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THE REACTION OF THE ATMOSPHERE TO SOLAR DISTURBANCES

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16. Abstract

The article discusses experiments conducted to ascertain the effect of solar activity on the thermosphere, the troposphere and atmosphere. Data, including eight figures are presented. It concludes that during periods of geoeffect solar disturbances, there is a connection between phenomena in the upper and lower atmospheres.

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In the "solar-terrestrial phenomena" problem, study of the effect of solar activity on processes in the lower atmosphere is most important. Within the framework of this aspect of study, research is being conducted aimed at establishing correlational connections between variations in solar activity and atmospheric features, and at producing physical models to explain these connections.

Hypothetically, the effect of solar activity on the troposphere may be direct or through the upper atmosphere, whose life is determined directly by solar activity: shortwave radiation and corpuscular solar radiation that changes sharply depending on processes inside the sun. In the latter case the transfer of energy from the upper atmosphere, from the thermosphere to the troposphere, should take place via the mesophere and the stratosphere. And accordingly, a study of atmospheric reaction, moving from above to below, to solar activity is needed. Unfortunately, there are at present very few data available, since experiments are not usually conducted simultaneously across a range of altitudes and results are not comparable.

What, then, is known? Let us review the basic results from experiments to study variations in atmospheric thermodynamic parameters and wind during a period of solar activity.

Thermosphere. Studies of the upper atmosphere using satellites have made it possible to discover that during a period of geomagnetic disturbance the density and temperature of the thermosphere increase; the amplitude of density variations increases with altitudes and latitude; and that, compared with geomagnetic disturbance, the lag effect in the development of atmospheric disturbance depends on latitude.

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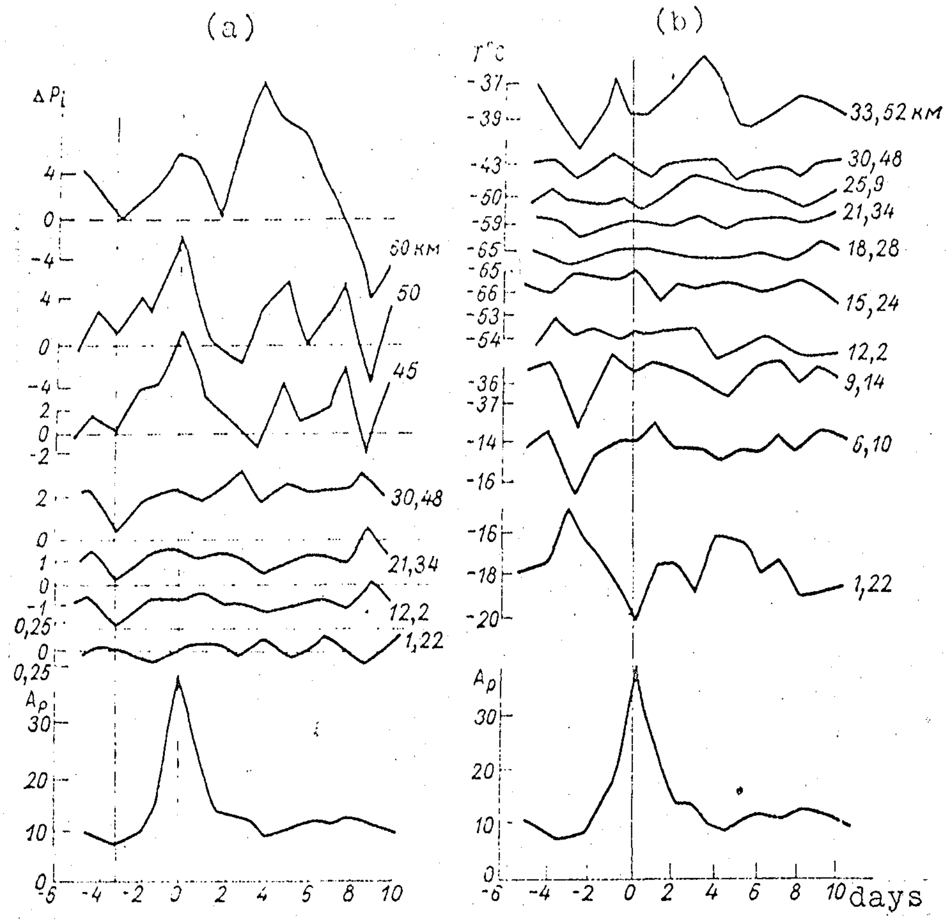

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Figure 1.

a - relative pressure change Δp_i (%) during a period of geomagnetic disturbances. Comparison was made from day 3, corresponding to minimum value of A_p; b - temperature change from sounding measurements at the White Sands station

Troposphere. As a result of statistical processing of data from meteorological observations, it has been established that variations in pressure and circulation, corresponding to geomagnetic disturbances, are observed in the troposphere [11].

