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Problem of the Nature of the Sunrise Effect in Diurnal Variations in the Electric Field in Kamchatka: 1. Time Variations in the Electric Field

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Abstract—The effect of sunrise in time variations in the electric field in the near-Earth atmosphere at the Kamchatka Paratunka observatory has been studied. Twenty-nine records under fair-weather conditions have been selected. It has been indicated that the estimated effect parameters—the times of the effect's onset and field strength maximum relative to the sunrise time, as well as the ratio of the strength maximum to its value before sunrise and the effect duration—coincide with the previously published data. Thereby, the conclusion is confirmed that the sunrise effect in diurnal variations in the electric field in the near-Earth atmosphere is related to the turbulence and convection processes in the atmospheric boundary layer at a change in atmospheric temperature.

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1. INTRODUCTION

The first report on the sunrise effect in diurnal variations in the electric parameters in the near-Earth atmosphere appeared in (Nichols, 1916). It was found that electric parameters, such as the electric field strength, air conductivity, conductivity currents, and spatial charge, tend to decrease during night and subsequently increase at sunrise. However, these records were only obtained at a ±15-min time interval relative to the sunrise instant. Later numerous measurements of electric field variations under fair-weather conditions at different points of the globe made it possible to distinguish the characteristic features of the effect, namely, a simultaneous increase in the field strength value and the vertical electric current density at the sunrise instant. In this case, the effect is most pronounced in the electric field behavior. The field strength value increases after sunrise, reaches its minimum with a certain delay, and decreases to the presunrise level by noon. The effect onset, the maximum strength value, and the delay relative to the sunrise instant depend on the state of the near-Earth atmosphere, season, and the geographic coordinates of an observation point. At sunset, the effect of an increase in the field strength is either undetectable or altogether absent.

The main characteristics of the sunrise effect in electric field time variations were studied in detail by many authors. It turned out that the effect starts either at the sunrise instant (Kasemir, 1956) or 20–30 min later (Marshall et al., 1999). Its duration is ~4–7 h (Muhleisen, 1958), ~4 h (Kamra, 1969), ~3–4 h (Selvam et al., 1980), and ~3 h (Marshall et al., 1999). The delay of the field strength maximum relative to the sunrise instant is ~2.5 h (Kasemir, 1956), ~2–4 h (Moore et al., 1962), and ~1–1.5 h (Marshall et al., 1999). The strength value at the effect maximum is larger than the presunrise level by factors of ~2.5–3 (Kasemir, 1956), ~3 (Muhleisen, 1958), and ~4 (Marshall et al., 1999).

Simultaneous measurements of the field strength and spatial charge density (Muhleisen, 1958; Moore, 1962; Selvam et al., 1980; Marshall et al., 1999) indicated that the positive charge density and vertical current value (Kasemir, 1956; Muhleisen, 1958) increase with increasing strength. The simultaneously measured condensation nuclei concentration was very high at night, and this level decreased at sunrise and became zero at local noon (Moore, 1962). This experimental result indicated that the convection process gradually developed in the atmosphere with increasing temperature at sunrise.

The intensification of the wind results in the weakening of the sunrise effect (Brown, 1936; Kamra, 1969; Selvam et al., 1980; Marshall et al., 1999). When fog is heavy and clouds are dense without precipitation, the spatial charge becomes negative, as a result of which the sunrise effect weakens and even disappears.

This is almost not observed in the mountains (Muhleisen, 1958).

The published results of studies of the sunrise effect in electric parameters in the near-Earth atmosphere were mostly obtained at continental observation stations. It was interesting to study this effect in time variations in the electric field strength in Kamchatka with the specific geographic position of this region and high seismic activity typical of this region. For this purpose, we used the electric field strength records obtained at the Paratunka observatory (φ = 52.9°N, λ = 158.25°E) in September 1999, October 2002, and selectively in 2004, 2005, and 2007. The work is divided into two parts: time variations in the electric field strength (see below) and the power spectra of these variations (see the next publication) will be analyzed in the first and second parts, respectively.

