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Influence of a Convective Generator on the Diurnal Behavior of the Electric Field Strength in the Near-Earth Atmosphere in Kamchatka

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Abstract—Diurnal variations in the electric field strength, electrical conductivity, and temperature in the near-Earth atmosphere under “fair-weather” conditions at the Paratunka observatory (Kamchatka) are considered. It is shown that the morning maximum in the electric field diurnal behavior is caused by air convection in the near-surface layer. The difference in the atmospheric temperatures near the Earth’s surface and at an altitude of 25 m is chosen as a measure of the convective air flow. A high correlation of the values of the temperature difference for these altitudes with the diurnal behavior of the electric field strength is obtained.

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1. INTRODUCTION

Diurnal variations in the electric field strength (EFS), depending on universal time, are simultaneously observed above the oceans and in open areas in polar regions under “fair-weather” conditions. This is the so-called unitary variation (UT variation) with a field strength minimum at 03–05 UT and maximums at 18–19 (in winter) and 20–21 UT (in summer) which is caused by diurnal variations in the global storm activity. However, in electric field measurements in the near-Earth atmosphere at continental stations, diurnal variations are substantially influenced by local meteorological processes that suppress the unitary variation. To select different effects in diurnal variations in elements of atmospheric electricity, observations are as a rule conducted under the conditions of the so-called “fair weather.” These conditions include the absence of thunderstorms, precipitation, mist, fogs, low cloudiness with total cloudiness no more than 3 at a wind velocity of up to 6 m/s (Manual, 2002). However, even under these conditions, the most striking local effect in diurnal EFS variations is the so-called sunrise effect that manifests itself through field strength enhancement and growth in conduction currents and spatial charge. The first report on this effect appeared in the work (Nicholas, 1916), in which EFS recordings were received only within an interval of ±15 min relative to local sunrise. The later EFS measurements at different points of the terrestrial globe enabled the characteristic features of this effect to be found. Already at early research stages, the authors tried to explain its physical nature. So, Brown (1936) clearly isolated this anomalous effect by excluding the unitary variation from the measured diurnal EFS variations. The author suggested a concept that there are positively charged condensation nuclei in the atmospheric exchange layer and they are transferred upward as a result of the processes of turbulence and convection in the atmosphere as the air temperature grows. The convection intensity, as is known, depends on the temperature difference between the layers, thermal conductivity, and the viscosity of the medium. In another work (Israel, 1953), the link between the EFS and the water vapor concentration is investigated and a conclusion is drawn that diurnal variations in the vertical distribution of the water vapor concentration depend on the convective processes in the atmosphere and hence influence the diurnal EFS variations. Measurements of the EFS and the density of the vertical electric current, which were performed on cloudless days (Kasemir, 1956), showed their simultaneous growth by a factor of 2–3 after sunrise. In this case, the electrical conductivity of the atmosphere increased by only 20% as compared to the appropriate values before sunrise. This result contradicted the theory of storm generators explaining the atmospheric electric field behavior by only the collective effect of storm generators that form the global electric circuit (GEC) of the atmosphere. Kasemir suggested that the so-called convective generator acting locally in the atmospheric exchange layer should be introduced additionally into the GEC. Its effect reduces to the mechanical transfer of the positive spatial charge accumulated at night near the Earth’s surface upward by a convective flow. This in turn leads to the enhancement of the electric conduction current and to an increase in the EFS, which is observed in experiments. Anisimov et al. (2006) also follow this point of view for explaining the positive correlation between the EFS and air temperature near the Earth's surface during the morning hours.

The proposed physical model of a convective generator received an experimental confirmation in the subsequent works of many authors devoted to the investigation of the sunrise effect in EFS variations in the near-surface atmosphere, including (Smirnov et al., 2012). Numerical evaluations of parameters of the convective generator model are presented in the report (Mareeva et al., 2011).

This work is a continuation of the study of the electric processes in the near-surface atmosphere at sunrise. In this case, apart from EFS observations, simultaneous recordings of the electrical conductivity of the atmosphere, as well as its temperature near the Earth's surface and at an altitude of 25 m, are additionally used. This experiment, aiming at the direct confirmation that there is a convective generator in the GEC, is performed for the first time.

