OTS: 60-11,517

JPRS: 2470

14 April 1960

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- USSR -

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Price: $0.50

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NEW YORK 17, N. Y.

JPRS: 2470
CSO: 3562-N/a

ATMOSPHERIC FLOW IN THE STRATISPHERE

[Following is a translation of an article by V. R. Dubentsov in Meteorologiya i Gidrologiya (Meteorology and Hydrology), No. 11, Moscow, 1959, pages 3-15.]

Our knowledge about air currents in the stratosphere is very limited. This can be explained, to a large extent, by the imperfection of the technique of sounding the atmosphere. Previously-obtained data provided information about the distribution of wind usually concerning some limited region, and, as a rule, not above 20 km. In 1956, Kokhanskiy and Vasko /3/ processed data for wind above all of North America, and constructed maps to the 25 mb (about 25 km) surface level. Data for other regions and for the entire Northern Hemisphere were yet not in existence.

In connection with the International Geophysical Year (IGY), several countries have taken steps towards a significant increase of the upper level of radiosonde investigations and, during 1957 and 1958, soundings have penetrated to the 30-20 and sometimes even 10 mb level.

All data obtained by approximately 500 stations was utilized for the compilation of mean maps of the Northern Hemisphere. From this quantity of data, soundings from only half of the stations have reached the 50-30 mb level. A still lesser number, especially during the cold period of the year, reached the level of 20 and 10 mb.

It should be pointed out that in many regions the quality of temperature observations appeared to be very low, and therefore the original data defied comparison. In order to make them comparable, corrections were introduced, which were obtained when different systems of radiosounds were compared in Payern before the beginning of the IGY. Yet even this has only partially improved the situation. Observations at a network of Soviet stations of 50 mb and higher levels have provided very low temperature values for the summer months. This is explainable by the fact that the radiational temperature correction has in many instances been too high. After comparison of day and night rises, it had to be markedly lowered.

Notwithstanding all of these measures, the quality of temperature data remained very low. Therefore auxiliary maps that gave temperature variations from one surface to another had to be drawn for the verification of mean temperatures on high levels; only after a careful selection of data were maps drawn of mean temperature for each surface, and then maps of the relative topography of the intermediate layers. A resulting wind was calculated for all stations which conducted wind observatinns. This permitted a more objective analysis of the maps.

Because of the great labor involved in the processing of data of radiosond investigations, it w as possible to compile maps only for four months (July and October 1957, January and April 1954).

In spite of the small quantity of data on high levels and their low quality, the maps provide sufficiently correct general representatinn of the geopotential field and the mean wind. Naturally, the geopotential values for levels above 50 mb can have only a relative significance. The present report contains maps only for July 1957 and January 1958.

Figures 1-3 represent maps of the basic topography for 200, 100, 50, 30, 20 and 10 mb surfaces. Before we proceed with a study of these maps, it is expedient to clarify to what degree July 1957 differed from normal at lower levels of the atmosphere. At sea level /2/, pressure deviatinns almost everywhere did not exceed 3-4 mb. Only in northwest Siberia, over the Karskiy and Bering seas, was the pressure 6 mb above normal. In the greater part of the Arctic regions the pressure was 4-6 mb below normal. Thus in July 1957 a slight depression was observed in the Arctic regions instead of an area of increased pressure, while the pressure was relatively high over Greenland.

On the 500 mb surface level significant positive deviations were observed in the north of Europe and in northwest Asia (up to 6-10 dkm) and over the Behring Sea (up to 10-15 dkm), and also over the Laptev Sea and the Eastern Siberian Sea. In connection with this distribution of anomalies, a disturbance of the normal zonal circulation was observed. Generally, however, July 1957 was close to normal. Let us turn now to the maps of the basic topography of higher levels.

At the 200 mb surface level, at high and moderate latitudes, a reconstruction of the thermic field begins. While at the lower levels the temperature gradient is turned towards the Pole (see /2/), at the 200 mb level it is turned from the warm area over the Arctic regions towards the moderate latitudes. In the lower latitudes the direction of the thermic gradient varies little as compared to the lower surfaces. Thus, the thermic wind sharply changes its direction only north of the 50th parallel.

Correspondingly, with such a distribution of temperature, the velocity of the wind at high latitudes decreased markedly, while the direction, however, remained unchanged. The weakest winds over Eurasia are observed in the moderate zone, and over America north of the 60th parallel. In the subtropics and in the southern part of the moderate zone, where the direction of the thermic wind remained unchanged, the velocity of the western current begins to increase and the intensity of the subtropical jet current reaches a maximum at this level. The axis of the subtropical anticyclone passes close to the northern tropic. Easterly winds predominate south of the tropic.

At the 100 mb surface level, the highest temperatures are observed in polar regions (-40°), and the lowest somewhat to the north of the Equator (-80°). Small single regions of relatively cold air are still preserved over Eurasia in the moderate zone, but at this level the general direction of the thermic gradient is turned from the Pole to the northern tropic. The thermic wind becomes easterly almost everywhere. Consequently, everywhere north of the tropic the western wind loses in force. To the north of Eurasia and over Greenland small anticyclones are forming and the wind on their southern periphery is already changing to an easterly. To the south of the tropic and approximately to 10° of north latitude the eastern wind gains with altitude.

At the 50 mb surface level (ca. 20 km) the thermic gradient is directed from the pole to the northern tropic, as well as at the 100 mb level, but the pole-northern tropic temperature difference here constitutes about 25°, while on the 100 mb level it reached 40°.

