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GEOPHYSICS

Response of the Electric State of the Surface Atmosphere to the Geomagnetic Storm of April 5, 2010

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In this paper we present the most complete set of the responses of the surface atmosphere electric fields to a magnetic storm at a mid-latitude observatory. The observation of a whole set of effects was caused by the conditions of the experiment and the peculiarities of the storm. Manifestation of three processes of development of the storm is demonstrated. A drop in the electric conductivity of the air is related to a decrease in the galactic cosmic ray flux (GCR), which is known as one of the main air ionizers. The sudden start of the storm caused induction effects in the electric fields. During the following stages of the storm, a significant excess of charged particles appeared in the surface air. Many publications have been dedicated to investigation of solar activity effects and related geomagnetic storms in the atmospheric electricity of the high and mid-latitudes (see, for example, [1]). Unfortunately, these results are very limited and contradictory. The latter fact can be related not only to the peculiarities of the physical processes in the surface atmosphere during individual magnetic storms but also, for example, to the choice of the place of recording and also to the state of the atmosphere before and during the storm, etc.

A positive correlation between the electric potential of the lower atmosphere and GCR intensity was found in [2]. A negative correlation between these parameters was found in the other experiments carried out in the mountains [3]. Contradictory results were also obtained in the observations on the plane terrain. An increase in the field strength relative to the background level five–six hours before a decrease in the GCR was shown in a series of works by the group headed by V.M. Sheftel [4–6]. This phase of the positive perturbation of the field continued up to the moment of the maximum Forbush effect in the GCR intensity, and then a positive phase of field perturbations started. A similar result was reported in [7]: a positive phase of the electric field strength perturbation (~2%) was observed on the day of the maximum Forbush-effect depth during strong electromagnetic storms, and then a long negative phase started with the gradual restoration of the electric field strength over ten days. During strong geomagnetic storms including the storm on October 30, 2003 [8, 9], a negative electric field potential gradient was recorded at Swider station. Coincidence of their duration with the duration of the peaks of rheometric absorption in the sub-auroral zone allowed the authors to suppose that an increase in the conductivity of the upper atmosphere caused by the intrusion of energetic electrons into the sub-auroral latitudes was the cause of the appearance of negative electric field potential gradients [8].

The suggested mechanisms of these effects are no less contradictory. A hypothesis is suggested in [2, 10] of the solar activity influence on the atmospheric electricity. Its essence is in the fact that conductivity of the global electric circuit (GEC) changes under the influence of the cosmic rays (one of the main ionosphere ionizers). The GEC is a closed current system, in which tropical thunderstorms are the main generators according to the model of a spherical condenser. The currents of this generator flow to the lower atmosphere through the air resistance and above it and then close through the unperturbed remote atmosphere and the surface of the Earth. These currents provide the charge of the Earth–ionosphere spherical condenser. The main atmospheric ionizer of the atmosphere at heights up to ~2 km in the lower part of this circuit is the natural radioactivity of the soil, while the GCR ionize the atmosphere at heights ~15–20 km. These currents can cause ionization when they penetrate to the lower stratosphere and upper troposphere, thus ionization leads to the intensification of the GEC currents. Therefore, in order to study the influence of the solar and geomagnetic activity the researchers started to use simultaneous observations of the atmospheric electricity and GCR parameters either in the mountains or

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isolated islands using the equipment on airplanes and balloons, i.e., higher than the exchange atmospheric layer. Local convective and turbulent processes in this layer significantly influence the variations in the electric field strength.

In a series of publications by Sheftel the advancing character of the electric field strength relative to the beginning of the Forbush-effect at high-latitude stations was related to the influence of the solar protons, while the effect of the positive phase of the field perturbation at the stage of deepening with the influence on the atmosphere was related to the hard muon component of the GCR, which reaches sea level and determines their contribution to the atmospheric conductivity at the place of the electric field recording. Positive strength of the electric field was observed at the Borok station during the main phase of the storm on March 28–31, 2000. In this relation, the author of [11] suggests a mechanism of penetration of the magnetosphere–ionosphere source into the lower mid-latitude atmosphere.

