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EFFECT OF SOLAR ACTIVITY ON THE LOWER ATMOSPHERIC LAYERS

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SUMMARY

This review paper considers the influence of solar activity on the Earth's magnetosphere, troposphere and stratosphere by means of solar corpuscular streams; these in their turn are the source of geomagnetic disturbances, aurorae and prolonged disturbances in the radiocommunications. Recent Soviet studies are analyzed. They show that the streams of nonstationary or quasi-nonstationary type, emanating from active regions on the Sun pertain to two groups, of which the "directed" ones influence our meteorological conditions, versus those that by-pass the Earth without any such effects. The author used the epoch-superimposition method, which allowed him to prove their influence on the ground atmospheric pressure.

The conclusions drawn from this lenghty discussion are that solar activity processes do reach the lower atmosphere layers, and these factors have to be introduced when solving problems of short- and long-range weather forecasting, and long-term climatic variations. It is even suggested that the clarification of the mechanism of solar corpuscular streams' action on the Earth's atmosphere may help in solving the problems of artificial interventions to influence weather and climate.

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As is well known, the solar activity is defined as the combination of the highly complex physical processes occurring in the surrounding sheath of the Sun. The number and the power of these processes vary in an average period of eleven years. The main formation on the Sun characterizing this activity is the so-called active region. It is precisely there that such well known phenomena as sunspots, chromospheric flares and so forth, make their appearance, develop and then disappear. The number of active regions and of the phenomena observed in them vary also within an 11-year cycle.

How can the solar activity affect the Earth? In the first place, this is a question as to how the fraction of solar energy precisely produced by solar activity, is transferred to the immense vastness of the interplanetary space and to the Earth in particular. Here we are faced with two possibilites: energy transfer by either wave (electromagnetic) radiation or corpuscular radiation.

It has been established that such geophysical phenomena as geomagnetic storms, aurorae and comparatively prolonged disruptions of normal radiocommunication conditions, are mainly determined by solar corpuscular streams. To all appearances, electromagnetic radiation generally plays a much less substantial role in solar-terrestrial physics. Therefore, only corpuscular streams will be the object of our forthcoming discussions.

The outermost and the exceptionally extensive sheath of the Sun, namely, the solar corona continuously passing into the interplanetary space, has a determining effect on the production of corpuscular streams and, by the same token, on the interaction between the Sun and the Earth.

When a solar corpuscular stream, constituting a high-temperature coronal plasma flux approaches the Earth, it is met first of all by the magnetosphere which is the outermost sheath of the Earth. On the average, the outer boundary of the magnetosphere is located at a level of several tens of thousand kilometers above the Earth's surface. The interaction between the corpuscular plasma flux and the magnetosphere results in the immediate onset of a geomagnetic disturbance. Moreover, charged particles of solar plasma are accelerated in the magnetosphere and induce polar aurorae at levels of 100 to 1000 km above the Earth's surface. Although the formation mechanisms of geomagnetic disturbances, as well as of solar plasma charged particle acceleration in the magnetosphere, are as yet unclear, the solar origin of these phenomena is nonetheless beyond any doubt.

Do corpuscular streams intruding into the Earth's magnetosphere affect also its lower atmospheric layers, namely the troposphere and the stratosphere?

Numerous investigations published on the subject lead to the conclusion that certain specific connections exist between solar activity and the state of the lower layers of the Earth's atmosphere. However, many investigations contradict each other, while some scientists generally deny the existence of these connections. One of the reasons of this confused state of the investigated problem is the fact that up until recently sunspots were used as indicators of solar corpuscular activity. However, studies of recent years have demonstrated that the dependence between this activity and the number of sunspots is very unclear.

This article will deal with the results of investigations carried out at the Astronomical Council of the USSR Academy of Sciences the Laboratory of Solar-Terrestrial Relationships of the USSR Hydrometereological Center and in the Volgograd Pedagogical Institute. During these investigations every endeavor was made to eliminate the basic shortcomings contained in the earlier works published on the subject.

The geomagnetic and ionospheric disturbances, polar aurorae and other geophysical phenomena related to them are produced by two types of corpuscular streams, namely the quasi-stationary streams and the streams from chromospheric flares.

The quasi-stationary streams are the more numerous. In 1943, when working on the forecasting of radio communication conditions, the author of this article came to the conclusion that active regions are the source of these streams. In 1960 he developed a model of such a stream. Recently, this model was corroborated by the results of investigations of cosmic rays.

