Proceeding Paper

Impact of Various Sources of Disturbances on the Atmospheric Electric Field and the Lower Ionosphere †

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Abstract: Possible impact of solar activity on the atmospheric electric field, thunderstorm activity and lower ionosphere was investigated. The investigation was based on the electric field measurements and ionospheric observations at Alma-Ata (Kazakhstan). The investigation showed a decrease in the atmospheric electric field (~40÷50 V/m) under "fair" weather conditions, fluctuations under magnetic storms and anomalous changes before and during significant and weak earthquakes. The study indicated a tendency for thunderstorm appearance with 1–2 days delay after impact of CMEs or HSSs events on the Earth magnetosphere. Noticeable changes in the lower ionosphere during the periods were found.

Keywords: thunderstorm activity; atmospheric electric field; earthquakes; effects in the ionosphere

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1. Introduction

The study of the interaction of dynamic processes occurring in different layers of the Earth's atmosphere and ionosphere is one of the most important fundamental problems of the physics of near-Earth space. Thus, interest in the problems of atmospheric electricity does not weaken. First of all, this is due to the understanding of the atmospheric electric field as an important environmental factor, closely interconnected with other components in the Earth's atmosphere/ionosphere system [1] and affecting human life. Ground-based data in combination with satellite observations will lead to a better understanding of the fundamental questions about the relationship between processes in the lower atmosphere-ionosphere region, to an understanding of the factors that control them. To date, not all processes in the atmosphere-ionosphere system are understood, especially their interrelation, which leads to the need for further research.

In the results of the analysis of data on the change in the electric field strength (E) in the atmosphere (as a measure of thunderstorm activity), it was previously shown [2,3] that after the passage of the active region through the central meridian of the Sun, after about two days, global thunderstorm activity on Earth is maximum. The authors conclude that the influence of the active region on thunderstorm activity is carried out through the high-speed solar wind emanating from this region. An increase in the number of lightning discharges, as well as an increase in thunderstorm days, which was observed by the authors of [4], coincided with an increase in the flux of solar energetic particles (SEP) that were not recorded on the earth's surface, but, nevertheless, penetrated to tropospheric heights and, as the authors of [3] suggest, under appropriate weather conditions, could initiate lightning discharges.

The purpose of this work is: to (1) study of features of the manifestations of various sources of disturbances in the atmospheric electric field at the Tien- Shan high-mountain experimental complex of the Institute of the ionosphere (Kazakhstan); (2) to study the relationship between the solar and thunderstorm activity using the data of registration of thunderstorm events at the complex.

2. Data and methods

The experimental complex for measuring atmospheric electric fields, "ELIS-TS", is installed at the high-mountain Tien-Shan station (3340 m above sea level, 43º02'N, 76º56'E). The complex consists of two detectors: detector of the quasistatic electric field and detector of the high frequency component of electric field. The detector of the atmospheric electric field is an electrostatic fluxmeter («field mill»), designed to measure the vertical component, Ez, in the range of ± 50 kV/m with a sensitivity of 10 V/m. The detector of the high-frequency component, dE/dt, registers a return lightning stroke in the range of +/-600V/m and, at the moment of the lightning discharge, generates a control signal, the trigger, for a complex of installations that measure various geophysical parameters. Both measuring systems can work in 2 modes: "slow" and "fast". The "slow" mode is intended for recording the measured parameters of the atmosphere in "fair weather" conditions and in the absence of lightning discharges (time resolution 0.05 s). The "fast" mode (time resolution 50 μs) is triggered by the trigger system when a thunderstorm front approaches, from a signal that comes from a sensor that measures dE/dt. The primary view of the results of measurements of the atmospheric electric field is carried out by the IDL program, which allows you to view the recorded information with different time resolutions, draw preliminary conclusions, and determine the time of occurrence and duration of thunderstorm events.

