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GEOPHYSICS

The Atmospheric Electric Field During the Total Solar Eclipse of 2008

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The results of the atmospheric electric field (AEF) measurements using two Gradient electric meters during the total solar eclipse in Novosibirsk on August 1, 2008, are presented in the paper. The results are similar to the results obtained earlier; however, their interpretation is significantly different. The model of this phenomenon is discussed, according to which the main influence factor at the moment of the eclipse is cooling of the surface and lower atmospheric layer. It is known that a temperature decrease leads to an increase in the AEF. The solar eclipse is quite a fast process; its duration is comparable with the characteristic time of conductivity in the atmosphere. In such a situation, during the discharge of condenser Earth–ionosphere, a displacement current (convective current) can appear. In this case, at the moment of the maximum AEF, the derivative should also be maximal, which was recorded in our case and in the majority of the previous observations on the behavior of the atmospheric electric field at the moment of a solar eclipse.

Investigation of the effects in atmospheric electricity during solar eclipses has a long history; however, the majority of papers were published in the 1970s and 1980s. The results are very contradictory both in the recorded anomalies and in the interpretation, which is explained by the difference in the applied instruments and in the conditions of observations, first of all, meteorological [1–7].

Figure 1 shows variations in the vertical component E_z of the atmospheric electric field (AEF) strength on August 1, 2008, at two points on the territory of the Novosibirsk Geophysical Observatory located at a distance of approximately 1 km from each other. The eclipse effect is clearly manifested in the records of two parameters, first of all, as a sharp increase in the AEF stress during the phase of the total coverage. At both points, E_z decreases before the beginning of the eclipse; however, the character of the variation is different. The anomaly during the eclipse is quite strong over the background of the mean level of E_z in nonperturbed days (approximately 500 V/m).

We interpret this result within a principally new model of the AEF [8], which is based on the idea of separation of charges in the atmosphere due to the gravity field. Our model of the AEF is a development of Frenkel's idea about the separation of the electric charges in a thunderstorm cloud applied to the atmosphere of "good weather." According to the model, electric charges in the atmosphere are formed due to its ionization by galactic cosmic rays (GCRs). Separation of the charges occurs in the gravity field of the Earth due to the fact that negative charges condense water vapor more intensely than positive ones and appear heavier than positive charges.

The value of the atmospheric electric field E_z can be estimated using the relation obtained by Frenkel taking into account the separation of the charges on water drops with radius r [9]: $E_z = \frac{\varepsilon_0 M g \zeta}{6\pi\eta\sigma_e}$, where M is the amount of water in the atmosphere $M = 10^{-2}$ g/m^3 (in a thunderstorm cloud $M \approx 1$ 1 g/m^3), g is acceleration due to gravity, ζ is the electric kinetic potential of water ($\zeta \approx 0.25$ v), η is viscosity of the air ($\eta \approx 10^{-5}$ Pa s), σ_e is electric conductivity ($\sigma_e \approx 10^{-14}$ Ohm^{-1} m^{-1}); and $E_z \approx 100$ v/m (in a thunderstorm cloud $E_z \approx 10^4$ v/m).

According to a simplified and modified version of Frenkel's relation [10], the condensation rate (s^{-1}/cm^{-3}) $K \sim \exp\left(-\frac{3}{\ln^2 S_C} + \ln S_C\right)$, here S_C is the oversaturation of vapor. In the evaporation (boiling) regime, drops are destroyed in the system and are replaced by vapor bubbles, whose rate of formation (sc^{-1} cm^{-3}) is $J \sim \exp\left(-\frac{W}{kT}\right)$, where W is the energy of the formation of bubbles of critical size (Fig. 2). It follows from this that

