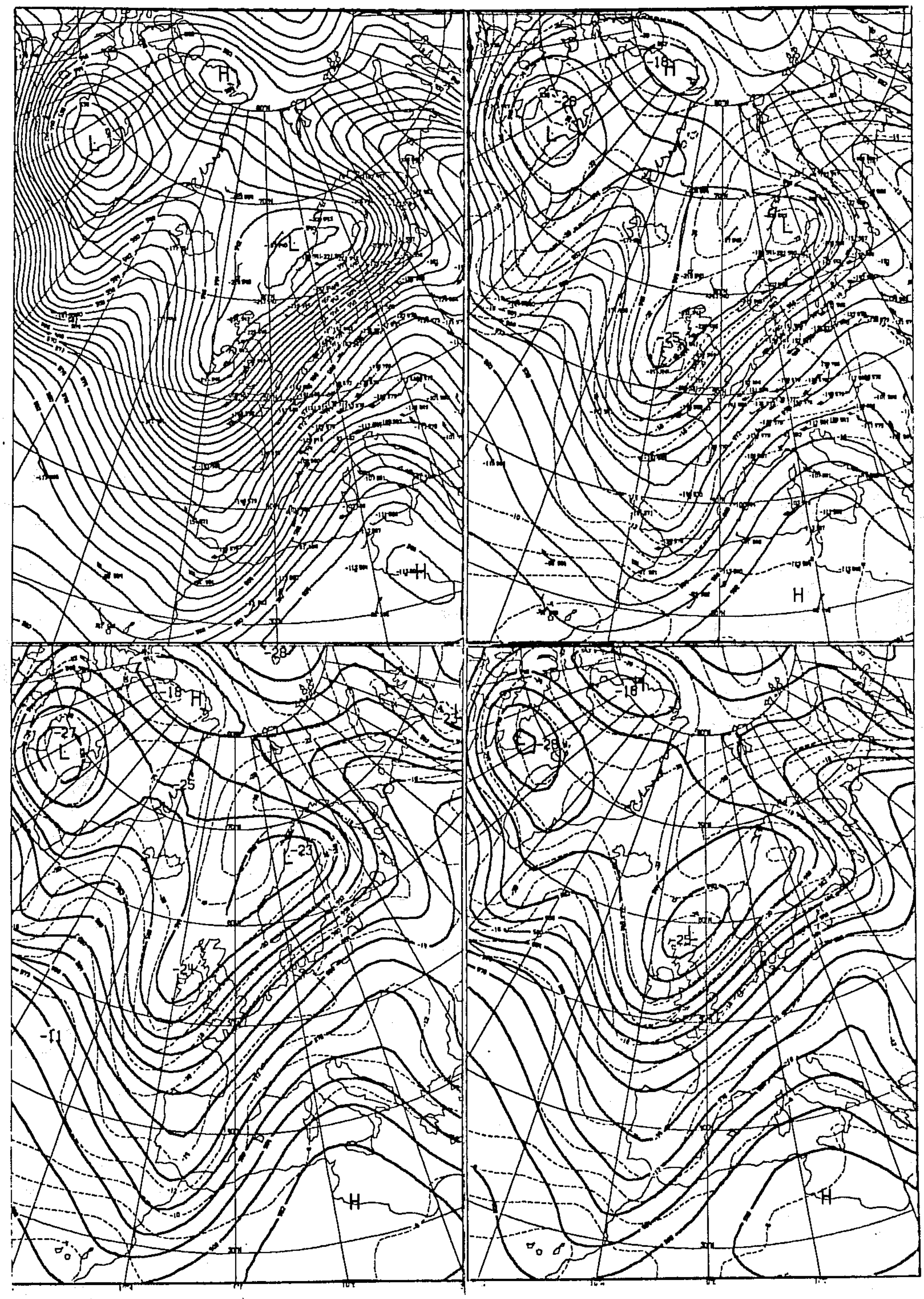


Fig. 2 500 mb height (solid lines) and temperature (dashed lines) fields valid 12 GMT 2 July 1981

Upper left: Uninitialized analysis

Upper right: Initialized analysis

Lower left: 6 hour forecast, first guess.

Lower right: 24 hour forecast from 1 July 1981.