2. METHOD OF MEASUREMENTS

EFS measurements at the Paratunka observatory (Kamchatka) of the Institute of Cosmophysical Research and Radiowave Propagation, Far Eastern Branch, Russian Academy of Sciences ($\lambda = 158.25°$ E, $\varphi = 52.9°$ N), were conducted using the Pole-2 instrument developed at the Voeikov Main Geophysical Observatory (Imyanitov, 1957). It was installed at the proving ground at a distance of 200 m from the administrative building at a height of 3 m. The area surrounding the instrument is treeless within a radius of 12 m. A signal from its output after digitization using a 14-bit analog-to-digital converter with a sampling rate of 1 Hz is recorded to the hard drive of a personal computer. With a periodicity of once in three months, a second instrument is mounted at ground (snow) level and a coefficient is calculated for converting data from the main instrument to the ground level according to the manual (Manual, 2002). Further, the data of measurements with the main instrument are used, taking into account the reduction coefficient.

Monitoring of meteorological parameters is conducted by the WS-2000 and WS-2300 digital meteorological stations. The output data from them enter the observatory via the radio channel at a frequency of 433 MHz. Two air temperature sensors are used in observations. One of them is installed at a height of 3 m on the shadow side of the administrative building. The special feature of the installation of another sensor consists in the following. From the northern part of the water tower, a beam is fixed at a height of 25 m with one of its ends distant by 5 m from the tower edge, at which a temperature sensor with a radio interface is fastened behind a white opaque screen. This construction permits the effect of tower heating by solar rays upon the temperature sensor to be avoided. A wind sensor is assembled at the same tower at a height of 25 m. The time discreteness of meteorological data is 10 min. Thus, we have the following meteorological monitoring data: the strength and direction of the wind and also the temperature at a height of 25 m; the atmospheric pressure, temperature, and air humidity at a height of 3 m; and cloudiness and precipitation according to the data from the local meteorological station. These data make it possible to choose days with "fair-weather" conditions that are extremely rare in the observatory region.

Simultaneously, measurements of the air electrical conductivity are conducted using the Elektroprovodnost-2 instrument, also developed at the Main Geophysical Laboratory. It has two inlets located at a 3-m height for measuring the electrical conductivity caused separately by positive (λ_+) and negative (λ_-) air ions. Further, the total electrical conductivity $\lambda = \lambda_+ + \lambda_-$ is used in formulas. All measuring instruments are spaced at a distance of no more than 200 m.

3. MAIN RESULTS

Typical diurnal EFS variations (*Ez*) under "fair-weather" conditions (and close to them) at the Paratunka observatory are shown in Fig. 1. For convenience of comparison with the UT variation and other geophycal parameters, the curves are presented as functions of universal time. The arrows indicate the sunrise (up) and sunset (down) time. In view of the observatory's geographical position, these time moments for each date were determined from the sunrise and sunset time given in Astronomical Almanacs for the zero meridian and were then calculated using the relationship LT = UT + 10.55, where $t = 10.55$ h is the hour angle for the observatory longitude $\lambda = 158.25°$ E. As can be seen in the plot, a maximum in the diurnal behavior is observed in the morning hours of the local solar time. On certain days, an evening maximum appears with a weaker intensity than the morning maximum. In the period of active snow melting (April–May), a similar feature of the diurnal behavior is as a rule violated. For analysis, not only days with "fair-weather" conditions were selected but also those with the stable operation of the entire complex of measuring equipment. There were 16 such days within the 2005–2009 period with an average diurnal EFS value of ~60 V/m and with a rms deviation of ~15 B/m. These low EFS values are explained by regional features and the low station position with respect to sea level (50 m). In this case, the morning growth in the field strength caused by convective processes most frequently increases the average level by a factor of 2.