The main conclusions drawn from studies of the thermosphere and troposphere have been described in detail in various works [9,11] and we shall not dwell on them here.

Troposphere - Thermosphere. In recent years special investigations have been made to study this field, and as a result a preliminary idea was established about atmospheric behavior during the period of interest to us.

In one work [9] data on temperature and pressure obtained during periods of geomagnetic distrubance during 50 rocket soundings measure-

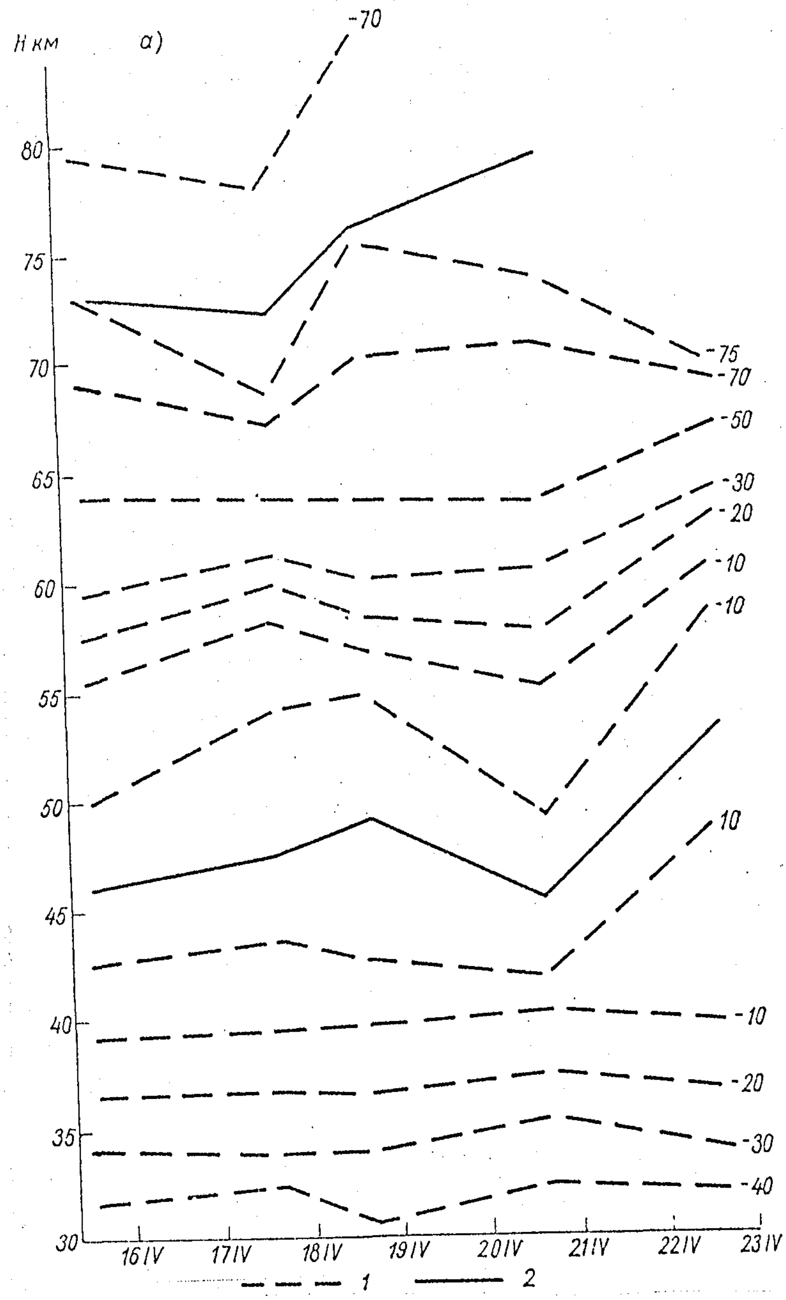

Figure 2. Atmospheric temperature at various altitudes based on data from rocket (a) and aerological (b) readings at the Volgograd station.