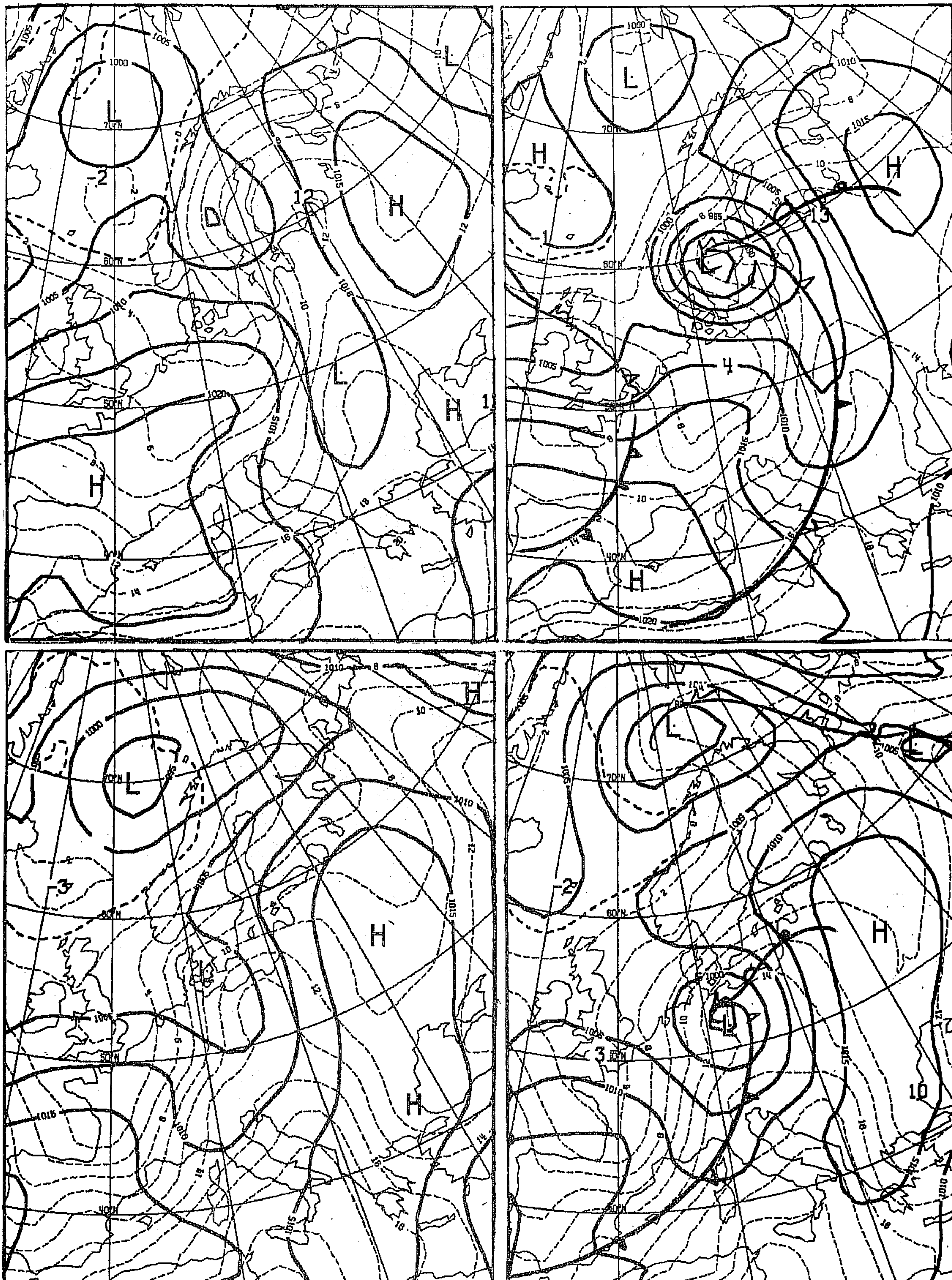
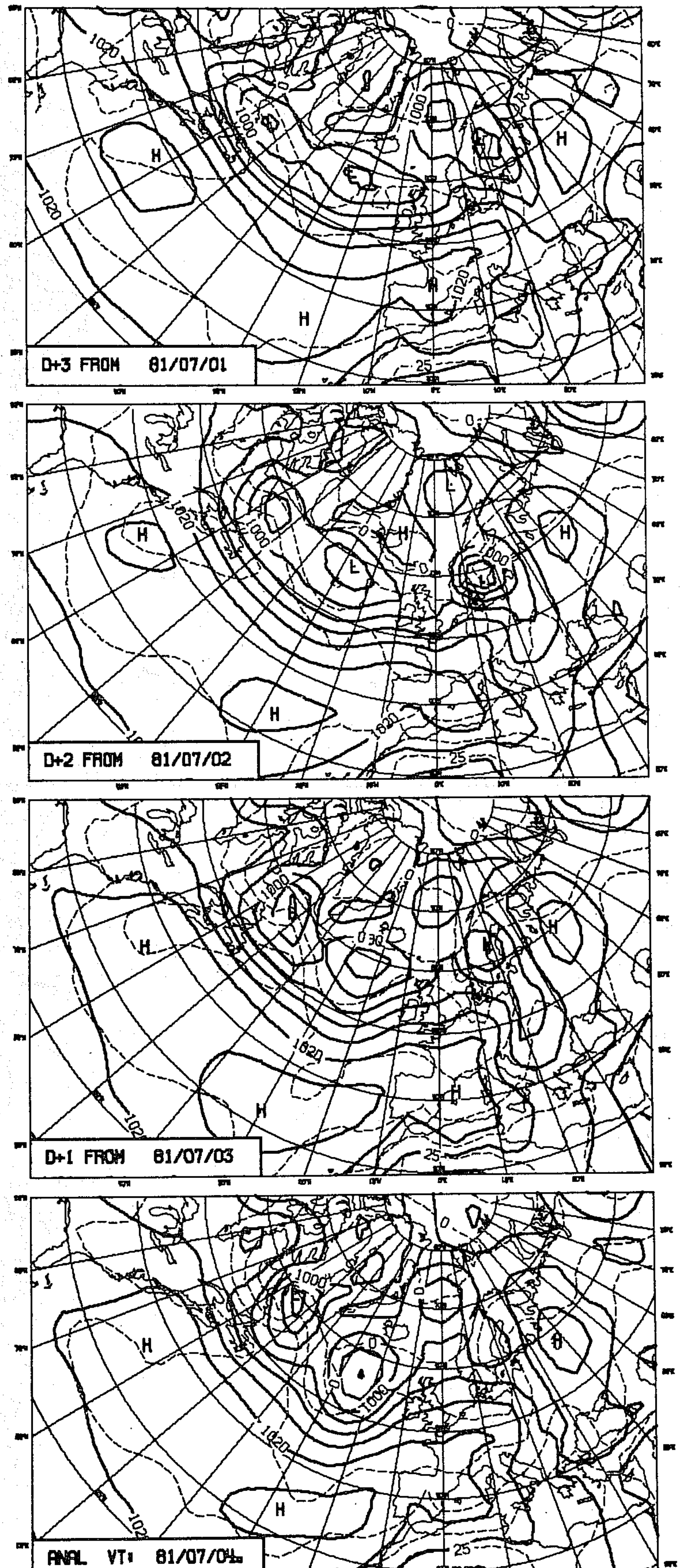


Fig. 3 Surface pressure in the ECMWF forecast from 2 July 1981 (right) and in the verifying analysis (left) for day 1 (lower panel) and day 2 (upper panel) over Europe.



a)
b)
c)
d)

Fig. 4 The day 3 (a), day 2 (b) and day 1 (c) surface pressure forecasts valid at 4 July 1981 12GMT and the verifying analysis (d).

