Variations of the atmospheric electric field during nepheline dust storms near Apatity town

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Observations over the electric field strength and the atmospheric electric current density have been carried out in Apatity town of Murmansk Region. It was found that under conditions of dust storms originating from the apatite and nepheline tailing pit the electrostatic field strength and electric current decrease and may change sign. The dust is of erosion origin being produced under conditions of dry summer weather and sufficiently high winds. The regression comparison of the electric field and current records has made it possible to determine the value of the air conductivity and to investigate the contribution of the electric current component being not caused by the conductivity. The obtained values of the air conductivity are close to those observed in midlatitudes. It is shown that the decrease of atmospheric electric field and current and change of their sign can be explained by the volume electric charge of the dust clouds.

Introduction

Dust is a part of aerosol content of the lower atmosphere. It can be of both natural (erosion, volcanic) and industrial origins. Near Apatity town of Murmansk Region there are the sites where the industrial wastes of the "Apatite" production association (the so-called "tails" or tailings pits) are stored. These contain a lot of fine matter, which is the result of rock treatment during apatite-nepheline production. In recent years, dust storms in Apatity town have become more frequent in summer, because in dry weather wind lifts up dust from tailings pits and spreads it over the town. The presence of dust during these events is visually detectable in the air. The phenomenon lasts from half an hour to several hours. The dust adversely affects forest ecology and health of the people.

Dust in atmosphere influences properties of the surface electric field.[1] The measurements in the West Africa carried out during dry-season characterized by strong north-east winds have shown that the surface electric field and current change their sign as dust clouds appear.[2,3] The strength of the inversed field can exceed that of the initial one by 50 times. The sign change takes about 10 min. Similar phenomenon, i.e., phase opposition of annual variations of the electric field strength and dust concentration, has been observed in Irkutsk.[4] As was shown in the studies on the influence of dust of volcanic,[5] erosion,[6] or industrial[7] origin on the atmospheric electric field, electric field variations can be explained if assuming the existence of volume electric charge distributed over the dust cloud. In this paper we show that dust storms near Apatity town are accompanied by strong variations of atmospheric electrostatic field and current which are explained following the hypothesis on the volume electric charge existing in dust clouds.

1. Instrumentation

The study of atmospheric electricity at the atmospheric station of the Polar Geophysical Institute located in the forest area ($\varphi = 67.5°$, $\lambda = 33.4°$) 2-km apart from the Apatity town has begun in April 2001 with measurements of the atmospheric electric current. The sensor is a doubled line of 100-m length hanged at about 3.5-m height made from bimetallic wires of 5-mm diameter horizontally spaced at distance of 1.5 m. According to equations from Refs. 8 and 9, the antenna effective area is 520 m^2. A signal is fed to an opamp DC-amplifier and then to an 18-channel 10-bit digital data acquisition system with the sampling rate of 1 time per minute. Data on air temperature, pressure, and humidity, wind speed and direction as well as illuminance in the visible range in relative units are also entered into this system.

Measurements of the atmospheric electric field have begun in the end of June 2002.[10] A "Pole-2" device is used as a sensor in measuring the electric induction. It is mounted on a flat roof of the two-storied building of the station in the center of a 3×3 m^2 square metal mesh. The device is switched off in case of precipitation. Because of no second device available for making comparison, a factor needed for reducing the roof-measured values to the surface ones is not yet determined. So this study uses just the directly determined field parameters. The field strength and electric current are recorded with the digital data acquisition system. The weather and other atmospheric conditions are visually monitored every 1 or 2 hour.