1 = isotherms 2 = stratopause, mesopause

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ments at the White Sands station during 1962-1964 were processed using the epoch superposition method. The results are shown in Figure 1.

It can be seen from the data presented that day-to-day relative pressure variations at altitudes from 12.2 to 60km are observed synchronously with the change in the geomagnetic index A_p: the minimum

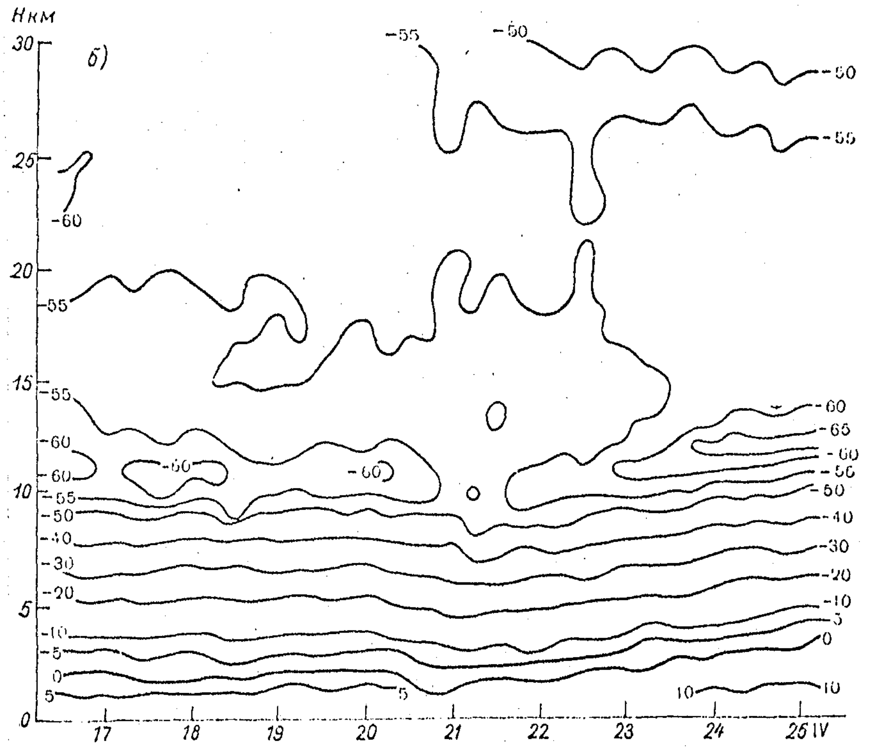

Figure 2 - Continued. /171

and the first maximum Δp coincide within accuracy of one day with the minimum and maximum values of A_p. At altitudes below 12 km a Δp of about two days is observed relative to A_p. The amplitude of Δp variations increases with altitude. Temperature change is quite different: ΔT at different altitudes have a different sign. Thus, for example, at an altitude of 1.22 km temperature changes sharply in the opposite phase, but at 6.10 km it is synchronous with A_p.

A complex of experiments making it possible to obtain comparable data simultaneously at various altitudes and to race the development of phenomena within a time frame typical for the processes being stuided was carried out in order to study atmospheric reaction to solar activity. The first such complex of experiments was conducted in April 1969 at the Volgograd rocket sounding station [4]. The greatest frequency of rocket soundings occurred during the period April 16 through 23. During this experiment data were obtained on /172
the reaction of neutral atmosphere, the ionosphere, and radiation characteristics.

In this paper only the results of investigations of temperature and pressure parameters and atmospheric wind are considered.

Thermodynamic parameters in the atmosphere were determined at altitudes from zero to 30 km using meteorological aerological observations, and from 30 through 95 km using M-100 rockets.

Wind parameters up to an altitude of approximately 30 km were obtained from aerological observations, up to approximately 60 km using rockets, and up to approximately 90 km using radar measurements of meteor trail drift.

