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Experimental observations of strengthening the neutron flux during negative lightning discharges of thunderclouds with tripolar configuration

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ABSTRACT

We consider neutron bursts (Yakutsk cosmic ray spectrograph,105 m above sea level) and the electric field during lightning discharges. It was found that the neutron bursts are observed in the negative lightning discharg only. We discuss the possibility of generation of neutrons in the lower part (the point of impact into the ground) lightning discharge.

1. Introduction

In 1923 Wilson (Wilson, 1923) suggested that the gradients of the potentials within thunderclouds may be sufficient to accelerate electrons, despite the resistance of the air to their motion. He noted that these runaway electrons can become a source of penetrating radiation.

In the fifties of the last century, with the appearance of the global network of neutron monitors designed to study the neutron component of cosmic rays, a continuous and systematic study of the variations of neutron flux in cosmic rays has begun. A neutron monitor basically records neutrons with energies from hundreds of MeV to several GeV using the secondary neutrons created by them and slowed down inside the monitor. The first experimental reference to neutron generation during lightning discharges was made by Indian physicists in 1983 (Shah et al., 1983). Analogous observational results were reported later (Shah et al., 1985; Shyam and Kaushik, 1999). At the present time, this phenomenon is being registered by modern installations both in the mountains (Chubenko et al., 2008) at sea level (Kuzhevsky, 2004) and on board orbital stations and satellites (Bratolyubova-Tsulikidze et al., 2004). In the communication (Libby 1973) discussed C14 production in thunderstorms and shown that its present day magnitude may be a few percent of C14 production by cosmic rays, so that hundred- year fluctuations in the frequency of thunderstorms could explain the short-term secular variations in radiocarbon in tree rings. Despite a relatively long history of observations of neutrons associated with lightning and a large number of theoretical studies, the question of the origin of these neutrons is still open (Gurevich et al., 2012).

One of the theories (Stephanakis et al., 1972; Shah et al., 1985; Kuzhevsky, 2004) assumes that the neutrons are generated in the lightning channel due to the synthesis of deuterium contained in water vapor in the atmosphere. According to another theory (Babich, 2007; Paiva, 2009; Smith, 2011) (actively developed in the last decade), the neutrons are generated by a complex mechanism of interaction between bremsstrahlung (produced by relativistic runaway electrons, which can occur during a thunderstorm) and the atmosphere.In this paper we present experimental results of the registration of the neutron component during the nearest thunderstorms in the years 2009–2011.

2. Experimental setup

The neutrons were detected with the Yakutsk cosmic ray spectrograph (Yakutsk, 61° 59.362' N; 129° 41.874' E) on the standard neutron monitor 24-NM-64 (altitude 105 m, geomagnetic cutoff threshold of 1.65 GeV, the correction factor for pressure 0.00723%/mb). In this paper we have used one-minute time resolution data. In the immediate vicinity of the monitor the electric field sensor (an electrostatic fluxmeter—our own design) was installed to register the electric field and its variations during thunderstorms. The electrostatic fluxmeter was calibrated in an artificial electric field and has a measurement range of +/-50 kV/m.

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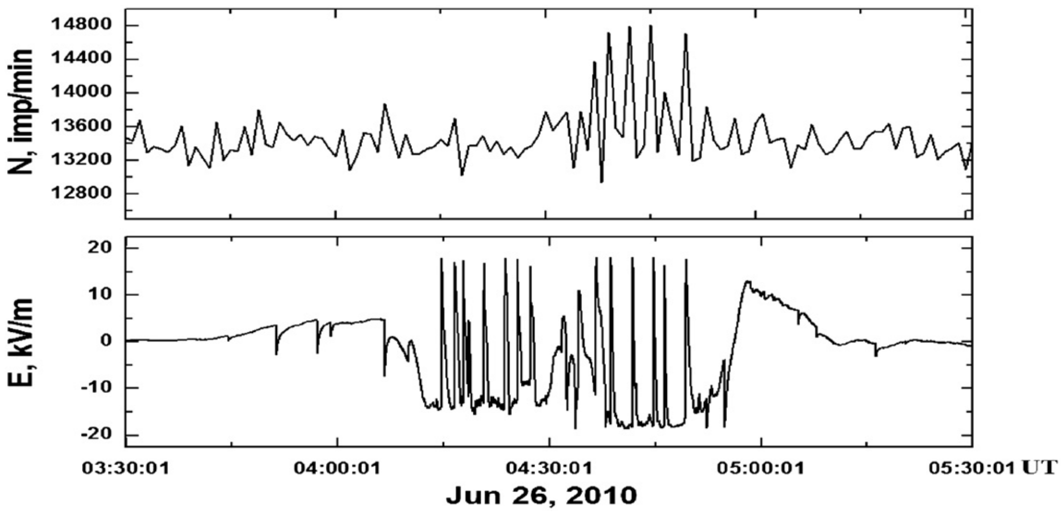