2. Measurement results

According to the results of visual observations in 2002 and 2003, 12 nepheline storms from those occurred in this period were accompanied by observations of the atmospheric electric field and/or current. All these observations have been performed in summer months. Dust appeared at the station when the wind blew from the tailings pit at a speed from 4 to 7 m/s. The tailings pit is situated near Khibiny railway station 8–10-km apart from the observation site. The tailings contain a number of alkali aluminum silicates, mainly the nepheline.[11] During strong nepheline storms, the horizon is invisible even under fair weather conditions. Dust haze reaches the heights up to hundreds meters. At the site of atmospheric electricity measurements, large specks of dust settle on the outdoor objects. These are particles of 10 to 30 μm size, mainly of feldspar.

Virtually all the considered cases occurred in the absence of precipitations and lasted from 15 minutes to several hours.

Analysis of data on the atmospheric electricity has shown that appearance of nepheline storms at the site is accompanied by a significant decrease of the voltage gradient. It does not only drop to zero but then it takes large negative values. Unlike the intense variations of the voltage gradient both up and downward occurring under bad weather conditions (precipitations, strong wind) only its decrease is observed during nepheline storms. Figure 1 shows the characteristic case recorded on August 13, 2002.

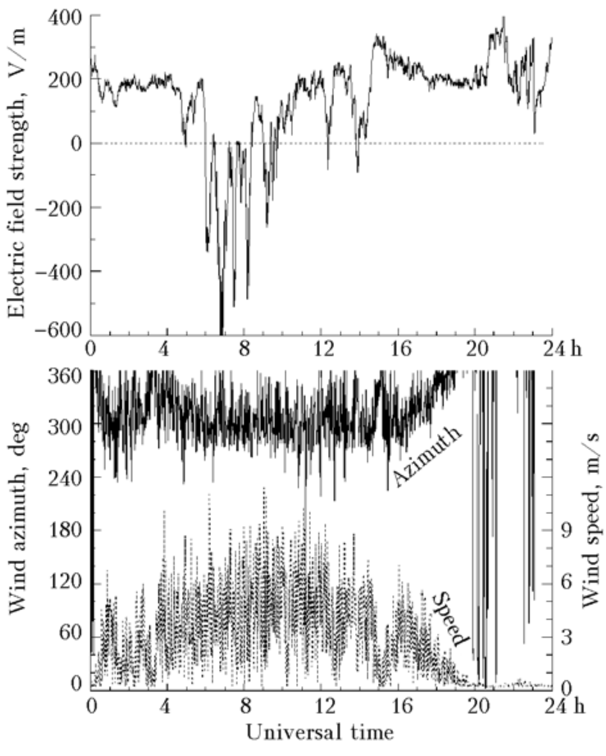

Fig. 1. Variations of the electric field strength, wind speed and direction during the day with a dust storm.

Light cirrus clouds were observed to 4:00 UT while then the sky was clear. From this time, the wind direction coincided with the direction to the tailings pit, azimuth of about 300°, and its speed increased to 4 m/s. At about 5:00 the electric field strength sharply dropped from 200 V/m to 0 and then it recovered to its unperturbed values for some time. Later on the field strength started to oscillate reaching the negative values of –600 V/m. At about 14:30 the wind almost dropped and the electric field strength got back to its positive values.

The similar behavior of atmospheric current was observed on June 24, 2003 during a dust storm (Fig. 2).

