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LARGE SCALE CIRCULATION PATTERNS IN THE
HIGH STRATOSPHERE DURING THE 1974/75

MID-WINTER WARMING

by

N R WATSON

126479

Met O 19
(High Atmosphere Branch)
Meteorological Office
London Road
BRACKNELL
Berks RG12 2SZ

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"Large Scale Circulation patterns in the high stratosphere
during the 1974/75 mid winter warming"

Met O 19
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1. Introduction

During the Northern Hemisphere winter of 1974/75 a stratospheric warming occurred. It was a "minor" warming in the lower stratosphere because, although the zonal mean temperature gradient reversed, the westerly wind **did** not change to easterly, a condition which is conventionally used to define a "major" warming. Watson (1976) has discussed the synoptic changes that occurred in the lower stratosphere during the warming. This paper deals with the large scale synoptic events in the high stratosphere (10 - 1 mb) during the same period and describes the method used to construct synoptic charts at these levels.

2. Data sources

Daily synoptic analyses up to 10 mb can be achieved with radiosonde and occasional rocket sonde observations. For higher levels (5, 2, 1 mb etc) there are effectively no radiosonde observations available, and with only 20 meteorological rocket stations in the Northern Hemisphere, mainly over America, any analysed chart must rely on satellite observations. The radiance data used for these analyses were from channels B12, B23, B34 and A1 of the Selective Chopper Radiometer on the Nimbus 5 satellite. This data was received in the form of daily mean and point values extending from the equator to 80°N at intervals of 4° latitude grid 10° longitude. On most days there were areas of missing data but normally these areas were relatively small. Thickness values were derived from these radiances by a multichannel regression technique. The coefficients of which were based on the observations from 97 rocket sonde launches within the two month period. Full details of the analysis are given in a separate Branch Memo (Watson (1977)). The values of these regression coefficients are listed in Table 1 together with the standard error of the estimated thickness.

3. Construction of charts

Geopotential height fields at 1 mb were drawn at weekly intervals throughout the

two month period on polar stereographic maps. The days chosen for analysis were December 5, 12, 19, 26 in 1974 and January 2, 9, 16 and 23 of 1975.

The 1 mb charts were drawn by adding graphically (gridding) the 100-1 mb thickness to a base 100 mb field. The 100-1mb thickness field was calculated from the regression equations and drawn on polar stereographic charts. Smooth contour lines were drawn through any areas for which there was no satellite data. The radiances used were daily averages of individual satellite observations and hence the derived thickness chart was taken to be appropriate to 12Z. The Central Forecast Office's 100mb 12Z analyses were also drawn on the same scale maps and used as base charts for the gridding. The contour interval chosen was 96 dcm. This was sufficient to show all the large scale features, but it meant that tropical areas tended to be featureless. To these 1 mb charts were added all rocket sonde winds measured within 1 day of the analysis days. No modifications to the height fields were made because of these winds, apart from some adjustment to accommodate the strong NE wind at Volgograd (48N 40E) on 2 January 1975. The 100-10 mb and 5 - 0.5 mb thickness charts for the same days were constructed using the appropriate regression coefficients. This series of charts was used to assess the effect of the warming on the lower and upper stratosphere. CFO's 100mb charts were subtracted ('de gridded') from the Stratospheric Analysis Group's 10mb charts for the same days. This produced a hand-drawn 100-10mb thickness chart based on radio-sonde data which could be compared with the satellite derived series. Strict comparison could not be achieved because the degridded charts were for 00Z, whereas the others were for 12Z, but major differences could be identified and are discussed in section 5.

4. Synoptic changes

a) At 1 mb

In early December 1974, the 1 mb vortex lay close to the pole with a strong zonal flow in mid latitudes (see figure 1(a)). Within the next 14 days, the low drifted south to Greenland and then north east to Spitzbergen. As the high

over North Africa maintained its position, the westerly wind over the Atlantic and Europe increased considerably, with 260/283 kt being reported at 1 mb at West Geirinish on 13 December.

Between 19 and 26 December the first effects of the warming were seen when the two highs over Africa and the Pacific, amalgamated to produce an elongated high from China westwards to Asia Minor. This high then moved northwards during the next 7 days and displaced the vortex southwards to Iceland. The vortex's central height increased by about 2 km during this time. Even so strong easterly winds at 1 mb were recorded at Heiss Island ($80^{\circ}\text{N } 60^{\circ}\text{E}$) and Fort Churchill ($59^{\circ}\text{N } 94^{\circ}\text{W}$). The north east wind at Volgograd must be interpreted as being caused by a south-westwards ridging of the high over western Russia. The warming was at a maximum on 2 January, when the high was at its most northerly position. During the next week the high declined and returned to near its position on 26 December while the vortex, still filling, moved eastwards to Sweden.

After 9 January, the vortex deepened and moved back towards the pole and by 23 January the conditions of early December had been re-established, but with a slightly weaker vortex centre.

Because of the gridding process, exact evaluation of winds from the contours is impracticable. However, the 1 mb rocket winds that have been added to the charts are in fairly good agreement with the contour spacing; the accuracy of the analyses is discussed in Section 5.

Inspection of these charts indicates that there probably existed a mean ^seasterly flow near the pole during the first week of 1975. Thus at 1 mb the criteria ^{on} for a major warming was achieved.

b) Upper & lower Stratospheric Temperature Changes

The 5-0,5 mb thickness fields were constructed for the same dates using the multi-

channel regression coefficients in Table 2, and these charts are shown in Figure 2 (a)-(h).

In the period before the warming the coldest air (lowest thickness) lay over the Canadian arctic with an increasingly strong baroclinic zone over the United States and Atlantic. By 19 December the thickness gradient over Newfoundland was about 190 dam per 10° latitude, which corresponds to a thermal wind of 320 kt. This gradient was caused both by the cold pool over Hudson Bay and by the warm air over the central N Atlantic. By 26 December 1974 this warm air had moved east-north-east to Central Asia and had increased in temperature still further. At the height of the warming the warmest air was at $80^\circ\text{N } 45^\circ\text{E}$, with an 1870 dam thickness at the North Pole. Within a week that thickness had fallen to 1660 dam as the cold air moved north over Canada and the warm air moved south to the Black Sea. By 23 January, the cold air was again dominating the pole with the strongest thermal winds in mid-latitudes.

In contrast to the upper stratosphere, the 100-10mb thickness (Figures 3(a) - (h)) showed considerably less movement of warm and cold area. The warmest air stayed over the Alaska/Kamchatka area whilst the coldest air was over the Scandinavian region. The greatest thermal contrast occurred on 19 December 1974 with a 140 kt North westerly thermal wind over the Canadian arctic. The thermal contrast started to weaken after the 9 January; (ie later than the upper stratosphere) and towards the end of the month little remained. The movement of the 5-0.5 and 100-10 mb warm areas can be seen in Figure 4.

The average temperature changes throughout most the stratosphere can be seen by inspection of the 100-1 mb thickness fields (Figure 5(a)-(h)). Early in December the stratosphere was cold at the pole with well established westerly thermal winds down to 40°N . The North pole's 100-1mb thickness is about 2770 dam, which is equivalent to a mean temperature within that layer of -68°C .

After 19 December the warm areas over the Mediterranean and Pacific amalgamated over China and then moved northwards until the whole of the Russian Arctic and

Alaska became warm. The coldest area meanwhile had also warmed by about 15°C and had drifted south to the North Atlantic. Between 26 December and 2 January the 100-mb thickness at the pole increased by $4\frac{1}{2}$ km which is equivalent to an average temperature increase of about 33°C . From 2 January the warmest area cooled as it continued to move to a position over the Canadian arctic while the coldest air swung eastwards to Scandinavia. By 9 January, the thermal contrast across the northern hemisphere was at a minimum (Fig 5f). The last sign of the warming can be seen on 16 January as a ridge over the Davis Strait, but by 23 January the cold area had re-established itself over the Canadian arctic with strong thermal winds in mid latitudes.

c) Effect of the Warming at Individual Rocket Stations

Temperature/time plots were constructed for the following rocket stations: West Geirinish, Wallops Is, Heiss Is and Fort Churchill. These are shown in Figure 6a, b, c, d.

West Geirinish's temperatures during the period show the stratopause descending from above 60 km on December 8 - 44 km on December 14, with a very cold temperature (-80°C) at about 25 km (20 mb). The steep temperature inversion between 25 and 45 km is a feature of the strong baroclinic zones that lay across the UK at this time (Fig 2b). Later, in January, the stratopause rose again to about the 55 km level.

The Wallops Island temperature shows little of interest as the warming tended to be some distance away from this station. The stratopause was well marked in January, at about 45 km and with temperatures exceeding 0°C during the last week of the month.

The Heiss Island temperatures show how extreme the variations can be at any one level when a centre of a warming passes near to a rocket station. The Stratopause, at the beginning of December, was above 60 km, and during December came down irregularly until, by 4 January, it was at only 36 km ($+18^{\circ}\text{C}$). The temperature at 36 km increased by 66°C in 12 days. The temperature profiles show the typical

-5-

sequence during warmings or a descending, warming stratopause with a strong lapse rate under the stratopause, followed by an almost isothermal stratosphere (22.1.75).

Fort Churchill also shows a similar sequence in its temperature profiles during the period but with a reduced amplitude. The "isothermal" stratosphere in mid-January can be clearly seen.

d. Radiance Analysis

In addition to the daily gridded radiances, the Oxford data contained zonal means and standard deviations of radiances, and also the amplitude and phase (longitude of maximum) of the radiance wave in the first 3 wave numbers.

In Figure 7 is plotted the change of the zonal means of the B12 radiance (weighting function centred at 2 mb) at 80°N , 60°N and the equator together with the B34 and A1 radiance means at 80°N . The dramatic rise in the radiances over the polar cap can be seen from 25 December 1974 to 2 January 1975, corresponding to an increase of over 30°C in the average temperature between about 5 and 0.5 mb. The increase in radiance values for channels B12, B34 and A1 at 80°N starts at about the same time, whereas the rise starts about 5 days earlier at 60°N indicating the northward progression of the warming. The corresponding decrease in the equatorial radiances during the polar warming can be clearly seen. Figure 8 shows the changes during the two months of the latitudinal variation of the B12 zonal means. The radiances stay approximately constant at 40°N and warmings (coolings) to the north are associated with coolings (warmings) to the south. The zonal mean radiances ranged from 47 to 90 RU at 80°N and from 71 to 79 RU in the Tropics.

Figure 9 shows the amplitude of the radiance wave in wave number 1 for channels B12, B23 and B34 throughout the period.

The amplitude increases first at mid latitudes and extends northwards with a speed of about 8° of latitude day^{-1} in the last few days of 1974. Figure 10 shows a

vertical section of WN1 amplitude at 60°N for the two months. The amplitude increases at high levels (B12) starts about 18 December and progresses downwards but the maxima appear at the same time (29 December) at all levels. This was caused by the rapid increase in the amplitude at WN1 observed in the B34 channel between 22 and 28 December.

The amplitude and phase (longitude of the maximum) of wavenumbers 1-3 for the B12 channel at 60°N are shown in Figure 11. The phase for WN1 stays between 20° and 90°E during the period while WN2 phase shows a steady eastward motion averaging about 8° longitude per day. The maximum rise in the amplitude of WN1 occurs when the WN2 wave approaches the standing wave (WN1) to the east of Greenwich.

The amplitude/time section shows how dominant was the wave number 1 amplitude in comparison with WN2 and 3. During late December the amplitude of WN1 was an order of magnitude greater than the amplitudes of WN2 and 3.

The phases of 3 channels for WN1 are plotted in figure 12 for two days, one before and one after the warming. On 26 December 1974, before the warming, the westerly tilt of the maximum temperature with height is apparent as is the SW to NE variation with latitude of the maximum for a given channel. On 9 January 1975 however, the latitudinal variation of the maximum exhibits a SE to NW pattern. The westerly tilt with height is maintained although at high latitudes the phases of channels B12 and B23 are almost coincident.

5. Analysis Errors

The **Statospheric** Analysis Group's 10 mb charts have been 'degridded' with CFO's 100 mb charts to produce a series of 100-10 mb 'handrawn' thickness charts which could be compared with the satellite derived ones (Fig 3). In general the differences between the two series are less than 48 dam apart from the period during the height of the warming when differences of up to 60 dam occurred (Fig 13) over NE Russia.

Aanensen (1973) computed 10 mb stratospheric heights from satellite data and compared them with radio-sonde (handrawn) charts. The mean difference chart he produced, for a period during a warming in February 1972, shows a very similar pattern to Figure 13. In both cases the maximum difference is centered near Novaya Zemlya, with the satellite heights or thicknesses greater than the handrawn.

In the present paper, some of the difference (estimated at about 20 dam) is caused by the time difference between the charts. Also the handrawn charts use Hawson corrections which are designed to make the various radio sonde systems compatible with the British sonde. In effect geopotential heights reported by Russian sondes are reduced at 100 mb by a fixed amount and by a greater amount at 10 mb. The result is that the 100-10 mb analysed thickness over Russia will be about 5-10 dam lower than the observed values. The remaining error is probably caused by the anomalous temperature structure present at that time. Over Heiss Island ($80^{\circ}\text{N } 60^{\circ}\text{E}$) on 2 January 1975, there existed a very warm layer between 30 and 45 km (Figure 6c). It is likely that an abnormally large proportion of the radiance measured in the Al channel originated at levels above 10 mb. As the 100-10 mb thickness is highly correlated with the Al channel radiances (see Table 1), this could lead to the 100-10 mb satellite derived thickness being anomalously high. Whenever the temperature structure is substantially different from the mean, significant errors in derived thicknesses will occur using linear regression techniques.

In the upper stratosphere, the accuracy of the 1 mb charts depends on the errors in the base 100 mb field and the 100-1 mb thickness. Because of the density of radio sonde data at 100 mb, the 100 mb errors are likely to be small over most of the northern hemisphere and negligible in comparison with the 100-1 mb thickness errors. The standard error of estimate for this thickness was 21.3 dam. That is the standard deviation of the differences between the actual rocket sonde thickness and the regressed value for 97 observations. Further errors will be incurred when the thickness values are transposed to the maps and the gridding process itself introduces errors, which are difficult to estimate. Overall, a pessimistic value

for the standard deviation from the 'truth' for the 1 mb heights would be 35 dam. This incorporates the random and bias errors of the height of the referenced level (ie 50 mb) for the rocket sonde.

The UAB (for their latest charts) used a single channel regression method involving some VTPR channels on NOAA 2 and 3 and the SCR channels on Nimbus 5 to deduce 100-5, 100-2 and 10-0,4 mb thicknesses (Quiroz and Gelman 1972). Presumably adjustments will be made to their regression coefficients to allow for changes in performance in the SCR in producing later charts (Watson 1977)

In the present paper the rocket sonde data which is used to compute the regression coefficients cover the same period as the analyses. This is inherently better than computing regression equations with data obtained before the analysis period. The effect of any deterioration in satellite instrument performance will be minimised. It may be possible to use this approach in future analysis work, but it is more likely that regression equations will be calculated from observations over a given period and then used for a further period, the length of which will depend on the stability of the satellite instrument. Aanensen (1973) in a similar study of parts of the 1972 winter, derived statistics of the differences between rocket sonde and chart winds. Such quantitative analyses have not been attempted here because the emphasis has been on the production of charts to show the large scale feature of the circulation. However it is obviously something that should be studied further.

In this trial, all rocket sonde observations were treated equally, ie no adjustments were made to the (relatively few) Russian observations. However there are temperature incompatibilities at high levels between Russian and American Data sondes (Finger et al 1975). Failure to apply these corrections, has probably increased the standard error of estimate and has reduced the thicknesses slightly. Any future analysis scheme, using regression techniques, should correct rocket sonde data, using the latest available figures, before that data is used in the

regression procedure.

As stated previously, the rocketsonde winds that were added to the charts were not used to amend the height fields but to assess the regression method. In general the winds are in good agreement with regards to direction but speeds are sometimes considerably in error. This is partly due to the asynoptic nature of the rocketsonde winds and to the time averaging of the radiance data which will tend to suppress strong geopotential gradients, especially if the spatial gradients are moving. However when strong gradients exist for several days at a given location their effects should be unimportant. Thus it is found that over the British Isles on 12 December, the 1mb geostrophic winds of the order of 300 kt is in good agreement with that measured at West Geirinish. It is unlikely that rocket sonde winds **could** be incorporated into any operational analysis scheme because of the delay in the receipt of ROCOB messages, but the winds would be vital for verification of satellite derived height fields at a later date. For meteorologically significant periods, a very careful analysis using the satellite derived height fields plus all ROCOBS would be required. At first it may be very difficult to establish the "weighting" to give to rocket sonde data, if objective analysis are to be used. More likely a certain amount of subjective assessment will be required.

It has not been possible to study any diurnal variations in height fields because of the time averaging of the satellite data. Being mid winter, there would have been little diurnal change over the solar regions, but over the sub tropical areas, the variation (if any), of the diurnal wave during a warming would have been worth investigating. With the arrival of SSU data different time means can be chosen to reveal diurnal variations. For example, taking separate radiance means over the periods of 0-12Z and 12-24Z would show about $\frac{2}{3}$ of the wave amplitude but this will not be feasible until both of the planned TIROS-N satellites are operating. It will be necessary to know precisely any differences in performance between the SSU's in the two spacecraft. At low latitudes the coverage provided by a single SSU will be incomplete and the analysis will probably need to be done on a larger **spatial** scale. This difficulty will not be completely overcome by the case of two satellites.

7. Conclusions

The mid winter stratospheric warming of 1974/75 started in the second half of December, when a warm area developed over the Atlantic between 5 and 1mb. This warm area moved East and later northwards and reached a position near the pole on 2 January 1975. A temperature gradient and circulation reversal took place above about 5 mb during the first week of January and so, in the upper stratosphere alone, a major warming took place. Points of interest during the warming were the large temperature and geopotential height rises that occurred at specific points. Near the Pole at 1mb, height rises of $4\frac{1}{2}$ km and temperature increases of 33°C in the 100-1mb layer within 7 days were observed.

It has been confirmed that, by using a multi channel regression-technique to compute thicknesses of layers within the stratosphere from satellite radiance data, that the large scale features of the stratosphere can be well represented during its more dynamic periods.

Acknowledgements

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I S Cook, K R Rich and B L Mudd provided assistance with the programming.

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BM No 40

TABLE 1

Regression Coefficients

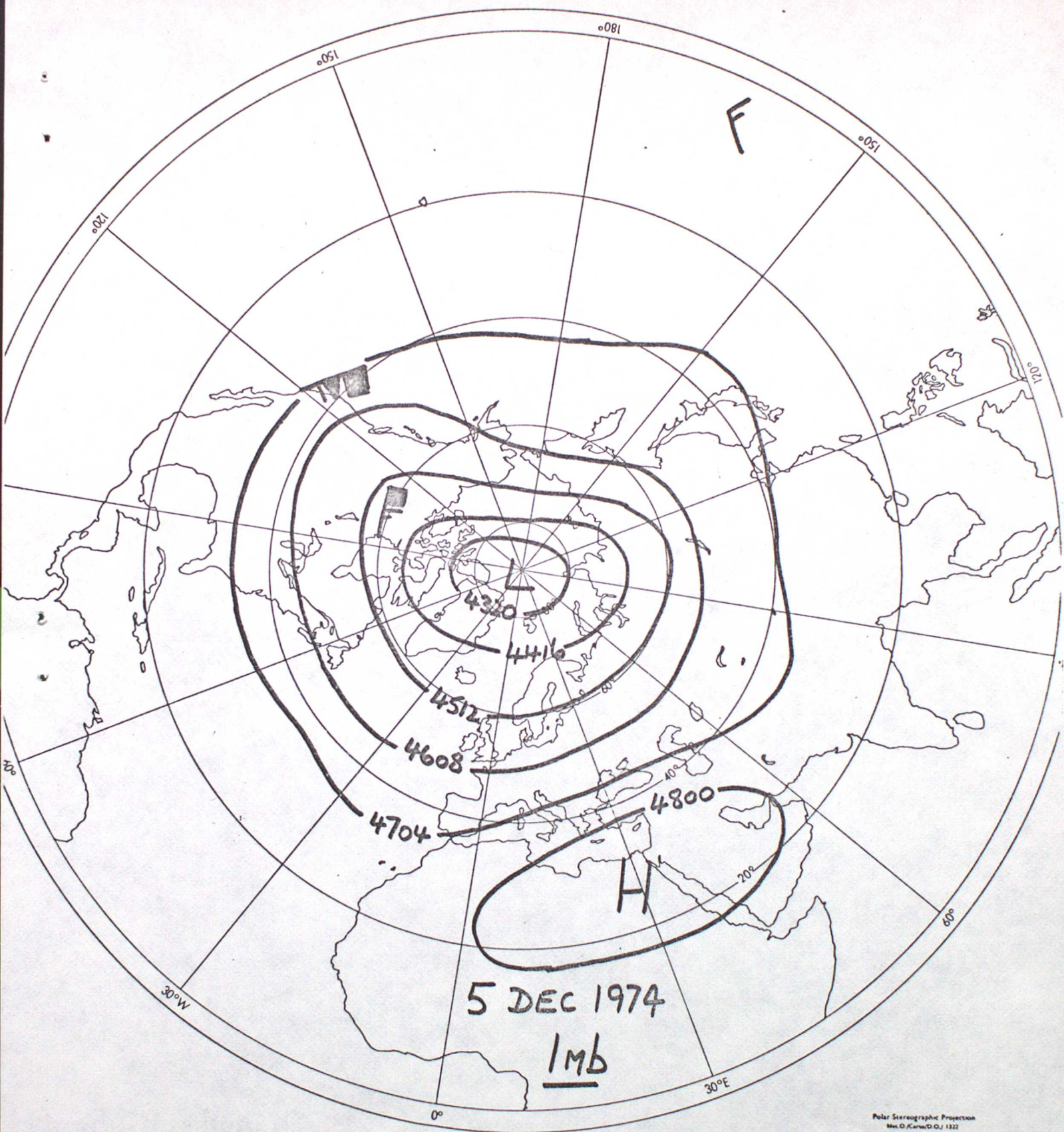
Channel	B12	B23	B34	A1	SE of
Wavenumber () cm^{-1}	668	668	668	669	estimate
Thickness	01	02	03	04	05 (dam)
100-10	-1.6899	0	-1.8798	10.6599	-76.1 10.1
100- 1	0	4.9061	0	11.5567	-667.8 21.3
5-0.5	6.2537	2.6971	0	0	-477.8 21.3

