Frequency and time analysis of the effect of sunrise in the electric field of the surface layer of the atmosphere*

Sergey Smirnov*

Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Russia.

ABSTRACT: In conditions of fair weather, a characteristic daily variation in the intensity of the potential gradient atmospheric electric field is observed with a maximum in the morning. Statistical estimates of the parameters are obtained: the time of the beginning, the time of the maximum, and its intensity and duration. It has been experimentally shown that the maximum of the diurnal variation in the intensity of the atmospheric electric field is associated with a change in the air temperature distribution over the altitude. At sunrise, the sun in the power spectra of the potential gradient enhances the oscillations in the period band T <1 h. A possible mechanism for the generation of these oscillations is associated with the vortex motion of convective cells originating at the sunrise in the exchange layer of the atmosphere.

INTRODUCTION

Diurnal variations in the potential gradient (PG), 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 PG 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 PG recordings were received only within an interval of ±15 min relative to local sunrise. The later PG 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 [Brown, 1936] clearly isolated this anomalous effect by excluding the unitary variation from the measured diurnal PG 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

*Contact information: Sergey Smirnov, Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Russia, Email: sergey@ikir.ru

temperature difference between the layers, thermal conductivity, and the viscosity of the medium. In another work [Israel, 1953], the link between the PG 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 PG variations. Measurements of the PG 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 sun rise. 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 PG, which is observed in experiments. [Anisimov et al., 2006] also follow this point of view for explaining the positive correlation between the PG 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 PG variations in the near ground atmosphere, including [Smirnov et al., 2012]. Numerical evaluations of parameters of the convective generator model are presented in the paper [Mareeva et al., 2011; Anisimov et al., 2017].

The main characteristics of sunrise effect in PG diurnal variations were investigated in detail by many authors. It turned out that the effect begins either at the moment of sunrise [Kasemir, 1956] or 20-30 min after it [Marshall et al., 1999]. The duration of the effect is ~ 4 - 7 h [Muhleisen, 1958], ~ 4 h [Kamra, 1969], ~ 3-4 h [Selvam et al., 1980], ~ 3 h [Marshall et al., 1999]. The PG maximum delay relatively the moment of sunrise is ~ 2,5 h [Kasemir, 1956]; ~ 2-4 h [Moore et al., 1962]; ~ 1-1.5 h [Marshall et al., 1999]. The PG value during the effect maximum increases with respect to the level before the sunrise by ~ 2,5-3 times [Kasemir, 1956], by ~ 3 times [Muhleisen, 1958], by ~ 4 times [Marshall et al., 1999].

Simultaneous measurements of PG and spatial charge density [Muhleisen, 1958; Moore et al., 1962; Selvam et al., 1980; Marshall et al., 1999] showed that positive charge density and vertical current value grow simultaneously with PG increase [Kasemir, 1956; Muhleisen, 1958]. Condensation nuclie concentration measured simultaneously was vary high at night. It decreased during the sunrise and fell to zero at local noon [Moore et al., 1962]. This experimental result showed gradual development of the convection process in the atmosphere with temperature increase at the sunrise.

Wind increase result in the sunrise effect weakening [Brown, 1936; Kamra, 1969; Selvam et al., 1980; Marshall et al., 1999]. During thick fog and dense cloudiness without precipitation, the spatial charge becomes negative, that causes the weakening and even disappearance of the sunrise effect. This effect almost does not manifest in the mountains [Muhleisen, 1958].

This paper continues the investigations of the electric processes in the near ground atmosphere at sunrise. Besides the PG observations, we additionally applied simultaneous records of atmospheric electric conductivity, as well as the temperature by the ground surface and at the height of 25 m.

