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MET O 11 TECHNICAL NOTE No. 121

The Use of Equally-Spaced Sigma Levels and Layers in the Met O 20 11-level model.

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1. Introduction

This is a further experiment in an attempt to explain differences between forecasts produced by numerical models. Differences between the 11-level model, described by Saker (1975), and the operational model are often significant after about 3 days of a forecast. In this experiment the distribution of the sigma levels and layers has been altered in the 11-level model to make its vertical resolution more comparable with that of the σ- coordinate version of the 10-level operational model. (Temperton 1976.) Three cases have been investigated. These were for 14/8/77, 8/5/77 and 1/1/78 and have been used in previous model comparison experiments. (Cullen 1978, Davies 1978.) In each case a control experiment was also run to examine the effect of a simplified boundary layer scheme used in the experiment. This simplified scheme was used since resolution in the lower layers of the model is decreased by equal spacing of the sigma levels.

2. The equally-spaced levels and layers 11-level model

The original choice of the distribution and spacing of the sigma levels of the 11-level model has been discussed by Rowntree (1971). The levels were chosen to give adequate representation of such features as fronts, extratropical cyclones, jet streams and the boundary layer. The vertical resolution is also adequate for the tropical troposphere. Furthermore, it was decided to have one layer wholly in the stratosphere to provide a stable lid on tropospheric vertical motions. These considerations led to the layer boundaries being chosen as shown in table 1. The levels were then chosen from a relationship required to conserve energy in the model finite difference scheme, viz.

$$\sigma_k = \Delta\sigma_k / \Delta(\log\sigma)_k \qquad (2.1)$$

where

$$\Delta(\quad)_k = (\quad)_{k+\frac{1}{2}} - (\quad)_{k-\frac{1}{2}}.$$

The above relationship does not hold for k=1 and σ_1 was chosen such that $\sigma_1 = e^{-1}\sigma_{1\frac{1}{2}}$. $\Delta(\log\sigma)_1$, follows from

$$\sum_{k=1}^{11} \Delta\sigma_k = \sum_{k=1}^{11} \sigma_k . \Delta(\log\sigma)_k = 1. \qquad (2.2)$$

Table 1. Sigma levels and layer boundaries.

	Original distribution		Equal layers and levels	
k	$\sigma_{k-\frac{1}{2}}$	σ_k	$\sigma_{k-\frac{1}{2}}$	σ_k
1	0	.02207	0	.04545
2	.06	.08856	.09091	.13636
3	.125	.15741	.18182	.22727
4	.195	.23047	.27272	.31818
5	.27	.31738	.36363	.40909
6	.37	.43626	.45454	.5
7	.51	.57717	.54545	.59091
8	.65	.71772	.63636	.68183
9	.79	.84380	.72727	.77273
10	.90	.93701	.81818	.86364
11	.975	.98744	.90909	.95455

In this experiment there are 11 equally spaced layers and levels. This gives the distribution shown in table 1. Compared with the original distribution it can be seen that resolution has been lost in the lower levels, increased in mid-troposphere and decreased at upper levels. The top layer is now above 90 mb instead of 60 mb. Moreover, the relationship (2.1) no longer holds ie the finite difference scheme no longer conserves energy. It should be noted that either the spacing or the levels (but not both) could have been equally distributed and the relationship (2.1) satisfied. However, it was decided to make these changes only if the results of this experiment needed further investigation.

The above changes require that alterations be made to the dynamical equations and radiation routines.

In the dynamical equations, (2.1) has been used in calculating the adiabatic term $\frac{KT\omega}{\sigma}$. We find that $\log \sigma_{1\frac{1}{2}}/\sigma_{\frac{1}{2}}$ is needed for the top level and $\sigma_{\frac{1}{2}} = 0$. Since $\sigma_1 = 1/22$ and $\sigma_{1\frac{1}{2}} = 1/11$ it was decided to use (2.1) and thus $\Delta(\log\sigma)_1 = 2$. Furthermore, with the levels now equally distributed, it is no longer necessary to weight the temperatures and humidity when calculating vertical differences.

Table. 2. The values given by (2.4) for each gas at the equally-spaced sigma levels.

k	H_2O	CO_2	O_3 long wave	O_3 short wave
11	.09002	4.411E-5	.09214	.09388
10	.08227	4.031E-5	.08852	.09388
9	.07443	3.647E-5	.08466	.09388
8	.06650	3.259E-5	.08053	.09388
7	.05846	2.865E-5	.07604	.09388
6	.05030	2.465E-5	.07112	.09388
5	.04199	2.057E-5	.06562	.09388
4	.03348	1.641E-5	.05933	.09388
3	.02472	1.212E-5	.05181	.09388
2	.01560	.764E-5	.04212	.09388
1	.00571	.280E-5	.02570	.09388

In the radiation routine, the path lengths for O_3 long wave, H_2O, CO_2 long wave and O_3 short wave are required so that the radiation fluxes may be calculated. (O'Neill 1974). These are pressure-level (and hence sigma-level) dependent. In the 11-level model, the path lengths are given by

$$y = \frac{p_* C_a}{g(1+\alpha_a)} \left\{ \sigma_{k+\frac{1}{2}}^{1+\alpha_a} - \sigma_{k-\frac{1}{2}}^{1+\alpha_a} \right\} . \qquad (2.3)$$

where C_a is a mixing ratio and α_a is a pressure scaling factor for each gas.

$\alpha_a = 0.4$ for O_3 long wave.

$\alpha_a = 0.9$ for H_2O and CO_2 long wave.

$\alpha_a = 0$ for O_3 long wave.

The mixing ratio depends upon the concentration of the gas and is calculated in the model except for CO_2 which is assumed to be well-mixed. In this case $C_a = 4.9\ 10^{-4}$. The quantity

$$\frac{10 \cdot 13C}{g(1+\alpha_a)} \left\{ \sigma_{k+\frac{1}{2}}^{1+\alpha_a} - \sigma_{k-\frac{1}{2}}^{1+\alpha_a} \right\}, \qquad (2.4)$$

is calculated for each gas at each level and is used to calculate (2.3). Values are given in table 2. $C = 1$ except for CO_2 where $C = C_a$.

The boundary layer routine used by the 11-level model takes into account the high resolution near the surface (see Saker 1975). In this model the resolution is decreased and a simplified boundary layer scheme is required. Details of the scheme are as follows.

(i) The top of the boundary layer is set at $\sigma = 0.9$.

(ii) The stress is assumed to satisfy the quadratic $\underline{\tau} = A\sigma^2 + B\sigma + C$ with $\tau = \tau_*$ at $\sigma = 1$, $\tau = 0$ at $\sigma = 0.9$ and $\partial\tau/\partial\sigma = 0$ at $\sigma = .9$, thus

$$\underline{\tau} = \underline{\tau}_* (100\sigma^2 - 180\sigma + 81). \qquad (2.5)$$

(iii) Since $\underline{\tau}_* = \rho_* C_D |\underline{V}_*| \underline{V}_*$ we need to find $\underline{V}_*$, which is given by

$$\underline{V}_* = \underline{V}_B + \frac{(1 - \sigma_B)}{(\sigma_B - \sigma_{B-1})} (\underline{V}_B - \underline{V}_{B-1}) \qquad (2.6)$$

where suffix $*$ denotes the surface value and B the bottom level.

(iv) The frictional effects of the boundary layer on the wind field are described by

$$\frac{\partial \underline{v}}{\partial t} = \frac{-g}{p_*} \frac{\partial \underline{\tau}}{\partial \sigma}. \qquad (2.7)$$

Using (2.5) and (2.6) we have

$$\frac{\partial \underline{v}}{\partial t} = \frac{-g}{p_*} \rho_* C_D |\underline{V}_*| \underline{V}_* (200\sigma - 180). \qquad (2.8)$$

The wind field at the lowest model level, ie the level in the boundary layer, is adjusted by adding on an increment $\Delta t \left(\frac{\partial \underline{v}}{\partial t}\right)$.

(v) The fluxes of sensible heat F_H and water vapour F_W at the surface are included as follows

$$\delta T = \frac{g}{c_p p_*} \frac{\delta t}{\Delta\sigma} F_H .$$

and

$$\delta q = \frac{g}{p_*} \frac{\delta t}{\Delta\sigma} F_W ,$$

where F_H and F_W are calculated as in the original 11-level model. The increments are added to the bottom layer.

It is possible to include this simplified boundary layer scheme when running the original 11-level model and this was done to provide control experiments to see whether changes were due to changing the distribution of the levels or the simplified boundary layer scheme.

3. Initialisation

To run the model an initial data set is required and this is prepared as in the original 11-level model. The initialisation programs are altered to take into account the new sigma levels onto which the winds, temperature and humidities are interpolated. For programming information, the routines that require modification are HOTFI, HOLOGP and HUMINT.

Before running the model the D-record, which contains global constants and integration control experiments, also needs amending. A large segment contains various functions and combinations of the sigma levels used in model calculations. A program was written to recalculate these and overwrite the appropriate D-records in the set-up program. Three data sets are used in the set-up program and all three D-records have to be changed.

4. Results

The three cases studied here have already been discussed by Cullen (1978). The main purpose of this experiment is to identify differences between the two 11-level models and the control experiment.

14/8/77 The 500 mb charts for day 5 are shown in figures 1 and 2 for the original 11-level model (OM) and the equally spaced layers and levels model (EM) respectively. Differences over the five days are small even by day 5. EM collapses the Atlantic ridge more successfully and there is perhaps a better indication of low pressure at about 60N 130W. The main faults in OM have not been rectified or made worse by EM.

Figures 3 and 4 show PMSL at day 5 for OM and EM respectively. The differences in PMSL forecasts were mainly small. The area of low pressure near NW France was not forecast by either model at day 1, but on day 2 both models develop low pressure near Northern Spain and move the depression NE towards the UK. From days 3 to 5 EM has a better pressure pattern over the UK but both models show similar handling of the depression up to day 5. Surface pressure West of Ireland was handled better by EM where there is a difference of more than 4 mb between the models over a large area. This links in with the collapsing of the ridge at 500 mb discussed above.

The models handle the area in the SW of the United States differently. In this area, the difference in surface pressure between OM and EM is greater than 8 mb at day 5, EM being much more realistic. The control experiment was run to see of the differences in this area were due to the use of a simplified boundary layer scheme. Figure 5 shows PMSL at day 5 for the control run. Near the UK the low pressure to the SE is not quite as good as either EM or OM, but to the West of Ireland the surface pressure forecast is nearer to that of EM. Over the Southwest United States the area of low pressure is only about 4 mb lower than in EM.

Another noticeable difference between the models is the high pressure area near 50N 110E in EM. OM declines this by day 5 with a small depression at its SE edge. The control experiment has pressure a little lower than in EM. However, none of the models forecast events correctly in this area.

<u>8/5/77</u> The 500 mb charts for days 3 and 5 are shown in figures 6 to 9. The depression approaching the UK is forecast better by OM as it crosses the Atlantic but the phasing in with the trough extending Southwards from the Arctic is better in EM and is similar to EM in the control. The depression over Nova Scotia is better in OM and in the control. By day 5 differences are still small. However, there is a difference of about 10 dekametres between the models over the UK with the control almost midway between. Another interesting difference occurs at about 60N 120E where the depression correctly has one centre in EM and in the control but is split in OM. Finally, the trough over the Black Sea is better in OM; EM and the

control appear to relax the trough too quickly.

PMSL charts are shown in figures 10 to 15 for days 3 and 5. On day 3, differences are mainly small. Near the UK there is a small difference in the handling of the complex low pressure area with both models and the control having the pressure too low over Scandinavia. OM has a depression near 30N 145E which appears to develop on day 1 and moves slowly NE and filling by day 5. There is no evidence of this in the actuals except for a development in that area at day 5. EM and the control are mainly correct in this area.

On day 5, surface pressure over the UK is 4 mb lower in EM than in OM reflecting the lower 500 mb height in EM with the control nearer OM. The depression near the UK is not far enough on in either model and both fail to develop a ridge West of Ireland. There are differences in detail between the models in the Northern extent of this complex low pressure area. Other differences include the low pressure over NW Africa in OM compared with the slack area indicated by EM with the control roughly between these.

Over the Western United States, the depression which should be near 50N 110W at day 3 is extended too far South and elongated by the models. This is worse in OM and the control than in EM. This depression is still a major feature by day 5 on the actual chart but has been lost by all the models. Pressure is still too low in the Southwest United States in OM. EM and the control are much better in this area.

1/1/78 Figures 16 to 19 show the 500 mb charts at days 3 and 5 for OM and EM. There is a difference in the movement of a trough across the UK and Europe. Zonal flow over the Atlantic and Northern Europe on day 1 changes as a ridge develops in mid-Atlantic and a trough extends SE from Norway over the UK. Both the trough and ridge move East. Both OM and EM fail to have sufficient amplitude in the ridge and heights over the UK are some 25 dekametres too low. Movement of the trough to day 5 is quite good in OM but too fast in EM being some 10° too far East by day 5. The control experiment follows OM more closely at 500 mb.

Another significant difference between OM and EM at 500 mb has important consequences in the surface forecast. On days 2 and 3, EM incorrectly amplifies the ridge over the Davis Straits and a trough develops East of Greenland which moves quickly East crossing the UK between days 4 and 5. Neither OM nor the control produce this trough.

There are small differences in detail between OM and EM over the Pacific and in the blocking anticyclone over Alaska which result in different behaviour of surface features.

Figures 20 to 25 show surface pressure charts for days 3 and 5 for OM, EM and the control experiment. All three models have insufficient ridging at day 3 reflecting the behaviour at 500 mb and consequently the anticyclone over Europe on days 4 and 5 is centred to the Southwest of its actual position.

