XV International Conference on Atmospheric Electricity, 15-20 June 2014, Norman, Oklahoma, U.S.A.

The Research of «Fair Weather» Criteria in Atmospheric Electricity Taking into Consideration Surface Layer Stability

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ABSTRACT: The paper describes efficiency of methods, used in atmospheric electricity to determine the "fair weather" conditions, the use of which will allow to evaluate global atmosphere electrical parameters according to the results of observations made from land. Comparative analysis of application of different criteria during selection of periods, when local electric field generators are not present in the atmosphere, is performed on the basis of a longstanding field experiment.

INTRODUCTION

Over many decades, the mechanisms of maintaining the atmospheric electric field and the causes of its variations are the subject of both theoretical and experimental studies of different parts of the global electric circuit [Anisimov and Mareev 2008; Mareev 2010; Roble and Tzur 1986; Rycroft et al. 2000; Williams 2009]. Significant variations in electric field in the vicinity of the land surface are associated with its local disturbances superimposed on its global variations. The effect of the local component may be noticeable, significant, or determining for the electric state of the atmospheric surface layer. This brings up the problem of isolating local variations in electric field and current in order to interpret and compare data obtained in difference places and at different times.

In order to eliminate the effect of local factors in studying atmospheric electrical properties, the "fair weather" conditions are used; however, so far no single approach to determining the criteria of these conditions has been found. In atmospheric electricity, the "fair weather" requirements include the absence of thunderstorms, precipitation, snowstorms, and mist and limitations on wind velocity, cloud amount, and on the amplitude and frequency of oscillations in the intensity of electric field during observations. This implies the absence of local electric field generators, when the electric state of the atmosphere is determined only by the effect of global generators. In this case, it is assumed that the density of vertical conduction current in the atmosphere does not change with height and that ions reach the land surface only under the effect of electric field.

One should keep in mind that using the above list of "fair weather" conditions does not

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guarantee the homogeneity of data array, because, even if all these conditions are satisfied, atmospheric physical conditions may significantly differ. The experimental-data arrays chosen in such a way are not statistical complexes [Petrov 2003]. Thus, for example, Israelsson [1978] notes that, when the weather is fine, the atmospheric stability may vary from stable at night to unstable in the daytime. The stability conditions significantly determine the vertical profile of the concentrations of radioactive elements in the vicinity of the land surface; the concentration of ions, the density of volume charge, and the intensity of electric field vary with height according to this profile. Therefore, it is suggested that the Richardson number be used as an additional criterion. It is assumed that observations will correspond to the absence of local generators, if, during these observations, no conventional disturbances of meteorological conditions are noted and the Richardson number varies within the range $-0{,}05 < Ri < 0{,}05$, which corresponds to neutral stratification [Israelsson 1978; Roble and Tzur 1986].

However, during measurements in the vicinity of the land surface under the “fair weather” conditions, it was found that the conduction current density has a complex profile and, consequently, in the region under study, there is a mechanical transfer current which can be considered as one of the local generators of electric field [Aspinal 1972; Panchishkina et al. 2009].

Thus, the absence of meteorological factors disturbing the “fair weather” conditions does not eliminate the mechanical transfer of charges in the lower atmosphere, which implies the presence of a local generator that violates the ohmic conditions of current flow in this layer. It was proposed by Dolezalek [1960] to estimate the degree of deviation from the Ohm law using the criterion:

$$\Omega = \frac{i}{\lambda E},$$

where i is the directly measured total vertical atmosphere-earth current density, E is the electric field intensity at the earth surface, and $\lambda = (\lambda_+ + \lambda_-)$ is the specific conductivity of the atmosphere.

If the criterion Ω is close to 1, the Ohm law can be used in describing processes occurring in the atmospheric layer under study. The results of measurements performed by Dolezalek [1960] showed that the criterion Ω may significantly differ from 1 depending on different factors. The monthly means (from 3 to 10) of the criterion Ω obtained by Dolezalek imply the presence of a high mechanical transfer current and, consequently, the violation of the Ohm law in the atmosphere near the earth surface.

