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Procedures used in the boundary layer height and wind analysis for the PHOXA-project.

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Abstract

As part of a German-Dutch cooperative project to model photochemical and acid transports and deposition, the so-called PHOXA-project, the KNMI has been contracted to analyse the boundary layer height field and the mesoscale wind field over Western Europe. This report describes the procedures that are used to obtain these analyses. A few examples of the analyses are shown, followed by discussion. It is concluded, that the produced analyses are reliable and consistent with a priori expectations. The difference in land- and sea regime of the boundary layer height is clearly analysed, the space- and time resolution of this height over the European continent is satisfactory. Evidence is presented that the present mesoscale wind analyses describe significantly small scale phenomena, that would not be presented in synoptic scale analyses.

Introduction

At the beginning of 1984 the Umweltbundesamt Berlin (FRG) and the Dutch ministry of housing, physical planning and environment started a four year "air pollution" program, the Photochemical Oxidant and Acid Deposition Model Application, (the PHOXA-project, October 1984). As part of the program TNO at Apeldoorn (the Netherlands) contracted the KNMI to make a grid-point analysis for the boundary layer height (BL-height) and the windfield during the photochemical episode, which was chosen to be July 24-26, 1980. To allow the photochemical model "to warm up", analyses for the two preceeding days, July 22-23, were required also. The area involved was the part of north-west Europe enclosed by 10°W, 24°E, 47.5°N and 60°N. The resolution of the analyses should be 80 km. The resolution of the PHOXA grid was much finer: 0.25° of latitude (approx. 28 km) and 0.5° of longitude (approx. 33 km). The interpolation from the analysis grid to the PHOXA grid was linear. This report describes the methods that have been used to obtain these analyses. Further, some results of the analyses are shown followed by a short discussion.

2. The boundary layer height.

2.1 Introduction

Twice a day, at 00 and 12 GMT, radiosoundings provide a vertical temperature profile in about 40 points over the area. It would be possible to estimate the boundary layer height at those points from the observed temperature profiles, and to interpolate to the required grid and to the required times of day. If, however, simple interpolation procedures would be used, the resulting boundary layer height field would suffer from serious deficiencies. To mention the most salient:

1. The radiosoundings are all over land. No observations over sea would be available; but the meteorological regime over sea is so much different from that over land, that the interpolated field would be useless over sea.
2. The temporal development of the boundary layer height during a day cannot be described by simple interpolation formulae. Rather, only a physical model can describe the daytime growth and the evening collapse of the boundary layer height.
3. The analysed boundary layer height should be representative for a grid area. It is not always possible to estimate such a representative value from the radiosonde point observation. For example, if the sounding happens to be in a local shower, completely erroneous values would be derived.

These shortcomings were avoided to a substantial degree by the use of a more sophisticated analysis procedure.

The vertical temperature soundings were advected with a representative wind and the properties of the air were modified along its trajectory; an air mass transformation (AMT) model (Reiff et al., 1984) was used to describe this. The AMT model defines a boundary layer height. In this way, for every 3 hourly time interval, about 40 pseudo-observations of boundary layer height were obtained. These were interpolated with an, in essence simple, analysis scheme to the gridpoints.

This procedure eliminates the above errors because:

1. The radiosoundings are advected; at the observation time no observtions over land are available, but after a short period of advection, some pseudo-observations will be found over sea.
2. The AMT model describes the diurnal cycle of the boundary layer height.
3. The applied analysis from pseudo-observations eliminates, or gives small

weight to, less reliable values, and achieves a more representative boundary layer height analysis.

The air mass transformation model is described in short in the next subsection, and the applied analysis method in 2.3. In those subsections it will become apparent that for every time 2 analyses of boundary layer heights are available. These were mixed according the procedure described in subsection 2.4. A discussion of the results concludes section 2.

2.2 The air mass transformation model

The air mass transformation (AMT) model has been described by Reiff et al. (1984); therefore only a summary of the model is given here.

The model consists of a trajectory part and a boundary layer part. The first describes the advection of air parcels in the boundary layer. The advection velocity is taken from the European Centre for Medium Range Weather Forecasts analyses. All 3 wind components are used. The boundary layer part of the model describes the transformation of the air properties along the trajectory. In unstable circumstances a mixed-layer model is used (Driedonks, 1982). In stable circumstances, the boundary layer height is related to the nocturnal cooling. In this relation, a cubed potential temperature profile is assumed, which leads to double boundary layer heights as compared to the model, where for practical reasons a linear profile was used (Fig. 4 in Reiff et al., 1984). The boundary layer height goes to the limiting value h_{lim}, given by (Nieuwstadt, 1981)

$$\frac{h_{lim}}{L} = \frac{c_1 u_*}{f L} \frac{1}{1 + c_2 h_{lim}/L} \qquad (2.1)$$

In here, f is the Coriolis parameter, u_* the friction velocity and L the Monin-Obukhov length. The constants c_1 and c_2 are 0.3 and 0.13, resp. The boundary layer height is not allowed to become less than 50 m.

The model handles transitions from stable to unstable and vice versa, and from land to sea and vice versa. The diurnal variation of the boundary layer height is mainly driven by surface fluxes of momentum, temperature and moisture. These have been parametrised according to Holtslag and Van Ulden (1983) over land; over sea, bulk parametrisations are used. These parametrisations require cloud cover and sea surface temperature. Grid point values of those quantities were obtained from observations using the procedure described in Appendix A.

The AMT model was applied over a period of 24 hours from the radiosoundings at 00 and 12 GMT. Consequently, for each hour of the day, two sets of pseudo observations are available, one originating from the most recent observation time, and one from the observation time 12 hours before that.

2.3 Analysis of boundary layer height

The pseudo-observations of boundary layer height, obtained from the AMT model, were interpolated to the gridpoints of the 80 km grid. This interpolation was done with a simple analysis scheme, based on the successive correction method SCM (Cressman, 1959).

Before SCM was applied, a guess field was generated from the observational data (the concept of "guess field" is elaborated upon in section 3.2). This was done by applying the pseudo-observed boundary height h_i at observation i at the 4 surrounding gridpoints of an extremely coarse grid (grid distance 300 km). If in this way at a gridpoint more than one value was obtained, the values were averaged with weights that linearly decreased with distance between gridpoint and observation. If after this procedure, at any gridpoint of the 300 km grid no value of the boundary layer height had been obtained, h was estimated as a weighted average of the surrounding gridpoints. Finally, the values at the 300 km grid were bilinearly interpolated to the gridpoints of the 80 km grid.

The successive correction method consists of a number of scans. During each scan, the input field is nudged towards the observations. For the first scan, the input field is the guessfield; for the subsequent scans the output field of the preceeding scan is used. The weights given to the observations depend on the scan index i ($i = 1 \ldots n_s$, where n_s is the member of scans), on the distance between the observation and the gridpoint R, and on the relative situation of the observation and the gridpoint with respect to the coast I_c: $I_c = 1$ if either, but not both of the locations are near the coast, $I_c = 4$ if one is over land and the other over sea, and $I_c = 0$ in the other cases. The weight given to observation k during scan i is then:

$$w_k = \frac{\alpha_k}{\sum_\ell \alpha_\ell} \; \frac{1}{1 + d\,I_c} \qquad (2.2)$$

where

$$\alpha_k = \frac{1}{1 + (R/r_i)^2} \qquad (i = 1 \ldots . n_s)$$

The coefficients n_s, r_i and d were for the boundary layer height analysis:

$n_s = 1$
$r_1 = 3$
$d = 6$.

(For r_i we adopt the units of gridpoint distances). The relatively big value of d concentrates the gradients of the analysed variable near the coast; over land and over sea, however, the analysis will be fairly smooth due to the relatively big value of r_1. (If more observations would have been available, it would have been sensible to do a second scan with $r_2 < r_1$. This second scan would then reveal gradients of the boundary layer height over land, or over sea).

2.4 The mixing of the BL-height analyses

Starting from the data obtained by the 00 GMT AMT-model run, 3 hourly analyses were made 24 hours ahead. The same was done starting from the 12 GMT AMT-model run. This means that every 3 hours two analyses were available. These analyses were manually inspected and mutually compared. As 40 datapoints do not suffice to describe the strong spatial variability of the BL-height, after this inspection some bogus data were added manually to the dataset. This was required in the situations where no pseudo-observations were available over a small body of land or sea. This occurred for example a few times over Scotland: after a few hours of advection available radiosoundings were all advected away from the land, onto the sea. In such a case, a bogus observation was added over Scotland. In a few cases, less reliable data were eliminated. Typically in each analysis one observation was added or deleted. From these manually corrected datasets, new BL-height gridpoint analyses were made. As a next step the two analyses, that were valid for the same time, were mixed with a weight according to the following scheme:

time on day D	00	03	06	09	12	15	18	21	24
weight-factor of 00 GMT-run on day D:	0	½	1	1	1	3/4	½	¼	0
	1	½	0	0	0	¼	½	3/4	1
weight factor of:	12 GMT-run, day D-1					12 GMT-run, day D			

The ratio behind this scheme is the following: At 00 GMT the 00 GMT-run is just started and has to "warm up". Data from the 12-GMT run of D-1 are more trustful in the first hour, therefore we start at 00 GMT with a weight of 1 for the analyses made with data from the 12 GMT-run of D-1 and mix the results of the 00-run of day D in at 03 GMT and 06 GMT. As the analyses of the 12 GMT-run day D-1, is less trustful after sunrise at day D, the mixing is completed at 600 GMT. At 12 GMT the analyses based on the 12 GMT run of day D become available. As described before, the model needed some time "top warm up", therefore at 12 GMT a weightfactor of zero is taken for the analyses based on data of the 12 GMT run, day D. During 15, 18 and 21 GMT the results of this run are slowly mixed in.