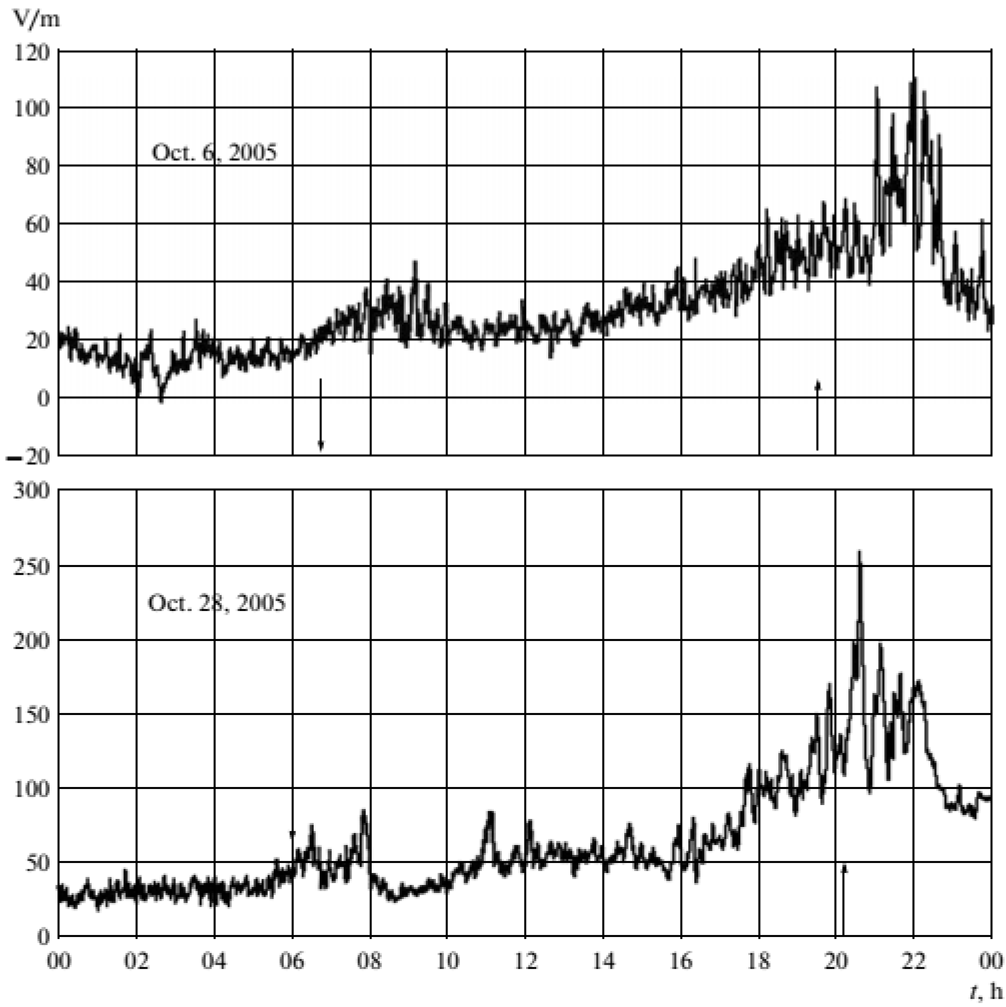

Fig. 1. Standard diurnal variations of potential gradient in "fair weather" conditions. Upward arrows indicate the sunrise, downward arrows indicate the sunset.

MEASUREMENT METHODS

PG measurements at the Paratunka observatory of the Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Kamchatka (λ =158.25°E; φ =52.9°N), were conducted using the Pole2 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 14bit 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 [RD, 2002]. Further, the data of measurements with the main instrument are used, taking into account the reduction coefficient.

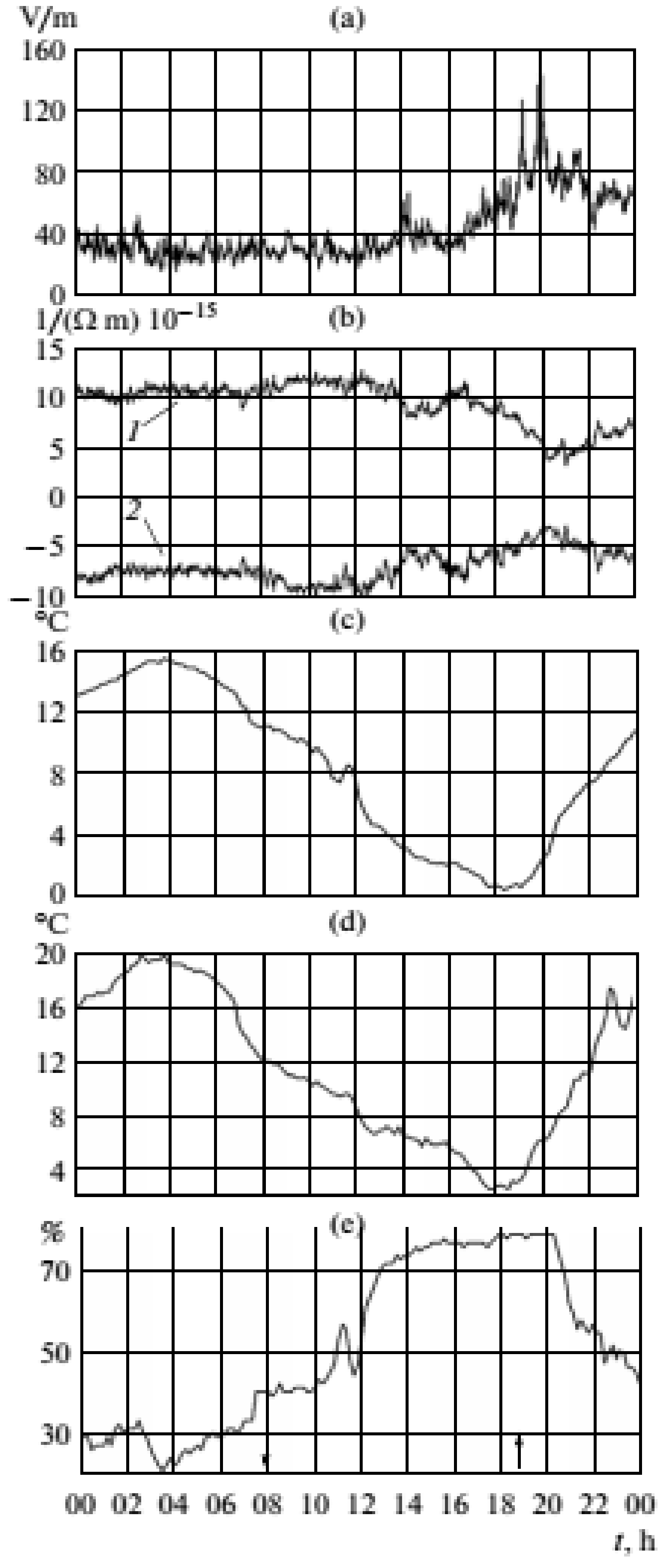

Fig. 2. Diurnal variations of potential gradient (a); air total electric conductivity caused by negative and positive ions (b); air temperature at the heights of 25 m (c) and 3 m (d), and humidity (e) on September 10, 2007.

