Short-Period Variations of the Vertical Electric Current in the Air

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Data on the measurements of the variations of the electric current in the air on mid-latitudes in the range 2.5-0.1 Hz and 0.1-0.01 Hz are given. It is shown that there are essential differences in the character of the variations of the vertical electric current and of the magnetic field in the range 0.1-0.01 Hz, namely of their distribution in local time and dependence on $K_p$-index. The previously unknown signals with V-form spectrum were registered in the vertical electric current and in the magnetic field in the range 2.5-0.1 Hz. The model of the oscillation of the space charge in the near Earth’s layer under the action of infrasound is suggested to explain some of the observed variations.

The study of annual, seasonal, diurnal variations of potential gradient, electric conductivity and vertical atmospheric electric current are traditional problems when dealing with atmospheric electricity. All these problems are closely connected with the verification of existing theories of atmospheric electricity, their development and the explanation of the unitary variation of potential gradient. Measurements of the atmospheric electric characteristics are of interest in connection with a number of other problems such as the study of the nature of geomagnetic pulsations, magneto-telluric studies, analysis of solar-biological relations and investigation of electric phenomena before and during earthquakes.

Recently some experimental papers (Chetaiev et al., 1975; Olson, 1971; Park, 1976) have appeared with the results which can't be explained by the statics model of the atmospheric electricity and the evidence for interconnection of electric phenomena in the low atmosphere with geophysical processes in the magnetosphere was stated. The observed disturbances of potential gradient in fair weather conditions in some cases were connected with magnetospheric sources (Olson, 1971). The correlation between potential gradient and the sector structure of interplanetary magnetic field (Park, 1976) indicates the interconnection of the atmospheric electric parameters with the processes in the cosmic space surrounding the Earth.

A new interpretation of ground based observations of the Earth’s electromagnetic field in the range of short-period fluctuations (Chetaiev et al., 1975) suggests the existance of the vertical electric component of the geomagnetic field.
pulsations in the air. However, simultaneous measurements of short-period fluctuations of the electric field in the air and of the magnetic field in middle latitudes do not show stable correlation. This can be connected with a high level of tropospheric electric noise as well as with possibility of different sources generating geomagnetic pulsations and variations of the potential gradient.

The paper presents an analysis of short-period fluctuations of vertical electric current density (VECD) in the air in order to estimate their amplitudes and to determine the regularities of these variations in two frequency ranges—namely 10–100 sec and 0.4–10 sec. The continuous measurements were made in calm atmospheric conditions in a region without industrial pollution. The records were made on charts and on magnetic tape. VECD variations in the atmosphere were measured by the potential drop method along a resistance which connects the antenna area with ground. The resistance value and the effective antenna area were calculated taking into account the amplifier noise level and its input impedance.

Two wire grids situated parallel to the Earth's surface one over the other at heights of 1.5 and 3 m were used as an antenna. The area of each grid was 50 m².

The differential method of measurements was used in order to make no errors caused by local space charge horizontal movements. The active band filter of the third order was used to distinguish pulsations in the period ranges 10–100 sec and 0.4–10 sec. The threshold sensitivity of the device was $4 \times 10^{-13}$ A/m². The study of fluctuations of the vertical atmospheric electric field and their correlation with pulsations of magnetospheric origin is hampered by frequent unfavourable atmospheric conditions such as cloudiness, wind, precipitations, remote thunderstorms, fog, convective movements and atmospheric pollution. The results of 20 twenty-four-hours continuous fair-weather observations at wind velocity no more than 2 m/sec were processed.

The fair-weather vertical current recorded on the Earth's surface is determined as a total current

$$j_z = j_{cd} + j_{cn} + j_{dp}$$

where $j_{cd}$ is a conductivity current, $j_{cn}$ is a convective current, and $j_{dp}$ is a displacement current.

The used method of measurement of the total VECD doesn't allow us to distinguish these components, but it shows that the level of fluctuations is in the range of $10^{-12} - 10^{-10}$ A/m². and depends on the period of fluctuations. Let's evaluate each component and compare the results with observations.

An average level of conductivity current of atmospheric electricity is $10^{-12}$ A/m² (Chalmers, 1974). The principle of quasi-stationary state being fulfilled, the amplitude of variations of the vertical current conductivity has the order of the average level. It is less than the value of the recorded fluctuations (Fig. 1).

The space charge movement driven by the forces of non-electric origin deter-
mines the convective current. Turbulent diffusion is one of the mechanisms responsible for convective current. It is proportional to wind velocity (GUL'ELMI, et al., 1978). Convective current generated by the space charge movement can be presented as

\[ j_{cn} = \sigma \cdot V \]

where \( \sigma \) is a space charge density, and \( V \) is a charge movement velocity.