For illustration purposes, Fig. 2 (September 10, 2007) presents a set of simultaneous diurnal variations in the (a) EFS, (b) electrical conductivities λ_+ (curve *1*)

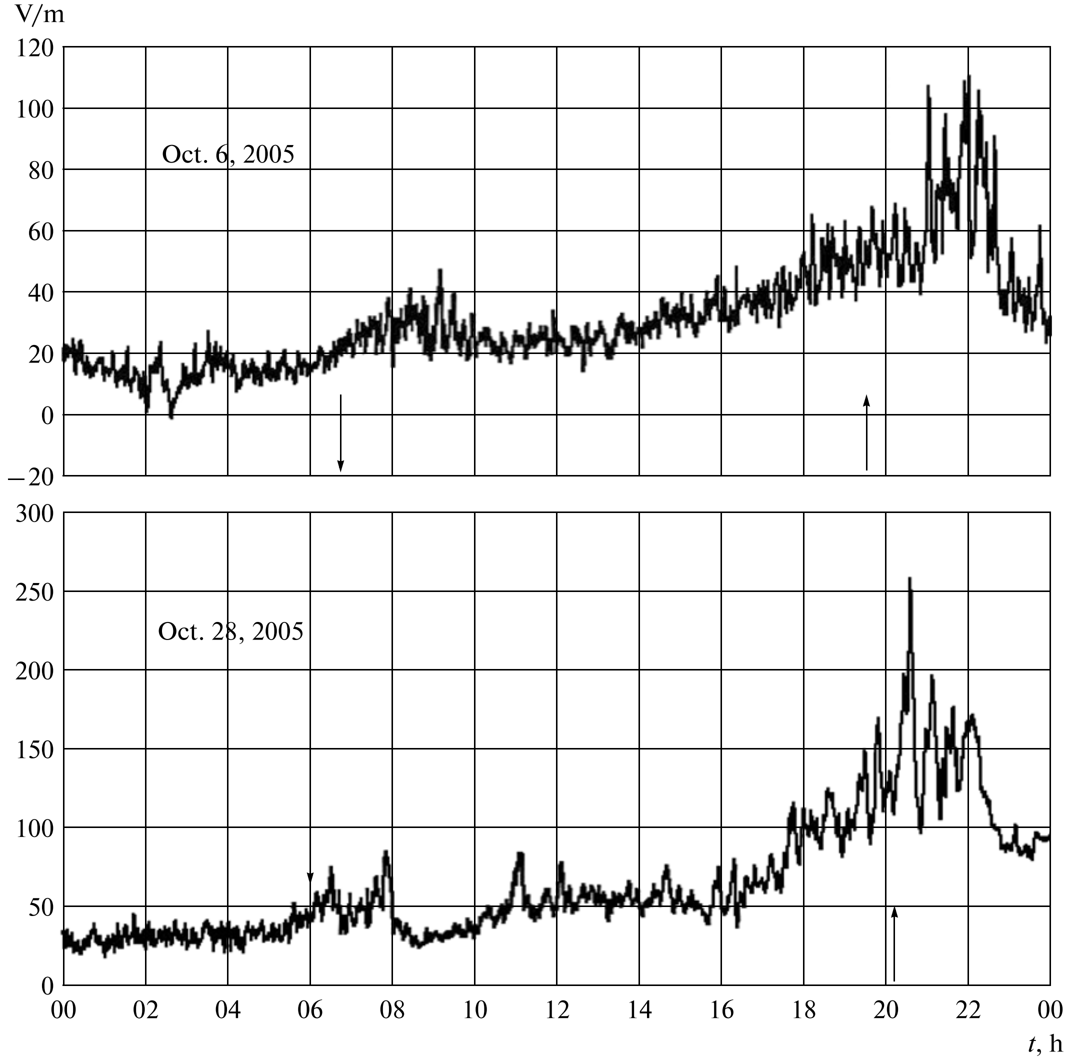

Fig. 1. Typical diurnal variations in the electric field strength under "fair-weather" conditions. The arrows pointed upward denote the sunrise time; those pointed downward, the sunset time.

and λ_-(curve *2*), temperatures at (c) 25- and (d) 3-m heights, and (e) the air humidity. It can be seen that the diurnal temperature curves at different heights are similar to each other and change in antiphase with the diurnal humidity curve, repeating the characteristic features of these parameters under "fair-weather" conditions (Matveev, 1965).

