M. I. Pudovkin and O. M. Rasponov. *Physical mechanism of the action of solar activity and other geophysical factors on the state of the lower atmosphere, meteorological parameters, and climate.*

1. It is well known that solar activity and disturbances of the interplanetary medium which it engenders influence the most diverse processes in all envelopes of the earth, including the magnetosphere, atmosphere, lithosphere, and biosphere. The fact that solar flares affect the state of the lower atmosphere was pointed out in 1882 by G. Vil'd.[1] Since then hundreds of works have been published in which different manifestations of solar activity in the variations of the earth's weather and climate, in the change in the earth's climate, and in the change in the parameters of the lower atmosphere are discussed. However, these works have been criticized in, for example, Ref. 2, as well as in a number of other works.

The main arguments against solar activity affecting the meteorological parameters are based on energy considerations. The characteristic power associated with atmospheric processes is of the order of 10^{26}–10^{27} ergs/day. At the same time, the flow of energy from the solar wind into the magnetosphere and subsequent processes in the magnetosphere and ionosphere are of the order of 10^{23} ergs/day, which is three to four orders of magnitude lower.

In our opinion, however, a different approach to this problem is also possible. For this it is sufficient to assume that the solar wind is not a source of energy for atmospheric disturbances, but rather it somehow modulates the flow of energy from some other, stronger source. This source is, undoubtedly, the sun because there is no other sufficiently strong source in the earth's neighborhood. In this case energy flow into the lower atmosphere is modulated mainly due to variation of the optical properties of the atmosphere—the atmosphere transmission. Here there is an agent which effectively acts on the physicochemical processes in the atmosphere, and variation of this agent in turn follows solar-activity variations. Such an agent are solar and galactic cosmic rays, which contain protons with energies of 10^8–10^9 MeV. Such rays act effectively on atmospheric processes at altitudes of 10–20 km and they undergo strong variations of tens of percent which coincide with solar-activity cycles even during individual postflare disturbances.

It is from this standpoint that a number of experimental studies and numerical estimates, confirming the physical nature of the action of solar activity and other cosmophysical factors on the state of the lower atmosphere, meteorological parameters and climate, were made.[3]

2. We now give a brief exposition of the results of the experimental investigations and numerical estimates. First, a series of average winter temperatures in St. Petersburg over the period 1775–1982 was analyzed.[4] The results of the analysis indicate the existence of a periodicity in the average winter temperatures with periods coinciding with the 11- and, to a significant degree, 22-year cycles of solar activity.

The winter temperature in St. Petersburg is determined by Atlantic cyclones. For this reason, the next step was to analyze the changes in the zonal circulation of the atmosphere during intense geomagnetic storms.[5] The results show that one or two days after a solar flare the zonal circulation of the atmosphere is noticeably intensified, and three to four days after the solar flare the zonal circulation

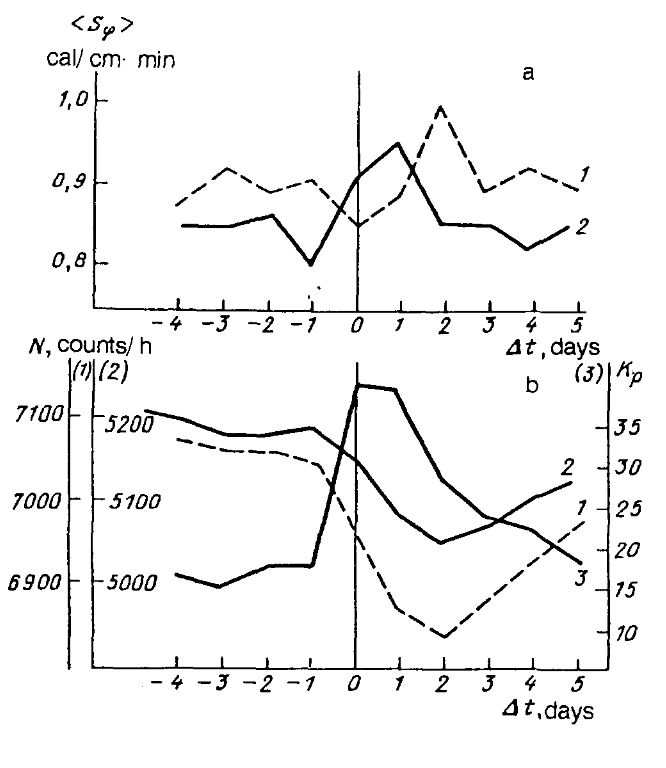

FIG. 1. a—Average direct solar radiation fluxes with respect to the times t_0 of the onset of intense geomagnetic disturbances for observatories located in the auroral (1) and subauroral (2) zones. b—Average time dependence of the index K_p of geomagnetic activity (3) and counting rates of neutron monitors at Apatity (*1*) and Krasnaya Pakhra (*2*) observatories.