The observations of the geophysical fields during the magnetic storm on April 5, 2010, were carried out in Kamchatka at the Paratunka Observatory of the Institute of Space Research and Radio Wave Propagation, Far East Branch, Russian Academy of Sciences (coordinates: $\varphi = 52.9°$ N, $\lambda = 158.25°$ E). The electric field strength was measured by the “Pole-2” sensor developed at the local branch of the Voyeikov Main Geophysical Observatory [12]. The “Pole-2” sensor was deployed in the study region at a distance of 200 m from the administrative building at a height of 3 m. The area around it with a radius of 12 m was cleared of trees. The output signal of this flux-meter after digitization using a 14-bit analog-to-digital converter (ADC) with a digitization frequency of 1 s was recorded on a hard disk of a personal computer.

Air conductivity was measured simultaneously using the Electropovodnost-2 instrument also developed at the local branch of the Main Geophysical Observatory. It has two air inlets located at a height of 3 m for measuring electric conductivity caused separately by positive and negative air ions.

The measurements of the field strength were carried out using two channels. The first channel has a resolution of 0.25 V/m and a dynamic range of ±200 V/m. The second channel has a resolution of 2.5 V/m and a dynamic range of ±2000 V/m. The readings of both channels were taken into account in the processing. The method of measurements corresponds to the manual of the Voyeikov Main Geophysical Observatory [13].

The meteorological parameters were recorded by digital meteorological stations WS-2000 and WS-2300. The data were transmitted to the stations through a radio channel at a frequency of 433 MHz. The sampling frequency for meteorological data was 10 min^{-1}. The following meteorological data were recorded: wind speed, wind direction, atmospheric pressure, air temperature, air humidity, and precipitation (in the summer period).

Variations in the geomagnetic field were measured using the FRG-601G fluxgate magnetometer with a digitization frequency of 1 s and an error of 0.01 nT.

The minimum of the 23rd solar activity cycle occurred in December 2008. The period from 2006 to 2010 is characterized by a low number of magnetic storms. On April 3, 2010, an X-ray burst of class B7.4 occurred on the Sun, which led to the emission of corona fiber. It was not intense but lasted for a long time (more than seven hours). On April 5, 2010, at 08:27 UT, the sudden beginning of the magnetic storm was recorded. Figure 1a presents a graph of the *H*-component of the geomagnetic field on April 5–6. The *Kp* index of this storm was 7. A previous storm of this class was recorded on October 11, 2008; thus it was the strongest storm in a period of one and a half years. The impact of the magnetic storm on the electric state of the surface air can be divided into three stages. The background level of the electric field before the beginning of the storm was approximately 25 V/m (Fig. 1b). The first stage from 04:25 to 08:27 UT was characterized by an increase in the level of the electric field up to 50 V/m. This could have been caused by a sharp decrease in the level of GCR penetration to the Earth’s surface. Two factors provide evidence supporting this interpretation. First, the density of the conductivity current in this period did not change significantly. This value was obtained indirectly from calculation $j = Ez(\lambda_+ + \lambda_-)$, where Ez is the strength of the electric field and λ_+ and λ_- are the air electric conductivities caused by the positive and negative ions, respectively. Second, the air conductivity sharply decreased in this period (Fig. 2a). The galactic cosmic rays along with radon are air ionizers. A decrease in the ionizing influence of the GCR led to a decrease in the electric conductivity (Fig. 2a) and correspondingly to an increase in Ez (Fig. 1b).

A sharp increase in the electric field and then its decrease occurred in the second stage from approximately 08:27 to 12:00 UT. This coincided in time with strong oscillations of the *H*-component of the geomagnetic field. The current density had a similar behavior. It is likely that such perturbations had an induction nature. Figure 1a shows a graph of the *H*-component of the geomagnetic field, and Fig. 1b shows the gradient of the electric field potential. It is seen in these figures that the beginning of the storm with a sudden start strongly changed the current system in the surface air layer. However, in the next stages the influence of the magnetic perturbation on the current system was weakly pronounced.

In the third stage, approximately from April 5, 12:00, to April 6, 01:30 UT, the electric field increased, which is related to an increase in the unipolarity coefficient (Fig. 2b). Unipolarity coefficient $K = \frac{\lambda_+}{\lambda_-}$