Thus, the thermic wind has an easterly direction almost from the very Pole to the Equator and its velocity reaches the highest values at this level. In accordance with this, a total reorganization of the fields of geopotential and of aerial currents occurs with a transition from the 100 mb to the 50 mb surface. At the 50 mb surface level, an anticyclone is established over the polar regions; on its periphery the wind over the entire Northern Hemisphere changes to an easterly from a northerly, and in some places from a southerly composite. The geopotential gradient still remains small at this level and consequently wind velocity does not exceed 20-30 km/h. To the south of the tropic and up to 10° north latitude a strengthening of easterly winds continues; they reach 50-75 km/h here and in some places 100 km/h.

At the 30 mb (ca. 24 km) surface level the temperature field does not vary much; the value of the temperature gradient decreases somewhat and accordingly the thermic wind likewise loses in force. The lowest temperatures are observed in the 10-25° north latitude zone.

Such a distribution of the thermic wind leads to a continued strengthtening of easterly winds over the entire Northern Hemisphere. It should be pointed out that many eminences and depressions which were well expressed at the 100 and 50 mb levels appear to be markedly smoothed out at the 30 mb level. This is also corroborated by the data of the resultant wind, which has almost everywhere an easterly direction. Wind velocities in the polar regions and in a large part of the moderate zone constitute about 20-30 km/h; they increase further to the south and reach 100 km/h somewhat south of the tropic.

At the 20 mb (ca. 27 km) and 10 mb (ca. 32 km) level of surfaces, neither the temperature field nor the geopotential field change substantially. However, it should be noted that the center of the warmth area in polar regions with temperatures about -30° is, at the 10 mb surface level, somewhat displaced from the pole towards the Canadian Arctic archipelago; and the region of the subtropical stratospheric cold with temperatures around -46°, is, as far as the data show, somewhat to the south of the tropic. Easterly winds at the 20 and 10 mb level continue to increase with altitude. The mean wind velocities in polar regions from 30-40 km/h increase to 80-100 km/h at the northern tropic, and at the 10-20° they even exceed 100 km/h.

Figures 4-6 represent maps of baric topography for January 1958 for the same isobaric surfaces as for July. January 1958 has deviated from normal to a much greater degree than July 1957. On the mean maps of pressure at sea level for January 1958, the cyclonic reginn on the north of the Pacific Ocean, as compared to normal, appears to be deeper (deviation of pressure from normal reaches here - 18 mb). The Siberian anticyclone was more voluminous and possessed two centers: one in the south of the Krasnoyarskiy Kray and the other over North China. The Iceland cyclone was of a lesser depth. The pressure on the Atlantic Ocean was substantially lower than the norm (5-10 mb).

Significant deviations from the norm were observed at the 500 mb surface level. The position of mean monthly positive and negative deviations at this level basically corresponds to their position near the ground.

At the 200 mb surface level, the direction of thermic gradients is the same as on lower levels, but the magnitude of the temperature gradient, as compared to the 300 mb surface, is somewhat smaller.

The lowest temperatures, below -65°, were observed above the Barents and Kara Seas, and also above the north-western part of Siberia. The highest temperatures are observed south of the tropic (about -48°, -50°), but over the Pacific Ocean the warmth region with temperatures above -45° appeared to be strongly displaced to the north.

The geopotential and current field, as compared to lower levels (see /3/) changed a little. The dimensions of geopotential gradients at this level reaches maximal values almost everywhere.

Three large depressions are prominent in the general zonal western current, one of which is located at the east of North America, the second over the northern part of the Atlantic Ocean and the Greenland Sea, and the third over Northeast Asia. In the latter of these depressions, over Yukatia, an independent cyclonic region is evolving. The most significant mean velocities of the western current (up to 200 km/h) are observed in the 20-40° N. latitude zone. South of 10-15° N. latitude, on the southern periphery of the latitudinally elongated anticyclonic region, easterly winds are observed.

At the 100 mb level in the stratosphere of polar regions and in the troposphere of tropical regions, the lowering of temperature continues. At the south of the moderate zone and in the subtropics, the temperature is rising slightly and a warmth region can be found here, elongated latitudinally over Eurasia and America along the 45th parallel; over the Pacific Ocean it is displaced to the north, to the 50-55° parallels. The lowest temperatures, up to -82, -83°, are observed in the equatorial zone of the Pacific Ocean. North of the warmth band mentioned above, the thermic wind is a northerly, while towards the south it is an easterly. In accordance with this, the gradient of the geopotential and of the velocity of the western current continues to increase in the moderate and high latitudes, while south of the 25th parallel they become weaker almost everywhere. The axis of the subtropical anticyclone changes its position just a little.

At the 50 mb (about 20 km) surface level, the character of the temperature field changes slightly. Decrease of temperature continues in polar stratosphere; however, the cold region with temperatures around -70° is not located at the Pole, but over Greenland and the Greenland, Barents and Kara Seas. South of the tropic an increase of temperature takes place, which is more pronounced at the Equator. The lower temperatures (below -65°) are observed in the 10-20° N. latitude zone.

As a consequence of such a distribution of temperature in the moderate zone and also in the polar zone (north of Alaska), there appears a further strengthening of the western current to 100-150 km/h. A weak depression develops in the southern part of the Pacific, approximately between the 10 and 20° N. latitude.

