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Response of Atmospheric Pressure and Air Temperature to the Solar Events in October 2003

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Abstract—Variations in the main weather parameters were studied for effects of solar flares and magnetic storms: the air temperature *T* and the atmospheric pressure *P*. We report the results of our comparison of these parameters measured at the mountain meteorological observatory near Kislovodsk (2100 m above sea level) to the monitoring data on strong solar-geomagnetic perturbations for October 2003. We observed a decrease in the value of *P* for medium and large flares (of the type M > 4) in nine cases (82%) and an increase in *T* after magnetic storms with $K_p > 5$ in 16 cases (84%). Hence, the manifestation of solar flares and magnetic storms in weather parameter variations (*T* and *P*) at an altitude of 2100 m was proven, and the contribution of the radiooptical three-step trigger mechanism to solar-weather relations was qualitatively confirmed.

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INTRODUCTION

One of the challenges of practical meteorology is to expand reliable forecasting of weather characteristics beyond the approximately two-week term that is presently considered in meteorology to be the limit given the current technique of forecasting physical conditions in the troposphere. In our opinion, a realistic possible means of increasing the periods of early forecasts of the weather and climate characteristics is to take into account solar variability and, particularly, factors of solar-geomagnetic activity. We described such capabilities in a number of papers (Avakyan, 2013a, 2013b) and in the RF Patent on a method of mid- and long-term prognosis of temperature anomalies in the near-surface air by variations of the cloudiness intensity (Avakyan and Baranova, 2014). The physics of the influence of flare-caused phenomena occurring on the Sun and in the terrestrial magnetosphere was described before by Avakyan (2008), who proposed a hypothesis on the radiooptical three-step trigger mechanism of the solar-magnetospheric and weather–climate relationship (see Fig. 1). It is worth stressing that all of the steps of the physical mechanism that we developed were experimentally confirmed (Avakyan, 2008, 2013a, 2013b; Avakyan and Voronin, 2011).

The purpose of the work was to determine the correlation degree in the response of the main weather parameters—the air temperature *T* and the atmospheric pressure *P*—on the strongest manifestations of the current activity of the Sun—solar flares and geomagnetic storms. The data source on the weather parameters was taken from observations at the Shadzhatmas mountain meteorological station (near Kislovodsk, at 2100 m above sea level) carried out in October 2003, when there was an unusually strong manifestation of solar-geomagnetic activity.

The diurnal courses of *T* and *P* were compared to all of the manifestations of flare-caused phenomena: X-ray flares on the Sun, principal magnetic storms, the arrival of solar proton fluxes—solar cosmic rays—at the terrestrial magnetosphere, and the Forbush decrease effect for the intensity of the flux of galactic cosmic rays (Fig. 2). For clarity we additionally show the standard course of the atmospheric pressure at the observational site for October (the curve labeled as *Tendency*) and the current values of the Total Solar Irradiance (TSI) (labeled as *SC*) in the considered period.

1. OBSERVATIONS OF THE RESPONSE OF METEOROLOGICAL PARAMETERS TO STRONG SOLAR-MAGNETOSPHERIC EVENTS

Figure 2 presents the changes of *P* and *T* from three-hour data of the Shadzhatmas meteorological station for October 2003. The best-known characteristics of solar-geomagnetic activity are also shown (the soft X-ray flux of the Sun and the magnetic activity index K_p are on the top and below, respectively). The changes of *P* under the influence of solar flares completely agree with measurements obtained earlier at the Jungfraujoch mountain station (3475 m, Germany) (Bogdanov et al., 2006), where two facts were