$$\text{Thickness} = {}^0_1 T_{12} + {}^0_2 T_{23} + {}^0_3 T_{34} + {}^0_4 T_A + {}^0_5$$

where $T =$ _____ and R is radiance in RU ($\text{MW m}^{-2} \text{ster}^{-1} (\text{cm}^{-1})^{-1}$)

$$= 1.19094 \times 10^{-5} \quad 3$$

$$= 1.43879$$



Polar Stereographic Projection
 Map O.K. 1222

KEY
 // DAY BEFORE ANALYSIS DAY
 x // " AFTER " "
 100 KT

HEIGHT INTERVAL 96 dam

FIG 1A

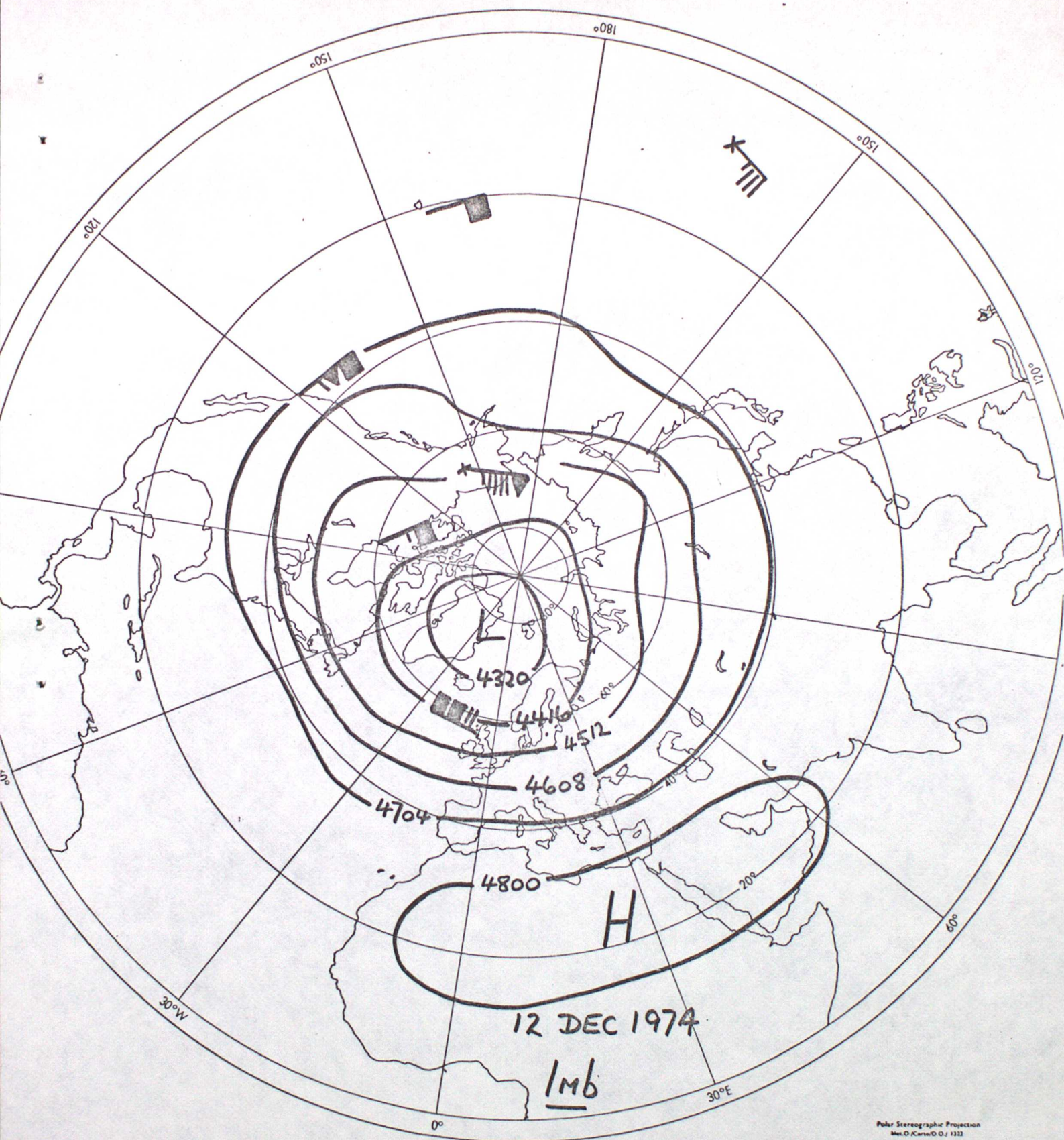


FIG 1B

