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Observation of Terrestrial Gamma-Ray Flashes in the RELEC Space Experiment on the *Vernov* Satellite

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Abstract—The RELEC scientific payload of the *Vernov* satellite launched on July 8, 2014 includes the DRGE spectrometer of gamma-rays and electrons. This instrument comprises a set of scintillator phoswich-detectors, including four identical X-ray and gamma-ray detector with an energy range of 10 kev to 3 MeV with a total area of ~500 cm^2 directed to the atmosphere, as well as an electron spectrometer containing three mutually orthogonal detector units with a geometric factor of ~2 cm^2 sr. The aim of a space experiment with the DRGE instrument is the study of fast phenomena, in particular Terrestrial gamma-ray flashes (TGF) and magnetospheric electron precipitation. In this regard, the instrument provides the transmission of both monitoring data with a time resolution of 1 s, and data in the event-by-event mode, with a recording of the time of detection of each gamma quantum or electron to an accuracy of ~15 μs. This makes it possible to not only conduct a detailed analysis of the variability in the gamma-ray range, but also compare the time profiles with the results of measurements with other RELEC instruments (the detector of optical and ultraviolet flares, radio-frequency and low-frequency analyzers of electromagnetic field parameters), as well as with the data of ground-based facility for thunderstorm activity. This paper presents the first catalog of Terrestrial gamma-ray flashes. The criterion for selecting flashes required in order to detect no less than 5 hard quanta in 1 ms by at least two independent detectors. The TGFs included in the catalog have a typical duration of ~400 μs, during which 10–40 gamma-ray quanta were detected. The time profiles, spectral parameters, and geographic position, as well as a result of a comparison with the output data of other *Vernov* instruments, are presented for each of candidates. The candidate for Terrestrial gamma-ray flashes detected in the near-polar region over Antarctica is discussed.

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1. INTRODUCTION: BRIEF OVERVIEW OF TERRESTRIAL GAMMA-RAY FLASHES

The experiment with the RELEC scientific payload on the *Vernov* satellite included observations of (a) transient (fast) energetic phenomena in the Earth atmosphere, (b) precipitations of magnetospheric relativistic electrons, and (c) variations in electromagnetic fields in the near-Earth space [1]. On July 8, 2014, the satellite was launched into the polar (640 × 830 km) sun-synchronous orbit with an inclination of 98.4°. The scientific payload included instruments for detecting gamma-ray flashes of terrestrial and cosmological origin, precipitations of magnetospheric electrons of relativistic and subrelativistic energies, and observations of transient luminous phenomena in the Earth atmosphere, as well as studies of electromagnetic fields in the near-Earth space. A detailed description of the equipment is given in [1].

One of the main goals of the experiment was the observation of Terrestrial gamma-ray flashes (TGF). It is usually supposed that TGFs arise in the upper atmosphere and are accompanied by some particular type of thunderstorm activity (positive intracloud bottom–up discharges). These gamma-ray flashes were discovered in a BATSE experiment on the Compton Gamma-ray Observatory (CGRO) [2]. Since 1991–2000, 36 flashes have been detected, some of which were associated with lightning. Initially, the TGF study was not planned to be the purpose of the CGRO BATSE experiment; the minimum duration of the time interval for generating the 64-ms trigger was not consistent with the typical TGF duration (less than 1 ms). For this reason, only very long and bright flashes have been detected in this experiment in the range of 0.01–3.0 MeV by means of 8 NaI(Tl)-type detectors with the total area of ~2000 cm^2.

Terrestrial gamma-ray flashes have also been observed during the *RHESSI* space experiment, whose basic purpose was to study the solar gamma emission. To date, more than 1000 terrestrial gamma-ray flashes were detected in this experiment [3, 4].

The new era in the TGF study is associated with the Fermi space gamma observatory, which was launched into orbit in 2008. For terrestrial gamma-ray flash detection, the Gamma-ray Burst Monitor (GMB) detectors were used in this experiment. To date, more than 2700 terrestrial gamma ray flashes were detected in the energy range of 10 KeV to 40 MeV, where the average detection rate is one flash per ~4 days [5, 6]. Along with TGFs, the beams of electrons associated with TGFs (Terrestrial Electron Beams, TEB) and even the beams of positrons were discovered in this experiment [7]. In energy ranges higher than 10 MeV, TGFs can be detected by a telescope (LAT) with an effective area of ~2000 cm^2 (for 10 MeV) in the Fermi gamma-ray observatory [8], and in the range up to 100 MeV in the AGILE gamma-ray observatory using the silicon tracker [9], as well as by the MCAL mini-calorimeter (with an effective area of ~500 cm^2 for 10 MeV). Using the latter instrument, 308 flashes have been detected in 2009–2012 [10], and it was confirmed that, in accordance with the *RHESSI* results, steepening of the spectrum was observed at an energy of ~10 MeV.