The criterion Ω can be calculated using the results of direct measurements of the total current density i and the mechanical transfer current density i_t at the ground-atmosphere boundary. If to take into account the fact that the conduction current density downward from the atmosphere to the earth can be represented as the difference $i_\lambda = i - i_t$, the Dolezalek criterion will be determined by the ratio:

$$\Omega = \frac{i}{i_\lambda} = \frac{i}{i - i_t}.$$

The relative character of the Dolezalek criterion should be noted. For example, if the mechanical transfer current density remains constant, a decrease in the intensity of electric field and, hence, a decrease in the conduction current density will result in high values of the criterion Ω:

$$\Omega = \frac{i}{i_\lambda} = \frac{i_\lambda + i_t}{i_\lambda} = 1 + \frac{i_t}{i_\lambda}.$$

The value of the ratio $\frac{i_t}{i_\lambda}$ determines the deviation of Ω from 1. In case of decrease of consequent i_λ even through such periods, when i_t is small to negligible, the Dolezalek criterion may take values, which considerably differ from 1. In order to determine the periods of observations, when the action of local generator is small to negligible, it is possible to use the immediately measured values of mechanical transfer current density, selecting only those hours of observation, when i_t is close to zero. On the basis of experimental data the paper studies the possibility of such an approach to evaluation of the "fair weather" conditions in comparison with the earlier propositions.

METHODS

The paper presents the results of field research, obtained during summer months in Rostov region and on the shore of Lake Baikal. 10-15 days were spent in every observation point during several seasons with the use of one and the same measuring complex:

– Measurement of total current density (i) and mechanical transfer current density (i_t) from atmosphere to earth is made by the plating method. Two round duralumin plates with the square of $\approx 0{,}2\ m^2$, covered with turf without grass stand (Fig. 1) are used as sensors. In order to avoid appreciable distortion of electric field intensity the plates are installed in the cutoff of the grounded guard bands. The plate for measuring mechanical transfer current density is screened from the atmospheric electric field by the grounded copper mesh with the dimensions of 1×1 m and mesh sell of 4×4 cm, installed at the height of 20 cm above the plate surface. The signal is transferred along the copper strings, fixed on teflon insulators inside the grounded screen, from the plates to measurement instruments (voltmeter-electrometer V7-30). Voltmeter-electrometers have the current measurement range of $10^{-8} \div 10^{-12}$ A, instrument lag equals to 100 sec, ratio error is 5% of measurement range.

As the immediately measured total current density (i) in the researched conditions presents the sum of conduction current density (i_λ) and mechanical transfer current density (i_t) from atmosphere to earth ($i = i_\lambda + i_t$), the conduction current density to earth surface may be calculated as follows: $i_\lambda = i - i_t$.

