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Effect of an Artificial Cloud on the Atmospheric Electric Field

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Abstract—Preliminary experimental data on the effect of an artificial steam–water cloud (SWC) on the atmospheric electric field are presented. The experiments were conducted on October 12, 2004, on the Kamchatka occurrence of thermal-power waters in the region of the active Mutnov power plant. The electric field strength was measured in the immediate vicinity of deep suspended geothermal wells opened during observations. The phenomenon of decreasing electric field strength during SWC existence is detected. Models are proposed and experimental results are discussed.

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(1) In October 2004, the authors of this paper were given an opportunity to take measurements of the atmospheric electric field (**AEF**) strength in the immediate vicinity of suspended deep geothermal wells opened at the moment of discharge of overheated steam. It was assumed that an aerosol formation of the cloud type would appear during the opening of wells and could have a marked effect on the AEF. This assumption is not meaningless, because clouds are known to be viewed as additional generators contributing to the production of a global potential difference between the Earth and the ionosphere [1, 2]. In addition, such an experiment could serve to verify the idea that the injection of charged aerosols from the Earth's surface into the atmosphere occurs for a certain time prior to the earthquake. According to [3], the electric field strength decreases in this case and can even change sign. In our experiments, aerosol injection is created artificially. The aim of these experiments on the artificial action on the AEF was to assess the effect of an artificial steam–water cloud (**SWC**) on atmospheric electricity. The problem was posed to elucidate experimentally what happens to the AEF when the well is opened and then closed, i.e., at the moments when a cloud alternatively appears and disappears. Observations of AEF variations in the vicinity of active natural sources (geysers, fumaroles, etc.) are not possible. The formulated problem included the determination of the polarity of the charge introduced by a steam–water cloud; the order and sign of change in the electric field strength E; and the role of fine (invisible to the eye) water aerosols, whose increasing concentration in the atmosphere predicts an earthquake in accordance with some models. Finding the answers to these questions in the course of experiments will help with the understanding of AEF physics.

This paper presents preliminary experimental results on the effect of an artificially produced steam–water cloud on the AEF. The experiments were conducted in the region of the active Mutnov power plant at three wells of thermal-power waters—steam hot springs.

(2) The Mutnov occurrence of steam hot springs is situated in the southeast of Kamchatka at an altitude of 800 to 900 m among three volcanoes (Mutnov, Gorelyi, and Vilyuchinskii) and is a submerged source of overheated steam. Steam with a temperature up to 175°C is formed during the contact of groundwater with a geologic body located in the Earth's upper mantle. The geologic body heated to a maximum temperature of 315°C relates to the group of long-lived magmatic centers and represents a deep heat source. The depth of the upper edge of the magmatic source is about 5 km; wells are drilled to a depth of 1 to 2 km. The steam pressure in the section of a well is several atmospheres, the mean output of a geothermal well is about 30 kg/s, and the mean concentration of steam contained in the steam–water mixture is about 25%.

(3) Measurements of the vertical component of the AEF strength E_z were taken with the aid of a Gradient M3 electric fluxmeter and a system of signal digitizing and recording to a digital carrier. Figure 1 shows the general view of three experiments on producing an SWC. When well 1 was opened (Fig. 1a), a steam column with a height of about 15 to 20 m was formed. Steam was carried by the wind, thus forming a cloud with a volume of up to 10^3 m^3. The fluxmeter was placed on the ground at a distance of 10 to 60 m from the well in the directions both with the wind and

Fig. 1. General view of experiments on producing a steam–water cloud (SWC) at wells (a) 1, (b) 2, and (c) 3.

