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BASIC FEATURES OF GLOBAL CIRCULATION IN THE MESOPAUSE-LOWER THERMOSPHERE REGION

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Circulation models, which cover heights up to the turbopause, i.e., practically up to the natural upper border of the homosphere, play an important part in the studies of general features of global atmospheric circulation. At present there are a number of circulation models for the height range up to 100-120 km. For the heights above the upper limit of standard radio sounding (~30 km) these models are based on rocket sounding data, with non-systematized data of meteor radar observations and ionospheric drift measurements used only in particular cases.

Meanwhile as continuous 24-hour meteor radar wind measurements convincingly indicate the resultant wind at 70-110 km (mesopause-lower thermosphere region) is a superposition of daily prevailing wind and of the winds originating from diurnal and semidiurnal variations of atmospheric parameters. And significant day-to-day and seasonal variations are observed in amplitudes and phases of diurnal and semidiurnal wind oscillations.

Thus average velocities of prevailing wind at 70-110 km can be obtained reliably enough only on the base of the methods which allow for daily and shorter period observations of resultant wind velocities with further selection of diurnal wind velocity means from the data obtained. These are first of all the radar meteor trail technique (D2 technique, according to URSI classification) and some versions of ionospheric methods of spaced receiver drift measurements (D1 technique), such as partial reflection method, drift measurements in the long-wave range, etc. But earlier circulation models for the heights of mesopause-lower thermosphere developed from D1 and D2 measurements were based on scanty data.

By now D1 and D2 techniques have been used and are being used for observations at a lot of stations located in the high, middle and low latitudes of both hemispheres. The systematical wind velocity measurements with these techniques make it possible to specify and to refine earlier mesopause-lower thermosphere circulation models. With this in view we have made an effort to obtain global long-term average height-latitude sections of the wind field at 70-110 km using the analysis of long-period D1 and D2 observations. Data from 26 meteor radar and 6 ionospheric stations were taken for analysis.

Observational periods at different stations do not always completely coincide and in several cases they even do not overlap. Thus the wind field model based on these data can be considered as a long-term average (climatic) model with the accuracy characterized to a first approximation by monthly mean velocity variance D resulting from year-to-year variations of the velocities. The estimates from long-period measurements at Heis Island, Molodezhnaya Station, in Kuhlungsborn, Obninsk, Jodrell Bank and Adelaide have shown, that on the average the value $\sigma_i = \sqrt{D_i}$ can be taken as $\sigma_i \simeq 7$ m/s (for the Northern Hemisphere $\sigma_i \simeq 5$ m/s, for the Southern $\sigma_i \simeq 9$ m/s).

An important point in developing the model was the assumption of zonal mean approximation being acceptable for a climatic description of the wind regime in mesopause-lower thermosphere. The assumption was established on the comparison of seasonal variation of zonal and meridional wind velocities at observational stations closely spaced along latitudes but significantly different with respect to longitude.

Figure 1 a,b,c,d shows monthly mean velocities of zonal (v) and meridional (u) winds for the stations located in two latitudinal belts of the Northern Hemisphere: 52°-57°N and 45°-50°N. (52°-57°N latitude belt includes the stations: Jodrell Bank (2°E), Kuhlungsborn-Collm (12°E), Obninsk (38°E), Kazan (49°E), Tomsk (85°E), Badary (102°E) and Saskatoon (107°W); 45°-50°N: Budrio (12°E), Kiev (31°E), Kharkov (30°E), Volgograd (44°E) and Khabarovsk (135°E)). It is easily seen, that despite the significant differences in longitude the features of seasonal variations of wind parameters remain essentially similar at all the stations. The respective variance of values over longitude D_λ is characterized by $\sigma_\lambda^{EW} \simeq 7$ m/s, $\sigma_\lambda^{NS} \simeq 5$ m/s, which is comparable with σ_i.

