Gradient of the atmospheric electric field as an indicator of atmospheric pollution

A.A. Krechetov and Yu.V. Shamanskii

Irkutsk State University

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Many-year measurements of the electric field in the region of Baikal pulp-and-paper plant are analyzed. In assessing atmospheric pollution by plant emissions based on the electric field measurements, it is necessary to separate natural variations of the electric fields and variations of meteorological and geomagnetic origin. For this purpose, the potential of the atmospheric electric field was measured at several sites in Baikal region. It is shown that anomalous values of the electric field gradient over Lake Baikal are mostly of aerosol origin and can be attributed to local air circulations, which transport aerosol emissions to the lake.

In recent years, along with the traditional application of data about electric processes in meteorology and geophysics, the interest has increased in the use of characteristics of the atmospheric electric state as indicators of industrial pollution of the air basin. The investigations in this field are focused on the electric conductivity of air.[5] The relation between electric characteristics of the atmosphere and industrial emissions is determined by two physical mechanisms: changes in the ion composition due to aerosols and the influence of natural volume charge of emissions due to their electrization. In some cases, the mechanism of electrization and the charge acquired by emissions are known, for example, when the missions pass through electrostatic filters set in stacks.[1,2] This paper analyzes the many-year measurements of the electric field near Baikal pulp-and-paper plant (BPPP). In assessing the character and the extent of atmospheric pollution by industrial emissions based on the electric field measurements, it is necessary to unambiguously separate these mechanisms, as well as to exclude natural variations of meteorological and geomagnetic origin.

To study the possibility of such a separation, we have organized measurements of the gradient of the atmospheric electric field potential at several sites in Baikal region. The sites are located at different distances from BPPP. The measurements were performed by collector setups of the same type. The potential of a radioactive collector was measured by semiconductor electrometers, developed at the Faculty of Meteorology of Irkutsk State University. The stationary shore observations of the electric field were complemented with measurements over Lake Baikal and accompanied by meteorological, aerological, and actinometric observations. The main results of the combined observations can be summarized as follows.

The Table presents the statistical characteristics of the gradient of the atmospheric electric field potential: daily mean value V; rms deviation σ_V, and asymmetry coefficient A.

Statistical characteristics of daily mean gradient of the atmospheric electric field potential at fine weather. Summer period (1980–1985)

Measurement site	Number of fine days	V', V/m	V	A
Murino	49	94	27	0.08
Central part of the Lake Baikal	28	127	2	1.63
Southern part of the Lake Baikal	13	128	39	–
Severobaikal'sk	15	60	8	–1.22
Taksimo	10	65	10	–0.34
Chernorud	11	70	10	–0.11
Khankhino (Barguzinskaya valley)	9	61	4	–1.53
Glubokoe	7	63	12	0.73
Lake Khubsugul (Mongolia)	10	7	7	0.11
Atmospheric-electricity stations of the USSR (1978–1985) [Ref. 3]				
Irkutsk	42	90	22	0.60
Dusheti	119	75	14	–1.44
Leningrad (Voeikovo)	107	151	33	1.17
Kiev	20	95	27	–0.42
Odessa	108	196	65	1.03
Verkhnee Dubrovo	63	143	42	1.25
Borispol'	23	90	26	0.83
Tashkent	459	98	32	0.52

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In determining the daily mean values V, only 24 hours of fine weather were taken into account. This allows uncertainty of V caused by the diurnal behavior of the gradient to be excluded. The sites: Severobaikal'sk, Taksimo, Chernorud, Khankhino, Glubokoe, and Lake Khubsugul are located quite far from the sources of atmospheric pollution and under different physical and geographic conditions. Therefore, the data on the electric field gradient for these sites can be considered as close to background for the Southeastern Siberia.