Data on the spectrum of atmospheric turbulence is given in (FOOKS, 1955). The average wind velocity being 2 m/sec, mean square velocity of the vertical
movements is about 30 cm/sec at a height 70 cm from the earth’s surface. Taking the average value of the space charge equal to \(500 \times 10^{-12}\) c/m\(^3\) (Chalmers, 1974) and assuming the velocity of the wind vertical movements given above, we can determine the convective current as \(j_{cn}=1.5 \times 10^{-10}\) A/m\(^2\). It is close to the average value of the recorded variations of the current density (see Fig. 1).

The model of the horizontal propagation of inhomogeneous plane electromagnetic wave suggests the existence of the vertical component of the electric field intensity in the air as an integral part of the primary wave. In this case the variations of the potential gradient of atmospheric electricity could be induced by the vertical component of the electromagnetic wave. According to the previous experimental data they can reach the values \(\sim 5\) V/m (Chetaiev et al., 1975) for continuous Pc2-3 pulsations in middle latitudes.

The observed variation of potential gradient with a period \(T = 10\) sec. gives for the displacement current the value

\[
j_{dp} = \varepsilon_0 \frac{\partial E_z}{\partial t} \sim 10^{-11}\ A/m^2.
\]

This value coincides with the amplitudes of the observed fluctuations.

Figure 2 presents the dependence of the average amplitudes of the VECD pulsations on their period. Amplitude of pulsations increases, by 6 db when periods increase by an octave. The dependence of the current amplitude variations is similar to that of geomagnetic pulsation amplitudes on periods.

Diurnal variation of the vertical current during the observed period is given in Fig. 3. Taking into account the obtained dependence shown in Fig. 2, the average amplitude of the variations is normalised to a period \(T = 10\) sec. The diurnal variation of the amplitudes have two maxima with values exceeding by 50\% the average value. Unlike the diurnal variation of atmospheric potential gradient with maxima falling on time intervals from 7 to 10 and from 19 to 22 UT,
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Fig. 3. Diurnal variation of the amplitudes of the short-period fluctuation VECD. The average amplitude of the variations (\(j_{av}^{10sec}\)) is normalised to a period \(T = 10\) sec, accounting the dependence shown in Fig. 2.

The maxima of short-period fluctuations of the VECD fall on 01–03\(^h\) and on 20 to 23\(^h\) UT. It is necessary to stress that for these maxima are responsible mainly fluctuations with periods \(T = 10–30\) sec typical for these time intervals. For the investigation of the correlation of these variations with magnetic activity we studied the dependences of the variation of the amplitudes (normalised to \(T = 10\) sec and of the relative number of VECD variations of the different periods (10–30 sec) from \(K_p\). In addition the number of observed cases was normalised on \(K_p\) (Fig. 4). Fluctuations with \(T = 10\) sec have a maximum of occurrence at \(K_p = 2\); 20 second fluctuations have a maximum at \(K_p = 4\). Fluctuations with \(T = 30\) sec were observed with approximately the same probability for all values of \(K_p\).

It is important to note that the dependence of \(Pc2-3\) occurrence on \(K_p\) in the electric field does not coincide with the well established one for geomagnetic pulsations. Indeed, it is known that for geomagnetic pulsations smaller periods are observed for higher values of \(K_p\). Figure 4 shows that the dependence of periods of fluctuations in the electric field on \(K_p\) is inverse.

Experimental results show that the variations with \(T = 20–30\) sec are most typical in the range 10–100 sec and their amplitude reach the values \(j_x = 10^{-11} - 10^{-10}\) A/m\(^2\). They are usually observed near midnight, however, regular geomagnetic pulsations \(Pc2,3\) with similar periods are observed during morning and day-time hours. These facts indicate the different origin of the observed fluctuations in \(Pc2-3\) range in geomagnetic field and in the electric field in the air.

In the range of 0.4–10 sec the spectrum of the variations of VECD is in most cases noisy. In the course of the experiment several clear cases of \(Pc1\) geomagnetic pulsations were recorded. The comparison with simultaneous records of VECD did not show any signal of \(Pc1\) type at the level of sensitivity of our
Fig. 4. Dependences of the amplitudes of the VECD variations normalised to a period $T = 10$ sec (dashed line) and relative number $N/n_Kp$ of the emergence variations of the different periods in the range 10 - 30 sec (solid line) on $K_p$ - index. The number of the observed cases was normalised to the number $K_p$.

The central frequency of such emissions is near 1 Hz with the relative width no more than 50%. In this case no pulsations with similar spectral structure were observed in the magnetic field.

A completely new and peculiar type (as regards its dynamic spectrum) of signal was observed in the considered and most probably higher frequency range (not covered by the frequency response of the equipment).

During the experiment, 18 cases of such signals were registered. The example of their dynamic spectrum is given in Fig. 6. They have a clearly expressed...
V-type shape. Such signals occur mainly during morning and evening hours. Only in one of these cases the signals were observed simultaneously in the electric current density and in the magnetic field. Such cases were observed independently also in magnetic field observations with high sensitivity (private communication, B. I. Klain).