In 1961 we have compiled for the 1907-1952 period a list of active regions generating the quasi-stationary corpuscular streams. In that same year, B.D. Fomenko, Assistant Professor at the Volgograd Pedagogical Institute used this list for studies of solar-terrestrial relationships and showed that as compared to sunspots selected active regions yield significantly clearer solar-terrestrial relationships. The works of B.D. Fomenko were the starting point of further studies of this problem.

One specific property of the investigated quasi-stationary streams consists in that they are approximately radial. The active regions can be divided accordingly into two groups. The streams emanating from the active regions of the first group (group I) are "directed"' so to speak, to the Earth. On the other hand, streams emanating from the active regions of the second group (group II) go past the Earth and, therefore, do not produce any geophysical events of corpuscular origin (such as geomagnetic disturbances etc.,). Consequently, streams proceeding past the Earth could be used as a peculiar "standard" for proving the reality of solar-atmospheric relationships. This was actually done.

The statistical method of superimposed epochs played an important role in working out the problem of solar-atmospheric relationships. It allowed us to ascertain the existence of a dependence between any given phenomenon and the effects accompanying it. We have used for such an initial event the time of the passage of the active region through the central solar meridian.

The application of the method of superimposed epochs to the quasi-stationary streams, flowing past the Earth, shows that in this case there exists no clear cut solar-atmospheric effect. On the contrary, in the case of streams directed toward the Earth the method of superimposed epochs yields a very definite effect. As an example, we present Fig.1, (V.V. Kubyshkin and I.V. Bonelis, Volgograd). This figure analyzes the behavior of the ground atmospheric pressure (expressed in millibars) for the meteorological stations of Eurasia located on the longitudinal range between the Far East of the USSR and England. Time in days is plotted on the horizontal axis of the figure (and of all the following figures) The time of the active region passage through the central meridian is taken as the zero time (0^d). To demonstrate the reality of the found solar-atmospheric relationships, all the material for 1907-1952 was divided into various subgroups. We may see that the truly active regions of group II do not produce any coherent effects, while the active regions of group I yield a relatively clear effect, namely maximum pressures, occurring on the average, on the sixth day.* A maximum of geomagnetic disturbance occurs approximately at the same time. Analogous results are also obtained at the use of corpuscular streams induced by chromospheric flares.

It should be underlined that the connection between the behavior of atmospheric pressure and solar activity resulting from Fig.1 (and other similar figures which are not given here) does not stem from any presently well known geophysical regularities. It represents that absolutely special aspect of solar-terrestrial physics which requires the most thorough study.

In investigations of this problem the utilization of purely solar data, namely data on active regions and chromospheric flares is beset with a number of uncertainties. The main uncertainty consists in that the plasma velocity in various fluxes is different. As a conseuqence, the determined statistical dependences turn out to be "washed out" so that it becomes impossible to determine, for instance, the time of the atmospheric reaction to the arrival to the Earth of a corpuscular stream. This is why in the middle of 1966, it was decided to apply a much more accurate indicator, pointing at the exact time when the corpuscular stream intrudes into the Earth's magnetosphere. The geomagnetic disturbances are such an indicator.

The time t_m, corresponding to the first day of geomagnetic disturbances, when the latter already became strong enough, was taken for the initial time. Taking this into consideration, the authos compiled 4 lists of t_m times containg about 830 moments of time (days) for the 1890-1967 period, quite independent from

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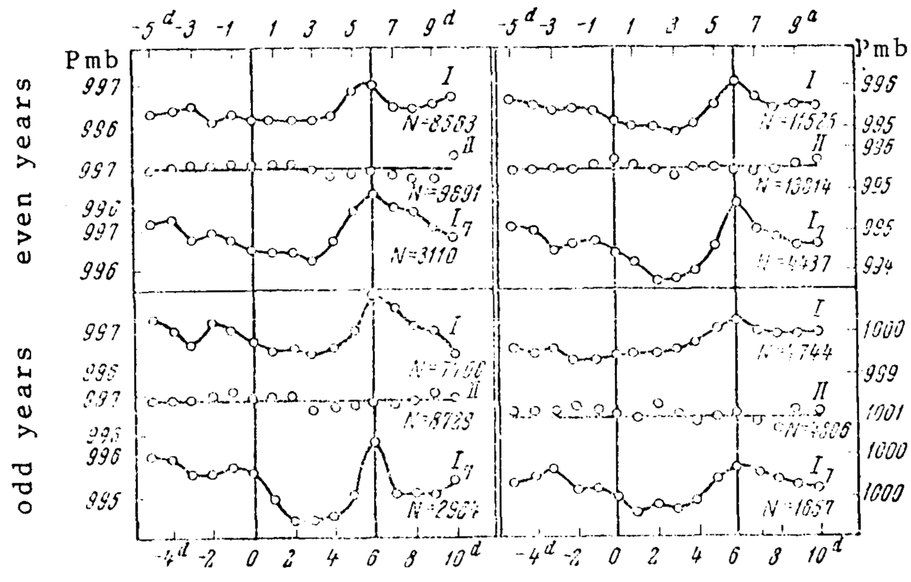
* Curves I_7 of Fig.1 correspond to cases for which the distorting influence of a mutual superimposition of effects from neighboring (close) active regions is comparatively low.