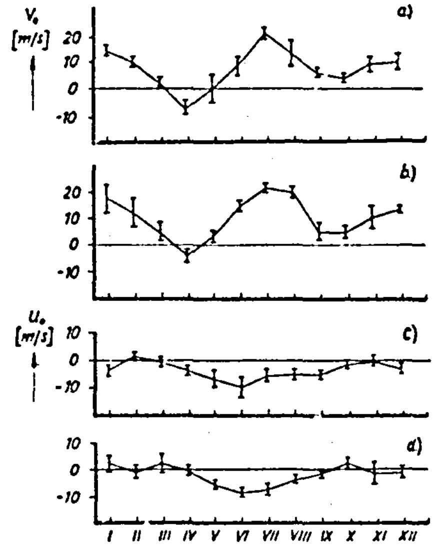

Figure 1. Seasonal variation of zonal (u_0) and meridional (v_0) components of the prevailing wind velocity at 95 km height, averaged over various longitudes for the two latitudinal zones: 52°-57°N (a,c), 45°-50°N (b,d).

It is necessary to point out that at a number of stations distributed well enough over the latitudes the measurements were taken with equipment enabling the measurement of altitude wind profiles in the height range of 70-110 km. (Kiruna, 68°N; Saskatoon, 52°N; Garchy, 48°N; Atlanta, 35°N; Punta Borinquen, 18°N; Townsville, 18°S; Adelaide, 35°S; Birdlings Flat, 44°S). As for the rest of the stations, measurements refer to the average meteor zone ~95 km and make it possible to specify the character of latitudinal dependence of wind velocities in the cross sections obtained.

Besides, for the 70-80 km height range, rocket measurements were also used. Comparison has shown the monthly mean wind velocities from rocket data to exceed (by 15-50%) those from D1 and D2 measurements. Basic regularities of seasonal variation however show a good qualitative agreement for all the three methods.

Height-latitude sections of zonal wind field were constructed as follows. For each month of the year wind velocity means obtained from experimental evidence were plotted on a two-dimensional coordinate grid over the range of $90°N < \varphi < 90°S$, $70\ km < h < 110\ km$. Isotachs were drawn on the obtained height-latitude sections taking account of the data plotted, and in some cases the data were smoothed within the range of acceptable errors in mean values. The experimental evidence available showed quite good agreement and on the whole enabled the basic circulation systems to be identified and their seasonal transformations to be traced.

Monthly mean wind velocities at height-latitude grids with a height step $\Delta h = 2$ km and a latitude step $\Delta\varphi = 3°$ were taken from the obtained monthly mean height-latitude sections by means of interpolation. The latitude dependence at each height level was approximated by a Fourier series up to the fourth harmonic, used to estimate latitudinally smoothed values for $V(\varphi, z)$. Height-latitude sections of the zonal wind field constructed in this manner are presented in Figures 2-5. They show that the spatial structure of the zonal wind field has a number of regularities and undergoes appreciable seasonal variations. These regularities are briefly discussed below for the main seasons of the year.

December, January, February (Figure 2)

Zonal component sections of the prevailing wind for winter in the Northern Hemisphere and summer in the Southern Hemisphere exhibit five basic dynamical structures.

(1) A region of westerlies in the Northern Hemisphere, dynamically connected with the strato-mesospheric winter low. An additional circulation cell develops in the upper part of this dynamic structure.
(2) A region of high-latitude easterly circulation in the lower thermosphere of the Northern Hemisphere.
(3) A low-latitude region of easterly circulation.
(4) A region of easterlies in the Southern Hemisphere.
(5) A westerly circulation cell in the Southern Hemisphere.

March, April, May (Figure 3)

These are the months of the seasonal reconstruction of the circulation in the meteor zone. They are characterized by the following dynamic structures:

(1) A region of easterly circulation in the Northern Hemisphere.
(2) A region of westerly circulation in the Northern Hemisphere.
(3) A low-latitude region of easterlies.
(4) A region of westerlies in the Southern Hemisphere.

June, July, August (Figure 4)

The height-latitude structure of the zonal wind field in these months is to some extent similar to that in December-February in the hemispheres with respective seasons. However, the circulation patterns in the summer (Northern) and winter (Southern) hemispheres possess some peculiarities which distinguish them from similar seasonal structures of the circulation in December-February. The following dynamic structures are clearly seen.

(1) A region of easterly circulation in the Northern Hemisphere.
(2) A region of westerly circulation in the lower thermosphere of the Northern Hemisphere.