At day 2, OM and EM have two depressions near Newfoundland, one NE and one SE. In the actuals this is an area of cyclogenesis. OM correctly produces the main centre but fails to deepen it enough and extends the low pressure Eastwards instead of NE with another centre near Iceland. EM keeps the main centre too shallow and too far West. The second centre phases in with the incorrect trough at 500 mb and deepens, moving quickly East. By day 5 this depression has reached Scandinavia with a second depression in mid-Atlantic. Thus the surface forecast for the Eastern Atlantic and the UK is poor in EM. OM and the control are better but the inability to build the ridge has caused the main errors.

Over the Pacific at day 3, EM has the anticyclone at 180E too intense and too far North. Consequently the depression at 150E is not far enough East as it is in OM and the control. However, in OM and the control it is not deep enough. On day 4, OM and the control correctly continue to move this depression East but OM fails to deepen it. The control experiment does deepen it but not enough. EM still has too intense an anticyclone in this area. By day 5 in OM the depression in mid-Pacific has its centre slightly Southeast of its correct position and is not deep enough. The control is much better with both position and depth. EM has only spread out the depression in the East Pacific.

Hovmöller diagrams were produced for each of the cases studied. Differences were small and it was decided not to include them here.

5. Conclusions

Comparisons were also made with the operational models and in none of the cases were the main differences between the operational and 11-level models changed. Changing the 11-level model so that its vertical resolution is similar to that of the operational model made small changes in two cases (May and August) and was detrimental in two areas in the January case. The 11-level model forecasts resemble each other more than either operational forecasts or the actuals. It is concluded that the distribution of the levels is not a feature which explains observed differences between model forecasts and that unequally spaced levels may be used without detriment.

The differences that are apparent at the surface often seemed to be due to the boundary layer scheme in the May and August cases and in one area in the January case. The 11-level model boundary layer scheme appears to be detrimental in some areas. A simplified boundary layer scheme may be adequate although further investigation is necessary.

Acknowledgements

I would like to thank Mrs J Collinson for helping to produce and run the programs for this experiment.

References

Cullen, M J P 1978 Six case studies from the forecast model intercomparison experiment, February 1977 to May 1978. Met Office Met O 11 Technical Note No 113.

Davies, T 1978 Potential temperature as a dependent variable in the Met O 20 11-level model. Met Office Met O 11 Technical Note No 105.

O'Neill, A 1974 The eleven level radiation scheme. Parts I and II. Met Office Met O 20 Technical Notes II/27 and 28.

Rowntree, P R 1971 Proposed vertical resolution in the new Met O 20 model. Met Office Met O 20 Technical Note II/1.

Saker, N J 1975 An 11-layer general circulation model. Met Office Met O 20 Technical Note II/30.

Temperton, C 1976 Comparisons between pressure and sigma coordinate versions of the 10-level mode. Met Office Met O 2b Technical Note No 29.

OM DAY 5 500 MB

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14/8/77

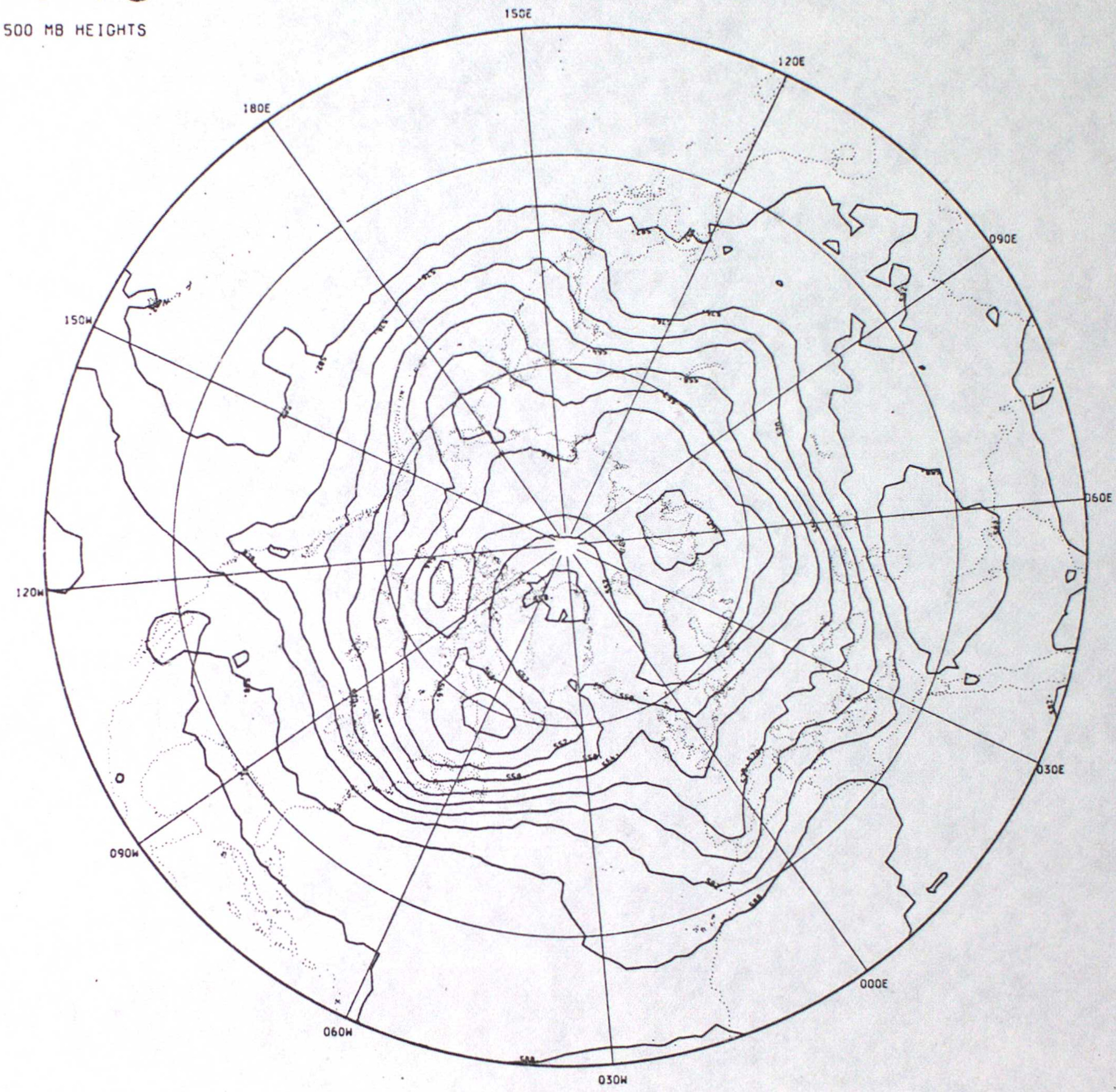

Figure. 1.

DAY 5 500 MB

EXPERIMENT TIME = 0005H00 500 MB HEIGHTS

CONTOUR INTERVAL = 6.00 DEKAMETRES

EM 14/8/77

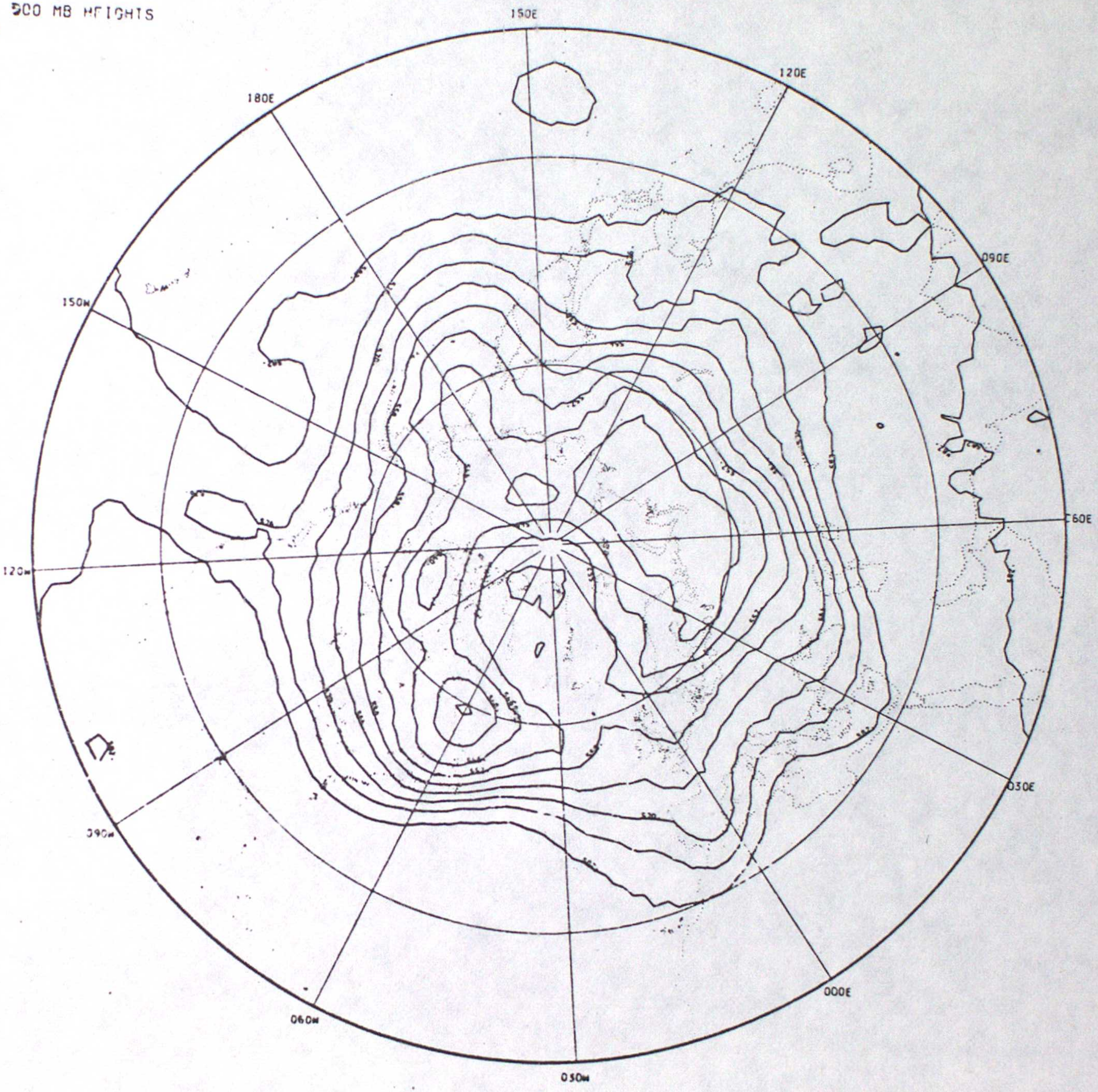

Figure. 2.

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CONTOUR INTERVAL = 4.00 MB

14/8/77.