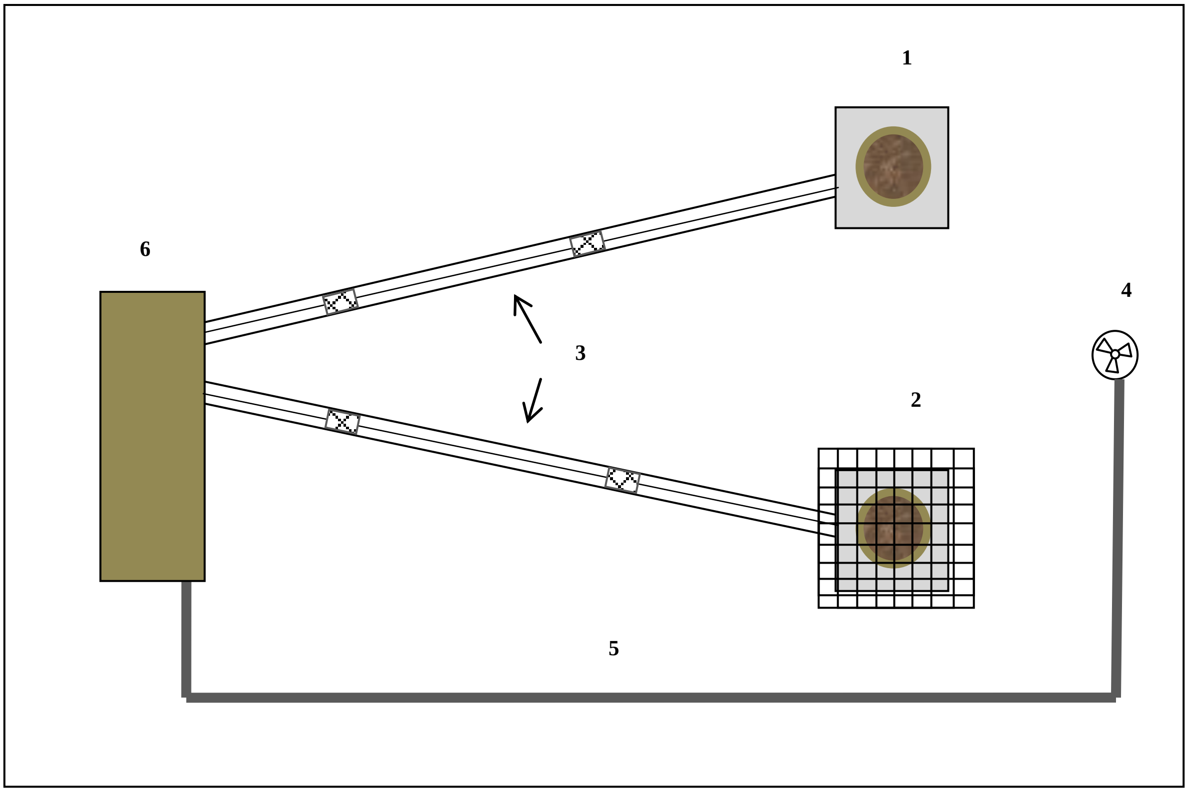

Fig.1. Diagram of sensors for measuring vertical electric currents installation (scale 1:80):
1 – plate for total current density measuring,
2 – plate for measuring of mechanical transfer current density,
3 – screened connection wire,
4 – flux meter,
5 – flux meter connection cable,
6 – shed for measuring instruments and recorders.

– Air temperature (0,5 m; 2 m) and wind speed (0,5 м; 2 м) were measured. The values of Richardson number Ri and turbulence factor D_T were calculated for each hourly set of measurements on the basis of the data about the air temperature and wind speed. Richardson number is widely used as the criterion of atmospheric stability: at $Ri < 0$ the atmospheric stratification is unstable, at $Ri = 0$ neutral, at $Ri > 0$ stable.

Every value of the measured parameter is an average for an hourly set of measurements. The measurements were made in the absence of precipitations, thunderstorms, big values and considerable fluctuations of electric field intensity. Drifting dust developed at wind speed higher than 7 m/s, and the measurements of current to the plate were stopped.

OBSERVATION RESULTS AND DISCUSSION

Series of hourly average values of conduction current density and mechanical transfer current density from the atmosphere to earth were chosen in order to compare the methods of determining the “fair weather” conditions. Statistical characteristics of vertical current component arrays i_t and $i_\lambda = i - i_t$ and Dozalek criterion $\Omega = i / i_\lambda$ are given in Table 1 for each observation point.

Coordinate system is selected in such a way, that the value of current density of any origin will have positive values, if at that positive charges are transferred to earth and negative charges from earth. The mechanical transfer current density in the points located in Rostov region have negative values, and in the area of Lake Baikal i_t is positive. From the ratio of i_t and i_λ one can see that the total current in average gives positive charge to earth. At the same time during several hours of measurements it can bring negative charge to earth, if i_t is negative and in its absolute value exceeds positive conduction current.

Table 1. Average values of the transfer current density, conduction current density and Dolezalek criterion

	Baikal	Mikhailovka	Pervomaiskoye
i_t, pA/m^2	0,52	-0,59	-0,31
Standard deviation, pA/m^2	0,27	0,81	0,47
$i_\lambda = i - i_t$ pA/m^2	1,04	2,70	0,88
Standard deviation, pA/m^2	0,53	1,00	0,93
Ω	1,63	0,82	0,50
Standard deviation	0,74	0,48	1,20
Number of hourly series of measurements	158	854	125

The average diurnal change of mechanical transfer current density from the atmosphere to the ground has its own peculiarities in each observation point. It is connected with the conditions, which influence the formation of space charge close to the earth surface, and with the change of intensity of diffusion processes during 24 hours.

Variations of mechanical transfer current density in the measuring points of Rostov region with similar orography (Pervomaiskoye and Platov settlements) have common regularities: all the average hourly values are negative, variations are synchronic (Fig. 2a, Line 1,2). For the above mentioned points in Rostov region the diurnal variation of turbulence factor, which is characterized by night minimum and maximal values during day time, is shown at Fig. 2a (Line 3,4).

Range of oscillation in diurnal variations of mechanical transfer current density at the Baikal is approximately three times less (Fig. 2b, Line 5). Due to stable wind related to breeze circulation there is no significant difference in turbulent mixing conditions during day and night.