2.4 Some results and discussion

As an example the BL-height analyses for the 26th of July 1980 are shown (Fig. 2). At night the BL-height does not show strong gradients. Over land as well as over sea a stable BL exists. During the night the BL-height decreases slightly due to a slight weakening of the wind. At 9 GMT the sun rises over the eastern part of the area and the BL-height increases. At 12 GMT the BL-height increases everywhere over land. The difference between the stable regime over sea and the unstable deep convective, layer over land is now clearly visible. The maximum BL-heights, over western Europe, occur in a cloud free area, associated with high surface fluxes of temperature. At 1800 GMT, the sun sets in eastern Europe and Scandinavia, while in western Europe the days maximum is reached. At 21 GMT the BL is stable everywhere and no clear differences in BL-height can be seen anymore between land and sea.

As a check we compared the analysed 12-GMT BL-heights with the heights read off manually from the radiosoundings. In general a good agreement was seen. The analysis shows a long correlation length between BL-heights over land, the observed data vary more from point to point. Above sea no observed data were available in the PHOXA-area.

Reiff et al. (1984) showed that advection is a very important process in a time period of 12 hours. Therefore, during the calculations of the BL-height in between 00 and 12 GMT, the development of the BL along the trajectory has to be taken into account. This is not only caused by the fact that trajectories often cross the land/sea interface, but also due to the fact that, in general, along the trajectories clear skies alternate with cloudy zones.

The differences in land/sea regimes are reasonably preserved in the analyses. However, a closer look reveals that the border between the two regimes in the 15 GMT analysis is situated over land in the Netherlands and Germany, while we expect that a new internal boundary layer is formed downstream from the coast, which, in this case with south easterly winds, would be over sea. This inconsistency is probably due to the coarse grid distance, 80 km. Further, it can be seen that the landcontours are not always closely followed by the BL-height isopleths. This is not amazing, as for instance Denmark and Great Britain are only represented by a few data points. In future versions of the analysis program, it will be possible to analyse more points, that will be obtained from starting points in between the radiosondes, for instance at upstream sides of the coastlines. In this way the regime above Britain can be described with a better resolution.

3. The wind

3.1 Introduction

The air pollution model requires gridpoint values of the two horizontal wind components (u west to east, v south to north). The values must represent transport winds, valid for the three model layers that describe transport: The lowest layer is the mixing layer, extending from the surface (z=0) to the mixing layer height ($z=h_m$). The middle layer ranges from h_m to 700 m, with a minimal thickness of 200 m. The top of this layer is thus at $z = h_2$ = max (700 m, h_m + 200 m). The uppermost layer extends from h_2 to the model top h_A = 2200 m, which is chosen in such a way, that it is 200 meters higher than the greatest mixing height of any grid point analysed during this specific period. The representative transport winds were constructed from analysed winds at 4 levels, namely 10 m, 70 m, 1500 m, 3000 m. The ECMWF analysed winds at 850 mb and 700 mb were used for the winds at 1500 m and 3000 m resp. The following subsections describe how the 10 m and 70 m winds were obtained, and how the vertical interpolation proceeded.

3.2 Analysis of the 10 m and 70 m wind

On the coarse (80 km x 80 km) grid, the winds at the two lowest levels were analysed with a multivariate threedimensional optimum interpolation scheme (Cats, 1984a). Observations of pressure and the two windcomponents were used, taken from SHIP, SYNOP, TEMP and PILOT-reports within the model area. Over land, pseudo-observations of wind at the 70 m level were generated with Holtslag's (1984) scheme. This scheme was similarity theory, with stability obtained from a parametrisation of surface fluxes.

The optimum interpolation method requires a "guessfield", which should be the best estimate of the state of the atmosphere at the analysis time, just before the observations at that time become available. This guessfield serves as a background field, into which the subsequently available observations are assimilated. In this way, the guessfield complements the observations over areas of low observation density; also in observation rich area, the guessfield serves useful purposes, e.g. in assisting in the elimination of erroneous observations.

In the present case the guessfield was generated by an atmospheric forecast model, run from the previous analysis. The model consisted of two parts: First, the mean sea level pressure was forecast by advecting the previous analysis; the advection velocity was derived from the ECMWF 500 mb analysis: It was taken to be 60% of the geostrophic wind at that level. To avoid divergence in the advection velocity, the geostrophic wind was calculated on an f-plane. Second, the wind field was forecast by integration of the primitive equations for the wind, averaged over the boundary layer. During this procedure the pressure guessfield was used. This model and a case study have been described by Cats (1984b). The analyses were performed every 3 hours; therefore, the guessfield models were integrated over 3 hours.

The horizontal resolution of the analysis in observation dense areas is equal to the meshsize (80 km). In the other areas the resolution is governed by a parameter in the analysis scheme, the influence radius b. In regions with medium to high observation density, b was 240 km for the 10 m wind analysis. At 70 m, and at 10 m in low observation density areas, b was 320 km.

For use in air pollution models, the gridpoint values of the analysed wind should be representative for an area around the gridpoint (a "gridsquare"). To achieve this, the 10 m wind observations were made more representative by applying Wieringa's (1976) correction factors. These factors are not available for all stations within the area. Where this happened, a terrain correction factor was estimated. Over part of the area the terrain classification by Van Dop (1983) could be used, over the rest default values were used, corresponding to the surface roughness values of 1 m over land, 0.3 m in coastal regions and 0.5 mm over sea. With these corrections for the *local* circumstances, the analysed winds become representative for open terrain. They were made representative for the *grid square* by a back correction using the same terrain correction factors. This back correction is not simply the inverse of the forward correction: E.g., land stations become more representative for the analysis over sea; furthermore, in the forward correction the Wieringa factors reduce the influence of the *local* upstream obstacles near the wind observation; in the back correction, however, the terrain factors are representative of the terrain around the gridpoints.

Because waves with a wavelength of two times the meshsize are harmful in many dispersion models, these waves were eliminated from the analysed wind fields.

3.3 Vertical averaging.

Through the winds at the 4 levels (10 m, 70 m, 1500 m and 3000 m) a profile was fitted. This profile was then averaged over the 3 model layers.

Especially with low boundary layer heights, the transport in the layer below 10 m cannot always be neglected. Therefore, this level was replaced by 1 m; the wind at that height was estimated by linear extrapolation of both wind components from the winds at 70 m and 10 m. It was not possible to use $z = 0$ as the lowest level, as will follow from the next paragraph.

Especially in the lower layers, a logprofile usually forms a good approximation to the wind profile. Therefore, the profile that was fitted through the 4 levels was loglinear between any two consecutive levels, separately for the two components. So, for given z if i is such that $z_i \leq z < z_{i+1}$ ($z_1 = 1$ m, $z_2 = 70$ m, $z_3 = 1500$ m, $z_4 = 3000$ m) the profile for the u component was given by

$$u(z) = \frac{u_i \ln\left(\frac{z}{z_{i+1}}\right) + u_{i+1} \ln\left(\frac{z_i}{z}\right)}{\ln \frac{z_i}{z_{i+1}}}$$

where u_i is the analysed u component at level z_i. (Similar for v). (Because of this logarithmic profile, z_1 had to be positive).

3.5 Some results and discussion

The meteorological developments through the entire 5 days episode were diagnosed with several tools.

The analysis of 10 m wind and pressure were plotted at every analysis time. We show as an example these fields on the last day, 26 July 1980, at 1200 GMT. By this time, a trough of low pressure, extending from Middle England to Belgium, had splitted the high pressure area that had persisted over the southern half of the area in the beginning of the episode. Of special interest is the sharp wind direction gradient across the trough axis in the analysis. This gradient is confirmed by the observations.

In Fig. 3a, the optimum interpolation analysis of the wind and pressure is shown. Fig. 3b displays the same fields, after application of the filter to eliminate the 2 gridpoint waves and of the terrain dependent back correction of wind speed. The final wind on the 80 km grid was obtained by the vertical averaging procedure. We show this wind in Fig. 3c.

Also in Fig. 3c the vertical wind speed at the top of the boundary layer is shown. This quantity constitutes a sensitive measure of the wind qualities. The main features of the vertical wind field are the meteorologically consistent ascending motion in the trough, the descending one on the western (downstream) coasts of Denmark and Wales and the generally upward motion over the South Eastern quadrant of the area, which is a low pressure area. The fairly intense, but small scale vertical motions over the Baltic sea are less understood. Presumably they are associated with the fairly complicated coast line in the region.

There are at present no satisfactory methods available to quantify the overall quality of the final, (vertically averaged) wind field. We therefore limit ourselves to some quality estimates of the optimum interpolation result.

The optimum interpolation theory provides an estimate of the accuracy of the analysis. For the wind components separately, this estimate varies from around 2 m/s, in observation sparse areas (notably the north west corner of the area) to 0.2 m/s over areas with high observation density. Especially the low estimates are known to be generally too optimistic. There are indications (Arpe et al., 1985) that a more appropriate estimate would be around double the OI estimate, i.e. 0.4 m/s. The value of 2 m/s for regions with few observations is presumably realistic.

The estimate over areas with high observation density is considerably better than individual observations. This highlights the power of the applied optimum interpolation technique: It forms an optimally weighted average of the observations.

The fit of the analysis to the observations is, as a consequence, much worse, namely of the order of the individual observation error (2 to 2.5 m/s). It is noted that the individual observation error includes a component caused by the lack of representativety of the observed value for the gridsquare value.