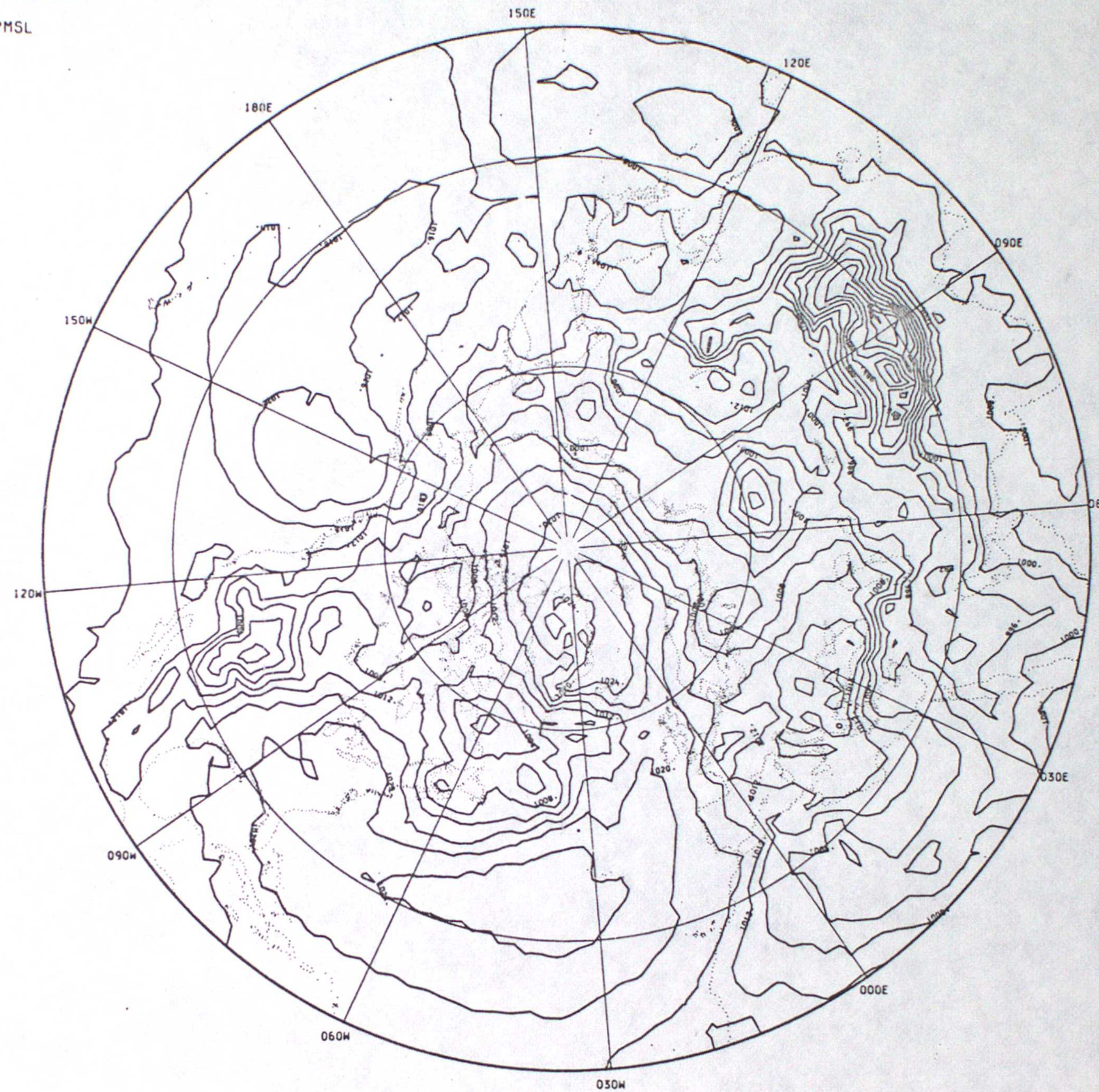

Figure. 3,

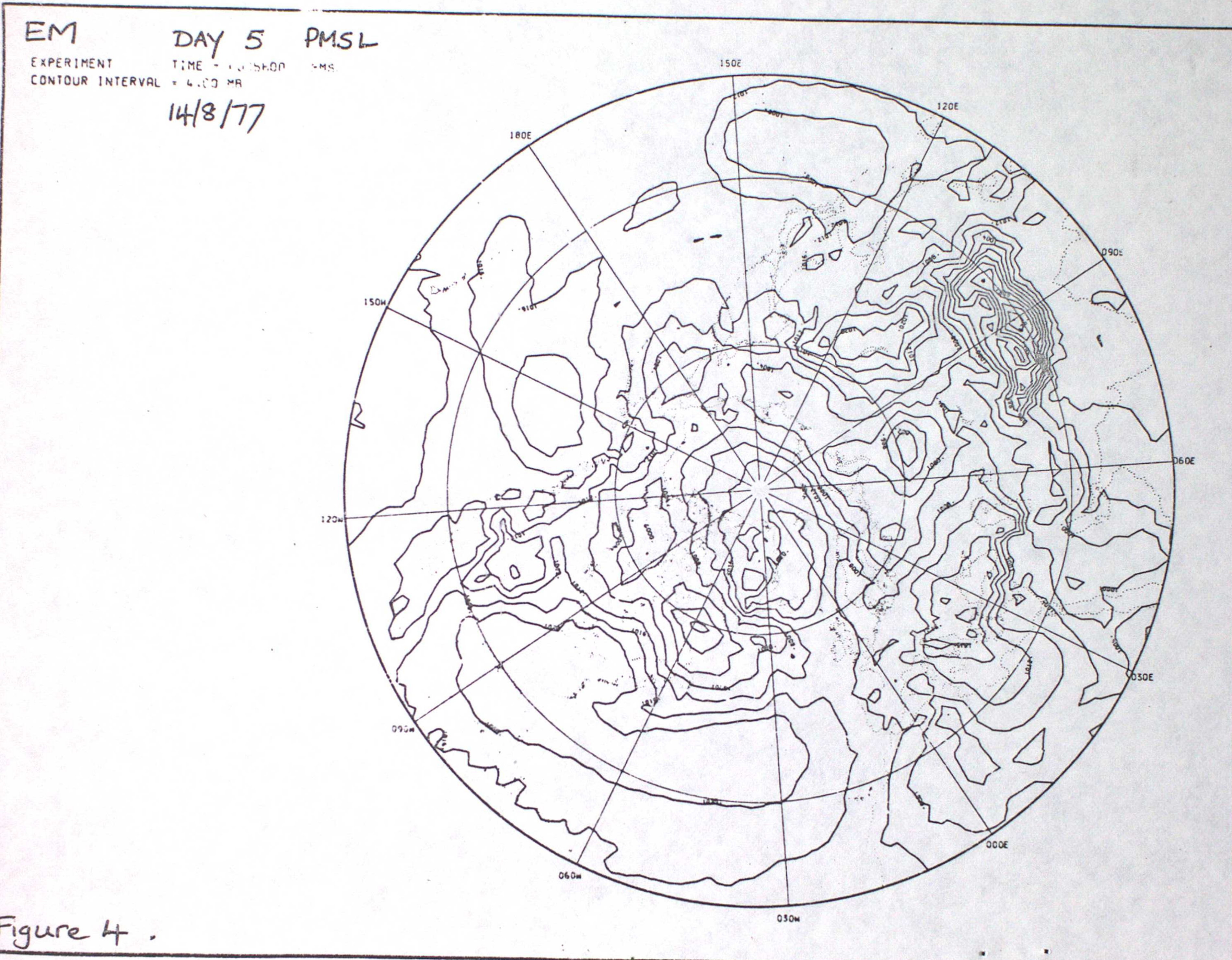
EM
DAY 5 PMSL
EXPERIMENT
CONTOUR INTERVAL = 4.00 MB
14/8/77
150E
120E
180E
090E
150W
060E
120W
030E
090W
000E
060W
030W

Figure 4.

CONTROL DAY5 PMSL

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CONTOUR INTERVAL = 4.00 MB

14/8/77.

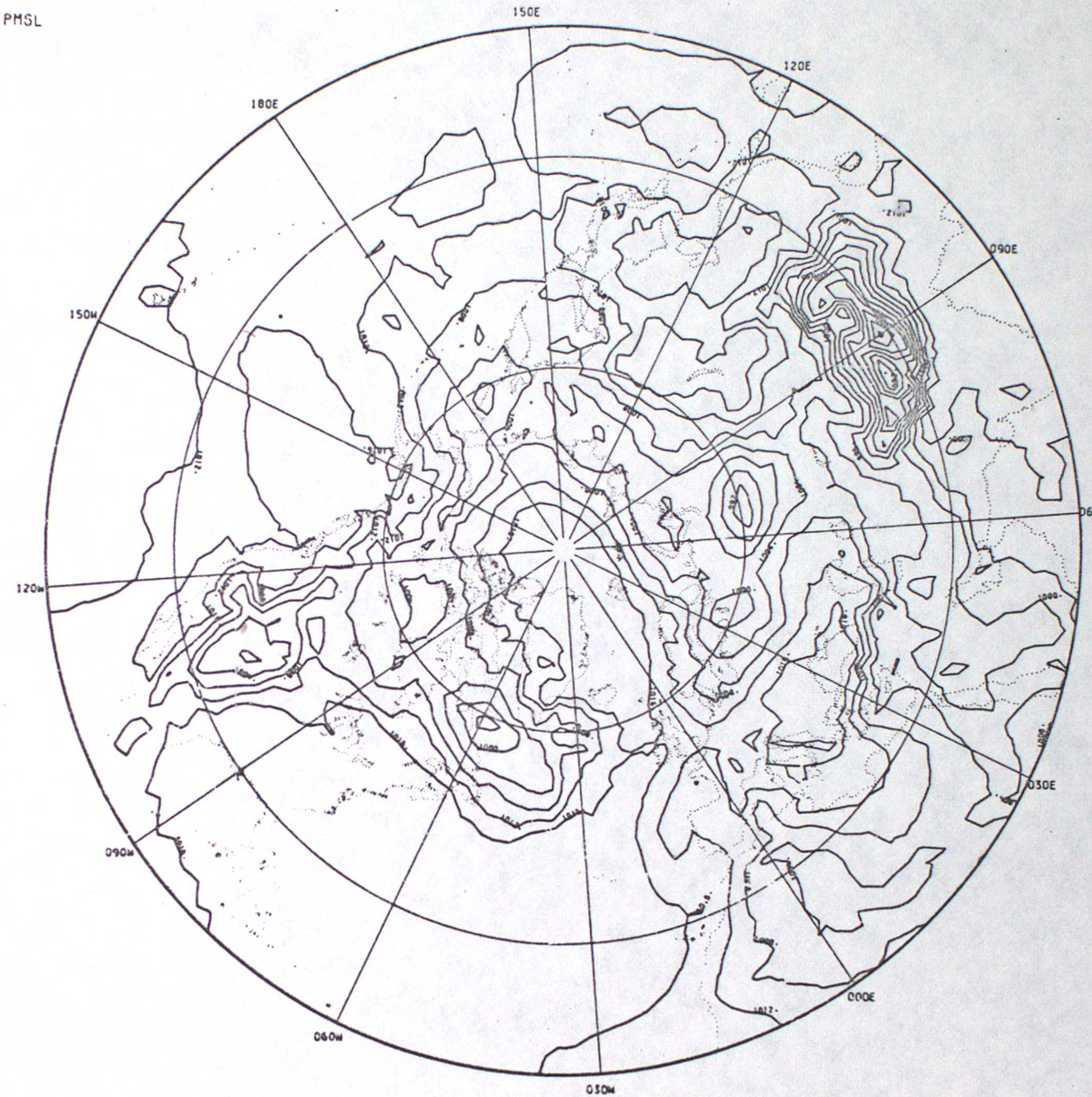

Figure 5.

OM DAY 3 500 MB

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8/5/77

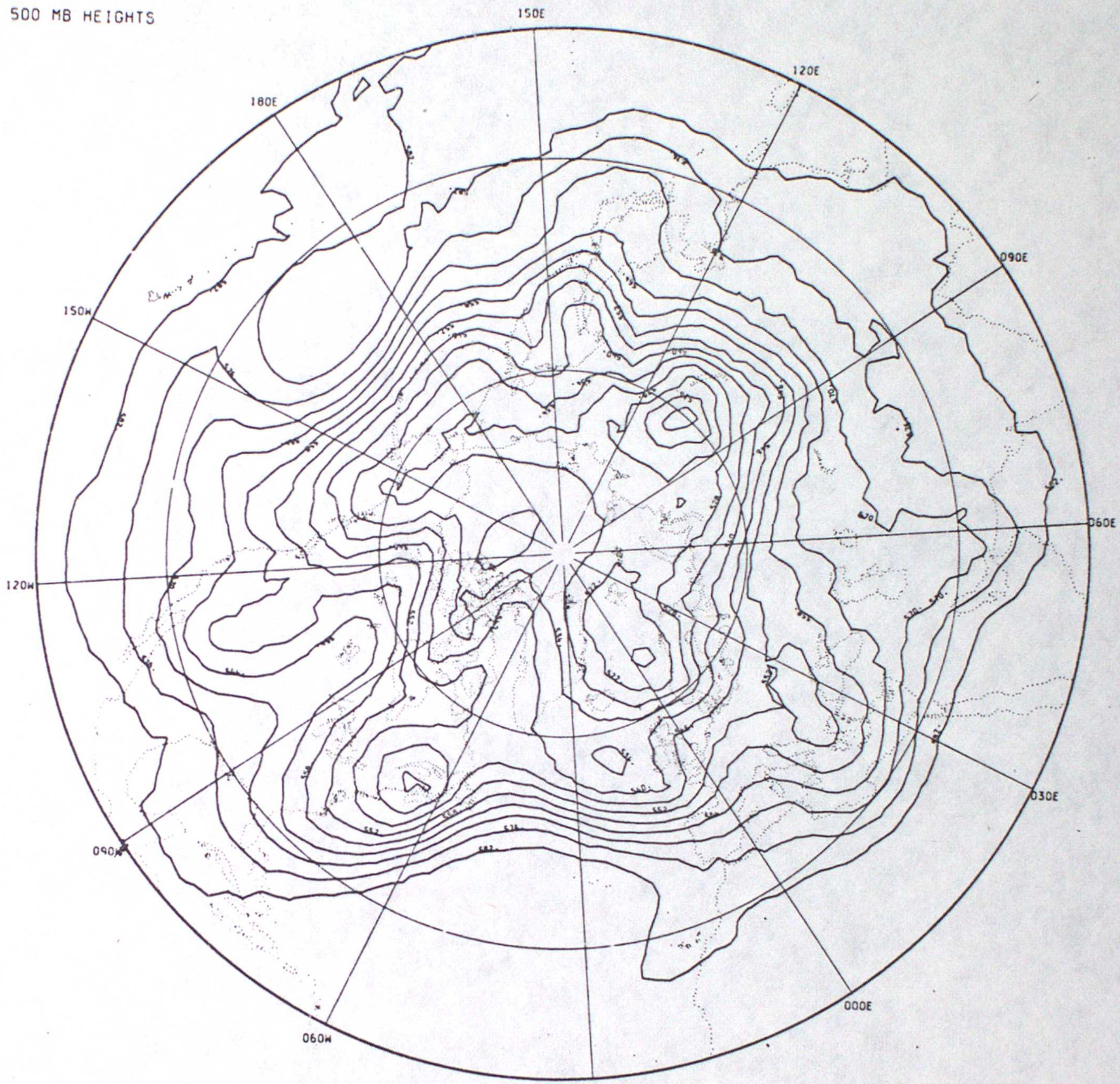

Figure 6.