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Variation in the atmospheric pressure following the time (t = 0) of passage of active regions through the central meridian of the Sun (31 stations)

one another. These lists have formed the basis for the majority of further calculations. The main feature of these lists is that only those geomagnetic disturbances that are relatively free from the effect of mutual superimposition have been selected (separately for quasi-stationary streams and streams from flares).

Before studying the first results of the calculations which have been carried out, it is necessary to make the following points. First of all, the atmospheric pressure along the Earth's surface is extremely irregular and its variation with time is virtually continuous. Therefore, each new atmospheric "disturbance" of solar origin meets at different points of the Earth different baric conditions. In the statistical curves of the method of superimposed epochs this is manifest in the form of statistical "noise". The higher the number of independent initial solar or geomagnetic data, the lower such a noise.

Secondly, it was found in earlier investigations of solar-atmospheric relationships (D. Walker, Ye.Ye. Fedorov, V.Yu. Vise) that those points of the Earth where for a given season cyclones predominate over anticyclones (decreased mean atmospheric pressure), the sign of solar atmospheric effects is, on the average, negative. This means that, generally, the invasion of corpuscles results in a decrease in pressure, while, on the contrary, pressure increases

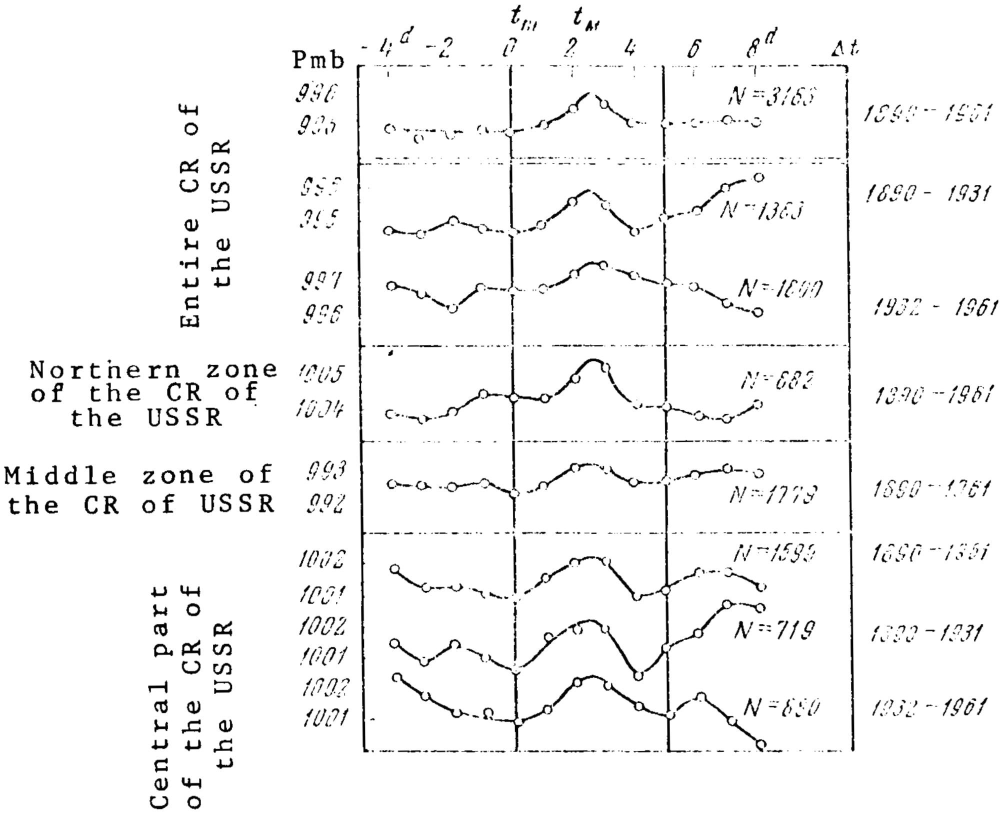
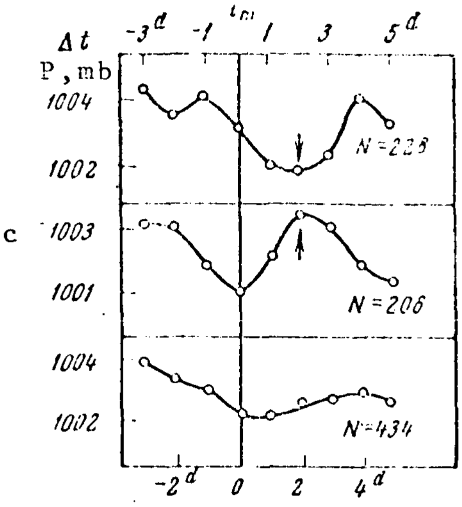