Fair-weather conditions suppose the absence of the fluctuations of velocity and space charge density in the near Earth’s layer of the air. However, one may assume that velocity fluctuations can arise in fair weather as a result of the effect of the infrasonic fluctuations on irregularly distribution space charges in the near Earth’s layer.

Let us consider the mechanism of generation of the convective current under the influence of such type of waves. We assume, that the source of infrasound is located above and that the infrasonic wave is incident at the right angle to the Earth’s surface. The fluctuation of the ions in the surface layer, under influence of these waves will lead to the fluctuations of the current. The relationship between the amplitudes of the fluctuation of ions of the medium is (FOOKS, 1955).
The magnitude of $\tau$ for the air does not exceed $10^{-5}$ sec. Therefore, $V \sim U$. It means that in the surface layer under the influence of infrasound the fluctuations of ions have the same amplitude and phase as those of the medium, i.e. they move as an integral part of the medium. In the medium the velocity of the particle oscillation under influence of infrasound is connected with excessive pressure $P$ as follows:

$$P = \gamma \varepsilon \cdot C_s \cdot V$$
where $\gamma_g$ is the medium density, and $C_s$ is the velocity of the sound.

When the average infrasound magnitude of pressure change by $10\mu$ bar (GOSSARD and HOOKE, 1975), the amplitude of the velocity variations $V$ is 0.2 cm/sec. The local changes in vertical electric current density which are due to space charge velocity variations under the effect of infrasonic wave can be written as:

$$j = \sigma \cdot V \approx 10^{-12} \text{ A/m}^2$$

(if the density of the volume charge is $\sigma = 500 \times 10^{-12} \text{ c/m}^3$). This value corresponds to the amplitudes of the observed fluctuations in the frequency range 0.4–10 sec.

Let's consider the possibility of occurrence of quasistationary, local fluctuations of the magnetic field connected with the space charge fluctuations generated by infrasound. Linear dimensions of space charges in the surface layer are around 100–400 m (VERG and JOHNSON, 1974).

If we take for the velocity of the volume charge fluctuations the obtained value $V = 2 \times 10^{-3} \text{ m/sec.}$, the amplitude of the magnetic field fluctuations is:

$$B = \frac{q}{4\pi \epsilon_0 \cdot C^2} \cdot \frac{V}{R} \approx 0.1 \text{ pT}.$$ 

This corresponds to the threshold sensitivity of the induction magnetometers, used during the experiment. If the magnitude of the space charge and its linear dimensions increase, one can expect the fluctuation of the magnetic field to reach several pT and be registered by the utilised equipment (sensitivity $\approx 0.2$ pT).

The considered effect of infrasonic radiation of the space charges in the surface layer yields satisfactory estimations, for explanation of some types of the VECD variations in the air. The natural sources of infrasound include, for instance, heavy thunderstorms, sea wave, aurora, earthquakes. Therefore, the presented model can open new directions to elucidate the possible connection between the variations of VECD and a variety of geophysical phenomena. Moreover, it paves the way for physical understanding of these connections.

Conclusions

The obtained experimental results reveal the existence of specific oscillations of VECD in the air. Their frequencies fall in the range of 0.01–2.5 Hz, and their amplitudes are of the order $10^{-12} \text{ -- } 10^{-10} \text{ A/m}^2$. Investigation of the interconnection between VECD oscillations (20 days of continuous registration) and geomagnetic pulsations (Around 50 cases of Pc2-3 and 6 cases of Pc1) showed significant differences between oscillatory regimes in the magnetic and the electric fields. This conclusion was reached as a result of comparison of their
dynamic spectra, and amplitude time records. However, as it follows from the estimates given in the paper, the identification of VECD connected with geomagnetic pulsations is hindered due to existence of convective currents in the lower troposphere.

It is necessary to stress that even in fair weather conditions the possibility of generation of VECD oscillation as a result of infrasound action on space charges existing in the near Earth's layer of the air is not excluded. The estimates given above show that changes in the pressure by 10 μbar lead to local VECD changes of the order of $10^{-12} \text{ A/m}^2$. This corresponds to the order of VECD amplitudes observed in the frequency range of 0.1–2.5 Hz. Very small local oscillations can be simultaneously generated in the magnetic field with amplitudes $\sim 1 \mu\text{T}$.

Special interest presents the discovery of a new type of a signal, having V-shape. These signals were observed mainly in the electric current, however, in one case this type of signal was recorded simultaneously in the magnetic and electric fields.

The results of this investigation show:

1. The presence of specific, short period VECD oscillation in the air, the sources of which need further studies;
2. The existence of specific VECD morphological properties which are different from those typical for geomagnetic pulsations;
3. The possible relation of VECD oscillations with geophysical phenomena connected with generation of infrasound (aurora, earthquakes, etc). It is suggested that the measurements of the density of the vertical electric current can be used, as a sensitive tool for investigation of such processes.

REFERENCES