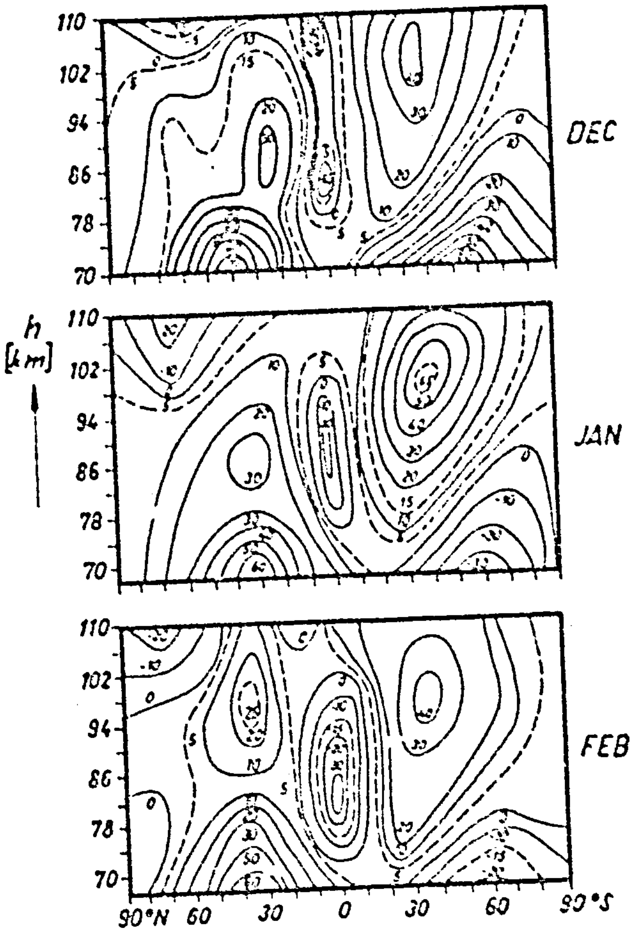

Figure.2: Height-latitude structure of the zonal wind field (m/s) for December-February (a-December, b-January, c-February; positive values are westerly wind).

(3) A large region of westerlies in the Southern Hemisphere.
(4) A region of easterly circulation in the lower thermosphere of the Southern Hemisphere which couples to the zone of low-latitude easterlies. Such field structure of easterlies in the winter Southern Hemisphere differs from the structure of easterlies in the winter Northern Hemisphere described above.

September, October, November (Figure 5)

November can be ranked among the months of steady circulation. In September/ October, several transformations of the circulation systems take place.

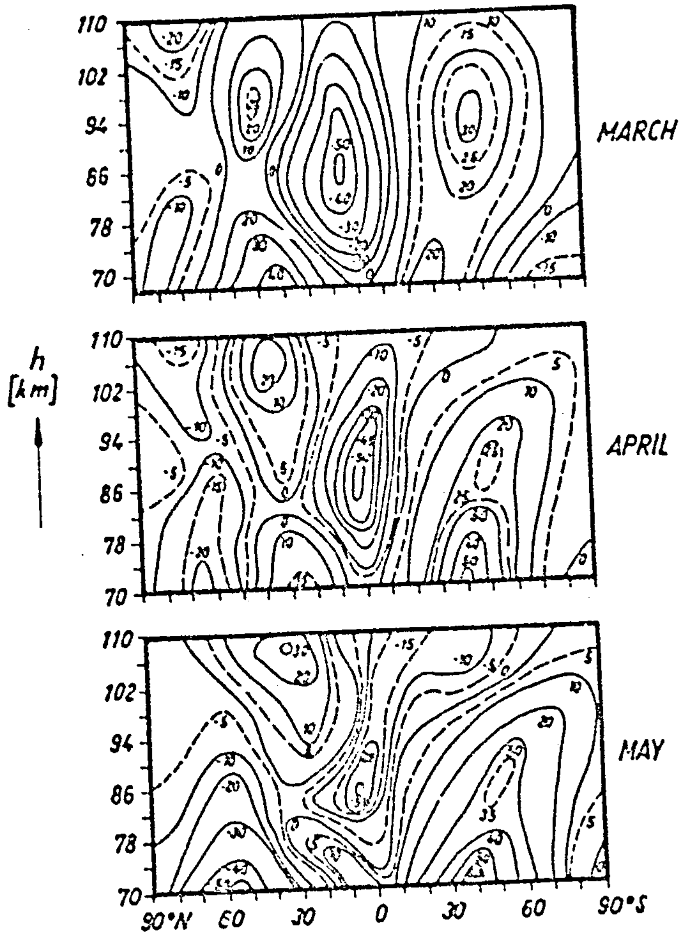

Figure 3. Height-latitude structure of the zonal wind field (m/s) for March-May (a-March, b-April, c-May).