At the 30 mb surface level, the temperature field changed very slightly, if we do not take into consideration the fact that the band of the highest temperatures over Eurasia and the Atlantic became displaced to the south. The thermic wind in middle and high latitudes preserves its direction and somewhat increases in force; a further increase of gradients of the geopotential and of the velocity of the western current occurs here. A substantial reorganization takes place over the Pacific Ocean. The center of the anticyclone is here markedly displaced to the north (from the 30th to the 45th parallel). The cyclonic region in the southern part of the Pacific has markedly increased in surface. Close to the Equator, easterly currents are preserved everywhere, while westerly only over the Pacific are preserved.

At the 20 mb (about 26 km) and the 10mb (about 30 km) levels, the general character of the temperature field remains the same, but the value of the horizontal temperature gradient in the moderate zone increases, as well as the thermic wind. All of this brings about a further increase of the westerly stratospheric jet current. The velocities of the western current at the 10 and 10 mb levels reach 200 km/h and more, and, in Northeast Asia and over the Chukotsk Sea, 300 km/h. In Eurasia the stratospheric westerly jet current at 25-30 km altitudes occupies space from the side of the northeastern end of Asia and Alaska; it is strongly displaced to the north and it passes here between the 60th parallel and the Pole. In the tropical zone, south of the 20th parallel, and over the Pacific south of the 40th parallel, the thermic wind is everywhere easterly, and at this level easterly winds are observed, the velocity of which does not exceed anywhere 50-70 km/h. The weakest winds are observed in the region of the subtropical stratospheric maximum.

A comparison of the maps of different levels demonstrates that while in January at the 200 and 100 mb levels the field of the currents is comparatively symmetrical in relation to the pole, such symmetry is nonexistent at the 50-10 mb levels.

This asymmetry is especially noticeably over the northern part of the Pacific Ocean, where the stratospheric jet current appears to be pressed to the Pole by a voluminous anticyclone. The temperature of air in the anticyclone region in the stratosphere is some 15-20° higher than in corresponding latitudes over the Atlantic Ocean and Eurasia and in southern latitudes of the Pacific. The presence here of such high temperatures cannot be explained by the advection of warm air from other regions, as some investigators would believe. The amplitude of temperature variations in the stratosphere does not exceed 10°.

The stable high temperatures in the stratospheric anticyclone are most probably determined by descending movements or by the immediate warming up of the stratospheric air as a result of an increased ozone content. However, this theory requires additional investigation. Masses of warm stratospheric air from this region often penetrate to North America and the Arctic Ocean up to the Pole. This was also noted by G. D. Zubyan /1/.

It should be noted that the apparently anomalous position of the region of warmth and of the stratospheric anticyclone over the Pacific Ocean is a quite frequent phenomenon. A similar position was observed in January 1957 /4/ and in January 1959.

In order to obtain a more general idea of the peculiarities of atmospheric structure during the summer and winter periods, a mean meridianal profile was constructed from the Pole to the Equator, the data for which was derived by averaging temperature values and zonal composites of the wind from latitudinal circles for July 1957 and January 1958 up to the 10 mb (30-33 km) surface level. Murgatroyd's /4/ profile was used for higher levels. This complex profile is represented in Fig. 7. The basic differences of summer and winter circulation are clearly visible in Murgatroyd's cross-section and in the maps given earlier. In summer in the troposphere from the pole to the tropic, relatively weak westerly currents predominate, while, south of the tropic, they are easterly. From the 20 km altitude a complete reorganization of the fields of pressure and wind takes place. A vast anticyclone is established in the stratosphere, and the wind over the entire hemisphere changes into an easterly, which reaches the maximum, 60-70 m/sec. at the 50-70 km altitude, south of the 40th parallel. The wind above 80-90 km changes into a westerly.

In the winter period of the year, western currents predominate everywhere in the stratosphere, while easterly do so only immediately at the Equator.

The axis of the subtropical jet current is located at about 12 km altitude between 20 and 30° latitudes. Mean wind velocities in the jet reach 50 m/sec. The jet current of moderate latitudes (as a result of its greater mobility) is only slightly expressed in the mean cross-section. Its axis is located at the 10-12 km altitude in the 40-60° latitudinal zone.

No significant reconstruction of the geopotential field occurs in the stratosphere. Condensation of polar atmosphere leads to a strengthening of cyclonic circulation at moderate and high latitudes. Along the periphery of the polar stratospheric cyclone, with increase of altitude, there takes place a strengthening of the western jet current, the axis of which is located at an altitude of about 60 km, and the velocities of the wind reach 100m/sec.

In the equatorial zone, in the troposphere as well as in the lower stratosphere, easterly winds are preserved, the mean velocities of which exceed 30 m/sec at the 30 km level. At the level of about 100 km, another reconstruction of aerial currents takes place and the wind becomes easterly. Such are the first, preliminary results of the aerological data processed during the IGY.

In view of the small scale of the maps, the resulting wind is not shown on them.

Concluding, the author wishes to express his gratitude to the specialists and the technical personnel of the Division of World Maps and of the Northern Hemisphere of the Central Forecasting Institute, and, particularly, to Junior Scientific Assistant A. S. Solovyeva, all of whom have rendered valuable assistance in the construction of the maps.