During the period April 10-24 1969 solar and geophysical activity was as follows: on April 10 a strength 2B solar flare accompanied by an increase in the stream of radio emission and disturbances in the ionosphere (SID) was observed. Strong absorption of radio waves at the polar cap (PCA) commenced on April 11 and continued through April 18. This flare also caused proton phenomena: from April 11 through 27 the number of protons considerably exceeded the background value.

Chromospheric solar flares were also recorded on April 14, 18, 20 and 21. They were accompanied by bursts of radio emission on the sun and sudden disturbance (except the one on April 20) in the terrestrial ionosphere (SID). The most powerful flares were those on April 18 and 21 [6].

It can be seen from aerological (Figure 2b) and rocket measurements [1] (Figure 2a) that within the period studied the temperature change was not the same at different altitudes (see also [3, 5, 12]. This can be seen particularly clearly on Figure 3 where, for example, between April 18 and 21 a rise in temperature was observed at altitudes of approximately 10 and 25 km, while at altitudes of approximately 50 and 80 km it fell.

Great variations were observed at the upper boundary altitudes. Thus, between April 16 and 21 in the daytime (1200 to 1400 hours) the height of the mesopause rose from 74 to 79 km, and that of the stratosphere from 42 to 47 km, while the level of the troposphere fell

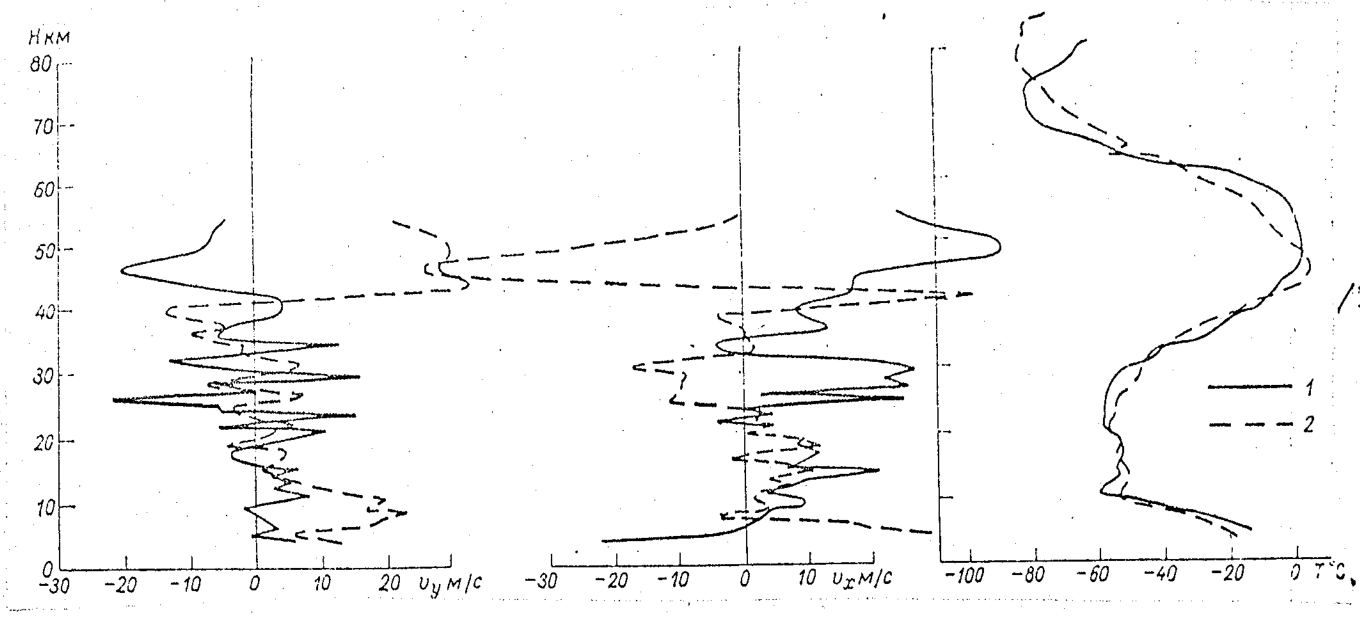

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Figure 3. Change in temperature and wind velocity components with altitude at 1330 hours April 18 1969 (1) and at 1346 hours April 21 (2) at the Volgograd station.

from 11 to 10 km.