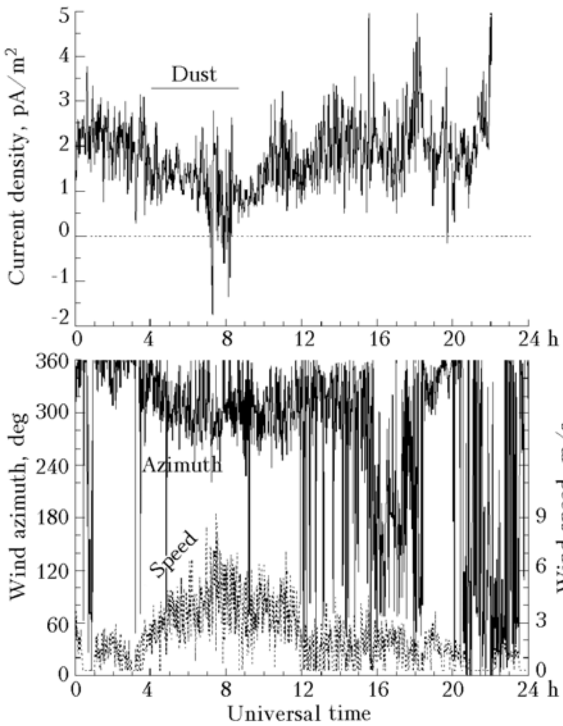

Fig. 2. Variations of the atmospheric current density, wind speed and direction during the day with a dust storm.

The horizontal line in the upper panel of Fig. 2 marks the period the nepheline dust storm was observed. At this time, the wind azimuth was close to that along the direction toward the tailings pit. Between 7:00 and 8:15 the average wind speed reached its maximum (about 5 m/s) and the electric current reversed the direction (upwards from the ground). The sky was covered with strato-cumulus. Beginning from 9:00, the wind dropped to 1.5 m/s at 12:00 UT, nepheline dust disappeared, and the electric current recovered its initial, unperturbed direction and value.

3. Correlation between the electric current and field

Comparison of the behavior of voltage gradient and electric current density during a nepheline dust storm is of a certain interest. Qualitatively, these parameters of atmospheric electricity behave similarly: when dust appears at the site, voltage gradient and current density drop and take negative values. Numerically, their variations differ. As an example, Fig. 3 shows the situation observed on July 13, 2003, when dust storm lasted only 30 min.

Behavior of both parameters before and after the nepheline dust storm is similar even in details. During the dust storm, which has begun at 15:20, they evidently dropped to minimum values almost at once and their variations are quite similar during this half an hour. But their negative values relative to unperturbed ones essentially differ: while the negative voltage gradient has the absolute value close to the positive ones, negative values of the current several times exceed the modulus of its positive values. As is also evident from Fig. 3, change of their signs concurs not simultaneously: the current crosses zero line earlier than the voltage gradient (both during the drop and rise).

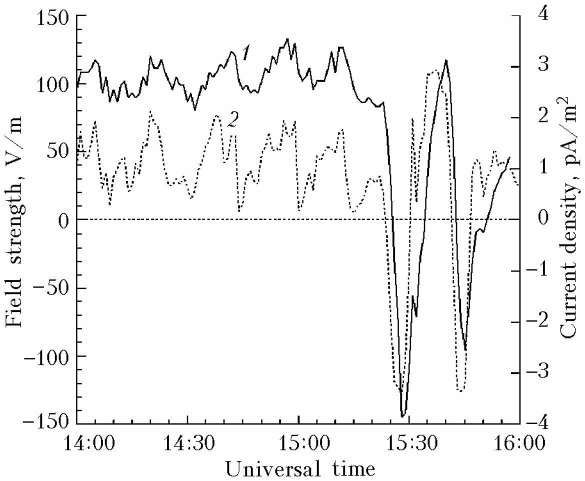

Fig. 3. Variations of the electric field strength (curve *1*) and the current density (curve *2*) during the dust event between 14:00 and 16:00 UT on July 13, 2003.

The similarity and difference between variations of the voltage gradient E and current density j can be expressed numerically, if one takes into account that the electric current recorded with a long-line comprises several components: conduction current j_{cond}, convection current j_{conv}, caused by wind transportation of the electric charges, and displacement current $j_{\text{disp}} = \partial E/\partial t$. Then the overall current density is expressed as

$$j = \lambda E + j^*, \quad (1)$$

where $j^* = j_{\text{conv}} + j_{\text{disp}}$. If the specific conductivity λ_c is known, the contribution of non-conductivity currents could be determined.