Several experiments devoted to *TGF* observations have been implemented in Russia. Among them was the experiment with the RGD instrument [11] on the *Chibis-M* microsatellite [12] in 2012–2014. One should also note that the Lightning-gamma experiment implemented in 2011 on the outer panel of the *International Space Station* (*ISS*) [13]. In the course of these experiments, terrestrial gamma-ray flashes from the Earth's atmosphere were not detected. At the same time, using the SONG-D detector of the AVS-F hardware, 47 events were detected on the *CORONAS-F* satellite; they were identified as TGFs [14]. A few events were noted that have been simultaneously detected in both this experiment and the *RHESSI* space observatory [14].

Finally, during the Earth's observations, using telescopes with a coded aperture of the INTEGRAL gamma-ray observatory, in 2006 [15] and 2012, the search for bright TGFs was performed in the data of the SPI instrument, which consisted of 19 high-pure Ge detectors with a total area of ~500 cm^2. Nearly ten candidates for TGFs have been found during the full time interval of observations of about 5 days. Here, the mean distance to the Earth was ~70000 km [16]. If the nature of these candidates will be confirmed, the estimate of luminosity in the TGF source may be increased by an order of magnitude.

Since only a dozen gamma-ray quanta are usually detected in each TGF, the properties of flashes are examined mainly by statistical analysis techniques. The median average duration of a typical terrestrial gamma-ray flash is ~0.1 ms, which follows from the distribution in the T_{50} value, obtained in the experiment at the Fermi Observatory [5] (T_{50} is the duration of a time interval, during which 50% samples are detected in one event). This drastically contrasts with the duration of flashes detected in the BATSE experiment, which is a few milliseconds. However, one should bear in mind that primarily bright, long-lasting events have been selected in this experiment. Most of the flashes are single-peak, and only some of them have light curves that contain two peaks. Here, the peaks are quite asymmetric [17] and can be approximated by the FRED (Fast Rise Exponential Decay)-type light curve [18]. When obtaining the average light curve by averaging the profiles of all flashes detected in the *RHESSI* experiment, the longer (compared to the peak) pedestal (~5 ms) was obtained [3]. The nature of this pedestal is not completely clear; however, it can be stipulated by the features of an averaging algorithm.

The TGF spectrum is usually studied by summing all photons over all flashes. The spectrum with TGF can be reasonably described by the model of the relativistic runaway electron avalanche (RREA) [19], which propagates in the Earth's atmosphere at 15–21 km and generates the bremsstrahlung [20]. Compared with X-ray radiation observations, in a thunderstorm cloud, the spectrum shifts towards higher energies (the maximum lies in the area of 300–500 keV). In this case, maximum energies of gamma–quanta can reach values of dozens of MeV. According to AGILE data, the TGF spectrum, detected by a silicon tracker, extends up to almost 100 MeV [9] and does not break at 10 MeV, which contradicts the RREA model, if only a large quantity of original low-energy electrons (so-called *seed electrons*) is not suggested. The alternative approach suggests multiplying electrons in the acceleration process, which is considered in the model of relativistic feedback discharge (RFD) [21].

The cold RREA theory considers the acceleration of thermal electrons up to relativistic energies, which requires high values of the accelerating electric field of about 280 kV/cm. For runaway electrons generated by a lightning current pulse, this may exist in strong fields near the streamer and edges of a lightning step-leader [22]. Due to the large number (~10^{12}) of cold electrons, the generation of a gamma-ray flash requires a rather small multiplication factor in an avalanche (~10^5–10^6). The duration of a coronal streamer discharge on one step of a lightning leader is very short (~10 μs); however, due to the Compton dispersion, the duration of gamma-ray quanta growth at satellite altitudes can be ~50 μs [23]. The gamma-ray flashes of this duration have been recently detected in the Fermi space observatory [24]. Thus, more typical flashes with durations of ~250–350 μs can be considered to be a superposition of gamma–quanta generated at individual steps of a lightning leader if the time between steps is less than the Compton scattering dispersion.

In the RFD model, it is assumed that a portion of the gamma–quanta pairs formed as a result of bremsstrahlung of accelerated electrons can undergo Compton scattering in the opposite direction and generate secondary avalanches due to the electrons that arise from the photoelectric effect and Compton scattering [21]. In addition, the contribution to secondary avalanches can be made by the positrons that arise in the process of the birth of gamma–quanta pairs. The RFD model suggests that the gamma-ray flash is generated in the process of lightning leader propagation between the charged regions of a thunderstorm cloud [25]. This implies that the gamma-ray flash should outstrip the lightning, which can, in principle, be checked by performing a thorough analysis of the accurate time of detecting the gamma-ray flash and the whistler accompanying a lightning. However, the latter can be generated by the avalanche of relativistic runaway electrons as such [25].

About half of flashes detected by the GBM instrument in the Fermi observatory is accompanied by very-low-frequency (VLF) radio signals [26], which are detected by the World Wide Lightning Location Network (WWLLN) [27]. Here, the time shift in TGF and WWLLN triggers is close to symmetrical one; that is, the outstripping of both TGF triggers and WWLLN triggers relative to each other is not observed [26].

Until now, the TGF geolocation is possible basically by searching correlations with WWLLN triggers. When the VLF signal from lightning is detected by several ground-based WWLLN stations, the coordinates of its source can be found with using triangulation. If there are no WWLLN stations in the TGF detecting area, the location of a flash source cannot be performed. In this case, one can assume that the source lies within the limits of a cone with an opening angle of 60° relative to the direction to the Nadir.

