Dependence of the atmospheric electric field strength in Irkutsk on aerosol pollution

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The statistical relation of the atmospheric electric field strength to the wind direction and speed, dust concentration, meteorological range, and type of clouds in Irkutsk is studied. The relation of the field strength to wind direction is presented by a three-dimensional regression. The strongest variability of the electric field is observed at low wind speeds, while at high wind speeds the variability is insignificant, which is explained by turbulent mixing and clearing of the atmosphere. The inverse relation was obtained between the dust concentration and the electric field strength; this dependence manifests itself in both monthly mean and diurnally mean values. The increase in the dust concentration leads to an increase of the air conductivity. The decrease of the electric field strength and the increase of the conductivity with the increasing dust concentration are explained by natural radioactivity of the soil dust and ashes from coal used for heating. The dependence of the electric field on the meteorological range is represented by the inverse linear dependence.

All electric characteristics of the atmosphere: air conductivity, electric field strength, and conduction current of the atmosphere, are sensitive to atmospheric aerosol pollution. Almost all aerosols are either electrically charged or their presence in air decreases the air conductivity, thus decreasing also the mobility of atmospheric ions. On the other hand, electric parameters of the atmosphere also affect aerosols, moving them in space and forming conglomerates, change the size of aerosol particles, and take part in transformation of the chemical structure. Many atmospheric aerosols originate from atmospheric ions, for example, through condensation and sublimation of water vapor on ions, decreasing the vapor saturation pressure over droplet nucleus. The effects of meteorological factors on the electric characteristics of the atmosphere at different time and at different places were analyzed in many papers.[1,2]

Further studying the relation of the gradient of the atmospheric electric potential to the ionization state and meteorological phenomena of local and global scales may prove useful in simulation of atmospheric physical processes, indication of atmospheric pollution, etc. Both meteorological and atmospheric electric parameters affect the human physiology; therefore, the interrelated electric characteristics and meteorological factors should be separated when analyzing their effect on the human health. Meteorological parameters have both direct (cloud charge, for example) and indirect effect (changing and mixing volume charges in the atmosphere and changing the air conductivity) on local changes in the electric field strength.

The air in Irkutsk is strongly polluted with both gaseous and solid-state admixtures: dust and soot. In Irkutsk there are several heat and power production plants, numerous boiler houses, and houses with furnace heating. High atmospheric pollution is connected, to a significant extent, with high occurrence of meteorological conditions unfavorable for dispersal of pollutants. Irkutsk is situated on the territory of maximum development of the Siberian Anticyclone characterized by strong temperature inversions and weak winds. At the same time, low sources of pollution (lower than 20 m) make up about 90% of all pollution sources. In summer, the soil is the main source contributing to the content of dust in air. The heat and power production plants, boiler houses, and furnaces burn predominantly the coal of the Cheremkhovo coalfield, which is characterized by very high ash content. The ash and slag contain rather high amount of radionuclides. In districts with furnace heating, ash is often used as a sort of paving. According to our measurements, the γ-radioactivity background on some streets near slag dumps exceeds the norm by three times.

The initial materials for our investigation were the measurement results on the electric field strength obtained in the Irkutsk Hydrology & Meteorology Observatory (HMO) for five years, the hourly mean values of the wind speed and direction, observations in the main synoptic periods, as well as measurements of the dust concentration in air.

The dependence of the electric field strength on the wind direction for three observation sites of the atmospheric electricity is given in Ref. 2 in the form of tables of mean values. For rural site, the electric field strength is independent on the wind direction, while for HMO located at the city center this relation is obvious. The highest values of the field strength in the warm season (30 dV/m) are connected with eastern directions, while the lowest ones (9 dV/m) – with western directions. In winter the electric field strength at the eastern wind directions achieves 69 dV/m. This dependence of the

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electric field strength on the wind direction is explained by the geography of the measurement site and local pollution sources.