As follows from the Table, at the sites remote from pollution sources, the daily mean gradient of the electric field potential is relatively stable and weakly depends on the local physical and geographic conditions. The rms deviation σ_V for these sites is much smaller than for the sites located in the urban areas and near pollution sources. Exclusion is a village of Dusheti, which was classified as a background regional one in Ref. 5. The widest statistical variability of the daily mean electric field strength is characteristic of the sites located in the Baikal hollow, in the zone of BPPP influence (Murino, water area of the Lake Baikal) and the sites of the network of atmospheric-electricity stations of the USSR.

It is worth noting the close correlation between the daily mean value of the potential gradient and its rms deviation: the coefficient of linear correlation is equal to 0.94. In probability theory and mathematical statistics, such a correlation is not presumed. Synchronous changes of V and σ_V in this case are likely caused by the same factor, namely, the atmospheric pollution. On the one hand, the increase of the aerosol content in the atmosphere leads to an increase of the potential gradient. On the other hand, aerosols under the effect of meteorological factors transform in time and space, giving rise to irregular fluctuations of the daily mean gradient of the atmospheric electric field potential.

The distribution of the daily mean values V in the most cases differs from the normal one. In the presence of sources of industrial emissions, large positive asymmetry tends to prevail. Under clean conditions, negative asymmetry prevails. Industrial emissions lead to the growth of the gradient, thus causing the prevalence of its largest values in the statistical series. Just this mostly leads to appearance of the right-handed asymmetry. Under clean conditions, the situation is quite opposite.

The values of the gradient observed over the water area of the Lake Baikal are increased as compared to the shore. This is characteristic of both the southern and the central parts of the Lake Baikal. The general regularities of gradient variation in the water area with the distance from the shore (in spite of stationary ones) are shown in Fig. 1. It can be seen that the gradient increases offshore. This regularity is caused by some factors. First, the issue of interrelation between the potential gradient and the air humidity was discussed many times.[4] The mechanism of this relation is that as the air humidity changes, the amount of condensation products in air changes as well, and, consequently, the air conductivity changes. This leads to the change of the potential gradient. The correlation analysis of the daily mean potential gradient and the daily mean absolute humidity suggests that the correlation between them is very weak. The correlation coefficient does not exceed 0.3 and is stable with the confidence interval at 0.9-probability level. The absolute air humidity, for which the correlation was studied, ranged within 6–13 g/m^3. Second, the high correlation was obtained between the gradient and the integral transmittance of the atmosphere. The correlation coefficient is equal to –0.67 and significant with the confidence interval at 0.99-probability level.

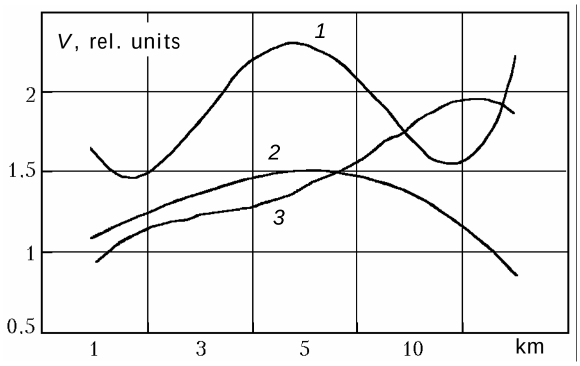

Fig. 1. Variation of the potential gradient with distance: BPPP–water area (*1*); Murino–water area (*2*); Tankhoi–water area (*3*).

Thus, the anomalous values of the potential gradient over the water area of Baikal Lake are mostly of aerosol origin and are associated with the aerosol transport to water area by local circulations. This conclusion is also supported by visual observations of formation and transformation of the smoke plume over the water area of Baikal Lake.

