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MEAN PRESSURE DISTRIBUTION AND GEOSTROPHIC CIRCULATION IN THE METEOR ZONE

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BOUTKO et al., (1982) used available satellite radiometer data to estimate 0.1 mb constant pressure heights in the mesophere and KOSHELKOV and KOVSHOVA (1984) derived, 0.1-0.005 mb or 0.1-0,001 mb layer thickness from which were compiled height fields of the 0.005 mb and 0.001 mb levels. The close relationship (z~0.95) discovered between mean thicknesses (calculated for each month at various latitudes from CIRA (1972) and zonal values of atmospheric radiances (LABITZKE and BARNETT (1981)) observed in channel 3000 of the pressure modulated radiometer (PMR) on board the Nimbus-6 satellite in 1975-1978 was used (see Fig. 1). An analysis of the geopotential height fields in the lower thermosphere of the southern hemisphere was carried out by KOSHELKOV (1984) and KOSHELKOV and KOVSHOVA (1984). The present paper deals mainly with northern hemisphere patterns. The analysis was limited to regions north of 20°N due to poor reliability of the thickness estimates from the PMR data at low latitudes.

Monthly mean maps of the geopotential heights of the 0.005 mb and 0.001 mb surfaces in the northern hemisphere are presented in Fig. 2. The lower of these characterize pressure distribution at geometric heights of about 81 to 84 km while the upper level corresponds to 91-94 km, i.e., to the lower part of the meteor zone. In this layer, as Fig. 2 confirms, the main feature of the pressure distribution in summer is the presence of an anticyclonic system centered around the pole. In accordance with observational evidence, the polar anticyclonic vortex dominating the stratosphere and mesophere attenuates with increasing height. It is markedly pronounced (though not so well as in the mesophere (KOSHELKOV, 1984)) at the 0.005 mb level, while at heights greater than 90 km (0.001 mb level) it is limited to polar regions north of 65°N where the circular low pressure area is located.

It should be noted that contraction of the area dominated by anticyclonic circulation with increasing altitude in the lower thermosphere (between the 0.005 mb and 0.001 mb levels) progresses more rapidly in the northern than in the southern hemisphere. Actually, the latitudinal pressure patterns at the 0.001 mb level were similar in the two hemispheres, and at the 0.005 mb level the pressure minimum was marked in the southern hemisphere near 40-45°S while a monotonous decrease from the pole towards low latitudes was observed in the northern hemisphere.

The center of the anticyclonic vortex during the period of its maximum development (in June-July, according to the present analysis) was located near the pole. In the middle latitudes geopotential values were somewhat higher in the American and Pacific areas as compared to other sectors of the hemisphere. As a result, the asymmetry of the pressure distribution relative to the North Pole was a little higher than that recorded for the southern hemisphere (ENTZIAN and TARASENKO, 1971; MININA et al., 1977); one cannot exclude, however, the possibility that the observed asymmetry in summer is largely related to limitations of the map compilation technique or partly to the short period of observation.

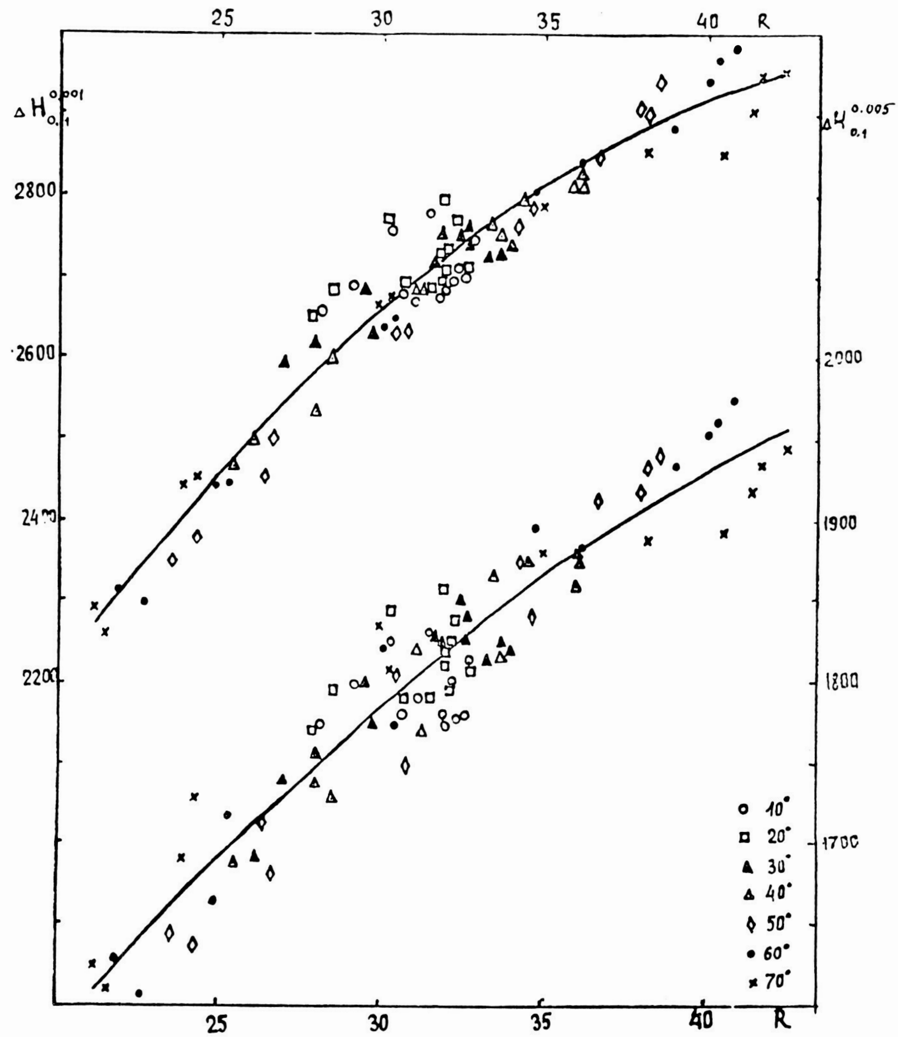


Fig. 1 Relationships between monthly mean PMR ch. 3000 radiances (W/m^2 sr cm^{-1}) in 1975-1978 and monthly mean thicknesses (dm) of the layers 0.1-0.001 mb (above) and 0.1-0.005 mb (below), calculated from CIRA 1972 for various latitudes (10° to 70°N).

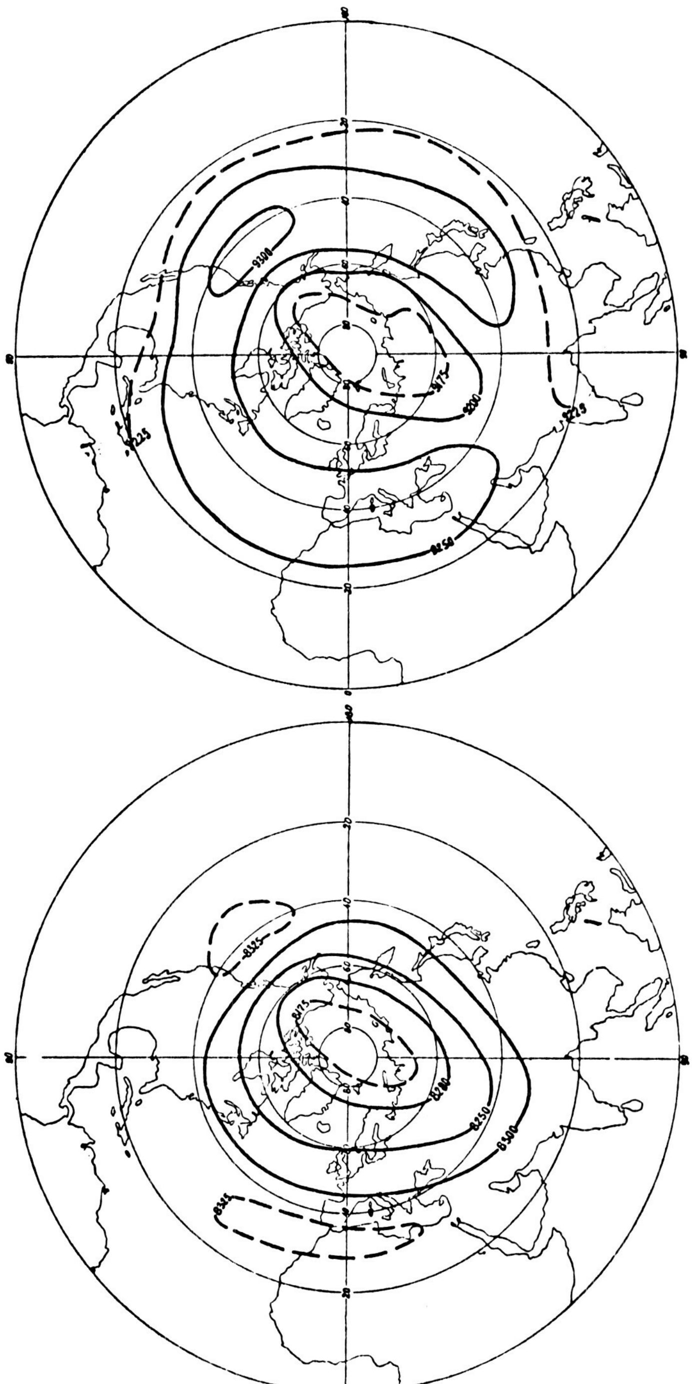
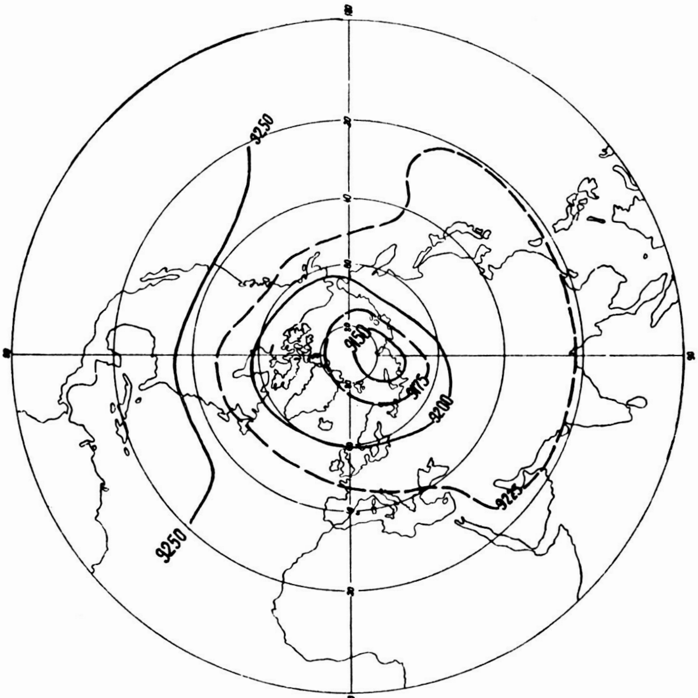