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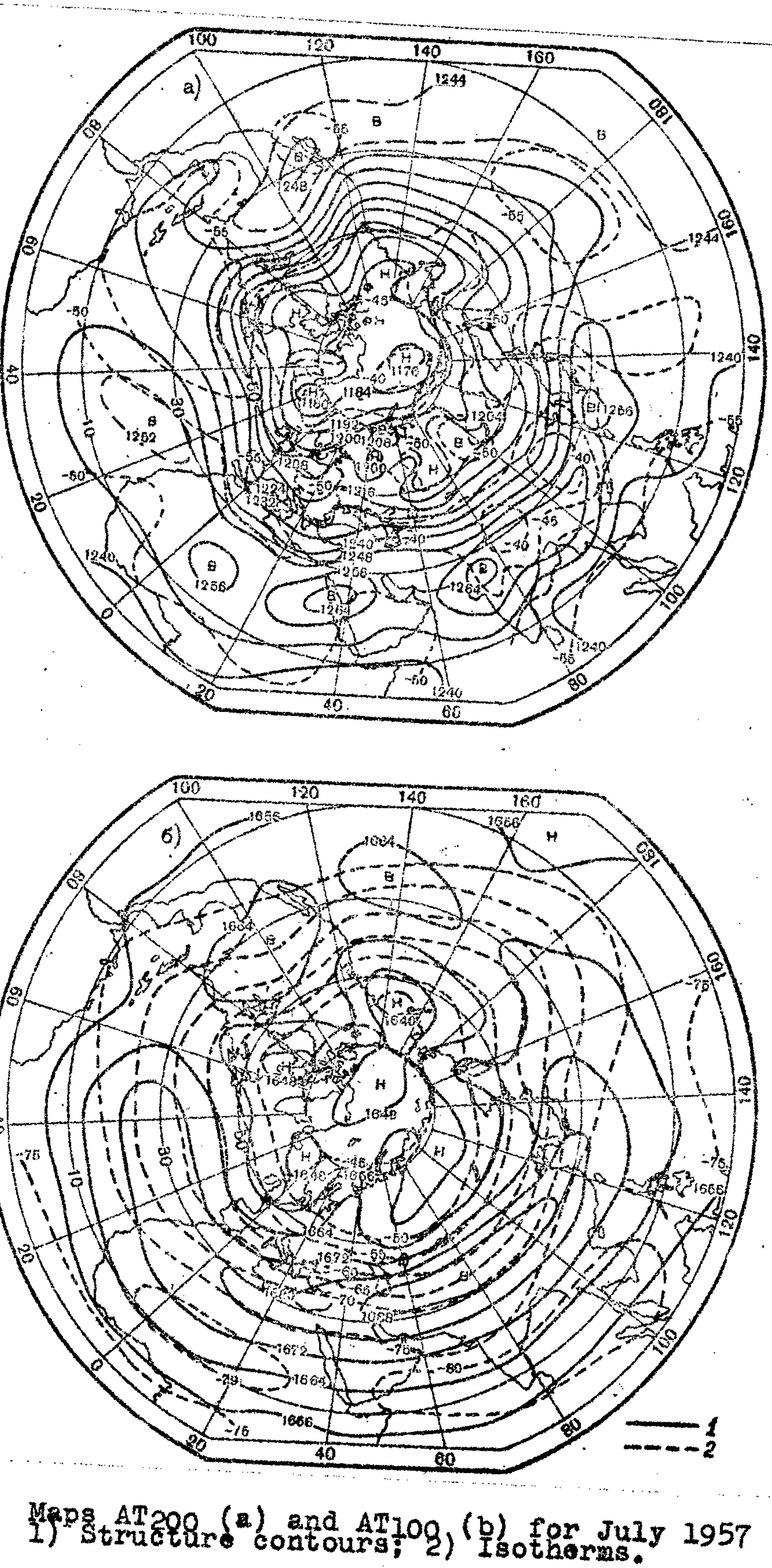

Fig. 1. Maps AT_{200} (a) and AT_{100} (b) for July 1957
1) Structure contours; 2) Isotherms.

