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Response in the surface atmospheric electric field to the passage of isolated air mass cumulonimbus clouds

K.N. Pustovalov [*], P.M. Nagorskiy

Institute of Monitoring of Climatic and Ecological Systems SB of RAS, 634055, Tomsk, Russia

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ABSTRACT

Convective clouds have a significant influence on the surface electric field. They are one of the most important components that support the global electrical circuit. To classify the response forms in the surface electric field to cumulonimbus clouds (*Cb*) at different stages of their development, the automated detection of the electric field response to the passage of isolated convective cells was carried out. The monitoring data of the surface electric field potential gradient (∇φ), registered in warm season over the period of 2006–2017 in Tomsk (south of Western Siberia), were used. In total, 9 types of ∇φ "slow variations" forms during the passage of isolated convective cells were identified. The main 6 types of ∇φ variations (97% of cases) were associated with different phases of the life cycle of the convective cell during its passage in the vicinity of the observation point. The main types of ∇φ variations were related to the *Cb* phases. Type 1 (12%) of ∇φ variations is unambiguously associated with cumulonimbus clouds in the growth phase and consists of one ∇φ disturbance with positive polarity. Type 2 (5%) of the ∇φ variations should be attributed to the "early" *Cb* mature stage, when there were shower, but without thunderstorm. Type 3 (19%) and type 4 (12% of ∇φ variations) can be associated with both "early" and "late" *Cb* mature phase. Type 5 (8% of ∇φ variations) should be associated with the "late" step of the *Cb* mature phase, when the intensity of the shower decreases and the intensity of the thunderstorm increases. Type 6 (41% of ∇φ variations) is a dominant one. It is associated with the *Cb* in the dissipation phase, when light shower and light thunderstorm are possible. These variations consist of one ∇φ disturbance of negative polarity. Thus, the general classification of response types in the electric field to the passage of isolated *Cb* in the vicinity of the observation point was suggested. It relates the types of ∇φ variations, the *Cb* development phases and the inclination peculiarities of its electric structure.

1. Introduction

It is known that well-defined weather fronts are associated with complex thick and horizontal cloud systems accompanied by long-lasting precipitation. At the same time, it is assumed that the cloud thickness of the warm front, occluded front and slow-moving cold front, as well as the intensity of precipitation from it practically do not change in the direction being parallel to the front line. However, at the end of the 20th century, the aircraft, radar and satellite studies of frontal clouds demonstrated that the structure of frontal cloud systems represented by stratiform or stratocumuliform clouds is characterized by meso-inhomogeneities reasoned by embedded convection composing small bands (Hobbs, 1978; Shmeter, 1990; Houze, 2014).

It is hard to detect embedded convection on the basis of visual observations. The presence of embedded convection in stratiform clouds can lead to a drastic increase in precipitation intensity and wind speed in this territory being rather hard to forecast for the above described reason. Thus, there is a need for additional sources of information on the meso-scale structure of frontal cloud systems, as well as for its acquisition methods. A potential source of information of that kind is the electric field of the surface layer that significantly changes under the influence of a cloud cover and various atmospheric phenomena (Thomson, 1872; Chalmers, 1967; Bennett and Harrison, 2008). To create a required methodological database of the mesoscale structure of cloud systems, it is necessary to have reliable data on the peculiarities of the influence of different cloud types and atmospheric phenomena on the surface layer electric field.

In addition, according to (Wilson, 1920; Williams, 2009), electrified shower clouds, which may not produce lightning, can have an important contribution to the global electrical circuit along with thunderclouds.

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[*] Corresponding author.
E-mail address: const.pv@yandex.ru (K.N. Pustovalov).

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Presence of low clouds at middle level leads to the reduction in absolute value of potential gradient and to the change of sign of potential gradient relative to fair weather conditions (Filippov, 1974; Bennett and Harrison, 2007; Popov, 2008). The most significant distortions of the electric field are observed during the passage of cumulonimbus clouds (*Cb*) (Filippov, 1974; MacGorman and Rust, 1998; Bennett and Harrison, 2007; Popov, 2008; Marshall et al., 2009). During lightning flashes occurs the rapid electric field change (duration is less 1 s) (Wilson, 1916; Wilson, 1920; MacGorman and Rust, 1998; Rakov and Uman, 2003). In compliance with (Bennett and Harrison, 2007; Popov, 2008), precipitation in the form of rain and rain/snow mixed leads to a reduction in the values of the potential gradient and their movement to the area of negative values, whereas snow and (or) blowing snow lead to an increase in $\nabla\varphi$ values.

The classification of $\nabla\varphi$ variations during thunderstorms is described in a range of publications. Thus, the results for the territory of Eastern Siberia are described in (Filippov, 1974, Toropov et al., 2013), but specific types of $\nabla\varphi$ variations are determined visually on the basis of a rather limited number of cases. Such publications as (Rakov and Uman, 2003; Bennett and Harrison, 2007) reflect the attempts to make model assessments of $\nabla\varphi$ variations during the passage of a cumulonimbus cloud. The distinctive features of the change in the $\nabla\varphi$ value during the passage of cumulonimbus clouds and the description of the most widespread types of $\nabla\varphi$ variations are presented in (Pustovalov and Nagorskiy, 2016). However (Pustovalov and Nagorskiy, 2016), do not analyze a connection between the described types of $\nabla\varphi$ variations and the passage of cumulonimbus clouds (isolated air mass clouds, frontal bands of cumulonimbus clouds, mesoscale convective complexes, etc.) that are in addition characterized by different stages of development. The passage of the adjacent convective cells of a multi-cellular storm, or the close passage of several ordinary cell cumulonimbus clouds is accompanied by the superposition of electric fields produced by separate clouds/convective cells. As frontal cumulonimbus is represented by the bands of multicellular clouds (Bluestein, 2013; Houze, 2014), it is bound to evoke a complex response in the electric field near the earth's surface.