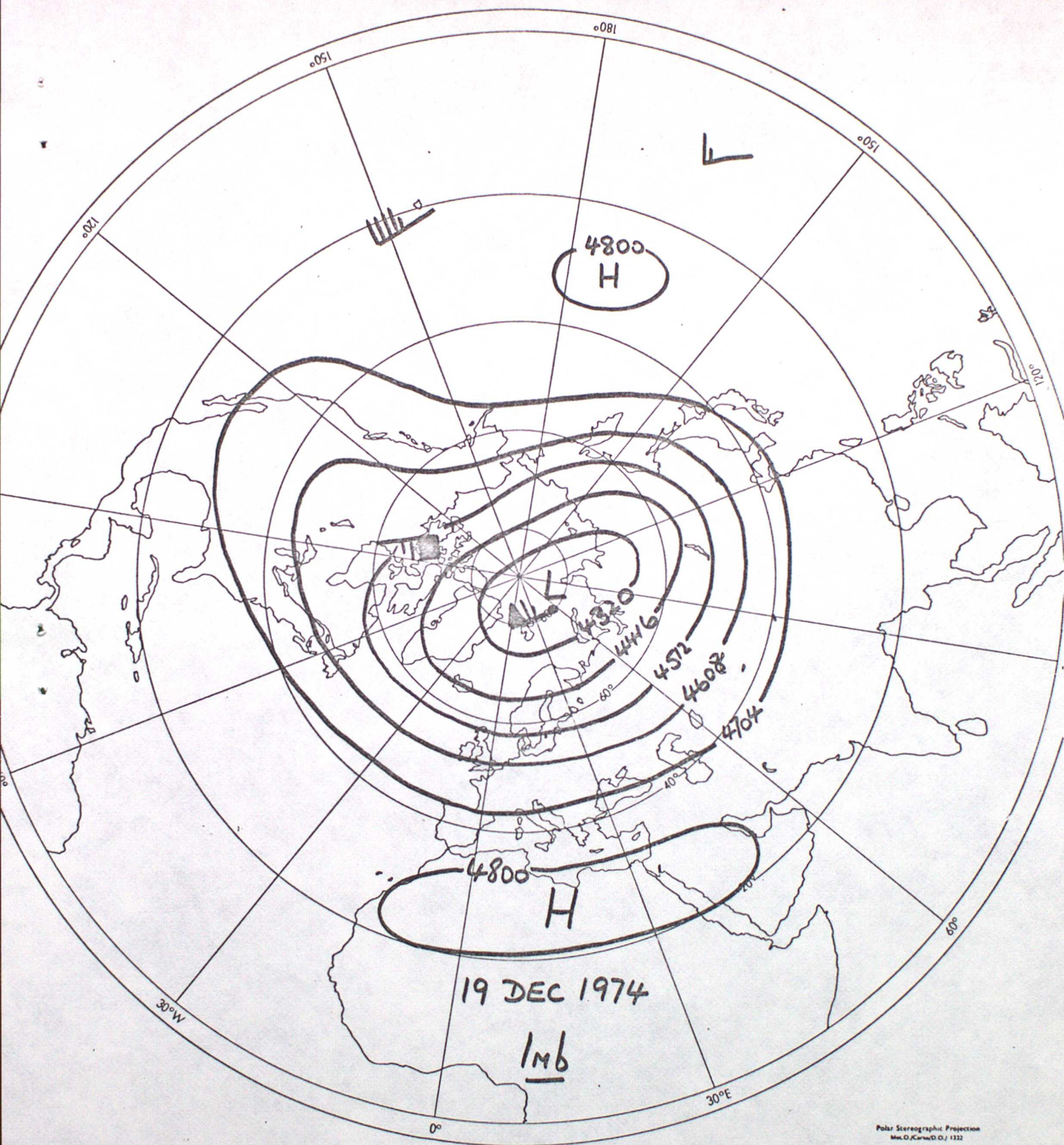


FIG 1c

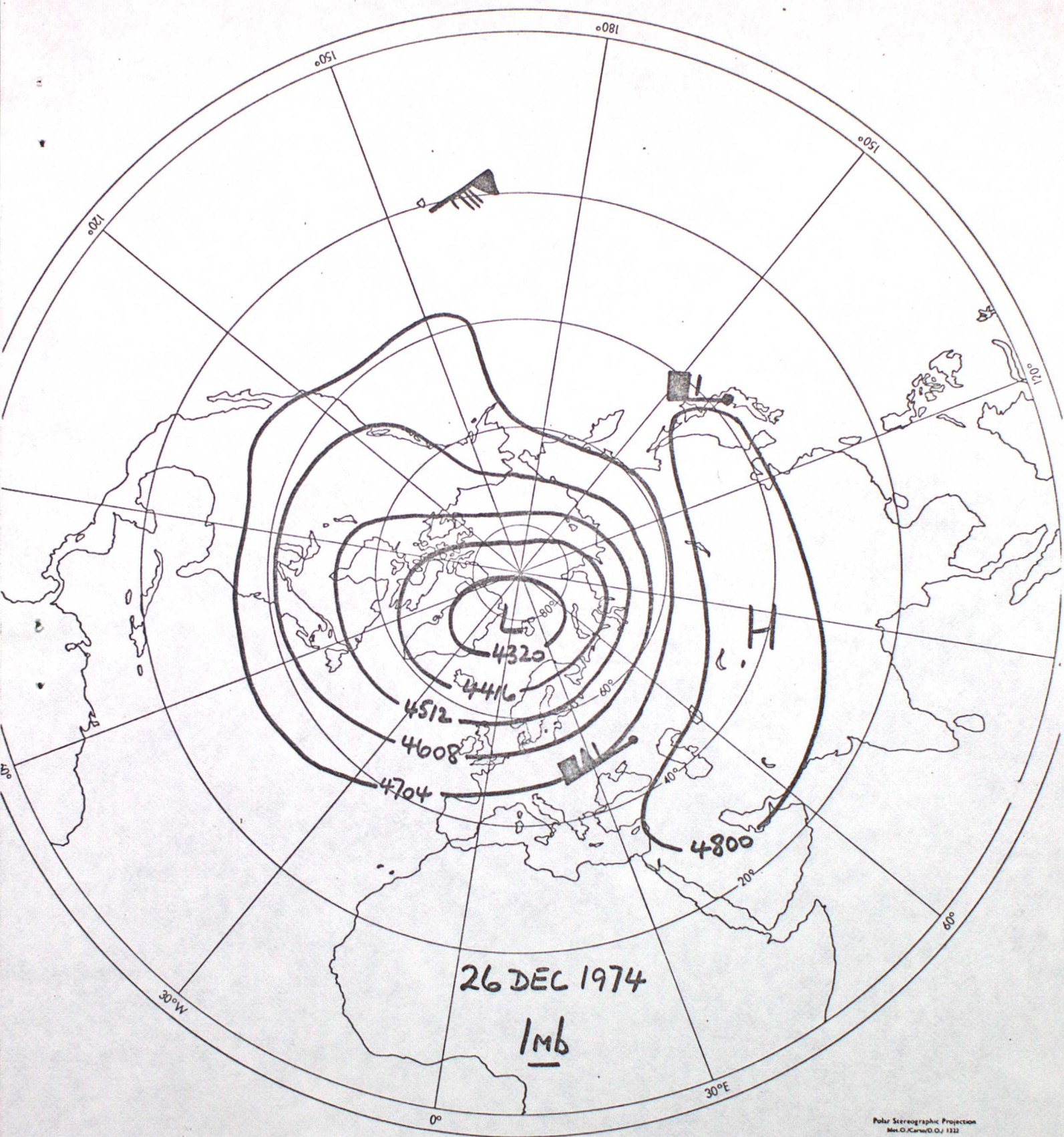


FIG 1D

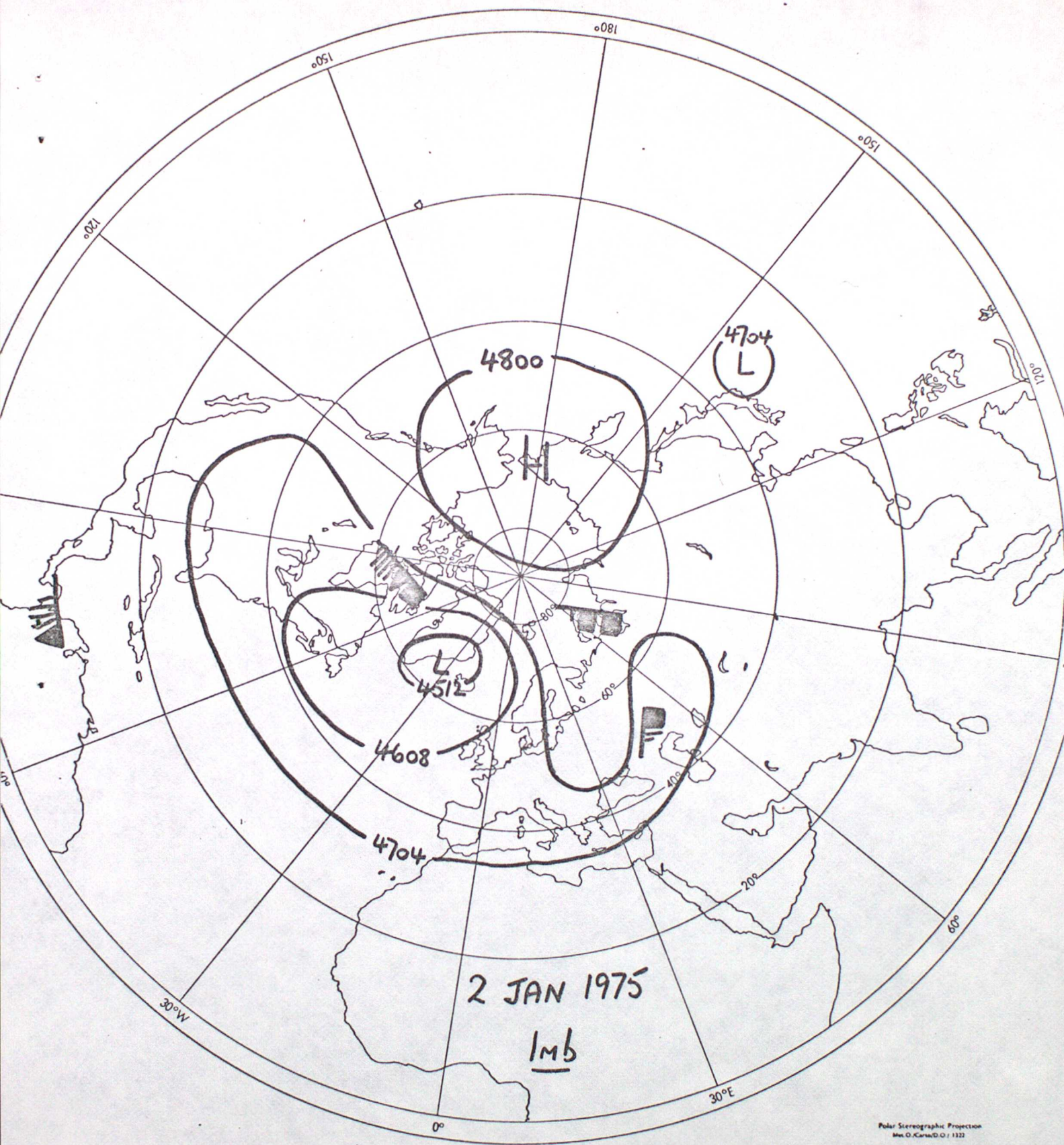


FIG 1E

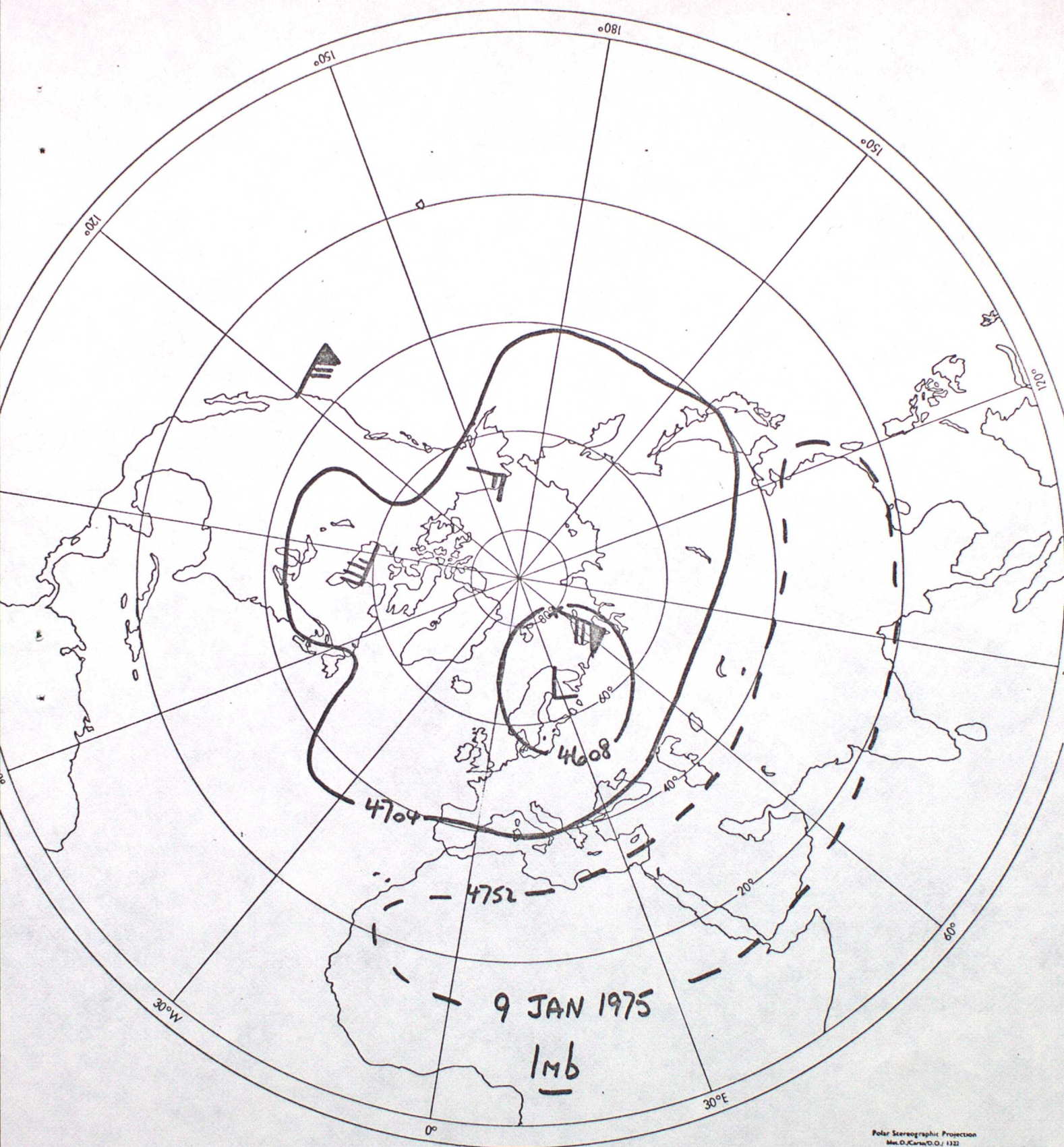


FIG 1 F

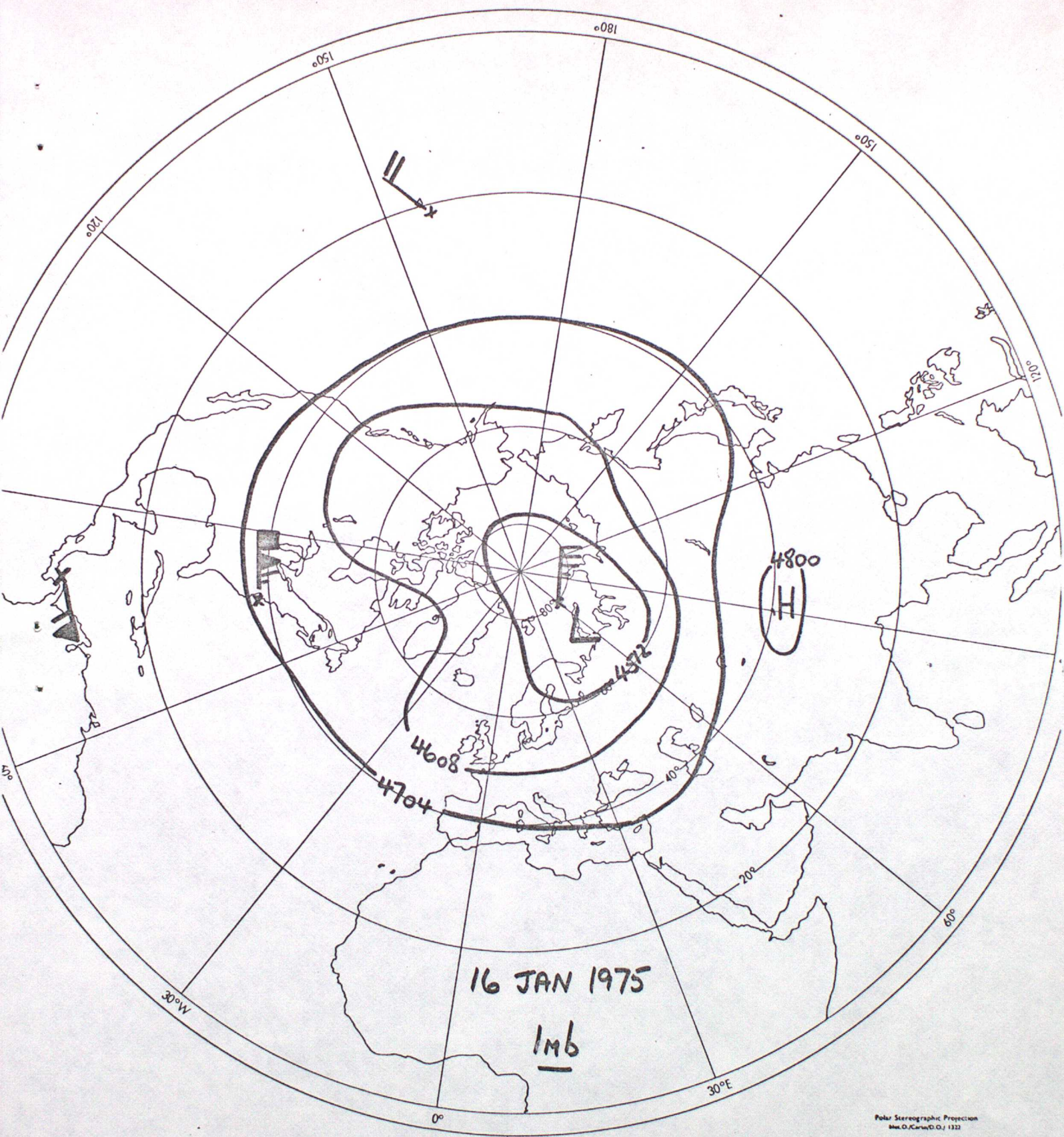
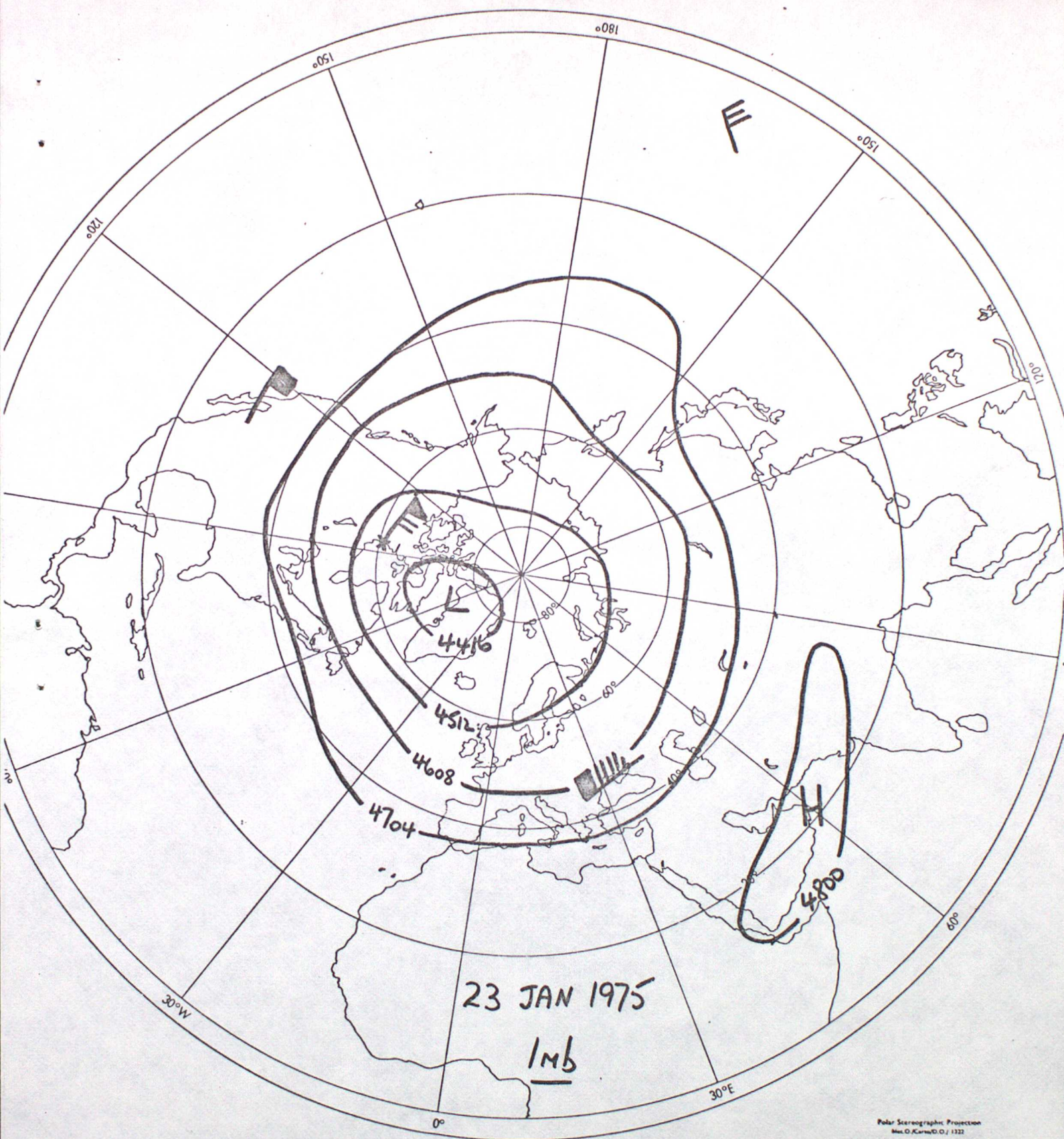


Fig 1G



Polar Stereographic Projection
Map O.K. 100/10/1322

FIG 1H

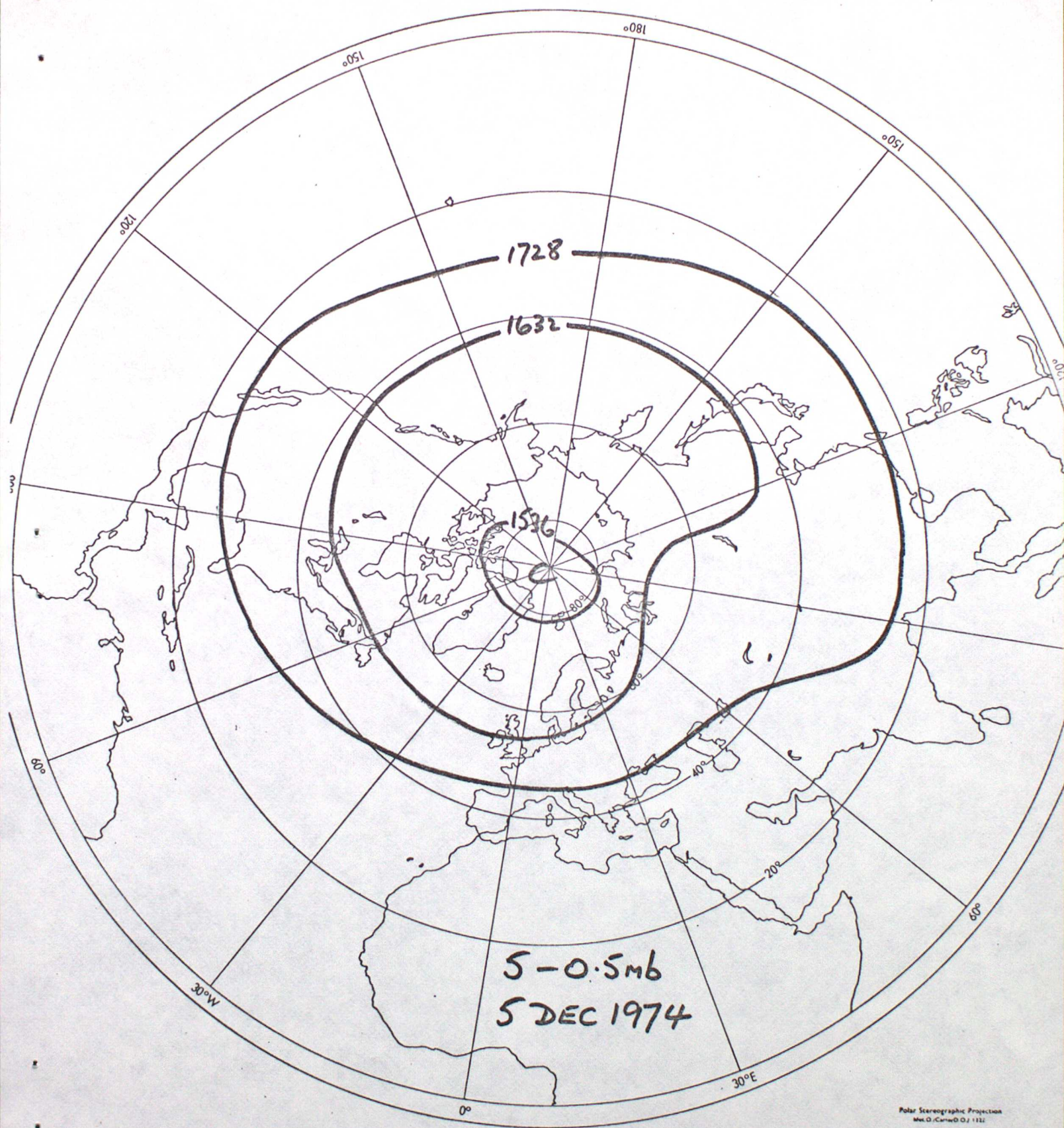
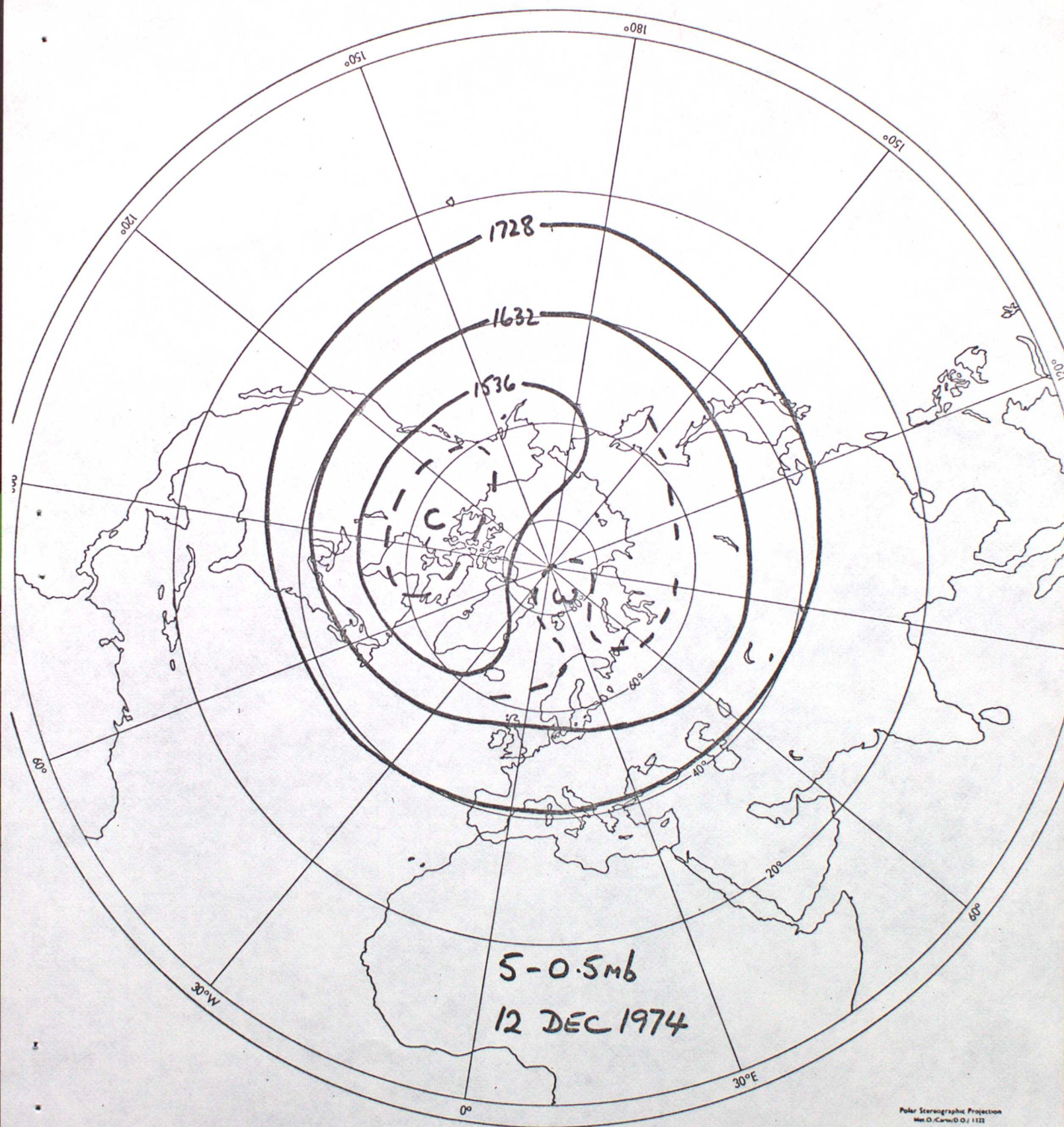