A significant change was recorded in wind direction and velocity, particularly in areas of relative fall or increase in temperature (approximately 10, 28 and 50 km) (Figure 4).

Variations in the meridional component of wind velocity at the tropopause and at an altitude of approximately 95 km [7] correlate well (Figure 4), and with the geomagnetic disturbances (Figure 5). It should be noted that the character of the change in wind from day to day was maintained for all times of the day in question.

A second complex of experiments was conducted in 1971 from September 20 through October 10.

Solar flares were recorded on September 19, 22 and 24 and October 1, 3 and 10. The most powerful and prolonged was the one on October 3 [13]. After this flare an increase was recorded in the number of protons. This reached a maximum on October 4 but had receded to the normal level by October 7 [14].

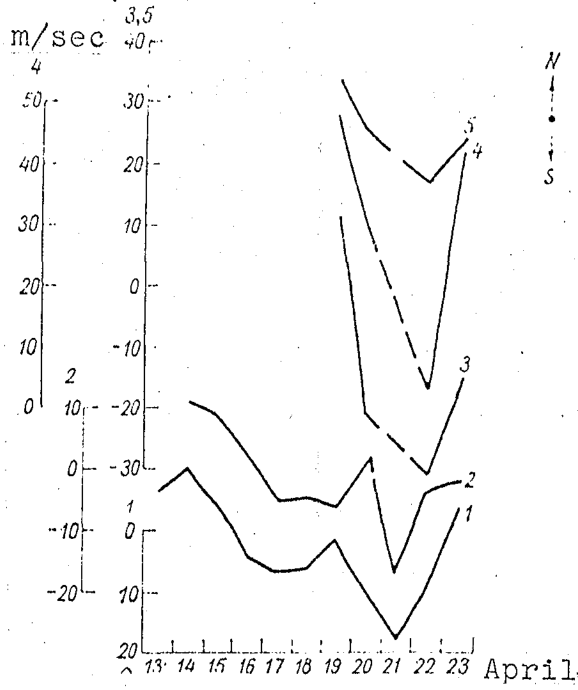

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Figure 4. Variations in meridional component of wind velocity at the tropopause altitude from radiosonde data [1,2] and at an altitude of 95 km according to data from meteor measurements [3,4,5].

1 - 3 hours; 2 - 15 hours Moscow time; 3 - 0-3 hours; 4 - 0-1 hours; 5 - 4-5 hours Moscow time.

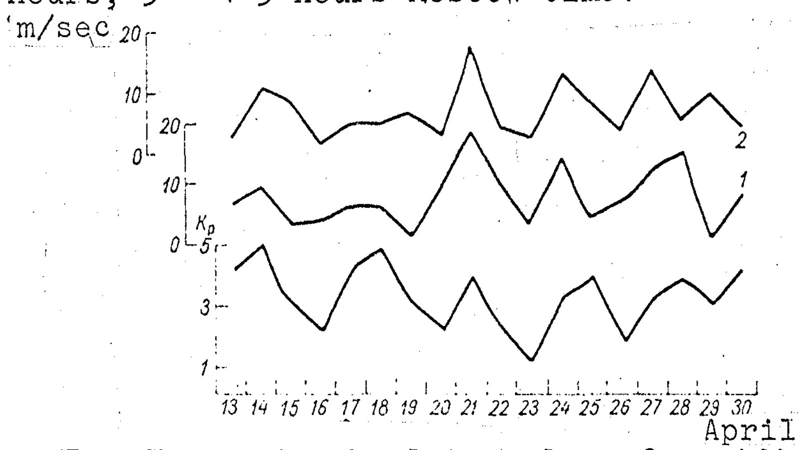

Figure 5. Change in absolute value of meridional component of wind velocity at the tropopause altitude and geomagnetic index K_p (0-3 hours)

1 - 0 hours; 2 - 12 hours GMT 1969

Maximum geomagnetic disturbances were observed on September 25-27 and 30 and October 3 and 8-9. Minimum values of the geomagnetic index were recorded on September 23 and 29 and October 4, 7 and 10 [14].

The results of temperature and meridional component of wind velocity measurements are presented in Figures 6 and 7. Since aerological observations were carried out every six hours (as in 1969) and rocket measurements only every day or two, a more detailed picture of atmospheric behavior was obtained for 30 km.