2. MAIN RESULTS

2.1. Measurement Method

A Field-2 device designed at the Voeykov Main Geophysical Observatory was used to study the electric field strength at the Paratunka observatory, Institute of Cosmophysical Research and Radiowave Propagation, Far Eastern Branch, Russian Academy of Sciences (IKIR DVO RAN). This device was installed at a distance of 200 m from the administration building at a height of 3 m. Trees were removed from the area around the device at a radial distance of 12 m. The output signal of this device was saved on the hard disk of a personal computer after digitization was performed using a 14-bit ADC at a discretization interval of 1 min. The meteorological parameters were simultaneously recorded. In contrast to continental conditions, under which the previous studies were performed, the observation conditions in Kamchatka have specific geophysical features. First, the ground constantly "breathes" as a result of increased seismic activity and heats the Earth's surface, releasing gases saturated with radon, which is the main ionization agent in the near-Earth atmosphere. Second, volcanoes constantly "breath" here, enriching the atmosphere with aerosols. Third, cyclones and anticyclones intensely operate on the peninsula (Kuznetsov et al., 2007). Therefore, the conditions of the so-called fair weather formulated in (Reiter, 1992; *RD* ..., 2002) are implemented exclusively rarely in Kamchatka. Therefore, we used here the data obtained on days without precipitation, thunderstorms, fog, and earthquakes when the average wind velocity was lower than 6 m/s and low stratocumulus clouds were present at $Kp \leq 4$. To study the sunrise effect, we used the diurnal variations in the electric field strength in September 1999 (13 days), October 2002 (5 days), August 2004 (6 days), October 2005 (2 days), and November 2007 (3 days). Figure 1 shows typical records of diurnal variations in the field strength observed under different geophysical conditions, including fair-weather ones.

2.2. Processing Method

First of all, we determined the sunrise and sunset instants for each day as instants when the upper edge of the solar disk appeared over the horizon and submerged below the horizon for the Paratunka geographic coordinates (*Astron.* ..., 1998 and others). Figure 2 illustrates a method for processing diurnal variations in the electric field, including the sunrise and sunset instants, as well as the midnight and noon instants. The onset time of the sunrise effect, its delay relative to the sunrise instant, the effect's duration, the time when the field strength was maximal, and the ratio of the maximum to the strength values before sunrise were registered on each curve. These parameters, determined based on all analyzed data with an accuracy of half an hour, are presented in the table. The minus sign in the column ($t_O - t_{SS}$) indicates that the effect in the field behavior begins before the sunrise instant. The "Note" column presents fair-weather conditions and the presence of thin clouds (less than 2 points). It is clear that the effect onset mostly coincides with the sunrise instant, except several cases when the effect began before sunrise. The field strength at the effect maximum is higher than this value before sunrise by a factor of 2–4; the effect maximum is shifted relative to the sunrise instant by 0–4.5 h, and the effect duration is 2–7 h. The effect disappears at local noon in almost all cases. The effect of field strengthening at sunset is much less pronounced than the sunrise effect, and only the strength value is shown in the table.

3. DISCUSSION OF RESULTS

The table indicates that the analysis results of the sunrise effect in time variations in the electric field strength at the Paratunka observatory closely coincide with previously published data with respect to all the distinguished parameters (see Introduction). This fact suggests that the common physical mechanism by which this effect is produced operates under the conditions of fair weather in the near-Earth atmosphere independently of the registration point's geophysical conditions. In their early studies, the authors tried to explain the nature of this effect. Thus, Brown (1936) clearly defined the anomalous effect during sunrise, when he eliminated the unitary variation in the measured diurnal field curves. This author assumed that positive condensation nuclei exist during this period in the exchange atmospheric layer and are transported upward as a result of turbulence and convection processes with increasing air temperature.

