The correlation between the gamma-ray flashes and electron bursts associated with thunderstorm activity in the near-Earth space

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Abstract. This paper is dedicated to study of the interrelation between gamma-ray flashes of atmospheric origin, associated with lightning discharges, and high-energy electron bursts registered in the near-Earth space below the radiation belt. The database of high-energy electron bursts in the energy range of 3-30 MeV obtained in ARINA and VSPLESK satellite experiments and the database of terrestrial gamma-ray flashes with energies up to 17 MeV registered by the NASA RHESSI satellite are used in the work. The results of the analysis of electron bursts and gamma ray flashes that coincide in time and located at the same L-shell are presented at this work.

1. Introduction
Associated with lightning activity gamma-ray flashes of terrestrial origin (TGFs - Terrestrial Gamma ray Flashes) were discovered in 1994 [1] by the BATSE instrument on board Compton cosmic gamma-ray observatory. The most common mechanism of their generation is bremsstrahlung emission of relativistic electrons, accelerated by atmospheric electric field above thunderclouds [2]. This work is devoted to study of the interrelation between TGFs and high-energy electron bursts, which have been registered in near-Earth space below the radiation belt. The database of high-energy electron bursts with energies from 3 to 30 MeV obtained in ARINA and VSPLESK satellite experiments and TGFs registered by Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) measuring gamma radiation with energies up to 17 MeV were used in this work. The most of high-energy electron bursts (70-80%) have the thunderstorm origin [3]. Most of these bursts are associated with precipitations of the electrons from the radiation belt caused by electromagnetic disturbance generated by the lightning discharges. But some bursts could have another origin, for example, associated with Relativistic Runaway Electron Avalanche (RREA) process (Gurevich’s mechanism [2]), whereby electrons are accelerated to high energies in high altitude electrical discharges above thunderstorm clouds. In this case, the electron bursts obtained in ARINA and VSPLESK satellite experiments could be accompanied with flashes of bremsstrahlung registered by the NASA RHESSI satellite.

2. Scientific experiments equipment
The database of high-energy electron bursts obtained in ARINA and VSPLESK experiments monitoring bursts of high-energy electrons in magnetosphere and database of TGFs [4] received from
the RHESSI Space Observatory, accumulated in the period from 2006 to 2013 were used together to search for a possible correlation between high-energy electron bursts and TGFs.

ARINA experiment was carried out on the Resurs-DK1 satellite with the orbital inclination of 70°, and the altitude in the range from 360 to 600 km. The energy range of registered electrons is from 3 to 30 MeV and the energy resolution of the detector for electrons is 15%.

RHESSI Space Observatory inclination is 38° and the altitude is about 600 km. The energy range of detected gamma-ray flashes is from 3 keV to 17 MeV with the energy resolution in the 3 to 5 keV range for energies of gamma-rays from 1 to 17 MeV.

3. Methods of data processing
As known the main areas of the thunderstorm activity on the Earth locate in the region of Indonesian islands, central Africa and South America. The highest intensity of lightning discharges places is in the two last regions. [5] The similar distribution is observed for TGFs. Therefore, it seems that origin of TGF is related to thunderstorm activity.

Figure 1. Scheme of runaway electron acceleration and bremsstrahlung generation. Figure 2. Movement of electron beam in magnetosphere.

Figure 1 schematically shows the process. The Quasi-Electrostatic field above a thundercloud [6] appears after a positive lightning discharge cloud-to-ground, creating condition for the development of high-altitude discharge. The presence of seed electrons with above-critical energies leads to development of avalanches of electrons and formation of runaway electrons and TGFs. Accelerating in a pulsed field, electrons move along the electric field to heights of about 35 km [7] and then they change the direction and move along the geomagnetic field lines. Bremsstrahlung gamma rays produced at a height of 30-35 km move upward into the space. Therefore the coordinates of TGF registration and approximate height of their generation define the L-shells of gamma-ray flashes. The L-shell of electrons is determined by the place of their registration in the near-Earth space. The difference between the TGF and high-energy electron burst L-shells should not exceed $\Delta L = 0.05-0.07$ [5].

If intensity of relativistic electrons beam moving in the magnetosphere is high enough (more than $10^5$-$10^6$ cm$^{-2}$s$^{-1}$) then beam-plasma instability can lead to the interaction of electrons with plasma
waves [7]. As a result of such interaction, electron pitch-angles may change and it can be assumed, that their mirror points can go up more than 100 km above the Earth (figure 2). Such electrons can drift along the longitude and can be registered by the instruments.

To test this theory, coincidences of electron bursts and gamma-ray flashes in time and L-shells were investigated. Temporal correlation was defined with a delay of registration of electron bursts from TGFs less than ten minutes (the maximum possible of the drift period of the electrons that had been detected in ARINA experiment) [8], if an electron burst is registered at another longitude of L-shell of TGFs.

4. Results of data analysis

To test the hypothesis selected electron bursts exceeding the background threads by more than $3\sigma$ standard deviation ($>3\sigma$). Data of catalogs [4] were evaluated and TGFs exceeding the background by more than $5\sigma$ standard deviation ($>5\sigma$) were selected for analysis.

The L-shell distributions of electron bursts ($>3\sigma$) and TGF ($>5\sigma$) were built are given in figure 3. As can be seen at graphs they are similar, therefore it suggests that electron bursts and TGFs can have a common physical nature.

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![Figure 3](image-url)

**Figure 3.** The distributions of high-energy electron bursts and TGF in the L-shells.

~42700 high-energy electron bursts ($> 3\sigma$) and ~1700 TGF ($>5\sigma$) registered during from 2006 to 2012 have been analyzed. As a result, 17 of events satisfied the following criteria were selected: electron burst and TGF should be located on the same L-shell with accuracy $|\Delta L| \leq 0.05$ [5] and time interval between observation TGF and electron burst should be less than 10 minutes (drift period).

Calculating of the longitudinal electron drift allows determining the electron energy [9] if the drift time of electron from the point of gamma ray generation (RHESSI position) to the place of the electron burst registration by ARINA instrument is known. This gives a possibility to reject the events with the electron energy out of the energy range of ARINA spectrometer.

Analysis of the electron trajectories allows rejecting of events in which the electrons cross the region of South Atlantic Anomaly (SAA) due to their most likely death there.

As a result of the analysis, they were found three events (electron burst and TGF) in a good agreement with all set criteria such as: correlations on time and the L-shell, the calculated energy is in
energy range of ARINA spectrometer and the trajectory of electrons doesn't cross SAA. These events are presented in figure 4.

**Figure 4.** Map of the global thunderstorm activity with the registration places of TGF and electron burst marked on it.

5. Conclusion

It was shown that the distributions of high-energy electron bursts and TGF in the L-shells are similar. It can be assumed that the genetically related events among correlating electron bursts and TGFs can exist. Therefore it is necessary to increase the statistic by adding the databases of ARINA and RHESSI experiments for 2014-2015 years.

The number of random coincidences would be calculated, and then it could be concluded of the reliability of this method.

Acknowledgments

We acknowledge David M. Smith from the University of California, Santa Cruz for providing of processed data of TGFs.

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