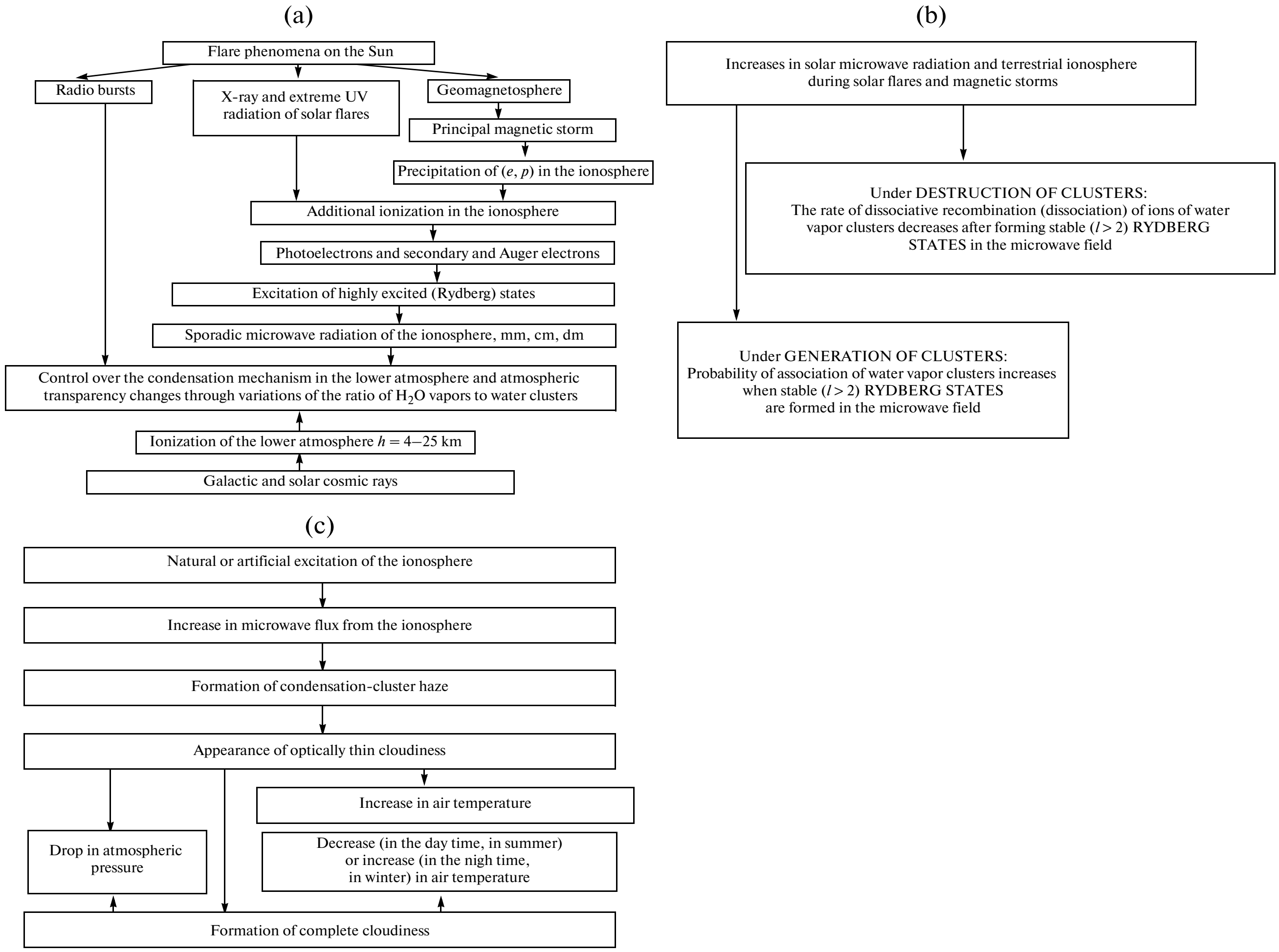

Fig. 1. Control over solar-geomagnetic activity factors, condensation mechanism in the lower atmosphere, and atmospheric transparency changes by variations of the ratio of H_2O vapors to water vapor clusters.

detected: the flare induces a decrease in atmospheric pressure, while a Forbush decrease in the intensity of the omnidirectional flux of galactic cosmic rays (GCR) near the Earth leads to an increase of *P*. In the considered period, the Forbush effect was observed only once from the beginning of the day on October 29; its abnormally strong maximum was at 14–16 UT, which was accompanied by a drop of the intensity of the GCR flux by 20%, as follows from the data from neutron monitoring at the Apatity station. This phenomenon ended at the beginning of the day on October 30 (Fig. 2) and was accompanied by a sharp surge of the atmospheric pressure *P*. Such a pronounced pressure peak was probably caused by the additional superposition of two strong arrival events on the terrestrial surface (i.e., Ground Level Events (GLE) (Miroshnichenko and Perez-Peraza, 2008))—the arrival of the fluxes of solar cosmic rays (SCRs) on October 28 at 12–20 UT and on October 29 at 00–03 UT. SCR events may influence the troposphere in the same way solar short-wavelength (X-ray) flares do (Veretenеko and Pudovkin, 1996): they increase the total cloudiness and, consequently, lead to a pressure drop. These two SCR events were actually accompanied by sharp terminations of pressure growth during the Forbush effect on October 28 and 29, and they clearly stood out against the background of the surging value of *P*. According to Veretenеko and Pudovkin (1994), the Forbush effect is connected with a decrease in the number of cirrus clouds; at the same time, it is known that, when such clouds appear (they are generated after solar flares and geomagnetic storms and, as a rule, produce a heating effect), the pressure decreases by 5–6 GPa, and, simultaneously, the air temperature slightly rises (Borisenkov et al., 1989). Hence, a decrease of the air temperature should be expected in the period of the Forbush effect; this was actually observed (down to the level of the absolute temperature minimum for the whole of October 2003) (see Fig. 2).