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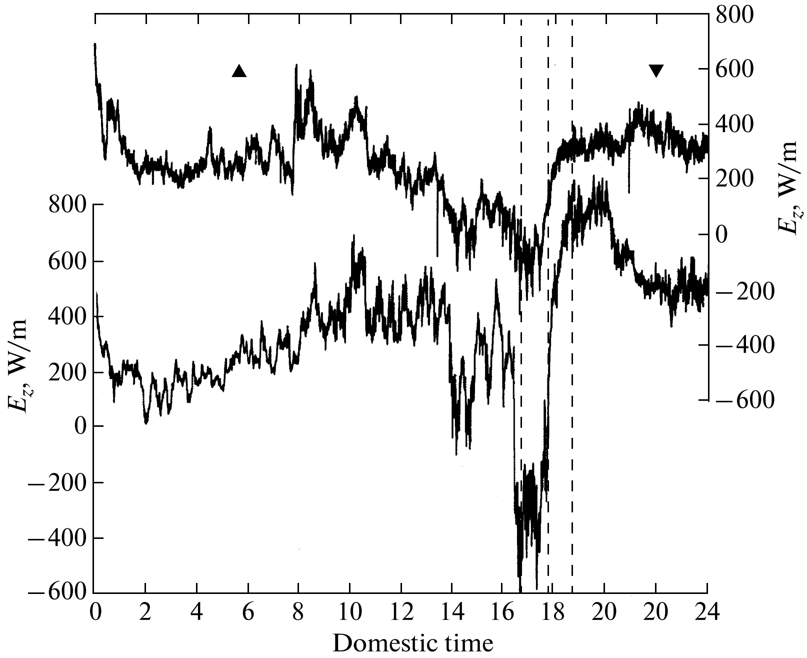

Fig. 1. Variations in the atmospheric electric field at two spaced points. Triangle markers show the moments of the sunrise and sunset, vertical lines indicate the beginning, maximum, and end of the eclipse. Local time is UT + 7 h.

at $T = T''$ $K = J$, and $E_z = 0$. Theoretically, such a situation can appear at $T'' \approx 26.5°C$, i.e., at the temperature of cyclone generation in the ocean.

The temperature of the Earth's surface has been increasing over the last 100 years. According to our model, the value of the AEF should decrease (Fig. 2).

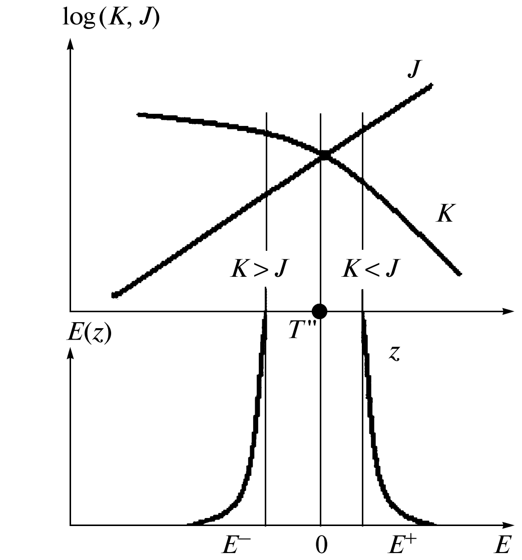

Fig. 2. Variations in the logarithms of the rates of condensation (K) and evaporation (J) as functions of temperature T (above). The lower pattern shows polarity of the electric field E (depending on height) as a function of the J to K ratio: E^+, when $J > K$ and E^- when $J < K$.

Indeed, an annual decrease in the AEF was shown by observations in Scotland (Shetlande) [11–13] and in a number of other observatories from 1920 to 1980 (Fig. 3).

The value of E_z decreased approximately two times from 1920 to the present time: $\frac{dE_z}{dt}$ $(E_z') \approx 2$ (with a rate of ~1 v/m, i.e., 1% per year), while during this time the temperature of the Earth's surface increased by 0.7–0.9°C (0.01°C yr^{-1}), which is approximately $\frac{dT}{dt}$ $(T') =$ 0.06, or 6% (the Earth's annual mean temperature is $T = 15°C$). The ratio of the rates of variation of parameters is $\frac{T'}{E'} = 0.03$.

In order to confirm the model, we have to obtain a theoretical dependence of E_z on temperature of the type $E_z \sim \exp(-T)$ or $M \sim \exp(-T)$ because $E_z \sim M$.