The need for the use of a finemesh analysis, as opposed to a coarse - and cheaper - analysis is demonstrated by Fig. 3d which shows the ECMWF analysis for the same time. By comparing this Fig. to Fig. 3b essential differences in the wind field become apparent. As points of attention we note the bad position of the wind direction gradient near the trough over Belgium, and the too weak coastal gradients in Fig. 3d. The latter leads to too high wind speeds over land (e.g. over The Netherlands), but to too low ones over sea. Important wind direction errors are notable over the centre areas of the North Sea and over the Polish coast. Without much effort the reader will find many other big differences between the fine and the coarse mesh analysis.

4. Conclusions

The procedure followed to obtain a BL-height analysis: AMT-model runs to create bogus data and an analysis scheme that takes especially care of the difference between land- and sea regimes, works well. It describes the difference in land and sea regimes of the BL-height, and the land regime over the European continent in a space- and time resolution which is satisfactory.

Above the British Islands a better resolution is desirable. This can be reached by computing more data points, achieved by choosing more starting points for the AMT-model for instance of points upstream of Great Britain.

The mesoscale wind analysis scheme gives also good results. A comparison with the ECMWF analyses reveals, that the mesoscale analysis shows some mesoscale systems which are hardly represented in the ECMWF analysis. In a comparison between the divergence fields calculated from the analysis and observed meteorological features, a satisfactory agreement is seen.

Appendix A.

Analysis of cloud cover and sea surface temperature.

The air mass transformation model requires an analysis of cloud cover and sea surface temperature. These parameters were analysed three hourly with a successive correction method (Cressman, 1959), similar to the one used to analyse the boundary layer height. The weights given to the observations were calculated with Eq. 2.2, with the following parameters:

(a) for cloud cover: $n_s = 2$
$r_1 = 3.$, $r_2 = 1.$,
$d = 1.$

(b) for sea water temperature: $n_s = 2$
$r_1 = 3.$, $r_2 = 1.$,
$d = 3.$

Because of the low quality and density of sea surface temperature observations, and the long time scale of fluctuations in this parameter, all sea surface temperature analyses between 22 July 1980, 00 GMT and 26 July 1980, 21 GMT were averaged. This average over 40 analyses was used by the AMT model.

References

Arpe, K., A. Hollingsworth, M.S., Tracton, A.D. Lorenc, S. Uppala and P. Kallberg, 1985: The response of numerical weather prediction systems to FGGE level IIb data. Part II: Forecast verifications and implementations for predictability. Quart. J. Roy. Meteorol. Soc., 111, 67-102.

Cats, G.J., 1984a: A scheme for mass and wind analysis on a limited area using multivariate threedimensional optimum interpolation: Scientific documentation and first evaluation. KNMI Tech. Rep. TR46 (53 pp., available from KNMI, De Bilt, The Netherlands).

Cats, G.J., 1984b: The generation of a guessfield for the optimum interpolation analysis scheme - a case study. KNMI Internal document FM-84-28 (28 pp., available from the author).

Cressman, G.P., 1959: An operational objective analysis system. Monthly Wea. Rev., 87, 367-374.

Van Dop, H., 1983: Terrain classification and derived meteorological parameters for interregional transport models. Atm. Env. 17, 1099-1107.

Driedonks, A.G.M., 1982b: Models and observations of the growth of the atmospheric boundary layer. Bound.-Layer Meteor., 23, 283-306.

Holtslag, A.A.M. and A.P. van Ulden, 1983: A simple scheme for daytime estimates of the surface fluxes from routine weather data. J. Climate Appl. Meteor., 22, 517-529.

Holtslag, A.A.M., 1984: Estimates of diabatic wind speed profiles from near-surface weather observations. Boundary-Layer Meteorol., 29, 1984, 225-250.

Meinl, H. and P. Builtjes, 1984: Photochemical Oxidant and Acid Rain Deposition Model Application (PHOXA), TNO-Apeldoorn, October 1984, 20 pp.

Nieuwstadt, F.T.M., and H. Tennekes, 1981: A rate equation for the nocturnal boundary-layer height. J. Atmos. Sci., 38, 1418-1428.

Reiff, J., D. Blaauboer, H.A.R. de Bruin, A.P. van Ulden and G. Cats: An Air-Mass Transformation Model for Short-Range Weather Forecasting. Monthly Weather Review, 112, 1984, 393-412.

Wieringa, J., 1976: An objective exposure correction method for average wind speed measured at a sheltered location. Quart. J. Roy. Meteorol. Soc., 102, 241-253.