When the pattern of the appearance of X-ray solar flares (according to the GOES spacecraft data (the upper curve in Fig. 2)) was compared to variations of the *P* value, only flares of medium and high intensity were taken into consideration (of type M, larger than 4).

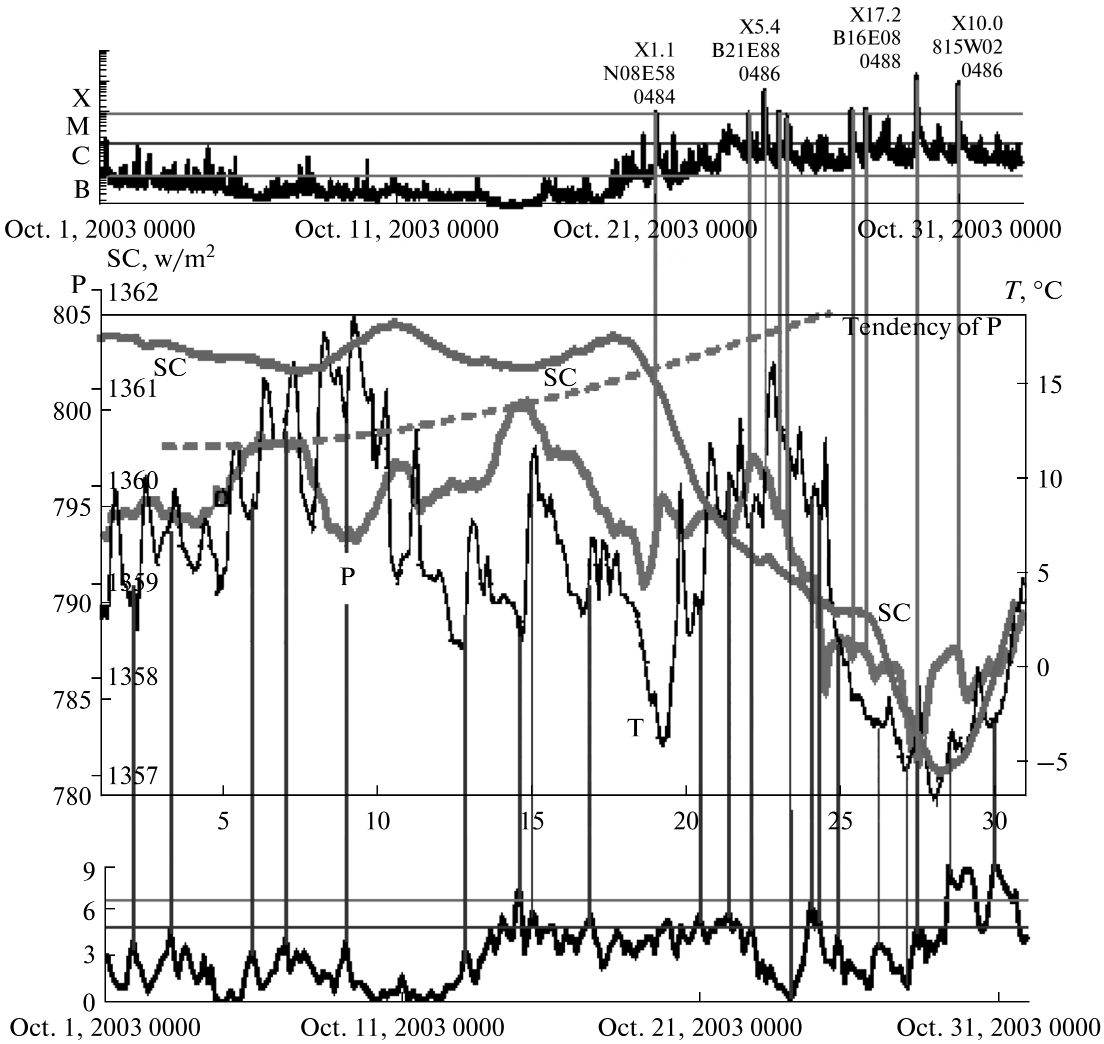

Fig. 2. Changes of the near-surface pressure *P* and air temperature *T* from the three-hour data of the Shadzhatmas meteorological station for October 2003 (see the text for details) as compared to the World Wide Web data on the X-ray flux of the Sun (upper plot with a scale of flare classes) and variations of the geomagnetic activity index K_p (lower plot with a scale of K_p).