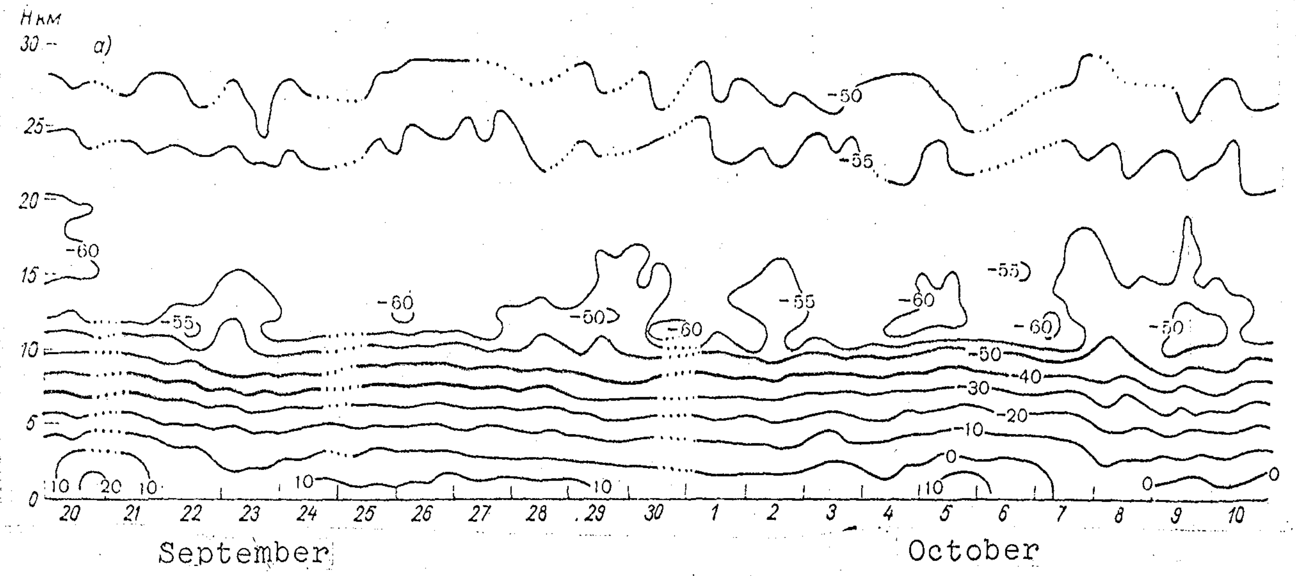

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Figure 6a. Atmospheric temperature at altitudes from zero to 30 km at the Volgograd station.

See Figure 2 for key to symbols.