Effects of solar activity on the lower ionosphere and thunderstorm activity were studied according to the ground based observations. The state of the lower ionosphere was estimated by studying the variations in the minimum reflection frequencies from the ionosphere (fmin) and the critical frequencies of the sporadic layer E (foEs), obtained by vertical radio sounding of the ionosphere at the station Alma-Ata [43.25N, 76.92E] during the considered thunderstorm events. Information about solar events (flares and their class), coronal mass ejections (SMEs), high-velocity solar wind streams (HSSs), their geoeffectiveness, and the date of their arrival at the Earth's magnetosphere boundary were obtained from weekly space weather surveys of the Space Weather Prediction Center (Space Weather Prediction Center) (ftp://ftp.swpc.noaa.gov/pub/warehouse/ (accessed on)). The activity of the geomagnetic field was estimated according to the Dst index (http://wdc.kugi.kyoto-u.ac.jp/(accessed on)) in accordance with the generally accepted classification, it is small ($-50 \le Dst = -30$), moderate ($-100 \le Dst = -50$) and a big storm ($Dst < -100$).

3. Results and Discussion

3.1. Peculiarities of Regular Variations of the Atmospheric Electric Field

Variations in the atmospheric electric field due to regular, periodic sources of disturbances reflect its dynamics under «fair weather» conditions. The classic example of the global variation of the electric field is the unitary variation, which is characterized by the diurnal change in the magnitude of the electric field with a maximum around 19:00 UT, the Carnegie curve [5]. The dynamics of the atmospheric electric field under "fair weather" conditions was studied on the basis of 15-year measurements at the high-mountain Tien-Shan station. The daily course of the atmospheric electric field for the summer and winter periods is shown in Figure 1.

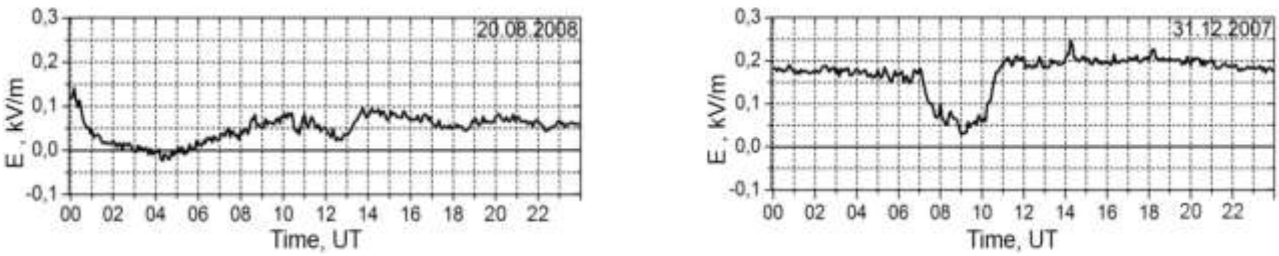

Figure 1. Diurnal variation of the electric field at the high mountain Tien-Shan station under «fair weather» conditions in summer and winter.

The absence of the Carnegie effect in the diurnal variation of the electric field at the high-mountain Tien-Shan station has been established. We consider, that the most probable explanation for this fact is the proximity to the thunderstorm source in the Himalayas. It is the mountain range of the Himalayas, that plays the decisive role for our region. The maximum thunderstorm activity at the high-mountain cosmic-ray station occurs much earlier than in other regions at our latitude, but located lower in height. The local features of the location of the high-mountain station prevail over the global effects that affect the dynamics of the atmospheric electric field in this case.

