ELECTRODE EFFECT UNDER ALPINE CONDITIONS

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ABSTRACT: Electrode effect theory consists of two extreme cases: classical (nonturbulent) electrode effect and turbulent electrode effect [Hoppe,1969, Kupovykh, Morozov,1992]. In the first case electrical processes in surface layer are determined by electric field. In the second case turbulent diffusion takes place simultaneously with the electric field, at that turbulent diffusion may be of the main role[Willet,1978, Morozov,1984]. Alpine electric observations near Elbrus are characterized by great values of the electric field potential gradient (about 500v/m), caused by orography [Kupovykh, 1999]. As a result classical electrode effect equations may be used for interpretation of data in particular for electric field global variations studying against a background of local changes, caused by meteorology.

DATA DESCRIPTION

The observations of the atmospheric electricity were made on alpine station “peak Cheget” (3040 m above sea level) near Elbrus.

Table 1. The main electric parameters of atmosphere at “peak Cheget”.

<table>
<thead>
<tr>
<th>Electric parameters</th>
<th>Definition</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Electric field</td>
<td>(400-700) V·m⁻¹</td>
</tr>
<tr>
<td>j₀</td>
<td>Electrical current density</td>
<td>(8-15)×10⁻¹² Amp·m⁻²</td>
</tr>
<tr>
<td>λ</td>
<td>Conductivity</td>
<td>(35-45)×10⁻¹⁵ S·m⁻¹</td>
</tr>
<tr>
<td>Q</td>
<td>Ionization rate</td>
<td>(20-25)·m⁻³s⁻¹</td>
</tr>
<tr>
<td>N</td>
<td>Aitken nucleus density</td>
<td>(400-500)·10⁶ m⁻³</td>
</tr>
</tbody>
</table>

The observations of the atmospheric electricity have been made according to “fair-weather” conditions information. The surface wind speed may reach 5-6 m·s⁻¹ and corresponding values of eddy diffusion coefficient are more than 0.1 m²·s⁻¹. Strong turbulent mixing may be the cause of local variations of electric field [Kupovykh, Morozov, 1992].

Diurnal variations of the electric field and electric current density in August-September.
current density at the “peak Cheget” have unitary and local components. Variations of unitary component differ in various seasons. Like the unitary variation E and $j_0$ curves have morning minimum (03-05) UT and evening maximum (17-21) UT. In April E and $j_0$ maximum is at (17-19) UT with electric field amplitude 40-45% from average value and in August-September - at (20-21) UT with electric field amplitude 10-15%. E and $j_0$ minimum is at (3-5) UT both in spring and summer with electric field amplitude 25-30%. However, E and $j_0$ curves have the additional maximum (08-10 UT) in August-September with electric field amplitude 35-40%. In April there is additional maximum E at (05-07) UT, but its amplitude is small. Most likely present effect is a result of the eddy diffusion coefficient changes due to meteorology [Kupovykh, 1999]. On some days under “fair-weather” conditions (according to Ohm’s law) the unitary variation may show itself even in one-day observations. Diurnal variations of the electric field and electric current density at the “peak Cheget” are given at the Fig. 1-2.

THEORETICAL BACKGROUND

The governing equations for turbulent surface layer according to the theory of electrode effect are:

\[
\frac{\partial n_{1,2}}{\partial t} + \frac{\partial}{\partial z} \left( b_{1,2} \cdot n_{1,2} E - D(z,t) \frac{\partial n_{1,2}}{\partial z} \right) = q - \alpha n_1 n_2; \\
\frac{\partial E}{\partial z} = 4\pi e (n_1 - n_2),
\]

where $|\gamma| \ll 1$ - eddy diffusion coefficient, $n_{1,2}$ – polar ions density, $b_{1,2}$ – mobility of positive and negative ions, $\alpha$ – recombination coefficient, $e$ – elementary charge.