We do not measure conductivity, however, λ_c and j^* can be estimated from Eq. (1) using the statistical approach. If considering sufficiently short time intervals, the correlation between the electric current density and field strength can be approximated by a linear function $j = aE + b$, where the coefficient a corresponds to the specific conductivity λ_c and the constant b to the non-conductivity current density j^*. In this case, the assumption of constancy of both parameters, i.e., λ_c and j^*, during the given time interval is accepted.

The day of July 13 was split into hourly intervals except for the period from 14:00 to 16:00, which was split into two intervals, i.e., 14:00–15:20, before the dust storm arrival, and 15:20–16:00, when the dust was observed. After 16:00 cumulus and then fog appeared. Hence, we do not consider the data after this time. Parameters λ_c and j^* as well as the coefficient of correlation between j and E were determined for each of 16 hourly intervals using one-minute values of j and E in the linear approximation (Fig. 4).

As in the above-considered cases, nepheline dust influences atmospheric electricity when the wind speed reaches 4 m/s. The coefficient of correlation between the electric current and field strength is quite high (+0.56) for all the period.

Large positive value of the coefficient of correlation between j and E can serve the condition of applicability of the approach using the assumption of λ_c and j^* constancy during the hour intervals. As a threshold, the value 0.5 has been chosen (dashed horizontal line). The solid lines correspond to λ_c and j^* for intervals with the correlation coefficient larger than 0.5; determined values of λ_c and j^* in other intervals are to be considered unreliable.

As it follows from Fig. 4, average values of the specific conductivity are between 0.015 and 0.035 S/m which is close to values measured in midlatitude atmosphere.[12,13] The absolute value of the current density j^* lies between 0 and 2 pA/m^2; j^* is negative within all the "reliable" intervals except for the dust storm interval from 15:20 to 16:00.

During this interval, the correlation factor is high and equals to 0.68 (see Fig. 3) and regression analysis is allowable here; the specific conductivity equals to 0.02 S/m here that is somewhat lower than the average value for time intervals of unperturbed atmosphere and is only 2/3 of the value for the previous interval 14:00–15:20. The current density j^* is +0.17 pA/m^2 in the time interval under consideration while it equals to −1.88 pA/m^2 in the previous interval, that has 11-times larger absolute value.

The current j^* consists of two basic components: convection current and displacement current. Before the storm (15:20 UT), j^* was negative and it almost vanished during the storm. Strong variations of the electric field (large values of $\partial E/\partial t$) during the storm (see Fig. 3) indicate the increased contribution of the displacement current. Therefore, one may assume that the displacement current compensates the convection one, which was determining for j^* and negative before the storm. Since the increasing displacement current became negative after 15:20 the convection current is to be positive at this time. The top-down direction is considered here positive and thus the increasing convection current can be related to sedimentation of large positively charged specks of dust to the ground. This agrees with common conception[1–3,14,15] of negative charge of small specks of dust and positive charge of large ones.

