Geophysics

1960

SovietRxiv

Abstract

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Geophysics

I. M. Imyanitov and E. V. Chubarina

Structure of the Electrostatic Field in the Free Atmosphere According to Data from Investigations during the International Geophysical Year

(Presented by Academician A. F. Ioffe, January 3, 1960)

To the present time the question of the nature of the electric field of the atmosphere has not yet been resolved, although there exist a number of hypotheses explaining its existence. The model of the "spherical capacitor" is most often used ([1,2]). An indirect confirmation of this model is the close correlation between the diurnal variation in the intensity of thunderstorm activity over the whole Earth and the diurnal variation of the electrostatic-field strength over the oceans and in polar regions, where it is little disturbed by local space charges (the unitary variation).

The theory of the spherical capacitor assumes: 1) a monotonic decrease of the electrostatic field with height and, correspondingly, a monotonic increase of the potential with height; the potential of the ionosphere, calculated from the assumed variation of conductivity with height, is taken to be equal to ~ 400 kV; 2) agreement of the phase and amplitude of the diurnal oscillations of the magnitude of the ionospheric potential with the phase and amplitude of the unitary variation observed on the Earth; 3) synphasicity of the changes and equality of the values of the potential of the upper layers at one and the same level above all observation points.

The rationality of the hypotheses explaining the origin of the electric field of the atmosphere can be assessed by investigations of its variation with height ([4]).

During the International Geophysical Year and the International Geophysical Cooperation, regular soundings of the electric field of the atmosphere were organized in the USSR with the aid of an Li-2 aircraft in Leningrad, Kiev, and Tashkent (for the instruments and measurement method see ([8])).

During the soundings the variation of the electrostatic-field strength E with height H was measured. The potential of the corresponding point was calculated by integrating the experimental curve $\bar{E} = f(H)$. It must be borne in mind that the main part of the resistance of the atmosphere is concentrated in its lower layers ([4]). Thus, about 66% of the total atmospheric resistance is concentrated in the 0–6 km layer; therefore it may be assumed that the potential at an altitude

Fig. 1

Figure 1: Fig. 1

of 6 km should not differ from the ionospheric potential by more than 30–35%; consequently, changes of the potential at 6 km should in the main be similar to changes of the ionospheric potential. Violations of this similarity may occur because of deviations of the atmospheric conductivity from "normal" values. Since these deviations occur chiefly in the 0–3–4 km layer and usually lead to a decrease of conductivity, the calculated values of the ionospheric potential may prove to be somewhat overestimated (4).

Processing of the measurement data yielded the following results:

1. The monotonic variation of the field strength with height, even on clear days, is often violated. Along with an exponential decrease with height H of the field

$$E = E_0 e^{-aH}$$

(a varies from 10^{-3} to $1.5 \cdot 10^{-3}$, if h is measured in meters), there is a number of cases in which at some height (more often 3000–4000 m) the field strength falls to zero or becomes stably negative. Cases are noted in which the electric field changes hardly at all with height, preserving up to great heights a value of 0.25–0.35 V/cm. Quite often a field variation is observed in which the strength has a maximum at a height from several hundred meters to several kilometers,

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usually located beneath the boundary of the temperature inversion (9). Above the maximum, the field strength changes sign and becomes negative.

2. A monotonic increase of potential with height is also often violated even in clear weather (Fig. 1).

Fig. 1. Variation of the electric potential with height. *I* —Leningrad, 1958 (75 ascents); *II* —Kiev, 1958 (50 ascents); *III* —Tashkent, 1958 (50 ascents). The solid curve is the course according to Gish (see, for example, (2)); *a* —measured values of the potential; *b* —heights at which the curve of potential variation with height has a maximum, i.e., above which the potential decreases.

3. The most probable value of the potential at an altitude of 6000 m proved to be lower than expected. As can be seen from Table 1, it lies within the range from 120 to 160 kV; the most probable value of the ionospheric potential is thus about 200–250 kV.

4. The diurnal variations of the potential at an altitude of 6000 m most often are not similar to the unitary variation and are different for all three observation sites at the same time (Fig. 2 A). Relative fluctuations of the potential:

Fig. 2

Figure 2: Fig. 2

Table 1

Repeatability of the value of the potential at an altitude of 6000 m in 1958 (number of cases).
The potential value at an altitude of 6000 m expected according to the Gish scheme (2) is +280 kV,
ionospheric potential +400 kV

Station	< −200	−200– −160	−160– −120	−120– −80	−80– −40	−40– 0	0–40	40– 80	80– 120	120– 160
Leningrad	2	2	3	4	2	5	8	26	38	40
Kiev	4	5	4	4	6	5	7	12	21	25
Tashkent (March and September)	1	1	1	1	1	1	4	10	17	15

Station	160– 200	200– 240	240– 280	280– 320	320– 360	360– 400	400– 440	440– 480	480– 520	> 520
Leningrad	36	23	22	10	8	5	2	2	2	2
Kiev	23	15	12	6	5	4	2	2	1	1
Tashkent (March and September)	7	3	3	2	4	3	2	1	1	1

during a day at altitudes from 500 to 6000 m tend to decrease with height. At an altitude of 3000-4000 m the smallest fluctuations of the potential are often observed, while higher up the relative fluctuations of the potential often increase again.