EM DAY 3 500MB

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CONTOUR INTERVAL = 6.00 DEKAMETRES

8/5/77

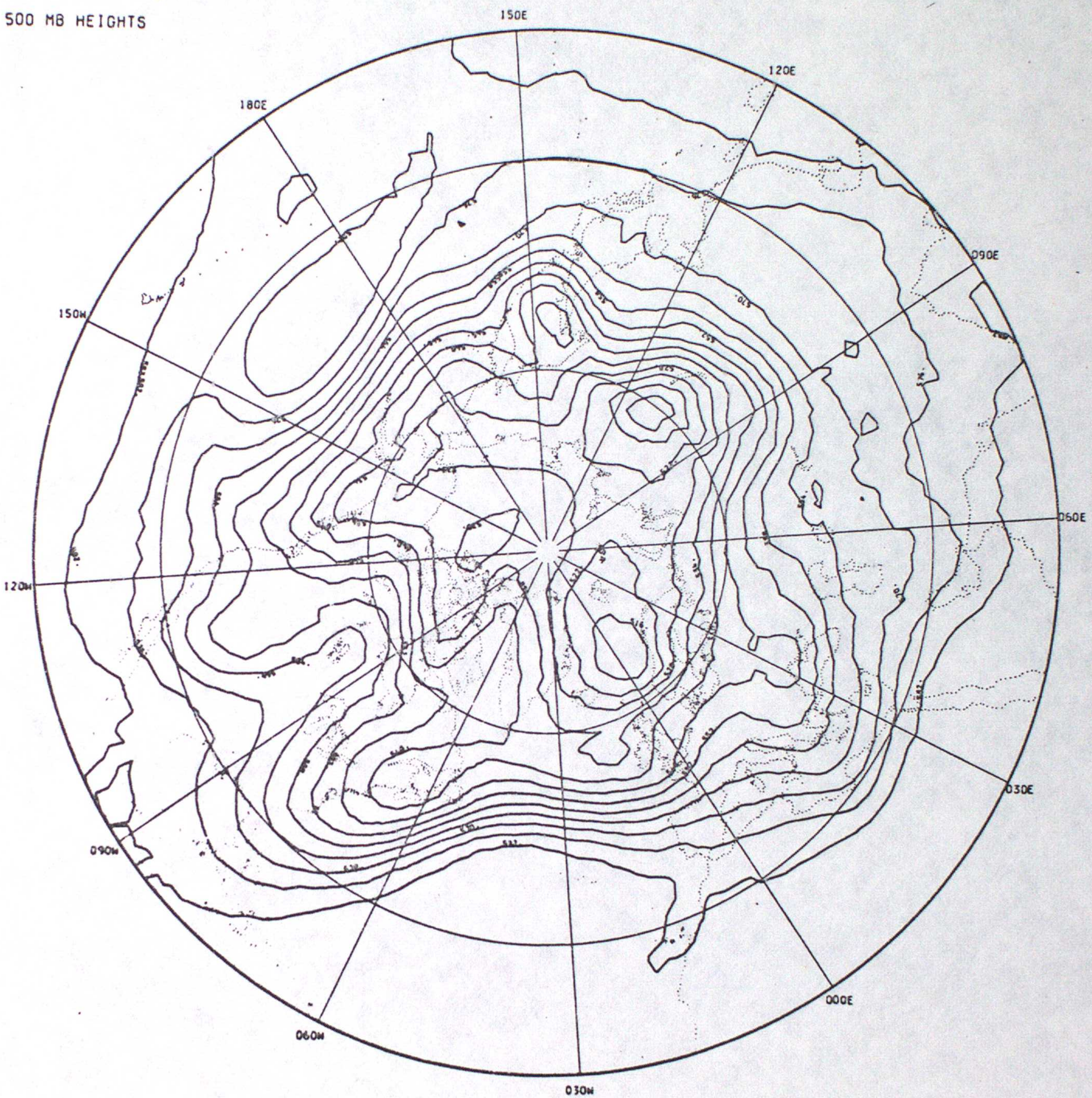

Figure. 7

OM Day 5 500MB

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CONTOUR INTERVAL = 6.00 DEKAMETRES

8/5/77

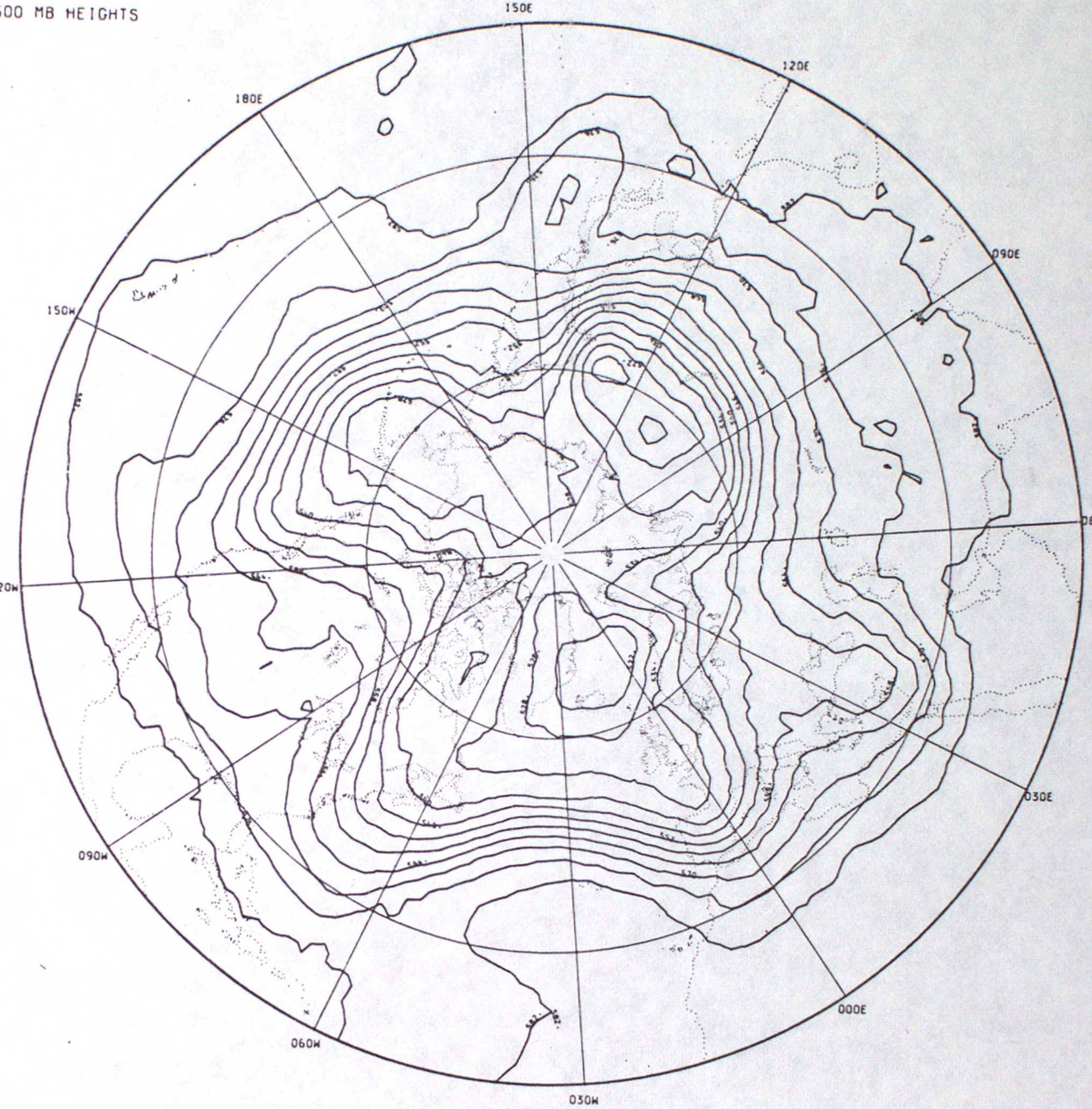

Figure. 8

EM DAY5 500MB

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8/5/77

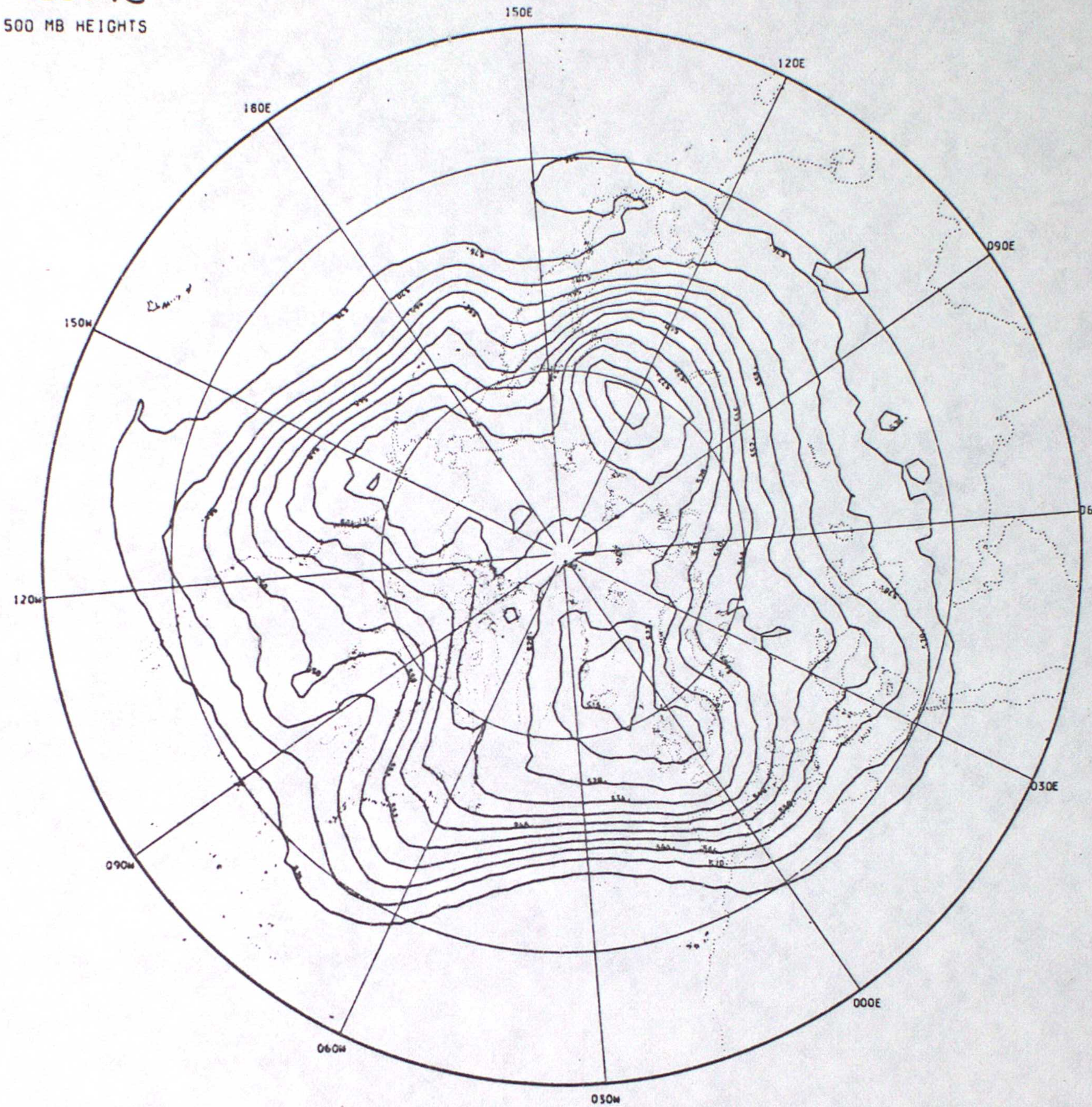

Figure. 9 ,

OM DAY 3 PMSL

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8/5/77

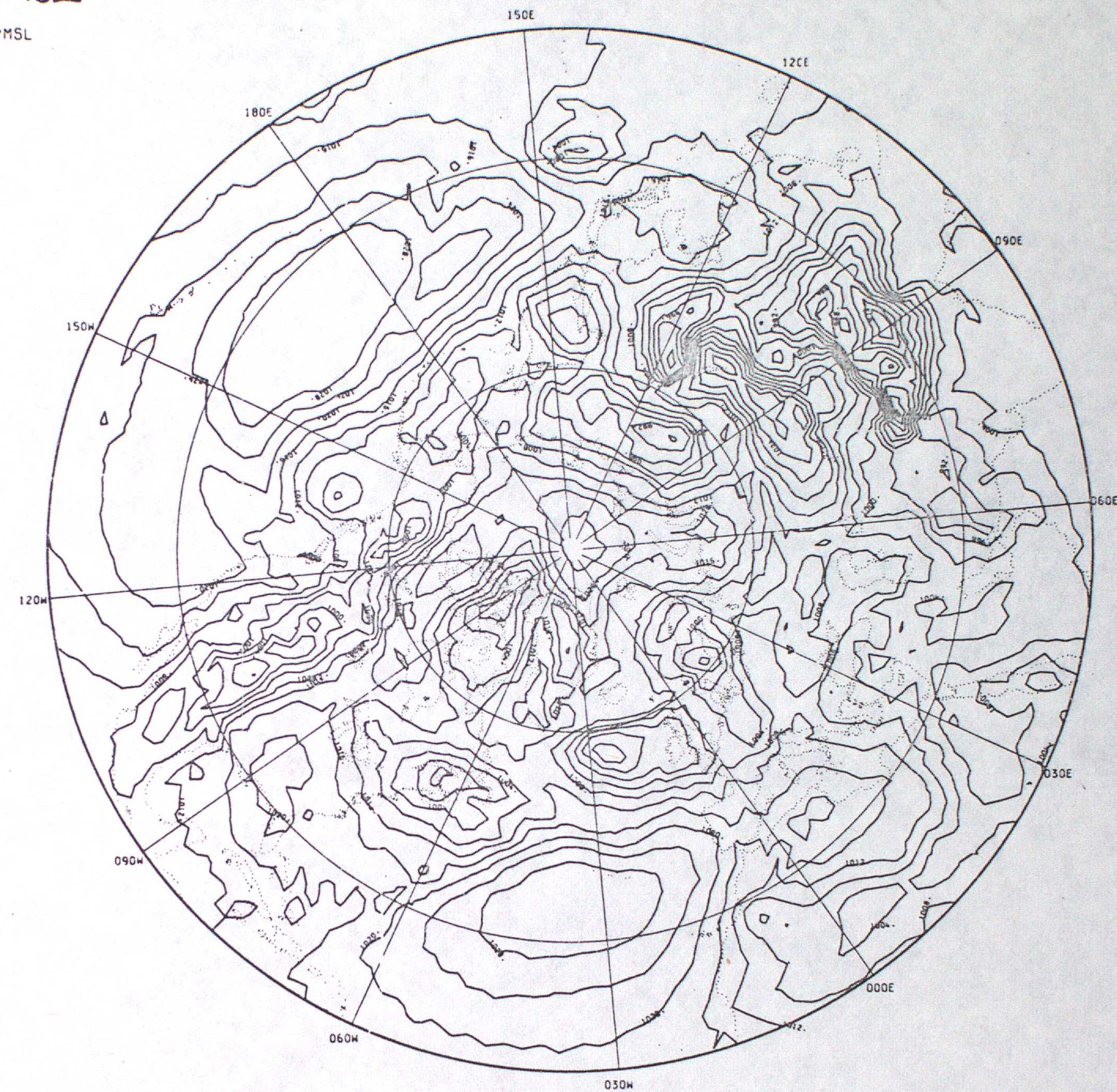

Figure 10.