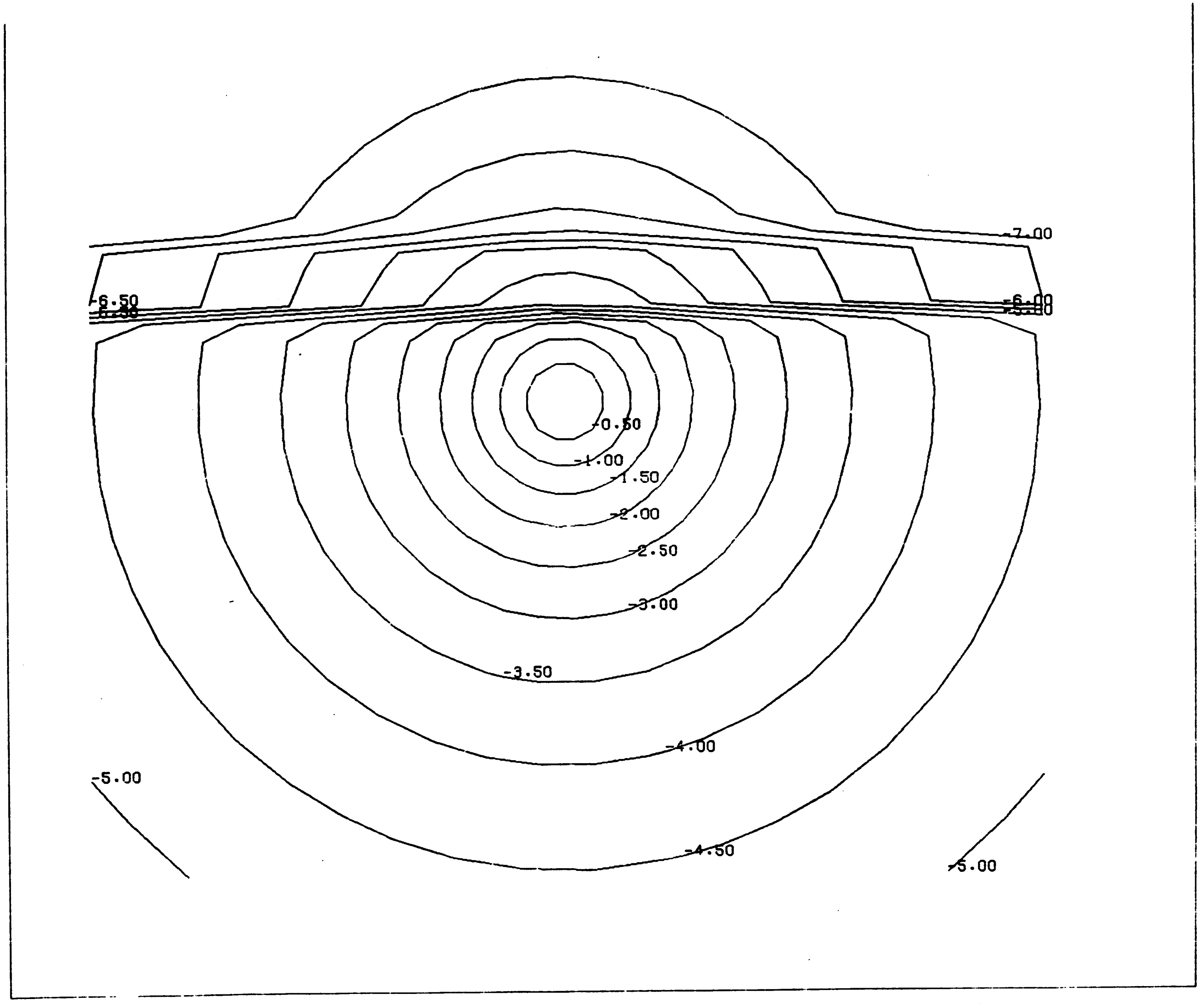
Figure captions

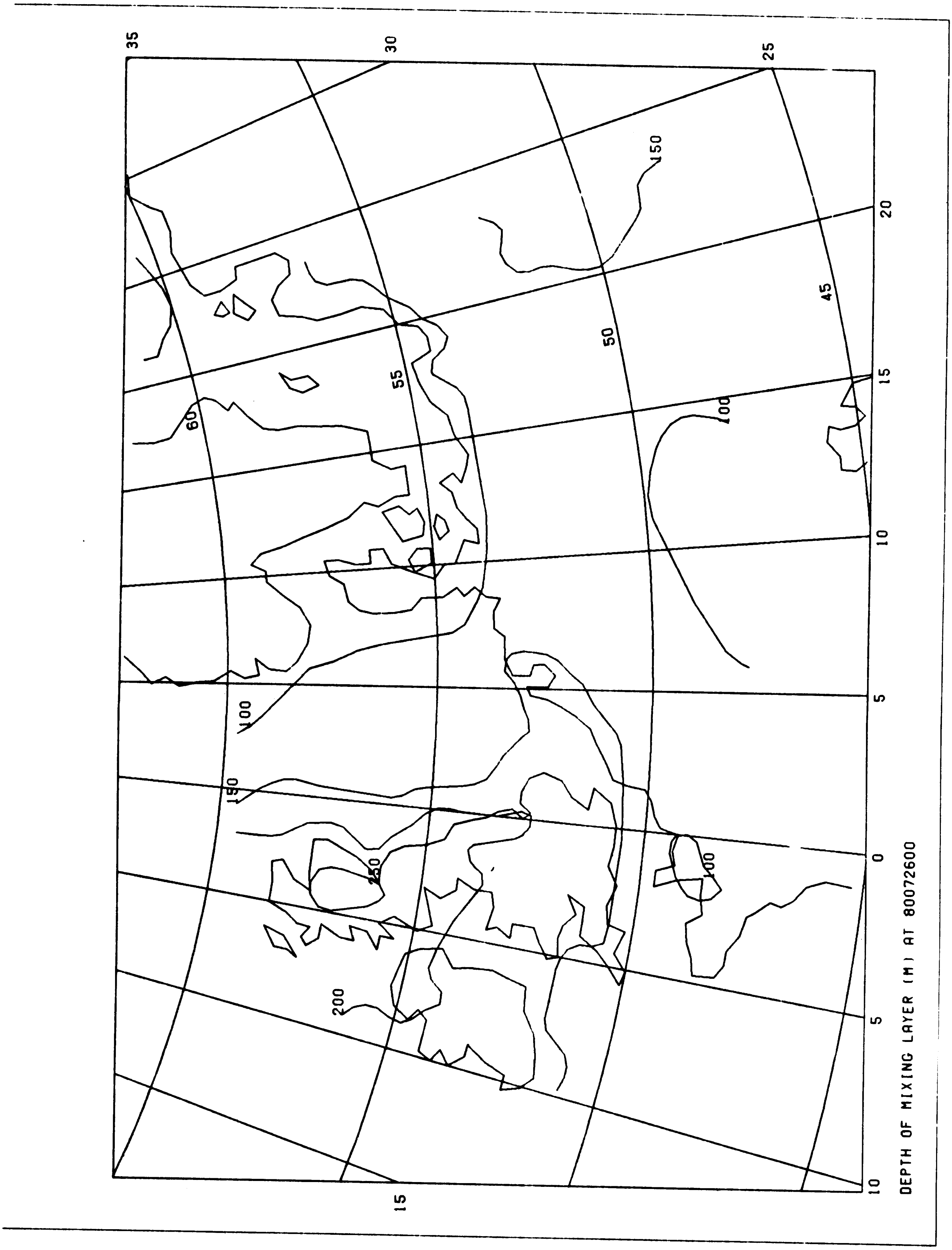
Figure 1: The logarithm of the weight given to a single observation, according to Eq. 2.2 with $d = 6$, $r_1 = 3$. At the observation position the weight is 1. The figure may be interpreted as valid for the observation either over land or over sea. A coastal area with a width of 4.4 griddistances separates the land and sea areas. At the transitions sea-coast and coast-land the weight has large gradients (the width of the coastal zone has been chosen for display purposes, and does not correspond to the width of the coastal zone in the analyses).

Figure 2: Analysed boundary layer heights for the PHOXA-area.
a) 26 July 1980, 00 GMT, b) 3.00 GMT, c) 6.00 GMT, d) 9.00 GMT,
e) 12.00 GMT, f) 15.00 GMT, g) 18.00 GMT, h) 21.00 GMT.

Figure 3: a) Wind and pressure analysis at 10 m at 26 July 1980, 12 GMT, as produced by optimum interpolation.
b) Wind and pressure analysis at 10 m after elimination of two-gridpoint waves and after correction of the wind speed for local terrain characteristics.
c) u and v-components of the wind averaged over the BL-layer, vertical wind isopleths at the top of the BL.
d) Wind and pressure analyses from the European Centre for Medium Range Weather Forecasts (ECMWF).

Figure 1



DEPTH OF MIXING LAYER (M) AT 80072600
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30
25
20
15
10
5
0
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10
15
60
55
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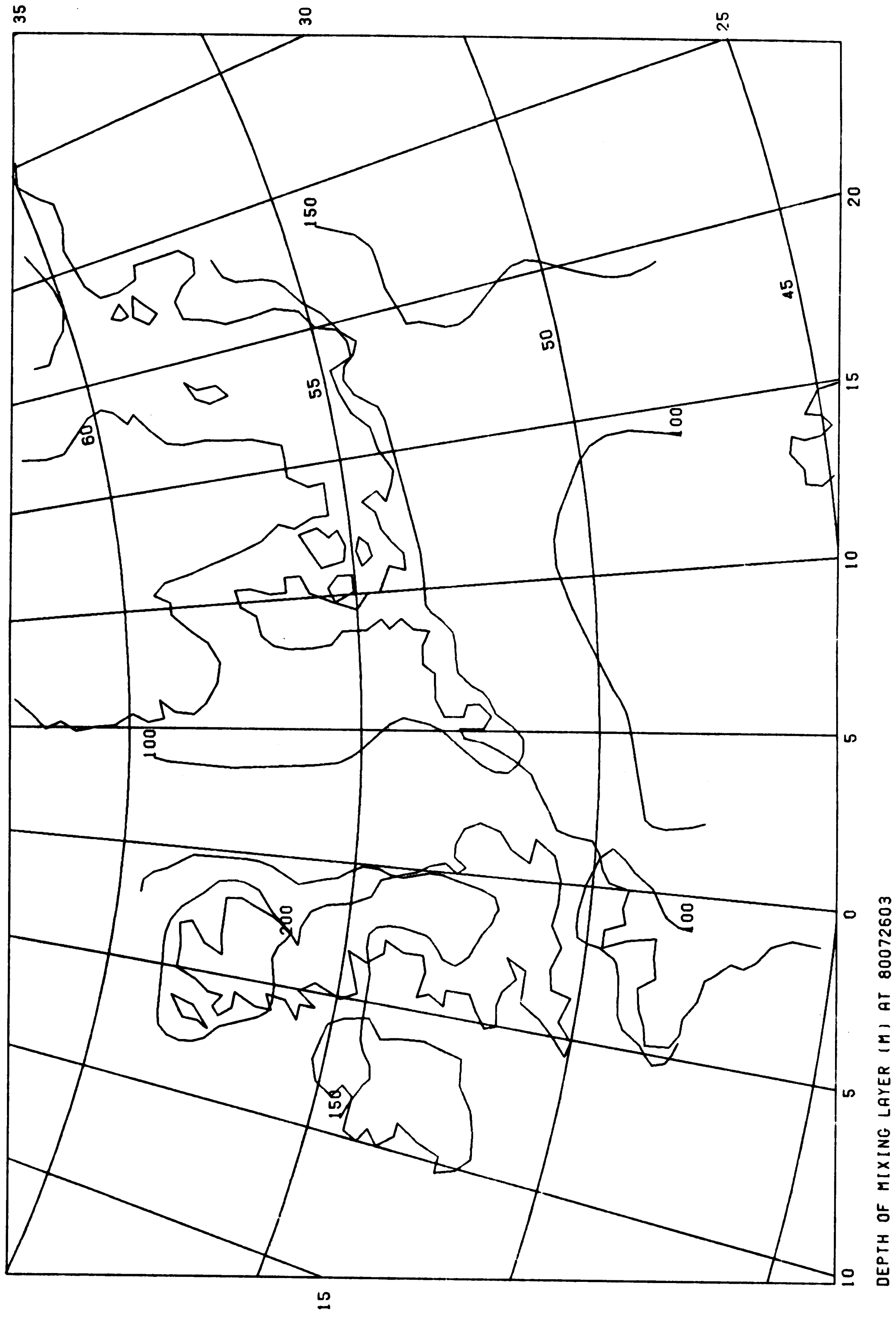
100
100
150
250
200
100

Fiqure 2a


DEPTH OF MIXING LAYER (M) AT 80072603
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100
200
150
100