The number of such flares in October 2003 was 11, and four of them are of the X type. It is worth reminding that, according to the radiooptical mechanism of the solar-terrestrial relations (Avakyan, 2008), the efficiency of X-ray flare manifestation in the troposphere depends on the solar illumination of the upper-laying ionosphere, at altitudes higher than 100 km, where microwave radiation is generated in the transitions between the Rydberg (highly excited) states.

It turned out that drops of pressure *P* (nine cases) were mostly observed for such flares, and only two cases showed growth—after flares of the (X17.2) and (X10.0) types. However, as was shown above, these exceptions are more than likely caused by the prevailing contribution of three other events; they were the strongest in October 2003: the Forbush effect and the two arrivals of solar cosmic rays of the GLE type.

Let us now consider cases of strong geomagnetic perturbations (principal magnetic storms with the planetary index of activity $K_p = 5$ and higher). According to the radiooptical mechanism (Avakyan, 2008), a storm in the troposphere works in the same way a flare does, at the expense of strengthening microwave flux generation in the excited ionosphere; consequently, it is accompanied by an increase in cloudiness, in which the cirrus—heating—form initially dominates. This is clear in the increase of the air temperature for 16 of 19 storm events (84%) (Fig. 2). The complexity of such a comparison lies in the known one-day or longer delay in the response of the tropospheric characteristics (especially the amount of clouds) to the storm effects of corpuscular precipitations, which was already noted by Dmitriev and Govorov (1972).

In general, the anticyclone started to disintegrate from the second half of October under the influence of

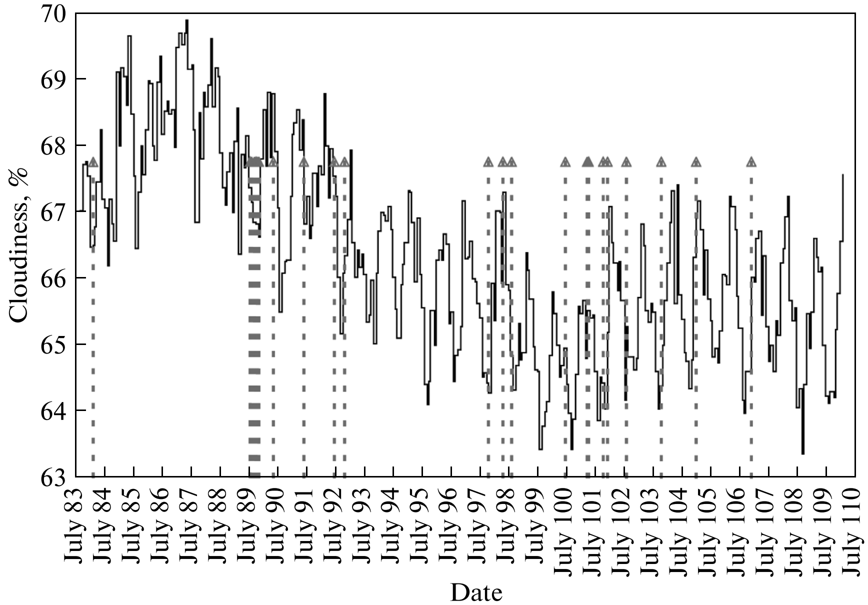

Fig. 3. Changes in global cloudiness from data of the International Satellite Cloud Climatology Project (ISCCP) (http://isccp.giss.nasa.gov/). Vertical errors show the known strong solar proton events (GLEs) (Miroshnichenko and Perez-Peraza, 2008).

a strong solar-geomagnetic activity. This disintegration was initially caused by the singular effect of geomagnetic perturbations (magnetic storms), though the absolute minimum in pressure and temperature was reached against the background of the strongest (X17.2) solar flare on October 28. This was mostly induced by the superposition of phenomena that are unique for the whole year: two SCR events (the flux of solar protons was detected on the Earth's surface) and the Forbush decrease in the flux of galactic cosmic rays, which was the most powerful of the year. As follows from the radiophysical mechanism, flares and storms, first of all, form optically thin (heating) cloudiness, usually in the upper (cirrus) layer. Second, flares and storms are followed by a decrease in atmospheric pressure. As a result, the anticyclonic weather type is substituted by the cyclonic. The observations showed that such a response is noticeable already 6 hours after the solar flare (Schuurmans, 1982) and 6–7 hours after the main phase of the magnetic storm (detected as a drop in the atmospheric transparency after a flare of the IBC III aurora (where IBC III is the International Brightness Coefficient indicating the aurora intensity) (Starkov and Roldugin, 1994)).