2. TECHNIQUE FOR SELECTION OF CANDIDATES INTO TERRESTRIAL GAMMA-RAY FLASHES

Detection of terrestrial gamma-ray flashes was carried out by means of DRGE-1 and DRGE-2 units of the DRGE instrument, which provided measurements of the fluxes and spectra of hard electromagnetic radiation with gamma–quanta energies in the range of $E = 0.01–3.0$ MeV; electrons with $E = 0.2–15$ MeV and protons with $E = 4–100$ MeV [1].

The instrument consists of three units, i.e., two identical DRGE-1, DRGE-2, and DRGE-3 units. The physical and technical parameters of the DRGE-1(2) are presented in Table 1. Each of the DRGE-1(2) units contains two identical detector units (DRGE-11, DRGE-12 and DRGE-21, DRGE-22) that consist of a scintillation phoswich-detector and a photomultiplier.

Table 1

Energy range of	
photons	0.01–3 MeV
electrons	0.2–15 MeV
protons	14–100 MeV
Effective area of a scintillation detector	$4 \times 120 = 480$ cm^2 (for 4 detectors)
Field of view	2π sr (±90°)
Mass	~10.4 kg (for a unit)
Dimensions	$(0.36 \times 0.36 \times 0.18)$ m^2 (for a unit)
Information capacity	~150 MBt/day
Power consumption	~9 W (for a unit)

The phoswich-detector's scintillator is made of NaI(Tl) crystals with thicknesses of 0.3 cm and diameters of 13 cm, and CsI(Tl) crystals with thicknesses of 1.7 cm and diameters of 13 cm. Both detectors are in the optical contact and are put into a protective case. The DRGE-1 and DRGE-2 detectors are pointed to the Nadir (towards the Earth).

During the experiment the continuous recording of DRGE-1(2) detector outputs was carried out in two modes, i.e., monitoring and event by event. To ensure the synchronous operation of all detector units with fine time resolution, each unit used the initialization of an internal timer at the instant of synchro-pulse arrival from the satellite board. The timer of each unit has a period of 15.48 μs. The timer stability of ~10^{-5} allows one to provide synchronization accuracy of ~15 μs.

In the monitoring mode, for each detection unit during exposure time (1 s), the average integrated count of gamma–quanta was measured separately for each NaI(Tl), CsI(Tl) crystal, and the total count in both crystals. The minimum threshold energy of a detected quantum was ~10 kev for NaI(Tl) and ~25 kev for CsI(Tl). Thus, in the monitoring mode, we had almost continuous time series of rates of counting gamma–quanta with energies >10 keV in NaI(Tl) and >25 keV in CsI(Tl), averaged over 1 s.

In the event-by-event mode, for each detected gamma–quantum, we determined the time of detection and the values of amplitude codes, which allow one to determine the part of the detector in which the interaction occurred and in which the energy is released in the crystals. In view of existing restrictions on the transmitted data volumes, restrictions were imposed on the number of successively recorded events. For each detector, in the case of a relatively low background count (<1000 pulses per second in both crystals), no more than 800 events can be recorded successively during each second. If the background count is >1000 count/s, then no more than 200 events can be recorded successively every second, and if the

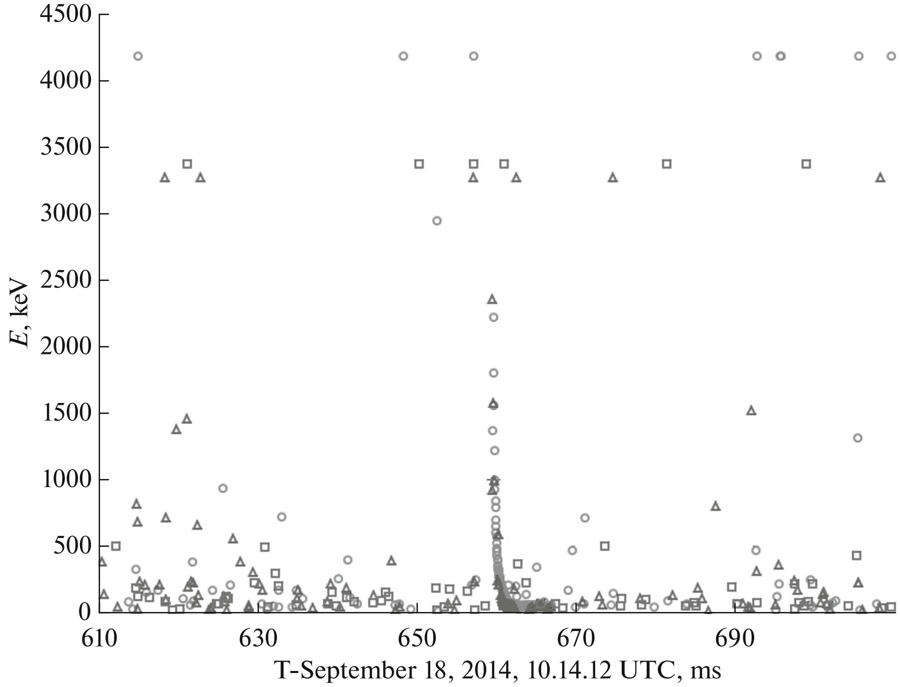

Fig. 1. Example of the energy release–time diagram, which shows events related to detecting heavy charged particles by DRGE-1 and DRGE-2 detector units. Events in detectors are marked by symbols: circle indicates DRGE1-1, triangle indicates DRGE1-2, square indicates DRGE2-1.

background count is >1500 count/s, then no more than 50 events. In the near-equatorial regions, the total background in both crystals was less than 800 pulses per second; that is, the data on all detected gamma–quanta have been recorded. In the area of polar caps, the total background was >1000 count /s; that is, only about one-fifth of the events detected per second had been recorded.