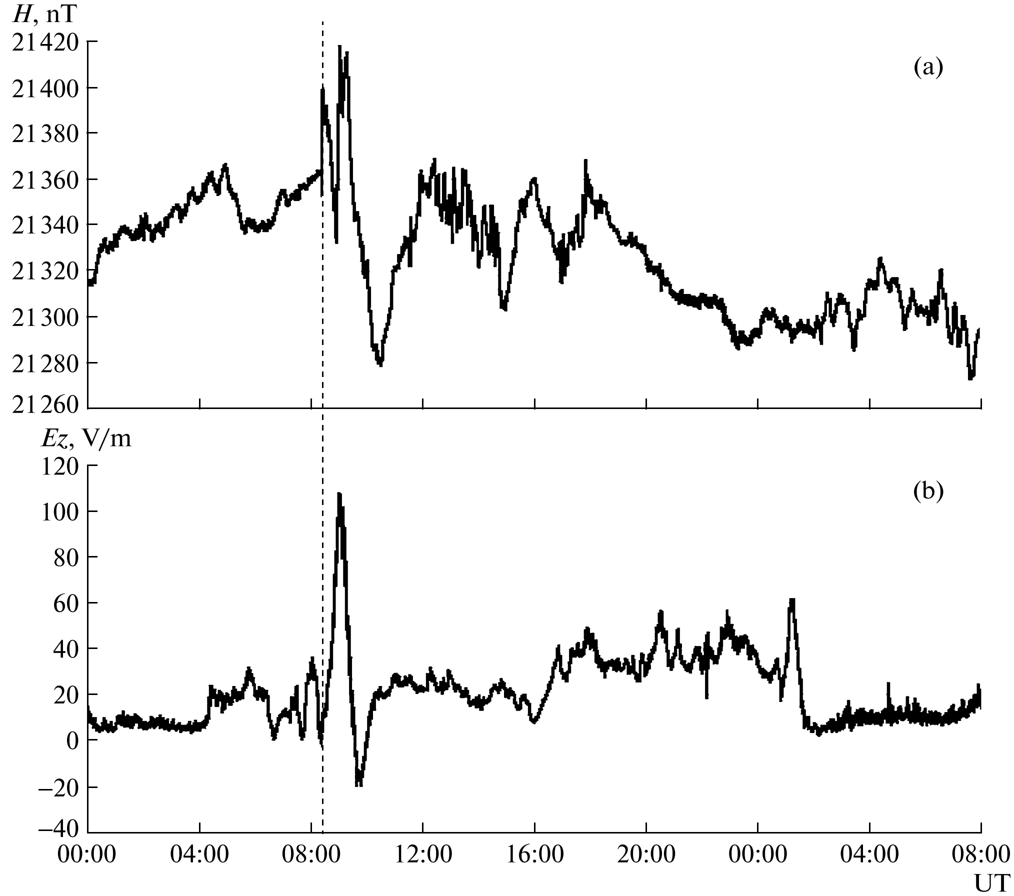

Fig. 1. Development of the magnetic storm (beginning is shown with the dashed line) on April 5–6, 2010. (a) *H*-component of the magnetic field; (b) gradient of the electric field potential.

shows the ratio of the concentration of positive ions to the concentration of the negative ions. The current density during this time exceeded the level that was at the second stage.

Many papers are dedicated to the influence of magnetic storms on the electric state of the surface air. Unfortunately, the results of these observations appear contradictory. This can be related not only to the peculiarities of the physical processes in the surface atmosphere during individual magnetic storms but also to the selection of the place of electric field recording. The suggested mechanisms of these effects are no less contradictory. The hypothesis about the correlation between the GCR and GEC was already discussed in the introduction [2, 10]. The authors of [4–6] correlated the increase in the electric field gradients at the initial stage leading the beginning of the Forbush effect with the influence of the solar protons. They correlated the increase in the field level at the next stages with the influence of the hard muon component of the GCR on the atmosphere. Variation in conductivity of the GEC under the influence of the GCR is suggested in [7].

We emphasize the following events among the peculiarities of the storm on April 5, 2010, and the accompanying phenomena: the storm started suddenly with a high jump in the strength of the field; an ionospheric warming setup was operating in Alaska; the active phase of Eyjafjallajøkull volcano eruption started in Iceland. It would be interesting to consider the latter two phenomena in the context of the joint geophysical manifestation.

Three effects can be seen in the development of this storm observed at the Paratunka observatory. The first is related to a decrease in the air conductivity (Fig. 2a). Such a decrease could have been caused by the "disconnection" of one of the air ionizers. Radon and GCR are ionizers at this level.

The seismic situation at this period of time was calm; hence, there were no significant deformation processes, which could have led to a sharp increase in radon emanation. Therefore, the decrease in the electric conductivity could have been related to the decrease in the GCR flux.