3.2. Peculiarities of Manifestations of Sporadic Disturbance Sources on the Dynamics of the Atmospheric Electric Field

Giant coronal mass ejections (CMEs) and high-velocity solar wind streams from coronal holes (HSSs) are the most geoeffective sporadic manifestations of solar activity. Their collision with the Earth's magnetosphere and atmosphere leads to magnetic and ionospheric storms, forbush-decrease in the intensity of cosmic rays, and other phenomena**.** Forbush effects and magnetic storms are often considered inseparable from each other as a consequence of one source of disturbances. Contradictory results appear in studies of the impact of sporadic solar activity phenomena on geophysical parameters in connection with this [6]. However, the most significant difference between them is that the Forbush effect is determined by the conditions in the extended heliospheric region, while geomagnetic activity depends on the local situation near the Earth [7]. Our studies were carried out taking into account features of manifestations of geoeffective sporadic phenomena of solar activity in the atmosphere and magnetosphere of the Earth: 1 - large Forbush effects and large magnetic storms, 2 - large Forbush effects and weak magnetic disturbance, 3 - large magnetic storms and Forbush effects of less 1%. Only periods of "good weather" were analyzed in this case. Both an increase and a decrease in the electric field are observed after the impact of powerful coronal mass ejections, CME, accompanied simultaneously by large magnetic storms and Forbush-decreases in cosmic rays. It should be noted that the increase in the atmospheric electric field in this events is insignificant and more rare. Perhaps the increase is due to a lower background level the day before. Obvious decrease in the atmospheric electric field is observed after the impact of powerful coronal mass ejections on the near-Earth space, accompanied by a significant decrease in galactic cosmic rays (Forbush-effect), but an insignificant magnetic disturbance. Values of the atmospheric electric field after the CME, accompanied by the large magnetic storm and the large Forbush- effect (left panel) and after the CME, accompanied by the significant Forbush-decrease and weak magnetic disturbance (right panel) are shown in Figure 2. The red vertical line in the figures is the arrival of a CME or HSS into the Earth's orbit.

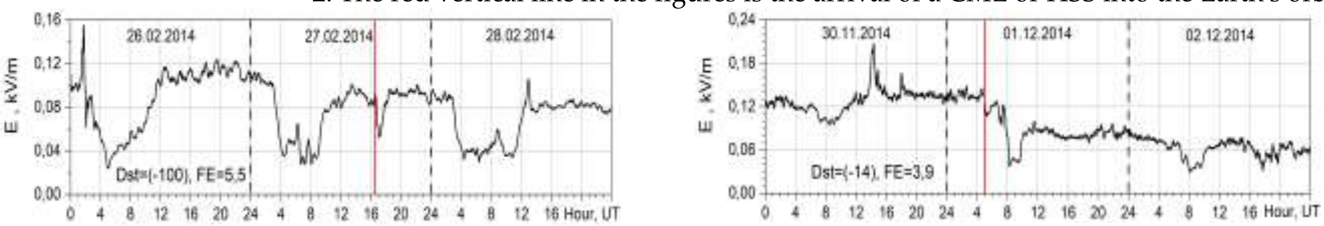

Figure 2. Values of the atmospheric electric field after the CME 27.02.2014 and 01.12.2014.

Galactic cosmic rays are the main source of ionization up to altitudes of 60 km. Near the earth's surface, radioactive gases serve as an additional source of ionization; above 60 km, ultraviolet radiation dominates [8]. The high stability of the intensity of cosmic rays ensures relatively small variations in the electric field. During Forbush-effects, the current in the Earth–ionosphere column decreases due to an increase in resistance due to a decrease in atmospheric ionization, which should lead to a decrease in Ez, according to estimates [9]. Our results do not contradict the statements of the authors [8,9], however, the relative contribution of radioactive gases to the ionization of the surface atmosphere needs to be clarified.

The values of the atmospheric electric field at the high-mountain station under the influence of a large geomagnetic storm, Dst-103, and under "fair weather" conditions for the November 14, 2012 event are shown in Figure 3 (left panel). The values of the electric field characteristic of "fair weather" conditions are not observed in this event, but significant field fluctuations are observed; from 40 to 120 V/m. The results of calculations of the normalized power spectra of variations in the atmospheric electric field during magnetic storms (red color) against the background of spectral estimates of the undisturbed atmosphere (blue color) are presented in the right panel of Figure 3. Spectral peaks exceeding the 95% confidence interval are observed in the minute ranges (10-3 ÷ 10-2) Hz, (10-2 ÷ 10-1) Hz.