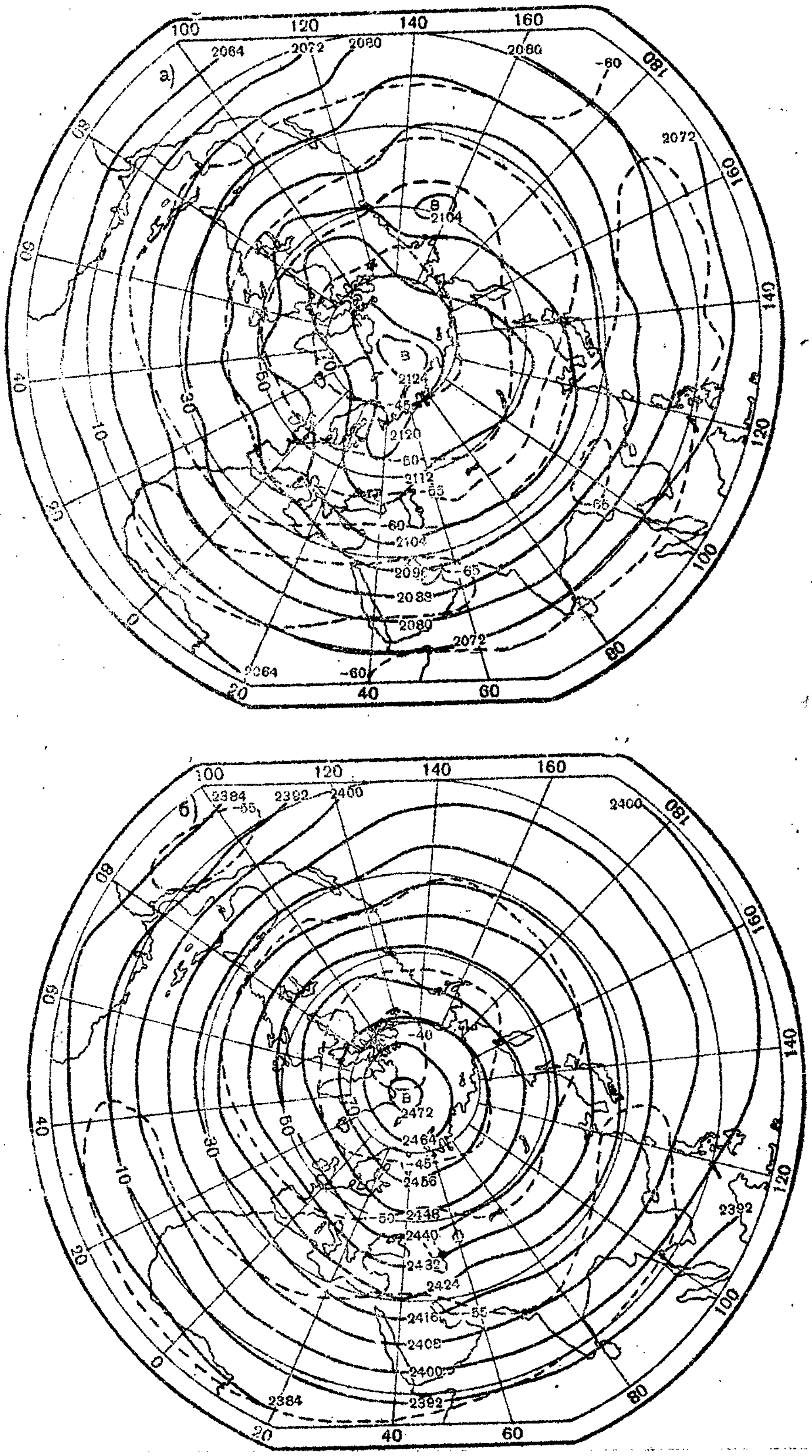

Fig. 2. Maps AT_{50} (a) and AT_{30} (b) for July 1957 (Denotatinns, same as in Fig. 1.)