Monitoring of meteorological parameters is conducted by the WS2000 and WS2300 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 withone 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.

Compared to the continental conditions in which the earlier investigation had been carried out, the observation conditions in Kamchatka have specific geophysical features. First of all, in the result of increased seismic activity, the ground here is constantly "breathing", heating the surface and forming gases saturated with radon, the main agent of ionization in the atmospheric near ground layer. Secondly, volcanoes here are also constantly "breathing" enriching the atmosphere with aerosols. Thirdly, cyclones and anticyclones are active on the peninsular. Thus, the "fair weather" conditions formulated in the papers [RD, 2002; Reiter, 1992] are rarely realized in Kamchatka. That is why we processed the data obtained on the days without precipitation, thunderstorms, fogs, at the wind velocity of less than 6 m/s and at the presence of the strato-cumulus cloud lower layer of less than grade two. (According to the conclusions of the papers [Moore et al., 1962; Kamra, 1969], weak nimbostratus without precipitation causes PG weak disturbances). To investigate the sunrise effect, we chose PG diurnal curves for September 1999 (13 days), October 202 (5 days), August 2004 (6 days), October 2005 (2 days) and November 2007 (3 days).

Simultaneously with that, air electric conductivity was measured by "Elektroprovodnost'-2" device also developed at the Main Geophysical observatory. It has two air intakes mounted at a height of 3 m to measure the electric conductivity caused by positive (λ_+) and negative (λ_-) air ions separately. Further in the formulas we use the total electric conductivity $\lambda = \lambda_+ + \lambda_-$. All the measuring devices are spaced at the distance of not more than 200 m.

Then for each day of processing we defined the moments of sunrise and sunset as the times of the Sun upper edge appearance over the horizon and disappearance over the horizon for geographic coordinates of Paratunka observatory. On each curve we marked the time of sunrise effect beginning, its delay relatively the sunrise time, effect duration, PG maximum time and maximum relation to PG value before the sunrise. PG value during the effect maximum exceeds the level before the sunrise by 2-4 times; effect maximum shift relatively the sunrise moment is from 0 to 4.5 h, and the effect duration is from 2 to 7 h. Almost in all cases the effect disappears at local noon.