against the wind. The readings of the instrument were recorded for 10 min, the well was opened, and measurements were performed for more 10 min. After that, the instrument was transported to another place, where further measurements were taken. The total observation time at each of the three wells under study was about 1 h. (As was elucidated during data processing and as will be shown below, this time was insufficient.) Figures 2 and 3 present AEF strength records. Prior to the shutdown of well 1 and to the start of steam egress (the flow rate $P_1 \approx 15$ kg/s), the quantity E_z varied in the range between 200 and 400 V/m at a mean of 300 V/m. After the well was opened, E_z decreased to 100–200 V/m, i.e., by one-half (Fig. 2a). The mean decrease in the field strength was $\Delta E \approx 150$ V/m, and the time of this decrease was $\tau_1 \approx 250$ s. Thereafter, E_z increased to a value somewhat smaller than the initial value of E_z (Fig. 2b). This increase occurred more rapidly than the aforementioned decrease ($\tau_2 \approx 100$ s). Next, the field strength E_z decreased slowly with a time constant $\tau_3 \approx 10^3$–10^4 s. Unfortunately, this value could not be refined, because of the limited time of the experiment. When well 2 was opened, a cloud smaller than that in the first case was formed (the flow rate $P_2 \approx 5$ kg/s, Figs. 1b, 3), and a change in E_z if any turned out to be insignificant. It is possible to present the upper limits alone: $\Delta E <$ 50 V/m and $\tau_1 < 50$ s. A result similar to that found in the first case was obtained when well 3 was opened (the flow rate $P_3 \approx 35$ kg/s, Figs. 1c, 3). In this experiment, despite the fact that the flow rate and the rate of steam outflow from the well increased rather than decreased with time and the cloud increased in size, a decrease in the AEF strength was observed for the time $\tau_1 \approx 100$ s: $\Delta E \approx 250$ V/m. The time of a partial restoration of the E value was approximately the same as in experiment 1: $\tau_2 \approx 150$ s. However, similarly to well 1, the initial field-strength value was not attained, although the tendency toward a slow increase in the field strength to its initial value held.

Table

Well, No.	Flow rate, kg/s	ΔE, V/m	τ_1, s	τ_2, s	τ_3, s
1	15	150	250	100	>1000
2	5	50	50		
3	35	250	100	150	>1000

The results obtained make it possible to estimate the rate of decrease in the field strength dE/dt at the moment of well opening for two of the three experiments (Fig. 2, experiment 1; Fig. 3, experiment 3): $dE/dt \sim 0.6$ V/m s and $dE/dt \sim 2.5$ V/m s in experiments 1 and 2, respectively. In experiment 2, this parameter could not be estimated reliably. The data of observations are presented in the table.

Analysis of the experimental data has led to the following results.

(i) In all the experiments, a decrease in the field strength was observed, depending on the SWC water content and the output of the well. The quantity ΔE changed from experiment to experiment in approximate accordance with the steam flow rate of the well.

(ii) The characteristic rate of a rapid decrease in the field strength is proportional to the steam flow rate, whereas the relaxation time, i.e., the time period of a