EM DAY 3 PMSL

EXPERIMENT TIME = D003H00 PMSL
CONTOUR INTERVAL = 4.00 MB

8/5/77

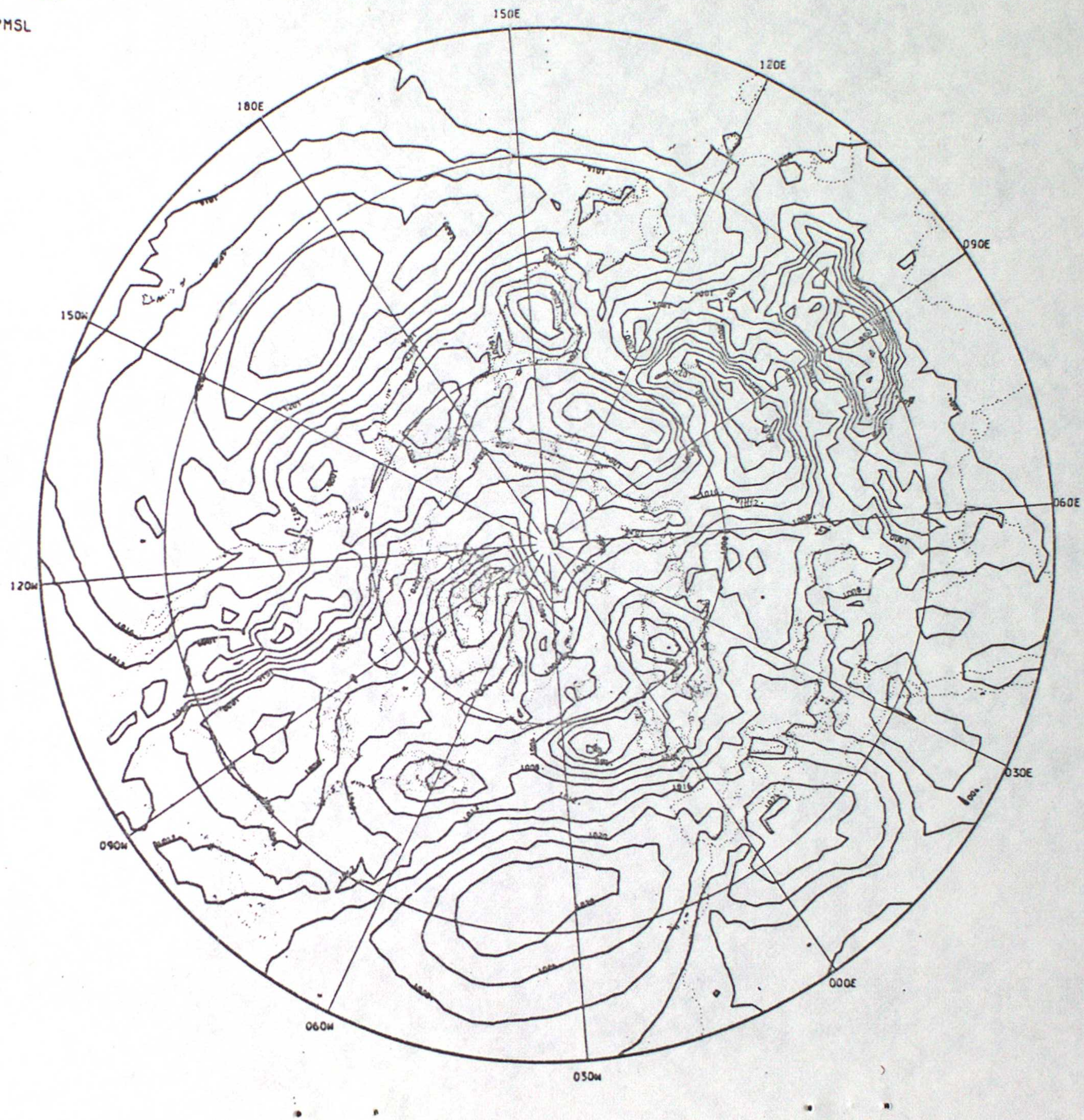

Figure. 11

CONTROL DAY 3 PMSL

EXPERIMENT TIME = D003H00 PMSL
CONTOUR INTERVAL = 4.00 MB

8/5/77

Figure. 12

OM DAY 5 PMSL

EXPERIMENT TIME = DOOSHOO PMSL
CONTOUR INTERVAL = 4.00 MB

8/5/77

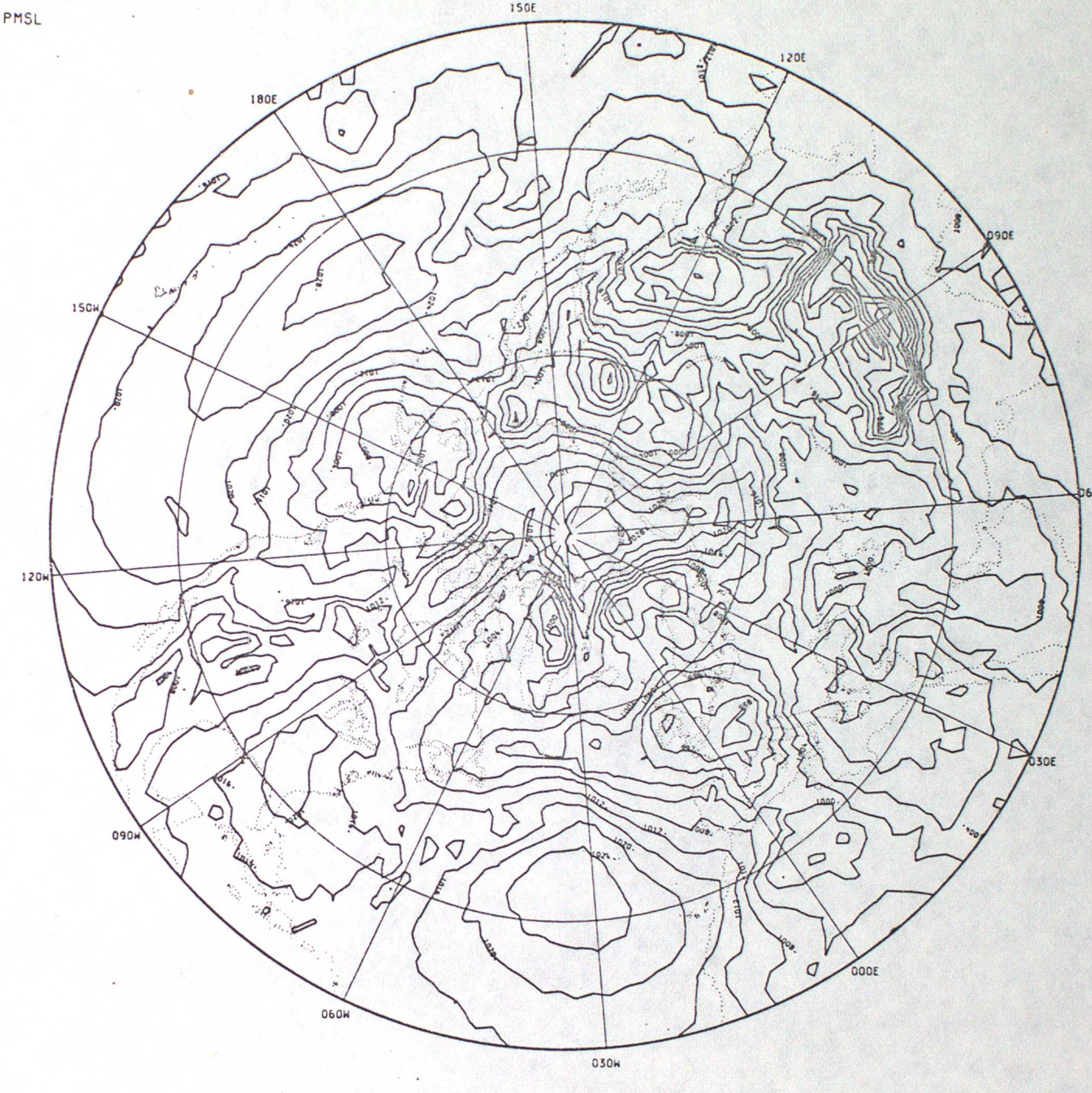

Figure 13.

EM DAY 5 PMSL

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8/5/77

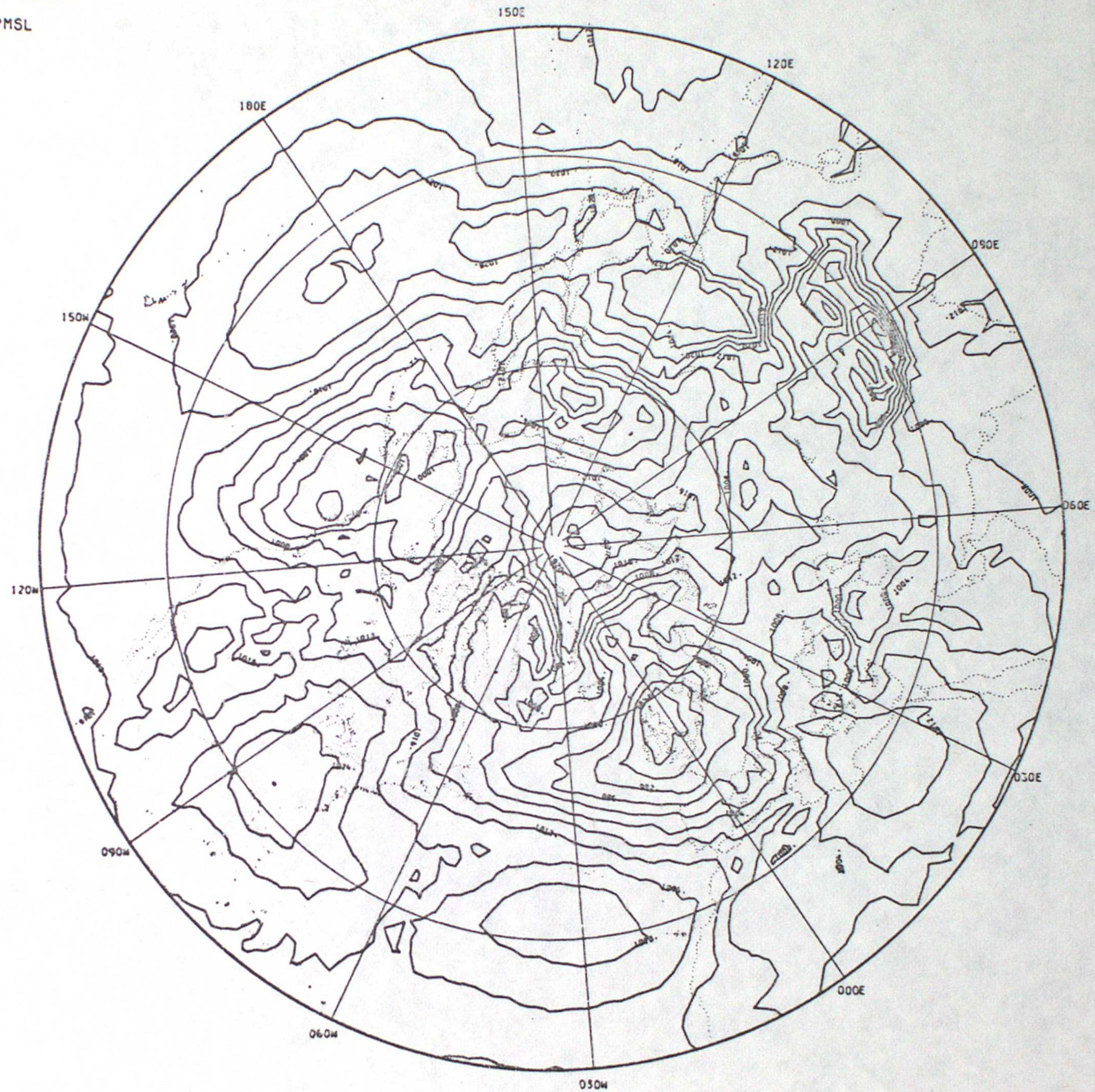

Figure 14.