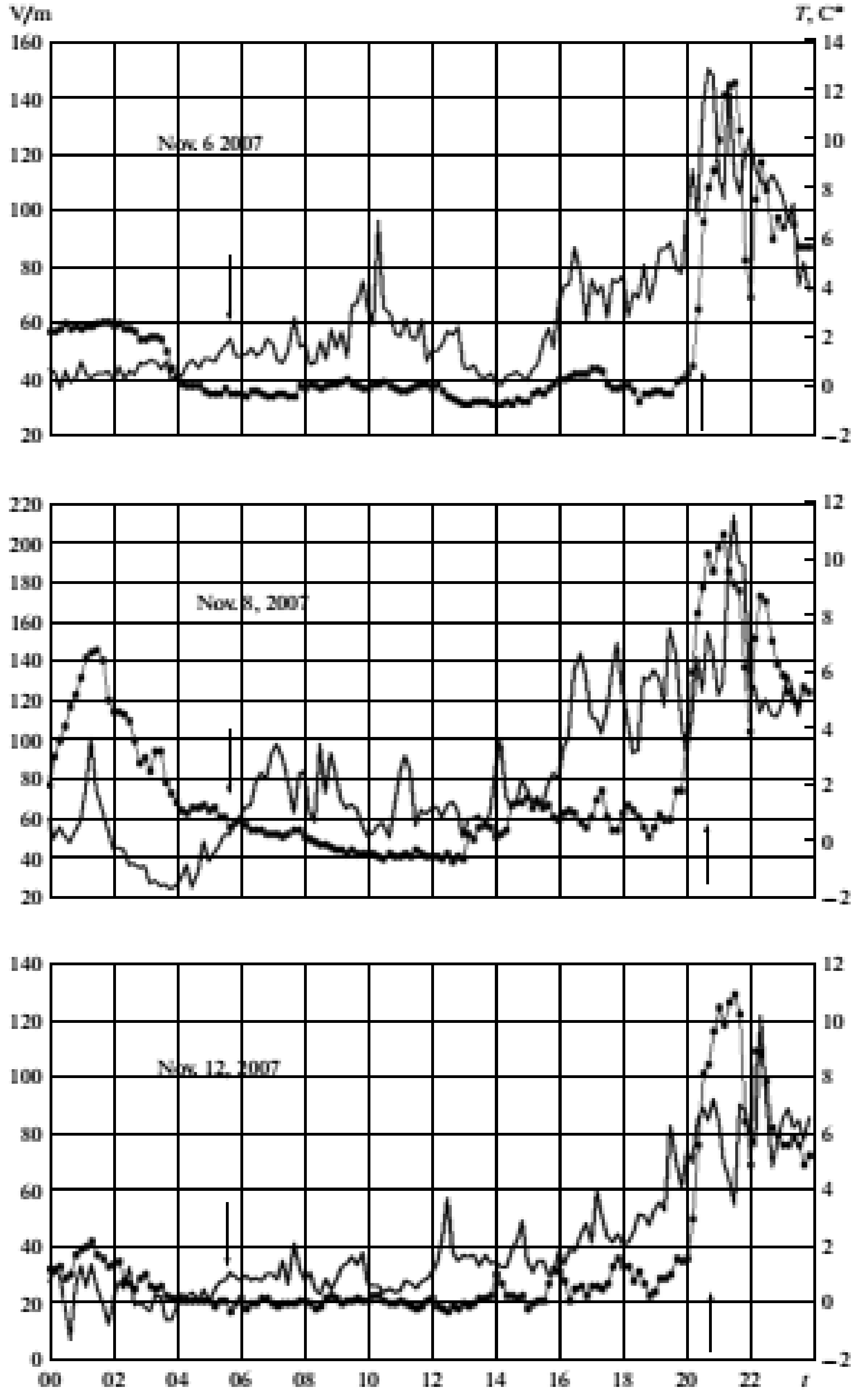

Fig. 3. Potential gradient diurnal variation (solid line, left scale) and temperature difference at the heights of 25 and 3 m (dots, right scale).

RESULTS

PG typical diurnal variations in "fair weather" conditions and close to them at Paratunka observatory are illustrated in Fig. 1. For ease of comparison with UT-variation and other geophysical parameters, the curves are presented in respect to the universal time. Arrows indicate the times of sunrise (upward) and sunset (downward). Taking into account the geographical location of the observatory, these times for each date were determined by the times of sunrise and sunset, presented in Almanacs for zero meridian, and calculated by the relation LT = UT + 10.55, where t = 10,55 h is the hour angle for the observatory longitude λ = 158,25° E. It is clear in the figure that the diurnal variation maximum is observed during the morning hours of the solar local time. On some days, evening maximum of weaker intensity compared to the morning one is observed. During the active snow melting period (April-May), such character of the diurnal variation is disturbed, as a rule. For our analysis we chose not only the days with "fair weather" conditions but also the days with stable operation of the whole measuring instrumentation complex. For the period 2005-2009 there turned to be 16 such days with PG average diurnal value of ~60 V/m and root-mean-square deviation of ~15 V/m. These low PG values are explained by the regional features and low location of the site relatively the sea level (50 m). The morning growth in field intensity determined by the convective processes often increases the average level by two-three times.

For illustrative purposes, (Fig. 2) (September 10, 2007) shows a set of PG simultaneous diurnal variations (a); total air electrical conductivity caused by negative and positive ions (b); air temperature at the heights of 25 m (c) and 3 m (d); air humidity (e). It is clear that temperature diurnal curves at different heights are similar and change in antiphase with the humidity diurnal cure repeating the characteristic features of these parameters in "fair weather" conditions [Reiter, 1992].

To estimate the convective generator effect which manifests the most brightly at sunset, we chose the temperature difference at the fixed heights of 3 and 25 m as a measure of convective flux intensity. An example of comparison of PG diurnal curves with temperature difference is shown in Fig. 3. The relation of PG variations with temperature difference manifests the most brightly at sunset with the correlation coefficient of ~ 0,6±0,1. In some cases, as we can see on November 12, 2007, the curves coincide closely whereas in other cases shown in the figure, the PG diurnal variation significantly deviates from the temperature difference curve allowing us to assume the presence of spatial charges of other nature in the near ground atmosphere.

DISCUSSION

The analysis results of sunrise effect in PG diurnal variations at Paratunka observatory for all the selected parameters closely coincide with those which had been earlier published in the papers mentioned in the Introduction. This fact implies that independent of geophysical peculiarities of a site for PG registration in the near ground atmosphere in "fair weather" conditions, a common physical mechanism is in action. In the earlier investigations, the authors tried to explain the nature of this effect. Brown [Brown, 1936], excluding the unitary variations from the measured PG diurnal curves, detected clearly the anomalous effect during sunrise. The author suggested an idea on the presence of condensation positively charged nuclei in the atmospheric exchange layer during this period and their upward transfer in the result of turbulence and convection processes with air temperature increase.

Simultaneous measurements of PG value and vertical electric current density carried out on clear cloudless days [Kasemir, 1956] showed their simultaneous increase by two-three times after the sunrise. Moreover, air electric conductivity increased by only 20% compared to the corresponding values before the sunrise. This results contradicts the thunderstorm generator theory explaining atmospheric electric field generation only by the collective effect of thunderstorm generators forming the GEC. Applying the results of these observations together with the experimental data described in the literature till 1956 Kasemir [Kasemir, 1956] suggested to introduce additionally an exchange convective [Atmosphere, 1991, p.395] generator into GEC which acts locally in the atmospheric boundary layer. Then the electric current density at the absence of thunderstorm sources is written as follows [Atmosphere, 1991, p.395]:

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

where λ is atmospheric electric conductivity, light ions contribute into it the most; ρ is electric charge density; V is the hydrodynamic velocity of medium motion; D_t is the turbulent diffusion. In a quasi-steady case, current density is determined by the first term and is attributed to the thunderstorm generator effect. After the sunrise, in the result of turbulent heat exchange, turbulent mixing processes ($D_t\nabla\rho$) and upward mechanic transfer (ρV) come into action by the air convective flow of positive spatial charges collected over a night near the ground surface. That, in its turn, results in the PG increase near the ground surface and electric conductivity current amplification that is observed in the experiment. The suggested model of convective generator was experimentally confirmed in the subsequent papers of many authors on the investigation of sunrise effect in electric parameter diurnal variations in the near ground atmosphere.