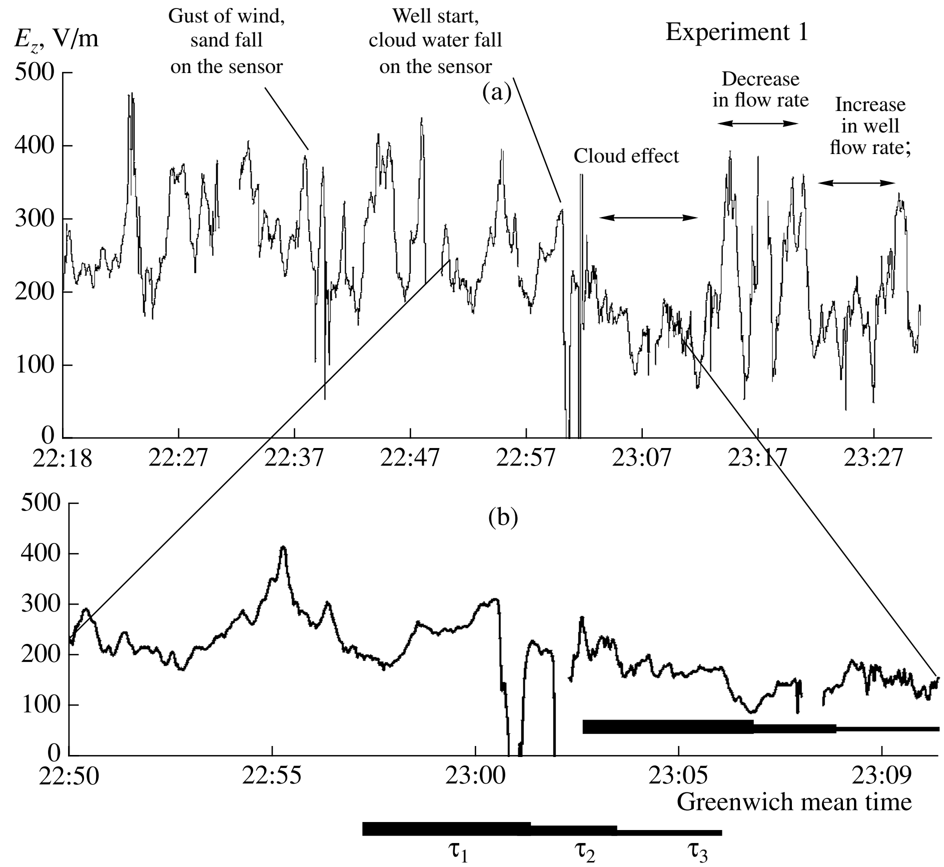

Fig. 2. (a) Temporal behavior of E_z (V/m) at well 1. (b) The moments of SWC formation, the start of E_z decrease, the termination of a rapid field relaxation, and the period of a slow relaxation are registered.

partial increase in the field strength that follows the period of its decrease ($\tau_2 \approx 100$–200 s), for well 1 differs from that for well 3 not so markedly as occurs for the time period of decrease.

(iii) The relaxation time of the field τ_3 is large and amounts to about 10^3–10^4 s. This relaxation time could not be determined more accurately. According to our estimations, the relaxation time is independent of the wind velocity because different gusts of wind occurred in all three experiments conducted at three different walls. If it is believed that this characteristic time is the time of sedimentation of charged aerosol particles from a height of about 10 m, it is possible to estimate the sedimentation rate as $\nu \approx 10^{-3}$–10^{-2} m/s. This estimate and the Stokes formula allow the size of aerosol to be estimated as 0.3–1 µm.

(iv) It seems likely that the parameter dE/dt characterizes the rate of charge formation (basically ions); in this case, this parameter is bound to be related to the ion-formation coefficient q (m^{-3} s^{-1}) adopted in the physics of ionized gases.

(4) To obtain tentative estimates, we will assume that the rate of steam flow from the well is about 20 kg/s. Along with steam, a significant amount of water, which is unknown for each of the wells under study, was ejected from the well. The water content of an artificial cloud, M, was estimated visually and appeared to be comparable to the water content of a cumulus cloud, for which it is accepted that $M \approx 0.1$–1 g/m^3. During the experiment, which lasted for 30 min for each of the wells, a precipitation of less than 1 mm occurred, a value that corresponds to a rate of precipitation accumulation ("rainfall" intensity) of about 0.5 mm/h. This rate corresponds to a drizzling rain. If the rate of rainfall from a cloud with a water content of $M \approx 0.1$ g/m^3 is estimated, the corresponding value will be about an order of magnitude smaller in the case of the full condensation of vapor. It follows that the occurrence of "rain" is most likely to be due to the presence of a rather large amount of water in the cloud. A steam flow rate of 20 kg/s at the outlet of a pipe with a radius of 10 cm will provide a directed velocity of motion of vapor molecules of about 10 m/s or more. During experiments at well 1, gusts of wind of 10 to 20 m/s had a marked effect on the cloud shape (Fig. 1a). In the course of experiments, the outlet velocity of vapor at well 3 was significantly greater than that at well 1 because gusts of 20 m/s or more did not affect the shape of a column rising to a height