The cross sections considered above reveal that despite some analogy in seasonal variations of basic dynamic structures in the Northern and Southern Hemispheres a complete mirror symmetry, suggested earlier, is not observed. The circulation systems of the Southern Hemisphere are distinguished from the systems of the Northern Hemisphere by a number of features. The most significant peculiarity of the circulation in the Southern Hemisphere is permanently larger values of wind velocities as compared to those for respective seasons of the Northern Hemisphere.

The height-latitude section, shown in Figures 2-5 represent an empirical zonal mean model for the zonal wind field in the meteor zone of the atmosphere, which describes climatic regime of the zonal wind at 70-110 km heights.

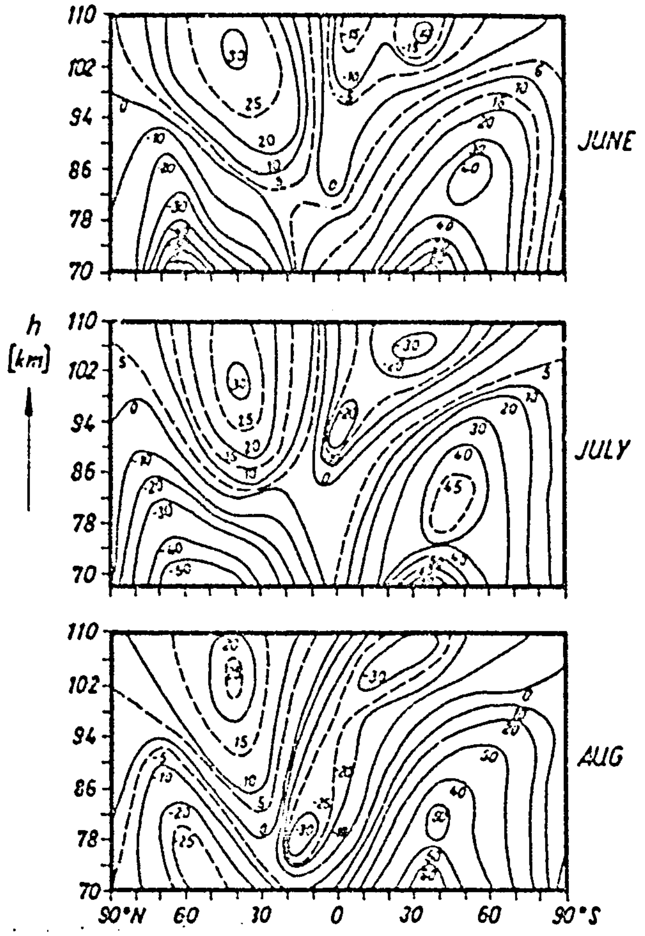

Figure 4. Height-latitude structure of the zonal wind field (m/s) for June-August (a-June, b-July, c-August).

In contrast to the data on zonal wind, statistically reliable data on the latitudinal structure of the ageostrophic meridional wind are mostly available for 95 km height. We have made an effort to parameterize Reynolds viscous stresses in the equation of motion for the meridional wind using the data on meridional wind velocities at 95 km and the height-latitude sections of mean zonal wind. The main contribution into the divergence of Reynolds stresses is proved to be given by the terms associated with the vertical eddy transport of the momentum. The resulting expression for meridional wind u_o is as follows:

$$u_o = K_{eff} \left(\frac{1}{H} \frac{\partial v_o}{\partial z} - \frac{\partial^2 v_o}{\partial z^2} \right) \cdot (2\Omega \cos\varphi)^{-1} \qquad (1)$$

