Dependence of the neutron burst amplitude on a jump of electric field and a height of lower cloud amount edge during thunderstorms over Yakutsk

STARODUBTSEV S.A., KOZLOV V.I., TOROPOV A.A., GRIGORYEV V.G., KORSAKOV A.A., KRYMSKY G.F., MULLAYAROV V.A., GOLOLOBOV P.YU.

Yu.G. Shafer Institute of Cosmophysical Research and Aeronomy of SB RAS, 31 Lenin Ave., 677980 Yakutsk, Russia

starodub@ikfia.ysn.ru

Abstract: On results of registration of short-term neutron bursts during 12 thunderstorms observed in 2012 in Yakutsk is informed. The data of neutron monitor and electrostatic fluxmeter arranged in one place of observation, are used. Experiments carried out by us on registration of 60 thunderstorms during 2009-2012 showed that because of orographic peculiarities of the locality, lightnings fall , mainly, either along a coastal line of the river Lena, or along the edge of terrace bordering the Tuymaada valley where Yakutsk is situated. In 2012 during 9 thunderstorms we registered the neutron bursts at a distance of $3 \div 6$ km from point of impact of lightning into the ground. In this case, the height of low edge of thunderstorm clouds was $0.9 \div 1.5$ km. It is shown that short-term (less than 5 min) bursts of neutrons with the amplitude up to 35% from the level of background are connected both with negative and positive lightning discharges. It is found that short-term neutron bursts during lightnings are registered when jumping the electric field exceeding the value of 2.5 kV/m.

Keywords: cosmic ray, neutron burst, thunderstorm, lightning.

1 Introduction

For the first time it was informed on the observation of short-term neutron bursts during thunderstorm discharges in [1]. Hereinafter, this phenomenon has been repeatedly confirmed by various experiments (see the review [2] and references in it). Later, for the purpose of establishing of possible physical mechanism responsible for this phenomenon, theoretical studies have been carried out. However, up to the present the nature of this phenomenon has not yet conclusively established [3, 4]. It is significant that these experiments have been carried out by means of the detectors installed at major heights in mountains [3, 5, 6, 7], i.e. they have been carried out under conditions when installations are practically at the same level as thunderstorm clouds [8] and measurements are made either inside clouds, or in the immediate vicinity of them. Unlike these experiments, our devices are arranged at the altitude of about 100 m above sea level and the registration of thunderstorm events is made at a considerable removal ($1 \div 3$ km) from the lower edge of cloudiness [9]. Our measurements are leading to the conclusion that events of neutron bursts are observed not at all thunderstorms. So, a problem of definition of conditions for the occurrence of such events appears.

2 Complex of instruments and data

To study neutron bursts during thunderstorms we used synchronized measurements of a complex of instruments installed in the Tuymaada valley of around Yakutsk [9]:

1) 1-min data of the cosmic ray (CR) spectrograph named after A.I.Kuzmin corrected for pressure. The spectrograph characteristics are the following: the geographic latitude is $61°59'21''N$, the geographic longitude is $129°41'52''E$, the altitude above sea-level is 95 m , the threshold of geomagnetic cut-off is 1.65 GV. The spectrograph consists of the neutron monitor 24-NM-64 and four muon telescopes of one type installed at levels 0, 7, 20 and 40 m of water equivalent (m w.e.) which are capable to measure the intensity of particles coming from 5 directions, i.e. the vertical, 30° and 60° from the north and south, respectively. In the neutron monitor the gas-discharge counters of SNM-15 type, and in the muon telescopes the counters of SGM-14 type are used.