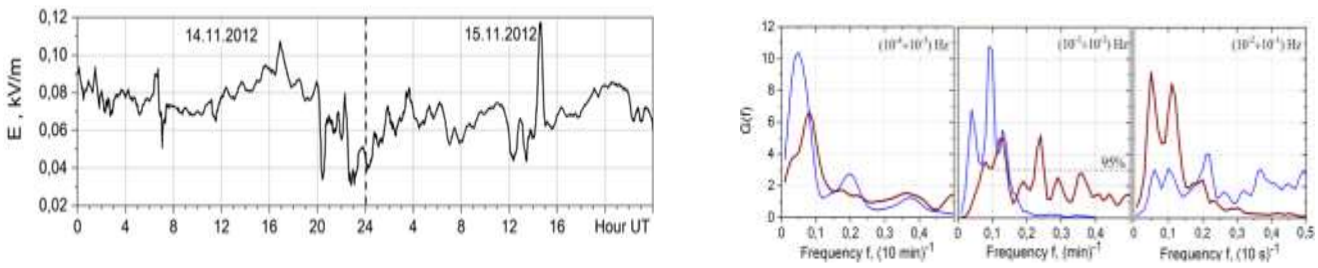

Figure 3. The values of the atmospheric electric field under the impact of the large geomagnetic storm (left panel) and power spectra of variations in the atmospheric electric field during magnetic storms (right panel, red color).

3.3. Investigation of the statistical relationship between thunderstorm activity and processes on the Sun

In general, 125 cases of thunderstorm events were recorded in the period; of these, 55 cases were characterized by the appearance of negative, 30 cases by the appearance of positive and 40 cases by the appearance of mixed discharges. The results of a joint analysis of geomagnetic, solar and thunderstorm activity showed that there is a tendency for thunderstorm activity to appear during periods of increased geomagnetic activity (geomagnetic storms) with the highest probability in the recovery phase to the level of a quiet geomagnetic field, as well as during the impact of geoeffective coronal mass ejections on the Earth's magnetosphere (CME) and high-velocity solar wind streams (HSS) observed during the considered periods. It was found that 21 events of lightning activity with positive discharges, 39 out with negative discharges, and 24 out of 36 events with mixed discharges were accompanied or preceded by the CME and HSS effects (see an example in Figure 4). In the figure, the symbols "↑", "▼", "♦" indicate the date of thunderstorm events with positive, negative and mixed discharges, respectively, powerful events are highlighted in red. The horizontal arrows in the figures mark the time intervals when the Earth was under the influence of the effects of CMEs and HSSs, the length of the arrows indicates the duration of their greatest impact.

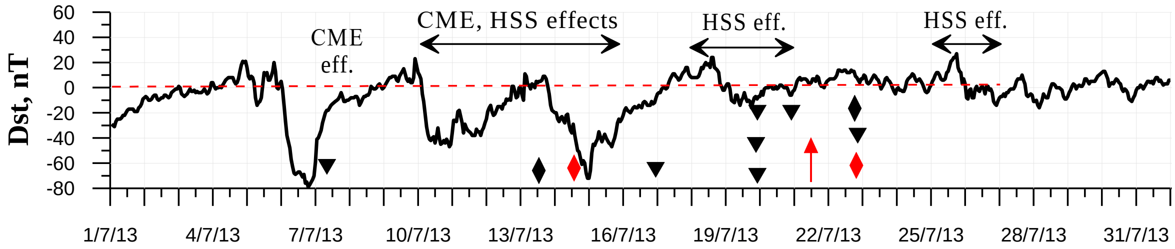

Figure 4. Variations of the Dst-index and the occurrence of thunderstorm activity in July 2013.

As a result, it was found that in no less than 70% of cases, thunderstorm activity was observed during periods of impact on the Earth's magnetosphere by CMEs and HSSs, and this suggests that the increase in thunderstorm activity occurs under the influence of high-speed flows of energetic particles of the solar wind (protons and electrons). Figure 5 shows frequency of occurrence of the thunderstorm events as a function of time delay between observed thunderstorm and the arrival of geoeffective CMEs and HSSs to the Earth. One can see that thunderstorm activity is usually most likely to increase during or 1-2 days after the arrival of geoeffective CMEs and HSSs to the Earth.