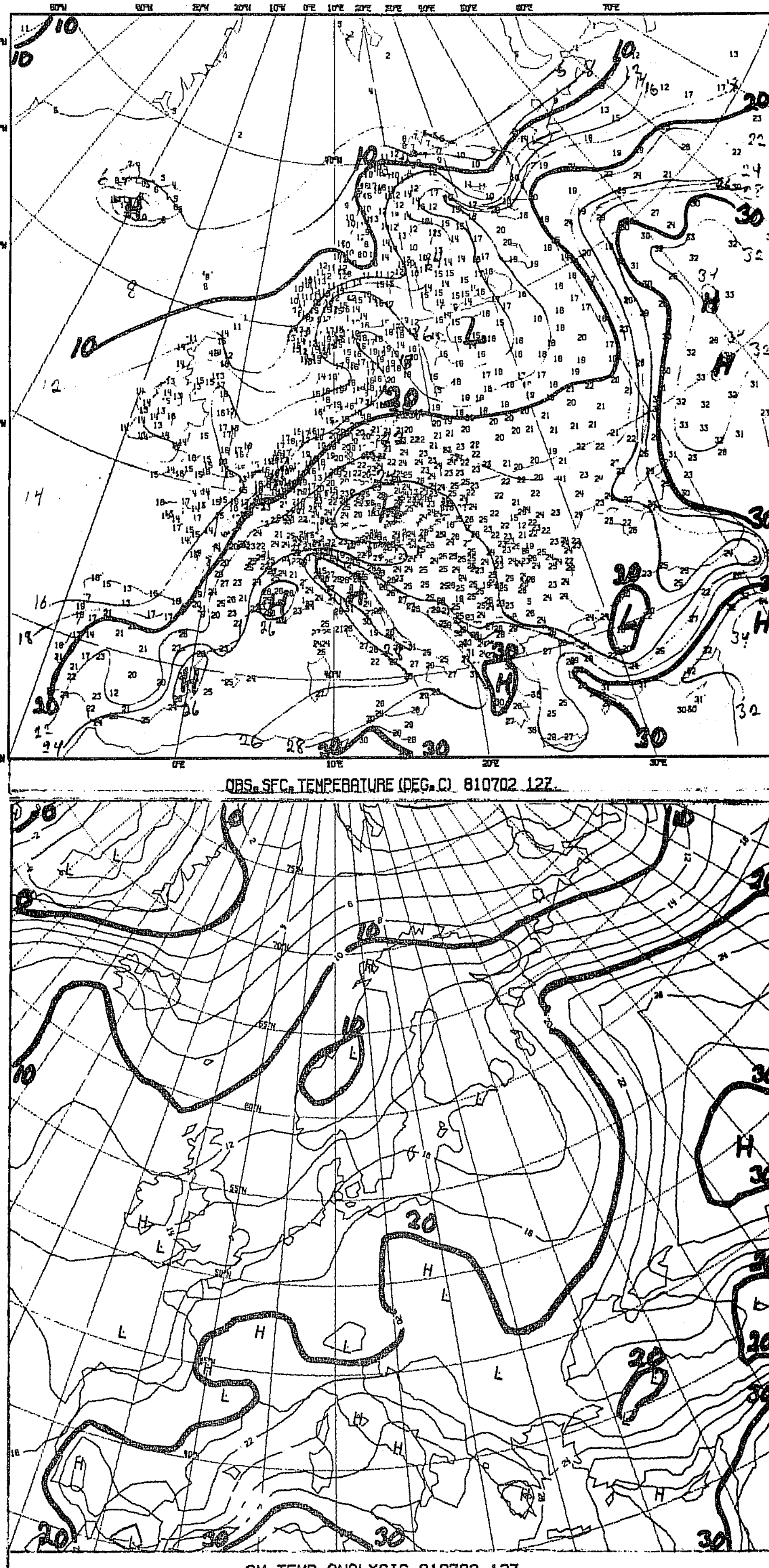


Fig. 5 Surface (2 m) temperature at 12 GMT 2 July 1981

Top: Observed

Bottom: Analysis

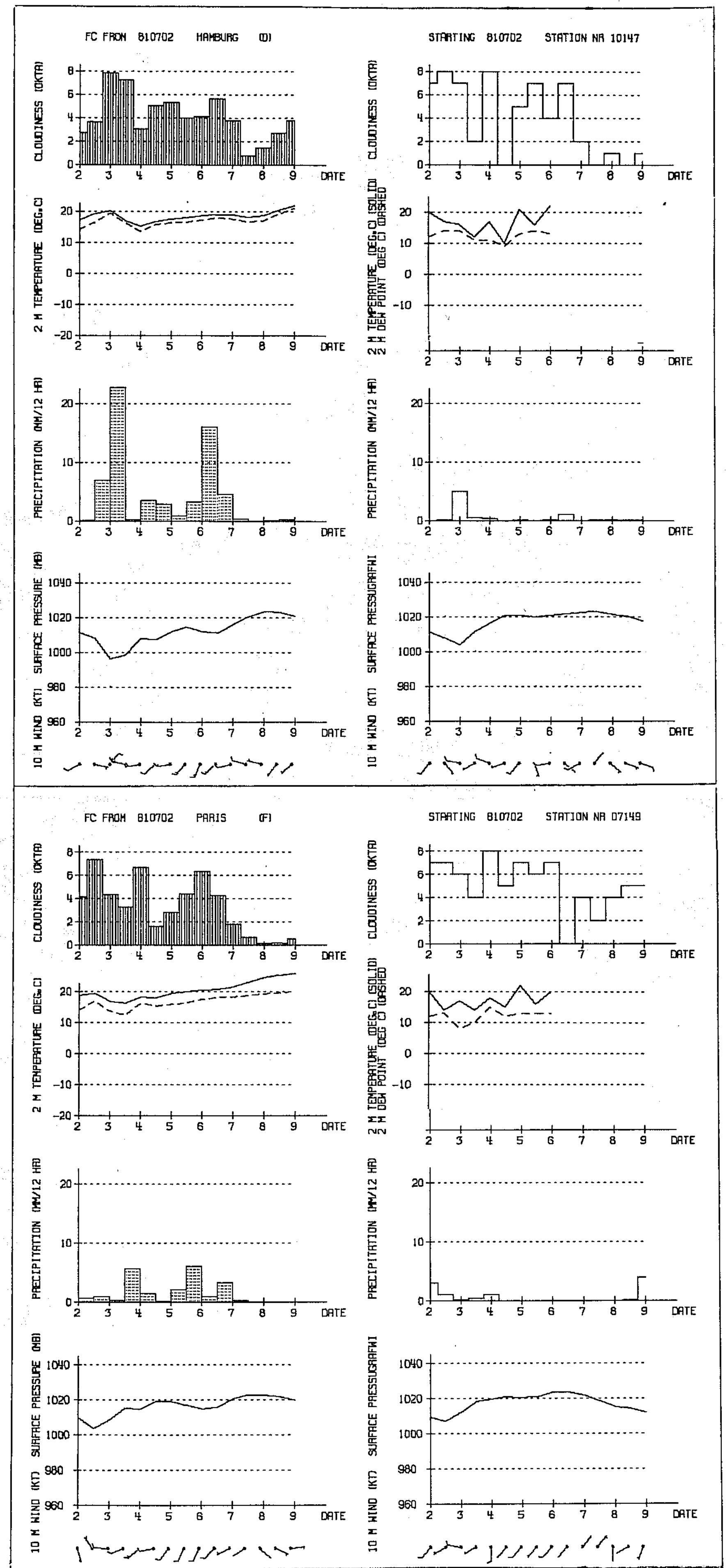


Fig.6 Meteograms for Hamburg (top) and Paris (bottom) for the time period 2/7 - 9/7 1981