The convective generator effect in the near ground atmosphere can be qualitatively traced by diurnal curves in Fig. 2. It is clear from the curves (d) and (e), air humidity sharply falls with the sudden temperature growth after the sunrise in the result of water evaporation rate increase. In this case the condensation positively charged nuclei are carried upwards. This process is reflected in the decrease of total air electric conductivity (curves 1 and 2 on the fragment (b)) and in simultaneous PG increase (fragment (a)) and lasts for several hours (2-7 h), achieving the PG maximum in 1-4.5 h after the sunrise. As a rule, the effect disappears at local noon at temperature maximum (fragment (c)) in the result of convective process maximum amplification and condensation positive charge nuclei transfer into higher altitudes of the atmosphere. As a consequence, total electric conductivity and PG change slightly during this period. After the noon, air temperature gradually decreases to the minimal value before the sunrise as solar radiation weakens. Air humidity gradually increases in antiphase causing spatial charge collection by the ground surface. Total electric conductivity and PG change slightly at nighttime.

To explain the observed relation of atmospheric temperature difference with electric field strength diurnal variations in the near ground atmosphere, we consider the field strength variation $\Delta E = \Delta E_{unit} + \Delta E_\lambda + \Delta E_\rho$ [Tverskoy, 1949], where:

$$\Delta E_{unit} = \frac{\Delta\varphi}{R} \cdot \frac{1}{\lambda} \qquad (1)$$

is the unitary variation, $\Delta\varphi$ is the earth-ionosphere potential difference, R is the earth-ionosphere air column resistance, λ is the air electric conductivity mean diurnal value;

$$\Delta E_{\lambda} = -\frac{E}{\lambda} \cdot \Delta\lambda \qquad (2)$$

is the variation associated with air electric conductivity, E is the field strength mean diurnal value, λ is the air electric conductivity mean diurnal value;

$$\Delta E_{\rho} = -\frac{1}{\lambda} \cdot \Delta(k\frac{d\rho}{dh}) \qquad (3)$$

is the variation associated with air convection, k is the turbulent coefficient, ρ is the spatial charge density, λ is the air electric conductivity mean diurnal value.

The latest formula takes the turbulent diffusion current density $-k\frac{d\rho}{dh}$ into consideration.

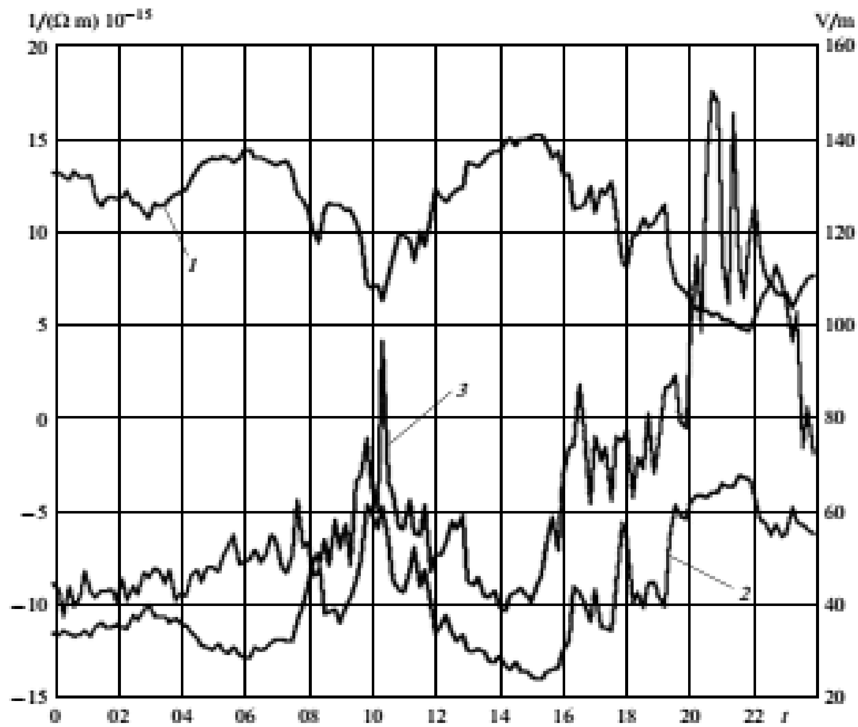

Fig. 4. Diurnal variations of air electric conductivity, left scale (1), of potential gradient, right scale (2) on November 6, 2007.

At Paratunka observatory, morning air convection, formula (3), contributes the most into the morning PG maximum, then, rarely, electric conductivity variation, formula (2), and unitary variation as long as the sunrise coincides with its maximum, formula (1). The convective mechanism of the morning maximum can be explained by the following. After the sunrise, the positive spatial charges collected over a night by the ground surface move upwards. When the temperature difference is large, up to 12 ^{0}C (Fig. 3), significant PG oscillations and temperature difference are often observed during the maximum. These oscillations are likely to be caused by the generation of convective cells with turbulent motion of condensation positively charged nuclei motion. The evening maximum is determined by electric conductivity variation, formula (2). To illustrate this effect, in addition to Fig. 3, Fig. 4 shows PG diurnal variations (curve 2, right scale) with the main maximum in the morning and the second maximum in the evening and air electric conductivity (curve 2, left scale). In the evening, the total electric conductivity falls and, correspondingly, PG grows. The second maximum in the evening and even during the nighttime can, evidently, be explained by weak fog which is condensed at the place of sensor installation.