However, the pollution conditions also depend on the wind speed, since it determines the volume of the air that moves and the surface concentration of aerosols from different sources. At strong winds, aerosols are spread to long distances from the points of their emission. However, there is some speed value, at which the plume formed by tall pollution sources goes down to the ground and the increased concentration level is formed. This value of the "hazardous" speed depends on the source parameters: emission height and temperature, as well as on atmospheric stratification. The maximum of the concentration is usually formed at the distance equal to 10–20 heights of the pollution source. Therefore, the relation can be shown most completely and illustrative as a 3D regression (Fig. 1), where isopleths show the electric field strength as a function of two variables: wind direction and speed.

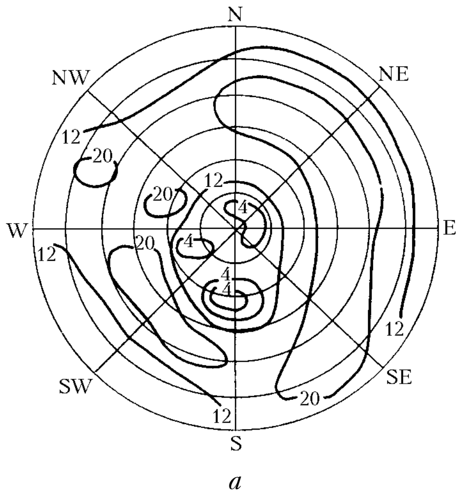

Fig. 1. Isopleths of electric field strength at different wind direction and speed for July (*a*) and January (*b*) (wind speed scale is 1 m/s; field strength in dV/m).

The wind velocity scale is shown as circles drawn with the interval of 1 m/s. The central part of the circle corresponds to calm conditions. The values of the field strength are averaged for 1 m/s intervals and over 16 rhumbs of wind direction. Isolines plotted are just for these average values.

The wind direction and speed distribution of the electric field strength is indicative of the complex character of the relation. The dependence on the wind direction is the strongest at low wind speed. At the speed of 1–2 m/s, turbulent mixing is insignificant; therefore, dust, smoke, and other industrial emissions, being charged aerosols, considerably change the electric field strength. This is especially marked in winter during anticyclones with powerful thermal inversion, as significant amount of aerosols is accumulated at the locking level of inversion. As the wind alternates from the northern to the southern one, the field varies from 12 to –4 dV/m in July and from 28 to 4 dV/m in winter at the wind speed of 1–2 m/s. At the speed of 4–6 m/s, turbulent mixing leads to natural air cleansing, and the field strength more weakly depends on the wind direction.

High speed of northwestern winds corresponds to unstable weather with cumulonimbus clouds having a significant electric charge and changing the direction of the potential gradient. At gentle winds (2–3 m/s) of the southern direction, the field strength decreases with alternation of the gradient to the negative one down to 4 dV/m in winter and –4 dV/m in summer. This decrease is associated with the high-voltage line lying to the south of HMO. This line induces the negative volume charge, especially significant in the presence of atmospheric haze. This explanation is given in Ref. 3. Such a phenomenon is connected with the fact that the corona discharge threshold for a negatively charged wire is lower than that for a positive wire. Thus, for the ac period in the high-voltage line the greater amount of negative charges come into the atmosphere from the corona-forming wire.

For direct investigation of the effect of aerosols on the electric field strength, we used the diurnally mean and monthly mean data on the dust concentration at Irkutsk HMO for the period of 1974 and 1979. Figure 2 depicts the smoothed variations of the monthly mean values for 1974 (Fig. 2*a*) and 1979 (Fig. 2*b*), which indicate that these characteristics vary in anti-phase. The correlation coefficients are respectively –0.66 and –0.71. The results obtained contradict known literature data[1,3]: the dust in air leads to the increase of the field strength because of the decreasing air conductivity, since the concentration of light ions decreases because of their adhesion to aerosol particles. The air conductivity is largely determined by the concentration of light ions, and, according to the Ohm law, the decrease of the conductivity must lead to an increase of the electric field. The relation observed could be believed accidental, since both the electric field and the dust concentration have an annual dynamics and are typical for continental regions, but analysis of the diurnally mean values indicates the presence of a feedback, though less pronounced (because of the wide variability of the characteristics), with the confident correlation coefficients of, on the average, –0.3.