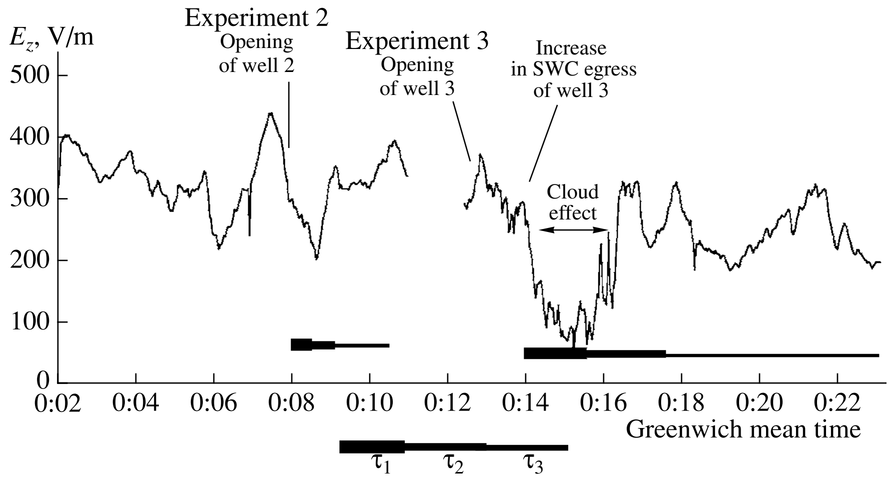

Fig. 3. Temporal behavior of E_z (V/m) at wells 2 and 3.

more than 20 m (Fig. 1c). The egress of steam from well 3 was accompanied by an intense sound, which testifies to a high velocity of egress, possibly close to the velocity of sound in air. In all three experiments, steam was carried by the wind, forming an SWC in the form of a bulk structure whose height was on the order of 10–20 m and whose base area was about 5×10 m^2. The amount of steam at well 2 turned out to be significantly smaller than at wells 1 and 3, and the cloud decayed rapidly after its formation when the egress of steam from the well terminated.

Leaving a well, steam heated to a temperature of 150°C expanded, cooled, and condensed adiabatically. Evidently, condensation under such conditions has a heterogeneous character; i.e., it occurs on condensation nuclei, which can be dust and charged particles.

The artificial SWCs investigated by us were white, which is characteristic of cumulonimbus clouds (Cb), and were superficially similar to cumulonimbus clouds. The sizes of droplets in our cloud were not measured specially; however, from general considerations, it can be suggested that their sizes amounted to about 0.08–0.10 mm and a significant number of smaller droplets with sizes of about 1 μm were present in the cloud. This conclusion can be made from the occurrence of a rainbow in the vicinity of the SWC [4]. The size of the rainbow was markedly greater than the cloud's size. This result indicates that the volume occupied by fine invisible water aerosol was significantly larger than the volume of the visible cloud.

In a rising vapor flow in a natural cloud, droplets condense, coagulate, crystallize, and break down. These processes, as well as similar processes, are responsible for the formation of electric charges [5]. It is possible that some of the aforementioned phenomena occurred in the experiments conducted by us. In principle, electric charges can form also during turbulent flow of steam along the well. These charges can serve as condensation nuclei. Since water molecules condense considerably more effectively on negatively charged aerosols than on positively charged aerosols, negatively charged droplets grow and descend to the ground more rapidly than positively charged droplets, thus providing not only a volume electric charge for the cloud but also its polarization. As a result of this process, a negative (positive) charge can accumulate at the lower (upper) "edge" of the cloud. This idea of Frenkel [6] is sometimes applied to a thunderstorm cloud [7]. In principle, this idea can also be used in our case if a marked charge separation is possible at such a small distance as 10 m. Nevertheless, there is reason to assume that the resulting artificial cloud possesses an electric charge in spite of the fact that its nature is not entirely clear. This assumption is based on some experience gained during observations and registration of electric charge in both artificial [8] and natural [9–12] aerosol formations.