To evaluate the effects of the convective generator that manifests itself most vividly at sunrise, we chose the difference between the temperatures at the indicated heights (3 and 25 m) as a measure of the intensity of the air convective flow. An example of comparing EFS diurnal curves with the temperature difference is shown in Fig. 3. The closest relationship between EFS variations and the temperature difference is revealed at sunrise with a correlation coefficient of ~0.6 ± 0.1. In certain cases, as can be seen for November 12, 2007, the curves match each other closely, whereas in other cases shown in the plot the diurnal EFS variation deviates considerably from the temperature difference curve, allowing us to suggest that there are spatial charges of a different nature in the near-Earth atmosphere.

4. DISCUSSION

The convective-generator effect in the near-surface atmosphere can be traced qualitatively by the diurnal curves in Fig. 2. As can be seen from the curves in (d) and (e), with sharp growth in temperature after sunrise as a result of the increase in the moisture evaporation rate, the air humidity also drops sharply. In this case, positively charged condensation nuclei are involved upward. This process is revealed in the reduction in the total electrical conductivity of the air (Fig. 2b, curves *1*, *2*) and in the simultaneous EFS growth (Fig. 2a) and continues for several hours (2–7 h), reaching the EFS

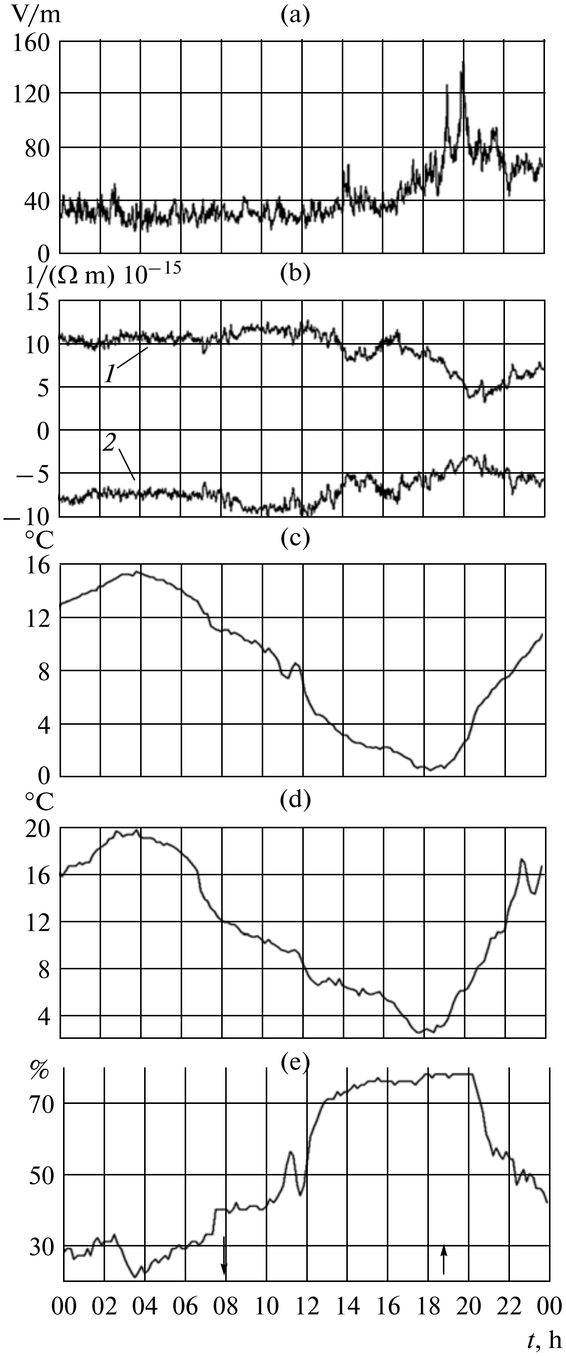

Fig. 2. Diurnal variations in the electric field strength (a), electrical conductivities of the air, caused by negative (*1*) ions and positive (*2*) ions with a factor −1 (b), and the air temperature at heights of (c) 25 and (d) 3 m, as well as (e) the humidity for September 10, 2007.

maximum during 1–4.5 h after sunrise (see also the table in (Smirnov, 2012)). As a rule, the effect disappears at local noon at the temperature maximum (Fig. 2c) as a result of the maximum enhancement of the convective process and transfer of positively charged condensation nuclei to higher layers of the atmosphere. Hence, in this period of time, the values of the total electrical conductivity and EFS change weakly. In the afternoon, with a reduction in solar radiation, the air temperature decreases smoothly down to the minimum value before sunrise; the air humidity also begins increasing smoothly in antiphase, leading to the accumulation of spatial charges near the Earth's surface. The total electrical conductivity and EFS change weakly in the night hours.