The example of event-by-event recording is presented in Fig. 1 in the form of an energy–time diagram. The abscissa axis in this diagram shows the time of detecting of each event, while the ordinate axis shows the total energy release in both crystals of the given detector unit. Thus, each point on the diagram reflects the detected event, while the diagram as a whole reflects the distribution of events in energy depending on the time. The noise path in the region of low energy releases corresponds to the signals conditioned by the intrinsic noise in the scintillators and in the photomultiplier. The path, which corresponds to the maximum values of energy releases, is associated with the electronics overloads caused by the detection of events that yield high-energy releases above the dynamical range limit.

Because terrestrial gamma-ray flashes are characterized by relatively low durations (<1 ms), to select them, we used the data obtained in event-by-event mode. In the near-equatorial regions, gamma–quanta are detected almost without any losses, which also favored the search for terrestrial gamma-ray flashes because they were observed mainly above the active thunderstorm formation areas, i.e., in the near-equatorial regions.

To select gamma-ray flashes, we used the condition of a significant excess of an average background count over the time interval of 1 ms in at least two detectors simultaneously. Because the TGFs have a hard spectrum, to search for candidates, we decided to consider only the events with energy releases of >400 keV, including those for which the energy release exceeded the energy range limit.

In this range, the average background count on the equator corresponds to detection of greater than one event per every few milliseconds and, as a criterion of significance, we choose the requirement of detecting at least five gamma–quanta in 1 ms at minimum by two detectors, or at least three gamma–quanta at minimum by three detectors. For the equator, this condition actually corresponds to the simultaneous detection of count rate increasing by two detectors at a significance level of 12σ, or by three detectors at the level of 7σ. For the polar cap region, the values of thresholds correspond to 8.5σ for detection by two detectors or 5σ for detection by three detectors. Taking into account the observation time, the presented significance levels give the expected number of random simulations for near-equatorial areas of no more than 0.0037 for a recording criterion no less than five gamma–quanta by two detectors and no more than 0.38 for a detection criterion of no less than three gamma–quanta by three detectors.

Table 2

No.	Time, UTC	Detectors 1234	Latitude, longitude	Duration, ms	Number of counts	ΔT (before)/ ΔT (after), WWLLN, s	Remarks
1	August 7, 2014, 22.20.55.135	++–+	26.2 W, 35.6 N	0.8	10	2954/16698	TGF
2	August 8, 2014, 00.31.07.030	+–++	132.04 E, 29.4 N	1.0	12	1/1	Candidate
3	August 16, 2014, 13.06.55.329	0+++	114.7 E, 24.2 N	0.8	10	1/4	Candidate
4	September 18, 2014, 10.15.34.922	+–0+	160.4 E, 8.3 N	0.4	31	42/14	TGF
5	November 2, 2014, 03.34.14.051	+0++	40.7 E, 77.6 S	2.3	18	87867/1736	Candidate

In fact, we have determined not the number of counts over an indicated time interval, but the duration of the interval occupied by several sequentially detected events. That is, the following requirement corresponds to the indicated criterion: for five sequentially detected events, the duration of the interval between the first and last counts must not exceed 1 ms. In addition, to prevent the detection of count rate increasing caused by intense background variations in the trapped radiation regions, we used an additional condition, i.e., the average background count in the interval of ±1 s from analyzed increasings must not exceed 1500 count/s.

As a result of applying the criterion considered above, we selected a variety of growths, but most of them turned out to be associated with the detection of heavy charged particles of galactic cosmic rays (see Fig. 1). These growths possess a specific shape in the energy release–time diagram: the first point corresponds to high-energy release, after which the monotonous decline is observed. This time profile shape is due to the fact that, when hitting the scintillation crystal, a heavy charged particle produces a very high ionization density in it, which results in drastic growth in multielectron noise in the photomultiplier tube (PMT) output. This is equivalent to the instantaneous illumination of a scintillator, which results in the amplitude overloading of input amplifying cascades. Here, the typical time that determines the duration of the decline is conditioned by nonstationary processes in the input circuit, the impedance of which depends both on interdinode PMT capacitances and on the input capacitance of a preamplifier and parasitic capacitances of electronics boards. To exclude the growths associated with detecting heavy charged particles, the additional criterion was developed for determining the declining monotonicity. This criterion is based on the requirement that, after the maximum energy release, all subsequent points on the energy release–duration diagram were characterized by a consistent decrease in energy release. As an optimum condition for the reliable identification of heavy charged particles, we choose the requirement that the number of these successive points was no less than 5.