Figure 2b

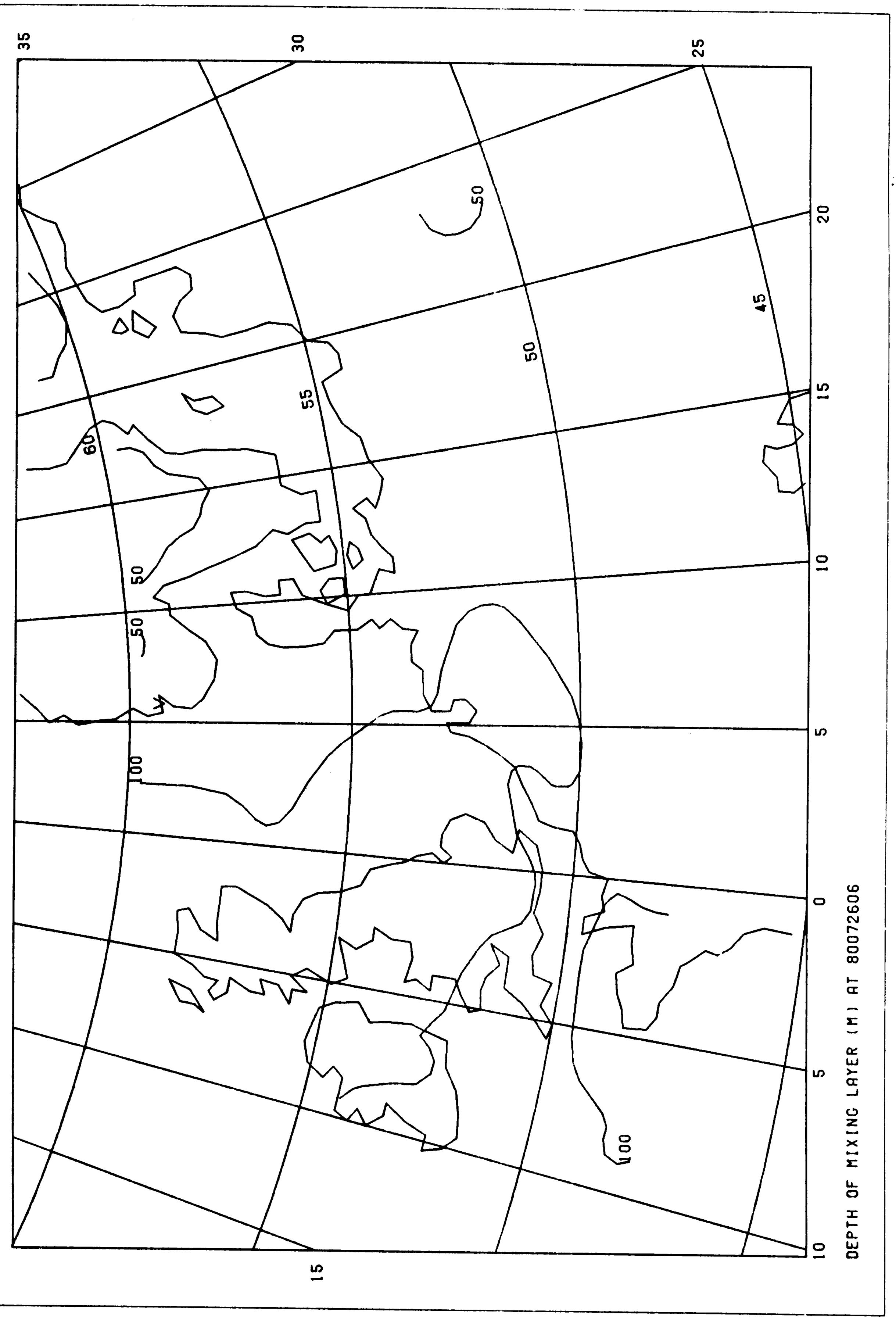
DEPTH OF MIXING LAYER (M) AT 80072606
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Figure 2c

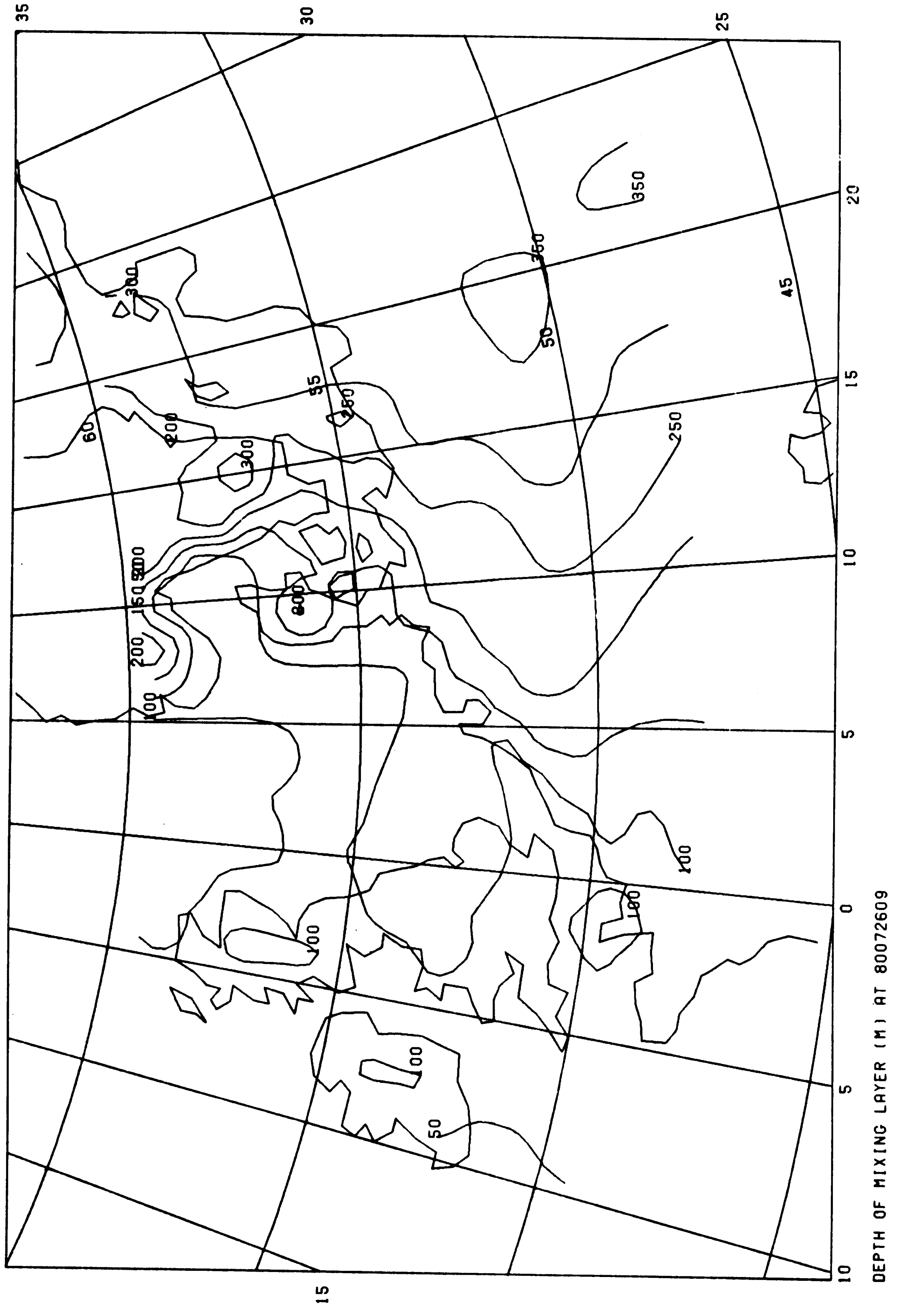
DEPTH OF MIXING LAYER (M) AT 80072609
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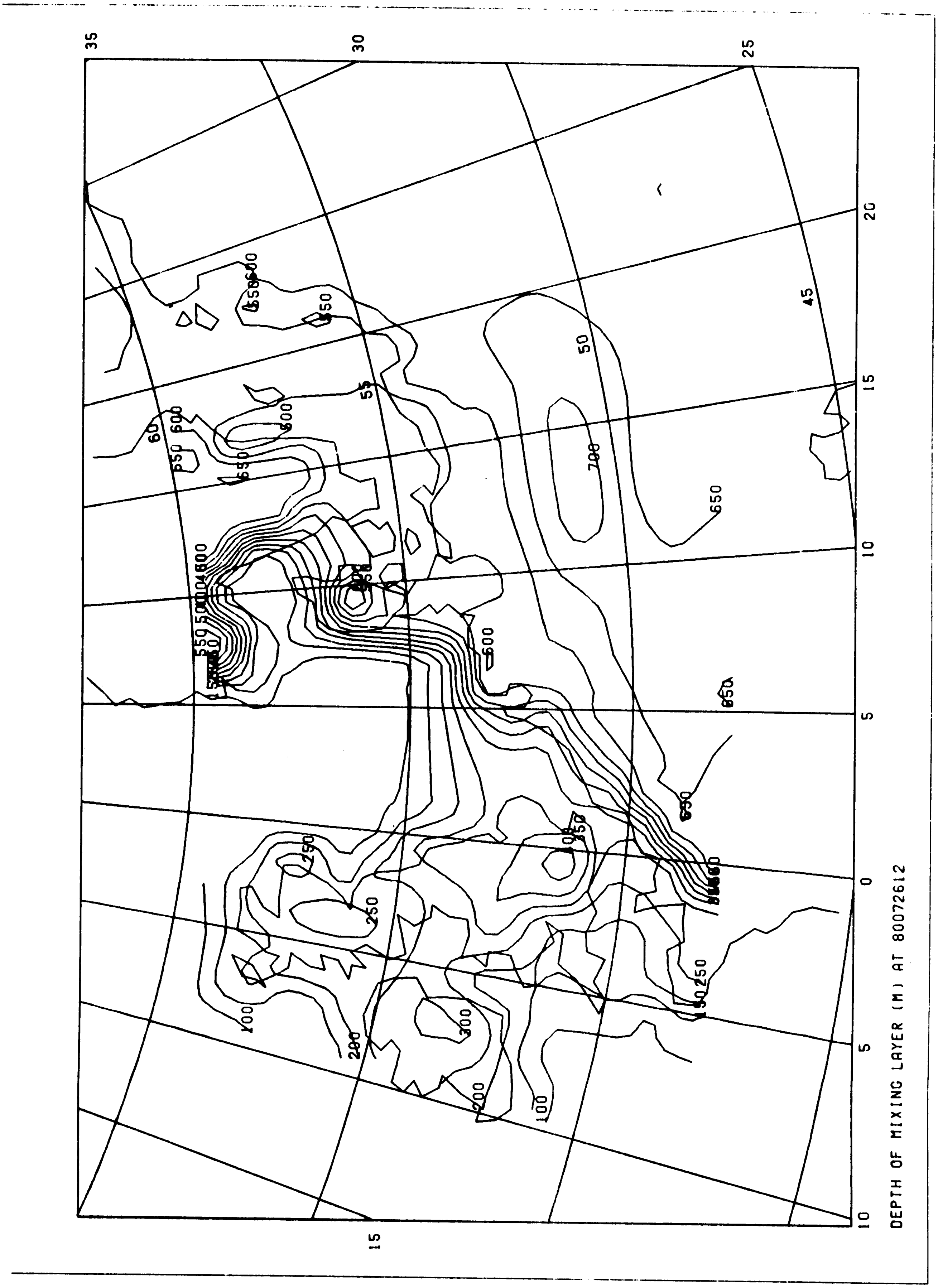
Figure 2d