Left: Forecast

Right: Observed

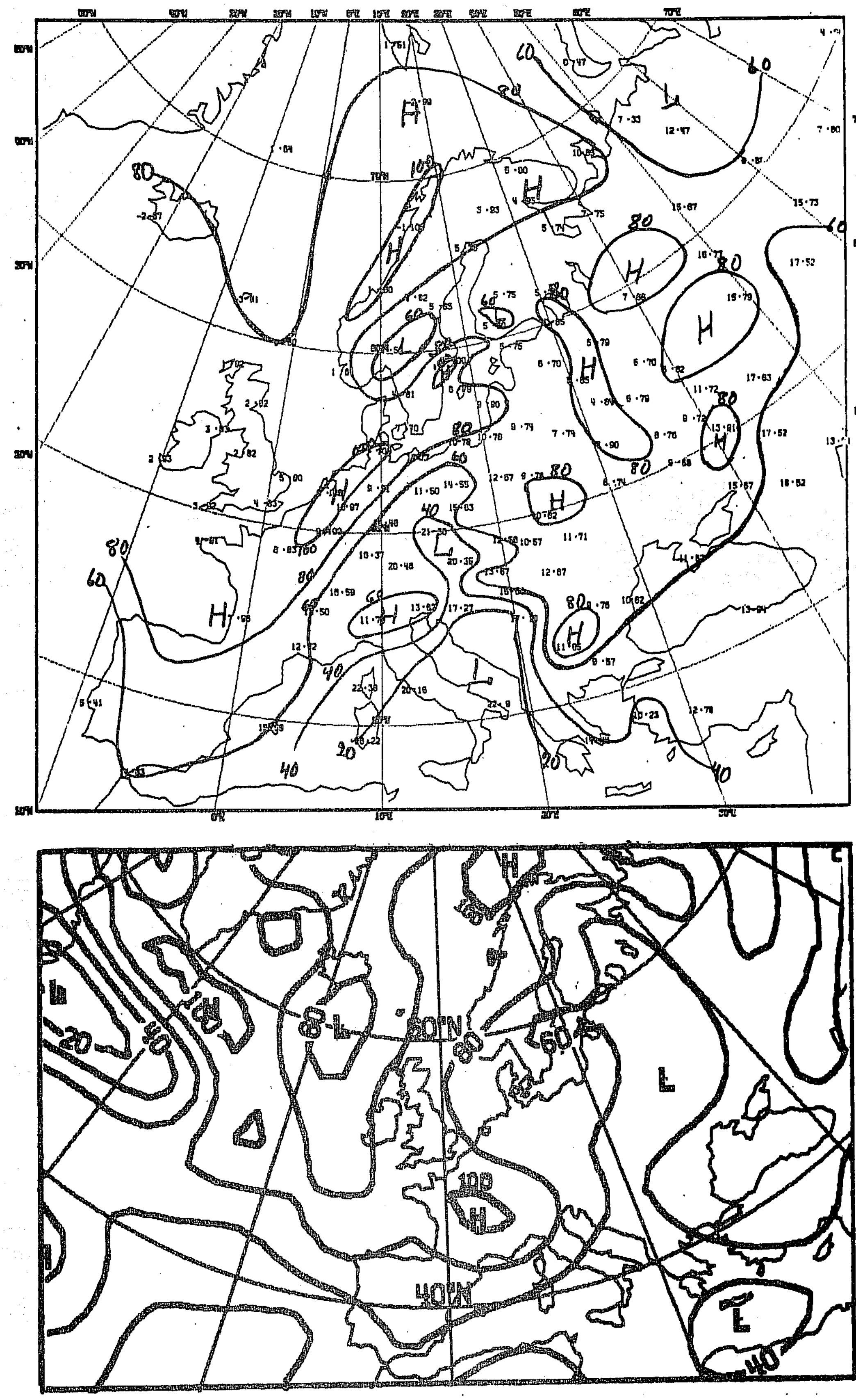
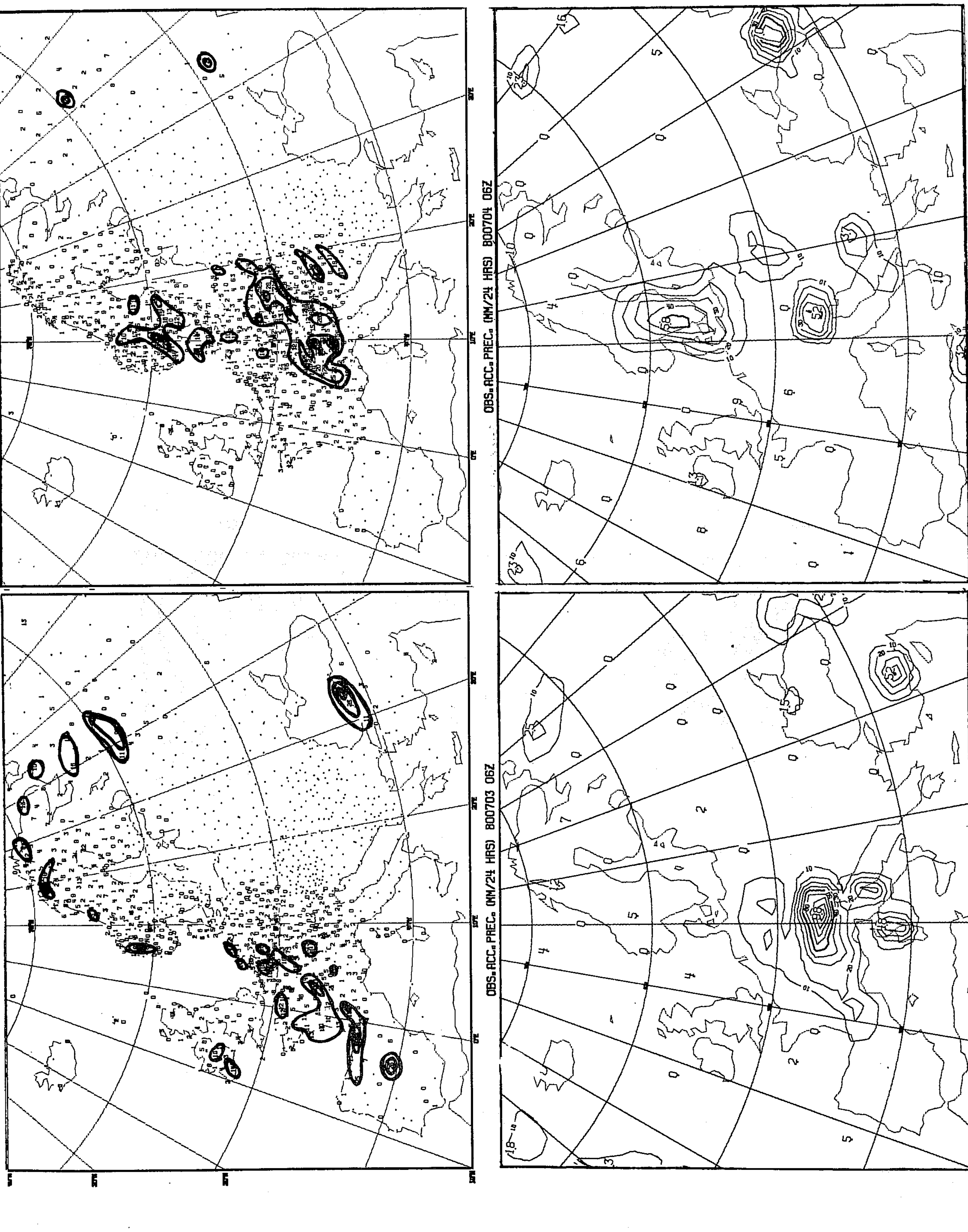