The second effect was manifested in sharp variations of the current at the initial stages of the storm. It

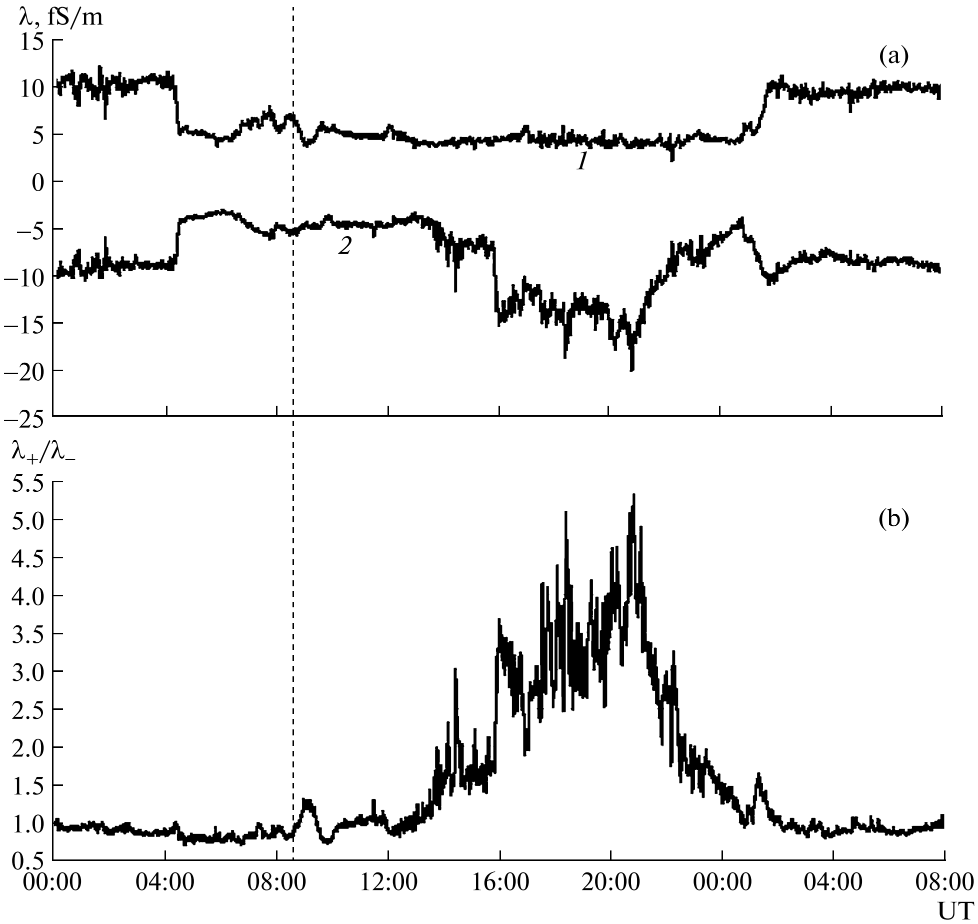

Fig. 2. Development of the magnetic storm (beginning is shown with the dashed line) on April 5–6, 2010. (a) Electric conductivity of the air caused by negative (*1*) and positive ions with a factor of −1 (*2*). *H*-component of the magnetic field; (b) unipolarity $\left(\frac{\lambda_+}{\lambda_-}\right)$ of the air.

is likely that it is related to the induction phenomena of the electromagnetic processes.

The third effect demonstrated positive coil-shaped variation in the unipolarity coefficient related to the domination of the concentration of positive ions. Such an excess could have been caused by their arrival from space or by very strong snow in the region of observations. Since there was no precipitation recorded, it is possible that precipitation in the form of small snowflakes was very low and superposition of these two phenomena took place.

Thus, the influence of the magnetic storm on the electric state of the surface air is manifested in the following three effects:

(1) A sharp decrease in the GCR flux caused by the solar wind. This effect caused an increase in the level of the electric field from 25 to 50 V/m. It started four hours before the sudden beginning of the magnetic storm and continued for approximately 20 h.

(2) Strong oscillations of the conductivity current were observed, which coincided with the beginning of the magnetic storm. Such perturbations could possibly have been induced by induction processes. The duration of this process was approximately 2 h.

(3) An increase in the unipolarity coefficient in the atmosphere was caused by an excess in positively charged particles. The effect occurred eight hours after the beginning of the magnetic storm and continued for approximately 13 h.

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