DEPTH OF MIXING LAYER (M) AT 80072612
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55
60
100
200
250
300
600
650
700

Figure 2e

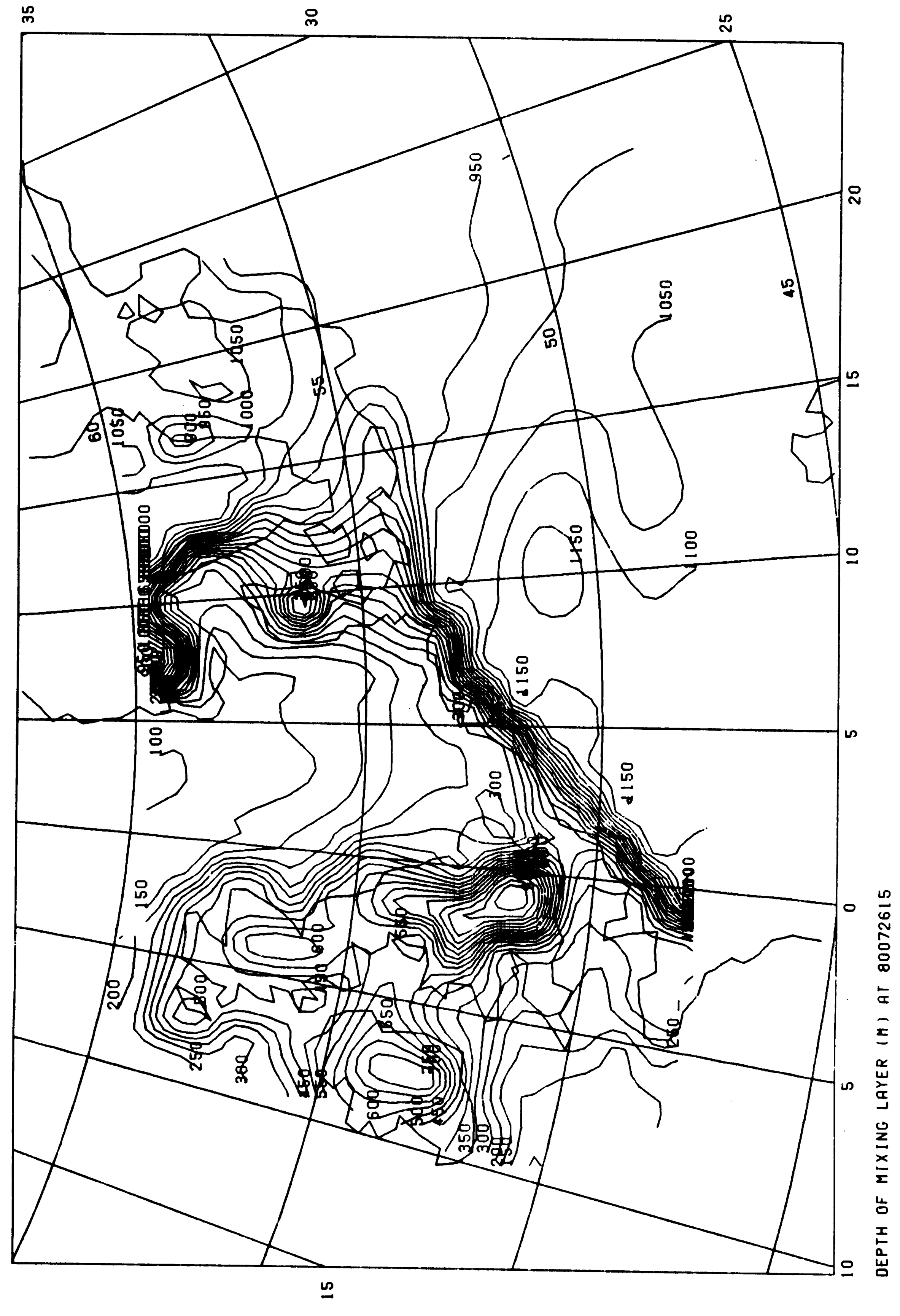

DEPTH OF MIXING LAYER (M) AT 80072615
35
30
25
15
20
15
10
5
0
5
10
45
50
55
60
950
1050
1050
1000
950
1150
1100
150
150
150
100
150
200
250
300
300
350
400
450
500
550
600
600

Figure 2f

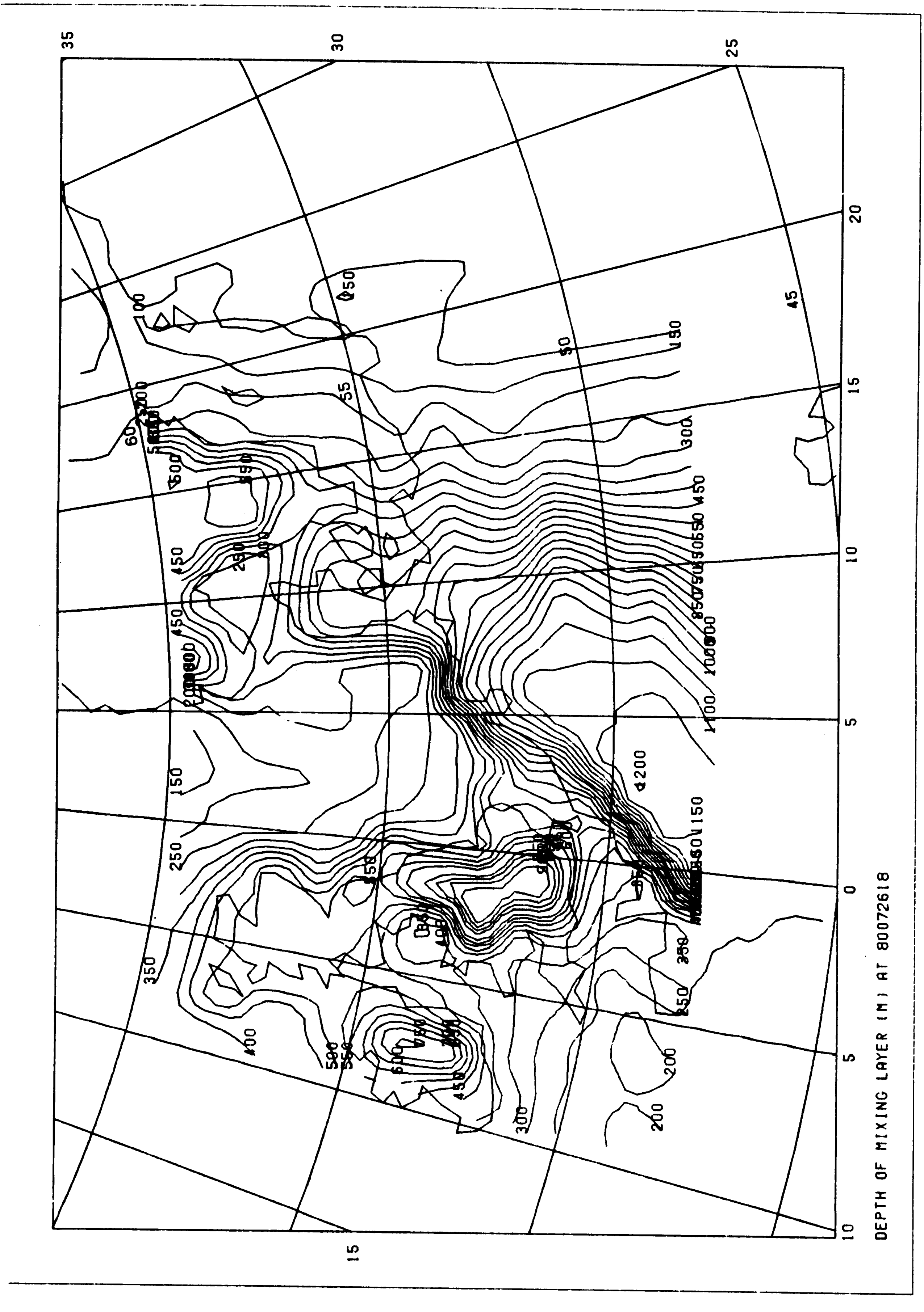

DEPTH OF MIXING LAYER (M) AT 80072618
35
30
25
20
15
10
5
0
5
10
15
45
50
55
60
100
150
200
250
300
350
400
450
500
550
600
650
750
850
1000
1100
1200