2) 1-sec data of registration of the value and variations of atmospheric electric field carried out with two electrostatic fluxmeters. One fluxmeter was developed at ShICRA of SB RAS, its measuring range is $\pm 50\ kV \cdot m^{-1}$ and its instrumental error is $1\ V \cdot m^{-1}$. This instrument is placed on the building of cosmic ray spectrograph at height of 5 m from the ground level. The second fluxmeter was developed at the Institute of Radio Physics (Nizhnij Novgorod, Russia) has a measuring range of $\pm 40\ kV \cdot m^{-1}$ and instrumental error of $1\ V \cdot m^{-1}$, it is placed on a roof of main building of ShICRA of SB RAS (the geographical latitude is $62°01'29''N$, geographical longitude is $129°43'32''E$) at height of 28 m above-ground. The distance between these points of measurements is 4.2 km. Both devices have been calibrated in an artificial electric field.

3) During several thunder-storms observed for 2011-2012 a high-speed (300 frames $\cdot s^{-1}$) video recording of thunderstorm discharges with the Casio EX-F1 camera was made.

4) Since 2012 a synchronous recording of electromagnetic signals and sound generated by thunderstorm discharges is also made. The application of this instrumental complex has allowed us to determine time, remoteness, the number of repeated discharges, place of shock and type of lightning.

3 Results and discussion

As an example, in figures 1 and 2 present the results of measurements of neutron intensity (a) and vertical component