2. ANALYSIS OF THE RESPONSE OF THE OCCURRENCE OF GLOBAL TOTAL CLOUDINESS TO SOLAR-GEOMAGNETIC ACTIVITY EVENTS

Figure 3 presents all cases of solar proton events (GLEs) detected by the neutron monitors on the terrestrial surface (Miroshnichenko and Perez-Peraza, 2008). For the first time, it was shown that such strong SCRs produce substantial influence on the global behavior of the total cloudiness on a monthly scale. After these events, the total cloudiness amount usually increases (in 82% of the cases). This phenomenon should be further analyzed and investigated with account of the time delay after SCR penetration through the polar cap. The discovered effect was preliminary considered in somewhat more detail by Avakyan et al. (2014). It was found that the detected effect appears more frequently, by 1.5–2 times, in June–July and September–October (~25 and over 30%, respectively), while the annual average of the event probability is 16.7% for the period of two months. Such inference well agrees with the results of statistical analysis of the data on the absorption of space radio-noise for the arrival of more than a thousand SCRs (Kozelov, 1975). In this data set, the periods of June–July and September–October are detected (together with March) as the time of SCR predominant appearance.

The influence of the main solar-geomagnetic activity factors on the total global cloudiness distribution was also detected on a secular-cycle scale. In Fig. 4, the tendencies in the behavior of this cloudiness in periods of different courses of secular solar-geomagnetic activity are shown according to the paper by Avakyan and Voronin (2011). (They cover the period from the secular maximum of electromagnetic and corpuscular activity of the Sun in 1985 and 1987 (Lockwood and Fröhlich, 2007), respectively, to the end of 2003, when the number of principal magnetic storms was maximal over the entire time interval of their instrumental observations.) The same figure also shows the data on month–season scales: variations of