Fig. 2. **A** —unitary variation (I) and diurnal changes of the potential (II, III, IV) at an altitude of 6000 m in September 1958 on clear days: II —for Leningrad; III —for Kiev; IV —for Tashkent. **B** —unitary wave (1) and diurnal course of the potential at altitudes from 500 to 6000 m in Tashkent on clear days in June 1958 (2-7): 2 —500 m; 3 —1000 m; 4 —2000 m; 5 —3000 m; 6 —4000 m; 7 —6000 m.

Figure 3 and Figure 4: graphs of the diurnal variation of potential and field at different heights

Figure 3: Figure 3 and Figure 4: graphs of the diurnal variation of potential and field at different heights

In the diurnal course of the potential at different altitudes, a displacement of the maximum with height is often observed (Fig. 2B). At altitudes of 200–300 m in Leningrad and Kiev, the unitary variation of the field intensity appears quite clearly (Fig. 4); higher and lower it begins to blur, and the maximum of the curve begins to shift.

Thus, the “spherical capacitor” model was not confirmed in our experiments.

The results obtained can be interpreted if one passes from the spherical-capacitor model to a model of a charged sphere surrounded by a volume charge. Since at the Earth' s surface in polar, mountainous, and oceanic regions a unitary wave is observed (5–7), and a good correlation is noted between the unitary wave of the field and the diurnal course of thunderstorm activity over the entire globe (3), it may be considered that the currents flowing to the Earth in regions with thunderstorms recharge it, and that the diurnal course of the field intensity near the Earth' s surface is, in essence, the course of the surface charge density of the Earth where it is not disturbed by local volume charges.

The Earth is surrounded by a volume charge whose field is superposed on the field of its surface charge, and its fluctuations “smear out” the fluctuations of the unitary variation; therefore fluctuations of the potential at heights are caused by changes in the distribution and magnitude of the volume charge of the atmosphere. Often the volume charge in the 3–4 km layer is already such that its field completely compensates the field of the Earth' s surface charge.

If, from the measured field intensity, one subtracts the intensity of the field produced by the Earth's own charge (the unitary E), then, to a first approximation, one can isolate the field due to the volume charge of the atmosphere. An example of such an analysis is given in Fig. 3. As can be seen, the fluctuations of the measured potential, even under undisturbed conditions, mainly repeat the fluctuations of the potential caused by the volume charge of the atmosphere. All regions of the globe can be divided into three areas:

I —regions of volume-charge generation. These include all regions covered by clouds; in these cases, as a rule, the electric-field profile is sharply disturbed.

Fig. 3. Diurnal variation of the potential at heights of 500 m (1), 1000 m (2), and 5000 m (3) on clear days in June 1958 in Leningrad. a —measured potential; b —potential due to the Earth' s own charge; v —potential due to the volume charge of the atmosphere.

Fig. 4. Diurnal variation of the field at heights from 200 to 500 m on clear days in 1958. I —for Leningrad, II —for Kiev. 1 —200 m; 2 —300 m; 3 —400 m; 4 —

500 m.

II –regions where the monotonic change of the electric-field strength with height is disrupted by volume charges introduced from region I. These cases should correspond to profiles departing from an exponential. The type of profile depends on the magnitude and distribution of charge in the atmospheric column.

III –regions where the volume charge of the entire atmospheric column is small and has no substantial influence on the field of the Earth' s surface charge. In these regions, both at the Earth and at altitude, the unitary variation should be manifested.

The fact that the unitary variation is observed in "disturbed" regions (of type-II region) only at certain heights ($\sim$ 200–300 m) (Fig. 4) is explained by the fact that the fields of volume charges located above and below this level (for Leningrad) balance one another, allowing the field of the Earth' s own charge to appear in pure form.

Thus, the experiments on sounding the electric field of the atmosphere did not confirm the propositions of the spherical-condenser theory. Judging from the measurement results, it is evidently more natural to pass from the model of a spherical condenser to the model of a charged sphere surrounded by a volume charge. In order to substantiate this model more seriously, further study is needed of the behavior of the atmospheric volume charge and of the conditions of its generation, transport, and distribution in the atmosphere.

Main Geophysical Observatory
named after A. I. Voeikov

Received
29 XII 1959

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