To explain the observed connection of the atmospheric temperature difference with diurnal EFS variations in the near-surface atmosphere, we consider the average diurnal variation in the field strength $\Delta E = \Delta E_{unit} + \Delta E_{\lambda} + \Delta E_{\rho}$ (Tverskoi, 1949), where the unitary variation

$$\Delta E_{unit} = \frac{\Delta\varphi}{R}\frac{1}{\lambda}, \tag{1}$$

$\Delta\varphi$ is the difference between the potentials of the ground and the ionosphere; R is the resistance of the ground–ionosphere air column; and λ is the electrical conductivity of the air; the variation associated with the air conductivity

$$\Delta E_{\lambda} = -\frac{E}{\lambda}\Delta\lambda; \tag{2}$$

the variation connected with the air convection

$$\Delta E_{\rho} = \frac{1}{\lambda}\Delta(k\rho), \tag{3}$$

k is the numerical coefficient of turbulence; λ is the electrical conductivity of the air; and ρ is the spatial charge density.

The morning EFS maximum at the Paratunka observatory is mostly contributed by the morning air convection (Eq. (3)); then, sometimes, by electrical conductivity variations (Eq. (2)); and by unitary variations because the local time of sunrise coincides with its maximum (Eq. (1)). The convective mechanism of the morning maximum can be explained in the following way. After sunrise, positively charged spatial charges accumulated during the night near the Earth's surface begin to rise upward. When the temperature difference is large (up to 12°C (see Fig. 3)), strong EFS oscillations and temperature differences are often observed in the maximum of the sunrise effect. Probably, these oscillations are caused by the nucleation of convective cells with turbulent motion of positively charged condensation nuclei. In our opinion, the evening EFS maximum is caused by electrical conductivity variations (Eq. (2)). For illustration of this effect, diurnal EFS variations (curve *3*, right scale) are given in Fig. 4, in addition to Fig. 3, with the main maximum in the morning hours and the secondary maximum in the evening hours. Curves *1* and *2* demonstrate the electrical conductivities of the air (left scale). In the evening time, the total electrical conductivity drops and, accordingly, the EFS grows. This secondary maximum in the evening time (and even in the nighttime) can be