Figure 2g

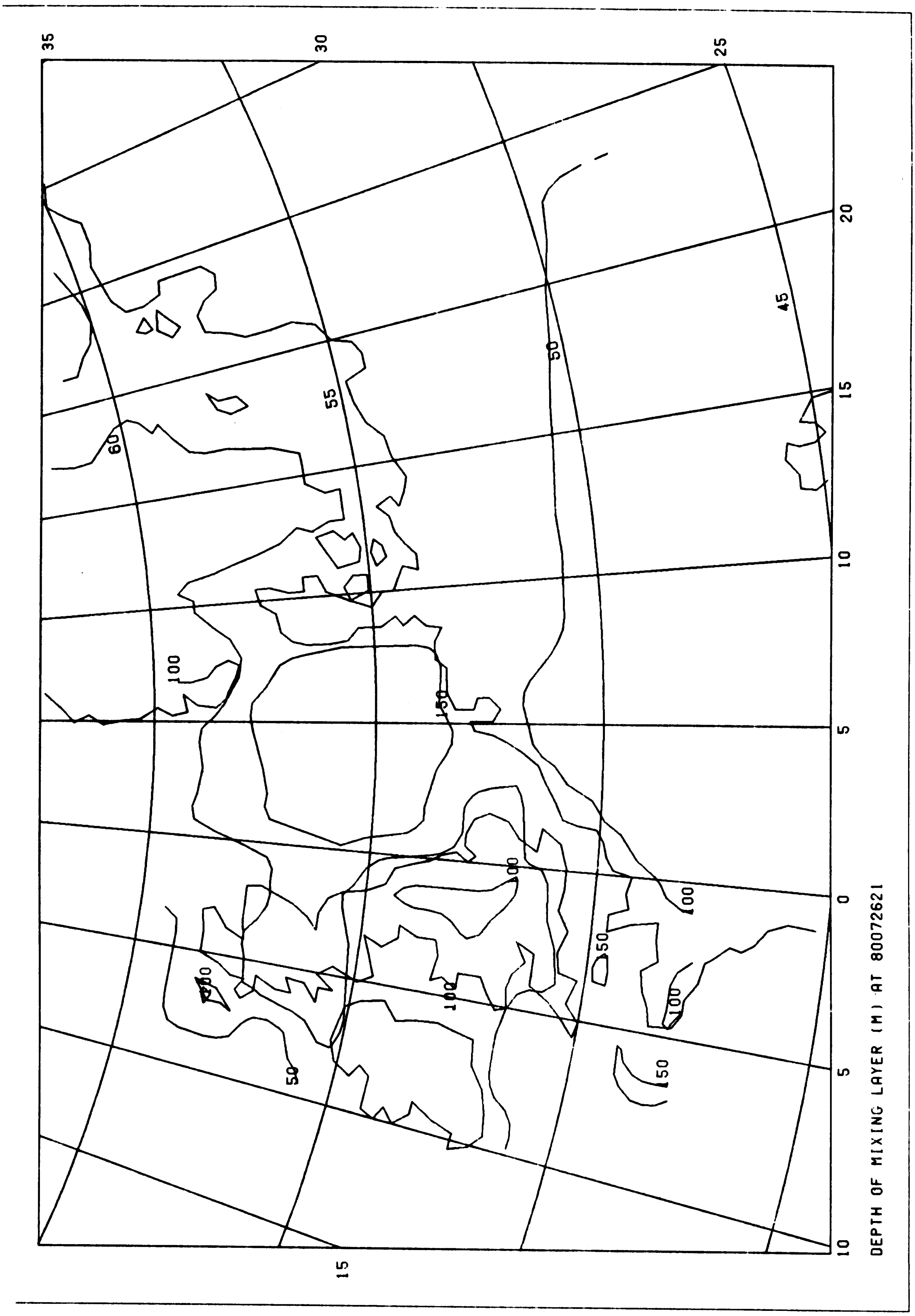

DEPTH OF MIXING LAYER (M) AT 80072621
35
30
25
20
15
10
5
0
5
10
15
60
55
50
45
100
150
100
150
100
150
100
50

Figure 2h

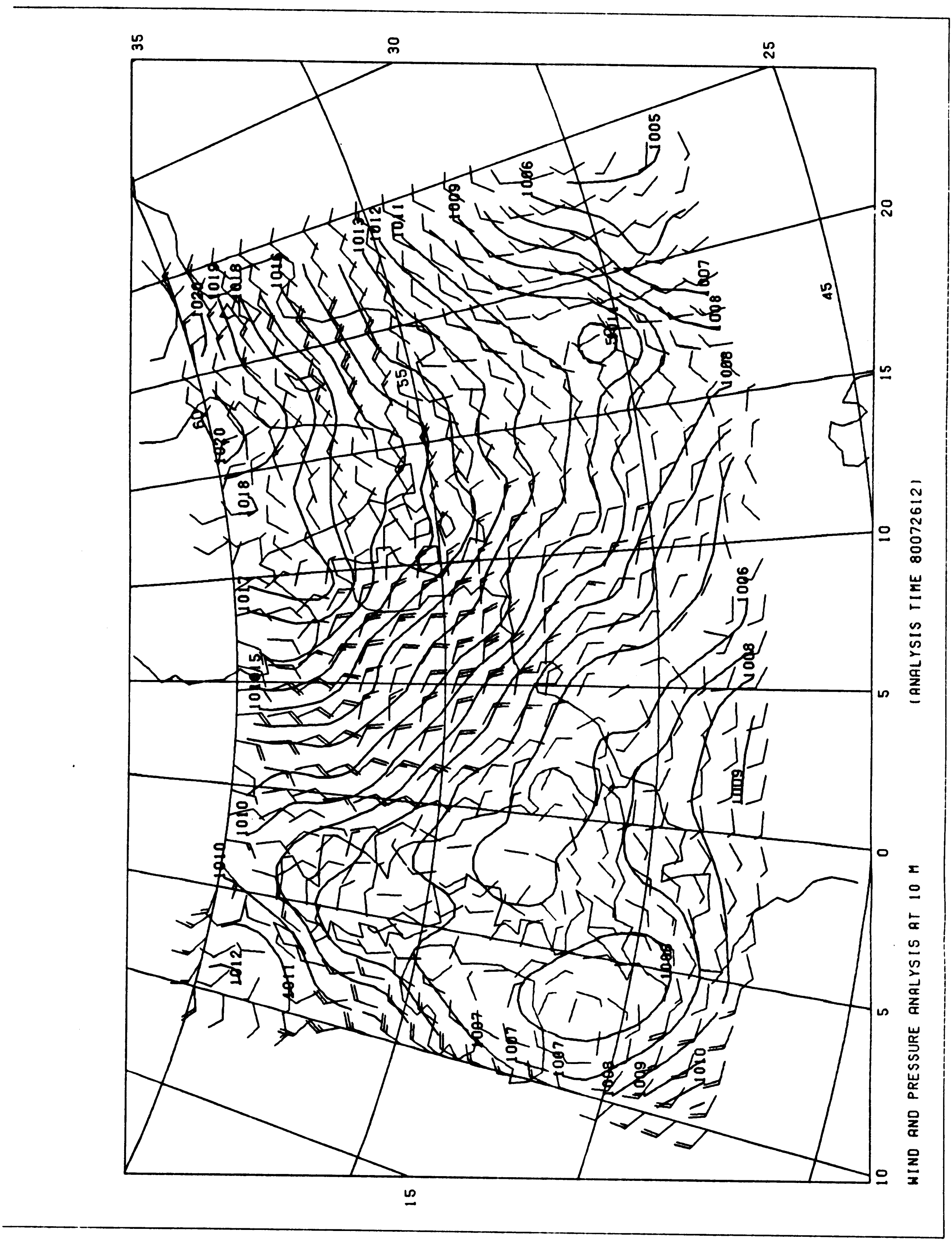

WIND AND PRESSURE ANALYSIS AT 10 M
(ANALYSIS TIME 80072612)
35
30
25
15
10
5
0
5
10
15
20
45
55
60
1005
1006
1007
1008
1009
1010
1011
1012
1013
1015
1016
1018
1019
1020