3. RESULTS OF SELECTING CANDIDATES FOR TERRESTRIAL GAMMA-RAY FLASHES

After excluding intensity increasings, associated with detecting heavy charged particles, there remained actual candidates for terrestrial gamma-ray flashes. In total, 5 candidates for TGFs were selected. The list of these flashes is given in Table 2. It indicates the flash detecting time, the sub-satellite point coordinates at the detecting instant, the time intervals between the instants of detecting the flash and the nearest to it in time (before – $+\Delta T$, after $-\Delta T$) lightning, detected by the WWLLN network within the region bounded by a circle with radius of 1500 km from the subsatellite point. The third column of the table indicates combinations of detector units as follows: (1) DRGE-11, (2) DRGE-12, (3) DRGE-21, (4) DRGE-22. Here, the "+" sign implies that the given unit has detected the count significantly exceeded the background value in accordance with the criterion considered above; the "–" sign implies that there was no exceedance, and the numeral "0" indicates the absence of data.

The upper part of Figures 2–6 for all the selected candidates for TGFs presents the gamma–quanta distributions on the energy release–time diagrams, and the lower part—corresponding time profiles. In the figures, various symbols mark the gamma–quanta detected by various detector units as follows: a circle indicates DRGE1-1, a triangle indicates DRGE1-2, a square indicates DRGE2-1, and a rhombus indicate DRGE2-2. It should be noted that the structure of distribution on the energy release–time diagram for candidates for TGFs qualitatively differs from the

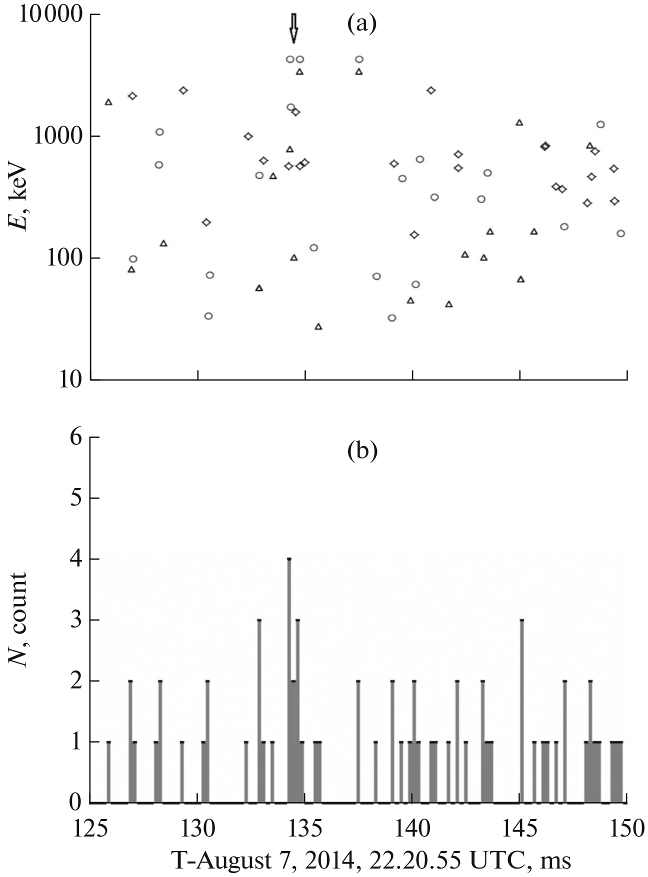

Fig. 2. Gamma–quanta distribution in (a) event-by-event recording and (b) time profile for candidate for TGF No. 1. Flash on energy–time diagram is marked by an arrow.

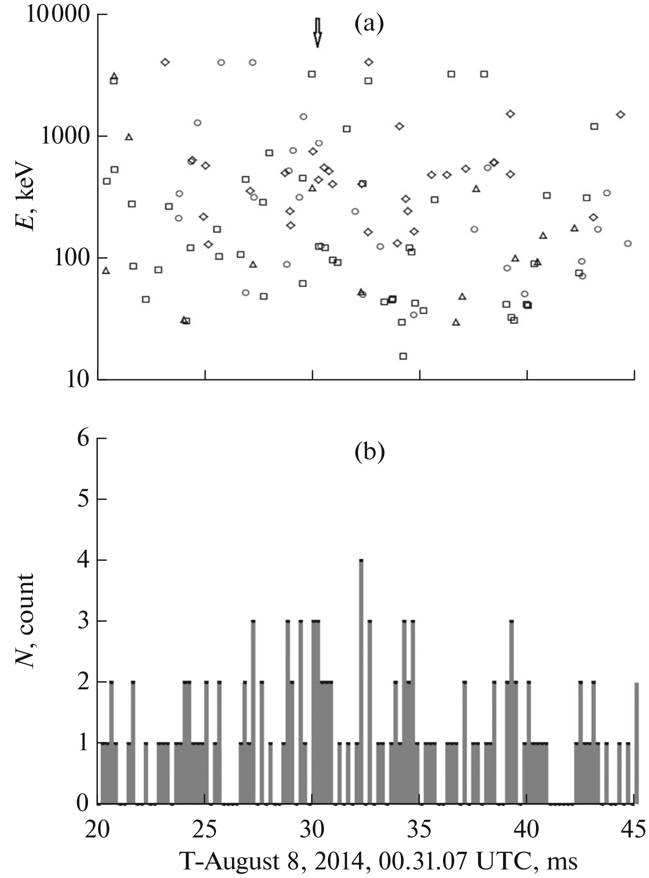

Fig. 3. Gamma–quanta distribution in (a) event-by-event recording and (b) time profile for candidate for TGF No. 2.