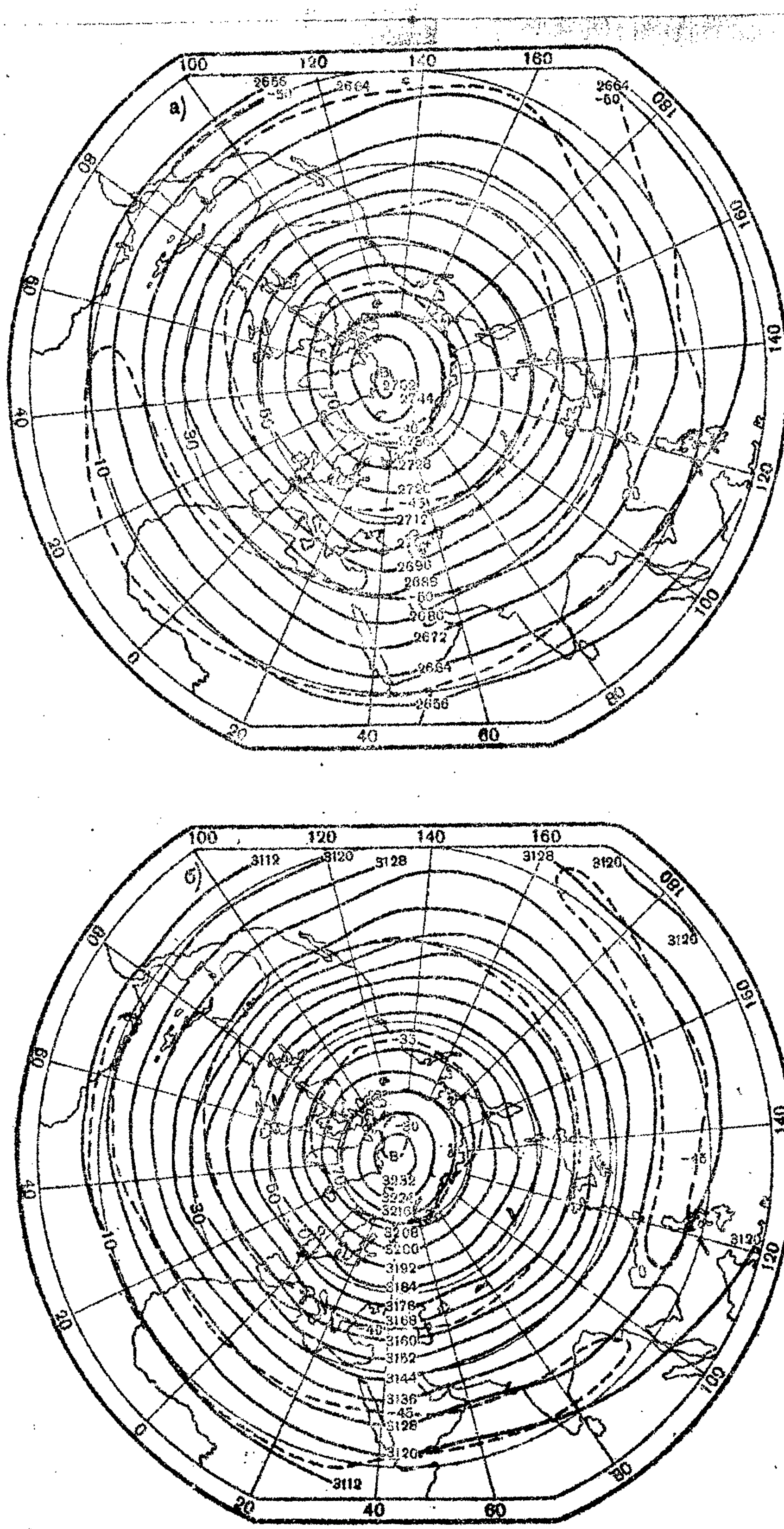

Fig. 3. Maps AT_{20} (a) and AT_{10} (b) for July 1957. (Denotations, same as in Fig. 1.)

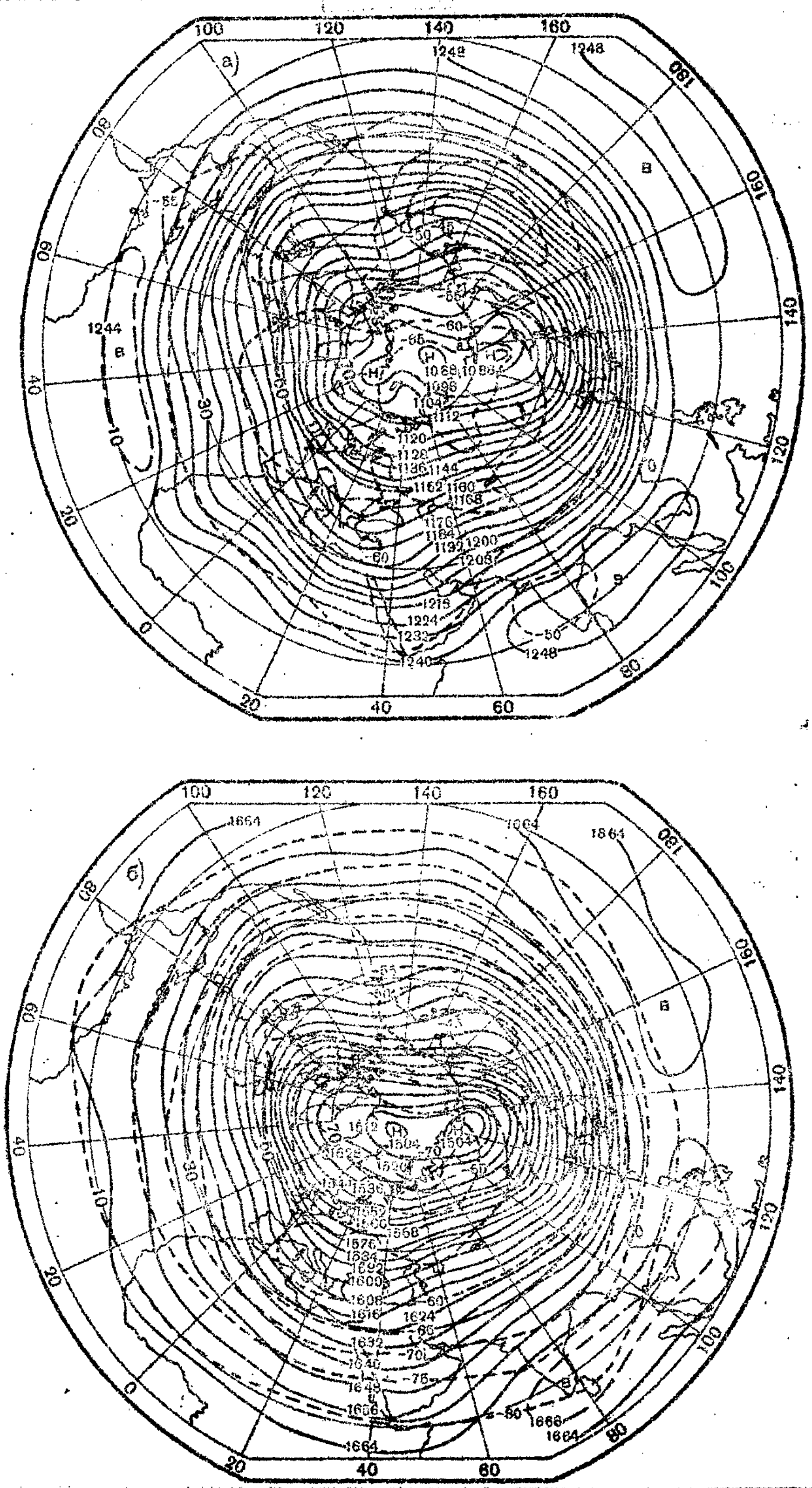

Fig. 4. Maps AT_{200} (a) and AT_{100} (b) for January 1958. (Denotations, same as in Fig. 1.)