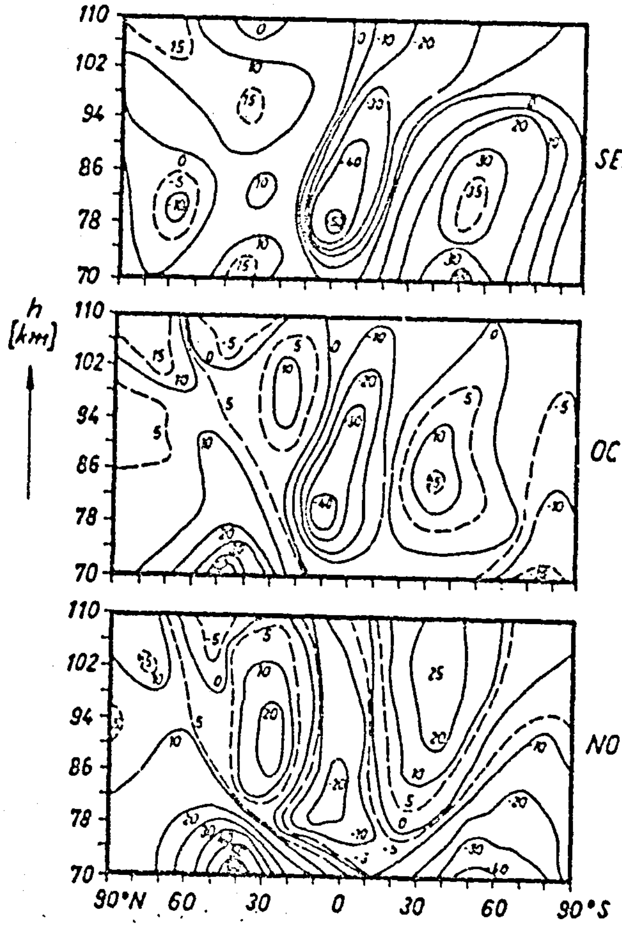

Figure 5. Height-latitude structure of the zonal wind field (m/s) for September-November (a-September, b-October, c-November).

where K_{eff} is a value with the dimension of the diffusion coefficient, v_o is the zonal wind velocity, Z is the height measure in the log-isobaric system of coordinates, H is the scale height, Ω is the angular velocity of the Earth's rotation, and θ is the colatitude. Using equation (1) for parameterization is justified by the fact that for seasons with steady circulation (winter, summer) at 95 km height there is a significant correlation between experimental values of u_o and the value of $\Gamma = (\frac{1}{H}\frac{\partial v_o}{\partial Z} - \frac{\partial^2 v_o}{\partial Z^2})$, which was obtained from height-latitude sections of the zonal wind field. An important moment here is that the changes in the sign of u_o with latitude are followed by similar changes in the sign of the parameter Γ and as a result K_{eff} is essentially positive at all the latitudes (except at the latitudes near the equator, where parameterization (1) is not valid). At about 95 km, according to our estimates $K_{eff} \simeq 10^3$

m^2/s, which is in agreement with other data at the heights above 100 km K_{eff} reaches the value of eddy diffusion coefficient at the level of the turbopause. The dependence of K_{eff} on height, normalized to K_{eff} at 95 km height, is considered here to be the same for all latitudes. Taking into account the values of K_{eff} obtained for various heights and latitudes from the data on the vertical and latitudinal structure of the zonal mean wind field applied to equation (2) we calculated the values of ageostrophic meridional wind velocities in the zonal mean approximation.

Figure 6 presents height-latitude sections of the ageostrophic meridional wind field for January (a) and July (b), obtained by the method discussed above. It clearly shows that on the average at all heights of the Northern meteor zone the wind is southerly in January and northerly in July, which agrees with the average movement of air masses from the summer hemisphere to the winter one.

In January, a region of northern winds is distinctly marked in the equatorial latitudes of the lower thermosphere. The picture is different, however, in July. While the regions of southern winds are well pronounced in the low and high latitudes, another region of southern winds is observed in the middle and subtropical latitudes of the Southern Hemisphere. On the whole,