CONTROL DAY 5 PMSL

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CONTOUR INTERVAL = 4.00 MB

8/5/77

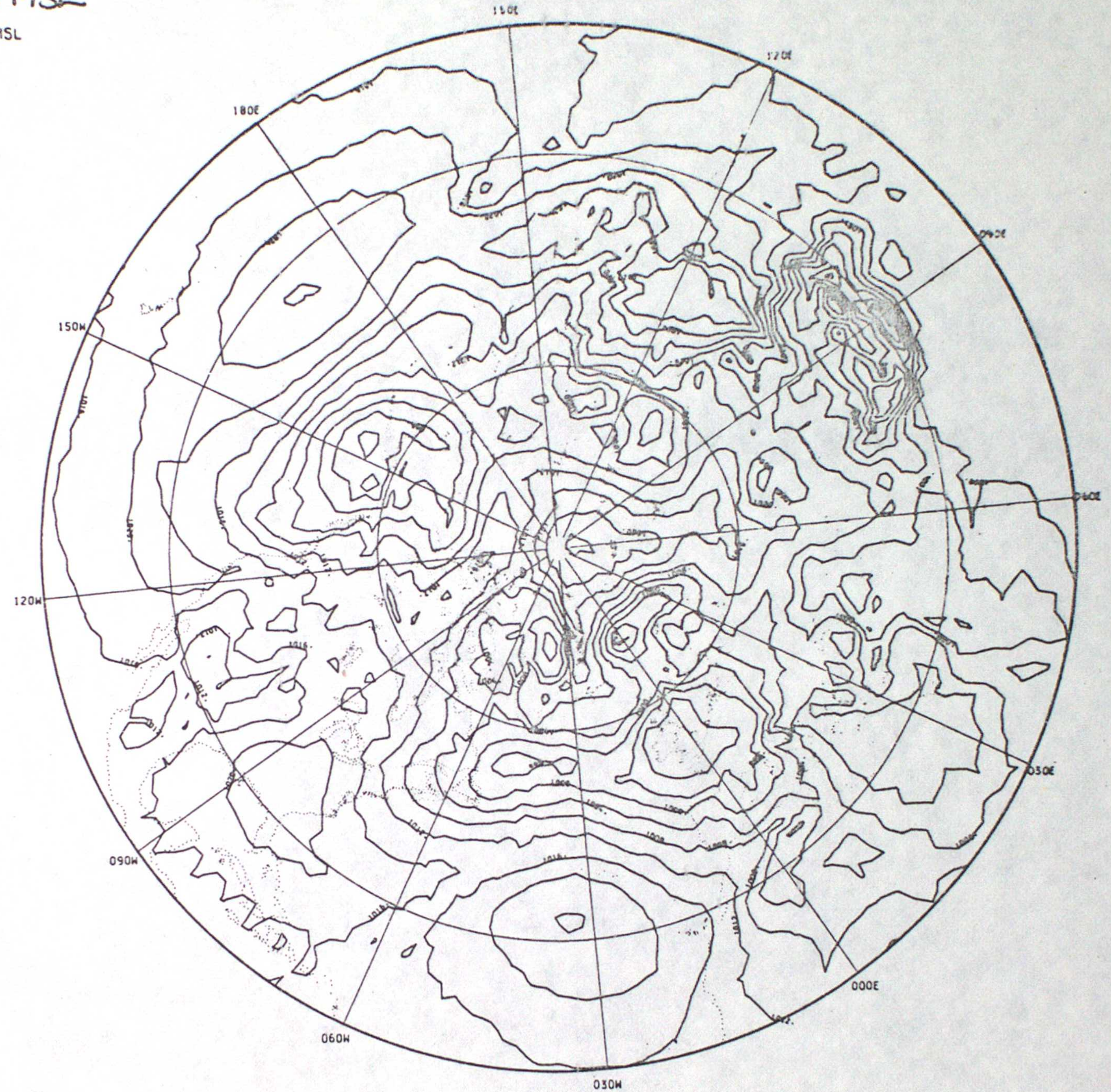

Figure. 15

OM DAY3 500MB

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1/1/78

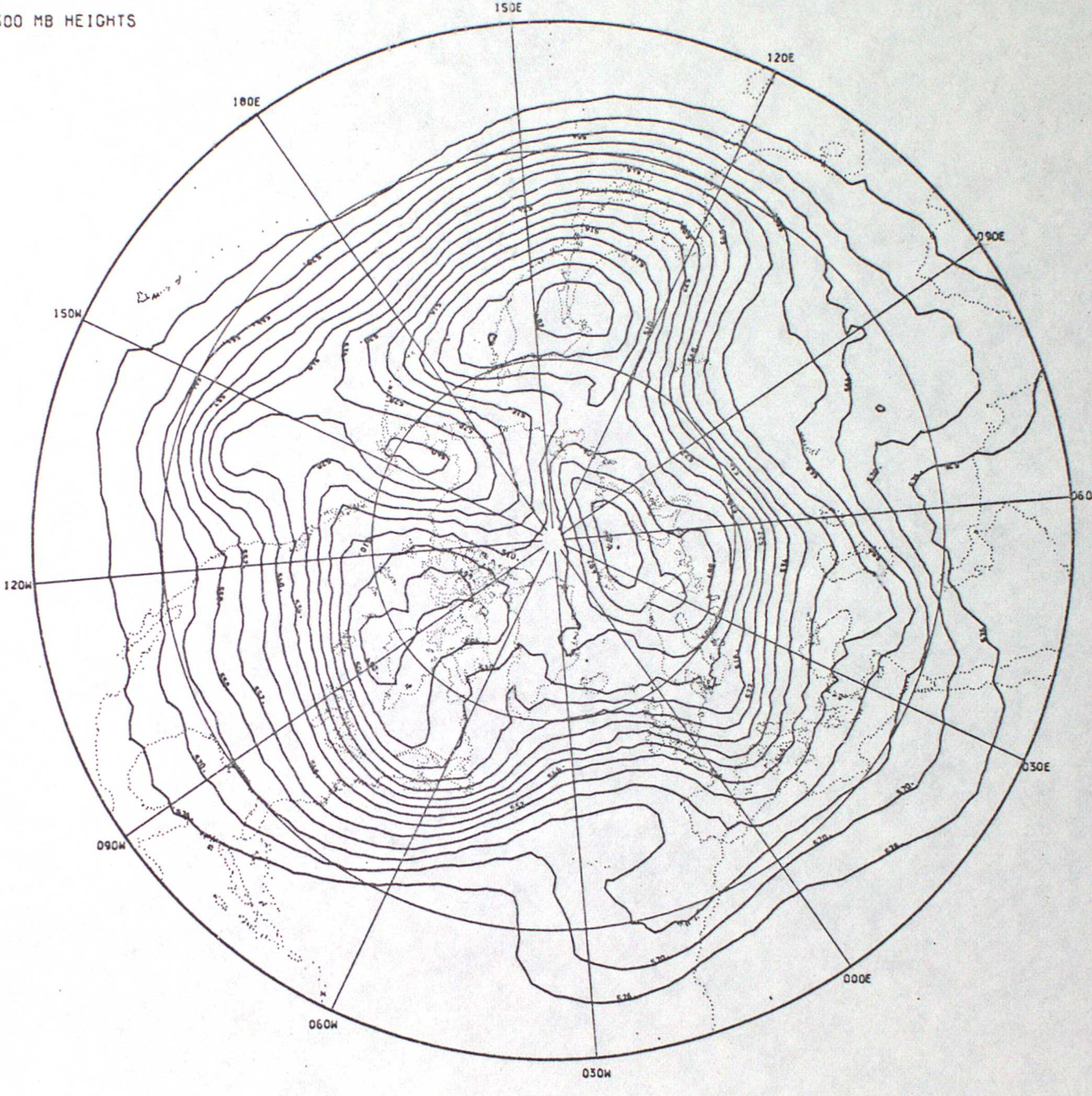

Figure. 16.

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1/1/78

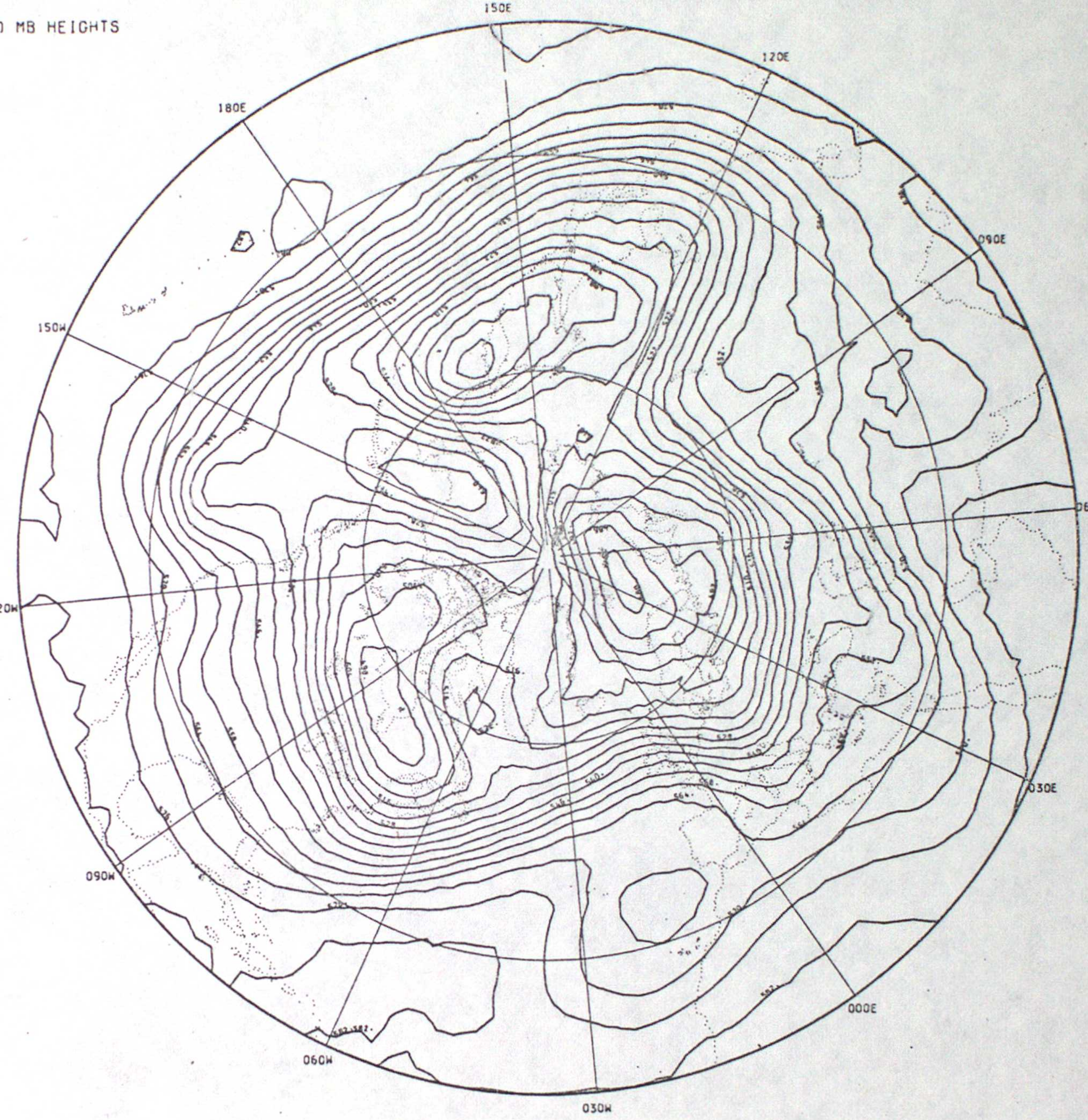

Figure. 17.