Fig. 2 Monthly mean maps of the geopotential height (dm) of the 0.001 mb (above) and 0.005 mb (below) levels in the Northern Hemisphere, January.



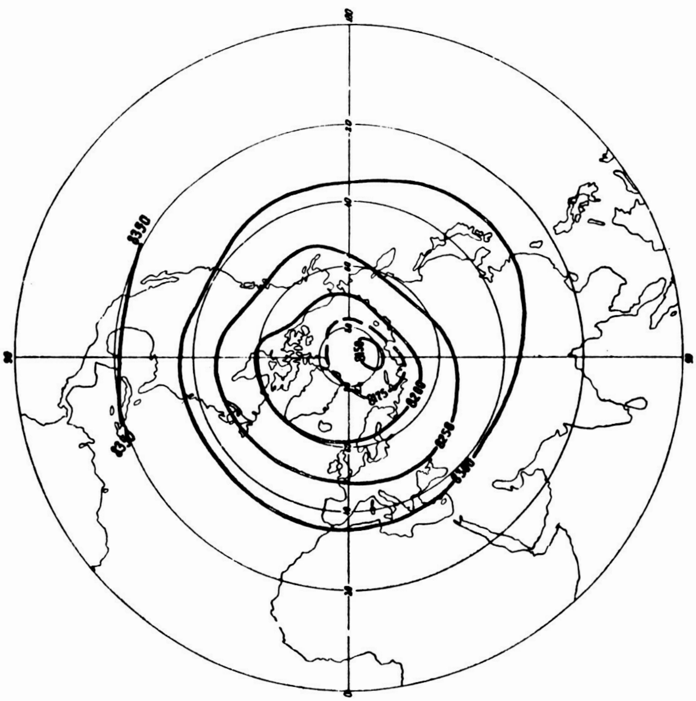


Fig. 2 (continued) February

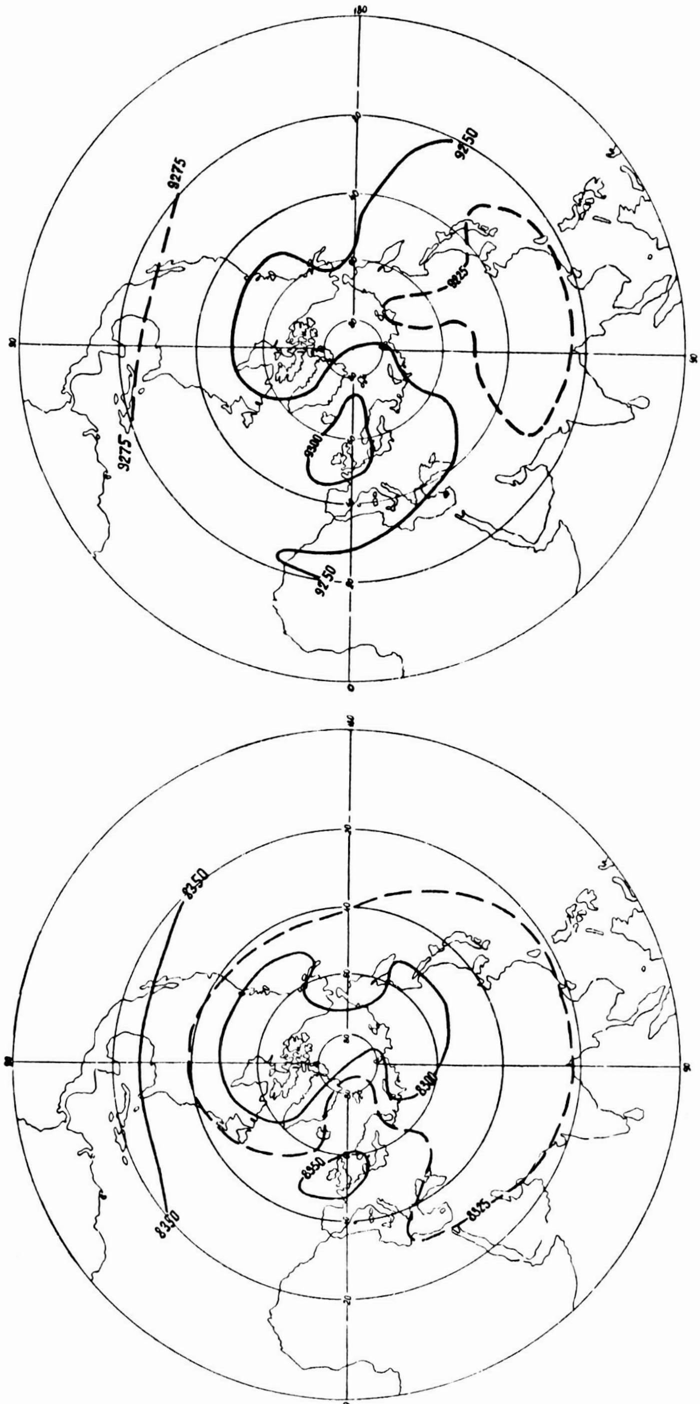


Fig. 2 (continued) March

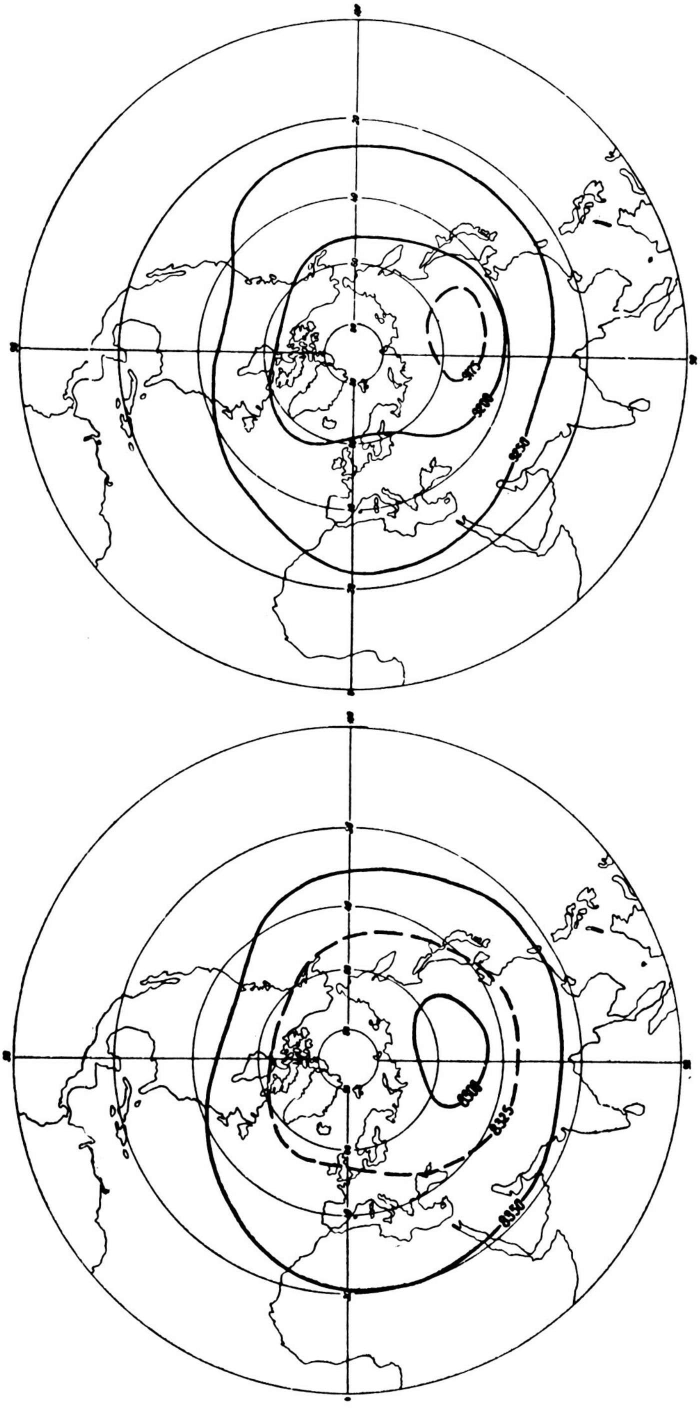


Fig. 2 (continued) April

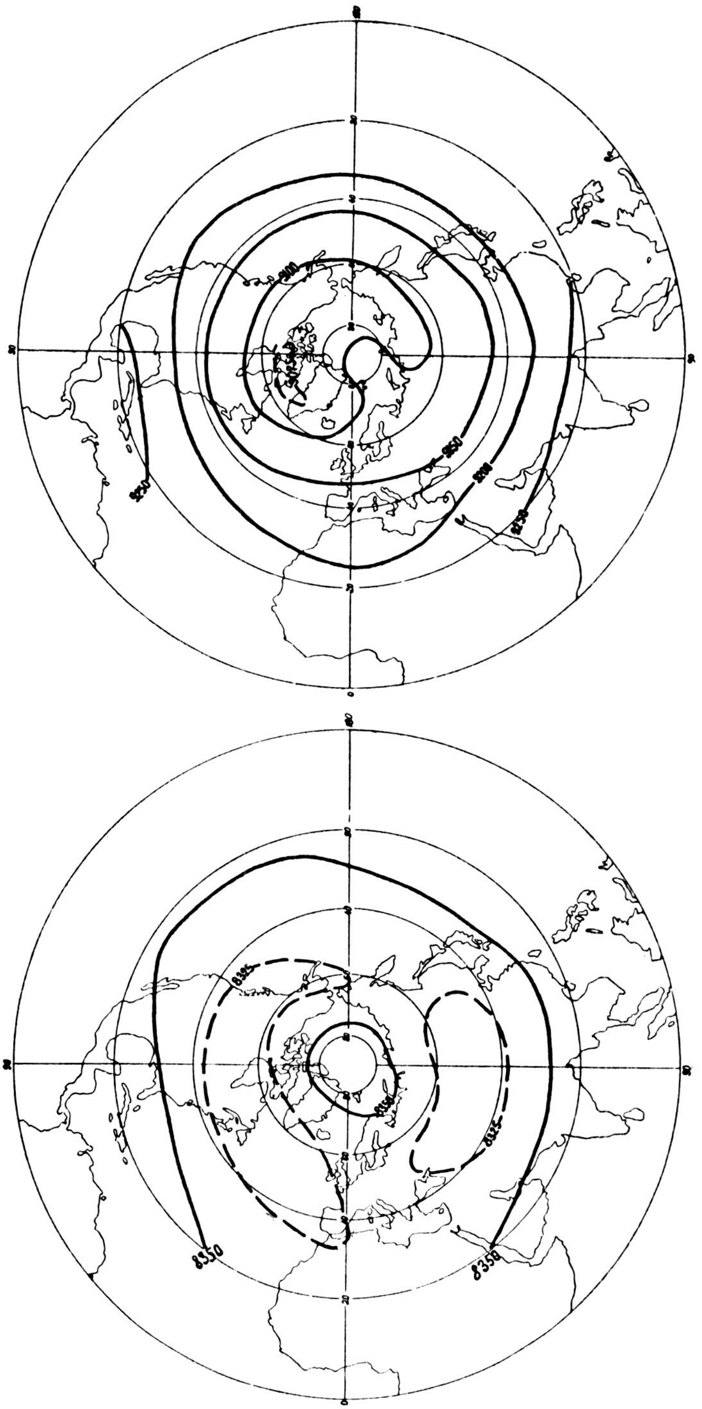