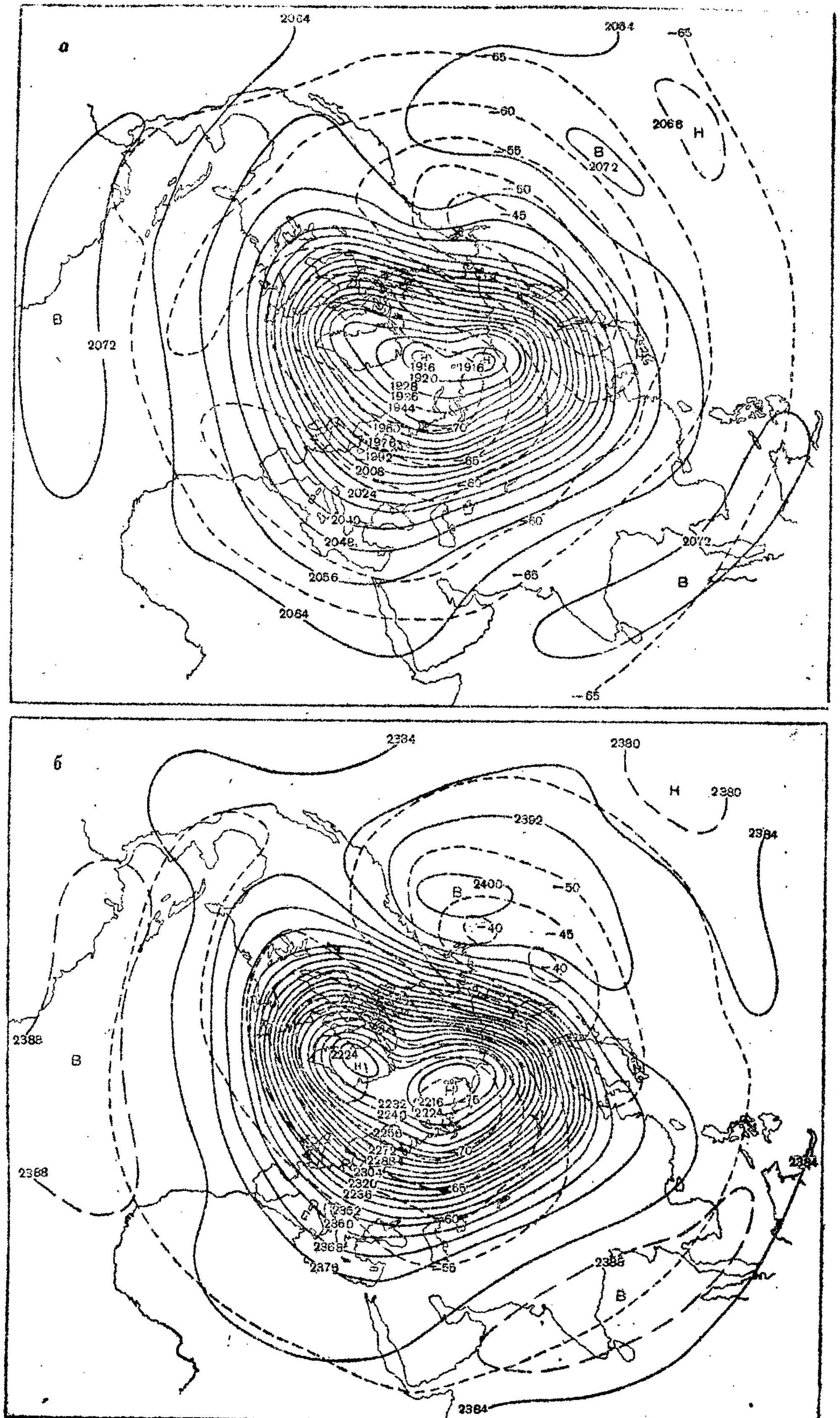

Fig. 5. Maps AT_{50} (a) and AT_{30} (b) for January 1958. (Denotations, same as in Fig. 1.)