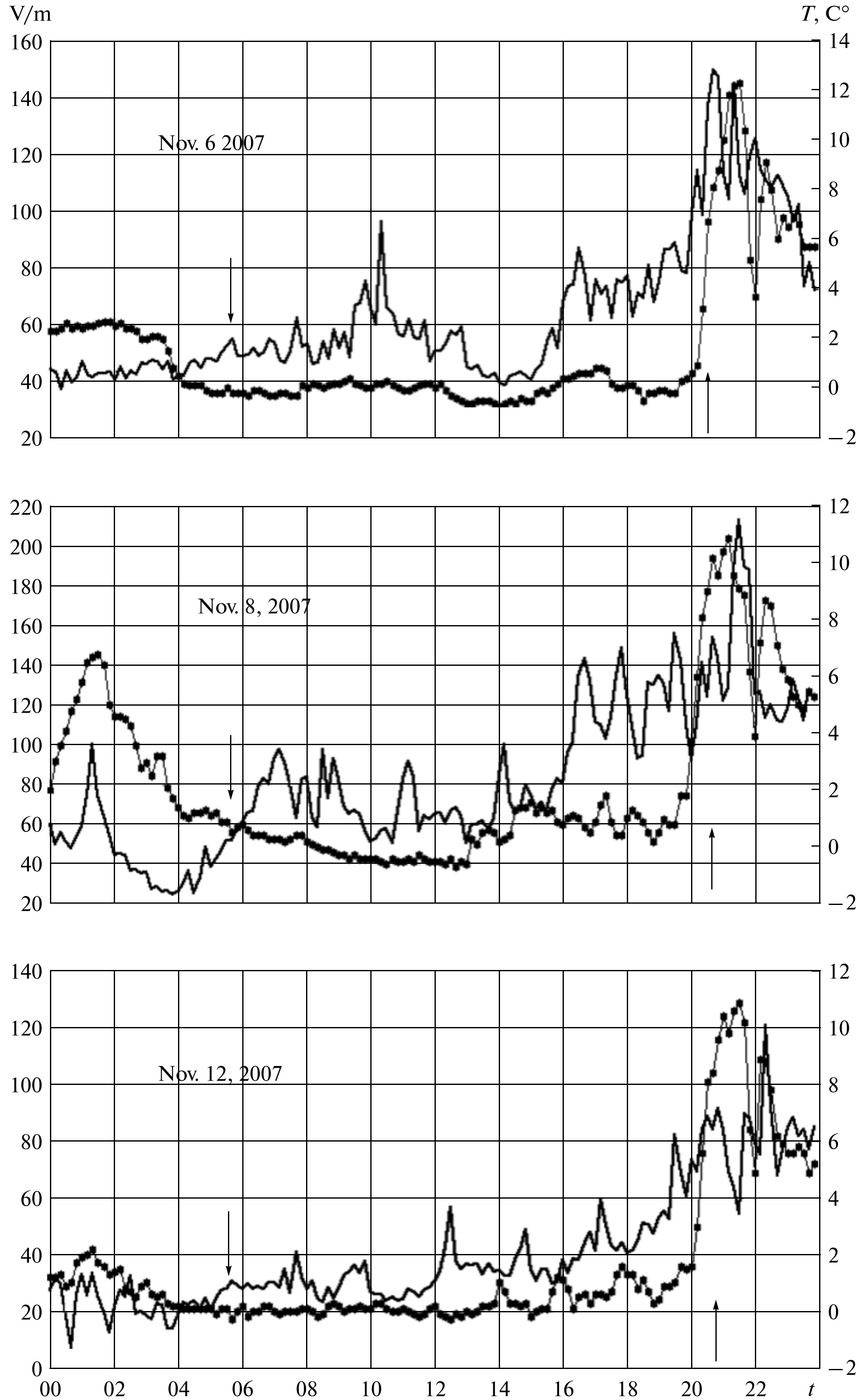

Fig. 3. Diurnal variations in the electric field strength (solid line, left scale) and the difference in the temperatures at heights of 25 and 3 m (dots, right scale).