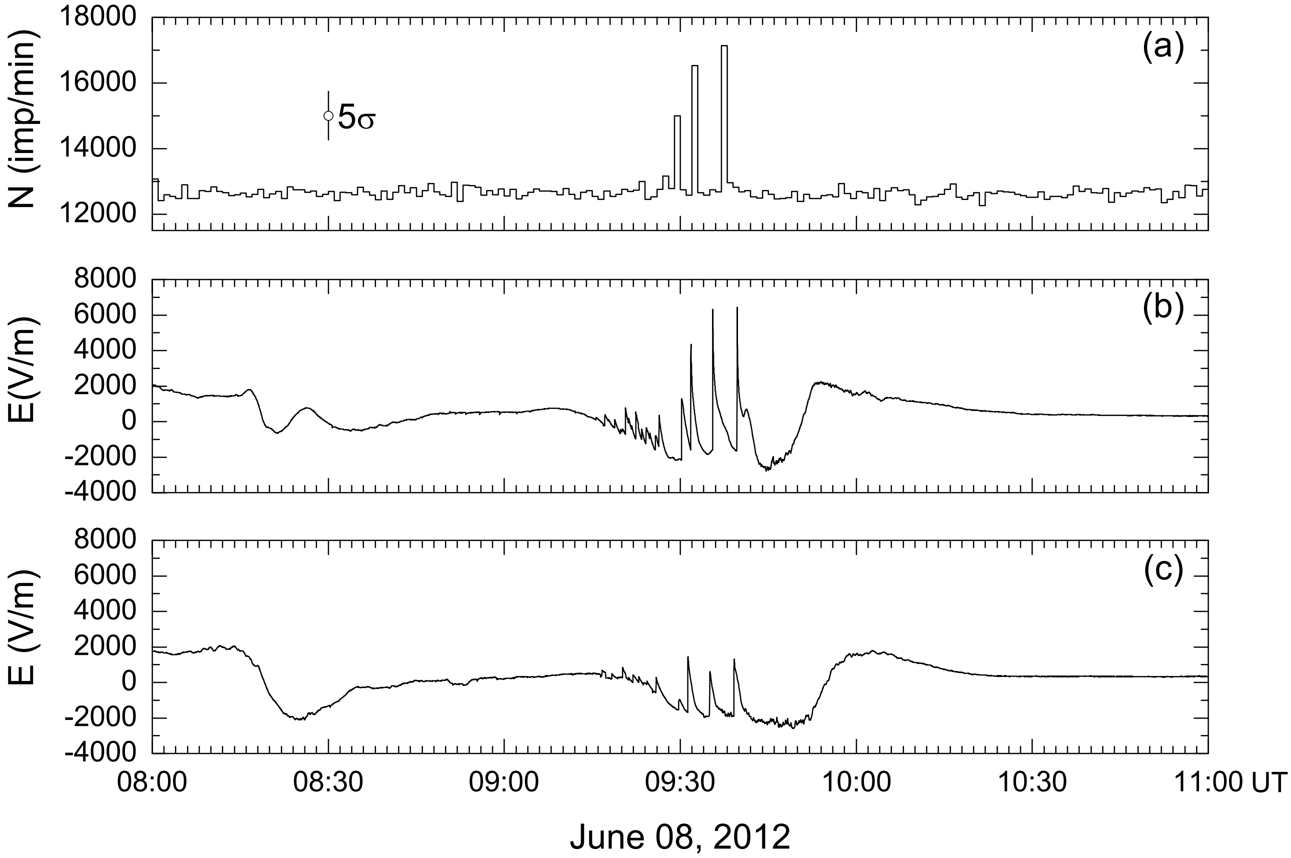

Fig. 1: Dependence of count rate of the neutron monitor (a), intensity of the atmospheric electric field registered by the electrostatic fluxmeters arranged around the CR spectrograph (b) and main building of ShICRA of SB RAS (c) on the time for the thunderstorm of June 8, 2012.

of the electric field (b) and (c) obtained in 2 points i.e. measurements using the CR spectrograph and measurements on the building of ShICRA of SB RAS. The figure 1 corresponds to the registration of lightnings with the negative discharges and figure 2 – with positive ones. As seen from the given Figures the neutron bursts are observed irrespective of the electric field direction in lightning discharges. It also follows from figures 1 and 2 that neutron bursts of neutrons are registered not at each discharge of a lightning. The analysis shows that from 53 thunderstorms observed in the Tuymaada valley for 2009–2012, statistically significant bursts of the fluxes of neutrons were registered during lightning discharges which happened during only 15 powerful thunder-storms. In this case we registered 13 thunderstorms with positive lightning discharges. In them only in the first case the events of neutron bursts were observed. In the rest 40 thunderstorms with the negative lightnings we registered 14 events of neutron bursts. Therefore, there is a natural problem on the possible mechanism of neutron generation, dependence of registration of neutron bursts on the direction and value of the jump of electric field during the lightning discharges, their remoteness from the point of observations and height of the lower edge of thunderstorm cloudiness.

The analysis carried out by us has shown that the used complex of devices can ensure a registration of lightnings observed within about 10 km radius of the CR spectrograph. In this case the point of impact into the ground, mainly, on the mountain terrace, or on the shoreline of the Lena river surrounding the Tuymaada valley in which our devices [10] are arranged. Besides, in the valley itself lightnings also get to the TV-tower of Yakutsk arranged at a distance of about 4 km from the CR spectrograph.

Our observations lead to the conclusion that the average amplitude of neutron bursts exceeds a statistical error of measurements by a value of 5σ and more, and their duration is 1 to 4 minutes. When passing a thunderstorm cloud over the point of observation at the surface against the background of atmospheric electric field of average intensity ($E \sim 100\ V \cdot m^{-1}$) the slow (to 1 hour) variations of field with the amplitude of $\sim 1000\ V \cdot m^{-1}$ are registered. At the same time at registering of lightning discharges the rapid jumps (their duration is of few seconds) of electric field may run up to $20\ kV \cdot m^{-1}$.

In figure 3, as an example the dependence of amplitude of neutron bursts of neutrons on the value of jump of the electric field caused lightning discharges, for 6 thunderstorms observed in 2012 is shown. From figure 3 follows that statistically significant neutron bursts are observed at values of a jump of electric field mainly exceeding the values of $2\ kV \cdot m^{-1}$. The dependence on a height of lower edge of the thunderstorm cloudiness (solid symbols) whose characteristic value accounts for 1500 m over the ground surface is simultaneously manifested. In the presence of lower cloudiness and jumps of the electric field less than $\sim 1\ kV \cdot m^{-1}$ either neutron bursts of small amplitude (not exceeding 3%) or usual fluctuations of neutron flux relative to average value (open symbols), not connected with lightning discharges are registered.