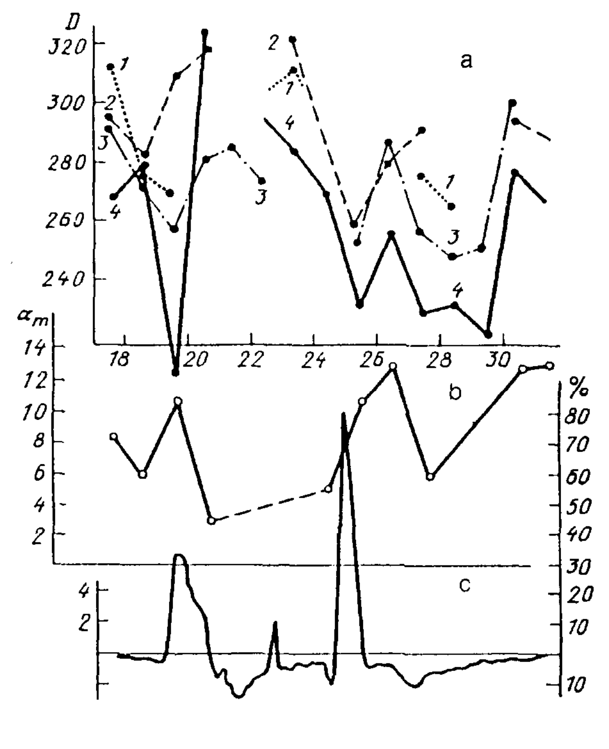

FIG. 2. a—Change in the total ozone content during the development of solar proton events in October 1989 at the Sodankylä (*1*), Oslo (*2*), Arkhangel'sk (*3*), and Reykajvik (*4*) observatories. b—Variations of the index of meridional circulation α_m of the atmosphere. c—Neutron-monitor data from Apatity.

becomes noticeably weaker. The energy required to bring about the obtained change in the atmospheric circulation was estimated to be of the order of 10^{26}–10^{27} ergs/day.

A change in the zonal circulation must be caused by a change in the atmospheric pressure. For this reason a special study of the variations of the meridional profile of the zonal (average along a parallel) atmospheric pressure during the development of intense magnetic storms was performed.[6] The results indeed confirmed the fact that an appreciable change in pressure occurs at latitudes from 55° to 90°.

As indicated, the enumerated changes in the atmospheric parameters (temperature, circulation, pressure) could be associated with the change in the atmosphere transmission during the disturbances. Figure 1 displays the results of investigations of changes in the average direct solar radiation fluxes $\langle S_\varphi \rangle$, with respect to the times t_0 at which intense geomagnetic disturbances start, for points located in the zone of polar auroras and in the subauroral zone. The plot was constructed by the method of superposition of epochs for 27 intense geomagnetic disturbances for the period 1961–1978. As one can see, the changes in $\langle S_\varphi \rangle$ can reach 0.11 cal/cm · min, i.e., 13% of the average value of the radiation at a given latitude.[7] An estimate of the additional energy flowing per day into the lower atmosphere due to the indicated change in transmission gives values of the order of $(1.5–2) \cdot 10^{26}$ ergs/day, and for a magnetic storm lasting for three to four days the total amount of additional energy can reach 10^{27} ergs. This value is comparable to the energy required for changing the zonal circulation of the atmosphere.

We note that in analyzing the experimental data indicated above, the statistical significance of the obtained results was estimated to be of the order of 90%.

The change produced in atmosphere transmission due to solar and geomagnetic activity is associated with physicochemical processes induced in the atmosphere (including cloud formation) by fluxes of galactic and solar cosmic rays. In order to check the validity of this assertion, the change in the total ozone content in the atmosphere during the development of solar proton events and subsequent geomagnetic disturbances was analyzed.[8,9] It was found that at high latitudes solar proton events can change the total ozone content (by up to 10–15%) and the content of nitrogen oxides. These changes must affect the optical properties of the atmosphere. As an example we present plots of the change in the total ozone content in the atmosphere observed at a chain of observatories from Reykjavik to Arkhangel'sk (a distance of the order of 3000 km) during the development of proton events in October 1989–October 19, 23, and 25 (Fig. 2). It is obvious that over a longitudinal distance of the order of 3000 km the change in the ozone content occurs virtually synchronously and over the time of the development of the event the ozone content decrease by 4–19%.[10] The figure also displays the values of the index of the meridional circulation of the atmosphere.