Frenkel expresses the quantity E_z within a cloud in terms of its water content [6]:

$$E_z = \varepsilon_0 M g \zeta / 6\pi\eta\sigma_e,$$

where M is the water content, which is taken to be $M \approx 1$ g/m^3 for a thunderstorm cloud; g is the free-fall acceleration; ζ is the electrokinetic potential of water ($\zeta \approx 0.25$ V); η is the air viscosity ($\eta \approx 10^{-5}$ Pa s); σ_e is the electric conductivity ($\sigma_e \approx 10^{-14}$ Ω^{-1} m^{-1}); and $E_z \approx 10^4$ V/m. We will use this formula to estimate the value of E in the case of charge separation in a fair-weather atmosphere saturated with moisture. The concentration of molecules of dry water vapor in such an atmosphere is known to be about 12 g/m^3. The atmospheric water content M (in the form of water aerosol) for E_z = 100 V/m must be one hundred times smaller than that in a cumulus cloud; i.e., $M = 0.01$ g/m^3.

The time of a partial restoration of the field strength $\tau \sim 100$ s is likely to be the characteristic relaxation time for the SWC electric charge: $\tau = \varepsilon_0/\sigma$, where ε_0 is the permittivity and σ is the SWC conductivity, whose value turns out to be smaller than $10^{-13}\ \Omega^{-1}\ m^{-1}$. (Note that this value is somewhat greater than the conductivity of a fair-weather atmosphere.) This estimate is justified because, for example, in a thunderstorm cloud, $t \sim 10$ s ($\sigma \approx 10^{-12}\ \Omega^{-1}\ m^{-1}$), whereas the relaxation time for the atmospheric electric charge is $t \sim 1000$ s ($\sigma \approx 10^{-14}\ \Omega^{-1}\ m^{-1}$).

(5) The main goal of our study was to find out whether an electric charge is formed during SWC formation and to determine the nature of this charge and its value and polarity. As was noted, it can be assumed that an electric charge is formed during a turbulent flow of a steam–water mixture in a pipe; however, in addition, an alternative point of view is valid: electric charges arise in the atmosphere during SWC formation. The authors, who performed observations of such natural steam–water emissions, believe that these emissions usually carry a positive electric charge [9]. For example, as follows from [10], a fumarole cloud of the Azuma eruption has a positive volume electric charge with a density of $\rho \sim 10^{-9}$ C/m^3. In [11, 12], it was likewise found that a positive electric charge with $\rho \sim 10^{-10}$ C/m^3 is present on the Karym volcano of Kamchatka. It was shown in [11, 12] that, at the moments of emissions of water vapor and volcanic gases from the volcano, rapid negative changes (jumps) in the AEF strength with an amplitude of $\Delta E \approx 20$ V/m were recorded. The recorder was mounted at a distance of 3.6 km from the volcano. O.P. Rulenko believes that negative changes in the AEF strength are related to electric discharges between a positively charged SWC and the volcano's crater [11, 12], although, in these studies, there are no indications that such discharges were observed anyway (visually, from electromagnetic radiation, etc.).

In our experiments, an increase in the field strength E was observed: $\Delta E \approx 100$–200 V/m. It is well known that, when a body moves in a turbulent flow containing aerosol, the body becomes charged; i.e., charge separation occurs [13]. The physics of this phenomenon is insufficiently clarified, so that the above unambiguous interpretation of this effect is questionable. The problem of AEF physics lies largely in clarifying the mechanism of electric-charge separation. It is our opinion that, if charge separation in a steam jet were so simple and efficient, this mechanism would long ago have found use in science and technology. It is noteworthy that, if charges are actually formed and separated during steam motion along the well, this can be checked by way of mounting an induction sensor at the section of the pipe and measuring the "electric current" in the pipe. If this idea is confirmed, this method could be used for remote control of the flow rate and steam water content in the well.