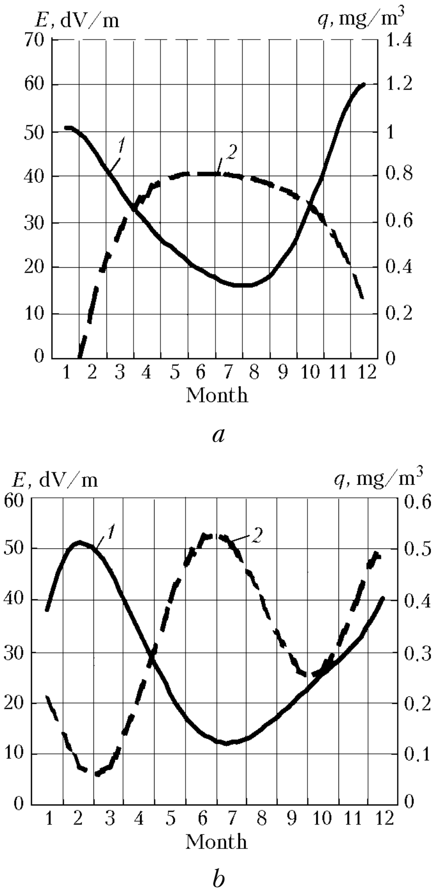

Fig. 2. Annual variations of the electric field strength (*1*) and dust concentration (*2*) in Irkutsk: 1974 (*a*) and 1979 (*b*).

The considered data on the total electric conductivity and the aerosol concentration for these periods demonstrate the increase in the conductivity with the increasing dust concentration (correlation of +0.6), that is, it can be assumed that aerosols form an additional source of air ionization under conditions of Irkutsk. The conductivity measurements do not involve trapping of heavy ions. Natural radioactivity of soil and radon gas are commonly believed the main sources of atmospheric ionization up to the altitudes of about 3 km. In the winter months the surface is covered with snow, the radioactivity decreases, the air conductivity decreases too, and the field strength increases. Thus, both the soil dust and ashes from coal burning can be extra sources of air ionization. Extra ionization and production of volume electric charges, as a rather short-term and rare phenomenon, can be observed at dust squalls, causing sharp variations of the field.

The meteorological range is determined by the aerosol concentration in air. At the same time, aerosols decrease the air conductivity and can carry electric charge. Thus, for the winter months in Irkutsk the relation between the electric field strength E (V/m) and the meteorological range in the region of 5–40 km can be approximated by the linear dependence:

$$E = -1.22\,D + 50, \tag{1}$$

and for the summer months

$$E = -1.63\,D + 50, \tag{2}$$

where D is the meteorological range, in km. Thus, the inverse dependence is observed between the field strength and the meteorological range. In the region of 5–40 km, the meteorological range mostly depends on the atmospheric haze, while fogs, with more complex electric processes that were excluded from the consideration, calls for a separate study. For analysis we used all the observed values of the electric characteristics. The observations of atmospheric electricity were divided into "all" and "normal." Normal values are observed in the absence of distorting factors: low clouds, wind higher than 6 m/s, and atmospheric phenomena. All stratus, stratocumulus, nimbostratus, and cumulonimbus clouds have a complex electric structure; therefore, clouds of different type and thickness have different effect on the electric field near the ground.

Thus, the electric field under urban conditions is a very sensitive indicator of the atmospheric aerosol pollution and variations of the meteorological state of the atmosphere.

References

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