The most probable mechanism among the suggested

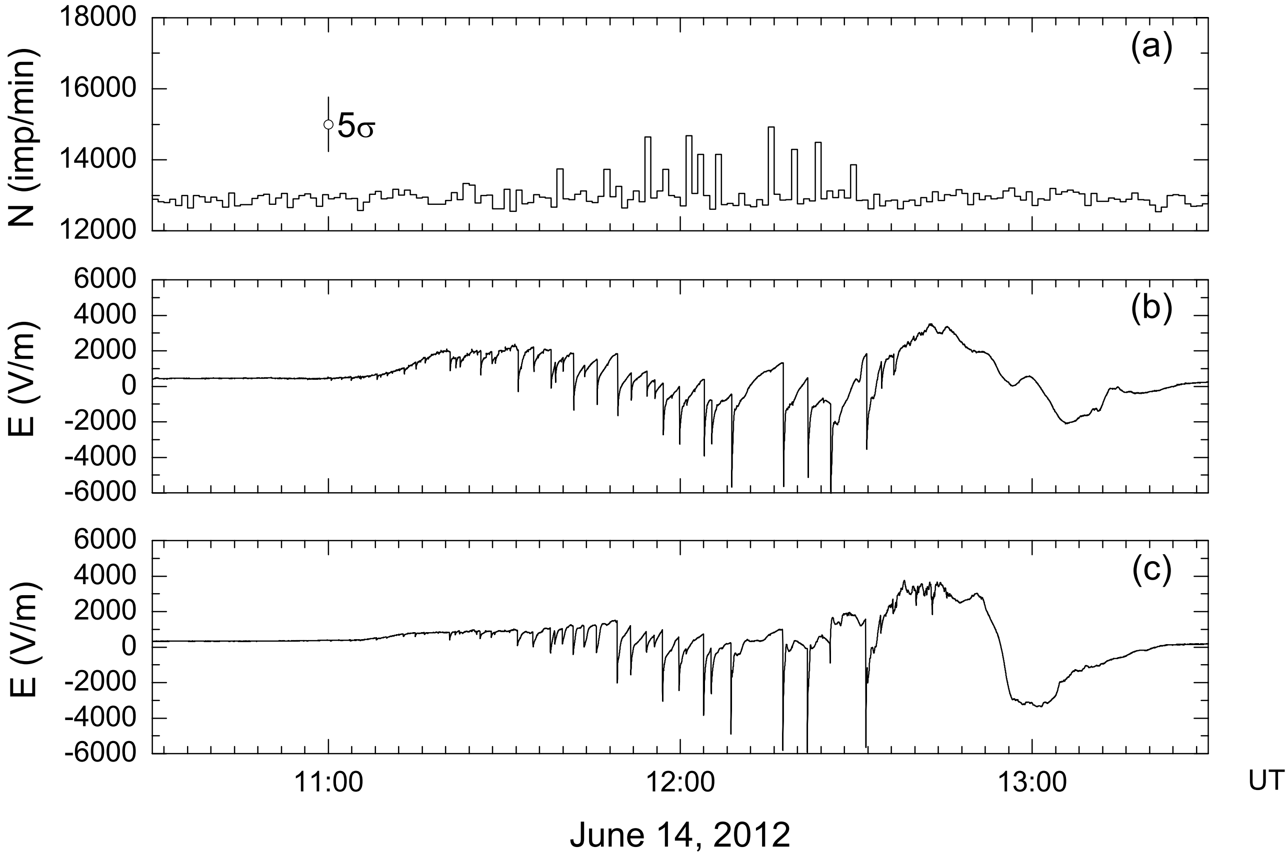

Fig. 2: The same for thunderstorm of June 14, 2012.