Fig. 2 (continued) May

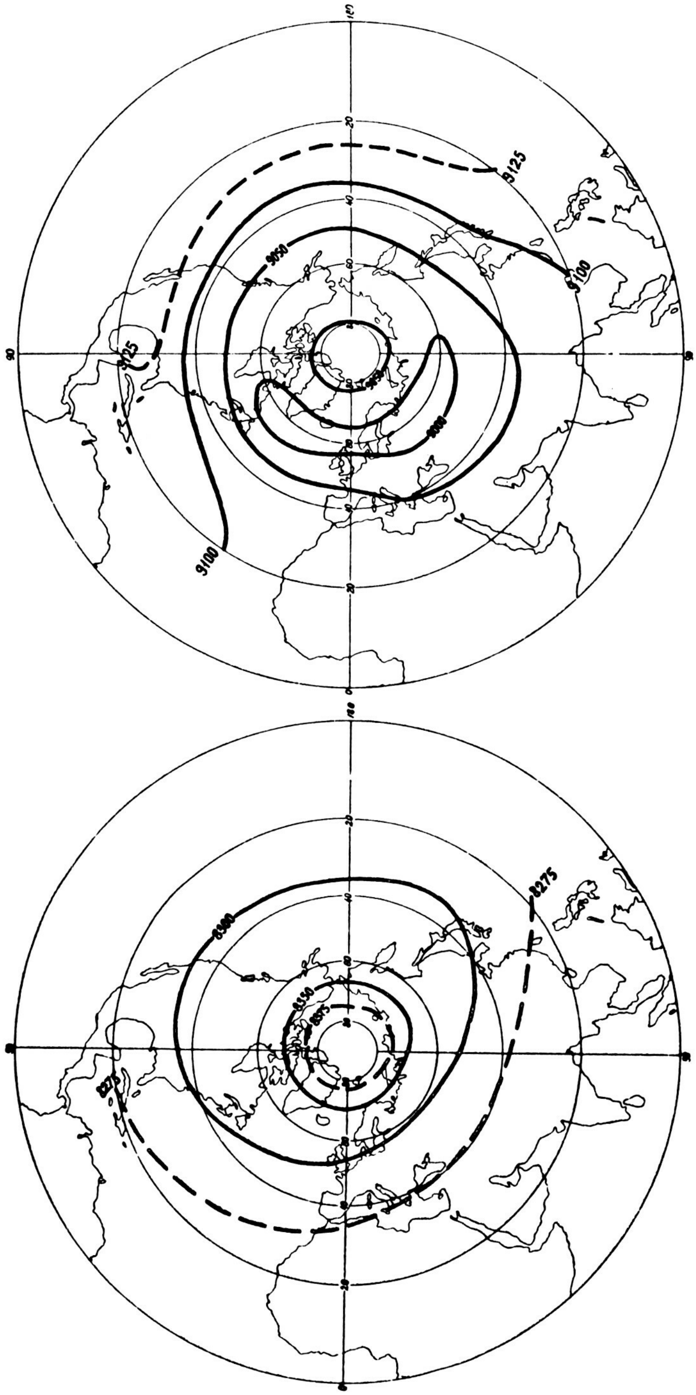


Fig. 2 (continued) June

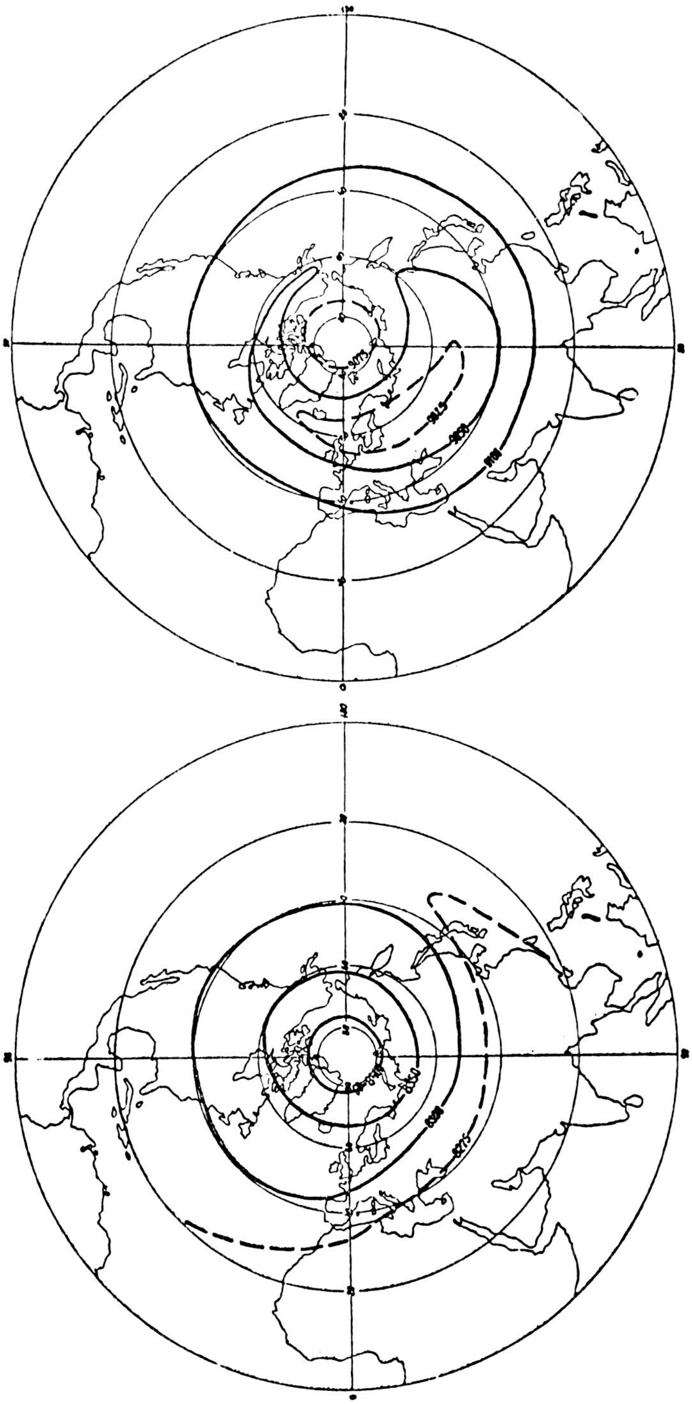


Fig. 2 (continued) July

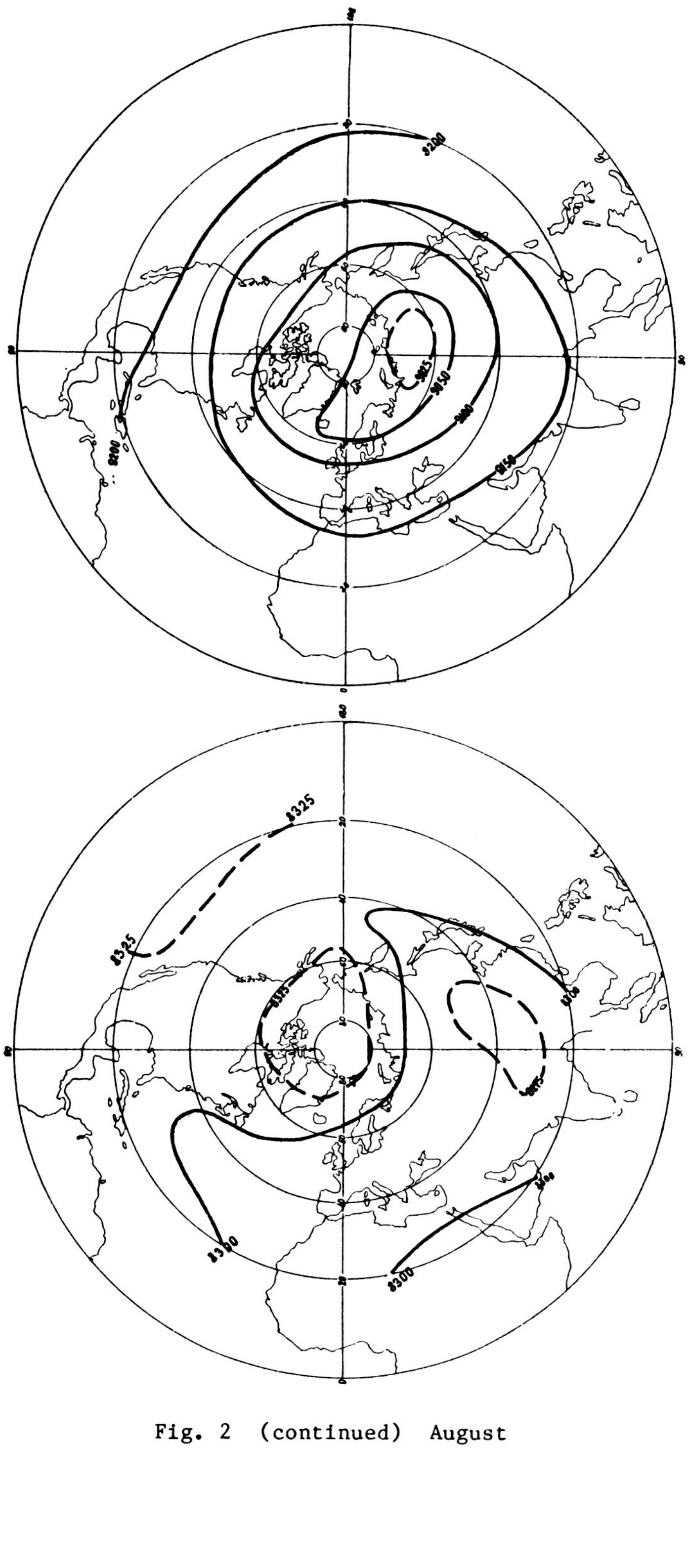


Fig. 2 (continued) August

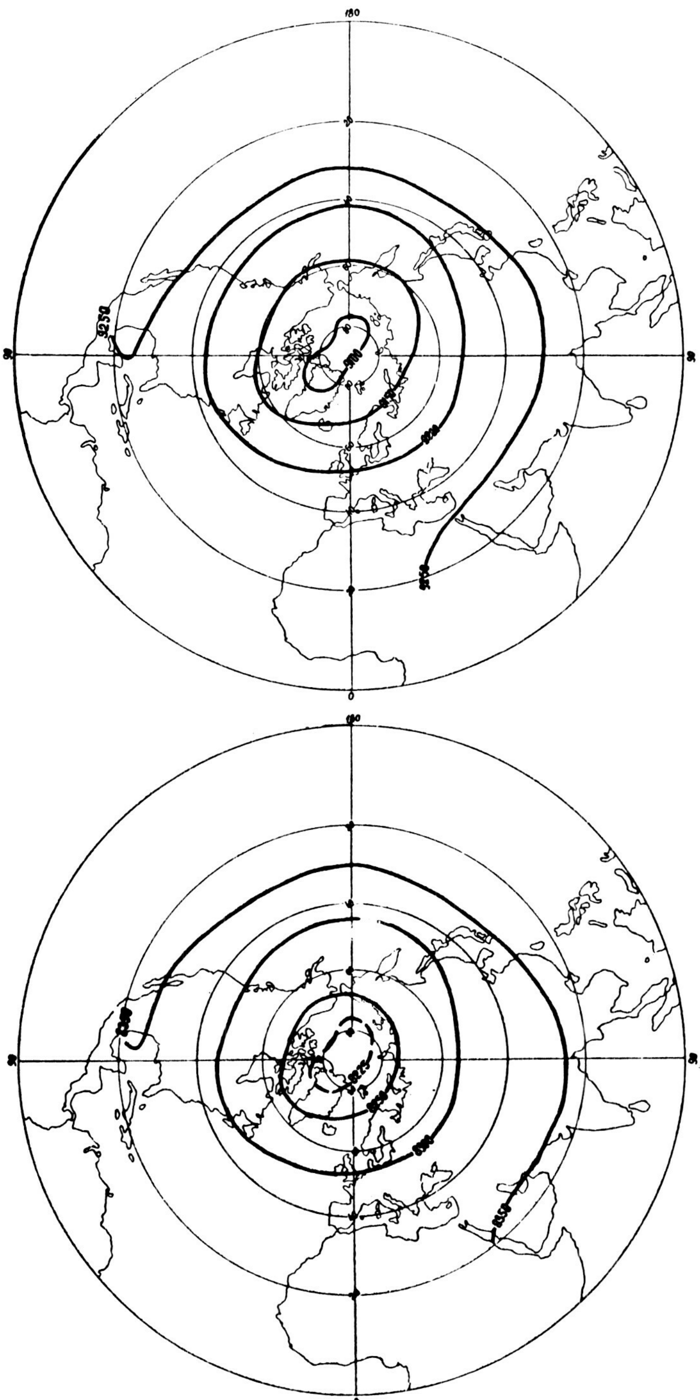


Fig. 2 (continued) September

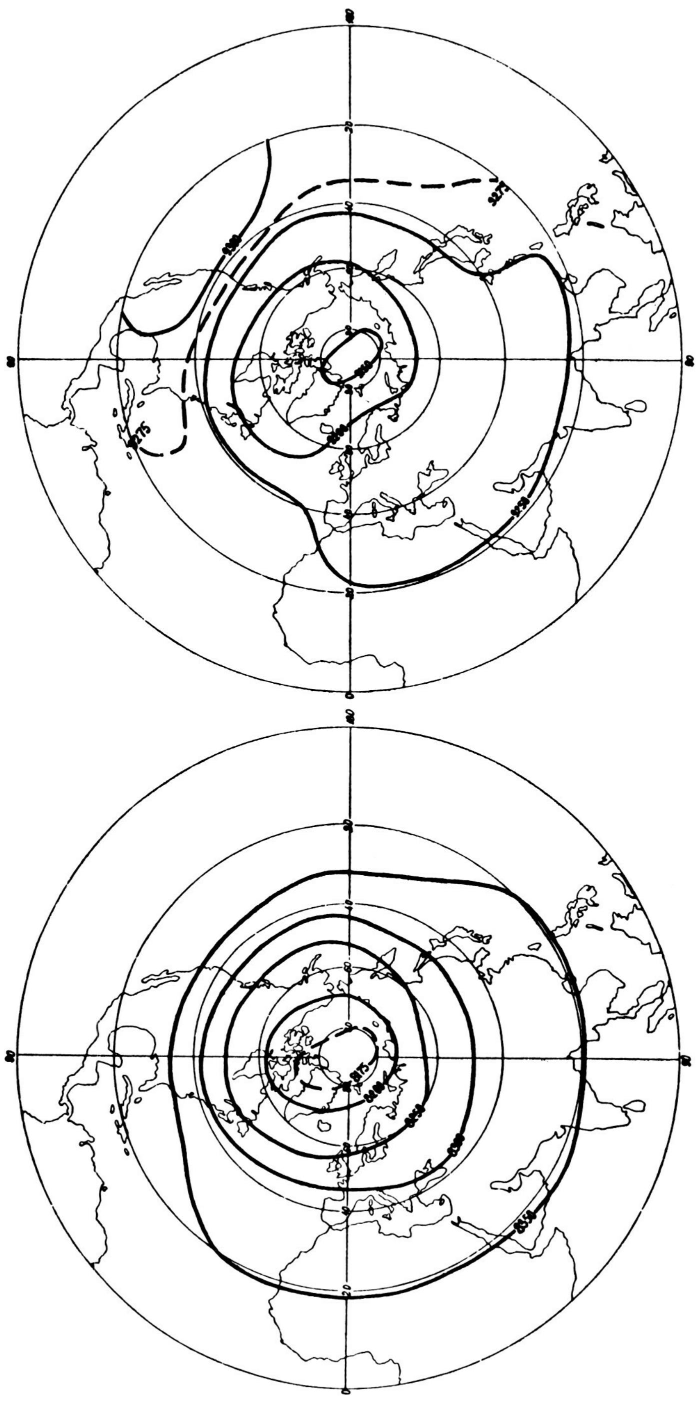


Fig. 2 (continued) October

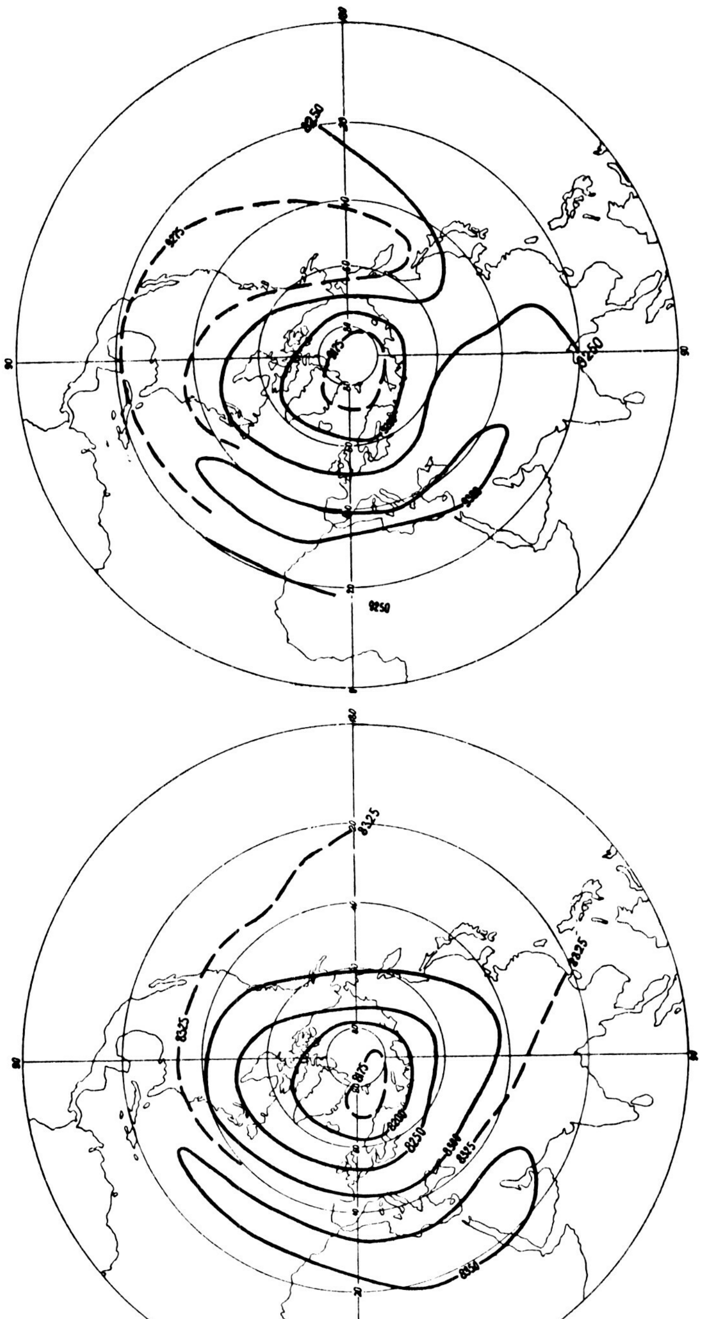