FIG 2A



Polar Stereographic Projection
Mer. O. Caron O. O. / 1122

Fig 2B

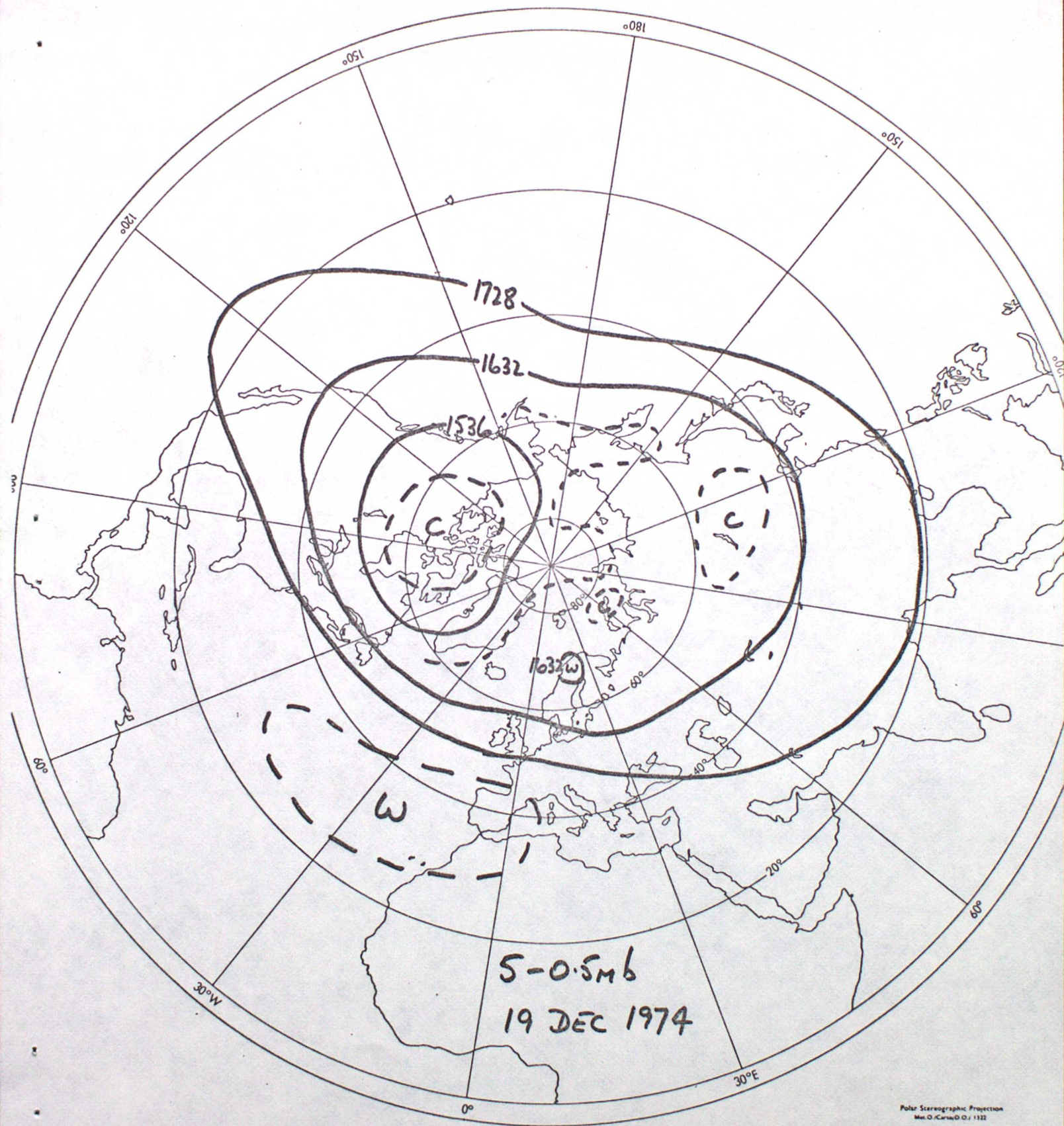


Fig 2c

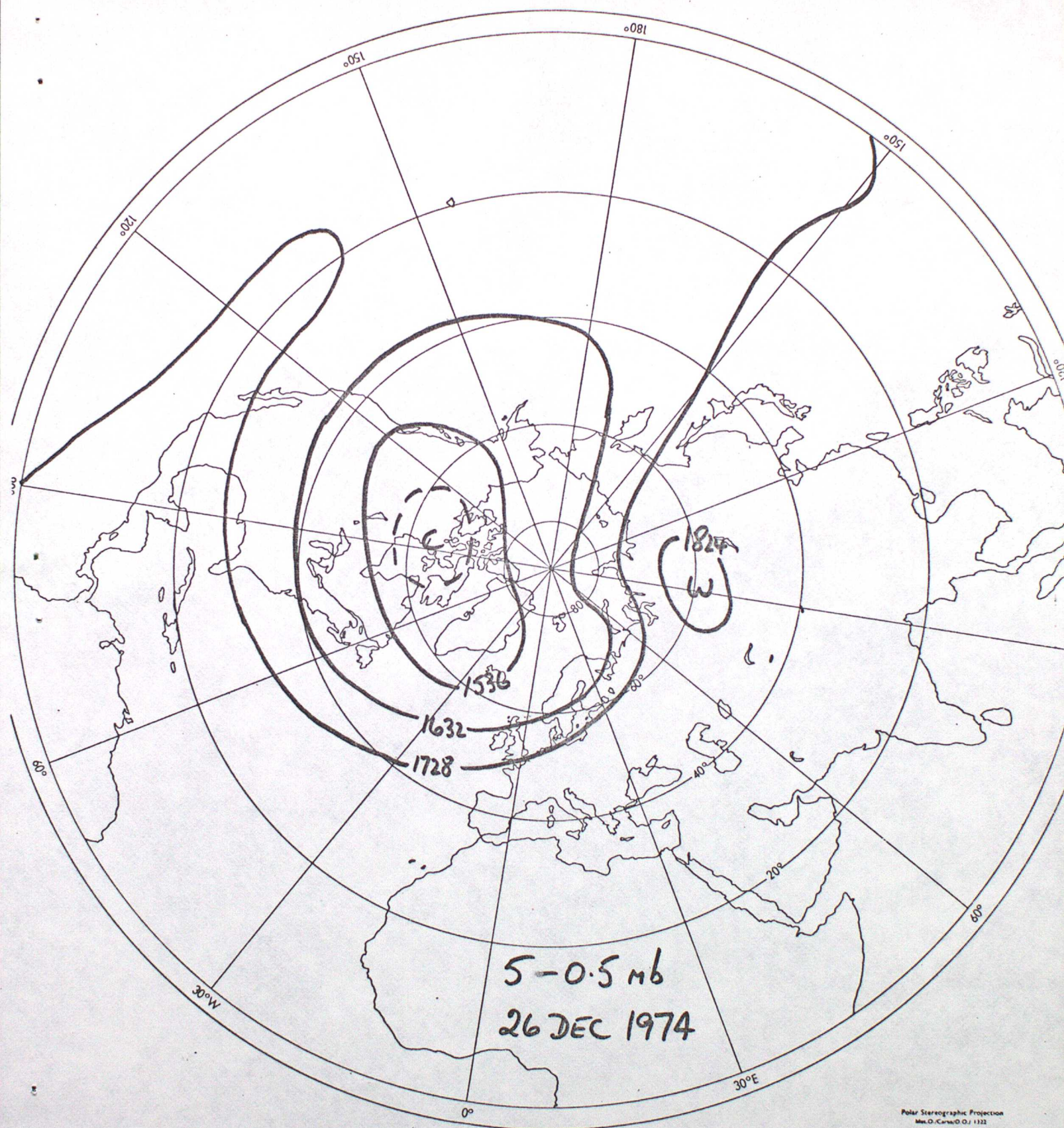


FIG 2D

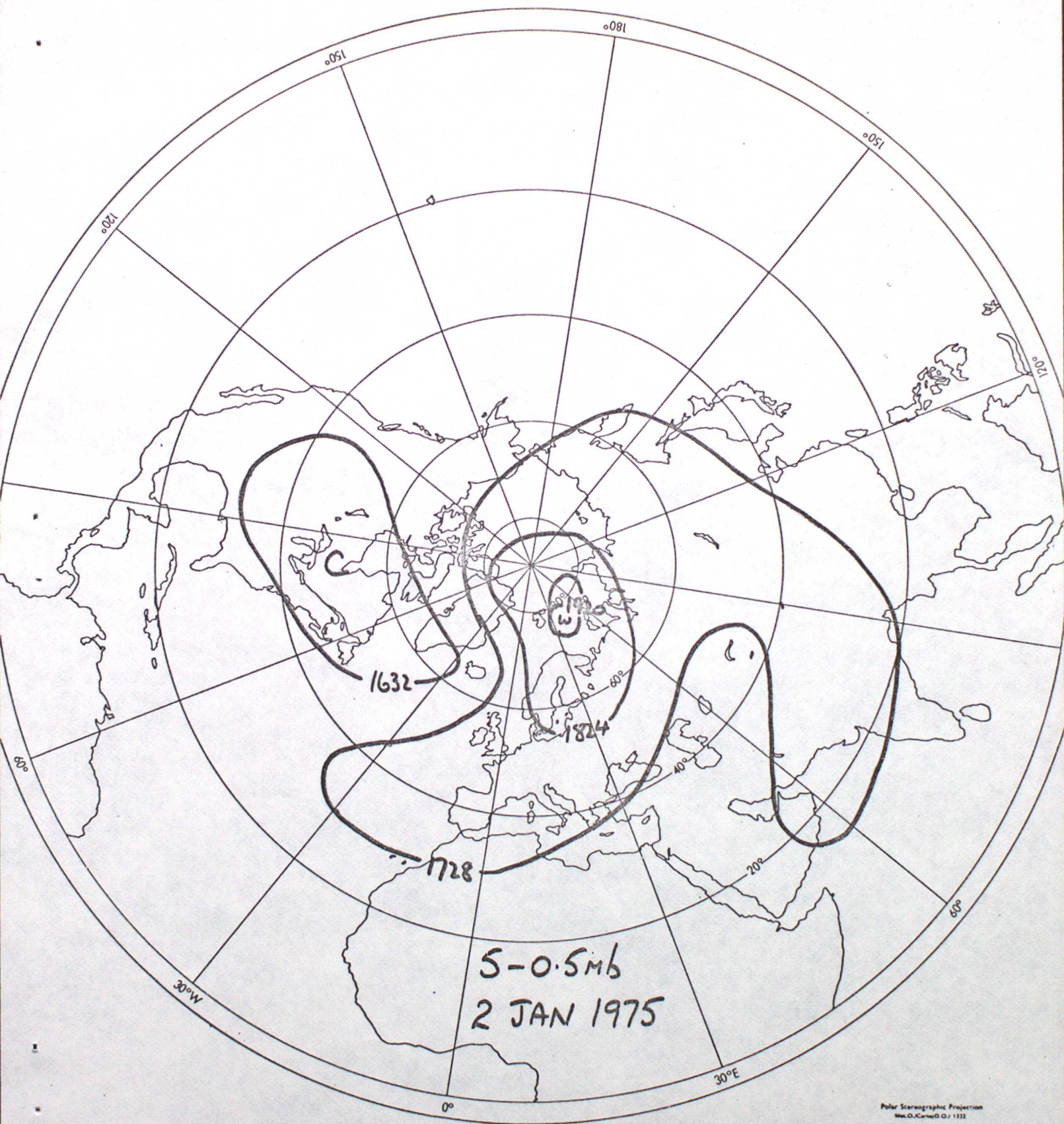
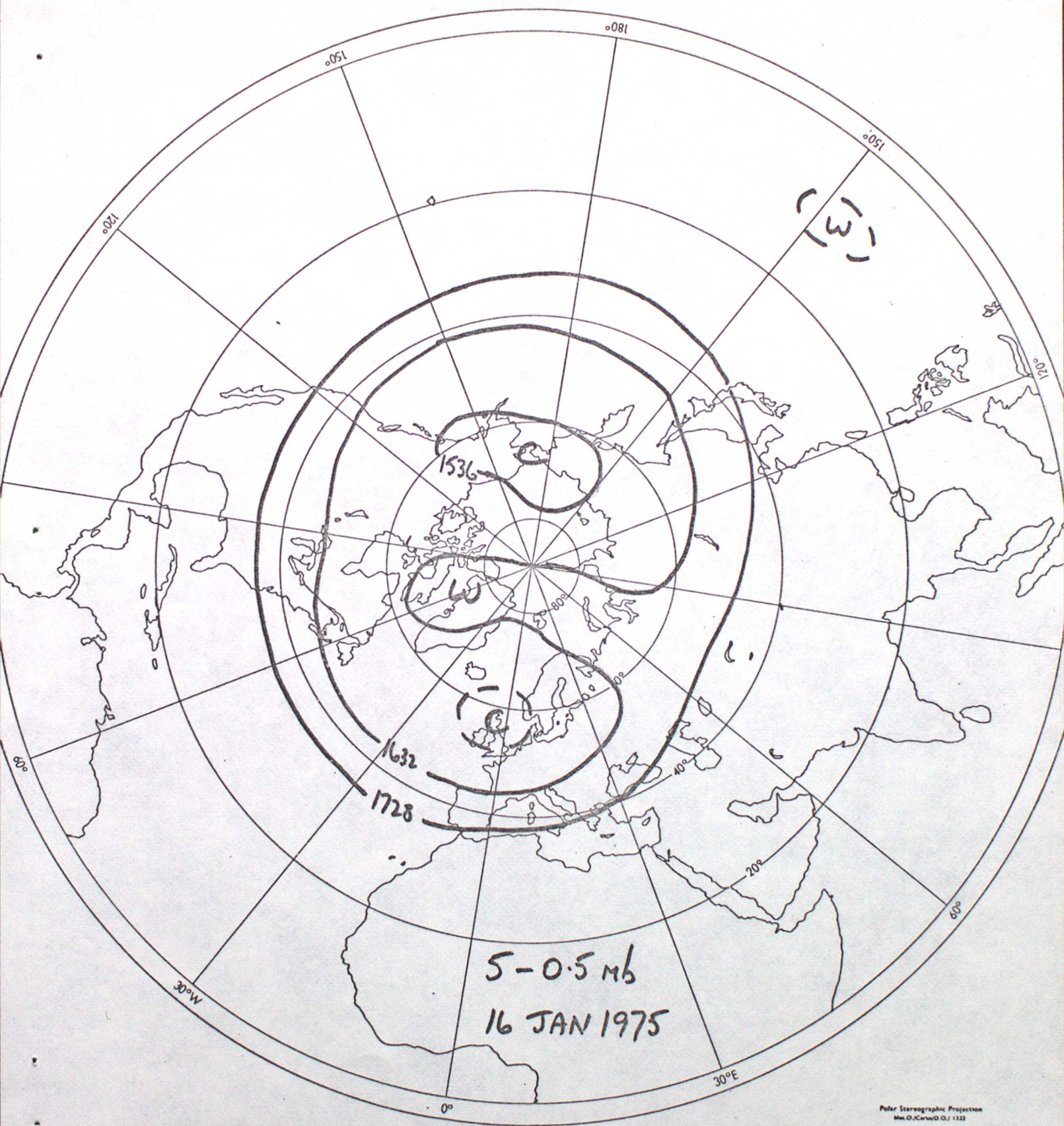
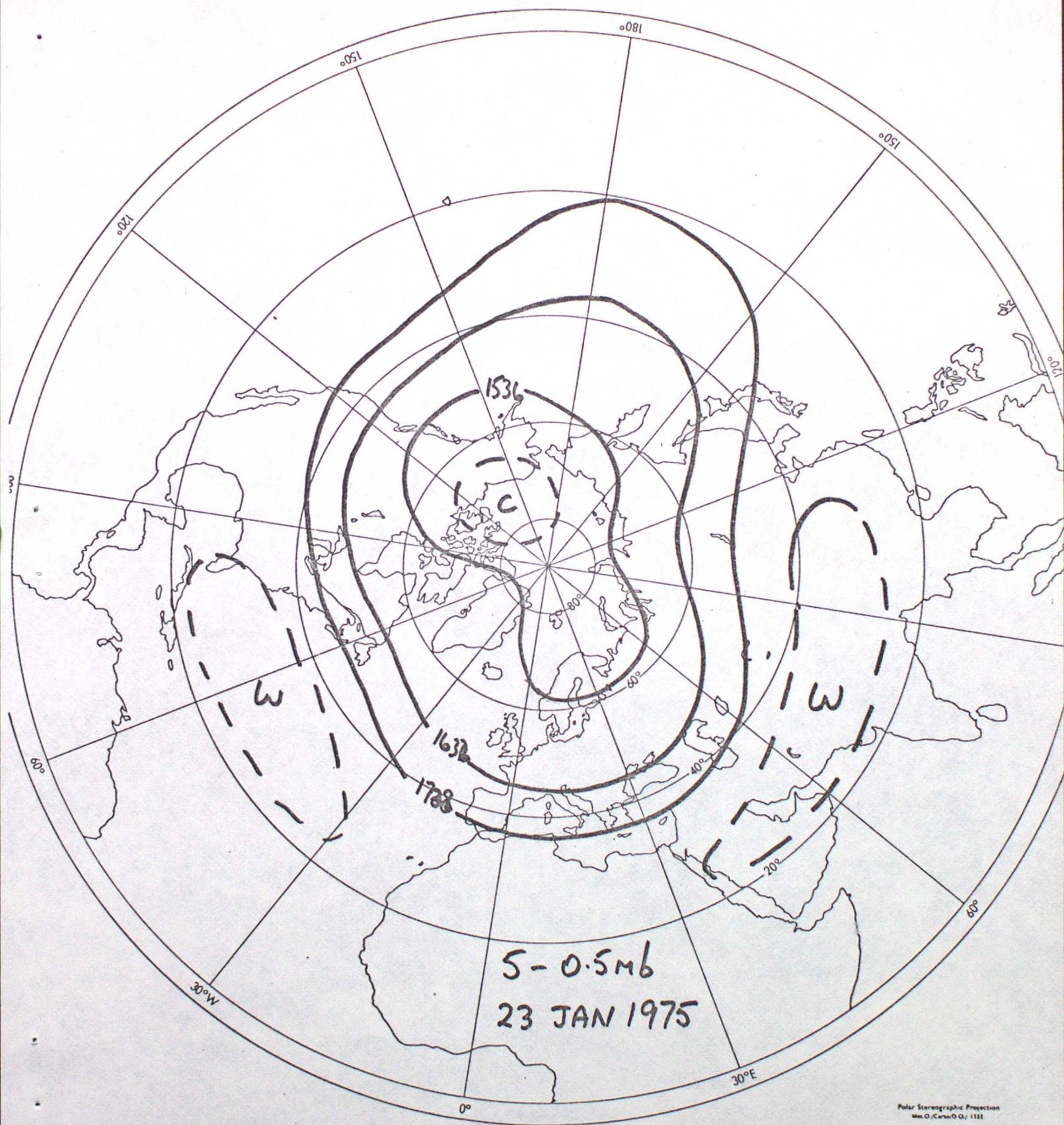


Fig 2E



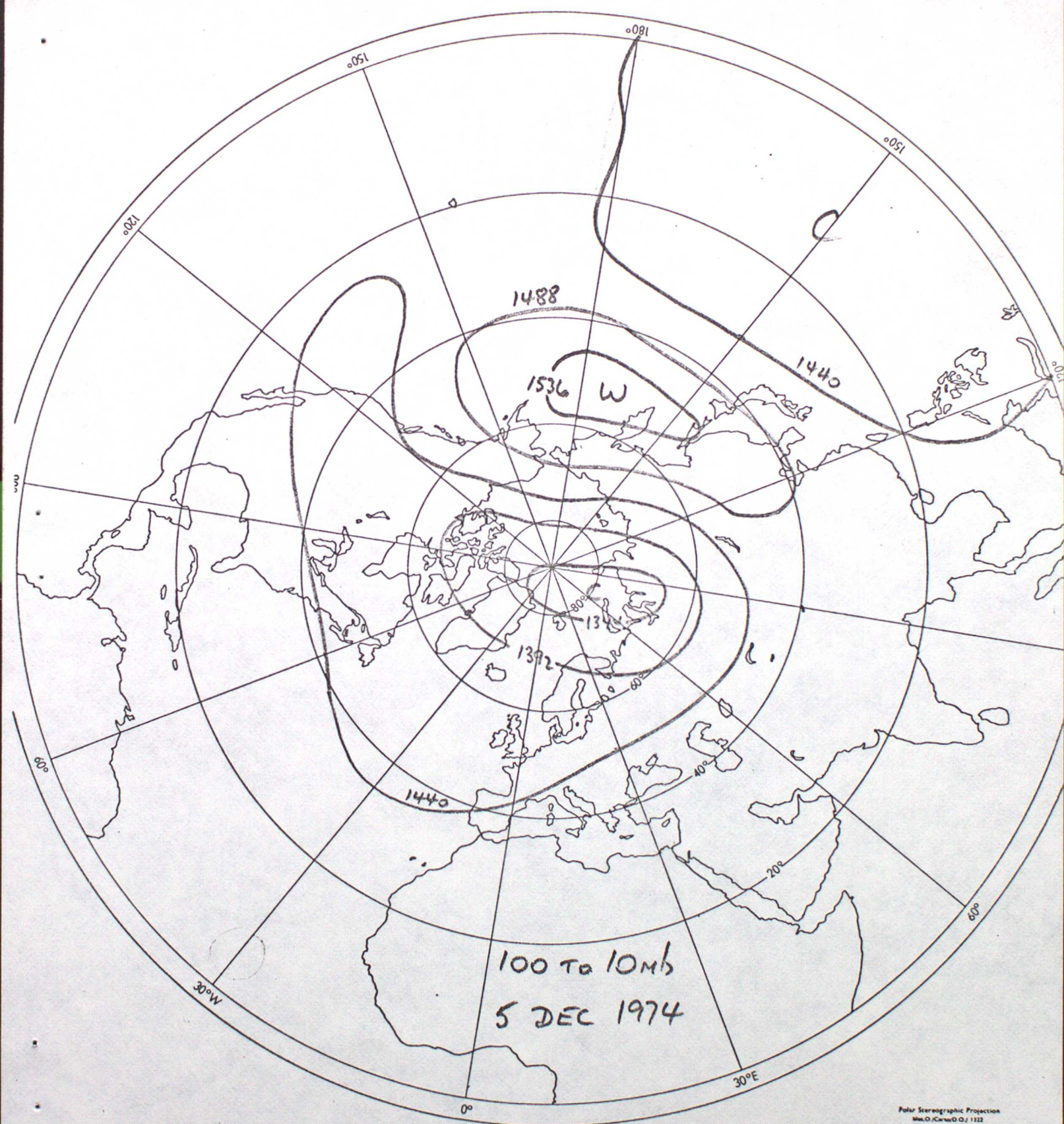
Polar Stereographic Projection
Mol.O./Caru.O./ 1122

Fig 29



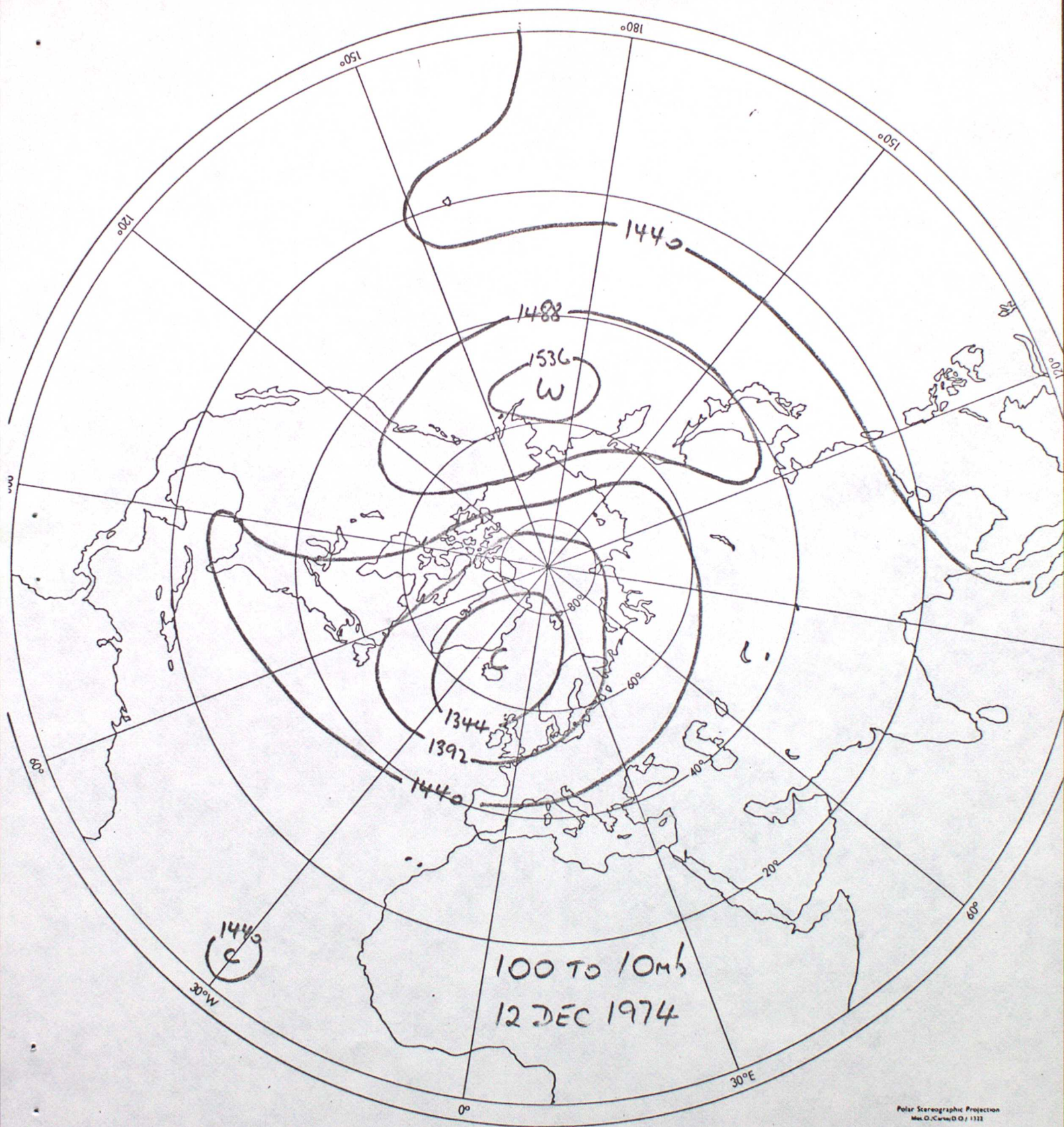
Polar Stereographic Projection
Moll. O. Caron O. G. 1322

FIG 2H



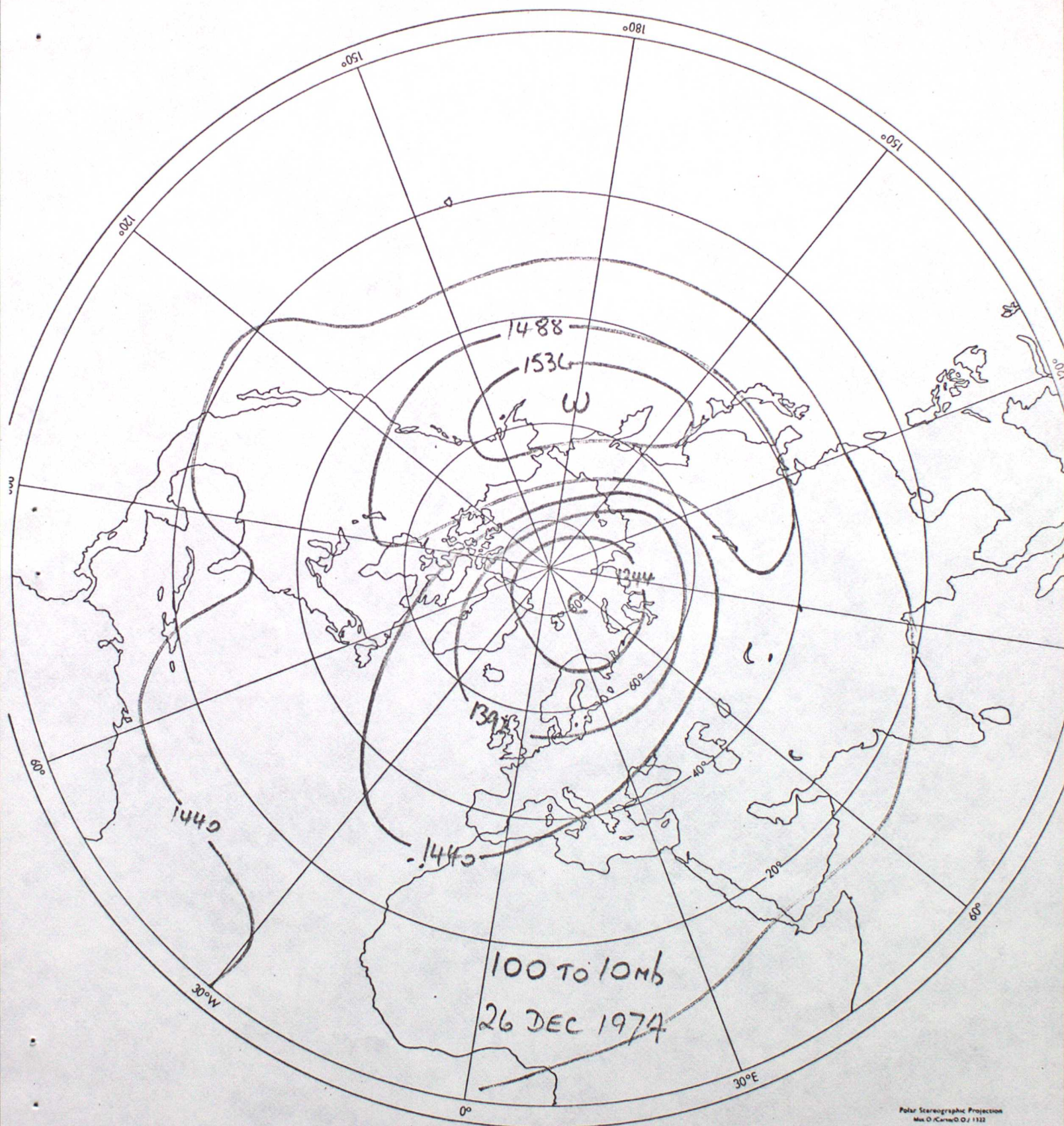
Polar Stereographic Projection
WGS 84 / WGS 84 Q / 1122