The Sun ultraviolet rays, being the main ionizer of the atmosphere at high altitudes, do not play a significant role in the atmospheric lower layers as long as all rays of short wavelength having enough energy for ionization of the gases, which are a part of the atmosphere, are absorbed at high altitudes. Only the rays which can make photoelectric effect reach the troposphere. However, owing to the low photoelectric effect of ground surface rocks, water and air born particles, the ionization is so small that it can practically be neglected [Tverskoy, 1949]. This conclusion was experimentally confirmed in the paper [Pak, 2003].

The estimate of the relation between the potential gradient and temperature difference can be represented in the form of the proportion:

$$\nabla\varphi \approx (6{,}0 \pm 0{,}2)\cdot \Delta T \qquad (4),$$

where $\nabla\varphi$ is the potential gradient, ΔT is the air temperature difference at the heights of 3 m and 25 m.

Unstable diurnal variation during spring months can be explained by the following factors. The show level near the observatory reaches 270 cm and this maximum of the snow cover usually occurs by the end of March. Such snow mass melts till the end of May and results in the complicated character of humidity diurnal variations at the observation site. We can trace how the air humidity affects the air electric properties on the example of Fig.2.

The convective character of PG maximum at sunrise, confirmed by measurement data, coincides with the results of the paper [Petrov, 2007], in which the authors measured air vertical motion by two vane anemometers at the heights of 0,5 and 1,0 m. Their sensitivity allowed them to trace even the weakest air motion upwards and downwards. Good correlation between the air vertical motion and conductivity vertical current density was obtained. Increase in the conductivity current density, when electric conductivity weakly changes, results in the growth of electric field strength in the near ground atmosphere.

A detailed spectral analysis of electric field strength time variations and of geomagnetic field variations was carried out to determine the nature of their short-period oscillations observed during the sunrise. The records of electric and geomagnetic fields made in September 1999 at Paratunka observatory, IKIR FEB RAS, were applied. The electric field measurement data were chosen for "fair weather" conditions and for weak geomagnetic ($Kp \leq 4$) and seismic ($M < 4$) activities. To find the relation between wave processes at different atmospheric heights and to determine the location of their source, we estimated the power auto- and cross-spectra also by the modified periodogram method.