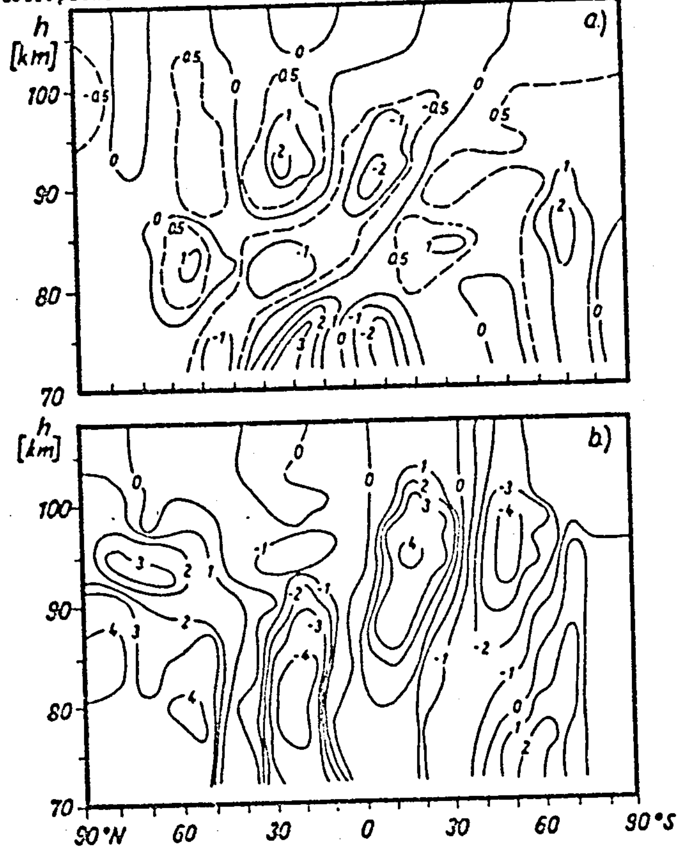

Figure 6. Height-latitude structure of the meridional wind field for January (a) and July (b).

however, the height-latitude sections of the meridional wind field given here should be considered as estimates which mostly give information about the sign of the meridional wind and to a lesser degree characterize the absolute velocities at the heights significantly different from 95 km.

Meridional wind calculations were used to obtain respective values of vertical wind w_0 by means of integrating the continuity equation.

Calculation results of field w_0 are shown in Figure 7 (a,b). They show that at 75-105 km heights there are rather large-scale structures of upward and downward flows, which can significantly affect many physical processes in this height interval and in particular the processes important for understanding D and E region aeronomy and formation of the mesopause thermal structure. The zones of downward and upward winds alternating along the latitude indicate there are global circulation cells in the meteor zone of the atmosphere. The most significant are direct circulation cells connected with the ascent of air masses in low latitudes and descent in middle latitudes. Indirect cells are likely to exist along with the direct ones in the middle latitudes. Despite a rather complicated structure of the vertical winds in the meteor zone of the atmosphere their regularity is clear.

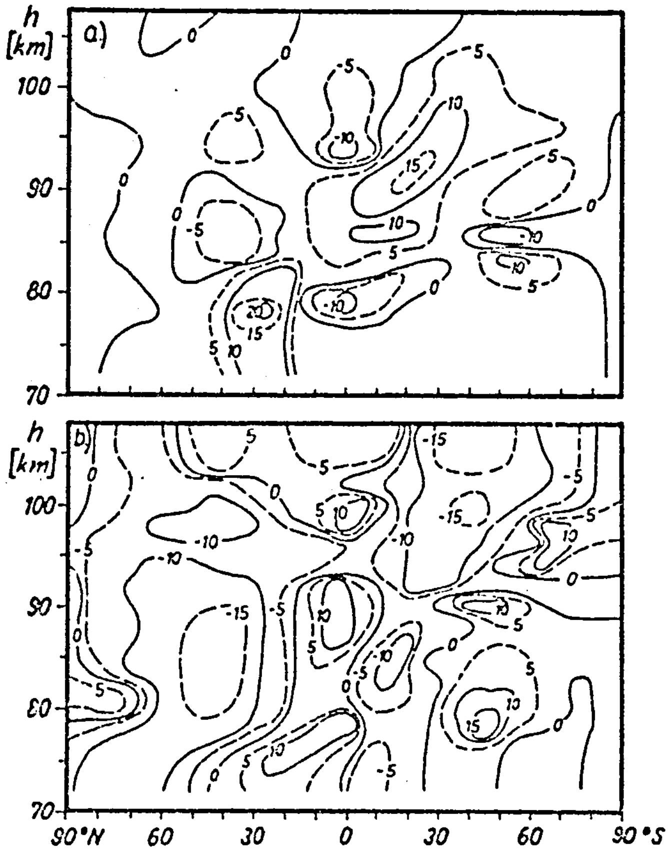

Figure 7. Height-latitude structure of the vertical wind field for January (a) and July (b).