Fig.2.

Variation in atmospheric pressure following the beginning of sporadic (flaring) disturbances during the cold half of the year in the continental region (CR) of the USSR

where anticyclones prevail over cyclones. This established regularity was called the "accentation" law. Studies of solar-atmospheric effects should be carried out taking this law into account.

The results of application of the method of superimposed epochs to the behavior of atmospheric pressure on the land territories of the USSR for the cold seasons are shown in Fig.2. The investigated material is divided both for various periods of time and for various territorial regions. The upper dependence is plotted for all the 85 meteorological stations investigated. It may be seen that the pressure has in all cases a certain maximum after 2.5 days following the time t_m (reaction time). At the same time "the statistical noise" to the right and to the left of the maximum actually decreases with the increase in the volume of the investigated information. According to the accentuation law, the presence of the maximum on Fig.2 was to be expected, because the investigated Earth's territory is characterized by anticyclonic conditions precisely in the cold time period.



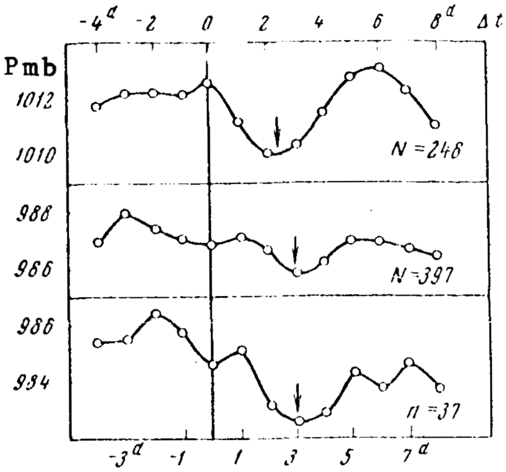
List B (geomagnetic)

Fig.3. Illustration of the "accentation" law with respect of two regions of North America under different baric conditions.

Let us now revert to places with cyclonic conditions. As the Soviet Union has almost no points with sharply expressed cyclonic conditions, we have used the territory of North America to the East and Northeast of Lake Hudson where cyclonic conditions play an important role almost year-round. The curve of the method of superimposed epochs plotted for this region is shown in the upper part of Fig.3. The middle curve is plotted for the meteorological stations of the territory located to the South of the Beaufort Sea where cyclonic conditions prevail during the cold season of the year. The lower curve shows the aggregate effect for both regions. It may be seen that Fig.3 fully corroborates the "accentation" law and indicates an approximately identical time for the atmospheric reaction (of the order of plus two days).

Modern meteorology denies the existence of simultaneous effects in different hemispheres. We have used the coastal antarctic stations for which cyclonic conditions are the more characteristic to study this problem with respect to solar-atmospheric effect. The curves of the method of superimposed epochs plotted for them were compared with the available data on analogous cyclonic regions in the northern hemisphere. The results of the respective calculations, which take into consideration the information on chromospheric flares, are shown in Fig.4. The middle curve was plotted for 14 antarctic stations, the lower curve for the French antarctic station Dumont d'Urville while the upper curve refers again to the region East of Lake Hudson. It can be seen, that the minimum of pressure occurring at the antarctic stations coincides in its location with an analogous minimum for the stations of the northern hemisphere. Moreover, the "accentation" law is confirmed.

Besides the aforementioned figures, a number of other examples demonstrating that the "accentation" law should actually play a major role in the analysis of solar-atmospheric effects could be presented. However, here immediately arises the question as to the interpretation of this law. In the foregoing we have given its "classical" formation according to which solar-atmospheric effects



Hudson Bay and Labrador Strait region

Antarctica (14 coastal meteorological stations).