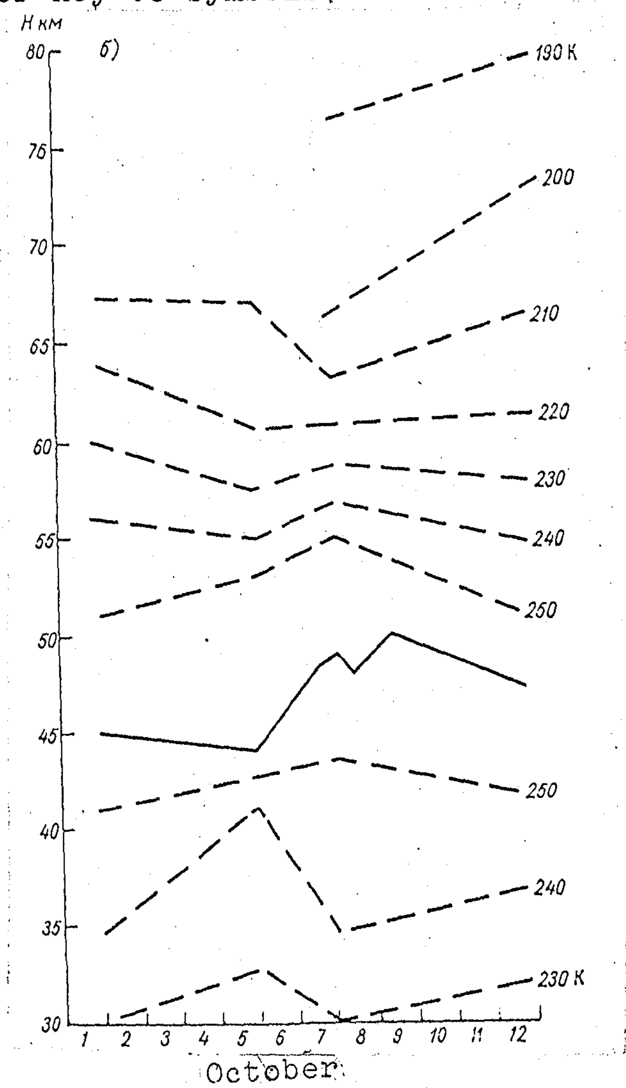

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Figure 6b. Atmospheric temperature at altitudes of 30-80km at the Volgograd station.
See Figure 2 for key to symbols.

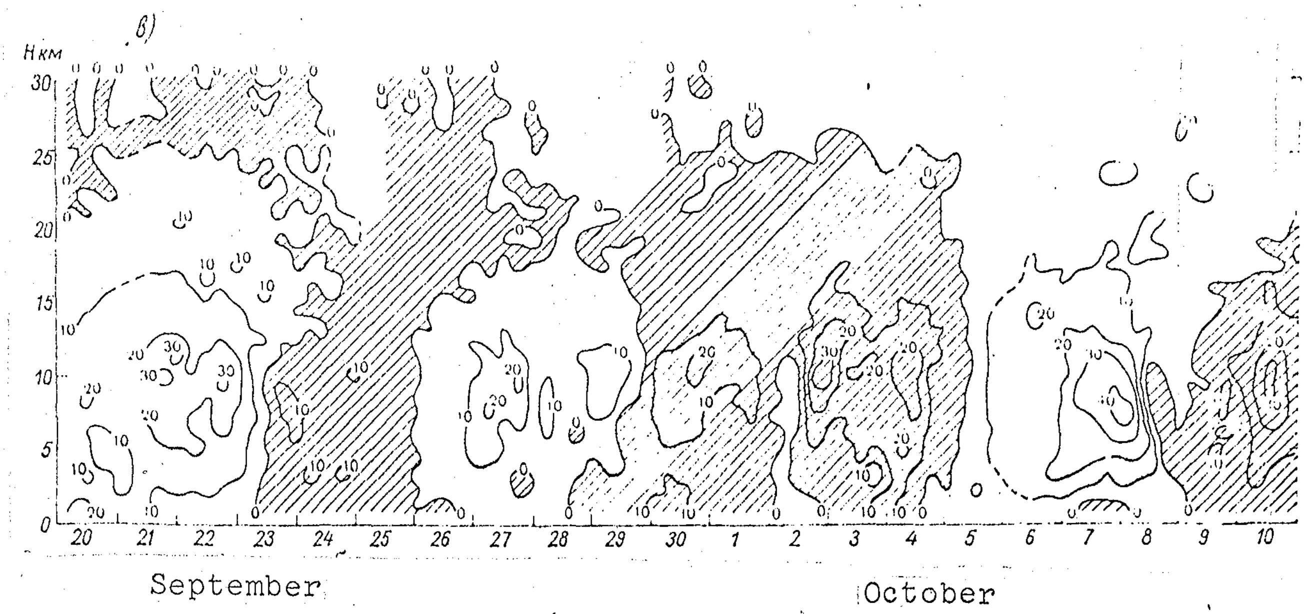

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Figure 6c. Change in meridional component of wind velocity at the Volgograd station

See Figure 2 for key to symbols

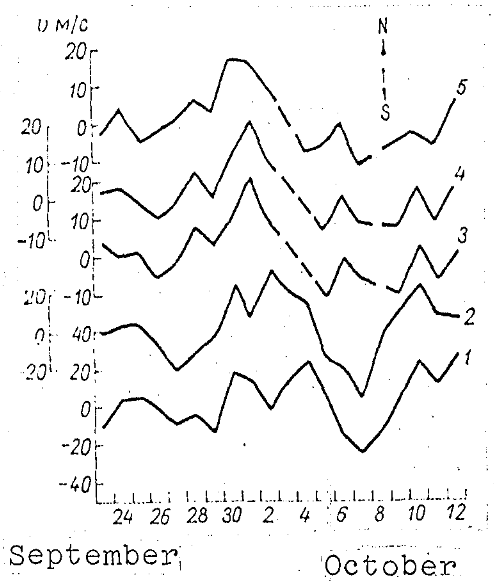

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Figure 7. Variations in meridional component of wind velocity at the tropopause from radiosonde data [1,2] at an altitude of 95 km from meteor measurements [3,4,5], 1971.