FIG 3A



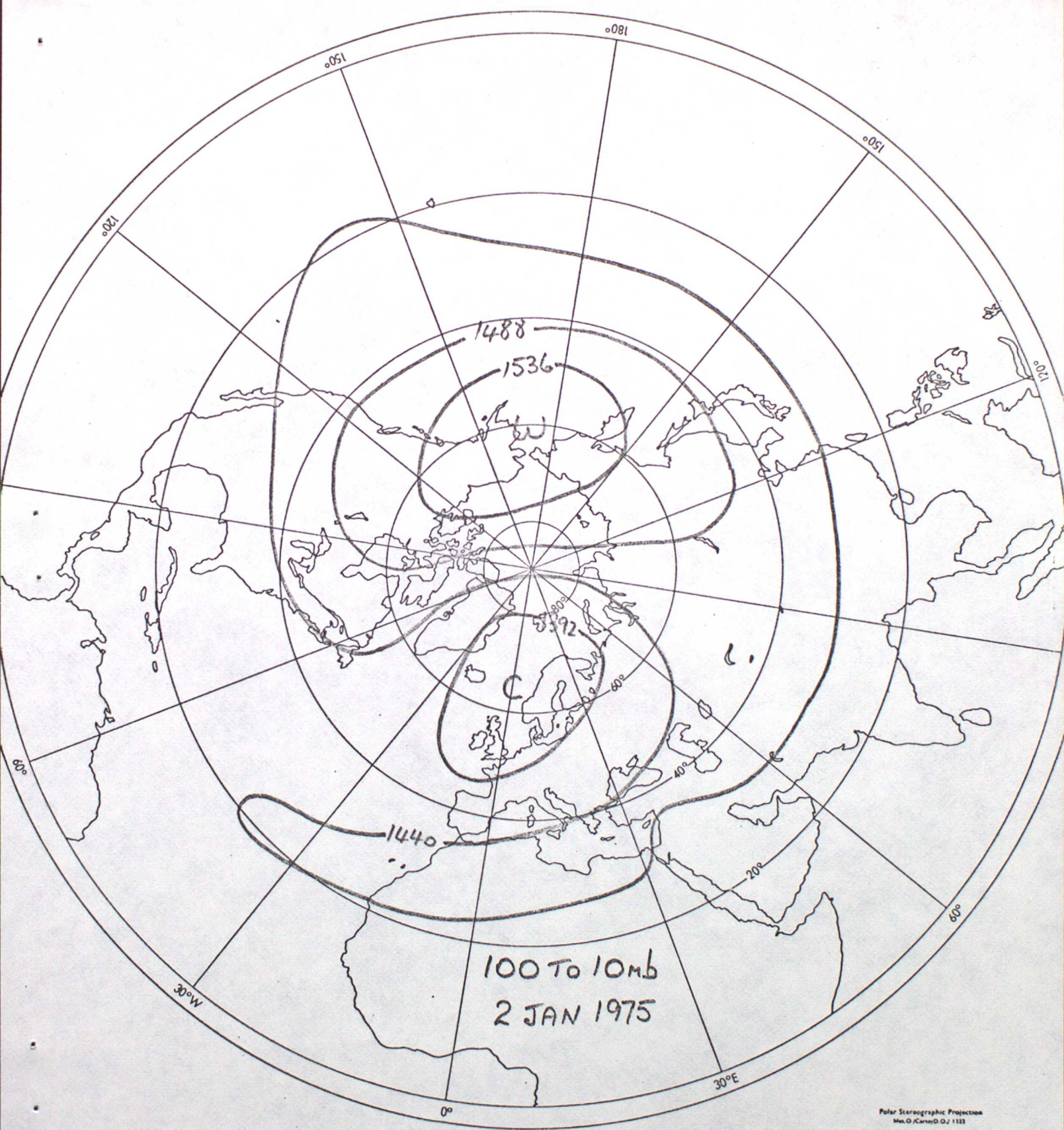
Polar Stereographic Projection
Map O-Case 00/1121

Fig 3B



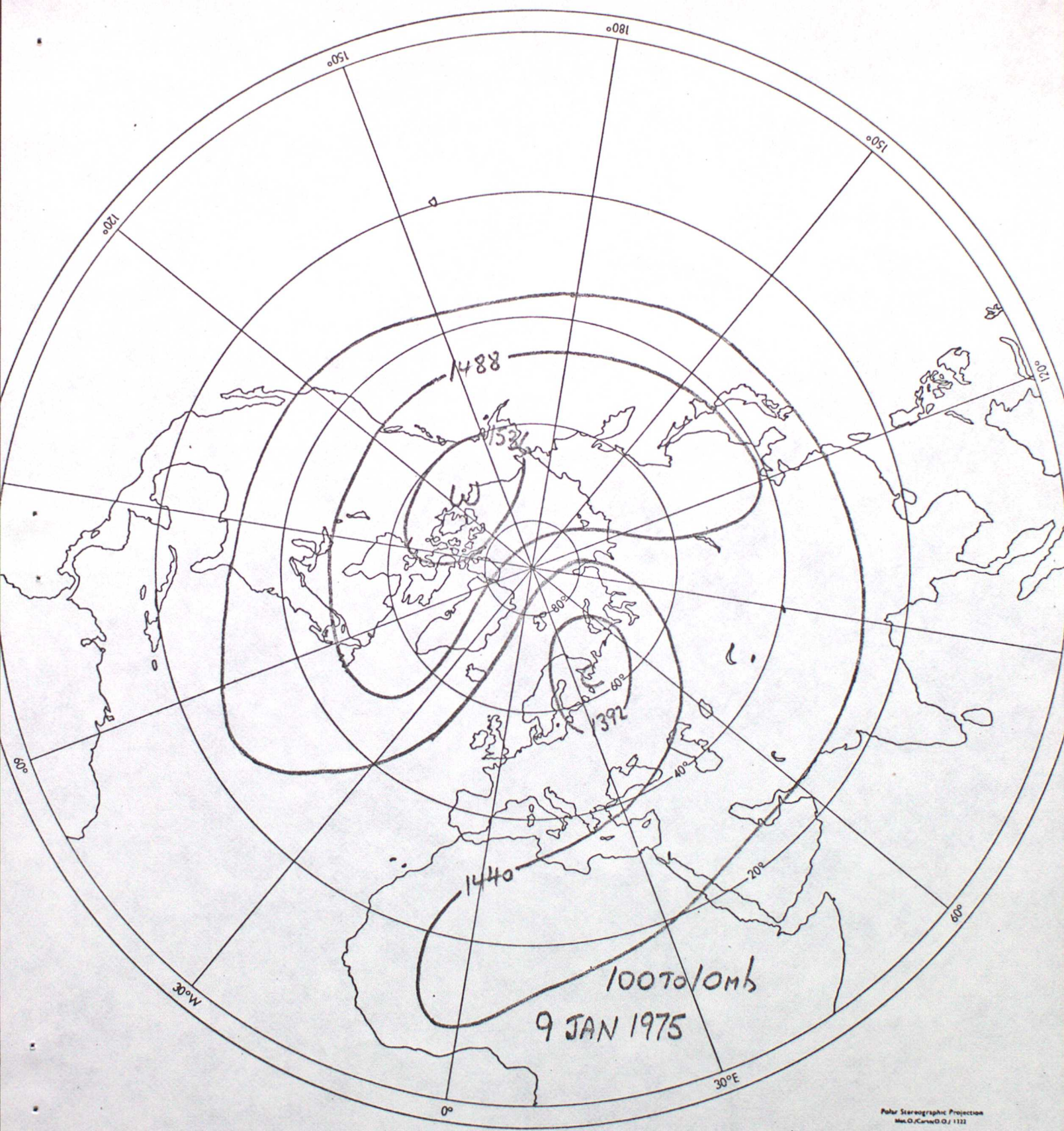
Polar Stereographic Projection
Map O/Curve O Q/ 1122

FIG 3D



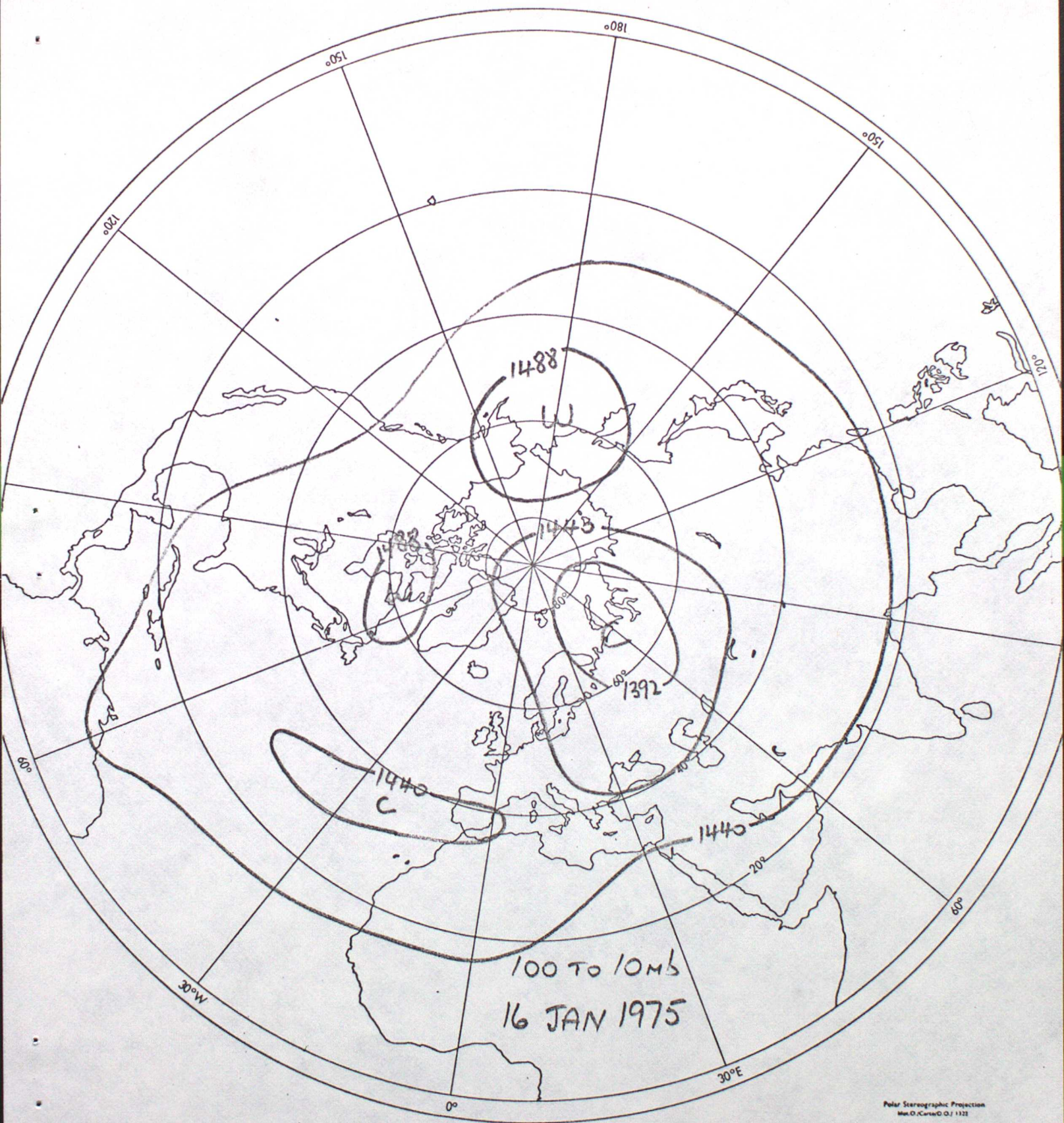
Polar Stereographic Projection
Map O/Covered Q. 1122

FIG 3E



Polar Stereographic Projection
Mm.O.Karw.O.O.J. 1121

FIG 3F



Polar Stereographic Projection
Map O.C. 1122

Fig 39

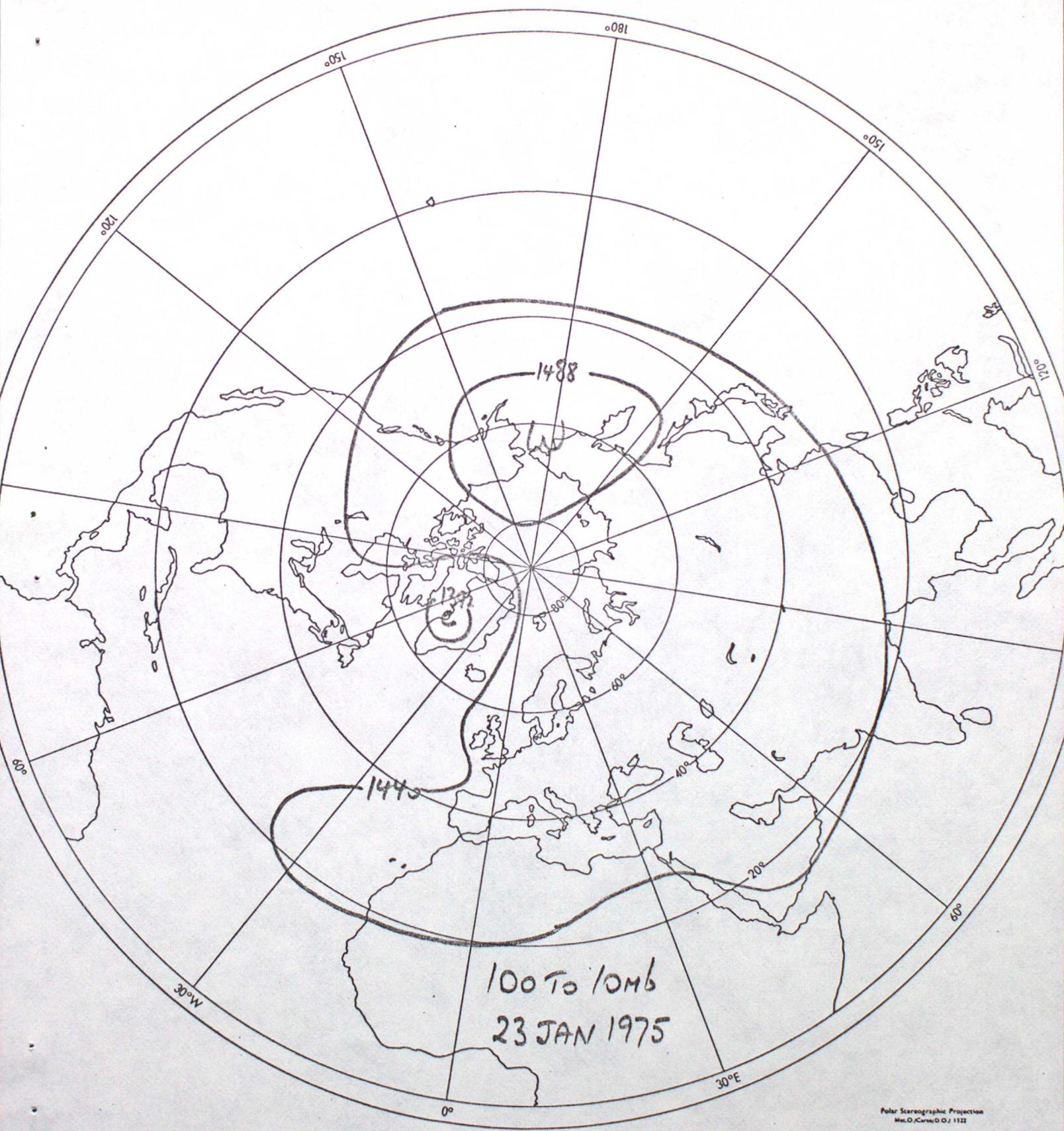
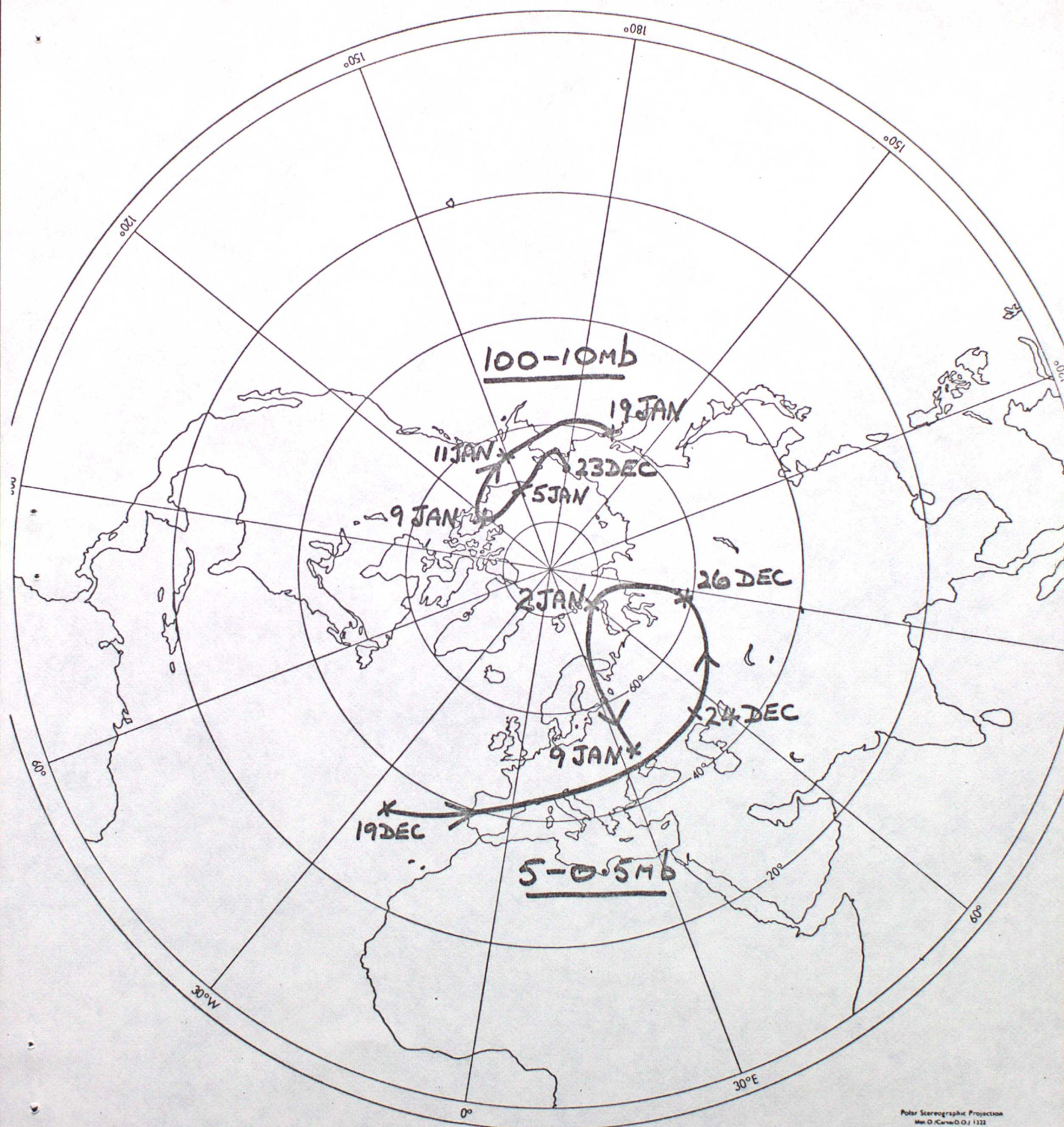