The water content in the atmosphere or the integral mass of water drops formed in the atmosphere M is determined by the nucleation rate, i.e., the rate of the drop growth. Let us use the relation of Zeldovich [14]: $M \sim nZ\frac{4\pi rPK}{(2\pi mkT)^{1/2}}$, where n is concentration, r is radius, m is mass of the condensation nuclei, i.e., embryos of drops, Z is the Zeldovich factor, P is pressure, K is condensation rate $K \sim \exp(-T)$, and k is the Boltzmann constant. Taking into account the dependence of E_z on temperature, we get $M \sim T^{-1/2}\exp(-T)$ or $E_z \sim T^{-1/2}\exp(-T)$.

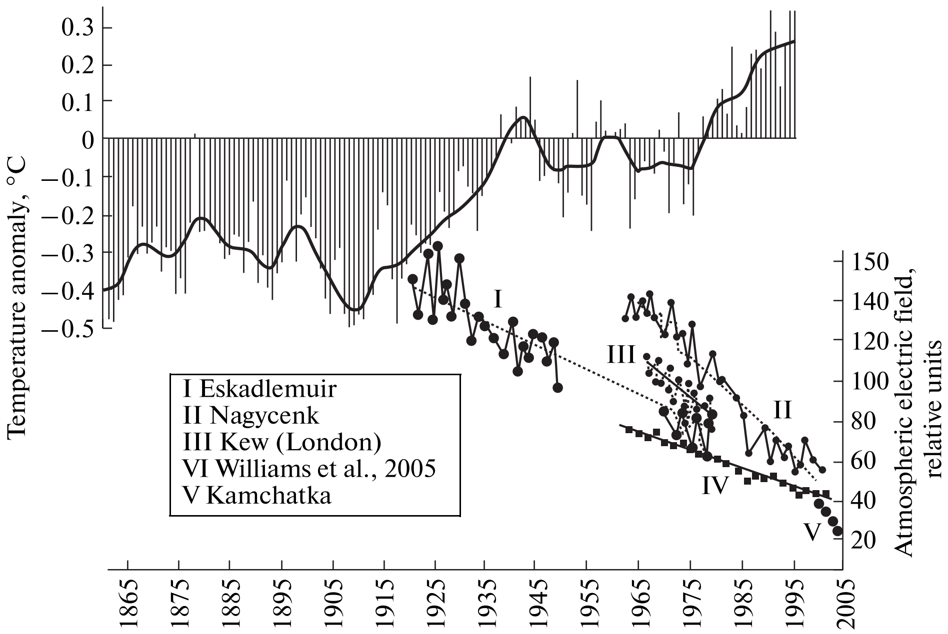

Fig. 3. Variations in the global temperature of the Earth. A decrease in the value of E_z at the observatories of Hungary, Great Britain [11-13], and Kamchatka.

The temperature of the Earth's surface was increasing more or less linearly with time during the time of observation t: $T = at$, then $T' = \frac{dT}{dt} = a$. We substitute this expression into the relation for E'_z and get

$$E'_z \approx [\exp(-at)(1+2at)/a](at)^{3/2},$$

and assuming that $t = 1$, we get that $\frac{T'}{E'} \approx 2a^{3/2}$. It was mentioned that $a = 0.06$ based on the observations; hence, $\frac{T'}{E'} = 0.03$, which can be considered as the confirmation of our model.

Such phenomena in the AEF as unitary variation (the Carnegie curve), Forbush decrease in the AEF, and terminator effects, like the role of thunderstorms and cyclones in the formation of the AEF, can be explained without contradictions within this simple and natural model. Let us use the main principles of this model to explain the behavior of the AEF during a total solar eclipse.