OM DAY 5 500 MB

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1/1/78

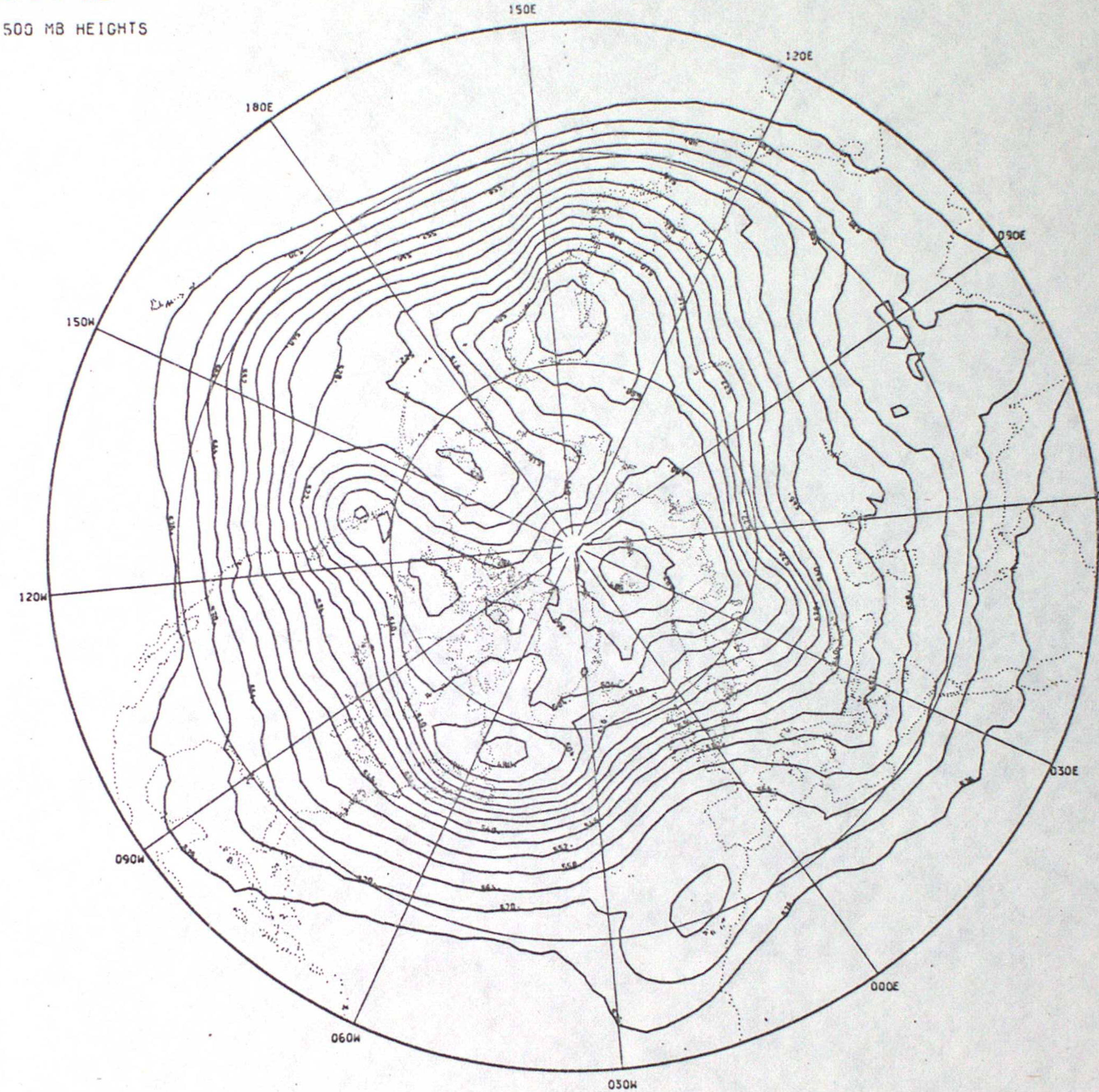

Figure 18,

EM DAY 5 500MB

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1/1/78

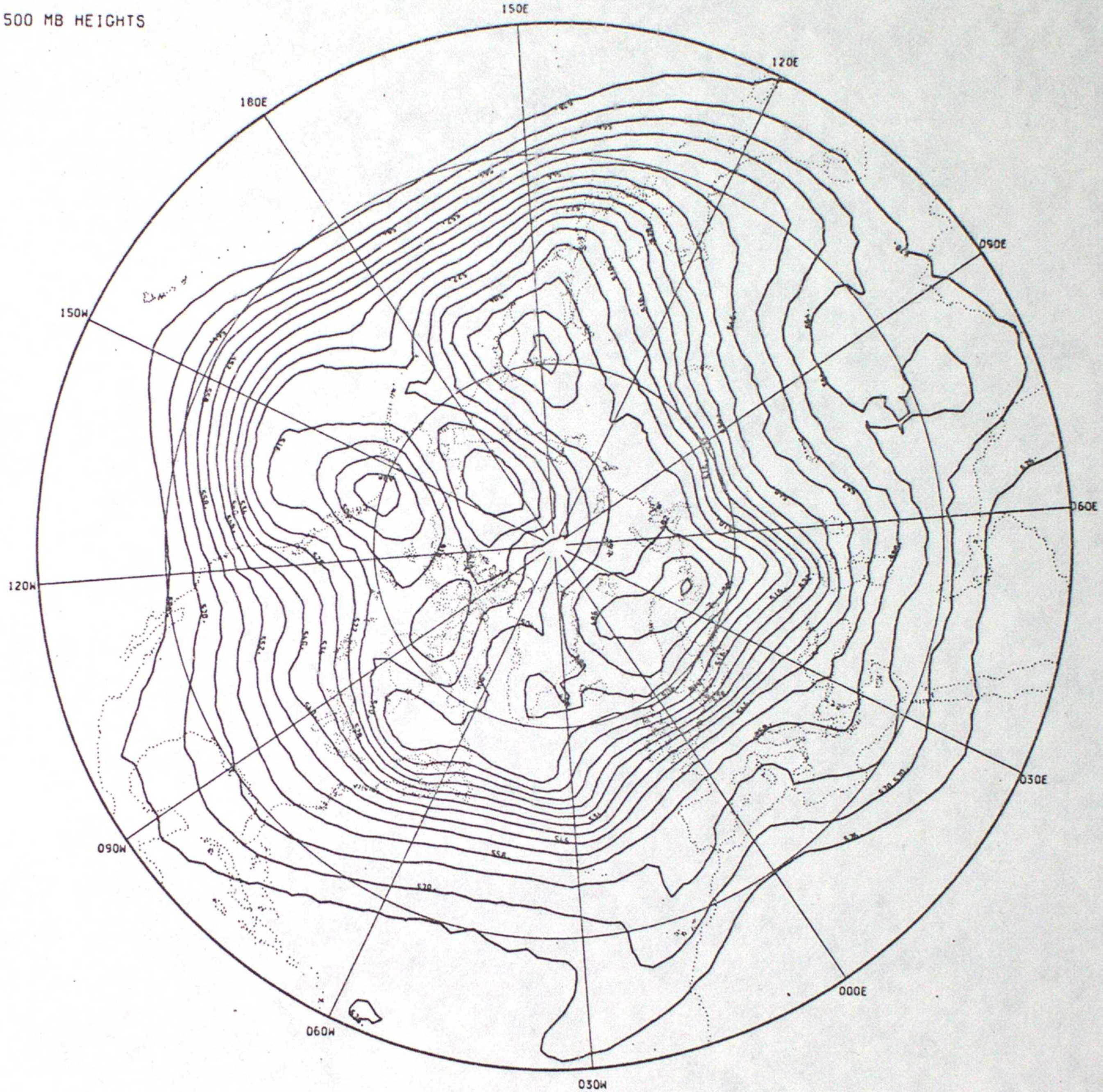

Figure. 19.

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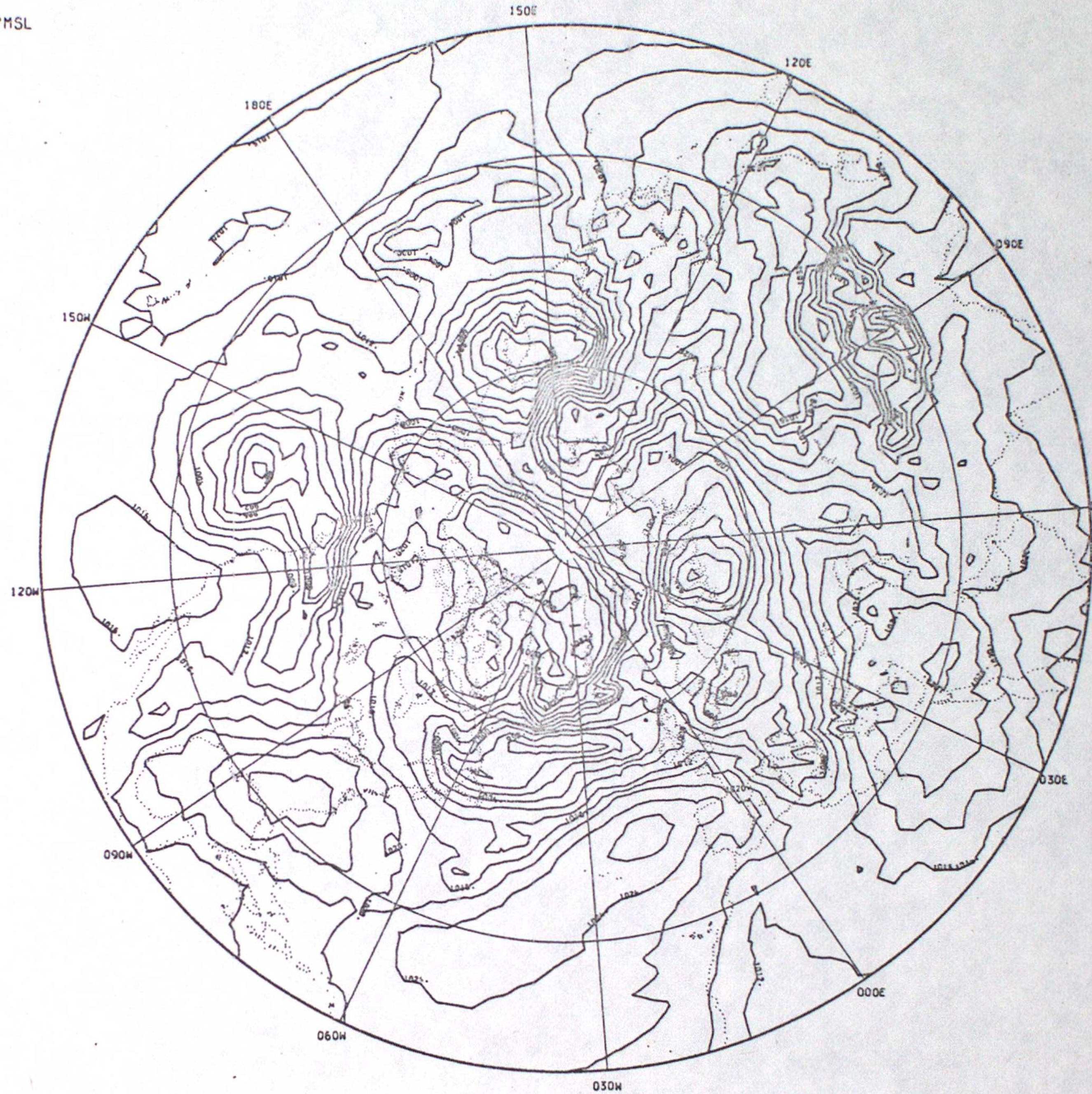

Figure, 20,

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1/1/78

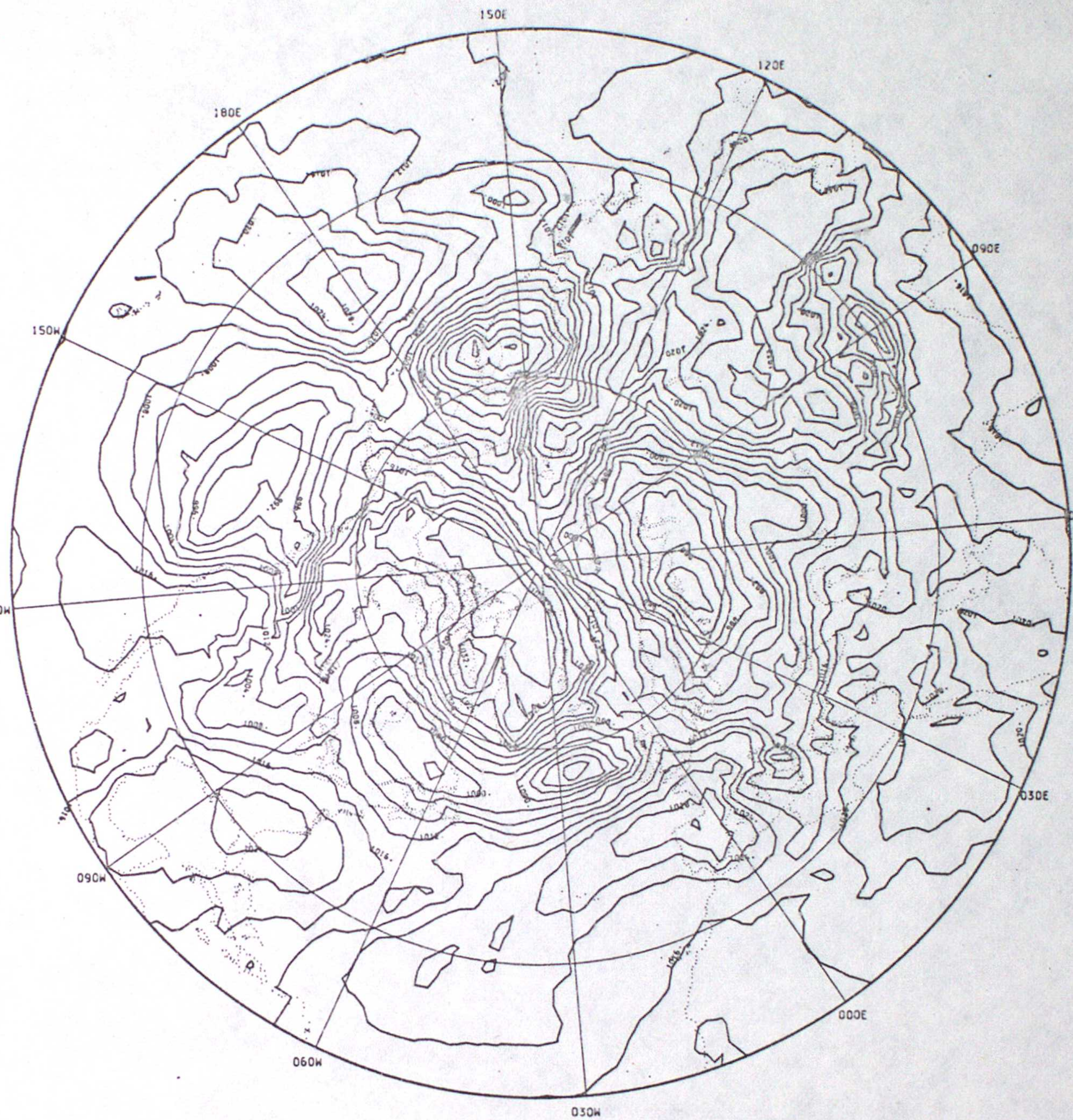

Figure 21.

OM DAY 5 PMSL

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1/1/78

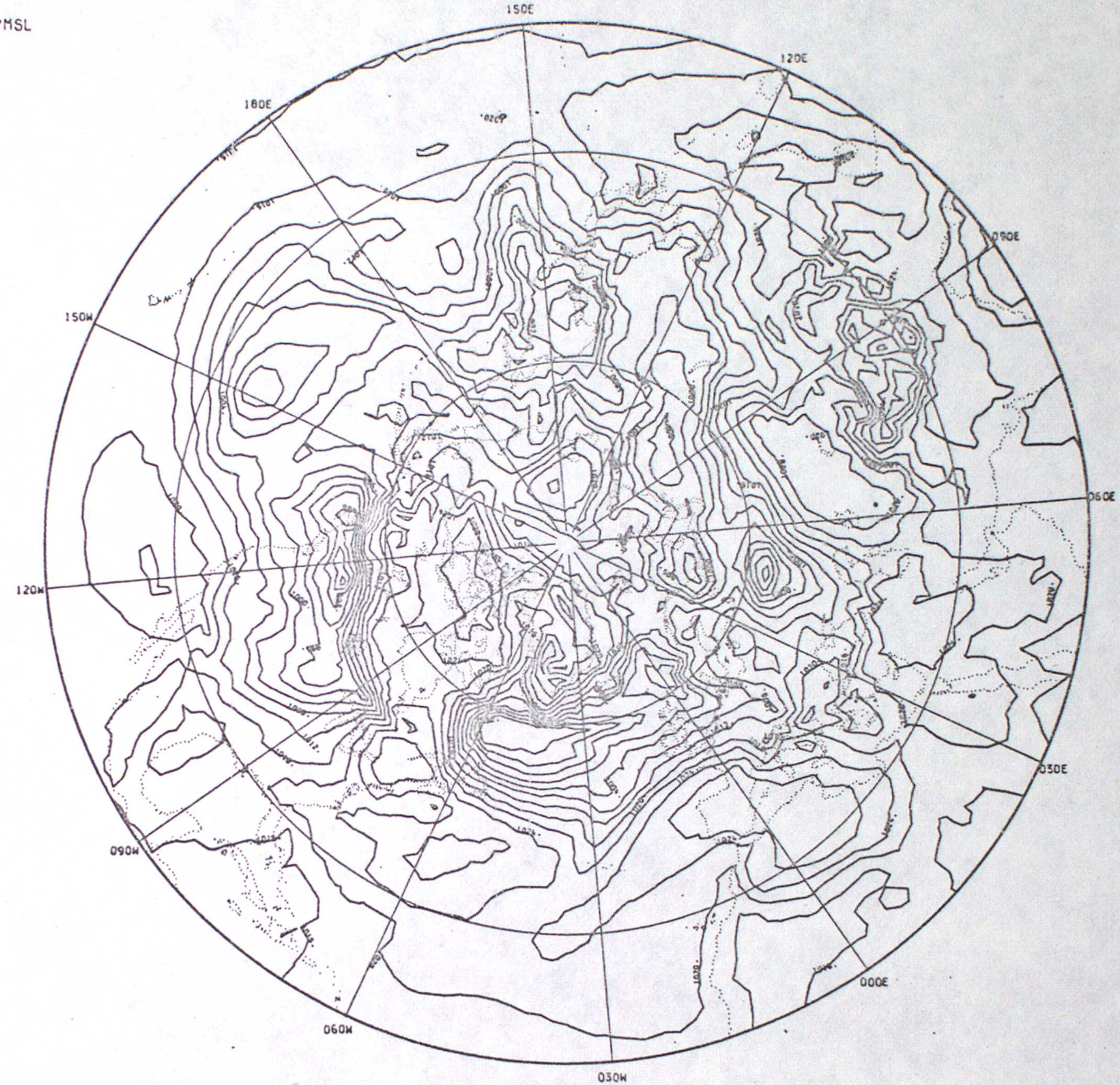

Figure 22.