mechanisms of neutron generation at present time one can consider the mechanism of a photodisintegration of air atoms by a braking gamma radiation from the escaping electrons (Gurevich's discharge [3]). This mechanism is well-grounded in works by Babich (see [4, 11] and references in them). However, the detailed comparison of the short-term increases of neutron monitor count rate with signals from lightning discharges shows that neutron bursts can precede prompt jumps of the electric field. Hence, the reason of bursts can be not related to the lightning channel. Apparently, in this case the neutron bursts are a consequence of electric field growth during the period before lightning discharge. Then one of the possible mechanism of this phenomenon can be the electric field effect on cascade nucleons of the secondary CR which ultimately make a contribution to the neutron intensity registered by the monitor. The electric field of the order of $1kV \cdot m^{-1}$ on the scale of 100 m is capable of adding tens of MeV to the energy of secondary nucleons. At particle energies of hundreds of MeV it will create the increase in tens percents that corresponds in order of the value to the observable neutron bursts. The mentioned mechanism can act only in those cases when the electric field is directed from a cloud to the ground. The event of June 14, 2012 (see figure 2) confirms such sign of the field. However, these are rare events and further observations for a set of sufficient statistics are required.

4 Conclusion

Thus, we have presented the our study results of the connection between thunderstorms and short-term neutron bursts observed in Yakutsk for 2009-2012. Although the thunderstorms in Yakutsk occur infrequently nevertheless we found the following:

1. It is established that statistically significant neutron bursts near to the sea level are observed far from in all thunderstorms. They are mainly registered during negative lightning discharges.

2.The dependence of neutron burst amplitude on the value of jump of the electric field caused by lightning discharges and height of the lower edge of cloudiness has been revealed.

Acknowledgment: This work was supported by the Russian Foundation for Basic Research (project No. 12-02-00174-a), the Presidium of the Russian Academy of Sciences (program No.10), the Council of the President of the Russian Federation for Support of Leading Scientific Schools (project No. NSh-1741.2012.2), Integration project of SB RAS (project No.79), and the Ministry of Education and Science of the Russian Federation (project No.8404).

References

[1] G.N. Shah et al., Nature 313 (1985) 773-775 doi:10.1038/313773a0.
[2] A.S. Lidvansky, Journal of Physics G: Nuclear and Particle Physics 29 (2003) 925-937 doi:10.1088/0954-3899/29/5/313.
[3] A.V. Gurevich at al., Physics Letters A 165 (1992) 463-468 doi: 10.1016/0375-9601.
[4] L.P. Babich, Geomagnetism and Aeronomy 47 (2007) 664-670 doi:10.1134/S0016793207050155.