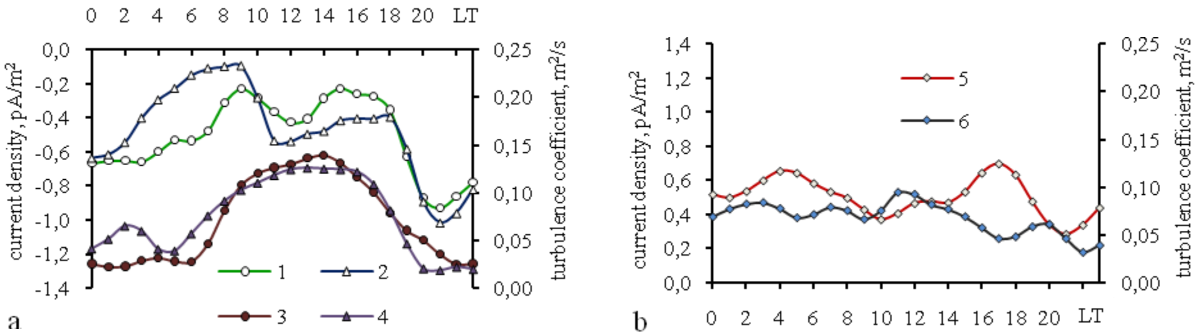

Fig.2. Daily variations of mechanical transfer current density and turbulence coefficient

a) Rostov region, Platov: 1 – mechanical transfer current density, 3 – turbulence coefficient
Pervomaiskoye: 2 – mechanical transfer current density, 4 – turbulence coefficient

b) Baikal: 5 – mechanical transfer current density, 6 – turbulence coefficient

The results of observations show that in every observation point under study the conditions were rare if ever, when the charge transfer occurred only as the result of conductivity current and there were no local generators of electric field [Petrov et al. 1996; Panchishkina et al. 2009; Panchishkina et al. 2011]. It was discovered that even if the “fair weather” conditions were not observed, the mechanical transfer current was present in the atmosphere and it was not possible to neglect the impact of local generators.

In order to compare different approaches to defining the “fair weather” conditions the experimental data were grouped as follows. The number of hourly series with the normal direction of electric field, when its average hourly values did not exceed 500 V/m, was taken as 100%. In the area of Lake Baikal this sample counted 163, in Pervomaiskoye settlement – 125, in Mikhailovka – 629 hourly series. Out of the above series there were selected such series, which could be attributed by the meteorological parameters to “fair weather” conditions (Fig. 3 – Column 1). Column 2 of the diagram corresponds to the hours, when the atmosphere could be considered as neutrally stratified $(-0{,}05 < Ri < 0{,}05)$. The number of series of measurements with Dolezalek criterion close to 1 $(0{,}9 < \Omega < 1{,}1)$ is shown in column 3. The last column of the diagram shows the number of hourly series, when the mechanical transfer current from the atmosphere to the ground was insignificant (small), that is the values of mechanical transfer current density were within the following range: $-0{,}10\, pA/m^2 < i_t < 0{,}10\, pA/m^2$. This interval is selected in such a way, that its boundary values make not more than 10% of the lowest boundary of the average values range of the conduction current, accepted in the atmospheric electricity for the fair weather areas.

From the diagrams presented at Fig. 3, one can see that for all the observation points the “fair weather” conditions according to meteorological conditions were present approximately in half the instances. Out of their number at the Baikal and in Pervomaiskoye the considerable proportion is made by the measurements made at neutral stratification $(-0{,}05 < Ri < 0{,}05)$. In these points the periods when the impact of the local generator was negligibly small were more rare (columns 3 and 4). At that in the hours of observations, which were included into the samples $0{,}9 < \Omega < 1{,}1$ and $-0{,}10\ {pA}/{m^2} < i_t < 0{,}10\ {pA}/{m^2}$, all types of atmosphere stratification were registered.