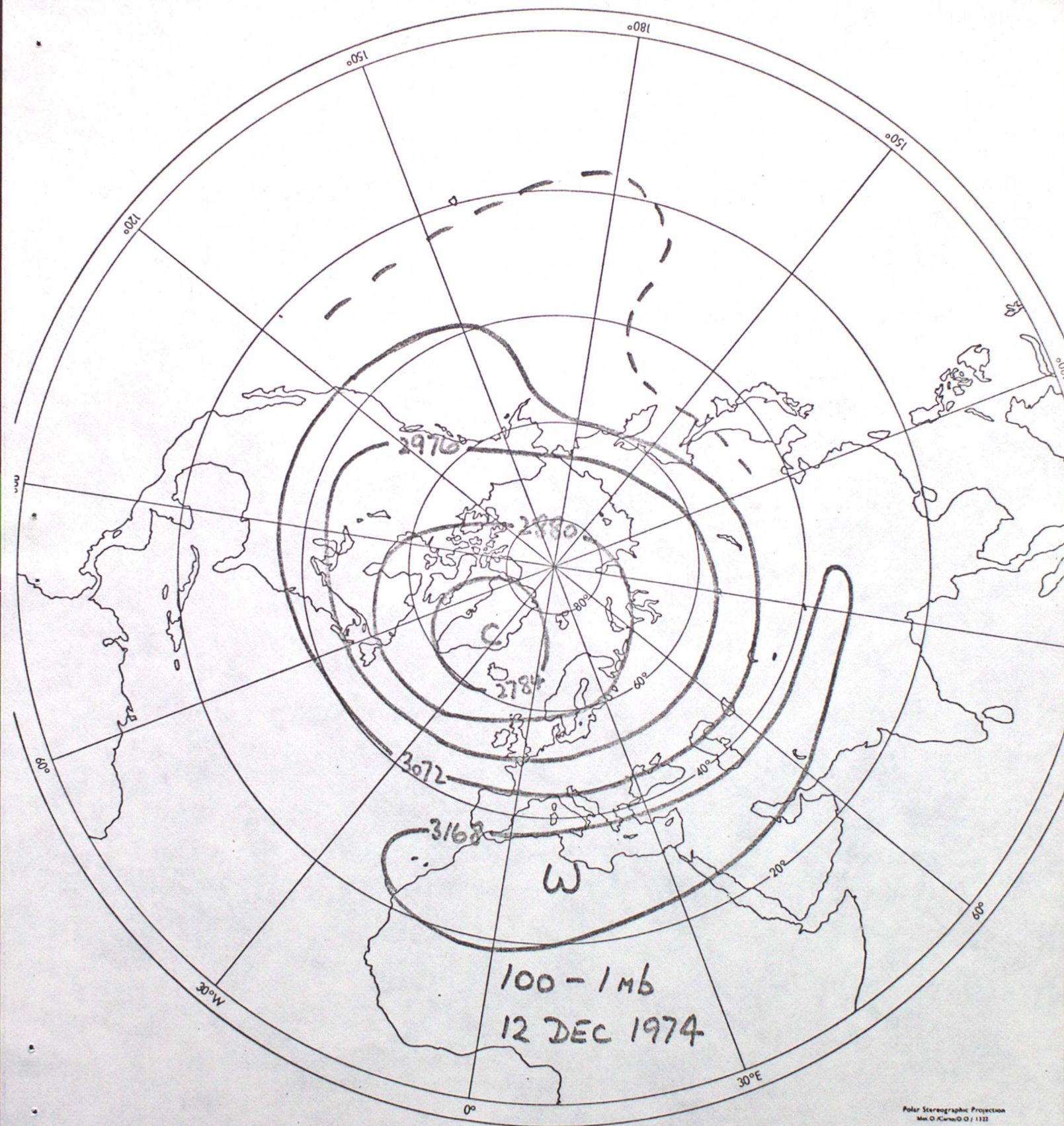
FIG 34



Polar Stereographic Projection
Map O/C/area O.C./ 1322

MOVEMENTS OF WARMEST AIR IN
LOW (100-10 mb) AND HIGH (5-0.5 mb) STRATOSPHERE

FIG 4



Polar Stereographic Projection
Map O/Curve/O/O / 1133

FIG 5B

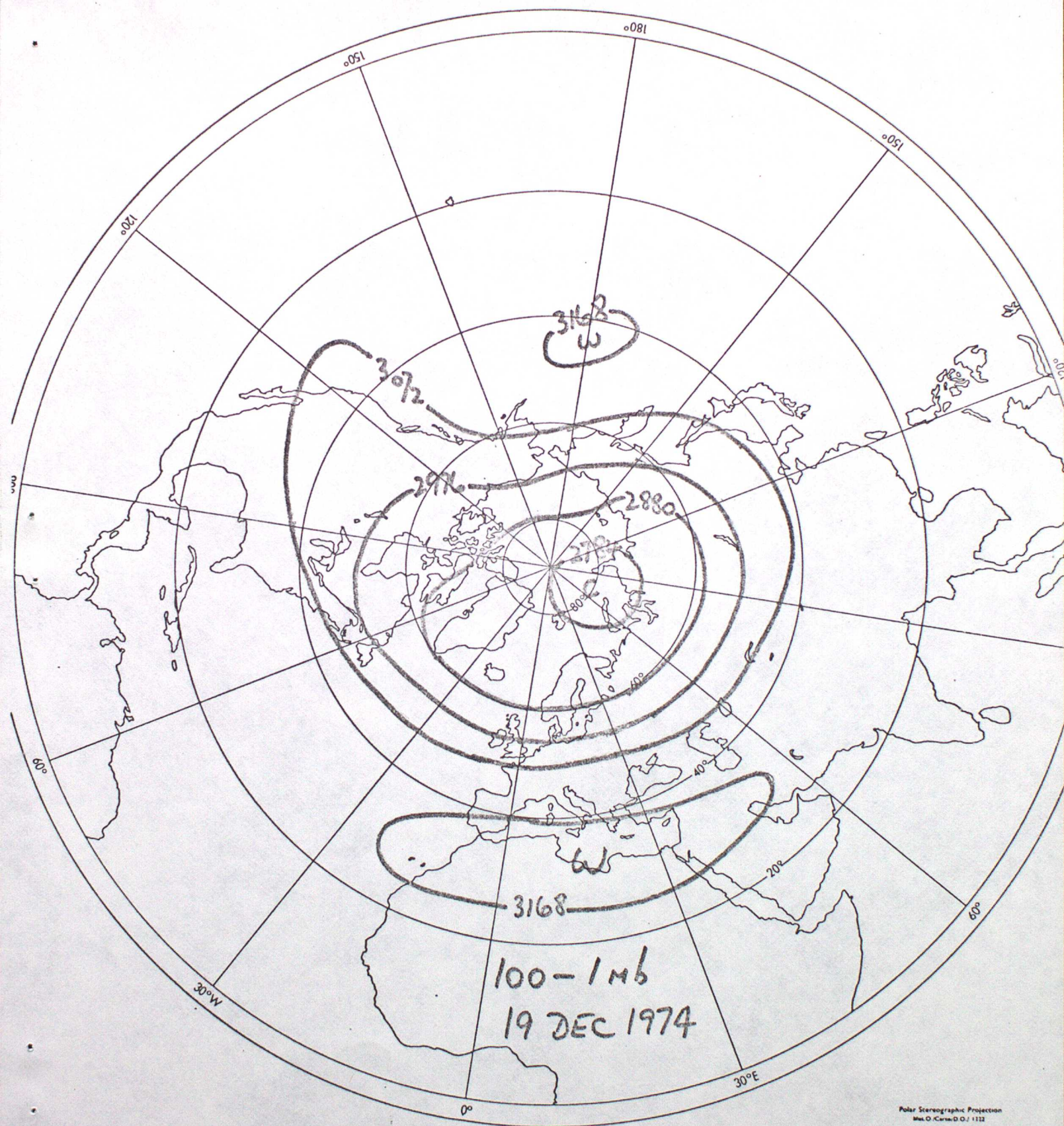
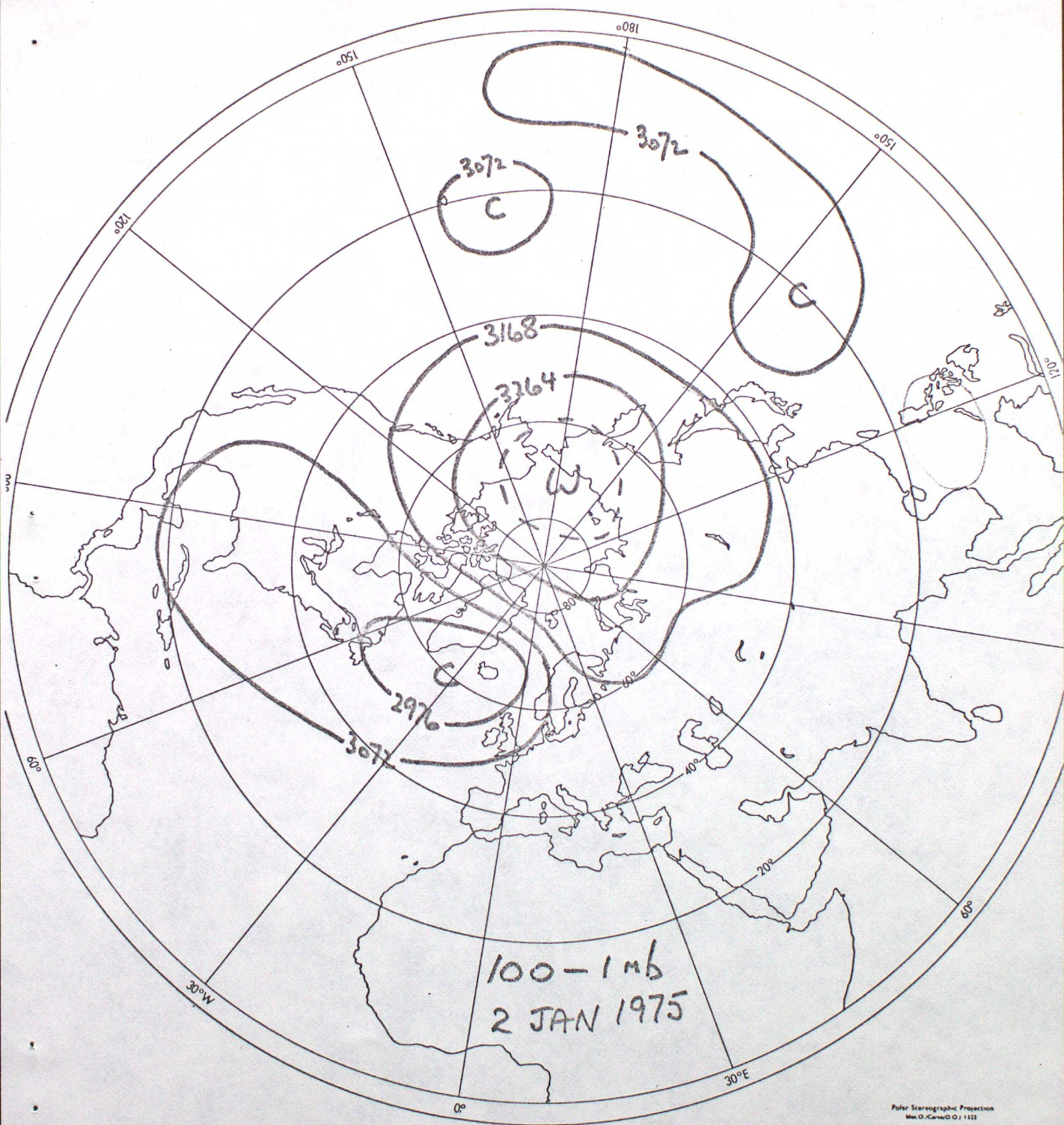


FIG 5c



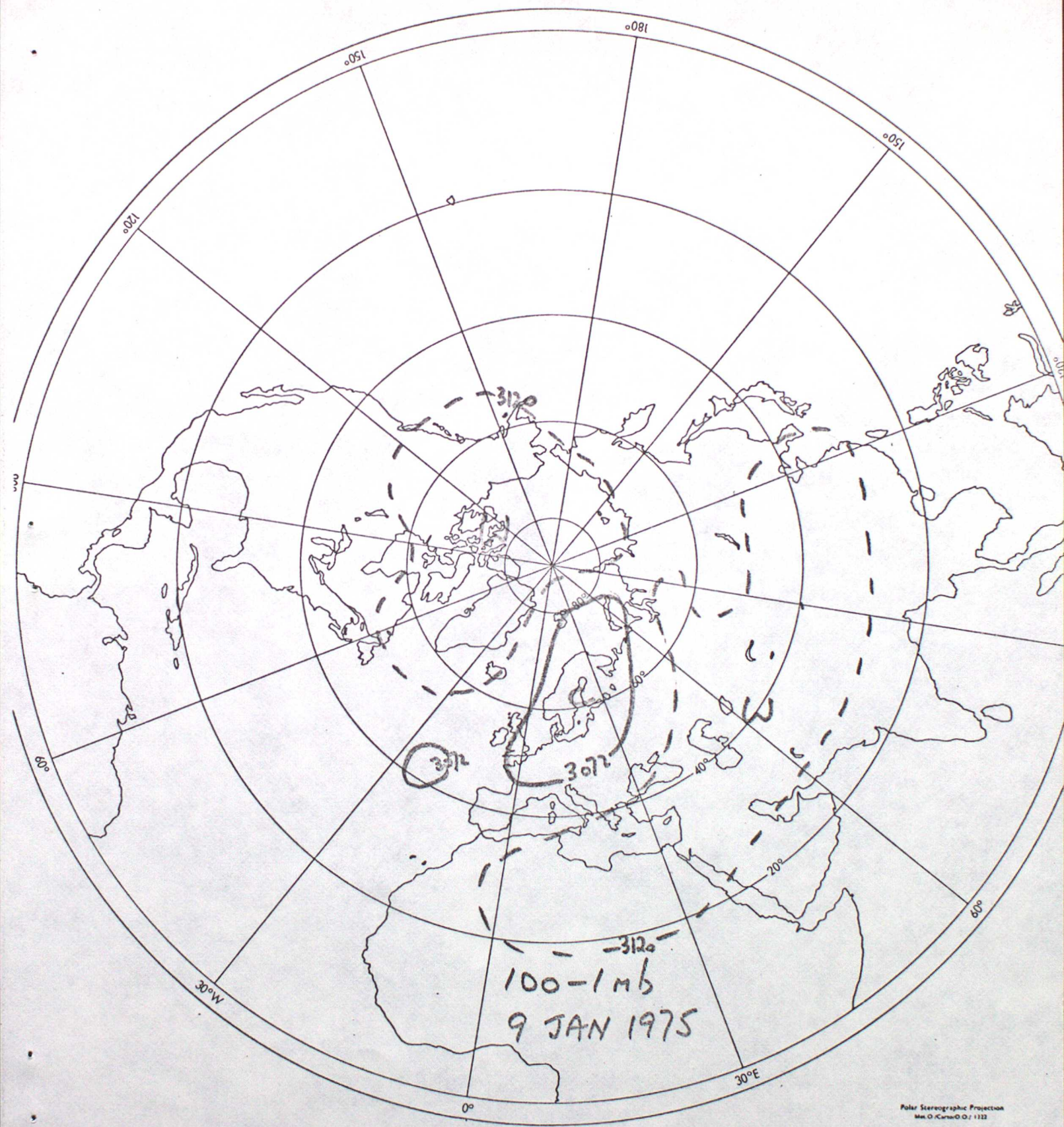
Polar Stereographic Projection
Max. O. Scale: 1:112

Fig 5D



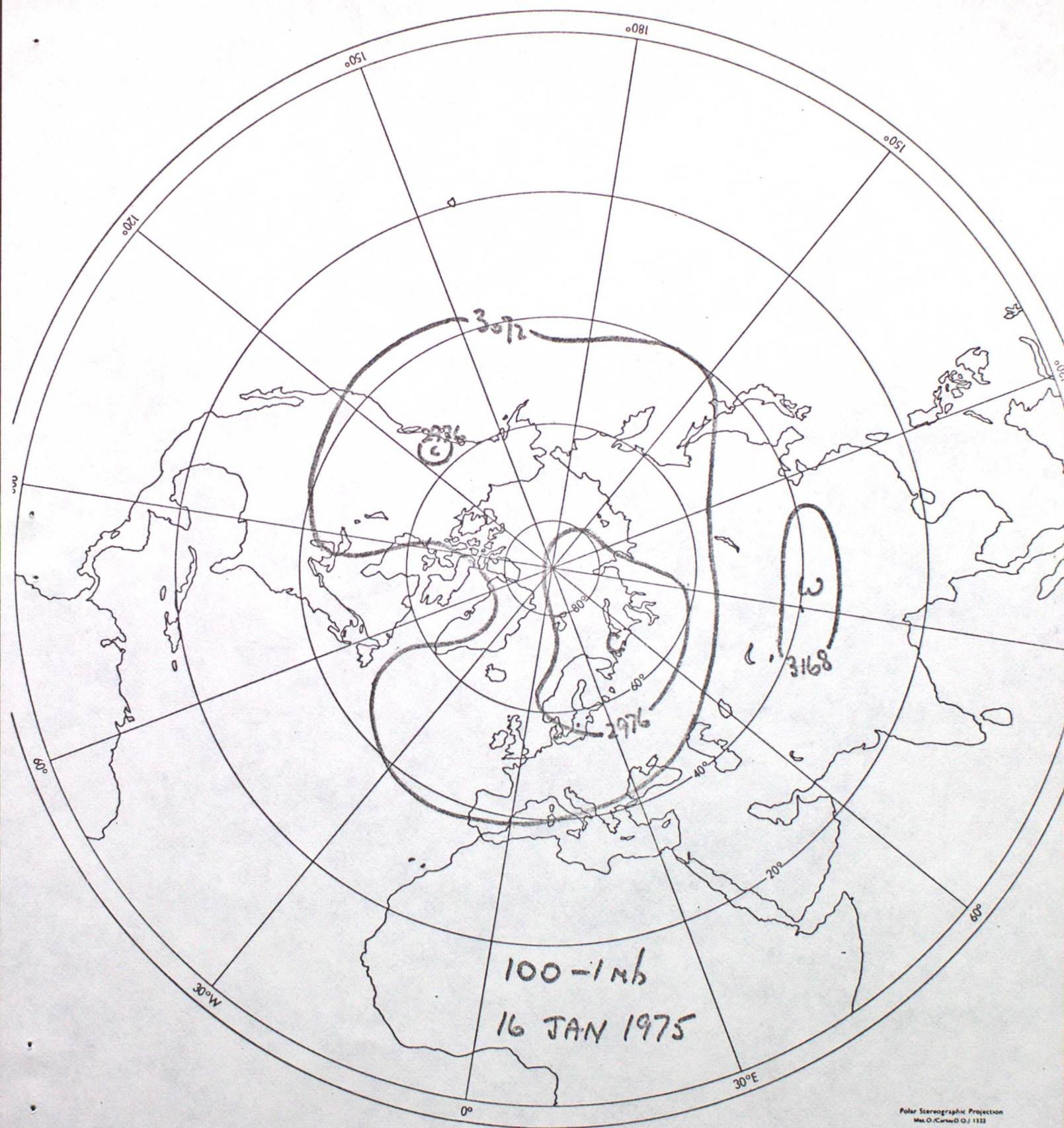
Polar Stereographic Projection
Max. O. Curve O. / 1122