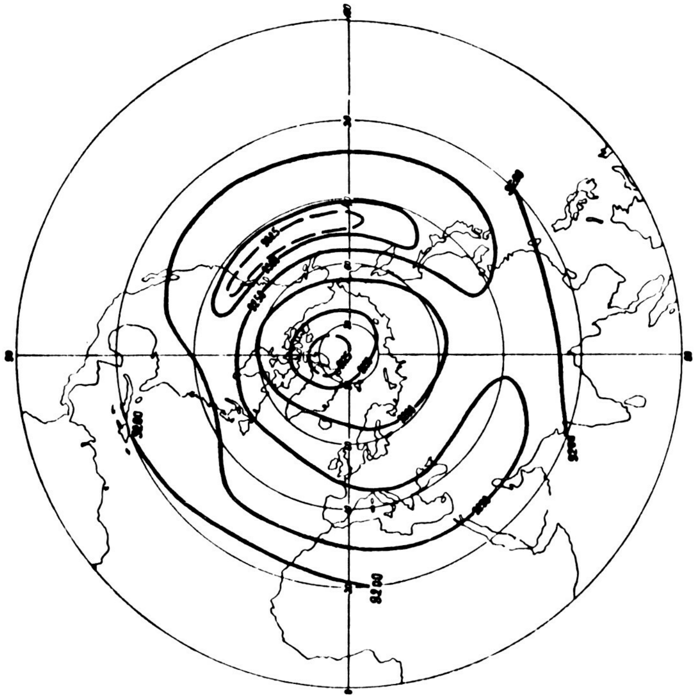


Fig. 2 (continued) November



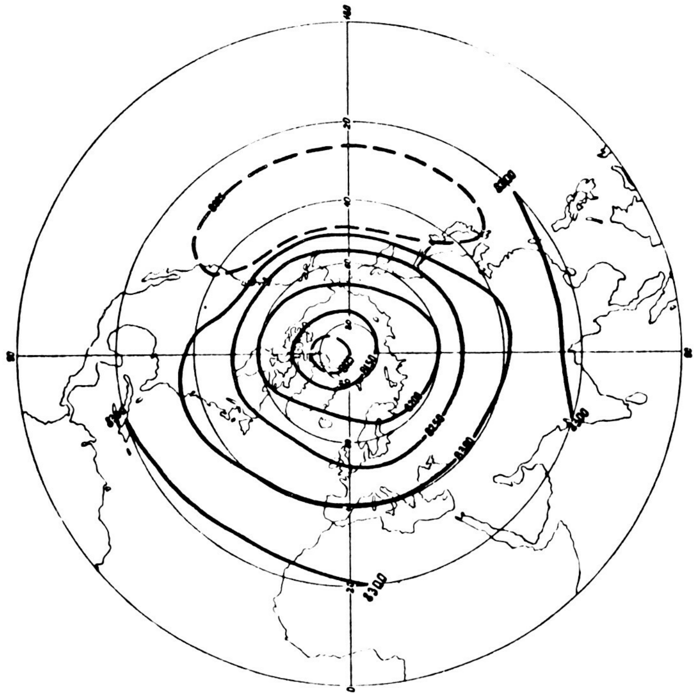


Fig. 2 (continued) December

Late in summer a destruction of the polar high takes place. In August, the center of the anticyclone which shifted to the Canadian sector of the Arctic could be traced only at the 0.005 mb level while in higher atmospheric layers it was not observed and a low pressure area could be seen arising over northern Asia. In September and October the latter occupied the polar region and deviations from the zonal pressure distribution were relatively small (two troughs appeared directed towards Greenland and northeastern parts of Asia). Some deformation of the cyclonic vortex (with troughs in the North American and Asian sectors) was also observed all through the winter months.