Fig. 7 850 mb relative humidity at 00 GMT 3 July 1981.

Top: Observed

Bottom: 12 hr forecast from 2 July 1981.

Fig.8. Observed (top) and forecast (bottom) precipitation.
Top left: Observed for the time period 06z 2.7- 06z 3.7 1981.
Top right: Observed for the time period 06z 3.7- 06z 4.7 1981.
Bottom left: 24 hr forecast from 2.7 1981 (12z 2.7- 12z 3.7 1981).
Bottom right: 48 hr forecast from 2.7 1981 (12z 3.7- 12z 4.7 1981).



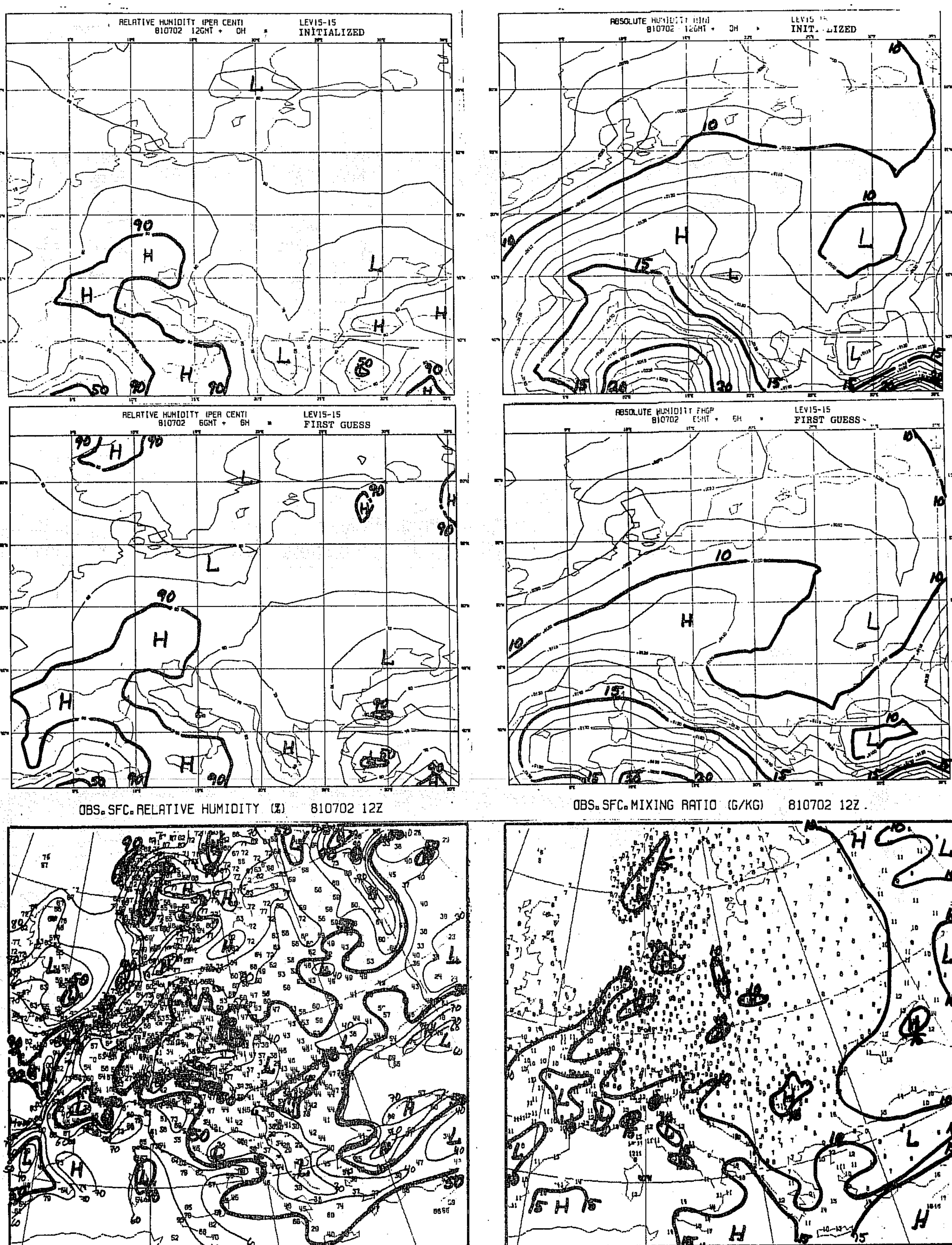


Fig. 9 The relative humidity (in %, left) and absolute humidity (in g/kg, right) in the initialized analysis (upper panel) and in the first guess (6 hour forecast, middle panel) at 30 m above ground, and as observed at the surface stations (lower panel) for 2nd July 1981 12GMT.