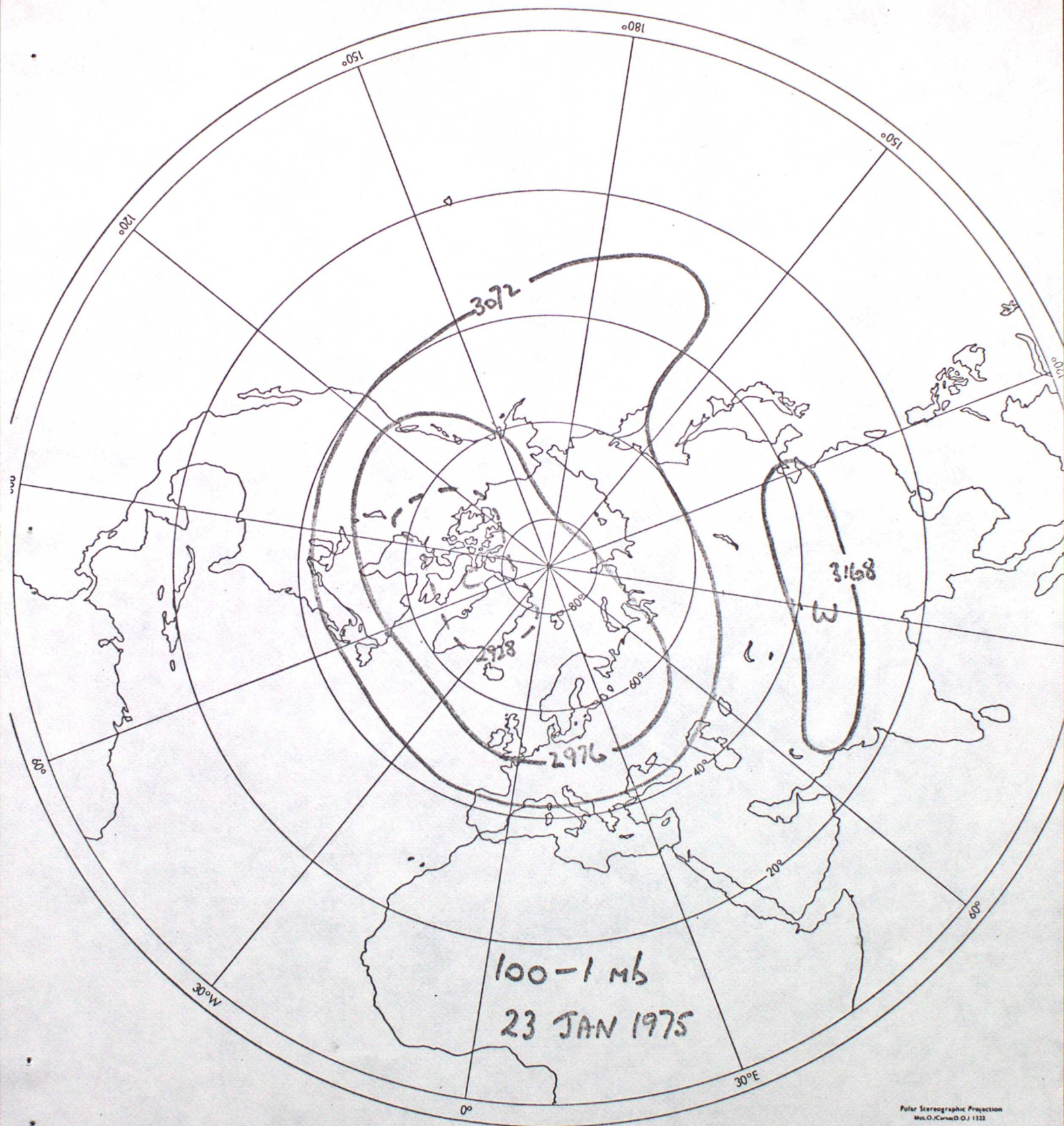
FIG 5E



Polar Stereographic Projection
Map O/Curve O/O / 1132

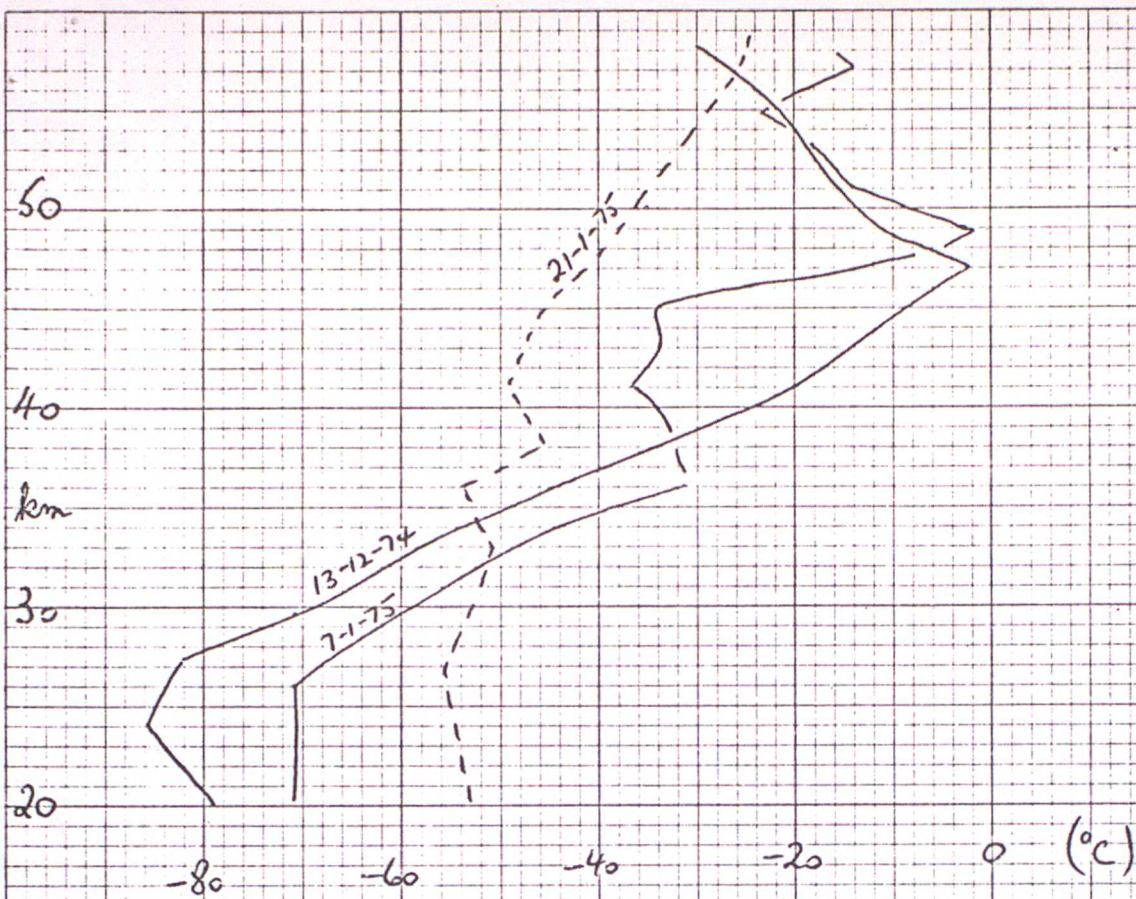
Fig 5F





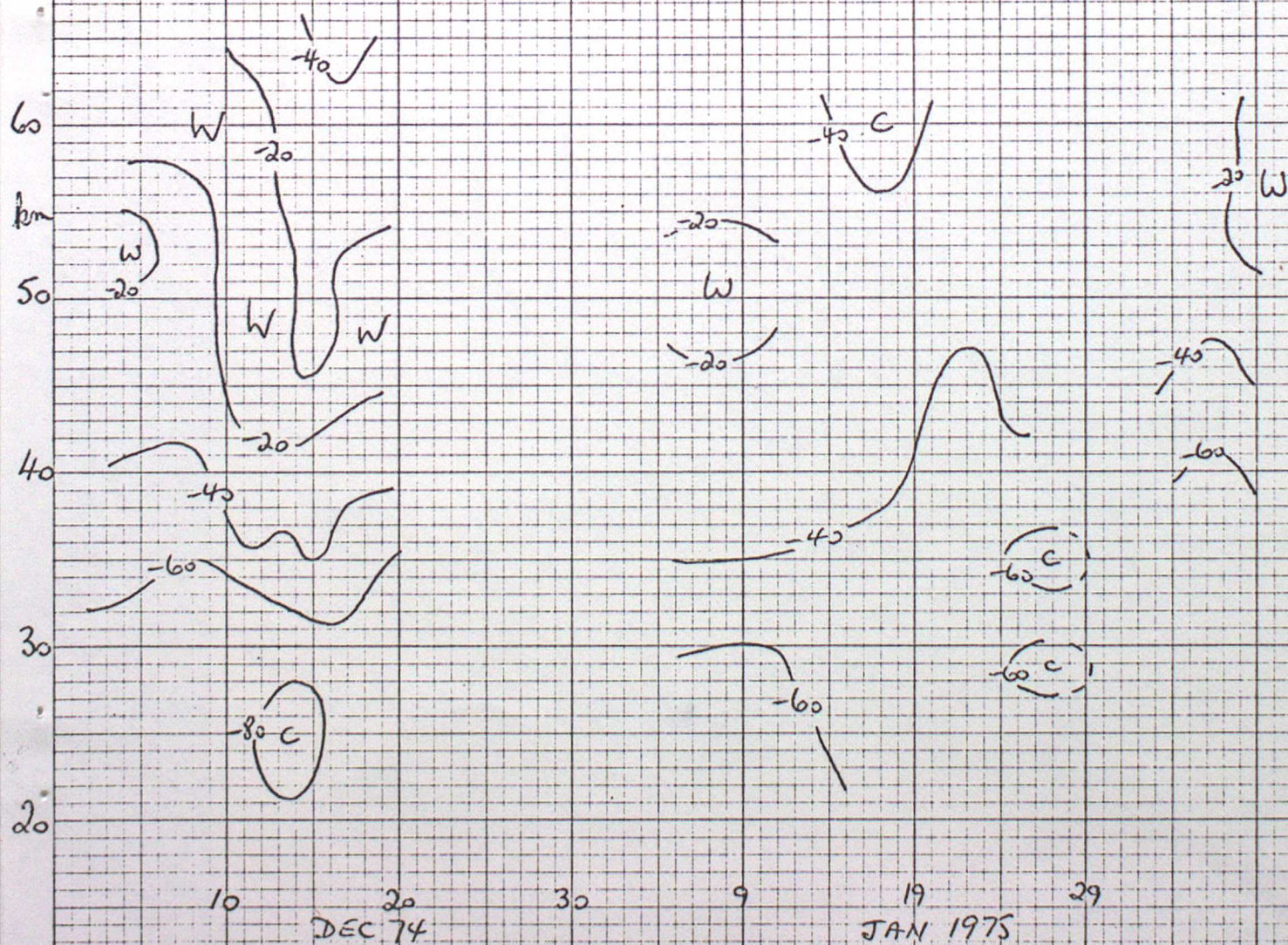
Polar Stereographic Projection
M.S.O. Curve O.D. / 1132

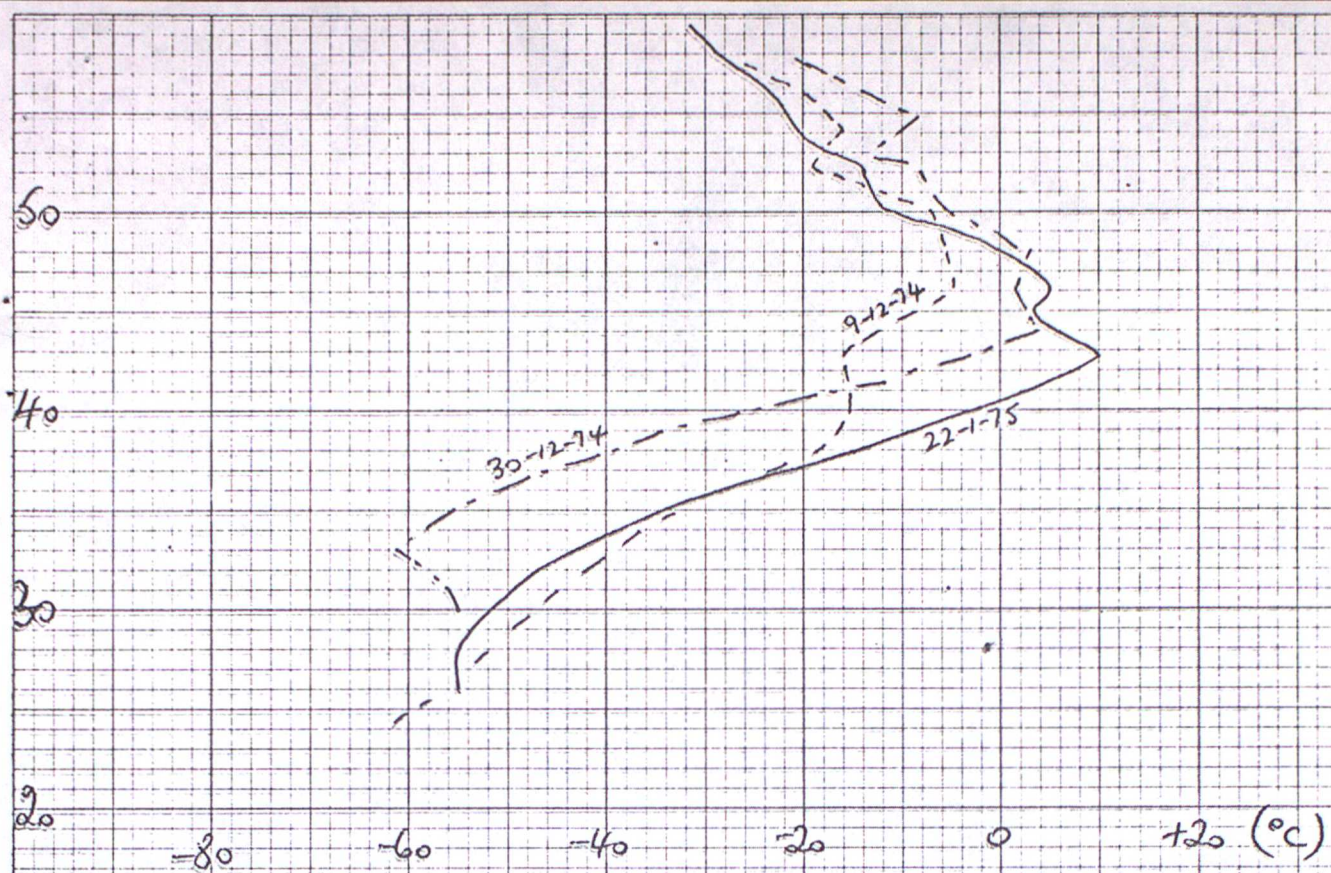
FIG 5H



WEST GEIRINISH

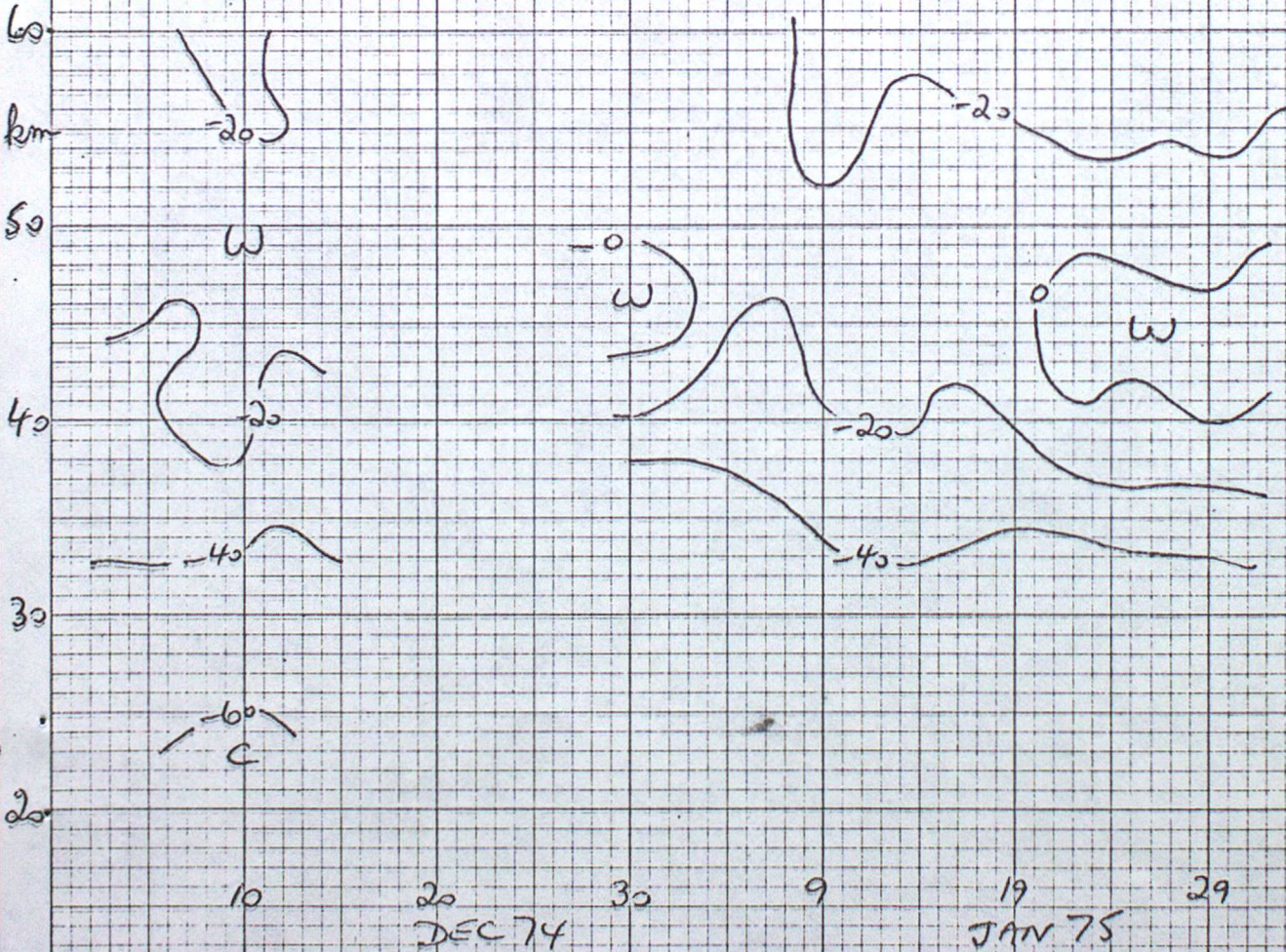
FIG 6A

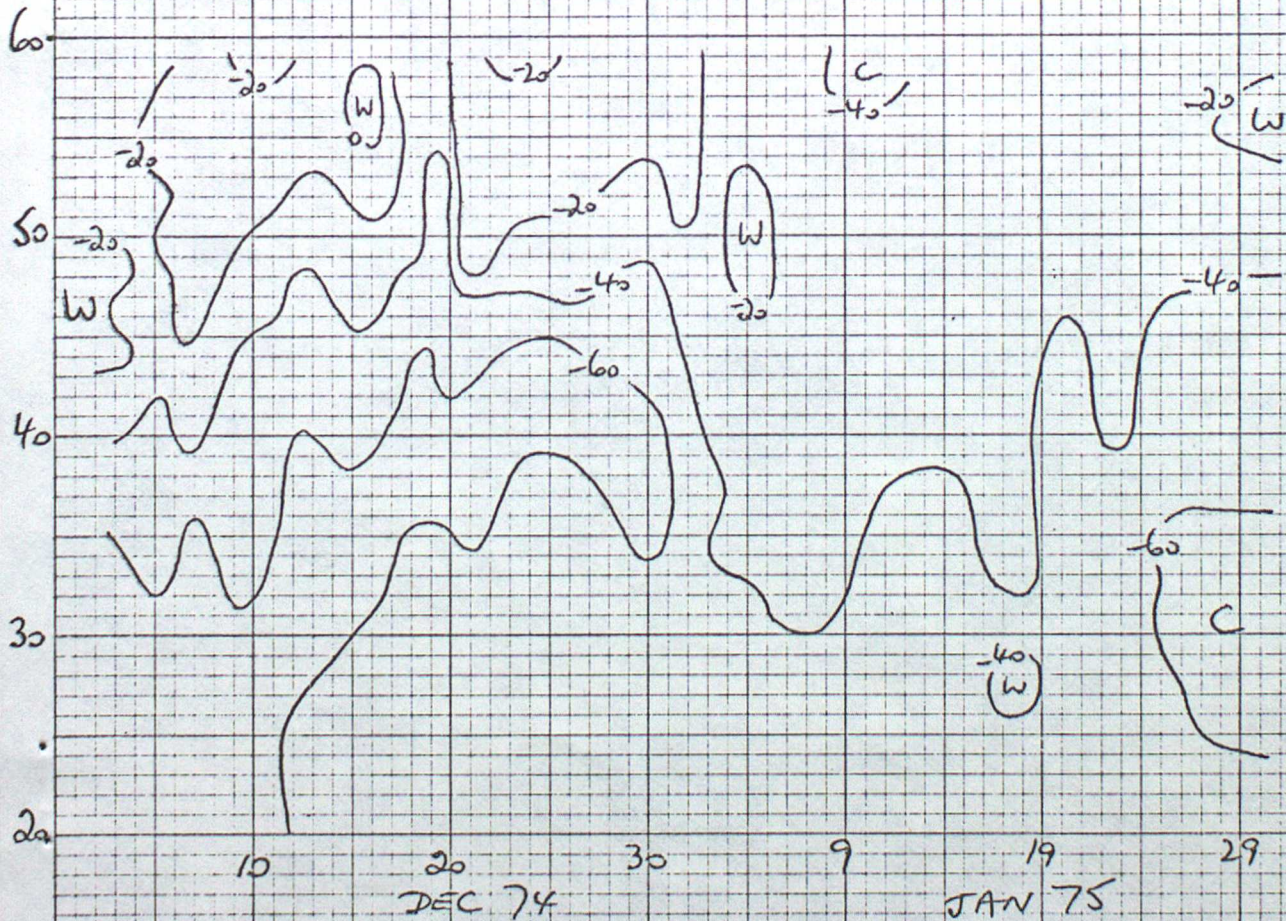
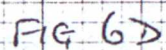