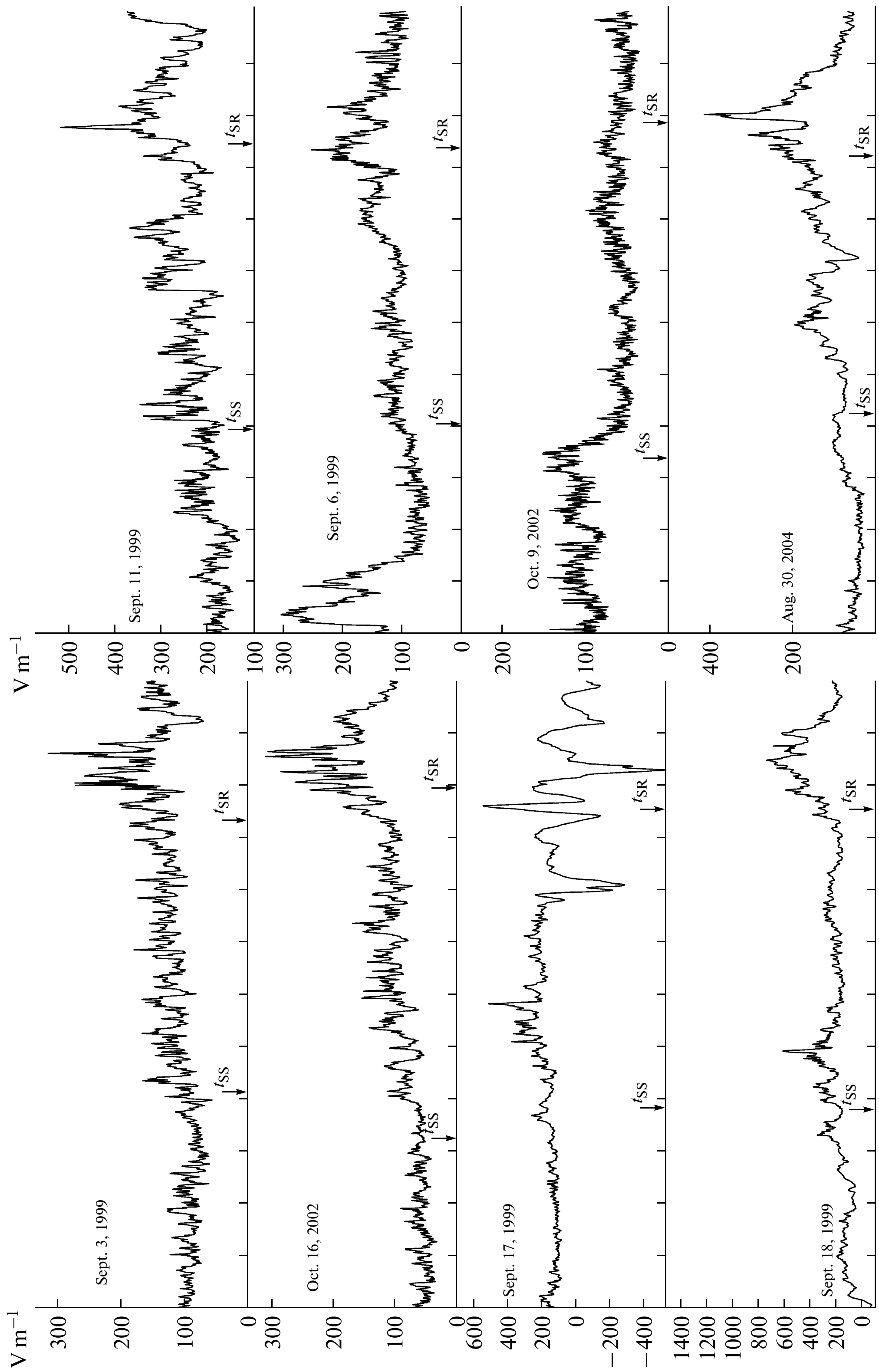

Fig. 1. Diurnal variations in the electric field strength under different geophysical conditions: conditions of fair weather on September 3, 1999, and October 16, 2002; anomaly before an earthquake on September 17, 1999; earthquake at 2128:33 UT on September 18, 1999; $\varphi = 51.21°N$; $\lambda = 157.56°E$; $h = 60$ km; $M = 6.0$; clouds with weak precipitation on September 11, 1999; an earthquake at 1504:52.81 UT on September 6, 1999; $\varphi = 52.10°N$; $\lambda = 159.15°E$; $h = 33$ km; $M = 5.0$; thick squall on October 9, 2002, low stratocumulus clouds (~10 points) but without precipitation; an earthquake at 1223:21.60 UT on August 30, 2004; $\varphi = 49.38°N$; $\lambda = 157.42°E$; $h = 40$ km; $M = 6.0$.