cases of detecting heavy charged particles. This is clearly illustrated on the diagram of Fig. 4a, in which both types of events are presented. In the case of a candidate for terrestrial gamma-ray flashes there is no typical decline; the points are concentrated in the narrow time interval (i.e., the event is short); the measured energy releases are relatively large, on the average (the energy spectrum is hard). These signs correspond to TGF parameters noted in the first section of this paper. The most intense event among the detected candidates for TGFs is the flash No. 4 (Table 2). As can be seen from Figs. 5a, 5b, this flash is rather short; its total duration is about 300 μs.

Figure 7 shows the map with marked positions of sub-satellite points for each selected candidate for TGF. With the exception of a single one, the flashes have been detected at low latitudes in the areas close to regions of intense thunderstorm formation.

4. DISCUSSION AND CONCLUSIONS

The total observation time during which the candidates for terrestrial gamma-ray flashes that satisfy the trigger condition were selected turned out to be 256.5 h or 10.7 days. The relatively short observation time was due to the fact that the *Vernov* satellite orbit had a high inclination; thus, the background conditions that are favorable for selecting the flashes and satisfying the trigger condition took place mainly in the geomagnetic equator region, the time of flying through which was less than 20% of the orbital period. At the same time, near-equatorial areas were mainly observed in other experiments conducted on spacecraft with orbits with low inclination. This allows one to compare the rate of detecting TGFs in the experiment on the *Vernov* satellite, i.e., about 15 flashes per month or one flash for several days, with the data of other experiments. The obtained recording rate, which has a smaller order of magnitude, does not contradict the results of the experiments on *RHESSI* [3], AGILE [32], and Fermi GBM [7], if in the latter one we only take into account the trigger flashes.

However, if we take into account the nontrigger flashes on the Fermi GBM, then the TGF detecting rate should be an order of magnitude higher [7]. This is due to the fact that the nontrigger flashes on the Fermi GBM were selected according to a softer (with respect to the threshold) criterion in the intensity;

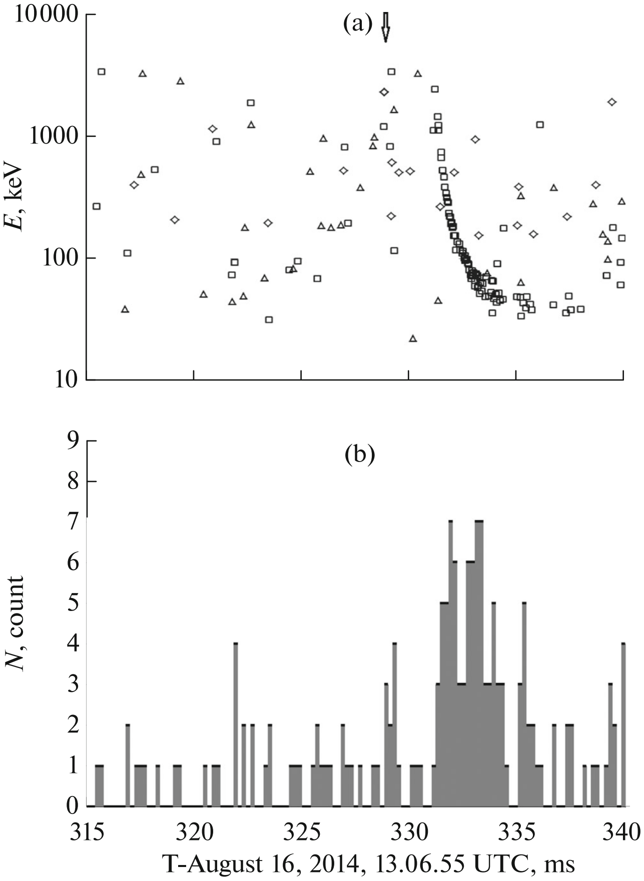

Fig. 4. Gamma–quanta distribution in (a) event-by-event recording and (b) time profile for candidate for TGF No. 3.