Industrial emissions influence not only the statistical characteristics of the daily mean values of the gradient, but also the diurnal behavior of the gradient. This influence also significantly depends on the distance from the source. At large distances, the main roles play the emissions from tall BPPP sources, forming the negative volume charge in the atmosphere. The value of this charge is so high that the electric field is negative in any season. The turbulent activity, breeze and hollow circulations, and meteorological self-cleaning of the atmosphere form large seasonal differences in diurnal variations of the potential gradient (Fig. 2). In winter (Fig. 2), the negative values of the gradient prevail all the day, except for the hours near noon. In this season, the inversion temperature distribution near Baikal'sk favors the accumulation of the volume charge, whose density at night is roughly equal to that of the positive volume charge of the clear atmosphere. In summer, due to enhanced turbulence and developed breeze circulation, the influence of the negative volume charge weakens, and the electric field is negative only at night.

These regularities in the diurnal behavior of the potential gradient in Baikal'sk are characterized by high stability, because they keep without significant changes in some years. The correlation coefficient for the diurnal behavior of the potential gradient in individual years and the mean diurnal behavior varies within 0.82–0.92. This is indicative of the high stability of the processes of diffusion of industrial emissions in this region.

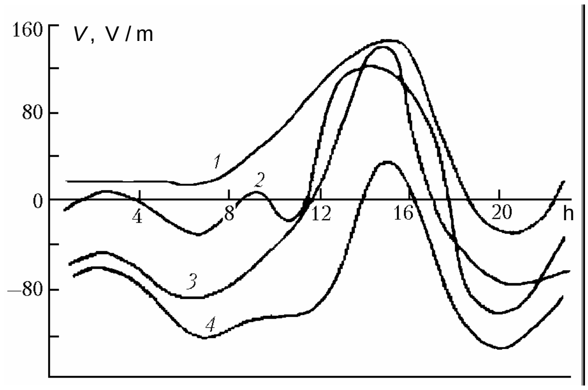

Fig. 2. Diurnal behavior of the gradient of the electric field potential in different seasons in Baikal'sk: summer (*1*); spring (*2*); fall (*3*); winter (*4*).

With the distance from BPPP, the diurnal behavior of the potential gradient undergoes some changes. Figure 3 shows the curves of the diurnal behavior of the gradient in summer at different distances from the plant. As can be seen from Fig. 3, at the distance of 20 km (curve *2*) the diurnal behavior of the potential gradient takes its typical form. At this distance, the negative volume charge dissipates, and the aerosols act on the atmospheric electric field as neutral and heavy nuclei. At the distance of 5 km (curve *1*), the curve of the diurnal behavior inverts, because in daytime, on some days, the negative volume charges reach such distances and the gradient of the atmospheric electric field potential becomes negative, keeping the sign for many hours. The most stable negative values of the potential gradient are observed at 12–16 LT, that is, in the period of the most developed turbulent activity. The diurnal behavior of the potential gradient, observed at the distance of 5 km, keeps in any direction from the plant, including the water area of the Lake Baikal.

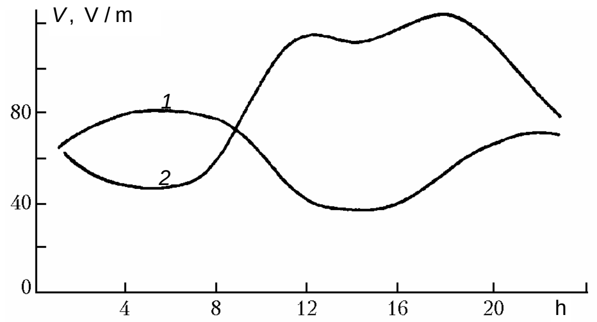

Fig. 3. Diurnal behavior of the potential gradient at different distances from Baikal'sk: 5 (*1*) and 20 km (*2*).

In conclusion, consider the behavior of the gradient of the atmospheric electric field potential in the period when BPPP was stopped for preventive repair. In this period, the gradient was positive all the time. At the third day after the plant was stopped, the daily mean value of the gradient was almost halved; at the fourth day, it decreased three times and became equal to 70 V/m, that is, approached the background value. It should be noted that on these days the weather conditions were favorable for aerosol diffusion and transport. The diurnal behavior of the potential gradient became the same as for the clear atmosphere.

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