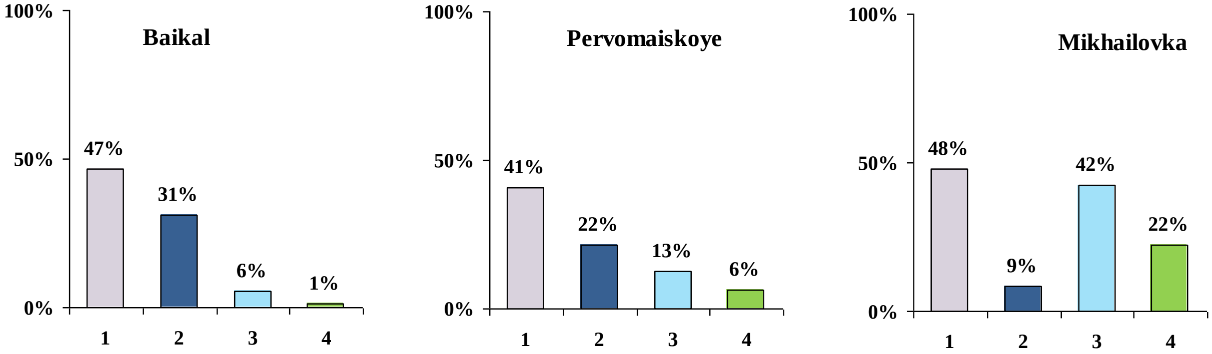

Fig.3. Comparison of “fair weather” criteria

Data about the number of hourly series of measurements, corresponding to “fair weather” conditions according to different methods, in percentage ratio to the total number of series of measurements in every point:

1 – “fair weather” according to meteorological parameters

2 – “fair weather” according to meteorological parameters, and Richardson number is in the following range $-0{,}05 < Ri < 0{,}05$

3 – Dolezalek criterion value is within the range $0{,}9 < \Omega < 1{,}1$

4 – mechanical transfer current density is within the following range $-0{,}10\ {pA}/{m^2} < i_t < 0{,}10\ {pA}/{m^2}$

In Mikhailovka the conditions of neutral stratification in the absence of disturbing meteorological conditions were observed in less than 10% of cases due to orographic peculiarities. The number of hours when the impact of local generators was weakened is shown in the third and fourth columns. As well as in other points the bigger portion of conditions in which these data were obtained refer not to the neutral, but to stable or unstable stratification.

As expected, less data entered the fourth column than the third due to more strict requirements to absolute value of mechanical transfer current density in all diagrams.

In all the observation points approximately half of criteria values, shown at the diagram by columns 3 and 4, have no match with the data from column 1. It means that the local generator of electric field may have no impact, even if the factors which disturb the meteorological conditions are observed. And vice versa it is not possible to neglect the impact of local generator when meeting the requirements of atmospheric electric data selection according to “fair weather” meteorological conditions.

This corresponds to main conclusions of Israelsson [1978], who demonstrated that under stable stratification, when meteorological conditions most often correspond to the “fair weather” conditions, the local generation of charges may be particularly intensive. Therefore, the results of our research, based on direct measurements of mechanical transfer current density, confirm the point of view, according to which generally accepted in atmospheric electricity complex of meteorological conditions, called “fair weather”, is not a sufficient criterion for sorting of experimental data on the subject of impact of atmospheric electricity local and global generators.

CONCLUSIONS

The results of the experiment demonstrate, that in most cases it is impossible to select the experimental data of observations from the land in such a way, as to exclude the periods of impact of local generators, which contravene the Ohm law, on the basis of the known criteria of “fair weather”.

Due to the limitation of wind speed during selection of “fair weather” conditions the bigger portion of the sample obtained refers to stable stratification. Weakening of mixing in the electrode layer with ion formation intensity varying by height determines the characteristic profiles of air electric conductivity, potential gradient, and conduction current. As a rule, at stable stratification the biggest gradients are observed in high altitude profiles of atmospheric electrical characteristics. Layers of space charge form close to the ground under the above conditions. Impact of space charge in the atmosphere and uneven distribution of the charge density by height causes the mechanical transfer current, which is one of the local generators of electric field.

The experimental data about vertical electric currents close to the earth surface and from the atmosphere to the earth may be used to clarify the role of local generators of space charge and more precise definition of “fair weather” criteria, used in the atmospheric electricity. In order to evaluate the local generator a conventional range of mechanical transfer current density values is proposed $-0{,}10\, {}^{pA}\!/_{m^2} < i_t < 0{,}10\, {}^{pA}\!/_{m^2}$, when it is possible to accept mechanical transfer current as small to negligible: in average for all observation points in such cases i_t does not exceed 10% of conduction current. The advantage of such a criterion as compared to Dolezalek criterion Ω is that its value is not related to the conduction current density value.

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