Using substitution of variables equations (1) are transformed to dimensionless form:

\[
\frac{\tau}{T} \frac{\partial n'_{1,2}}{\partial t'} + \frac{\partial}{\partial z'} \left( b'_{1,2} \cdot n'_{1,2} E' - D(z') \frac{\partial n'_{1,2}}{\partial z'} \right) = \frac{q}{q_\infty} - n'_{1} n'_{2}; \\
\frac{\partial E'}{\partial z'} = \gamma (n'_1 - n'_2),
\]

where $t' = t/T$, $z' = z/l_1$, $n'_{1,2} = n_{1,2} / n_m$, $E' = E / E_\infty$, $n_m = \sqrt{q_\infty / \alpha}$, $l_1 = D \cdot \tau$, $\gamma = (q_\infty \cdot \alpha)^{-\frac{1}{2}}$.

Typical time of surface layer changes (T) is about several hours whereas the value of $\tau$ is 250 s for $q=10^7$ m$^3$s$^{-1}$ and $\alpha=1.6 \times 10^{-17}$ m$^3$s$^{-1}$. Therefore the stationary approximation for the atmospheric electric state research may be used legitimately. In this case $D(z) = D_1 z$ and the boundary conditions are $n'_{1,2} (z \to 0) = 0$, $n'_{1,2} (z \to \infty) = 1$, $E' (z \to \infty) = 1$ for turbulent electrode effect and $n'_2 (z \to 0) = 0$ - for classical one. Electrode layer thickness and diffusion
coefficient are $l_1=2.5-25m$ and $D=0.01-0.1m \times s^{-1}$ for nonturbulent and turbulent cases correspondingly. The equations (2) are characterized by two dimensionless parameters:

$$\xi_{1,2} = \frac{b_{1,2} E_{\infty} \tau}{l_1}, \quad \gamma = 4\pi e l_1 \frac{n_{\infty}}{E_{\infty}}. \quad (3)$$

For $|x|<<1$ an electric field caused by electric charge density near surface may be ignored. For $\xi_{1,2}<<1$ the limit of strong turbulent mixing takes place in atmosphere [Morozov, 1984]. When $\xi_{1,2} \geq 1$ classical electrode effect determines electric structure of surface layer.

RESULTS
The computing results of electrode effect ($E/E_{\infty}$) and polar ion density ($n_{1,2}/n_{\infty}$) for the strong electric field near the surface $E=-500 V/m$ are presented in Table 2: classical electrode effect for aerosol free atmosphere (row 1) and for Aitken nuclear density $N=5 \times 10^8 m^{-3}$ (row 2); turbulent electrode effect for $D=0.1m^2 s^{-1}$ (row 3).

<table>
<thead>
<tr>
<th>N</th>
<th>$z=1m$</th>
<th>$z=2m$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$n_1/n_{\infty}$</td>
<td>$n_2/n_{\infty}$</td>
</tr>
<tr>
<td>1</td>
<td>0.91</td>
<td>0.06</td>
</tr>
<tr>
<td>2</td>
<td>0.92</td>
<td>0.08</td>
</tr>
<tr>
<td>3</td>
<td>0.98</td>
<td>0.29</td>
</tr>
</tbody>
</table>

The values of positive ion density ($n_1/n_{\infty}$) are nearly constant and electrode effect even increases with the presence of turbulent mixing. The influence of aerosol on atmospheric electrical parameters under alpine conditions is not significant.

The values of dimensionless parameters calculated for alpine conditions are $\xi_{1,2}=3.3-0.33$ and $\gamma=0.38-3.8$ (for nonturbulent and turbulent surface layer correspondingly). Obviously the influence of space charge (electric field consequently) near the surface is significant and may exceed turbulent diffusion transfer effect.

CONCLUSIONS
The theoretical and experimental results may be summarized as follows. In spite of turbulent mixing in surface layer the classical electrode effect determines variations of atmospheric electrical parameters under alpine conditions because of strong electric field.

REFERENCES