It is generally accepted that the atmospheric current is combined of the conductivity current j and displacement current $\frac{\varepsilon_0 \partial E}{\partial t}$. Usually, if condition $t \gg \tau$ is satisfied, where t is the process time and $\tau = \frac{\varepsilon_0}{\sigma_e}$ is the atmosphere relaxation time ($\tau \approx 10^3$ s), the displacement current is neglected. In this case the solar eclipse observation condition $t \gg \tau$ is not satisfied, and it is likely that the displacement current should be taken into account even more because during the eclipse there is no evident cause for the variations in the conductivity current j: $E \sim \sigma\left(j - \frac{\varepsilon_0 \partial E}{\partial t}\right)$, where σ is the conductivity of the medium. It is known that the displacement current appears in the condenser ionosphere–Earth at the moments of its charging and discharging, which provides the closure of the circuits of any nonconstant currents, which corresponds to the AEF model.

The essence of our idea is as follows. Observations of temperature variations at the eclipse moment allow us to present the temperature variation in the lower atmospheric layer at the moment of the eclipse as a normal distribution: $T \sim T_0 - t\exp(-t)^2$, where T_0 is the initial temperature, t is time. It is known from numerous observations that $E_z \sim \frac{1}{T}$. Then, $\frac{\partial E}{\partial t} \sim -\frac{\partial T}{\partial t}\frac{1}{T^2}$.

The obtained dependence $E_z \sim \sigma\left(j - \varepsilon_0 \frac{\partial E}{\partial t}\right)$ is very close in form to the curve of $E(t)$ recorded in the AEF (Fig. 4) at the moment of the solar eclipse. As was noted by many authors, here, the maximum rate of E_z variation is confined to the maximum decrease in temperature T, which corresponds to the phase of the total eclipse.

This can mean that, at the moment of the solar eclipse, our instruments recorded the variation in E_z

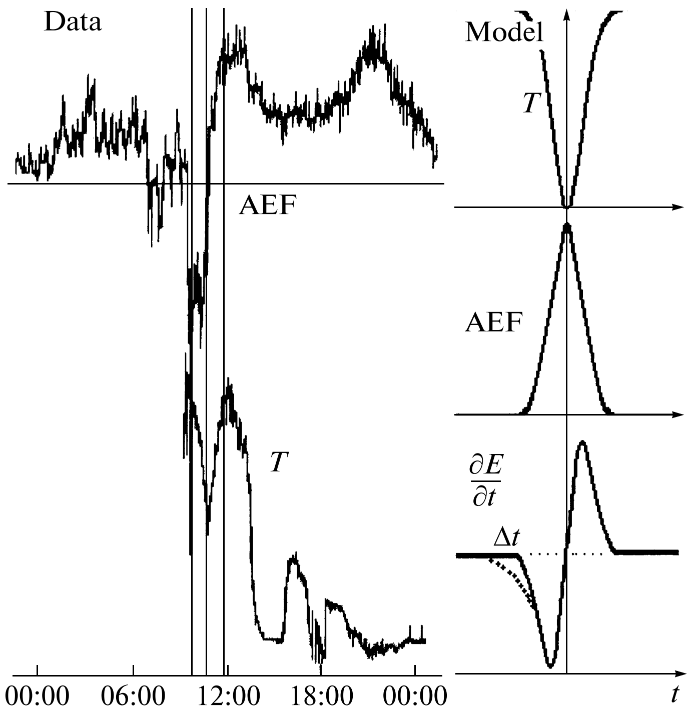

Fig. 4. The data and model of temperature variations at the surface, AEF and $\frac{\partial E}{\partial t}$.

caused by the displacement current $\frac{\varepsilon_0 \partial E}{\partial t}$. The fact that this curve does not fully correspond to the observed value of E_z means that the distortion can be related to the existence of a variation in the conductivity current.

The motion of the eclipse spot with a size of approximately 100 km occurs in the Novosibirsk region for 2.5 minutes. The advance in the beginning of E_z decrease relative to the beginning of the temperature decrease is $\Delta t \approx 20$ min $\left(\text{see the graph of } \frac{dE}{dt} \text{ in Fig. 4}\right)$. We can consider that the electric meter begins recording the variations in the AEF occurring at a distance of @800 km from the sensor. This result agrees with our measurements of the AEP long-range action obtained during the investigation of the AEF influence in the approaching cyclone [15]. In the case of the solar eclipse in Novosibirsk, the value of long-range action appeared approximately two times smaller than in the case of cyclones in Kamchatka.

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