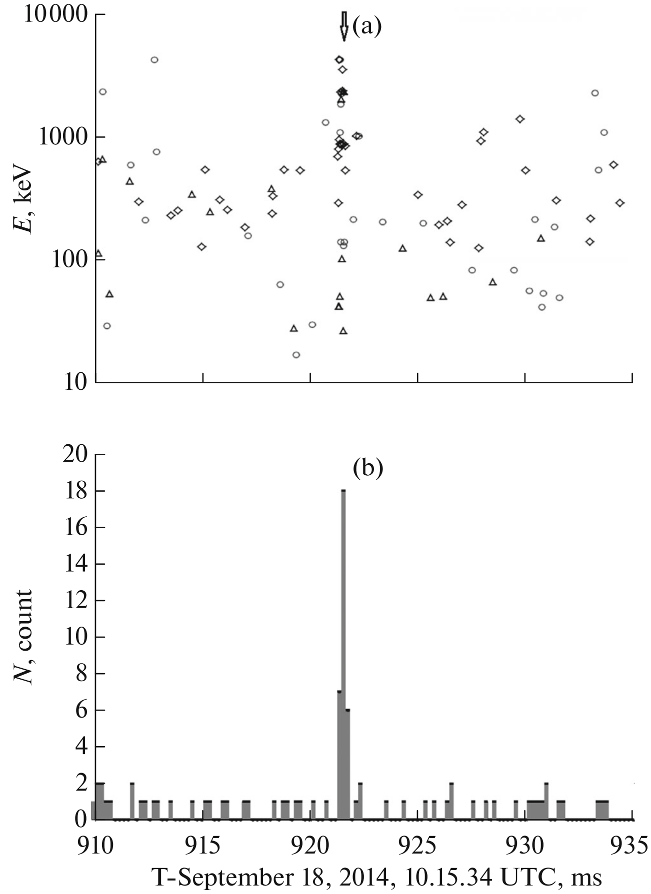

Fig. 5. Gamma–quanta distribution in (a) event-by-event recording and (b) time profile for the candidate for TGF No. 4.

therefore, they were less intense than the candidates for TGFs we have selected. It is known that the $N(S)$ distribution of terrestrial gamma-ray flashes has a power-law distribution in the observed intensity S of the form $N(>S) \sim S^{-\lambda}$; that is, the lower the detecting threshold S, the higher the number of events that should be observed (see, e. g., [3]). In addition, one should take into account that the Fermi observatory orbit is, on the average, 150 km lower than the *Vernov* satellite orbit. Thus, taking into account the ratio of the squares of distances, the detection of weak flashes on the *Fermi* was more likely. However, the main factor is the smaller effective area of DRGE detectors (480 cm^2, compared to the effective area of Fermi GBM detectors (2000 cm^2). Though the majority (except a single one) of the selected candidates for terrestrial gamma-ray flashes have been observed in the areas adjacent to thunderstorm regions, as can be seen from Table 2, none of them coincided with lightning detected by the WWLLN network. The time interval between the instant of detecting the candidate for TGF and the nearest-in-time lightning (both before and after the flash) exceeded the average interval between lightning strikes in this region.

We have also analyzed the data of the RFA (radio frequency analyzer) instrument that was a part of the RELEC payload [1]. The RFA instrument has measured the values of three components of electromagnetic wave's electric field in the frequency range from 50 kHz to 15 MHz. For all considered candidates for terrestrial gamma-ray flashes, except a single one (No. 5), the RFA data are available; however, any significant increasing of electromagnetic radiation intensity, which had duration comparable with lightning discharge typical times (~100 ms), have not been observed. This does not contradict the results obtained in the experiments onboard the *Chibis* spacecraft [28].

Thus, we may conclude that, according to the data of gamma-ray detectors of the RELEC instruments on the *Vernov* satellite, several terrestrial gamma ray flashes and some candidates were detected. The estimate of the flash detecting rate has shown that, with regard to the order of magnitude, it coincided with the recording rate of the trigger events of other experiments. The majority of candidates for TGF have been observed in areas adjacent to the active thunderstorm formation regions; however, there were no direct indications regarding the coincidence of gamma-ray

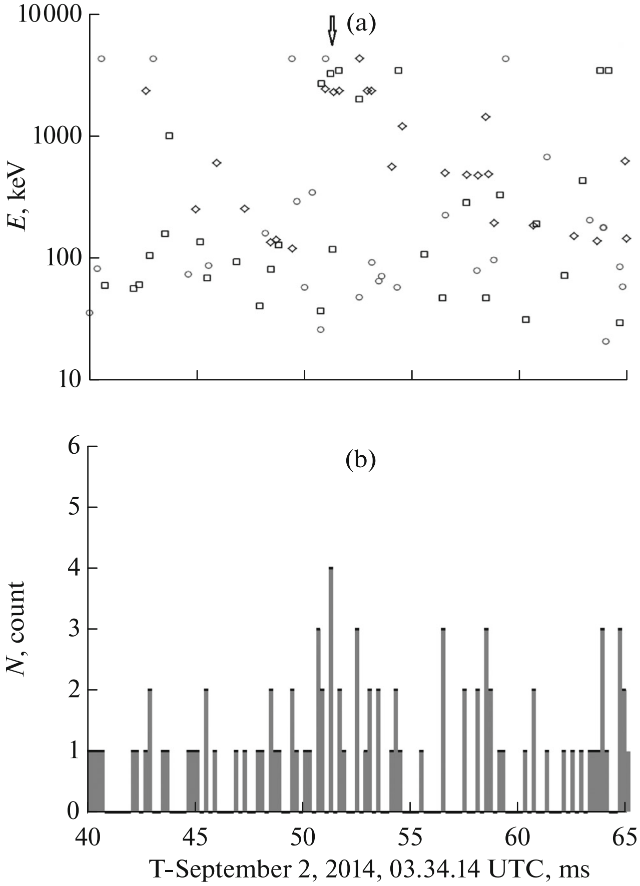

Fig. 6. Gamma–quanta distribution in (a) event-by-event recording and (b) time profile for candidate for TGF No. 5.

flashes with radio or optical flashes that usually accompany the lightning discharge.