Beginning in November, the area of westerly flow within the cyclonic circumpolar vortex was contracting along with the appearance of a high pressure belt in the subtropics (near 30°N at the altitude of 83-84 km and 40°N at 93-94 km). The belt was pronounced until January and dissipated in February. In March two pressure ridges became active, stretching from lower latitudes towards northern parts of the Pacific and Atlantic oceans and forming a high pressure center near 60°N in the Atlantic region. In April, the available date for the years considered did not reveal further progress of the anticyclonic system (as may be the case in the climatological situation (MININA et al., 1977, 1981)), and only the May geopotential patterns showed the development of the polar high pressure area - better at the 0.005 mb level than at 0.001 mb.

It is known that the time of the seasonal reversals of meridional pressure gradients and the change of sign of zonal circulation in the meteor zone can vary significantly from year to year (ENTZIAN and TARASENKO, 1971; KAZIMIROVSKY and KOKOUROV, 1979; MININA et al., 1977). Thus the reliable climatological picture of seasonal variations in atmospheric pressure and geopotential heights of constant pressure surfaces in this zone may be determined only in the future, provided the duration of the period of satellite observations is long enough.

It is of interest to compare the satellite-based maps with the results of an earlier analysis (GAIGEROV, et al., 1983) of the 0.001 mb level geopotential fields based on other observational techniques. The comparison confirmed general similarity of pressure patterns depicted in the two series of maps, though the winter cyclonic system shown in that paper was significantly deeper than its counterpart in Fig. 2 of the present analysis.

The pressure patterns depicted for the lower thermosphere of the northern and southern hemispheres were found to have much in common, e.g., in seasonal change of polar cyclonic and anti-cyclonic vortices. Main hemispheric asymmetry (besides that shown above concerning the area of domain in the anticyclonic vortex at the 0.005 mb level) can be seen in the following; meridional gradients of geopotential height between the tropics and the pole in the winter season were generally weaker in the northern hemisphere; there was no evidence of a high pressure belt at 30-40°S similar to that visible at the northern hemisphere maps in November-January.

The presence of stationary waves in the mean geopotential fields was investigated by means of Fourier analysis applied at various latitudes. Amplitudes and phases of disturbances with zonal wave numbers n=1 and n=2 in the northern hemisphere are shown in Fig. 3 for the winter and spring

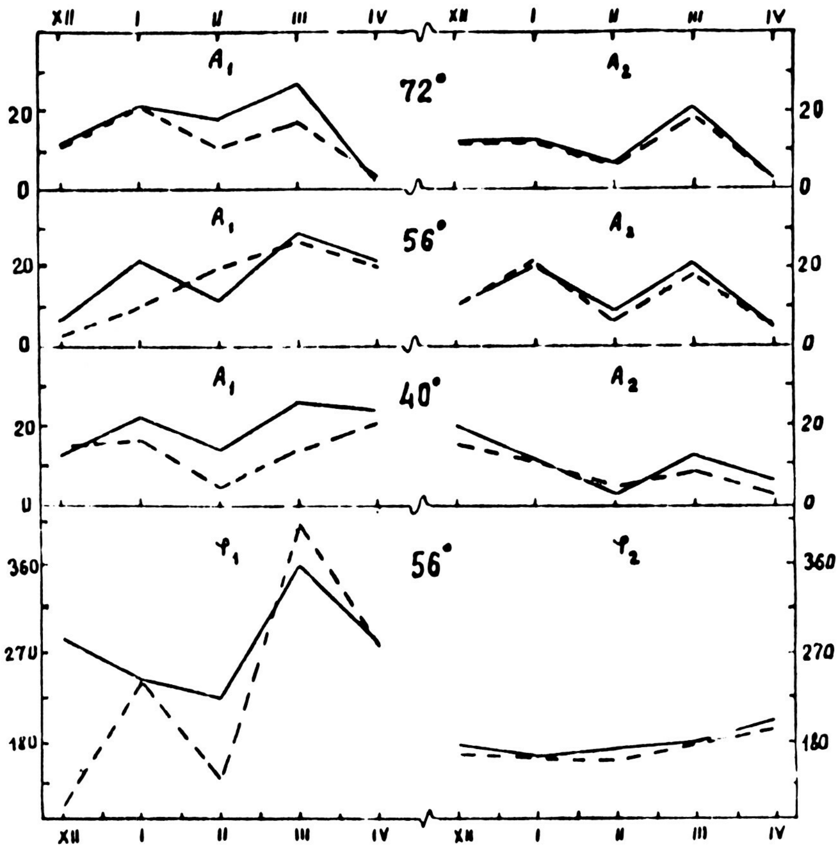


Fig. 3 Amplitudes (A, dm) and phases (ϕ, °E) of zonal waves 1 (left) and 2 (right) of the heights of the 0.001 mb (solid line) and 0.005 mb (dashed line) levels at latitudes 40, 56, and 72°N.

seasons. The amplitudes are presented for 3 latitudes (40, 56 and 72°N) and the phases only for 56°N since the phase values have not revealed systematic change with latitude. It should be stressed that the amplitudes of the second harmonic were not much less than those of the first harmonic. This was not the case in the southern hemisphere where wave 1 was commonly much more significant than wave 2. The amplitude of the first harmonic in mid-latitudes of the northern hemisphere revealed some increase in early spring (March), but it was in general not as great as in high latitudes of the southern hemisphere. Thus the transition to the anticyclonic pattern via the development of ridges of high pressure in a certain region in spring was not so pronounced in the northern hemisphere during the years considered as it was in the southern hemisphere. This is corroborated by the high variability of phase in case of wave 1 in Fig. 3. Conversely, the phase of wave 2 was practically invariable during all months of the winter and spring period (the ridges near 0° and 180° long), with orientation of the troughs towards the continents. There was no definite trend in the magnitude of the amplitude of wave 2 during winter and spring; the values of the amplitude were not very different in the northern and southern hemispheres. In general, deviation from zonality in mean pressure fields in the lower thermosphere during the winter and spring periods considered were less pronounced in the northern than in the southern hemisphere. However, additional observations are needed to see if this hemispheric asymmetry is confirmed in the long run.

Variations of wave amplitudes in the lower thermosphere of the northern hemisphere with latitude were not substantial; however, the amplitude of wave 2 in some months was not as large at 40°N as at higher latitudes.

A comparison of the amplitudes in the thermosphere and mesophere was made which showed that in winter (December) the amplitude of wave 1 in the mesophere (BOUTKO et al., 1985) was greater than at higher levels. Similar reduction of the amplitude (with little change of phase) was found in the case of wave 2.

It is of interest to compare zonal mean values of the geopotential heights obtained from the maps to appropriate values from a reference atmosphere. It should be kept in mind that the maps described in this paper represent one of the first attempts to picture pressure fields at heights greater than 80 km with the help of satellite data and they are possibly neither very accurate nor representative since only crude estimates of the geopotential can be obtained from one-channel radiances and the period of the observation was limited. With this in mind, it seems encouraging to see (Fig. 4) good agreement of seasonal variations of the geopotential obtained from the maps and from CIRA 1972 data. The agreement is better in higher latitudes, so the compiled maps seem to be more reliable north of 25-30°N.

As for the seasonal variations of heights of the constant pressure surfaces, the curves of the seasonal course in Fig. 4 are generally similar in low latitudes for the two levels considered, while they reveal an out-of-phase relationship north of 50°N. This is reflected also in the distribution of the phases (Fig. 5) - in the case of the annual wave (which was dominant in all latitudes north of 30°N at the 0.001 mb level and north of 50-60°N at the 0.005 mb level) the phases at the two levels were close together in low latitudes and revealed an abrupt change of phase north of