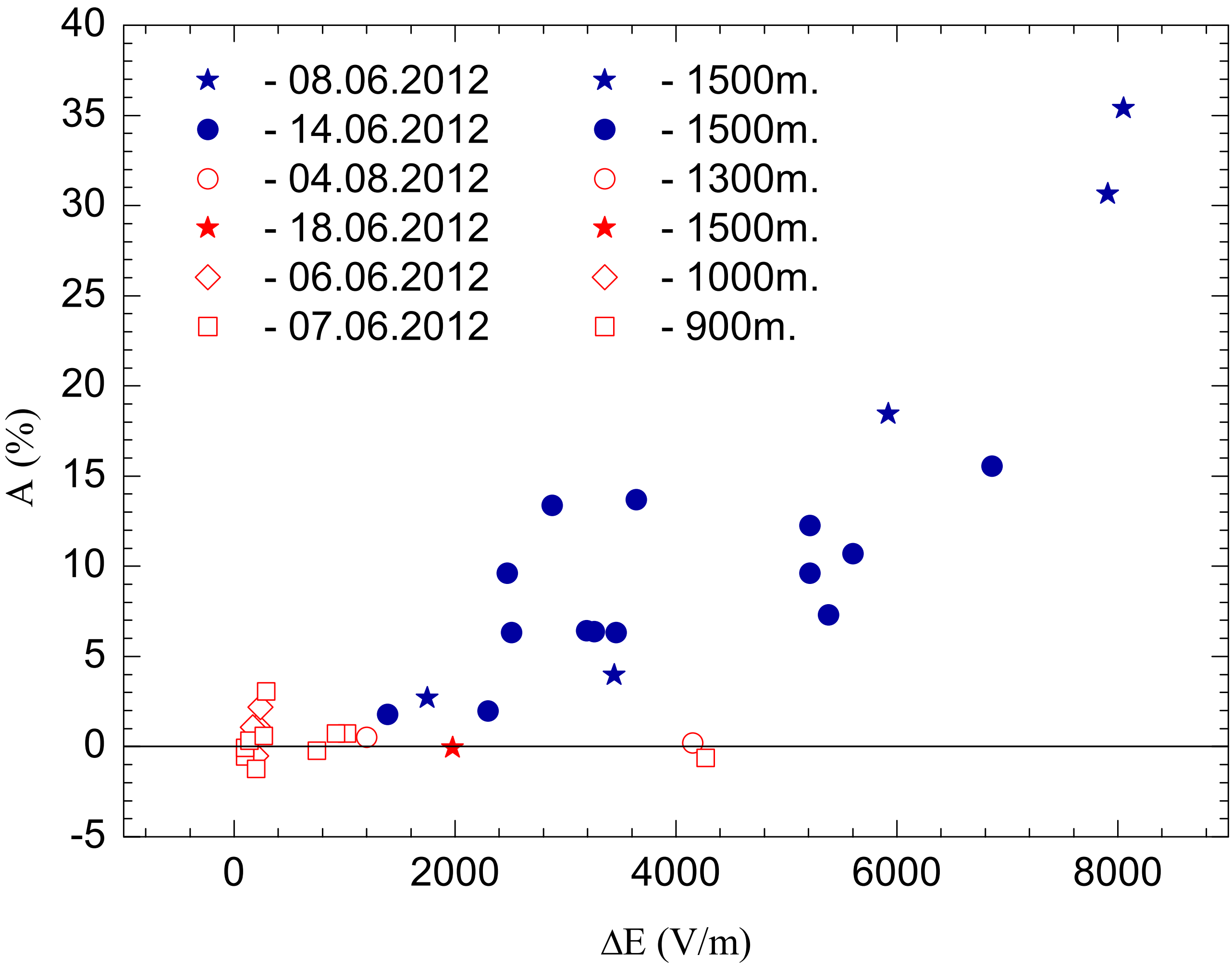

Fig. 3: Dependence of the amplitude of neutron bursts on the value of jump of the electric field caused by lightning discharges for the events of thunderstorms of 2012 registered in Yakutsk. The zero level of neutron flux fluctuations before the onset thunderstorms is shown by a solid line. The symbols show the date of thunderstorm events and height of the lower edge of cloudness.

[5] A.P. Chubenko et al., Journal of Physics G: Nuclear and Particle Physics 35 (2008) 085202 doi:10.1088/0954-3899/35/8/085202.
[6] N.S. Khaerdinov et al., Atmospheric Research 76(2005) 346-354 doi:10.1016/j.atmosres.2004.11.012.
[7] A. Chilingarian et al., Physical Review D 82(2010) 043009 doi:10.1103/PhysRevD.82.043009.
[8] A.V. Gurevich et al., Physics-Uspekhi (Advances in Physical Sciences) 52(2009) 735-745 doi:10.3367/UFNe.0179.200907h.0779.
[9] S.A. Starodubtsev et al. Journal of Experimental and Theoretical Physics Letters 96 (2012) 188-191 doi:10.1134/S0021364012150106.
[10] A.A. Toropov et al. Journal of Atmospheric and Terrestrial Physics 94 (2013) 13-18doi: 10.1016/j.jastp.2012.12.020.
[11] L.P. Babich et al., Journal of Experimental and Theoretical Physics Letters 97(2013) 333-339 (in Russian) doi:10.7868/S0370274X13060015