1 - 0 hours; 2 - 12 hours; 3,4,5 - 1, 5, 13 hours respectively.

It can be shown from the data shown that on September 22-23 and 28-29 and October 4-5, 7-8 and 10, a restructuring of circulation took place and considerable variations in atmospheric temperature [10] were observed. The way in which temperature changed at different altitudes was different, just as in 1969.

During the period covered by the experiment, variations in the meridional component of wind velocity at the tropopause and at an altitude of approximately 95 km [7] for different times of the day correlate well, as in 1969 (Figure 7).

Periods of restructuring of atmospheric temperature stratification and changes in wind velocity direction and their minimum values correspond to minimum values of the geomagnetic index A_p, and the change in the direction of the interplanetary field [8] (Figure 8). This last circumstance is particularly interesting, since discovery of the correlation makes it possible to connect into a single whole, processes on the sun, in the interplanetary medium, the magnetosphere, the ionosphere and the earth's upper and lower atmospheres. (The existence of a connection between solar activity and the lower atmosphere is still not a generally accepted fact).

As a result of the investigations carried out, several initial conclusions may be reached:

- during periods of geoeffect solar disturbances, a reaction is observed in the atmosphere, from the tropopause to an altitude of 100 km, that is, there is a connection between phenomena in the upper and lower atmospheres;
- variations in atmospheric parameters correlate with changes in the geomagnetic index; /179
- periods of minimum values, wind velocity and geomagnetic index coincide;
- when there is a restructuring of temperature stratification, the temperature change sign is different at different altitudes.

On the basis of the above, and taking into account the fact that global spatial changes in pressure, temperature and wind are also different [11] it can be supposed that as a result of the solar activity, a transfer of energy takes place in the atmosphere from one field to another, as a consequence of which it can be expected that restructuring of the atmosphere does not require additional, large amounts of energy but takes place mainly through stored energy.

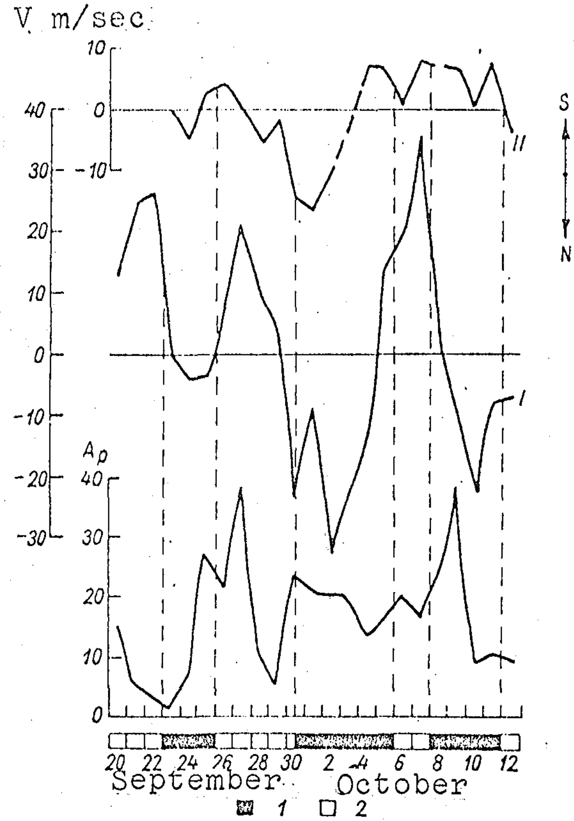

Figure 8. Variations in meridonial component of wind velocity at the temperature (I) and at an altitude of approximately 95 km (II), the geometric field, and the direction of the inter-planetary magnetic field.

1 - interplanetary magnetic field away from the sun;
2 - toward the sun

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