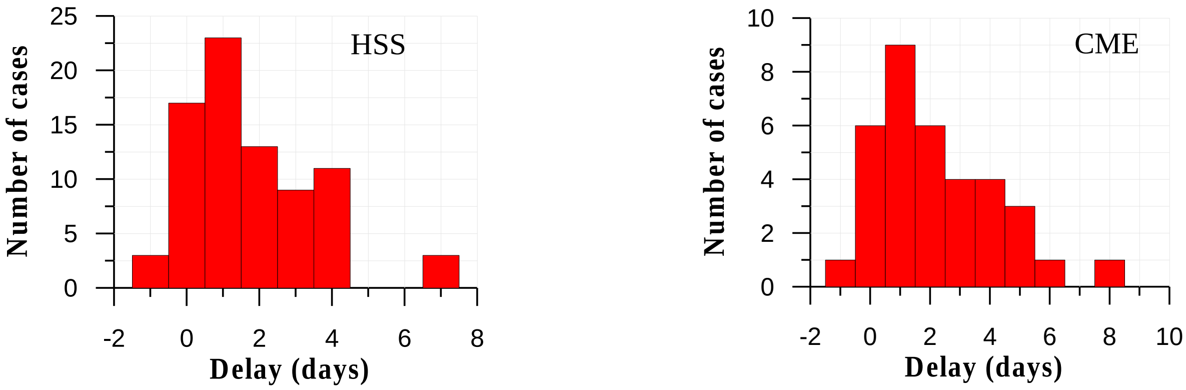

Figure 5. Lightning occurrence as a function of time delay between observed thunderstorm and the arrival of geoeffective HSSs (left panel) and CMEs (right panel) to the Earth.

Of course, it should be said that certain meteorological conditions are necessary for the formation of lightning discharges and thunderstorm activity in general, which is not always the case. Therefore, there are many (about a quarter of all cases considered) examples when, in the presence of CMEs and HSSs, little or no thunderstorm activity is observed (about a quarter of all considered cases of thunderstorm activity). Conversely, a number of cases have been identified when thunderstorm activity is observed in the quiet geomagnetic field, i.e. when, say, CMEs and HSSs events are not observed or these events are not geoeffective (not shown here). In this case, an increase in the values of fmin and intensification of the sporadic layer Es were observed, which indicates an increase in the level of absorption of radio waves in the D-region of the ionosphere and the level of electron density at altitudes of 100–120 km (not shown here).

4. Conclusions

No Carnegie effect in diurnal variations of the electric field at the high-mountain Tien-Shan station.

Decrease in the atmospheric electric field is observed after the impact of powerful coronal mass ejections on the near-Earth space, accompanied by a significant decrease of galactic cosmic rays (Forbush-effect).

Atmospheric electric field fluctuations (40÷120 V/m) in the range (10^{-3} ÷ 10^{-1}) Hz are observed under the impact of the large geomagnetic storms.

In at least 70% of cases thunderstorm activity was observed during periods of impact on the Earth's magnetosphere by CMEs and HSSs, and this suggests that the increase in thunderstorm activity occurs during the arrival of high-speed streams of energetic particles of the solar wind.

There is a tendency for thunderstorm appearance with 1-2 days delay after impact of CMEs or HSSs events on the Earth magnetosphere that is in agreement with the [1,2] findings.

There are noticeable changes in the state of the lower ionosphere during these periods, an increase in the critical frequencies of the sporadic layer E up to 8–10 MHz, and short-term bursts of fmin values.

Future data analysis and observational efforts are needed to understand the thunderstorm initiation from the solar activity.

Author Contributions: V.A. has conceived, designed and performed the evaluation, wrote the Sections 3.1 and 3.2, and corrected the manuscript. G.G. has guided the current research work related to the ionosphere, prepared the tables and figures, and wrote the Sections 3.3 of the manuscript. V.L. and S.K. have guided the measurements, collected the data related to the atmosphere, prepared the tables and figures. All authors have read and agreed to the published version of the manuscript.

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