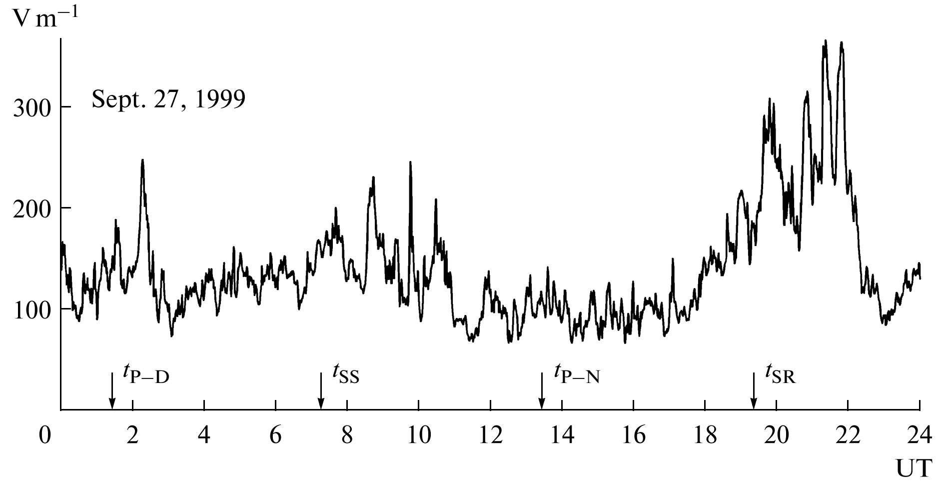

Fig. 2. Typical diurnal variations in the electric field strength under fair-weather conditions: t_{SR} and t_{SS} are the sunrise and sunset times.

The measured field strength and vertical electric current values on fair and cloudless days (Kasemir, 1956) indicated that these values simultaneously increased by a factor of 3–5 after sunrise. In this case, atmospheric conductivity increased by only 20% as compared to the corresponding values before sunrise. This result contradicted the thunderstorm generator theory, which explains that the atmospheric electric field is only generated as a result of the joint action of thunderstorm generators that create the global atmospheric electric circuit (GAEC). Using these observations together with experimental data published before 1956, Kasemir (1956) proposed to additionally introduce the so-called exchange (convective (*Atmosfera* ..., 1991)) generator into the GAEC, which locally operates in the boundary atmospheric layer. In such a case, the electric current density is written as follows in the absence of local thunderstorm sources (*Atmosfera* ..., 1991):

$$j = \lambda E + \rho V + D_t \nabla \rho,$$

where λ is atmospheric conductivity (light ions mainly contribute to this conductivity); ρ is the electric charge density; V is the hydrodynamic velocity of the medium; and D_t is the eddy diffusion coefficient. In the quasistationary case, the current density depends on the first term and is attributed to the action of thunderstorm generators. Turbulent mixing processes ($D_t\nabla\rho$) and mechanical upward transport (ρV) by convective air flows with a positive charge accumulated at night near the Earth's surface become effective after sunrise as a result of turbulent heat exchange. This in turn results in an increase in the electric field strength near the Earth's surface and in an amplification of the conductivity current, which is observed during experiments. The proposed convective generator model was experimentally confirmed in the following works of many authors devoted to studying the sunrise effect in time variations in the electric parameters in the near-Earth atmosphere.

Muir (1975) additionally proposed a possible alternative mechanism related to the increase in the electric potential of the classical capacitor upper wall under the action of solar radiation. This in turn results in an increase in the electric field strength at the sunrise instant. A more detailed discussion of this mechanism is outside the scope of this paper.