EM DAY 5 PMSL

EXPERIMENT TIME = DOOSHOO PMSL
CONTOUR INTERVAL = 4.00 MB

1/1/78

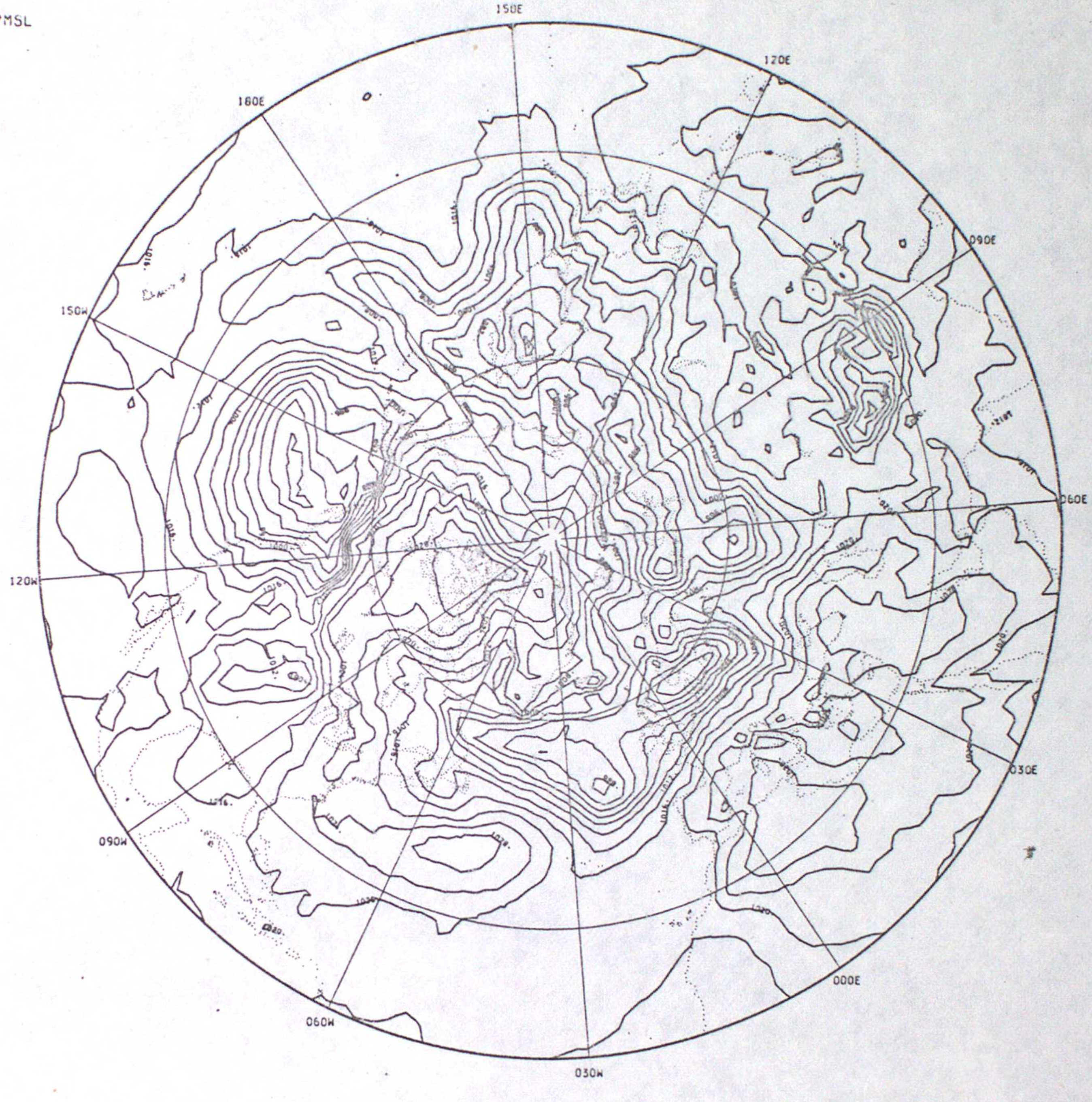

Figure 23.

CONTROL DAY 3 PMSL

EXPERIMENT TIME = DG03H00 PMSL
CONTOUR INTERVAL = 4.00 MB

1/1/78

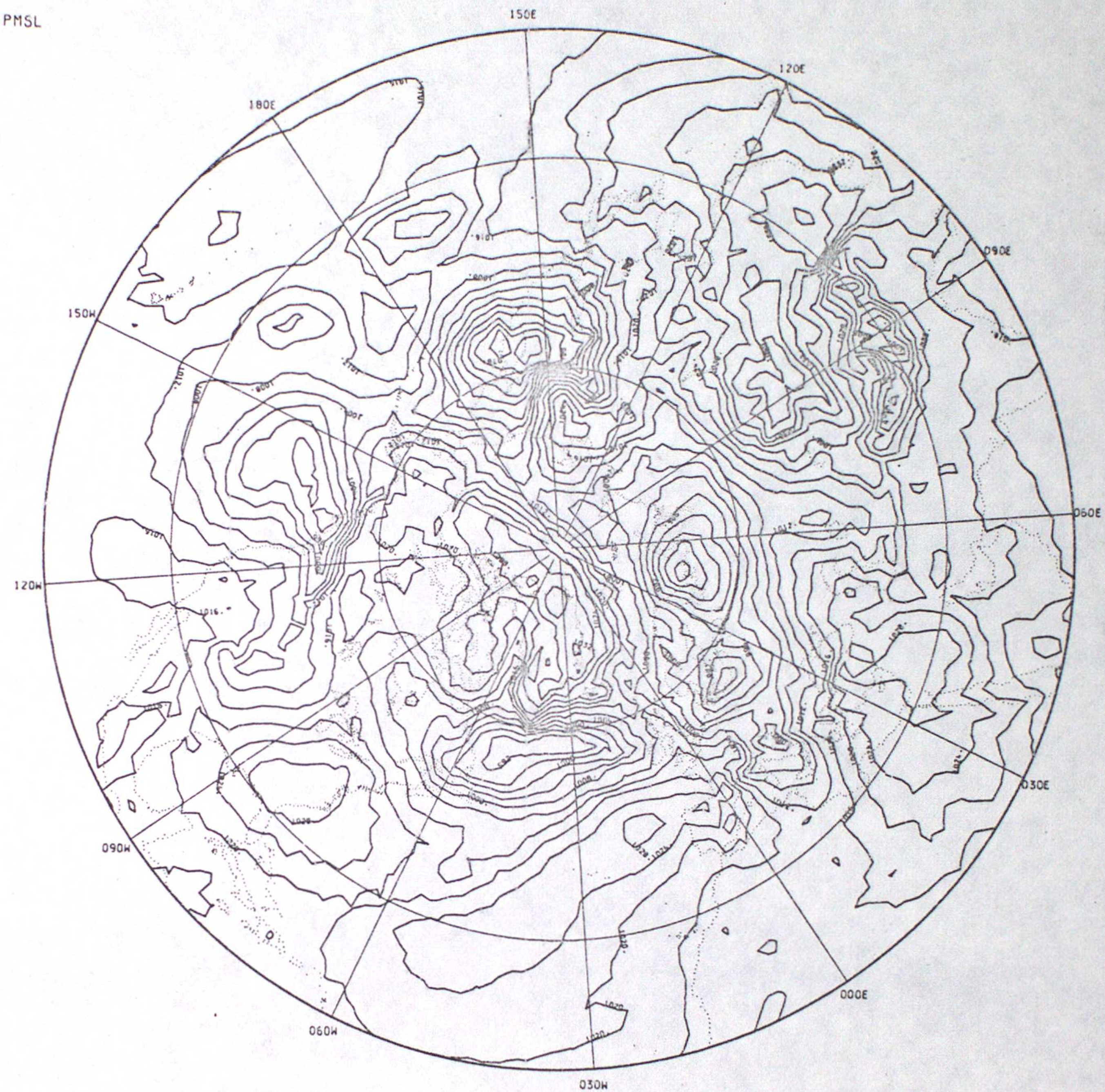

Figure 24.

CONTROL DAY5 PMSL

EXPERIMENT TIME = D005H00 PMSL
CONTOUR INTERVAL = 4.00 MB

1/1/78

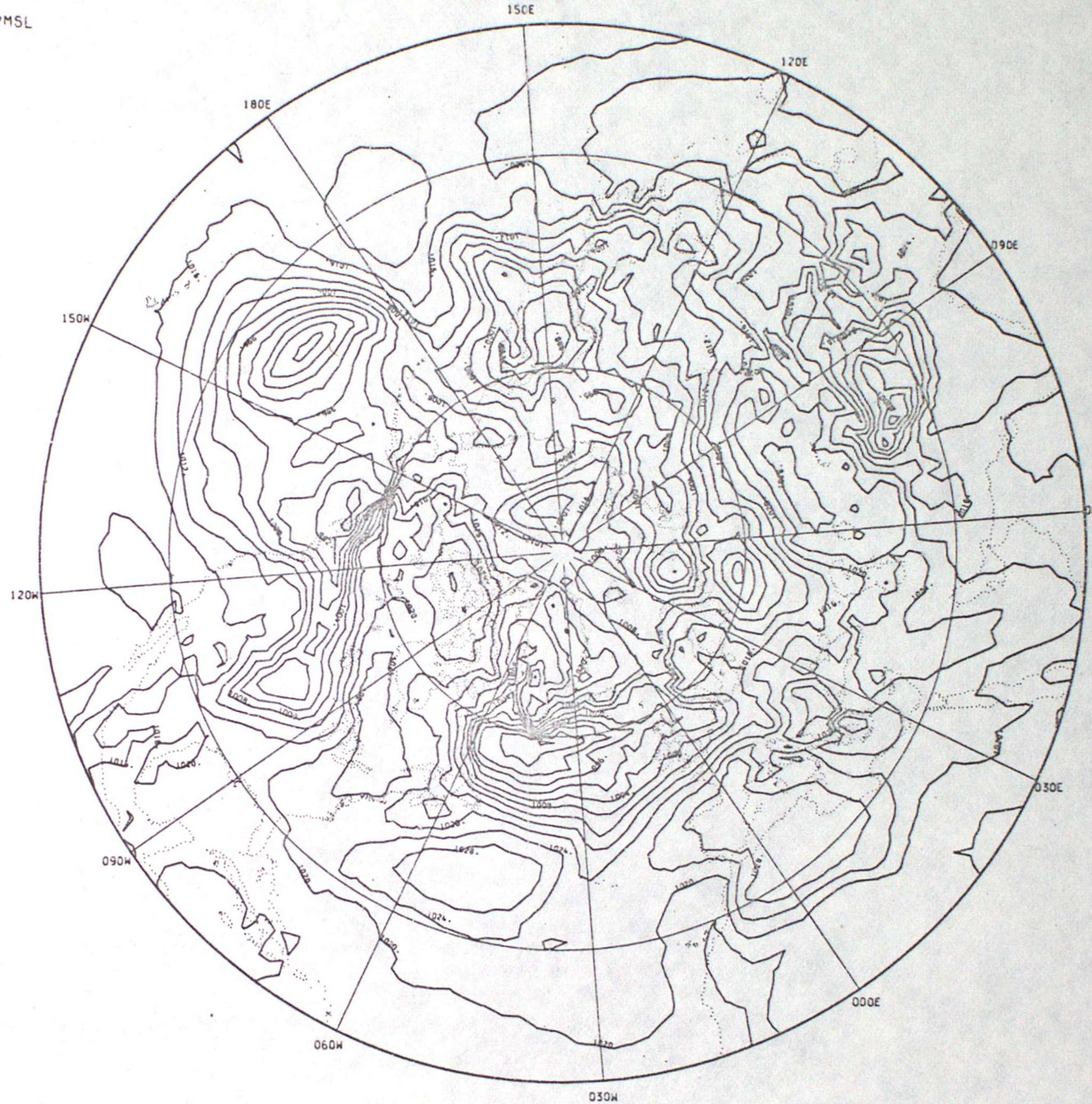

Figure. 25.