Dumont d'Urville

Fig.4. Simultaneity of solar activity effects on the Earth's atmosphere following flares in the southern & northern hemispheres.

that occur in regions of decreased pressure are usually accompanied by an "additional" drop in pressure. On the contrary, in regions with elevated pressure, solar-atmospheric effects are accompanied by an "additional" increase in pressure. However, these regularities are very difficult to understand and, in this connection, the author has investigated this problem from a completely opposite standpoint.

In reality one should bear in mind, that, for example, on a synoptic chart covering a large number of years, a region of decreased pressure is merely a region in which cyclones prevail over anticyclones during a given season. The opposite is true for regions with increased pressure. Therefore the following question can be raised: is the "accentation" law not simply the result of the fact that in a given region of the Earth, say, with decreased pressure the corpuscular streams themselves generate more often cyclones and more seldom anticyclones. At the present time, this problem can be studied quantitatively, since we are now aware of the time of atmospheric reaction to the arrival of a corpuscular stream to the Earth. To this end, individual cases of pressure variations following the time t_m should be selected and one should analyze whether or not following this moment, low pressure actually preceds by 2-3 days a decrease in pressure, while high pressure precedes by an equal period the increase in pressure. Our calculations contradict the "classical" interpretation of the "accentation" law and confirm thereby the assumption that the entry of the Earth into a corpuscular stream plays an essential role in the existence of regions with an increased or decreased pressure. Therefore, corpuscular streams must generally play a very important role in the triggering of the essential weather-forming phenomena, i.e. cyclones and anticyclones. However, it is obvious that these conclusions require further investigations.

Now let us briefly dwell on some considerations on the action mechanisms of solar corpuscular streams on the Earth's atmosphere.

First of all one must understand how a "solar" disturbance, having originally appeared in the magnetosphere, reaches the lowest atmospheric layers, namely the troposphere. This is an extremely complex problem, since, as already mentioned, we do not even know how a geomagnetic disturbance occurs and how the charged solar corpuscles are accelerated in the magnetosphere. In particular, variations in pressure, density and temperature occurring during geomagnetic disturbances in the magnetosphere at 200-300 km levels remain as yet unexplained. It should be mentioned that these investigations have been started quite recently. At the symposium of the Intern'tl Meteorological Organizaton held in Vienna in 1966, reports were presented bearing witness to the existence in a number of cases of an interaction between the upper (ionosphere) and the lower (stratosphere) layers of the Earth's sheath. However, these are only preliminary results.

Problems concerning the energy of solar-atmospheric effects are of essential importance. Here, cyclones and anticyclones which are the most important forms of large-scale atmospheric motions present the greatest interest. The problem of the origin of cyclones (and anticylones) has not yet been solved. However, the majority of theories links the formation of cyclones to instability phenomena in the Earth's atmosphere. For instance, according to the wave theory of Norwegian investigators, waves of different lengths may develop under the influence of some outside causes on little-mobile frontal planes of the atmosphere. Some of these waves are unsteady and become atmospheric eddies. Thus, the cyclone serves as an example of transformation into kinetic energy of the potential energy previously accumulated in the atmosphere. In this connection, it is possible to assume that a corpuscular stream intruding into the magnetosphere, represents one of the factors contributing to a rapid development of instability in atmospheric masses ("triggering" mechanism). The fact that several cyclones are sometime found on the main atmospheric front where cyclones usually occur, may speak in favor of this assumption.

Therefore, we must not "require" of corpuscular streams an excessive energy. In any case, we must eliminate immediately the assumption according to which an increase in atmospheric pressure is equal to the increase of pressure from a corpuscular stream. And it should indeed be borne in mind that upon arrival of a stream to Earth increase of pressure is observed at some points and decrease at other ones. Moreover, according to the available evidence, cyclonic phenomena are playing in the investigated problem a more important role than the anticyclonic phenomena, and in case of cyclones we are faced with pressure decrease.

What are the conclusions that can be drawn from our results?

1. The effect of solar activity reaches the Earth's surface. Therefore, the Earth's atmosphere is not, as is usually assumed, an insurmountable barrier for solar activity.

2. Study of processes occurring in the Earth's atmosphere requires the introduction of new factors due to solar activity.

3. The study of solar-atmospheric effects may be used in solving problems of short- and long-term weather forecasting.

4. Apparently, solar activity is an important factor in determing long-term climatic variations.

5. It is possible that the elucidation of the action mechanism of corpuscular streams on the Earth's atmosphere will help us to solve problems of artificial measures influencing the climate and weather.

* * * THE END * * *

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