The work by Cherneva and Kuznetsov (2005) has a special place in the series of works devoted to studying the sunrise effect in diurnal variations in the electric field strength. This work illustrates simultaneous measurements of the field strength, conductivity of positive (λ_+) and negative (λ_-) light ions, and unipolarity coefficient (λ_+/λ_-) in the near-Earth atmosphere over Paratunka. A comparison of these data during sunrise indicated that *{the effect of an increase in the Ez value during the morning solar terminator does not manifest itself in the relative conductivity of light ions through the unipolar variation coefficient. An increase in Ez in the morning hours has a clearly defined oscillatory character with an oscillation period about 0.5–1 h ⟨...⟩. Precisely internal gravity waves supposedly result in an increase in Ez in the morning hours}* (Cherneva and Kuznetsov, 2005). This result contradicts the thunderstorm generator theory, which explains that the atmospheric electric field is only generated by the joint action of thunderstorm generators that create the global electric circuit in the atmosphere and the convective generator model. Precisely the conclusions drawn in this work stimulated a more detailed study of the sunrise effect in time variations in the electric field, the results of which are presented in this paper.

Parameters of the sunrise and sunset effect in diurnal variations in the electric field strength (EFS)

Date	EFS B_{max}, V m^{-1}	EFS B_{max}/background	$T_{ef.\,SR}$ h	t_{max}–t_{SR} h	EFS$_{SS}$ V m^{-1}	t_O–t_{SR} h	Note
September 1999							
01	300	3	4	1.5	100	0	FWCs
02	400	2	2	2.0	200	0.5	FWCs
07	300	3	7	3	100	0	Thin clouds
14	500	2	4	2	250	0	Thin clouds
16	200	2	3	1.5	100	0	Thin clouds
18	600	3	4	2	200	0	maxB coincided with an earthquake
20	400	4	6	2	100	0	FWCs
21	200	2	4	2	100	0	FWCs
24	200	2	5	2	100	0	Thin clouds
27	300	3	3	2	100	0	Thin clouds
28	200	2	5	2.5	100	–5	FWCs + series of earth-quakes with M ~ 4.5
29	300	3	5	1.5	100	0	FWCs
October 2002							
16	200	2	4.5	2	100	0	FWCs
17	200	2	–	3	100	0	Thin clouds
20	250	2.5	5	1	100	–2	Thin clouds
25	200	2	3.5	2	100	0	FWCs + thin clouds
26	250	2.5	5.5	1	100	–2	FWCs + thin clouds
August 2004							
15	200	2	5	3.5	100	0	FWCs
16	150	2	6	3.5	50	0	FWCs
27	350	7	5	3.5	50	0	FWCs
28	200	2	4	2.0	80	0.5	FWCs + thin clouds
29	300	3	4	1.5	70	–3	FWCs + thin clouds
30	400	4	5	1.5	100	–2	FWCs + an earthquake
October 2005							
06	100	5	4	2	20	0	
28	200	4	6	0	25	–2.5	
November 2007							
06	140	2.5	4	1.5	50	0	
08	200	3	4	1.5	60	0	
12	100	3	5	2.5	30	0	

Note: t_{SR} is the sunrise time, t_O is the effect onset time, t_{max} is the time of the EFS maximum, B_{max} is the EFS maximum value, and the background is the EFS value before sunrise.

4. CONCLUSIONS

An analysis of the sunrise effect in time variations in the electric field strength in the near-Earth's atmosphere over Kamchatka under fair-weather conditions indicated the following:

1. The estimated effect parameters are as follows: the times of the effect onset and maximal value, as well as the ratio of the maximum to the effect value before sunrise and the effect duration, closely coincide with previously published data.

2. The achieved results confirm the physical mechanism by which the sunrise effect develops, proposed in (Kasemir, 1956). According to this mechanism, anomalous variations in the electric field strength near sunrise are caused by the processes of turbulence and convection in the atmospheric boundary layer at a change in atmospheric temperature.

3. A detailed spectral analysis of the field time variations should be performed in order to verify the hypothetical nature of the sunrise effect proposed by Cherneva and Kuznetsov (2005).

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