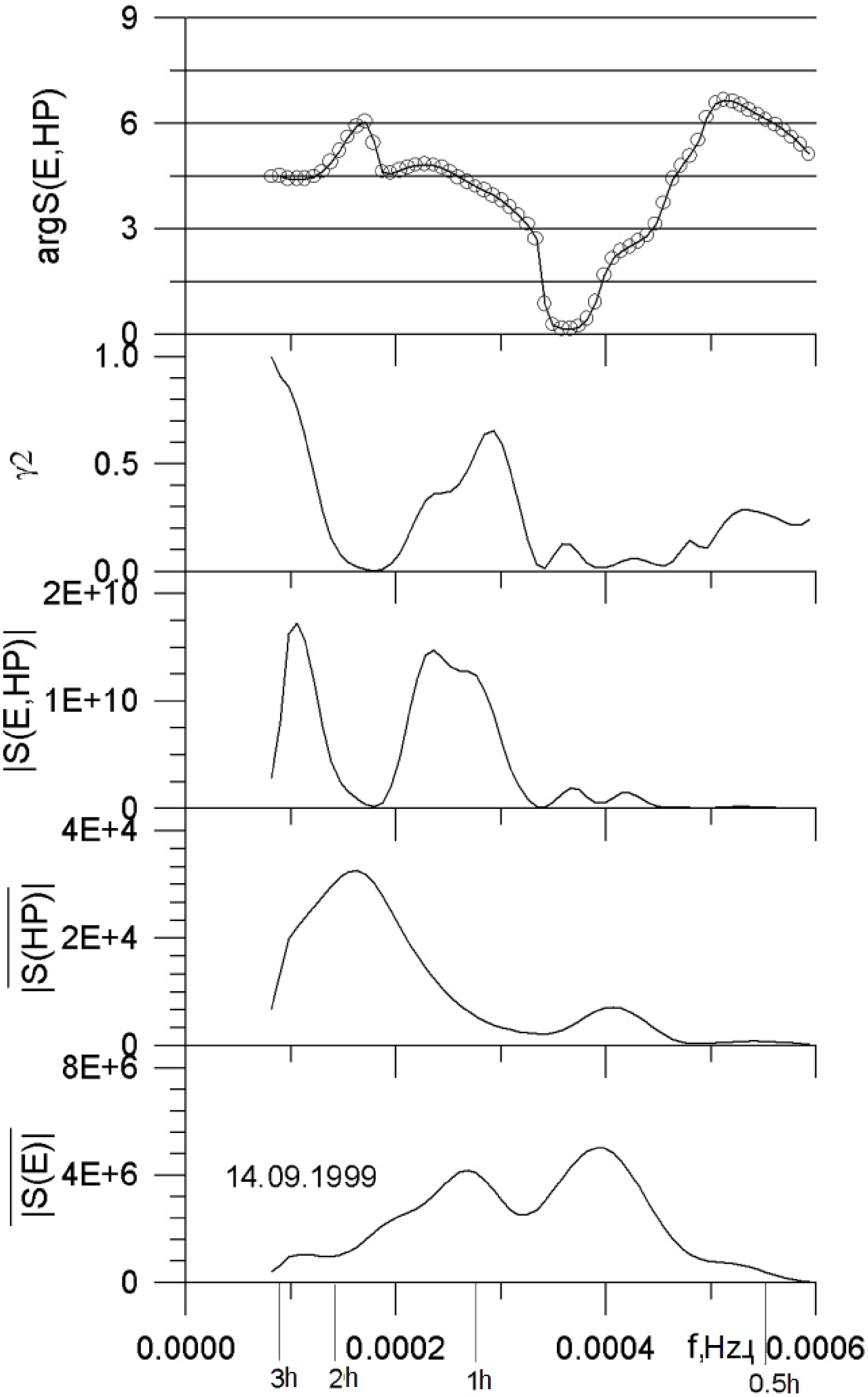

Fig. 5. An example of spectral processing of simultaneous records of electric field strength (E) and geomagnetic field horizontal component (HP) on the time interval of 12-24 UT including the sunrise (see in detail in the text.

The cross-spectrum module characterizes the contribution of separate sources into the mutual process and its argument allows us to determine the delay or advance of one wave process relatively another one. In relative units, the relation of two wave processes is characterized by the coherence function square $\gamma^2(f) = |Sxy(f)|^2/(Sxx(f)Syy(f))$. Value $\gamma^2(f)$ is analogous to the square of normalized correlation function at this frequency. It is small in the cases when the useful signal - noise relation is small, when two process are not connected linearly, when the second process (Y) depends not only on the basic process (X) but on other sources. An example of the suggested method for initial record processing for the period of 12-24 UT including the sunrise time is shown in Fig. 5. The electric field strength variations are accepted to be the basic process X and the geomagnetic field variations at Paratunka observatory are Y. It is clear that oscillations in the period band of T < 1 h and T ~ 1 h prevail in the auto-spectrum of electric field strength variations S(E). Their intensity significantly exceeds the oscillations with T ~ 2-2,5 h. Whereas, oscillation in the period band of T ~ 2-2,5 h prevail in the auto-spectrum of geomagnetic field variations S(HP) with slightly expressed oscillations at T ~ 0,7 h. In the cross-spectrum S(E,HP) the latest oscillations are significantly suppressed as well as the coherence value γ^2 ~ 0,1, that indicates the absence of the relation of wave processes in the dynamo-region and near ground atmosphere. Thus, the electric field oscillation source is focused in the lower atmosphere.

Two other maxima in the cross-spectrum at T ~ 2-2,5 h and T ~ 1 h with the coherence coefficient γ^2 ~ 0,9 and 0,6, respectively, show the relation of the processes in the lower atmosphere and in the dynamo-region of the ionosphere. It follows from the argument curve character of the cross-spectrum, that the source of this oscillations is located in the first case above the dynamo-region (the argument is almost constant) and in the second case, it is located in the lower atmosphere (the cross-section phase shows that the process is delayed in the dynamo-region relative to the near ground atmosphere).

Oscillation amplification in the period band of T < 1 h was determined in the quasi-static electric field strength power spectra in the near ground atmosphere during the sunrise in Kamchatka (Paratunka observatory). Their energy is not enough to pass to the heights of dynamo-region in the ionosphere. One of the possible sources for these oscillations may be the swirl motion of generating convective cells in the atmospheric boundary layer which transfer spatial charges upwards when air temperature increases during the sunrise. Other sources for these oscillations are possible.

CONCLUSIONS

The analysis of diurnal variations of electric field strength, electric conductivity and temperature in the near ground atmosphere in "fair weather" conditions at Paratunka observatory showed the following:

1. Estimated parameters of the effect: times of its beginning and achievement of the strength maximum relatively the sunrise, the relation of the maximum to the value before the sunrise and effect duration agree well with the data which had been published before.
2. The obtained results confirm the physical mechanism of the sunrise effect development suggested in [Kasemir, 1956]. Based on this mechanism, the electric field strength anomalous variations near the sunrise are determined by the turbulent and convection processes in the near ground atmosphere during the atmospheric temperature change.

3. The morning maximum of the electric field diurnal variation in "fair weather" conditions is determined by convective processes in the atmosphere during temperature sharp increase at sunrise. The maximum intensity with correlation coefficient of the order 0,6±0,1 is associated with the temperature difference at the heights of 3 and 25 m.
4. The evening maximum of electric field diurnal variations was weakly or not associated with temperature difference that allowed us to assume fog effect by the ground surface on electric conductivity and the electric field strength.
5. The proposed experimental method for temperature difference measurement at different atmospheric heights as a measure of convective processes turned to be very effective in the investigation of atmospheric electricity parameter diurnal variations.

At sunset, in the power spectra of quasi-static electric field strength in the near ground atmosphere over Kamchatka, we determined the following:

1) Amplification of oscillation intensity in the period band of 2-2,5 h.