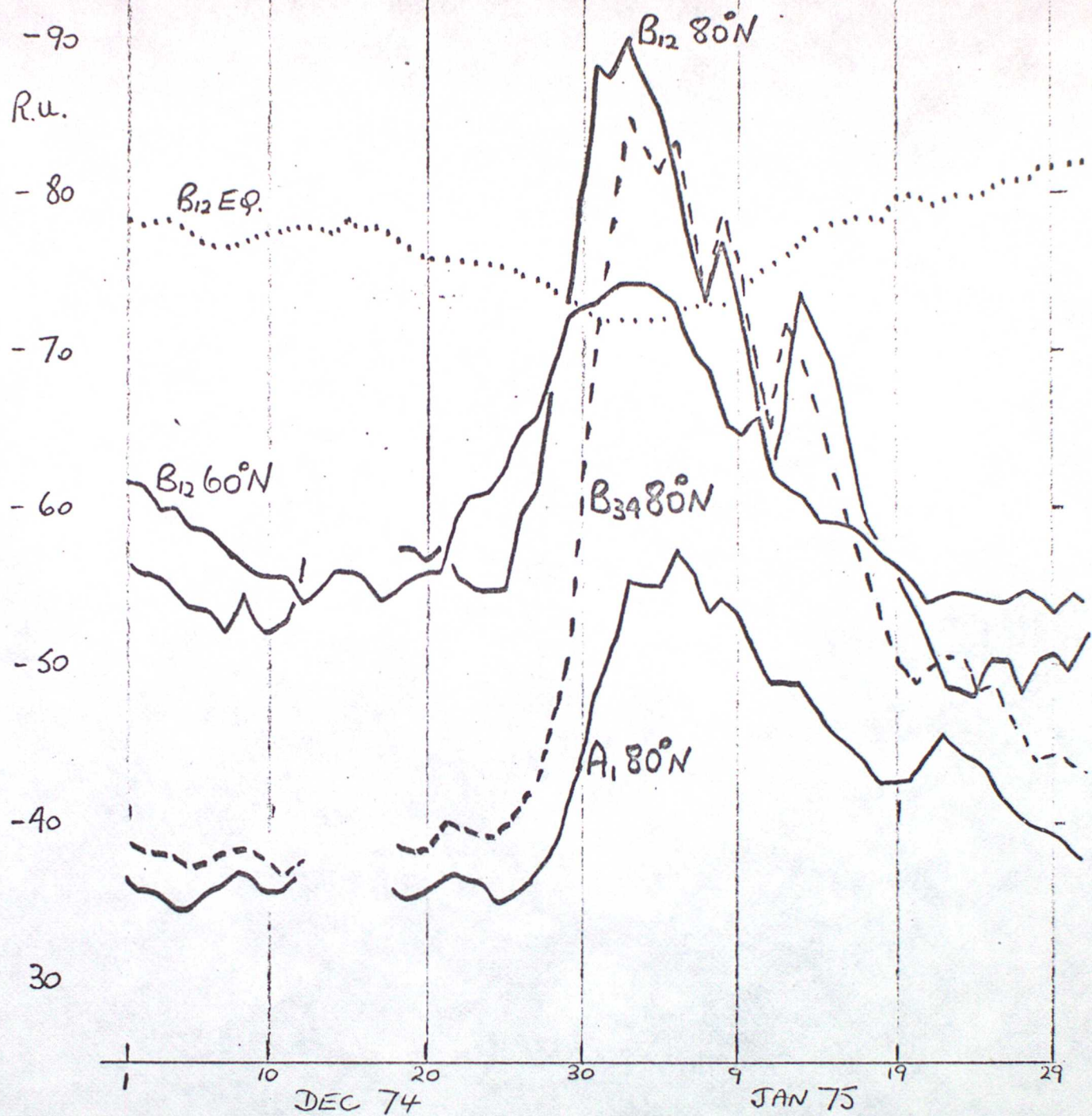


WALLOPS ISLAND

FIG 6B







ZONAL MEAN RADIANCES

FIG 7

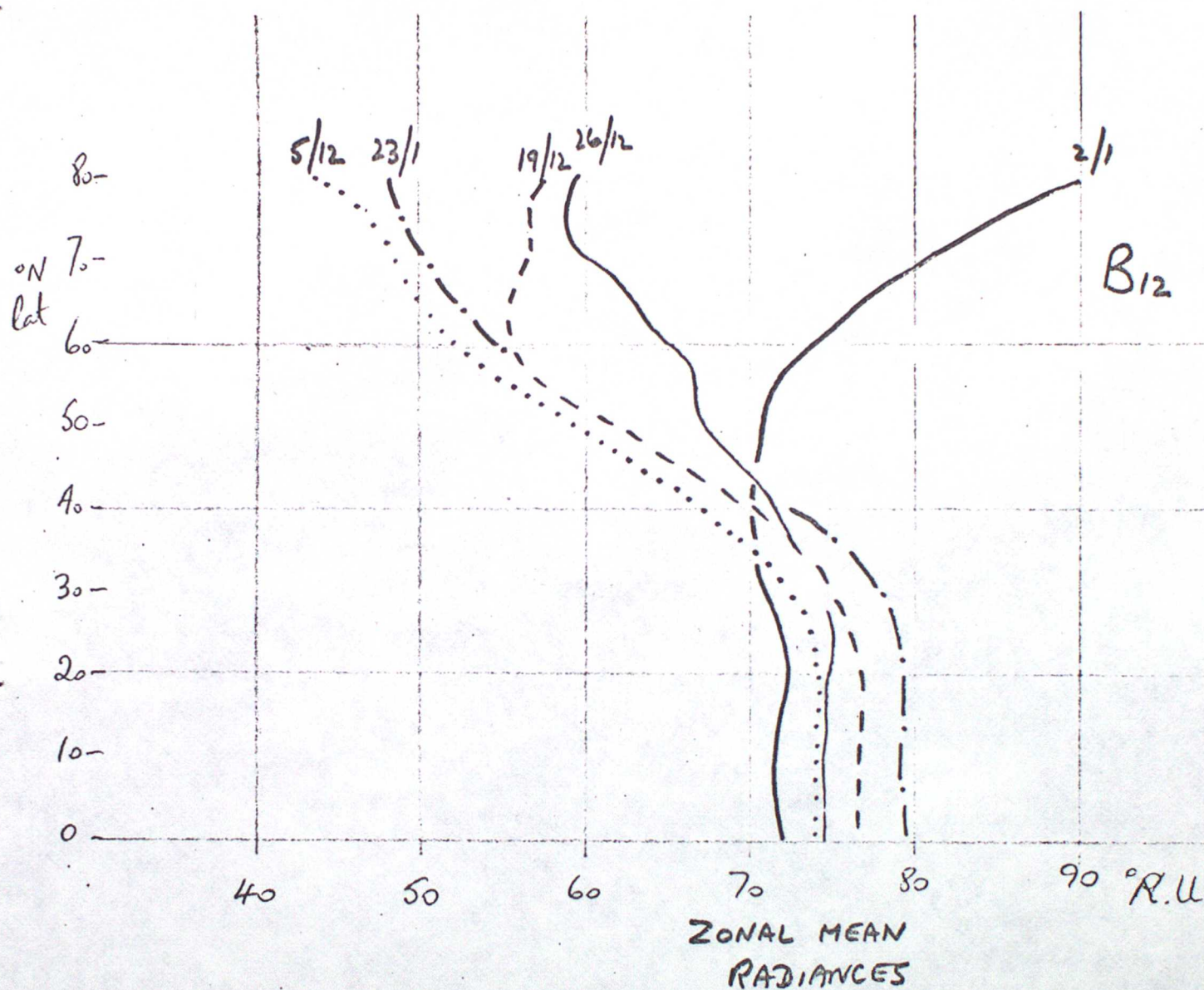


FIG 8

Dec 74

Jan 75

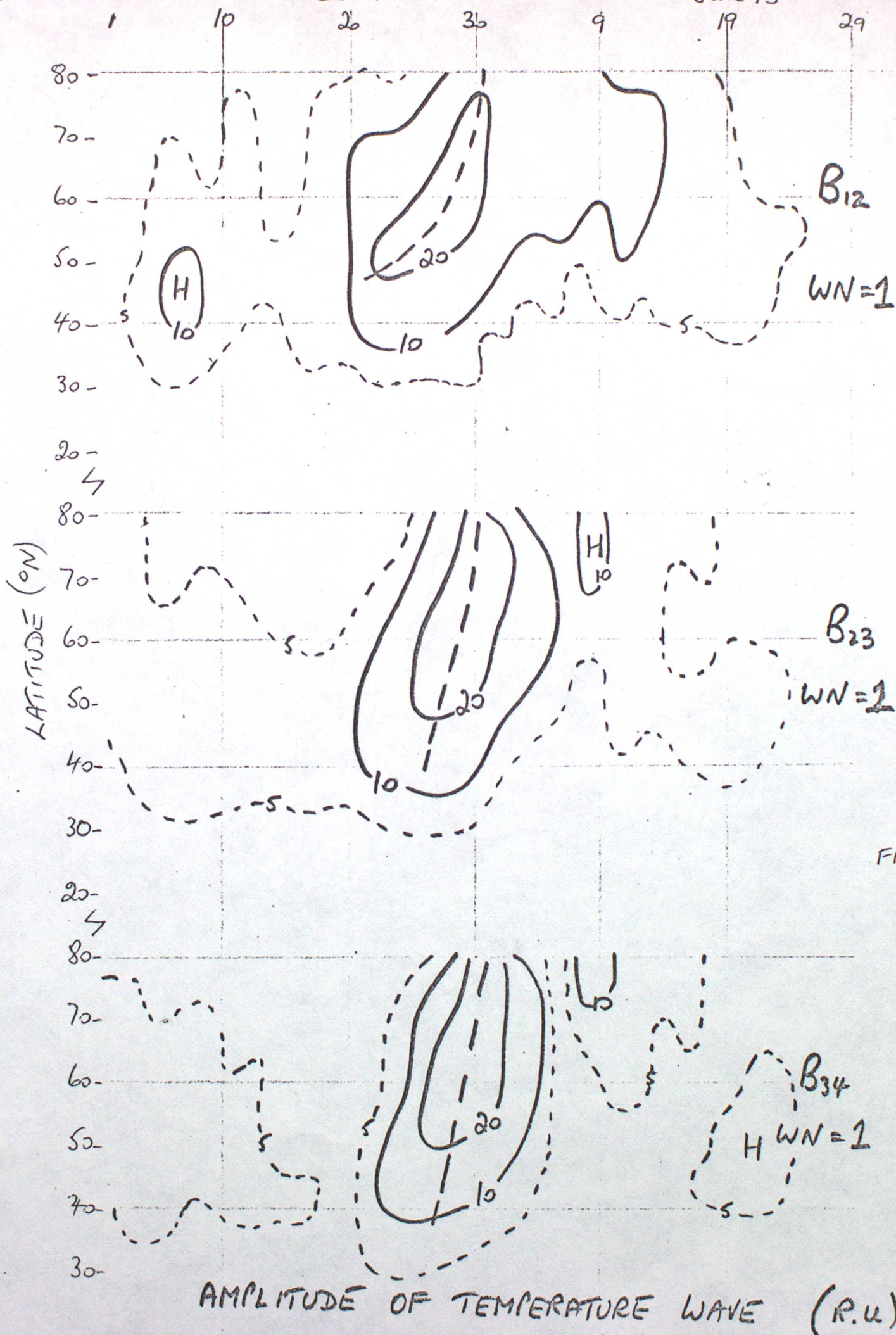


FIG 9

AMPLITUDE OF $WN=1$ at $60^{\circ}N$

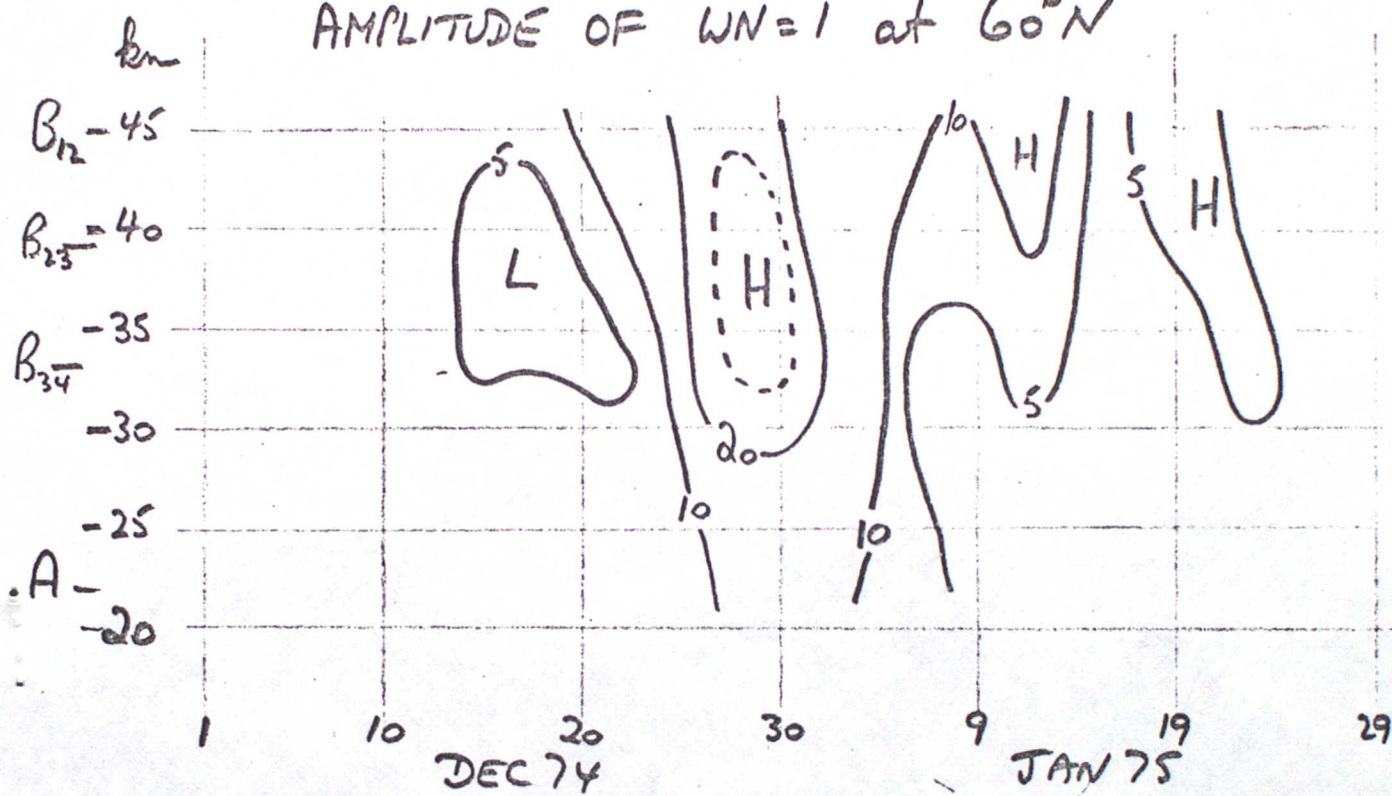
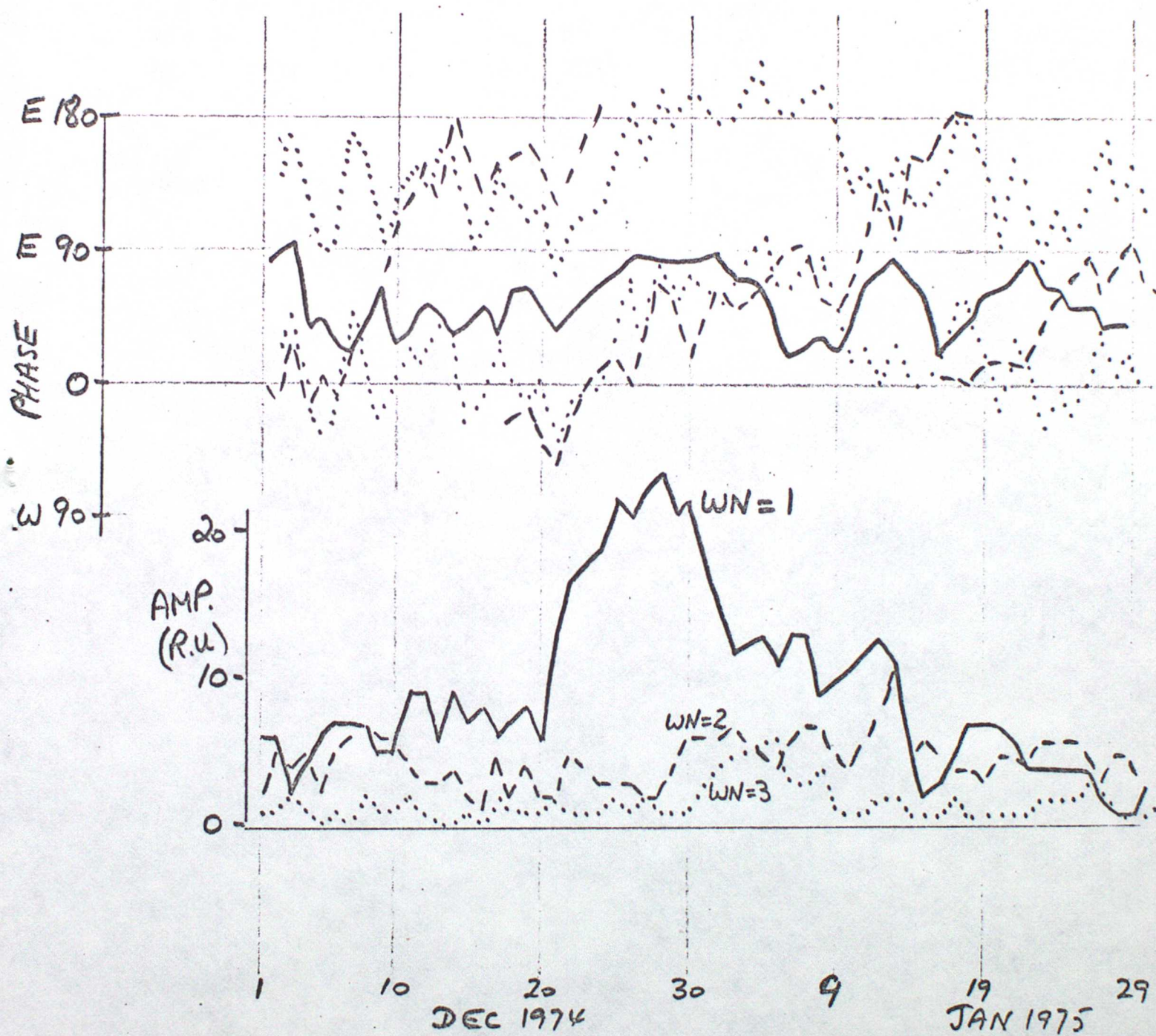
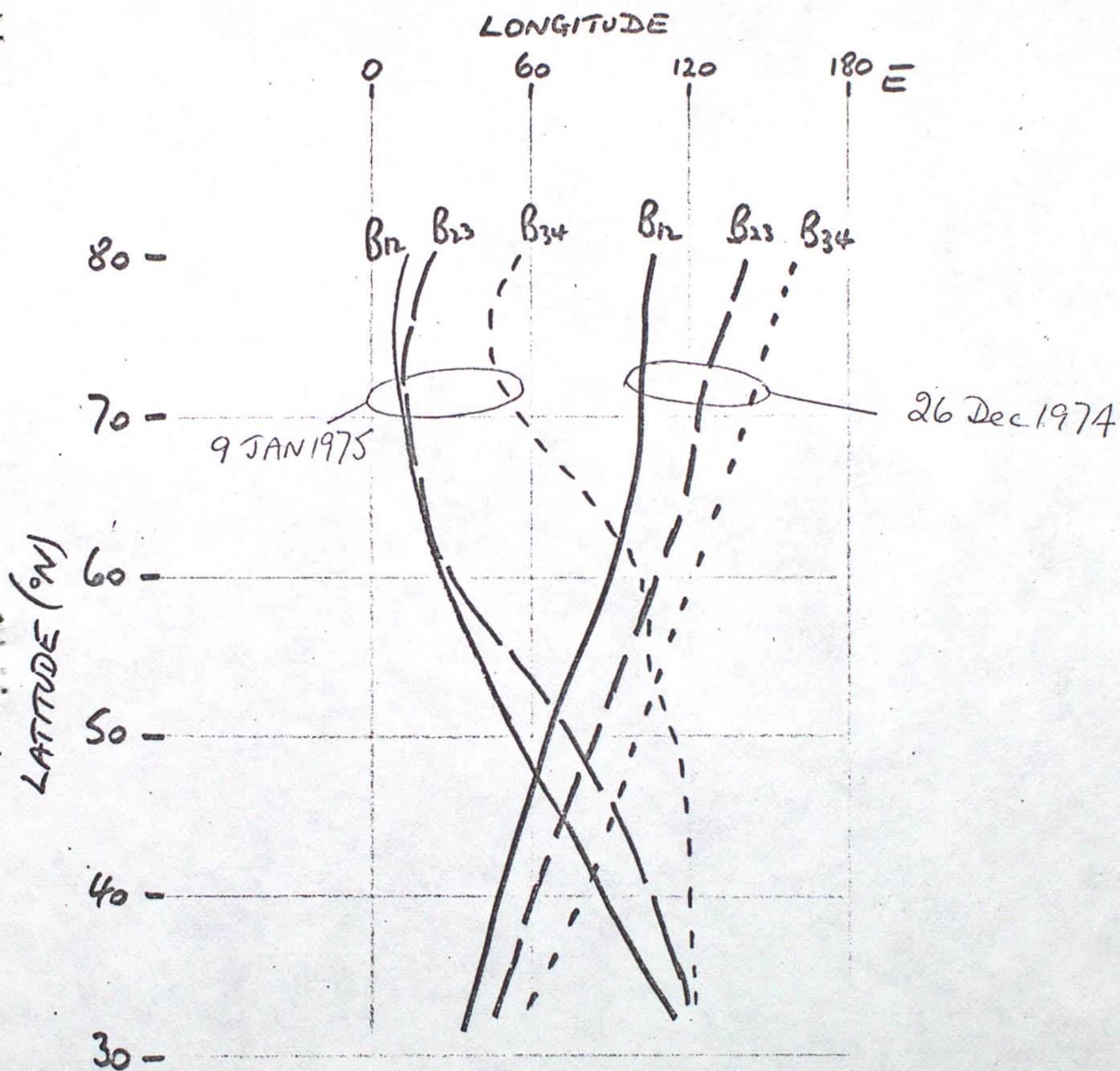


FIG 10



AMPLITUDE AND PHASE OF FIRST THREE
WAVENUMBERS OF B_{12} RADIANCES AT $60^\circ N$



LATITUDE VARIATION OF PHASE
BEFORE AND AFTER WARMING.

FIG 12

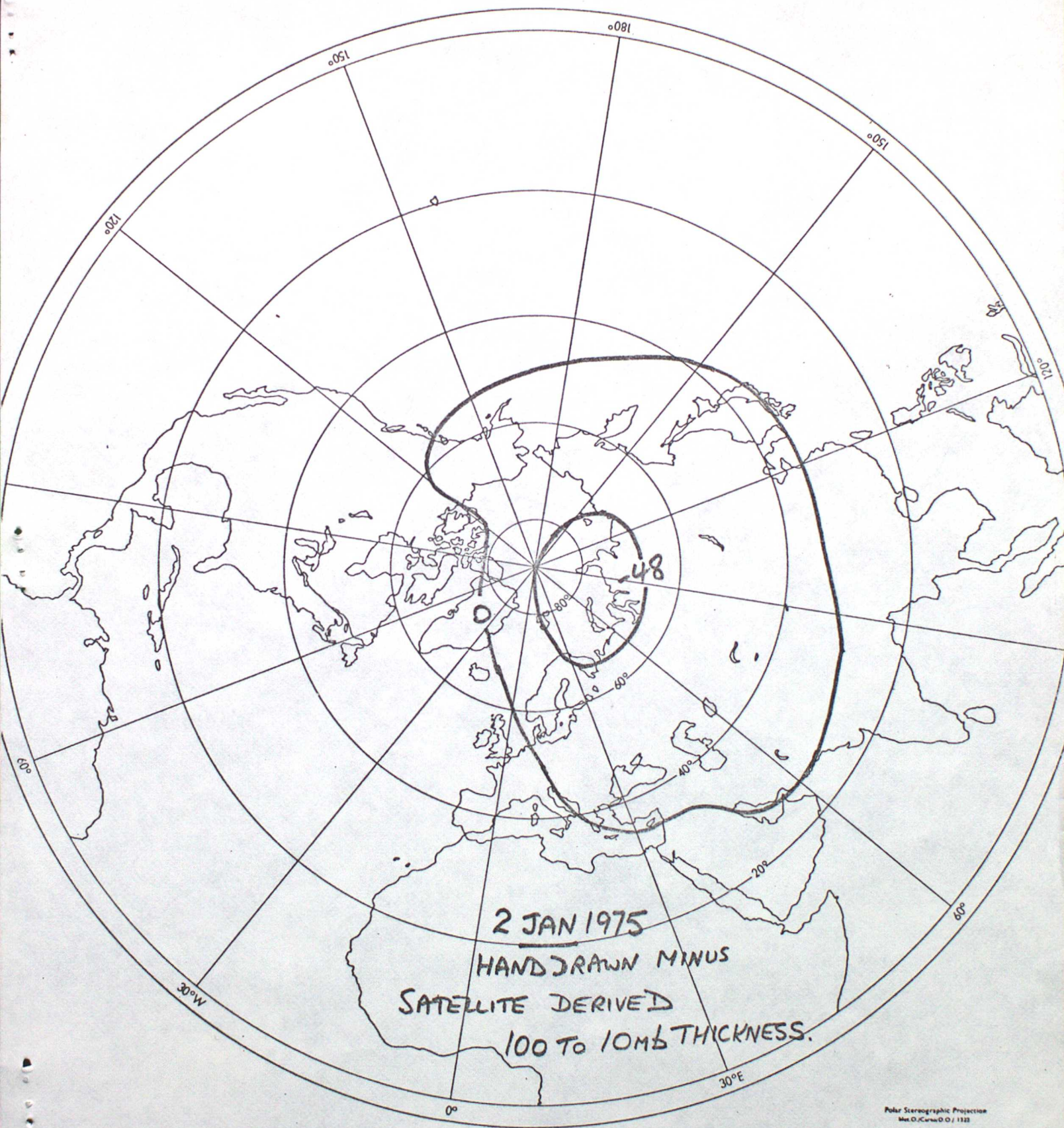


FIG 13