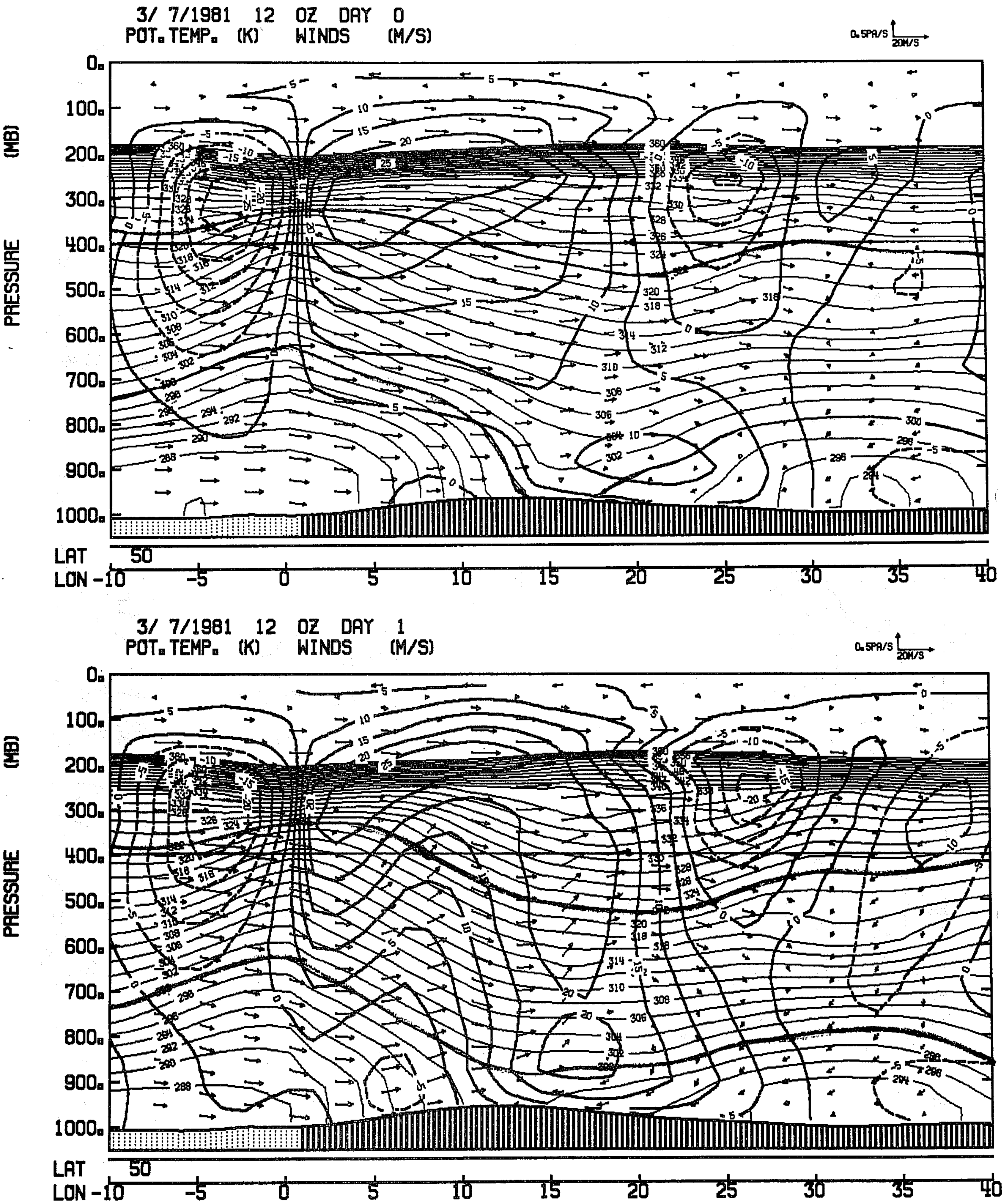


Fig. 10 Cross sections of potential temperature and winds along latitude 50°N, longitude 10°W-40°E.
Top: ECMWF initialised analysis 3 July 1981 12GMT.
Bottom: ECMWF operational day 1 forecast from 2 July 1981.

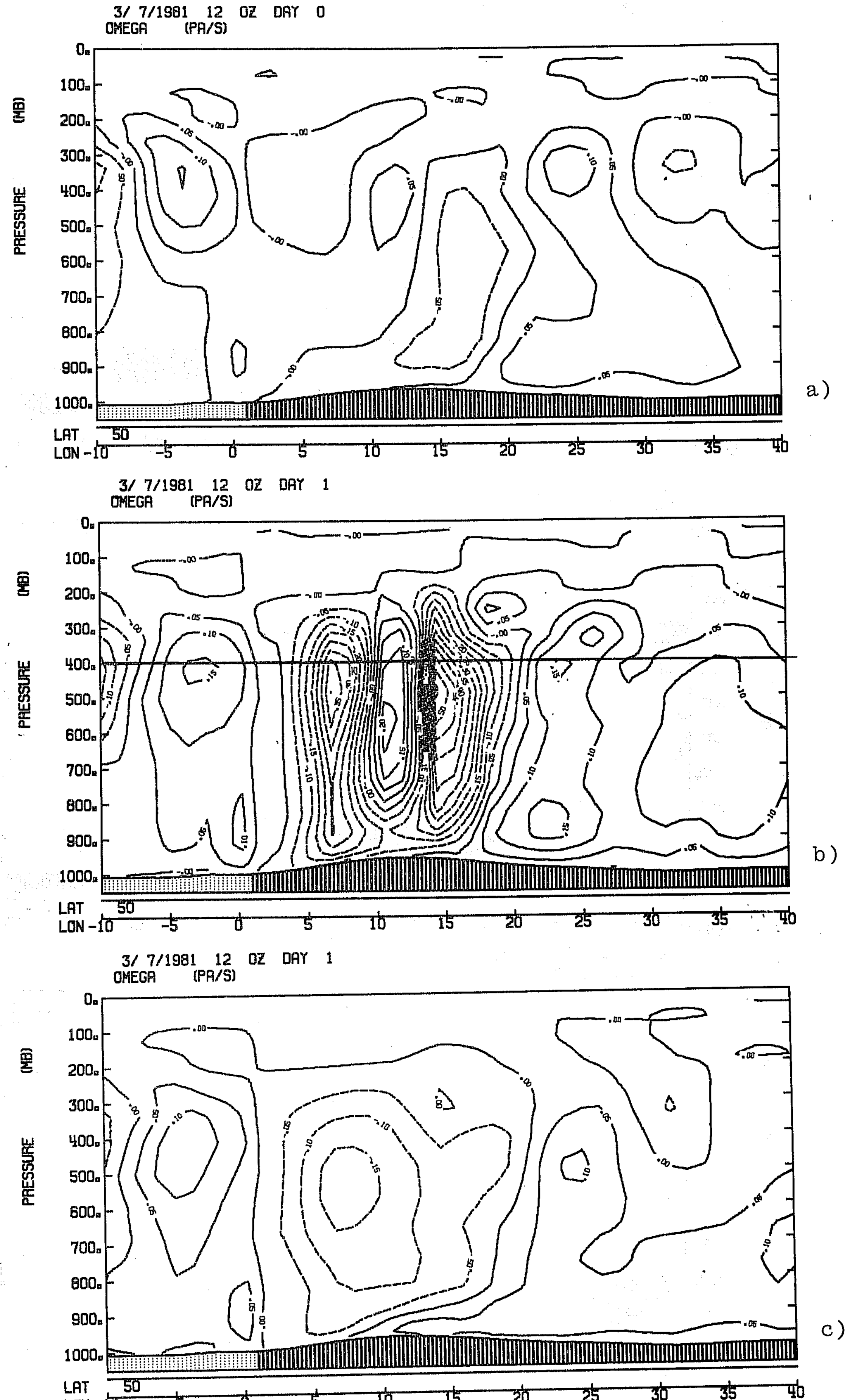


Fig.11 Cross sections of vertical velocity (Pa/s) along latitude 50^{O}N.

a) verifying analysis at 3 July 1981 12 GMT

b) operational day 1 forecast

c) experiment III day 1 (no latent heating in the model).