Fig. 1. An example of neuron bursts at the moment of lightning discharges during the thunderstorm on June 26, 2010. Top panel—the level of neutron counting. Bottom panel—variations of the electric field over the neutron monitor

The second electrostatic fluxmeter is located 4 km from the monitor, on the building of the institute. This fluxmeter is similarly calibrated and has a measurement range of +/-41 kV/m. Both fluxmeters allow us to register lightning discharges within a radius of 10–15 km. In this paper we have used one-second resolution data. In the course of two storms a high-speed video (300 fps) was recorded.

3. Results

During the observation period in 2009–2011 the neutron monitor of the Yakutsk cosmic ray spectrograph repeatedly detected bursts of neutrons during lightning discharges. An example of such bursts is shown in Fig. 1. Fig. 1 shows two curves: the count rate of the neutron monitor (top panel) and the electric field strength. The time is UTC. During the lightning discharges some typical jumps are observed in the electric field, after which the field is restored to its original value in seconds and tens of seconds. In Fig. 1 these strong electric field jumps start at 04:15:00 UTC.

During the summer seasons of 2009–2011, 39 thunderstorms were registered in the vicinity of the neutron monitor. In nine of them the neutron flux level was up by a fairly significant value. Distribution of thunderstorms over the years is shown in Fig. 2 (white column), while distribution of thunderstorms with a response in the neutron component is shown in Fig. 2 (gray column).

When a thunderstorm cloud passes over the observation point at the earth surface, relatively slow (from tens of minutes to hours) variations of the electric field are registered. Depending on the electrical structure of a thundercloud, these variations can be divided into four main types. The first type is associated with the clouds where a positive charge dominates in the upper part, while a negative charge dominates at the bottom—(the so-called cloud of positive polarity). The second type of field variations occurs with the same clouds, but has an additional compact positive charge at the bottom.

The third type is associated with the clouds where a negative charge is dominating in upper part, while at the bottom—a positive charge dominates (a negative polarity cloud). The fourth type of variation is associated with the clouds of positive polarity with the upper positive charge and the lower negative charge shifted relative to each other.

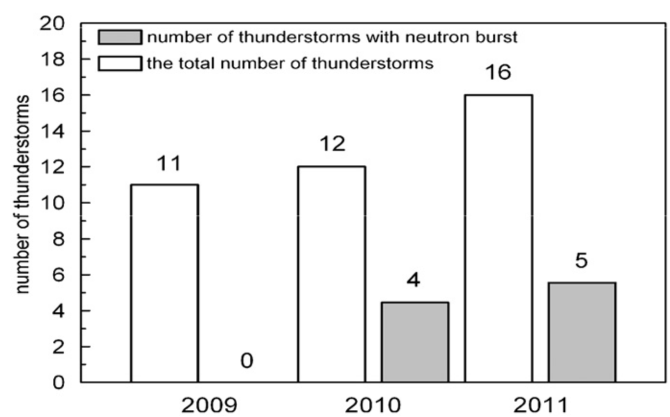

Fig. 2. The number of thunderstorms observed in the vicinity of the neutron monitor within three years of observations, and distribution of thunderstorms with a response in the neutron component.

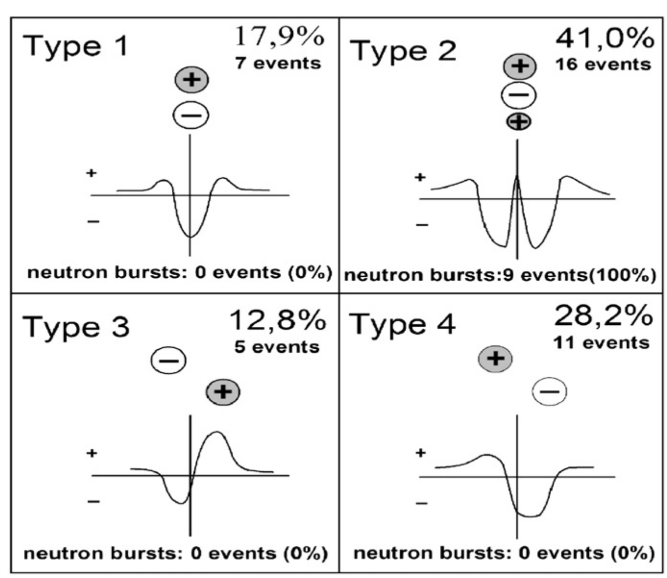

Fig. 3. Probability of different types of variations of the electric field strength during the thunderstorm, and probability of the types of thunderclouds that caused bursts in the neutron component.