2. Experimental material description

Atmospheric electricity quantities have been measured at the geophysical observatory of the Institute of Monitoring of Climatic and Ecological Systems of the Siberian Branch of the Russian Academy of Sciences (IMCES SB RAS), Tomsk, since 2006. The potential gradient in the electric field of the surface layer is measured with the field mill Pole-2.[1] The field mill Pole-2 is located on height 1 m on the metal grid (3 m × 3 m). The metal grid reduces the influence of surface corona space charge on the electric field potential gradient values measured of the field mill Pole-2”. Simultaneously, the observatory monitors the main meteorological quantities, as well as visible and ultraviolet light and natural radioactivity with the time resolution of 0.5–1 min.

Meteorological conditions were measured with the help of surface weather charts with a frontal analysis http://gpu.math.tsu.ru/maps. Cloud cover characteristics were determined via the MODIS instrument http://ladsweb.nascom.nasa.gov/data/at the times of Aqua and Terra satellite overpasses at local noon. In the framework of this study, the data from meteorological radars were not used due to the absence of any radar within a radius of 300 km from the monitoring point.

The potential gradient monitoring in case of ordinary cell air mass *Cb* shows that $\nabla\varphi$ variations are usually represented by 1–3 disturbances of varying polarity (see Fig. 1 (*a, b, c*)). In certain cases when a heavy thunderstorm is registered in close proximity to the monitoring point, a *Cb* response in the electric field can have a more complex look, which is connected with both the impact of close lightning discharges on the value of $\nabla\varphi$ and the potential influence of the lower positive charge in a cloud (Williams, 1989; MacGorman and Rust, 1998; Rakov and Uman, 2003).

The analysis of the duration, amplitude and form of the time structure of $\nabla\varphi$ variations during the passage of isolated cumulonimbus clouds, as well as the knowledge of *Cb* electrical structure at different development stages (Wilson, 1956; Vonnegut et al., 1966; Kamaldina, 1968; Imyanitov, 1981; Dye et al., 1989; Williams, 1989; MacGorman and Rust, 1998; Stolzenburg et al., 1998a, 1998b; Stolzenburg and Marshall, 2008; Marshall et al., 2009; Mikhaylovsky and Kashleva, 2012; Wang, 2013) have allowed developing a method to determine a connection between $\nabla\varphi$ variations and specific *Cb* development stages. For example, Fig. 1 (*a*) shows a positive $\nabla\varphi$ disturbance that is presumably connected with the passage of a single *Cb* at the growth stage. The negative $\nabla\varphi$ disturbance being the mirror image of Fig. 1 (*a*) is reasoned by the passage of isolated *Cb* at the dissipation stage. A combination of 2–3 disturbances of opposite polarity is typical of the passage of mature *Cb* at different moments of this stage (see Fig. 1 (*b, c*)) near the observation point. A more complex type of surface layer electric field dynamics represented by 4 $\nabla\varphi$ disturbances and reasoned by the passage of thunderstorm *Cb* with a well-defined lower positive charge in close proximity to the observation point is shown in Fig. 1 (*d*). Variations of gradient potential in Fig. 1 (*d*) is an example of the End-of-storm oscillation (EOSO), described in the paper of Marshall et al. (Marshall et al., 2009).

3. Automated data selection, processing and formalization methods

In order to determine the form of surface atmospheric electric field variations and their connection with the passage of *Cb* undergoing specific development stages with automated methods, it is necessary – apart from using data on $\nabla\varphi$ variations – to use additional information, and namely – assessments of atmospheric phenomena of convective origins. For this purpose, the authors used measurement data from weather station (Tomsk) obtained during a standard meteorological period http://aisori.meteo.ru/ClimateR and from the geophysical observatory of IMCES SB RAS on an on-going basis in daylight hours indicating an exact start and end time of the phenomenon. The geophysical observatory of IMCES SB RAS and weather station are located on the eastern and southern suburbs of Tomsk, respectively, the distance between them is ~6 km.

From the meteorological data obtained at Tomsk weather station for 2006–2015, the authors selected the synoptic hours for the warm half-year season (May–September) when the weather conditions were characterized by the following peculiarities:

- presence of cumulonimbus clouds (*Cb*);
- absence of altostratus (*Altostratus, As*) and stratus (*Stratus, St*) clouds;
- absence of snow showers, rain/snow showers mixed;
- absence of continuous and drizzle precipitation;
- absence of fog, mist and smoke from forest fires.

The following conditions were also considered acceptable: *Cu*, *Sc*, *Ac* and *Cc* accompanying cumulonimbus clouds and being their forerunners, as well as *Ci* and *Cs* forming an anvil clouds. As bulk charges in these genera of clouds are significantly smaller than in cumulonimbus clouds (MacGorman and Rust, 1998), their influence on the electric field of the surface layer was taken to be insignificant and screened out during the automatic processing procedure.

When working with the synoptic hours characterized by cumulonimbus clouds obtained at the weather station, the authors were using surface weather charts with a frontal analysis and MODIS satellite images to select only those where *Cb* development was ensured by air mass convection. The air mass cumulonimbus clouds are usually ordinary isolated cells (Ahrens, 2012; Houze, 2014).

The selecting of cumulonimbus clouds that are just above the electric

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[1] Pole-2 was produced and calibrated by the calibrator of electric field strength KNEP-1M (range – 0 ± 5 000 V/m, basic error – 1.5%.) in the Voeikov Main Geophysical Observatory (Russia, St. Petersburg).