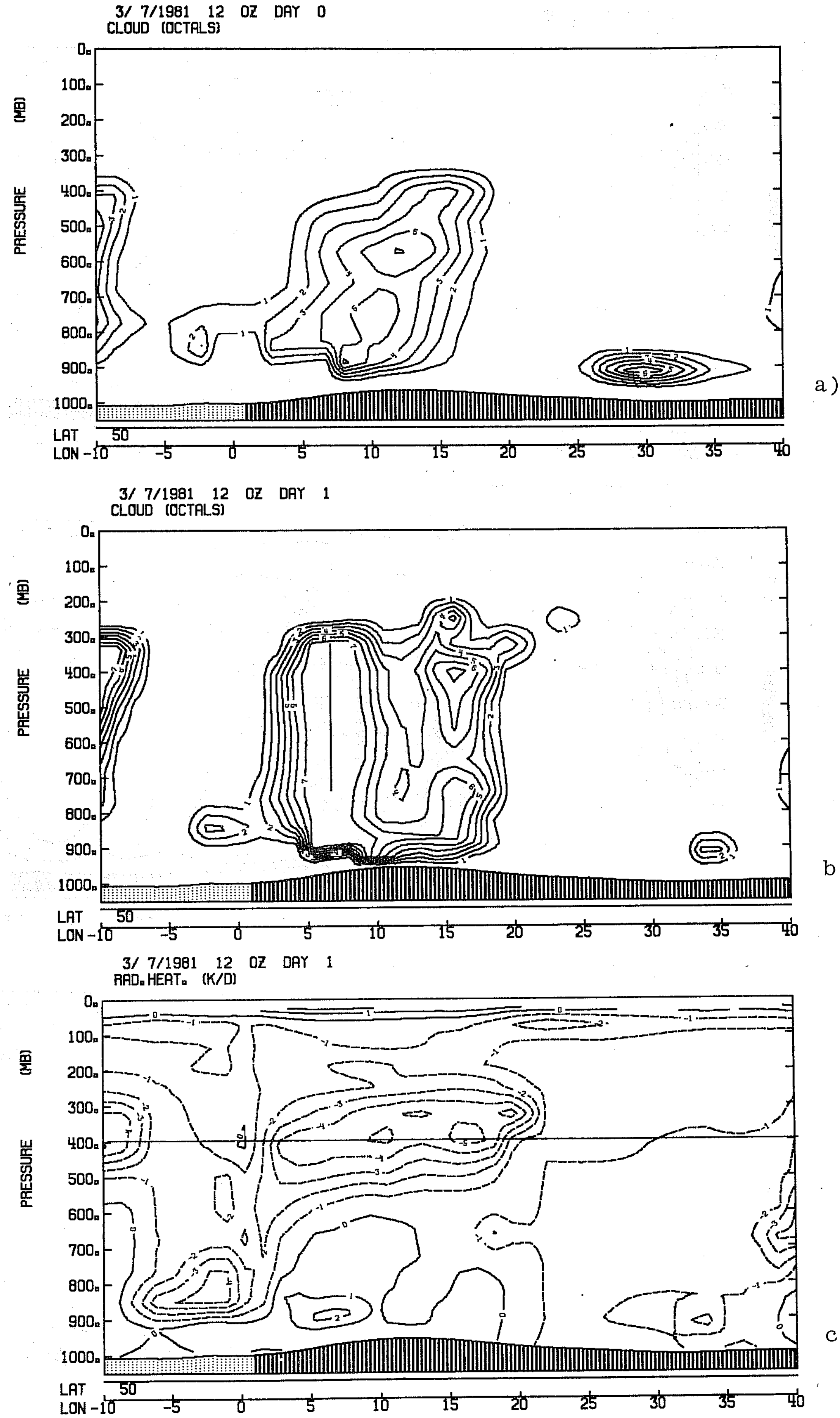


Fig. 12 Cross sections along 50°N

a) Cloud cover (octals) in the verifying analysis 3 July 1981

b) Cloud cover (octals) day 1 forecast

c) Radiative heating (degrees/day) in the day 1 forecast.