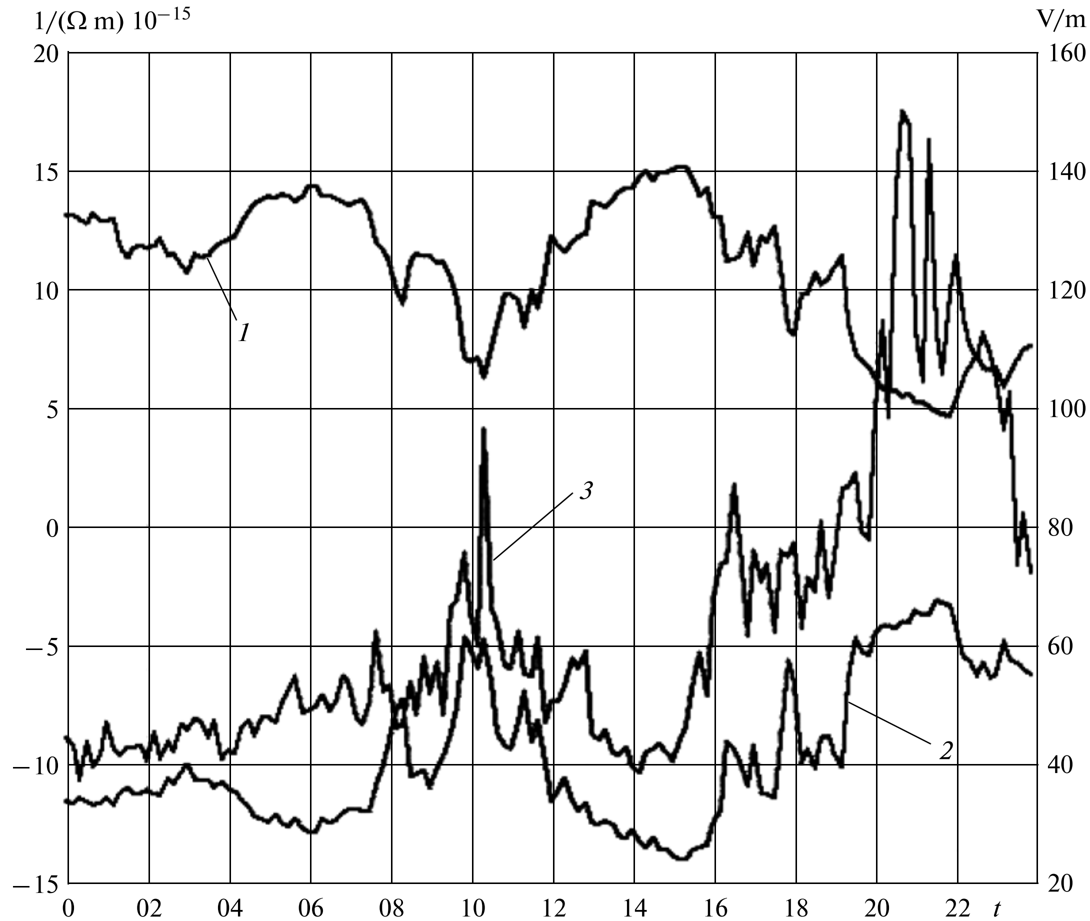

Fig. 4. Diurnal variations in the positive (*1*) and negative (*2*) electrical conductivities (left scale) and in the electric field strength (*3*) for November 6, 2007.

probably explained by the presence of a weak fog that condenses at the installation site of the sensor.

Solar UV rays, which are the main ionizer of the atmosphere at large altitudes, do not play a substantial role in the lower layers of the atmosphere, because all rays with small wavelengths and energies sufficient for the ionization of gases included in the composition of the atmosphere are absorbed already at high altitudes and only rays that can produce a photo electric effect reach the boundaries of the troposphere. However, due to the small photoelectric effectiveness of rocks on the Earth's surface and water and particles suspended in the atmosphere, the ionization is so small that it can be almost neglected (Tverskoi, 1949). This conclusion received a direct experimental confirmation in (Pak et al., 2003).

The evaluation of the relationship between a gradient of the electric field potential and the temperature difference from the seven most characteristic diurnal curves can be presented as the proportion

$$\nabla\varphi \approx (6.0 \pm 0.2)\Delta T, \tag{4}$$

where $\nabla\varphi$ is the gradient of the electric field potential and ΔT is the difference between the air temperatures at heights of 3 and 25 m.

The absence of any stable diurnal behavior in the spring months can be explained by the following factors. The snow level in the observatory's region reaches 2.7 m, and the maximum snow cover height is observed at the end of March. This snow bulk extends the period of melting until the end of May and leads to complicated behavior of diurnal variations in humidity at the observation point, the influence of which on the electrical properties of the air can be traced in Fig. 2.

The convective behavior of the EFS maximum at sunrise, which is experimentally confirmed in this work, agrees with the results in (Petrov et al., 2007), where the vertical air motion was measured using two winged anemometers at heights of 0.5 and 1.0 m. Their sensitivity enabled even the weakest air movements up and down to be noticed. Good agreement was obtained between the vertical air motion and the density of the vertical conduction current. An increase in the current density with weakly varying electrical conductivity leads to the enhancement of the electric field strength in the near-surface atmosphere.

5. CONCLUSIONS

An analysis of diurnal variations in the electric field strength, electrical conductivity, and temperature in the near-surface atmosphere under "fair-weather" conditions at the Paratunka observatory for 2005–2009 has shown the following:

1. The morning maximum in the diurnal behavior of the electric field is caused by convective processes in the atmosphere during the sharp temperature growth at sunrise. The intensity of this maximum with a correlation coefficient on the order of 0.6 ± 0.1 is connected with the difference in the temperatures at heights of 3 and 25 m.

2. The evening maximum in the diurnal behavior of the electric field appeared to be correlated weakly or not correlated at all with the temperature difference, which allowed us to suggest that a fog near the Earth's surface influences the electrical conductivity and, accordingly, the electric field strength.

3. The proposed experimental method for measuring the temperature difference at different atmospheric altitudes as a measure of convective processes appeared to be very effective in studying diurnal variations in parameters of atmospheric electricity.

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