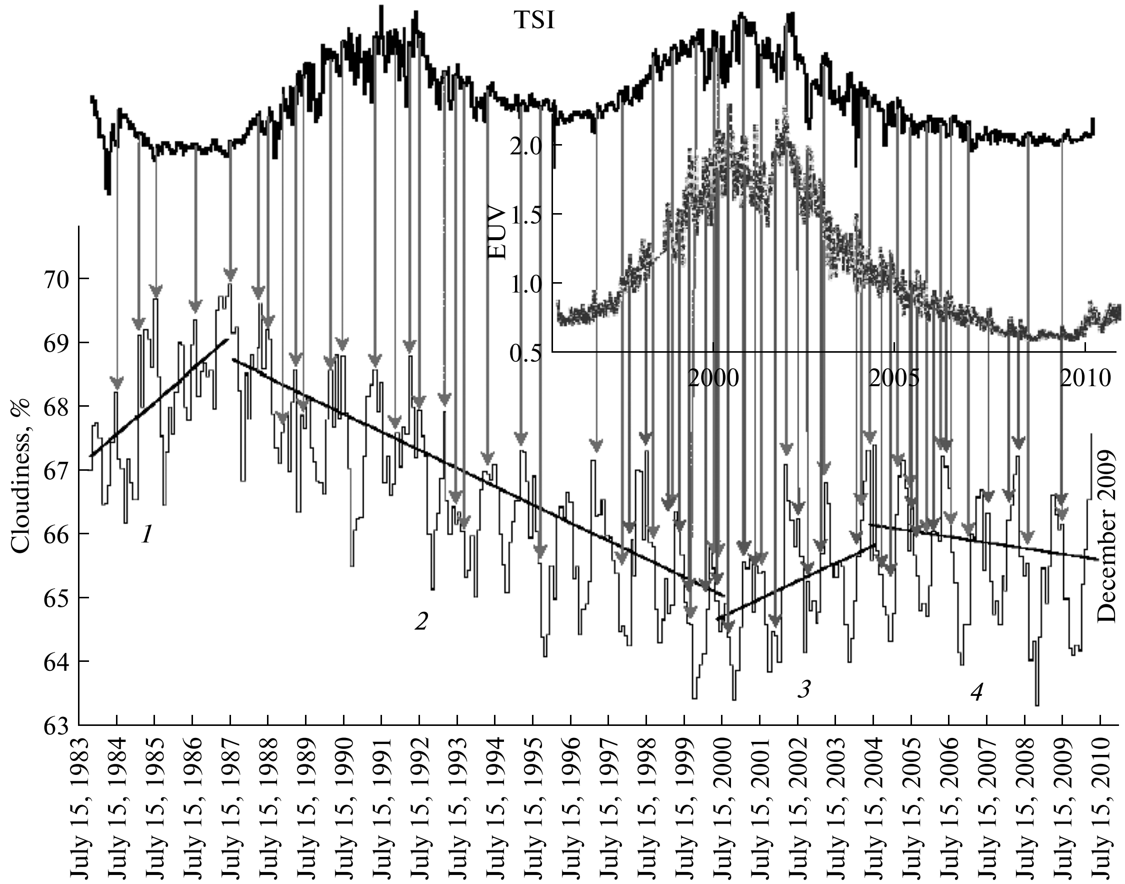

Fig. 4. Changes in global cloudiness from the data of the International Satellite Cloud Climatology Project (ISCCP) (http://isccp.giss.nasa.gov/) averaged over months. The following trends are indicated: (*1*) from 1983 to 1985: a growth in cloudiness due to an increase in solar electromagnetic activity and an increase in geomagnetic activity (the number of principal magnetic storms); (*2*) from 1987 to 2000: a drop in extreme UV radiation and the number of flares on the Sun; (*3*) from 2000 to 2003: further growth of the number of principal magnetic storms continuing until the end of 2003; (*4*) from 2004 to the present day: a general fall in geomagnetic activity (Miroshnichenko and Perez-Peraza, 2008). Other designations: "TSI" is for variations in total solar irradiance (monthly values according to Fröhlich (2012), and "EUV" is for the data from SOHO/SEM and SDO/SolACES space experiments on variations of the solar flux in the wavelength range from 26 to 34 nm (Wieman et al., 2014).

the TRI value and radiation flux from the whole solar disk in one of the strongest lines of the solar spectrum at 30.4 nm werer obtained from spacecraft monitoring. From the comparison of these data to the behavior of variations in global cloudiness, it follows that up to 77% of the TSI peaks (35 events in the period from 1983 to 2009) coincide with the cloud area peaks. Moreover, around 80% of the solar flux peaks measured in the wavelength range of 26–34 nm (16 significant events for the whole period of measurements from 1996 to 2009) fall either at the start of the development of maxima in the cloud cover or the end of the periods of decreased total cloudiness area.

The data in Fig. 4 give direct evidence on the contribution of the radiooptical three-step trigger mechanism (Avakyan, 2008) to the response of the global total cloudiness prevalence to the increase in solar-geomagnetic activity (which is always accompanied by strengthening of the microwave radiation of the excited ionosphere). This is seen from the behavior of cloudiness trends. This mechanism is also confirmed by the current variations of the cloud cover during the surges of the TSI values (associated with the development of the atmospheric activity on the Sun and with its manifestation—UV floccules or flare fields) and the extreme UV radiation flux in one of the strongest lines in the ionizing solar spectrum (30.4 nm).

3. CONCLUSIONS

The comparison of the weather parameter values at the mountain station near Kislovodsk (2100 m above sea level) and the monitoring data on strong solar-geomagnetic perturbations for October 2003 are presented. It was directly demonstrated that the values of the air temperature and atmospheric pressure immediately respond to all solar-terrestrial perturbation events—flares in the soft X-ray range, principal magnetic storms, SCR arrivals, and Forbush decreases in the intensity of the GCR flux. The sign of these responses confirms the conclusions of the other authors.

Analysis of the data obtained from satellite monitoring of the global distribution of total cloudiness revealed correlations (i) between variations in solar-geomagnetic activity in the maximum of the current secular cycle and tendencies in cloud cover occurrence and (ii) between the cloudiness area and Total Solar Irradiance surges and the extreme UV flux in one of the strongest lines of the ionizing solar spectrum (30.4 nm). Thus, the results of the analysis of both the data from the mountain station and from changes in the global cloudiness distribution detected from satellites for the last decades qualitatively confirm the contribution of the radiooptical three-step trigger mechanism to the solar-weather relationship. Proposals for experimental verification of the considered approach to the mechanism of solar-magnetospheric influence on weather–climate characteristics are presented in the paper by Avakyan (2012).

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