Figure 3a

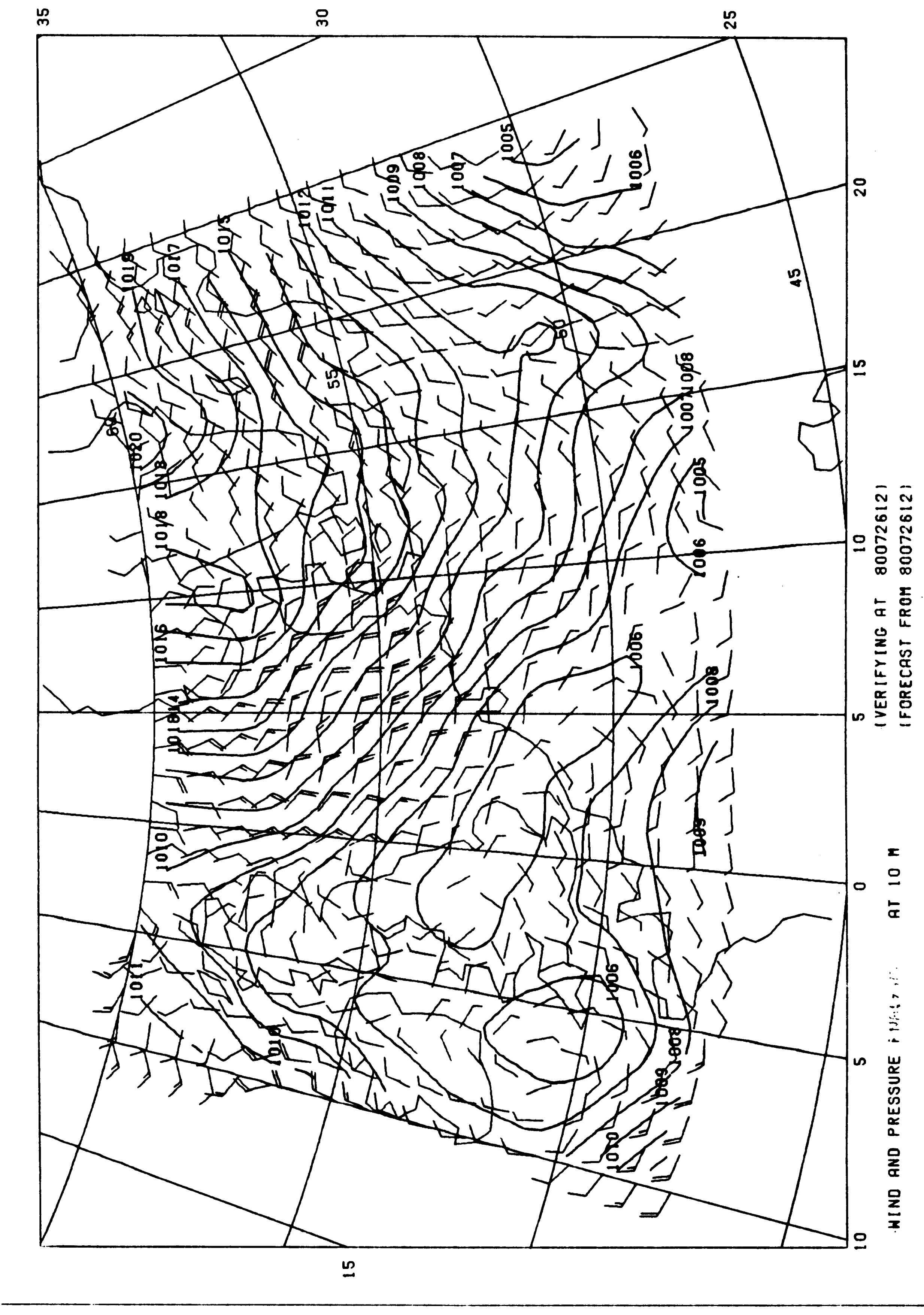

WIND AND PRESSURE AT 10 M
(VERIFYING AT 80072612)
(FORECAST FROM 80072612)
35
30
25
15
10
5
0
5
10
15
20
45
50
55
60
1020
1018
1016
1014
1012
1011
1010
1009
1008
1007
1006
1005

Figure 3b

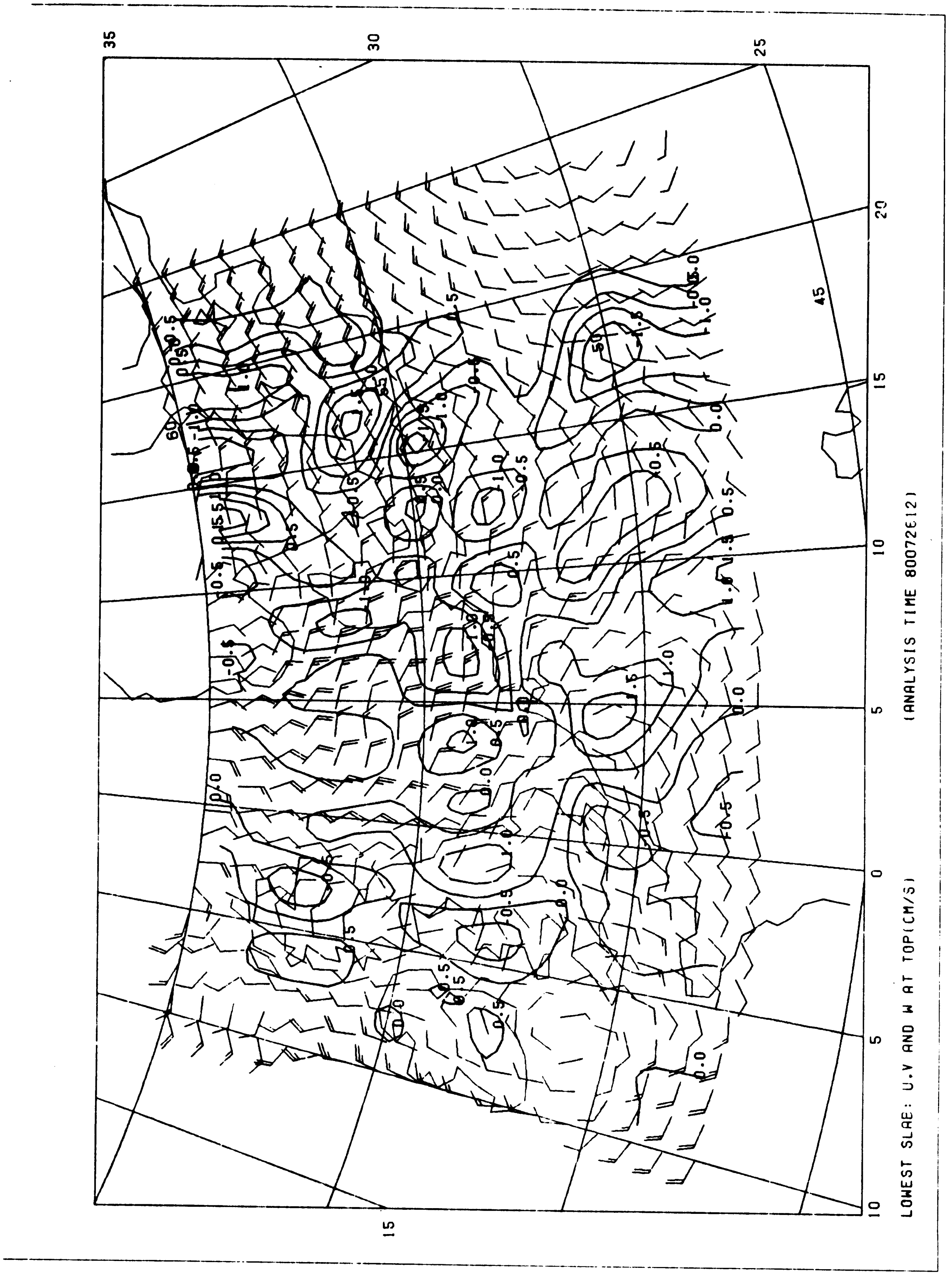
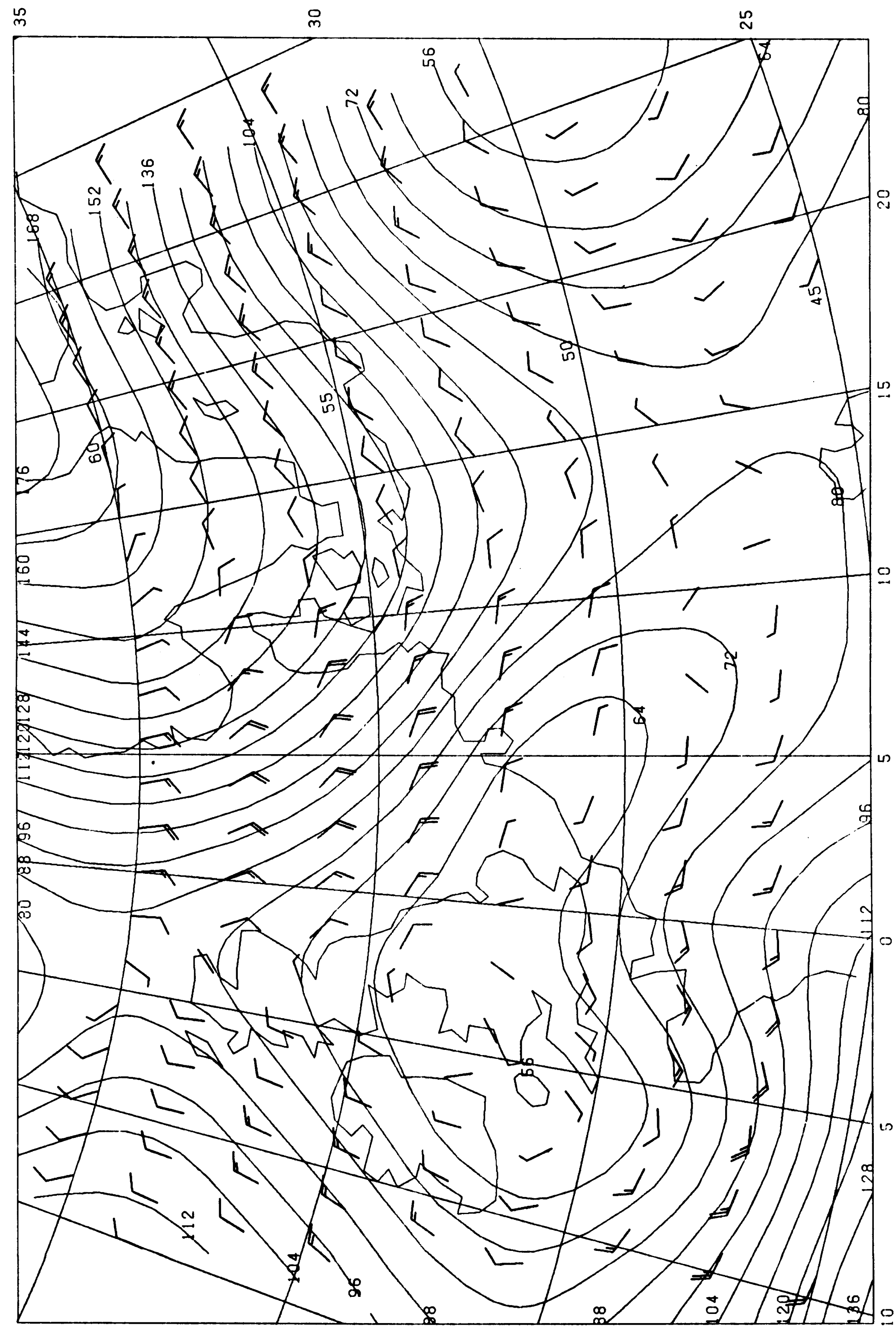

LOWEST SLAB: U,V AND W AT TOP(CM/S)
(ANALYSIS TIME 80072612)
35
30
25
15
20
15
10
5
0
5
10
45
50
60

Figure 3c

Figure 3d



ECMWF 1000MB PRESSURE AND WIND ANALYSIS AT 80072612