The high-latitude candidate No. 5 (77.6° of south latitude, see Table 2) deserves separate discussion. For the time during which the criterion selection condition was fulfilled, nine counts have been detected. In this case, as follows from Fig. 2a, only two of them have fallen within the dynamic range boundaries, and the energy release of most of them exceeded the upper limit. This satisfies the selected trigger criterion because, as was noted above, the events for which the energy release exceeded the upper limit of the dynamic range are also included in the number of counts from which the candidates for TGF have been selected. At the same time, for the remaining selected candidates, including the most reliable candidates (2, 4), the opposite picture is true, i.e., the majority of counts during the flash lies within the dynamic range limits. It should be noted that the excess of events with energy release at the level of a boundary of instrument's dynamic range has been observed during the time interval of ~2.5 ms. In principle, the overloads can arise in detecting not only gamma–quanta of high energy (>3 MeV), but also the charged particles (see, e. g., [29]). Indeed, in the case of detecting high-energy protons of cosmic rays that interact with the spacecraft body, the avalanche of secondary particles can be generated, which interact with all detectors simultaneously. The counts were detected by three detectors simultaneously. The long duration of a candidate might be explained by the birth of short-living isotopes in detector's material. However, when detecting charged particles, some typical tail should be pres-

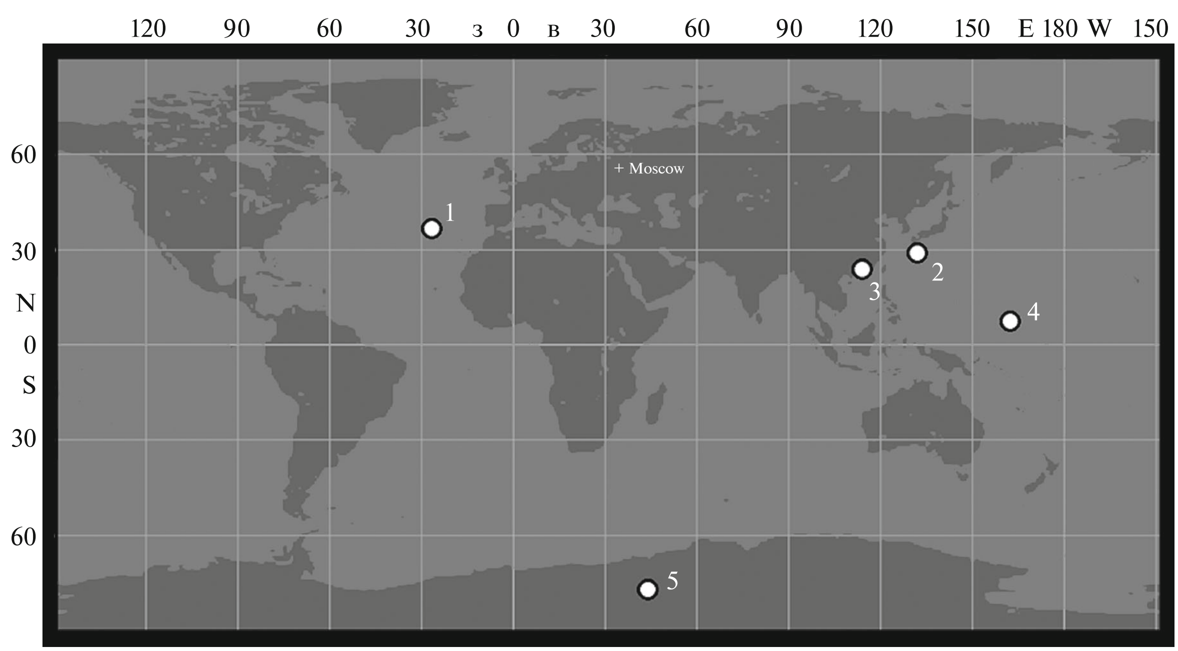

Fig. 7. Map illustrating the positions of subsatellite points (and, accordingly, the directions of axes of the detectors) at the instant of event detection, i.e., candidates for TGFs. Digits indicate numbers of candidates from Table 1.

ent on the energy release–time diagram (see Fig. 1), which is not observed in the case of the candidate under consideration (see Fig. 6a). Furthermore, the duration of a candidate could be explained by two successive TGFs that overlap in time. The relativistic electrons can also be considered a possible factor of gamma-ray flash simulation. However, no significant increasing was observed in the electron-detection channels during flash detection. Although the nature of this candidate cannot yet be identified unambiguously, there are no formal reasons to strike the high-latitude flash from the list of candidates for TGFs. If this candidate will be confirmed as a TGF in the subsequent data analysis, then it will be discovered for the first time that TGF activity at high latitudes is probably not associated with thunderstorm activity.

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