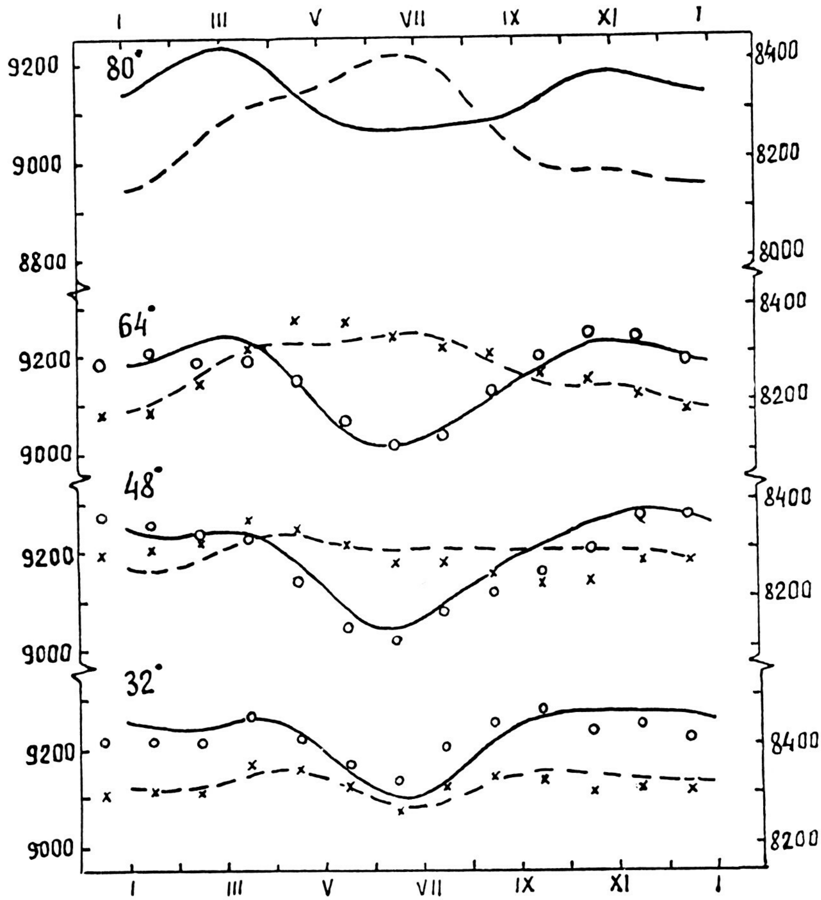


Fig. 4 Seasonal variation of heights (dm) of the 0.001 mb (solid line) and 0.005 mb (dashed line) surfaces in the Northern Hemisphere. (Circles and crosses 0.001 mb and 0.005 mb heights, respectively, calculated from CIRA 1972.)

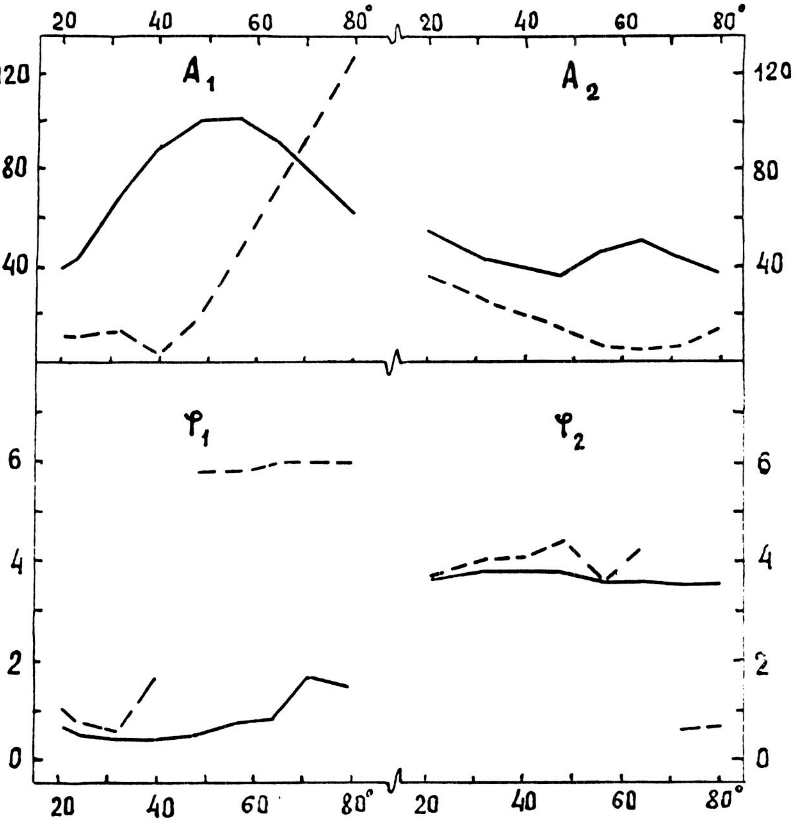


Fig. 5 Amplitudes (A, dm) and phases (ϕ, month) of the annual (left) and semiannual (right) variations of heights of the 0.001 mb (solid line) and 0.005 mb (dashed line) surfaces in the Northern Hemisphere (ϕ = 0 on 15 December).

45°N (maximum in June at the mesopause level and in January at heights of about 93 km). Such shift of the phase of the annual variation with increasing height in the lower thermosphere of the Arctic and Subarctic from the middle to the beginning of the year is related to the attenuation of the polar anticyclone at heights greater than 90 km. It should be marked that the change of the phase of the annual wave with height in the 0.005-0.001 mb layer was not as rapid in the southern hemisphere over the Subantarctic. A specific feature of seasonal variations in the low latitude thermosphere is the simultaneous appearance of the annual wave maximum (in January) in the two hemispheres which is undoubtedly related to the corresponding phase of the annual temperature wave in the equatorial mesophere (KOSHELKOV, 1984).

For most of the northern hemisphere the amplitude of the annual variation was greater at the 0.001 mb level, and only in the Arctic north of 70°N was the reverse proved to be true.

The comparison of the amplitudes of the annual variation in the two hemispheres confirmed that at levels close to the mesopause (0.005 mb) the amplitudes were significantly greater in the southern hemisphere. This is also true for the stratosphere and mesophere (BOUTKO et al., 1985). The asymmetry is related to lower values of the geopotential in the southern hemisphere relative to the northern hemisphere in the winter season as well as to the similar phase of the annual wave (maximum in summer) in the extratropical latitudes of the two hemispheres. At the 0.001 mb level the geopotential height values in winter remained lower in the southern hemisphere (maximum in winter), and the amplitude was no longer greater in the southern than in the northern hemisphere.

The semi-annual wave in the lower thermosphere of the northern hemisphere was more pronounced at the 0.001 mb level than at the 0.005 mb level. The phase was almost independent of latitude (the first maximum in April). The amplitudes of the semi-annual and annual variations were comparable in low latitudes while the latter dominated at higher latitudes.

The constant pressure contour maps compiled for the lower thermosphere enabled an estimate of zonal mean geostrophic circulation to be made (Fig. 6). The geostrophic zonal wind speed was calculated with the help of zonal mean values of the geopotential heights, with some smoothing in latitude and time (using a 1-2-1 scheme). For the comparison with the geostrophic calculations, some recent results of radio wind measurements in the meteor zone are also presented in Fig. 6; these involve an empirical model (PORTNYAGIN, 1984) and wind analyzed data for 9 radiometeor and ionospheric stations in Europe, North America and Japan (MANSON, et al., 1984). The actual wind data were derived from the cross-sections presented in MANSON et al., (1984) and PORTNYAGIN (1984) at the geometric heights corresponding to the location of the 0.001 mb and 0.005 mb surfaces for each month. The wind values from PORTNYAGIN (1982) for the stations with similar latitudes were averaged during the preparation of Fig. 6.

The distributions of zonal geostrophic and actual wind speeds in Fig. 6 have much in common. In particular, a seasonal change of easterly and westerly flow has been recorded. Maximum values of both easterlies and westerlies were similar in both geostrophic and actual winds. The well-known decrease of zonal wind with increasing height in the lower thermosphere was confirmed. In accordance with this fact, the amplitude of