2) Oscillation amplification in the period band of $T < 1$ h the intensity of which is comparable with IGW intensity before weak earthquakes with the magnitude of $M < 6$, is not enough to pass to the dynamo-region heights in the ionosphere.

3) Argument variations of the cross-spectra of electric field strength and geomagnetic field horizontal component variations allowed us to determine the location of the oscillation sources, in particular, in the lower atmosphere.

4) One of the possible sources for these oscillations may be the swirl motion of generating convective cells in the atmospheric boundary layer which transfer spatial charges upwards when air temperature increases at sunrise. Other sources of these oscillations are possible.

REFERENCES

Anisimov, S.V., E.A. Mareev, and N.M. Shikhova, 2006: Mechanisms by which the electric field is related to the temperature field in the lower atmosphere. *Radiofiz.*, 49(1). 35–52.

Anisimov, S.V., S.V. Galichenko, and E.A. Mareev, 2017: Electrodynamic properties and height of atmospheric convective boundary layer. *Atmospheric Research*, 194, 119-129.

Atmosphere, 1991: A Handbook. Gidrometeoizdat, Leningrad, Russia, 395 pp.

Brown, J.G., 1936: The effect of wind upon the Earth's electric field at the surface. *J. Geophys.Res*., 41(3), 279-285.

Imyanitov, I.M., 1957: *Instrumentation and methods to investigate atmospheric electricity*. Gostechizdat, Moscow, 483 pp.

Israel, H., 1953: *The atmospheric electric field and its meteorological causes. Thunderstorm Electricity*. Univ. Chicago Press, Chicago. 4--23.

Kamra, A.K., 1969: Effect of wind on diurnal and seasonal variations of atmospheric electric field. *Journal of Atmospheric and Terrestrial Physics*, 31(10) 1281--1286.

Kasemir, H.W., 1956: Zur stromungstheorie des luftelektrischen feldes III: der austauschgenerator. Archives for meteorology. *Geophys. Bioclimat. Ser.A.*, 9(3), 357--370.

Mareeva, O.V., E.A. Mareev, A.V. Kalinin, and A. A. Zhidkov, 2011: Convective Generator in the Global Electric Circuit: Analytical Approach and Numerical Consideration, Proc. XIV Int. Conf. Atmos. Electr., Rio de Janeiro, Brazil, August 2011.

Marshall, T.C., W.D. Rust, M. Stolzenburg, W.P. Roedes, and P.R. Krehbiel, 1999: A study of enhanced fair-weather electric fields occurring soon after sunrise. *J. Geophys. Res.*, 104(D20), 24455--24469.

Mikhailova, G.A., and O.V. Kapustina, S.E., 2013: Smirnov Nature of the sunrise effect in daily electric field variations at Kamchatka: 2. Electric field frequency variations. *Geomagnetism and Aeronomy*, 53(2), 234-242, https://doi.org/10.1134/S0016793213020126

Moore, C.B., B. Vennegut, R.G. Semonin, J.W. Bullock, and W. Bradley, 1962: Fair-weather atmospheric electric potential gradient and space charge over central Illinois, Summer 1960. *J. Geophys. Res*., 67(3), 1061--1071.

Muhleisen, R., 1958: *The influence of water on the atmospheric electrical field. Recent Advances in Atmospheric Electricity*. Pergamon press, London, 213--222.

Nichols, E.H., 1916: Investigation of atmospheric electrical variations at sunrise and sunset. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 92(642), 401--408.

Pak, V.V., Z.S. Teodorovich, Yu.I. Kulakov, A.V. Buldakov, I.I. Ippolitov, and S.V. Smirnov, 2003: To the interaction between the atmospheric electric field strength and UV luminosity. The 5th Russian Conference on Atmospheric Electricity. V.1. Vladimir. Gos. Univ., Vladimir, Russia, 90–92.

Petrov, A.I., G.G. Petrova, I.N. Panchishkina, N.A. Petrov, and A.P. Krivosheev, 2007: 6th Russian Conference on Atmospheric Electricity, Novgorod, Russia, 85–87.

RD 52.04.1682001, 2002: *Methodical instructions: Observations of the Electric Field*. Gidrometeoizdat, Leningrad, Russia, 58 pp.

Reiter, R. 1992: *Phenomena in atmospheric and environmental electricity*. Elsevier. Amsterdam- London – New York - Tokyo. 541 pp.

Selvam, A.M., G.K. Manohar, S.S. Khandalgaonkar, A.S. Ramachandra Murty, and Bh.V. Ramana Murty, 1980: Diurnal and seasonal variations of space charge, electric field and cloud condensation nuclei in the lowest layer of the atmosphere, *Tellus*, 32(3), 232--244.

Smirnov, S.E., G.A. Mikhailova, and O.V. Kapustina, 2012: Problem of the nature of the sunrise effect in diurnal variations in the electric field in Kamchatka: 1. Time variations in the electric field. *Geomagnetism and Aeronomy*, 52(4), 507-512, https://doi.org/10.1134/S0016793212040135

Smirnov, S.E., 2013: Influence of a convective generator on the diurnal behavior of the electric field strength in the near-Earth atmosphere in Kamchatka. *Geomagnetism and Aeronomy*, 53(4), 515-521, https://doi.org/10.1134/S0016793213040142

Tverskoy, P.N., 1949: *Atmospheric Electricity*. Gidrometeoizdat, Leningrad, Russia, 252 pp.