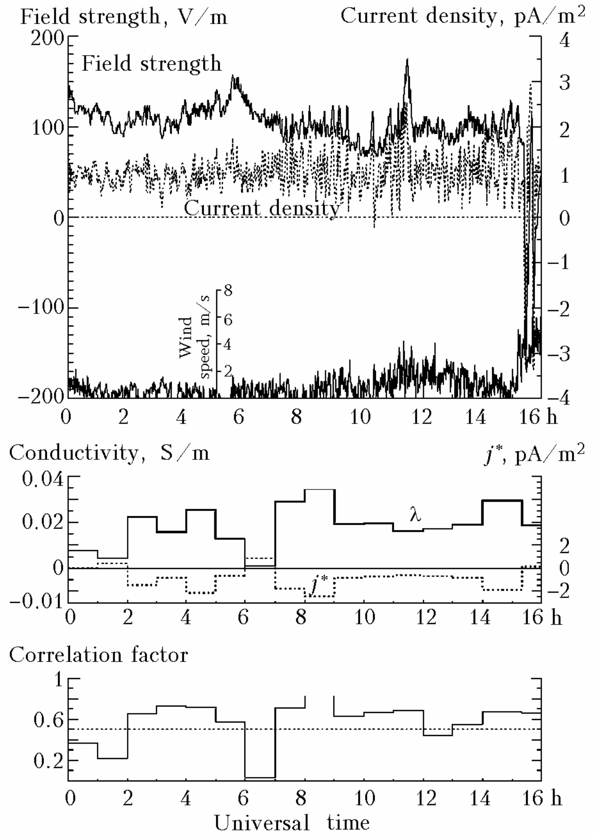

Fig. 4. Electric field strength, current density, and wind speed measured at the atmospheric station on July 13, 2003; specific conductivity λ_c and non-conductivity current density j^*, calculated for the mentioned time intervals, as well as the coefficients of correlation between the field strength and total electric current density during the corresponding time intervals.

4. Discussion

A simplified physical interpretation of the observed phenomenon can be given by considering the electric charge of a dust cloud. Under conditions of dry weather, wind blows the dust off the tailings pit surface and transports it to the surroundings. The specks of dust can acquire charge both during blowing off and via electrization during transportation.

Appearance of a charged dust cloud results in change of the quasi-stationary electric field near the surface. Consider for example, a dust layer with the thickness h and horizontal sizes much larger than h, which bears a uniform negative charge of the volume density ρ. The layer produces the electric field E_d which is vertical out of the layer and at its boundary and directed toward the layer having the strength produced by the layer of a uniformly charged surface with the surface charge density $\sigma = \rho h$, i.e., $E_d = \rho h/2\varepsilon_0$, where $\varepsilon_0 = 8.85 \cdot 10^{-12}$ f/m. According to visual observations, the thickness of the dust layer is about 100 m. To neutralize the background of undisturbed field of $E_0 = 100$ V/m, the volume charge density $\rho_1 = 2\varepsilon_0 E_0/h = 1.77 \cdot 10^{-11}$ C/m^3 of the layer is needed. To achieve the field strength $E = -600$ V/m shown in Fig. 1, the charge density should be $|\rho_2| = 7|\rho_1| = 1.24 \cdot 10^{-10}$ C/m^3 for the given h and E_0.

If the dust cloud is electrically neutral then charge separation in it is required, at which positive specks of dust are to be at the bottom of the cloud and negative ones at its top. In this case, the reversion of the total atmospheric electric field is possible.

Probable electrization mechanism for a dust cloud is described in Ref. 2. Wind perturbation breaks the dust, large specks of dust (> 5 μm) take positive charge while small ones (0.1–0.4 μm and smaller) negative. While transported, positively charged specks of dust fall down to the ground under gravitation and the dust turns out to be charged negatively at long distances. According to estimates for Nigerian dust storms, the separation occurs at distances of 10–12 km (Ref. 3) that is close to the distance from the atmospheric station to the tailings pit in our case. Investigation of dust sediment at the site has shown the presence of specks of dust about 10 μm in size and larger. Therefore, one can assume the presence of positively charged particles near the ground as well.

The field strength decrease with the increase of dust concentration in Irkutsk is explained[4] by other mechanism, i.e., increase of air conductivity due to γ-radioactivity of dust. In our case, current decrease, reversion of signs of the field strength and current, calculated decrease of conductivity during a dust storm evidences of non-radiation electrization of dust.

Conclusion

Decrease of the voltage gradient and density of the atmospheric electric current and reversion of their sign was recorded during dust storms, arriving from tailing pits, near Apatity town. The dust is of erosion origin and produced in dry summer weather at high enough wind. The obtained values of air conductivity are close to those observed in midlatitudes. It has been shown that the decrease of the absolute value and the change of sign of the voltage gradient can be explained by the volume charge of a dust cloud. The cloud can be either negatively charged or electrically neutral. In the latter case, the cloud is to be polarized in a specific way. The result can be important for the ecology of the region near Apatity.

Acknowledgements

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