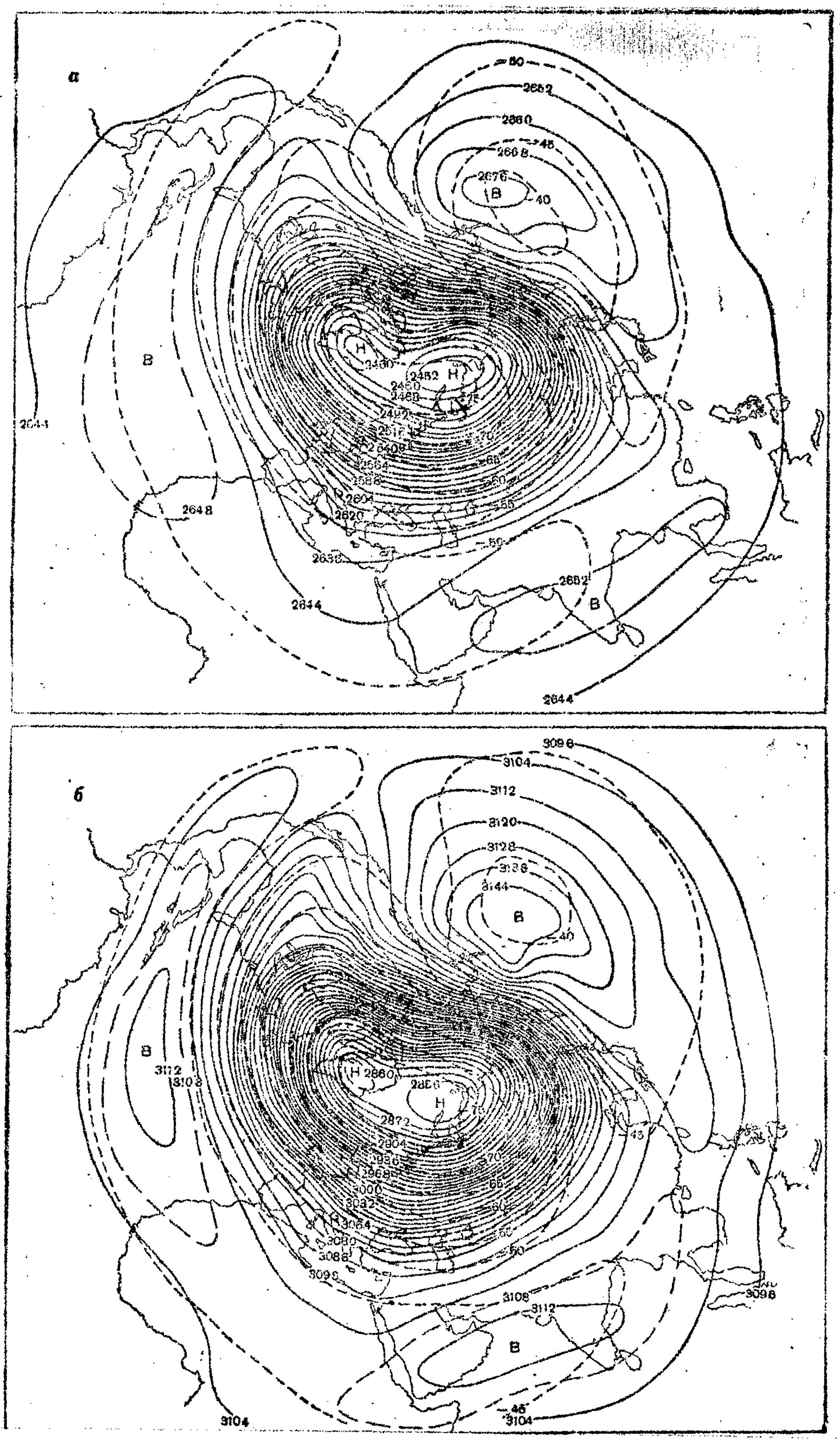

Fig. 6. Maps AT_{20} (a) and AT_{10} (b) for January 1958. (Denotations, same as in Fig. 1.)

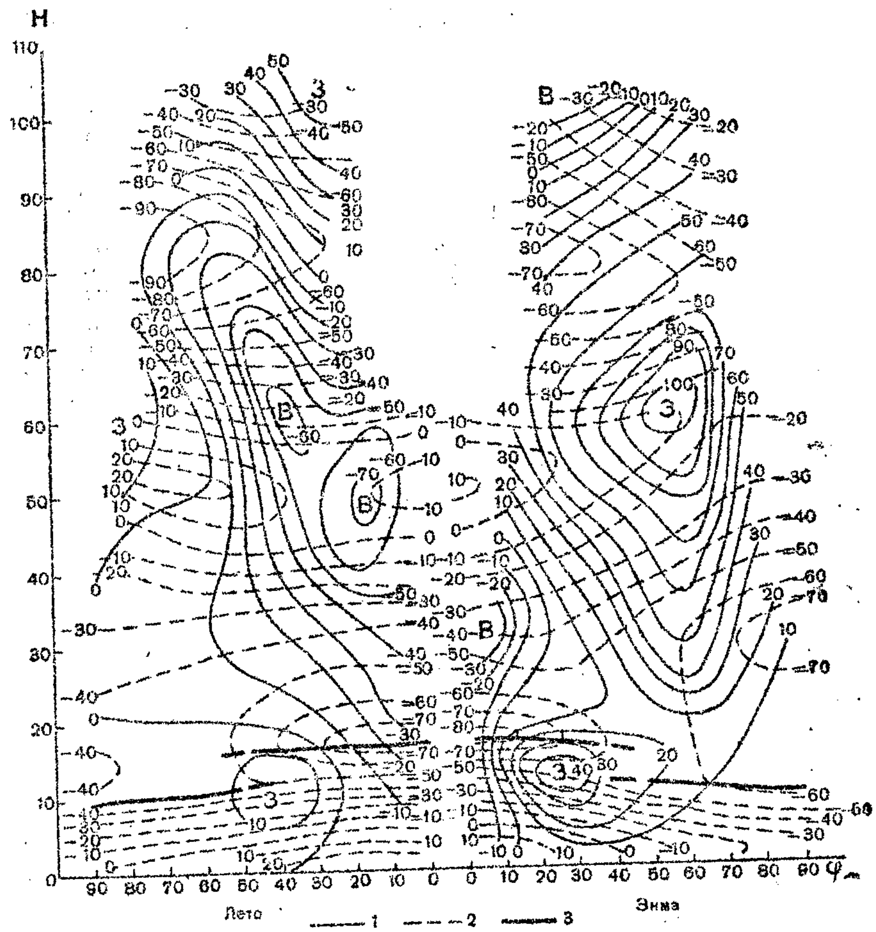

Fig. 7. Mean vertical profile. 1) equal velocity lines of the zonal composite wind velocity; numbers represent velocity in m/sec., positive - western composite, negative - eastern composite. Z - center of the region of maximal values of the western composite, B - same for the eastern composite; 2) isotherms; 3) tropopause.

END