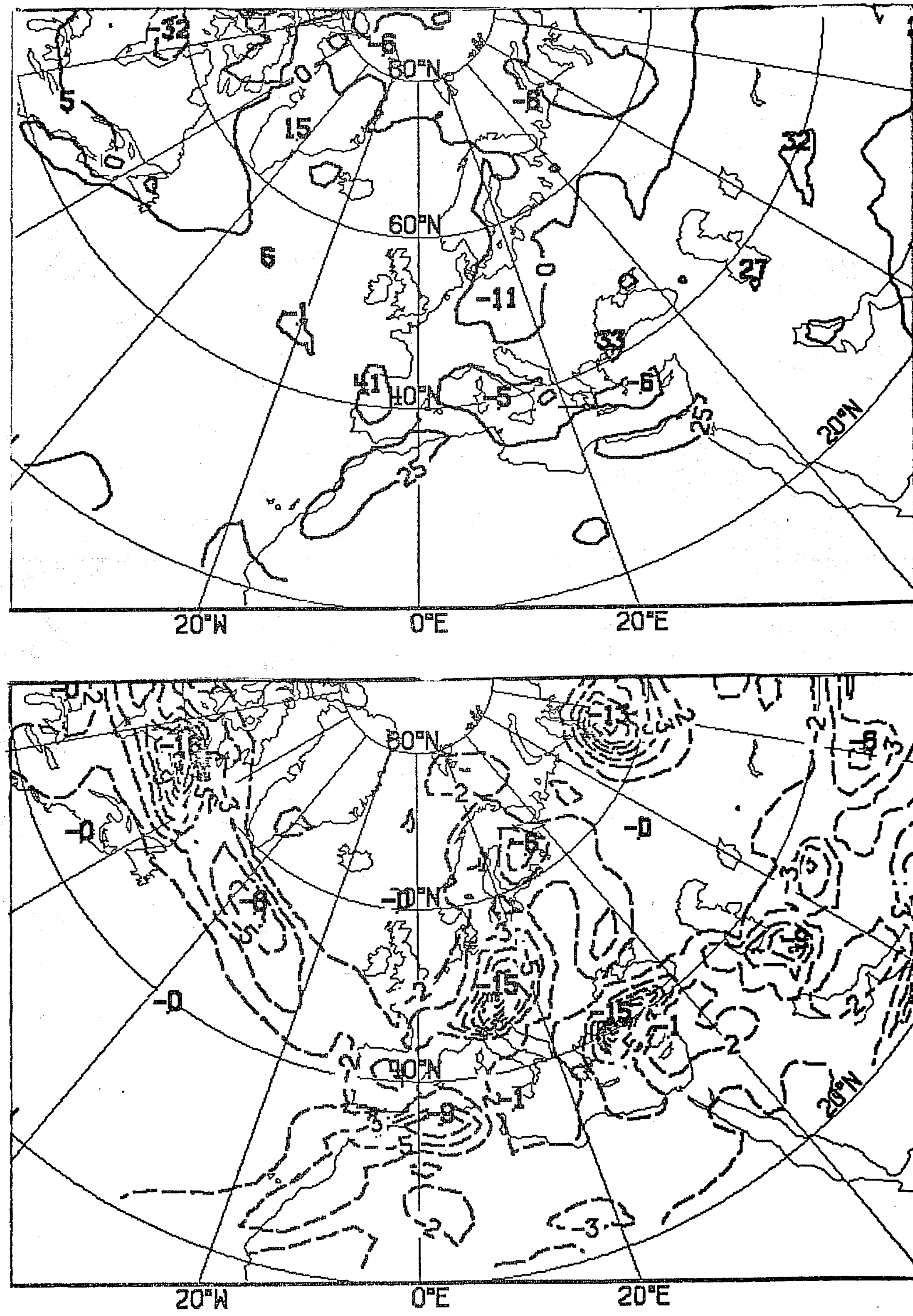
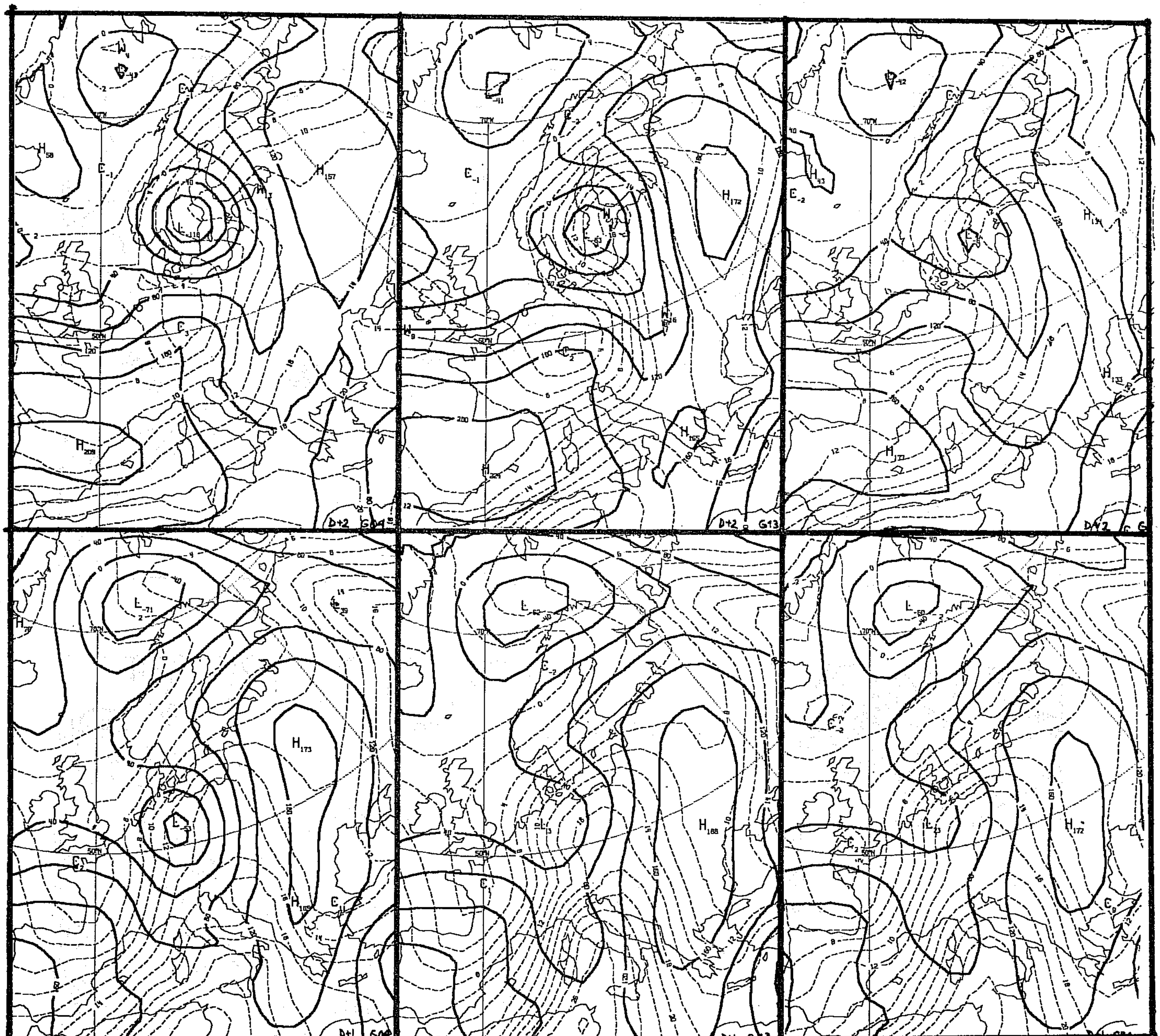


Fig. 13 a) The average surface heat flux (W/m^2) from day 0 to day 1 in the E.C.M.W.F. operational forecast

b) same as a) but for boundary layer vertical diffusion (W/m^2).



no conv, no rad minimum physics no latent heating

Fig. 14 The 1000 mb height and 850 mb temperature forecasts for day 1 (bottom) and day 2 (top) with variable parameterizations from 2 July 1981 12GMT initial data. Cf. Fig. 3.

Left: No convection, no radiation
Middle: Simple surface friction and dry convective adjustment
Right: No latent heating