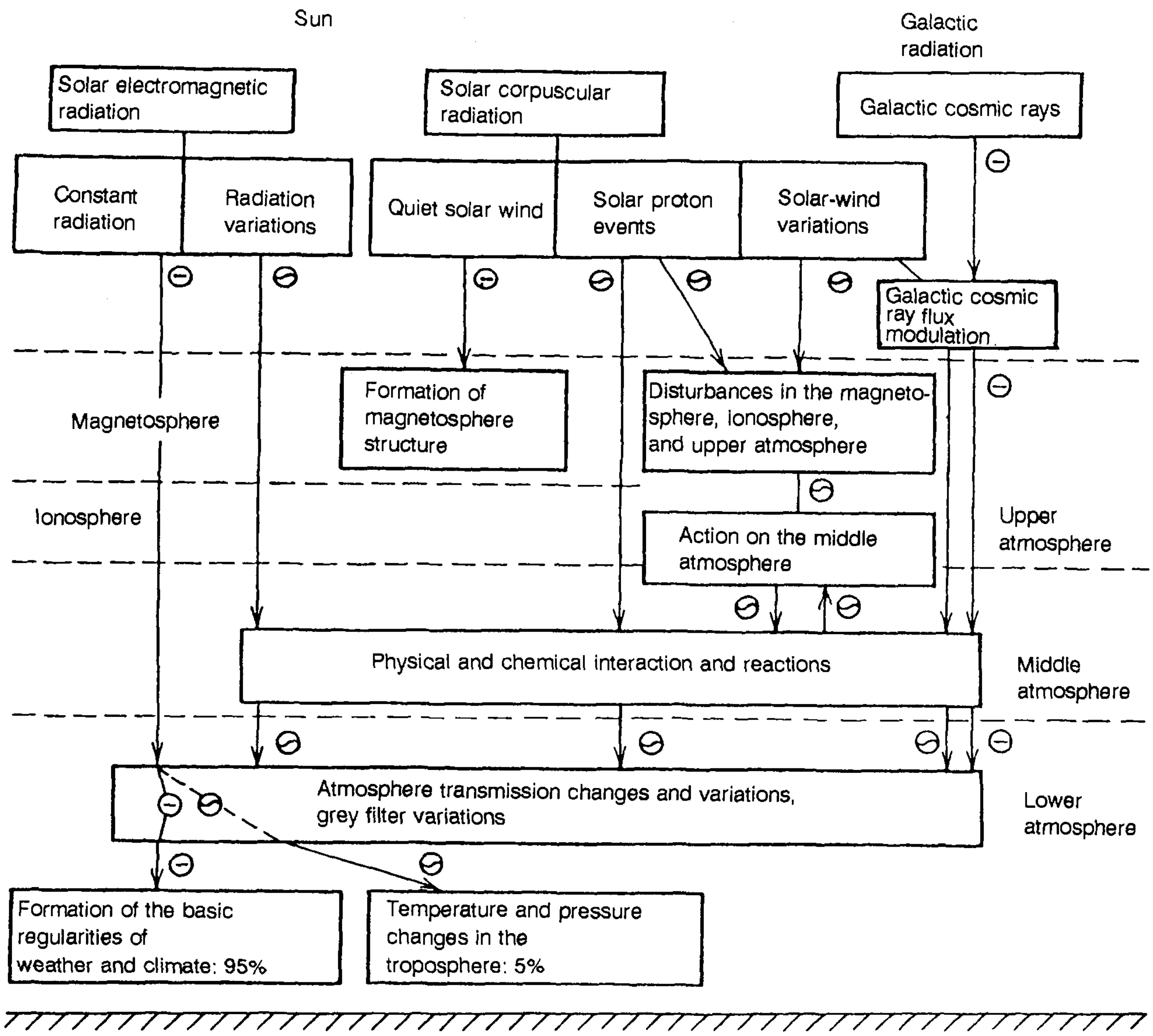

FIG. 3. Scheme of the action of solar and geomagnetic activity as well as other cosmophysical factors on processes in the lower atmosphere and on the meteorological and climatic parameters.

It is obvious that solar flares stimulate a sharp change in atmospheric convection, which was already pointed out previously. In concluding our analysis of the experimental results we mention that in Ref. 11 it was shown that the cloud index changed in a number of regions of the northern hemisphere after x-ray bursts on the sun. This result also confirms the fact that the atmosphere transmission changes with the development of solar and geomagnetic activity.

3. In conclusion we present a scheme of the action of solar activity and other cosmophysical factors on processes in the lower atmosphere and on the meteorological and climatic parameters (Fig. 3), and we briefly summarize the problems considered in this work:

a) The physical mechanism of the action of solar and geomagnetic activity as well as other cosmophysical factors on processes in the lower atmosphere and on the meteorological parameters and climate, the determining element being the change in the atmosphere transmission under the action of primarily variations of galactic and solar cosmic rays, was investigated.

b) Experimental confirmation was proposed for the named mechanism. The confirmation is based on analysis of changes in transmission, pressure, and circulation of the atmosphere during a geomagnetic disturbance and analysis of variations of the air temperature during solar-activity cycles.

c) The change in atmosphere transmission is associated with the change in the composition of the atmosphere: with the development of the nitrogen cycle of the physicochemical reactions under the action of variation of galactic and solar cosmic rays, UV-radiation, and x-rays, and with the action of the hydrogen cycle of the physicochemical reactions, including stimulation of cloud formation.

d) It was shown that the additional energy flowing into the atmosphere as a result of a change in the atmosphere transmission during a disturbance is approximately the same as the energy of the processes excited in the atmosphere.

Thus a physical mechanism for continuous action of solar and geomagnetic activity on processes in the lower atmosphere and on the meteorological parameters and climate has been proposed for the first time.

The proposed physical mechanism is correct from the energy standpoint, since it presupposes a balance between the additional energy flowing into the lower atmosphere and the energetics of the processes excited in the atmosphere.

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