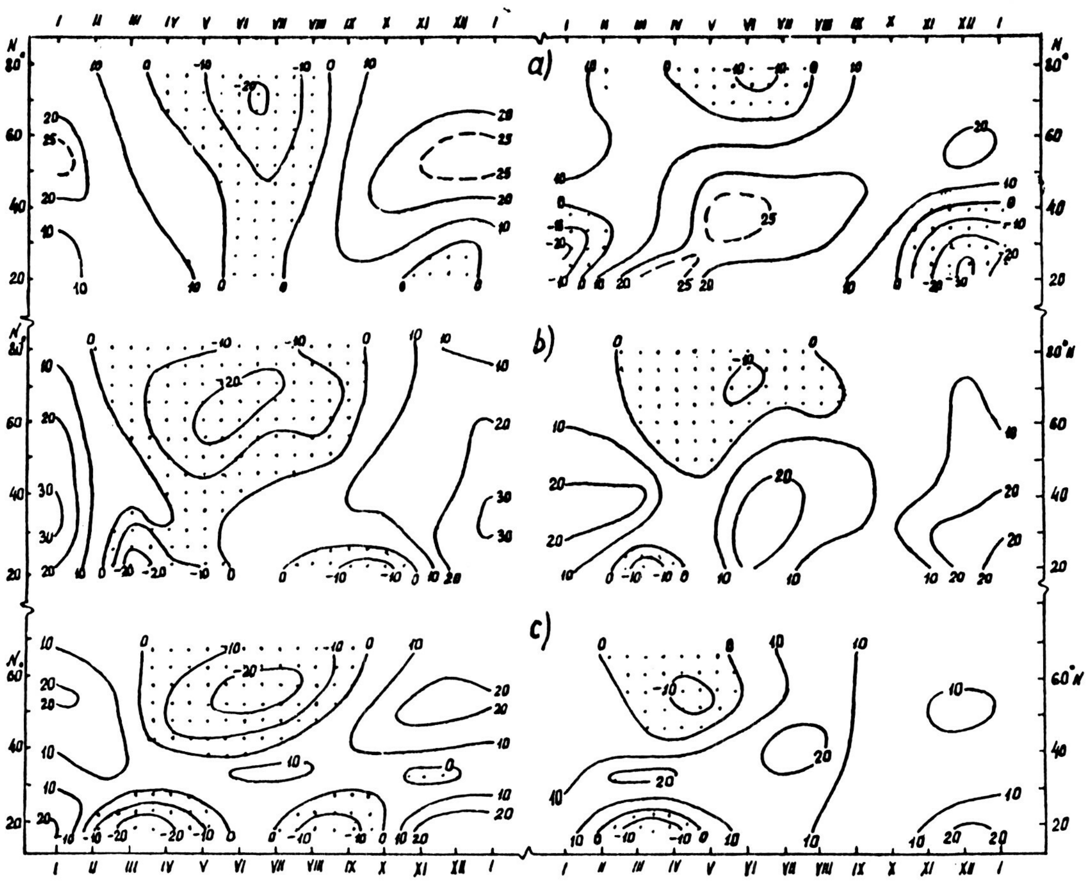


Fig. 6 Latitude-time sections of mean zonal wind (m/s) in the lower thermosphere of the Northern Hemisphere: a) zonal geostrophic wind speeds at the 0.005 mb (left) and 0.001 mb (right) surfaces, b) actual wind speeds at the 0.005 mb (left) and 0.001 mb (right) surfaces, compiled from PORTNYAGIN (1984), c) actual wind speeds at the 0.005 mb (left) and 0.001 mb (right) surfaces, compiled from MANSON ET AL. (1984).

the annual variation of geostrophic zonal wind (Fig. 7) north of 40°N was greater at the 0.005 mb than at the 0.001 mb level. At the 0.005 mb level the phase was reversed in low latitudes (maximum in summer).

The distributions of zonal geostrophic and actual winds in Fig. 6 also reveal substantial discrepancies. These are particularly serious in low latitudes, e.g., in the seasonal position of easterly and westerly flow areas. It is evident that in general actual wind measurements could provide a more reliable representation of prevailing winds than geostrophic estimates. Of special interest is, however, an area of easterly geostrophic flow south of 40°N in early winter at the 0.001 mb level, which is related to the development of a high pressure area in November-January in this region. The continuous appearance of the easterlies during a 30 month period seems to corroborate their reality. In this case the reason for this "anomalous" circulation might be attributed to specific features of the years considered, and so significant interannual variability of the prevailing flow might be a possibility in the subtropical lower thermosphere.

Certain derivations of geostrophic flow estimates from mean radiometeor and ionospheric drift wind data also appear in Fig. 6 in the extratropical latitudes. In particular, it has long been known from actual wind measurements that the spring appearance of easterly circulation takes place earlier in the lower thermosphere than in the strato-mesophere, and a semi-annual wind variation with westerly wind maxima in winter and summer is typical for the circulation in the meteor zone (ENTZIAN and TARASENKO, 1971; KAZIMIROVSKY and KOKOUROV, 1979; MININA et al., 1981; PORTNYAGIN, 1982).

This is not obvious in the case of the geostrophic calculations (Figures 6 and 7). The existence of the discrepancies is not surprising if one keeps in mind that, first, geostrophic wind estimates at high levels are probably not accurate; second, geostrophic winds may differ from actual; and third, satellite-based maps need to be improved.

It should be added that differences also exist between various analyses of actual wind measurements in the meteor zone. These can be seen in Fig. 7, e.g., in the duration of the period of easterly flow in spring and summer at the 0.001 mb level or in the latitudinal structure of the westerly flow in winter. So it seems without doubt that, with the continued progress of satellite observations, constant-pressure contour maps can contribute not only to characterizing pressure fields in the lower thermosphere but also to analyzing circulation in the meteor zone.

An attempt at comparison of the geostrophic zonal wind in the lower thermosphere of the two hemispheres was made which testified to generally higher values of westerly flow in the southern than in the northern hemisphere (Table 1). The differences are however noteworthy only in lower latitudes (near 30° lat.) while it follows from the actual wind analysis (PORTNYAGIN, 1984) that a difference of this kind may be observed in most latitudes. According to the geostrophic calculations, the axis of the winter westerly flow at levels close to the mesopause (0.005 mb) was located nearer to the equator in the southern than in the northern hemisphere (35-40°S and 50-55°N, respectively). Somewhat different values are given by the wind model of PORTNYAGIN, (1984), namely, 45°S and

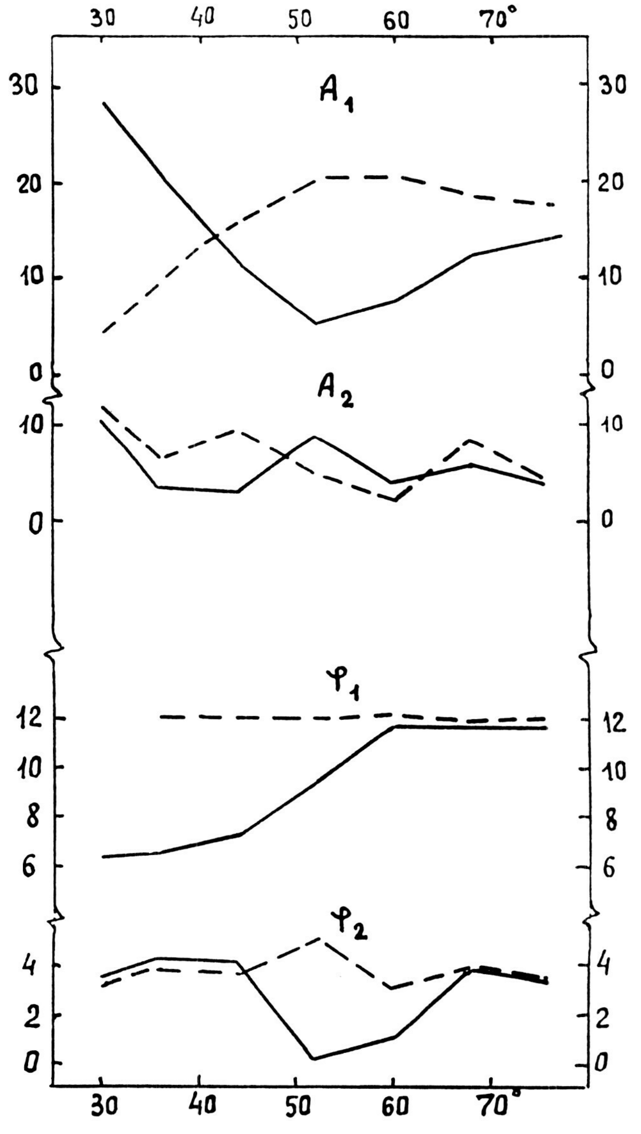


Fig. 7 Amplitudes (A, m/s) and phases (ϕ, month) of the annual (1) and semiannual (2) variations of the geostrophic wind speed in the lower thermosphere of the Northern Hemisphere. (0.001 mb, solid line; 0.005 mb, dashed line, zero phase on 15 December.)

Table 1

Mean differences in speed (mps) of the zonal geostrophic wind in the southern and northern hemispheres at the 0.005 mb level (81-83 km) (top) and respective differences for the actual wind (PORTNYAGIN, 1984) (bottom) for 3-month seasons.

Lat.	Season			
	Winter	Spring	Summer	Autumn
70	5/18	-6/10	2/14	0/9
50	-2/27	8/21	4/13	18/18
30	41/9	14/25	15/18	22/9

Mean speeds of zonal geostrophic wind averaged for the two hemispheres are presented in Table 2. These values can serve to characterize the circulation in the lower part of the meteor zone as derived from satellite data irrespective of the hemisphere.

Table 2

Mean wind speeds (mps) of zonal geostrophic wind in the lower thermosphere (two hemispheres combined). 0.001 mb level (91-93 km) - top, 0.005 mb level (81-83 km) - bottom.

Lat.	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
70	16/20	8/10	-4/-1	-2/-6	-1/-9	-4/-15	-4/-16	3/-5	11/10	12/15	16/18	19/22
60	12/19	1/9	0/3	5/1	8/-4	5/-12	4/-14	11/-2	14/15	17/23	17/23	18/24
50	7/22	0/15	4/12	16/11	23/5	20/-4	18/-8	20/1	22/18	23/32	23/35	18/31
40	7/30	7/26	11/22	22/20	31/11	31/1	27/-1	24/6	21/18	19/32	17/39	10/38
30	0/26	10/30	15/24	20/17	28/9	31/4	31/6	26/12	20/18	12/22	0/25	-7/24

NOTE: Month 1 refers to Jan. N.H. and July S.H., 2 to Feb. N.H. and Aug. S.H., and so on.

35-40°N. It seems reasonable that a more detailed analysis of hemispheric asymmetry in geostrophic circulation may not be justified.

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