(6) An effort can be made to explain the effect of decreasing AEF strength on the basis of a mechanism of charge separation in the cloud. Let us estimate the extent to which the electric field arising in the cloud (E_0) affects the strength of the measured atmospheric electric field E by using the Thomson mapping [14]. We realize that this approach is not entirely applicable to our case, where measurements are taken near an SWC. Nevertheless, as follows from our estimates, the cloud charge is $Q \sim 10^{-7}$ C and the distance from the cloud's center to the measurement point is $r \sim 10$ m; therefore, according to Thomson, the contribution of the field is $\Delta E \sim Q/4\pi\varepsilon_0 r^2 \sim 100$ V/m, which was found in our experiments. The polarity of the field E_0 is opposite to the polarity of E, so that the cloud field causes the field strength E to decrease.

(7) As was noted, during measurements, the field sensor was placed on the ground, i.e., in the spatial region where atmospheric electric phenomena are controlled by the so-called electrode effect [15]. This effect denotes a set of processes occurring in the immediate vicinity of the electrode, for which the conducting ground surface is meant.

Three causes of AEF external disturbances are usually considered in relation to the electrode effect: the presence of turbulence, additional aerosols, and the emanation of radioactive elements at the measurement site. The third cause is eliminated from our consideration because it should not have an effect on the AEF variations recorded by us, whereas the first two causes are present in our experiments and contribute to the AEF. The turbulence, as well as variations in the aerosol concentration, is directly related to SWC formation. It is well known that introducing an additional amount of aerosols into the atmosphere is responsible for an increase in the field strength E. Moreover, the turbulence leads to an increase in the thickness of the electrode layer.

The decreased E values observed in our experiments seem to contradict the above considerations. Actually, this is not the case provided the sign of E_0 is opposite to the sign of E. It seems likely that the effect of aerosol and turbulence led to an increase in the absolute value of E_0, the sign of E_0 being opposite to the sign of E. This finding confirms our assumptions that an SWC is responsible for the formation of a charge Q of negative (relative to the ground) polarity. If it were possible to record the field E at the SWC upper edge, a conclusion could be made about the polarity of the charge and about its possible separation in the cloud. Such experiments are planned for the future.

(8) Thus, a more or less plausible explanation is given for the results obtained in the experiment. Our

observations have shown that, in addition to an evident effect of a visible cloud of large droplets on the atmospheric electric field, the latter is affected by fine (invisible to the eye) aerosols, which were detected owing to large rainbow sizes. In studies on atmospheric electricity, fine aerosols are often disregarded; this approach does not always appear to be justified.

(9) The result obtained should be assessed from the standpoint of an important problem of using variations in atmospheric electricity for earthquake prediction. In some studies [3], it is assumed that, prior to an earthquake, charged aerosols are injected from the ground surface into the atmosphere and, according to the statements of some authors, the electric-field strength decreases in absolute value and can even change sign. In our experiments, the injection of aerosols was done artificially during SWC formation. According to our estimates, in order to decrease the field strength to zero and to change the sign, the egress of steam from the well must be at least an order of magnitude greater. If such a large-scale phenomenon actually occurred prior to an earthquake on the Earth's surface, it would be necessarily registered. These considerations call into question the idea of relationship between earthquakes and the injection of charged aerosols.

(10) The number and quality of the observations described in this study are insufficient to solve the formulated problem in full measure. However, the authors had no opportunity to prepare the experiment more thoroughly. The point is that a planned shutdown of wells in a technological scheme of a geothermal station, when their use for conducting experiments is possible, is performed rather rarely and is not always known in advance. Attendance at the Mutnov thermal power plant is very problematic because the road to it passes through two passages that are closed for most of the year. Within a week after we terminated our observations, the hydrothermal field turned out to be unaccessible until July of the next year, when the snow melted away. Nevertheless, we believe that the conducted experiments and the preliminary results obtained by us have shown the expediency of continuing our study.

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