Radiation belt local disturbances of lightning and seismic origin

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Abstract. The results of the observation of bursts of high-energy charged particle fluxes in the near-Earth space, caused by local disturbances of the radiation belt and particle precipitation from it, in satellite experiments ARINA (on board the Resurs-DK1 from 2006) and VSPLESK (on board the International Space Station from 2008) are presented. New specialties were revealed in geographical distribution of particle bursts, pointing out that the large part of high-energy electron bursts interrelates with thunderstorm and seismic activities, at that some part of bursts locates in the regions of tectonic faults. Results of observation of high-energy electron precipitation from the radiation belt over the Japan region during the powerful seismic event, started on March 11, 2011, are analyzed.

1. Introduction
Currently, of great interest are studies of the changes in radiation conditions in the near-Earth space below the radiation belt, which appear as bursts of charged particles (sharp short-term increases in particle fluxes) in a wide energy range. High-energy charged particle bursts were first discovered in 1985 in the MARIA experiment performed by the MEPhI on board the Salyut-7 orbital station [1]. Later, extensive experimental and theoretical studies in this field were fulfilled. The interrelation between particle bursts and various solar-magnetospheric and geophysical (seismic, thunderstorm, etc.) processes was established (see [2-6] and references therein). Among the most important experiments are: MARIA, MARIA-2 [3, 4, 5] and SAMPEX/PET [5, 7] at high energies (5-50 MeV); Demeter (0.3-5 MeV) [8] and POES (0.3-2.5 MeV) [9] at low energies.

These studies showed that the formation mechanism of high-energy charged particle bursts (observations are mostly related to electrons with energies on the order of tens of MeV) is associated with local disturbances of the radiation belt and is as follows [2, 3]. High-energy electrons trapped by geomagnetic field interact with low-frequency electromagnetic emission generated in various geophysical and magnetospheric processes, which result in pitch-angle diffusion of particles and lowering their mirror points. As a result, particles precipitate from the radiation belt to altitudes below its boundary. Precipitated particles, if their mirror points are not too deep in the residual atmosphere (above 60-80 km), drift around the Earth and form a wave of precipitated particles (referred to as the GKV wave), propagating along the L-shell containing an local disturbance region. The time of the complete longitudinal revolution of high-energy particles around the Earth is from several tens of seconds to several minutes. Therefore, for same time, the L-shell is completely filled with precipitated particles. When a spacecraft crosses such a perturbed L-shell, instruments register a particle burst.
which, obviously, can be observed at any longitude not necessarily coinciding with the longitude of the local disturbance region. As well as particle burst can be formed in the magnetically-coupled zone corresponding to this region.

2. Instruments
The ARINA and VSPLESK satellite experiments are designed for radiation monitoring of the near-Earth space with the aim to study the physics origin of high-energy charged particle bursts.

The ARINA and VSPLESK scintillation spectrometers developed by the MEPhI are fully the same in physics schemes, have the same physics parameters (geometrical factor, energy range, energy resolution, etc), detect and identify electrons (3-30 MeV) and protons (30-100 MeV), measure particle energies (with accuracy ~ 10%), and allow to study energy spectra and time profiles of particle fluxes. The instrument acceptance is about 10 cm²sr. This value is several tens of times higher than the acceptance of the instruments using earlier for observation of seismic effects in particle fluxes [5, 7]. The physics scheme and performances of the instrument are described in detail in [10].

The ARINA and VSPLESK experiments are carried out on board the low-orbit spacecrafts. The ARINA instrument is installed on board the Resurs-DK1 satellite with an altitude of 350-600 km and an orbit inclination of 70°. The experiment is executed since the July, 2006 [11, 12].

The VSPLESK instrument is installed on the International Space Station. Orbit altitude is 350-400 km, an orbit inclination is 51°. Measurements are carried out since August, 2008 [13].

In the present study, we used the ARINA and VSPLESK experimental data on the total electron flux in the energy range of 5-30 MeV.

3. Experimental results
Bursts of particles at the level of 4.5 standard deviations and with duration from several seconds to few minutes were selected for processing and analysis in each experiment. About 200 particle bursts were detected in the experiment ARINA, and VSPLESK observed about 70 bursts.

The geographical distribution of particle bursts was studied. L-shells of position of particle bursts detection in the range 1.12 - 2.2 were taken in the analysis. To exclude from the processing the region of the radiation belt (where the reliable identification of particle bursts is practically impossible) the measurements with geomagnetic induction $B > B_0$ were selected ($B_0$ is the atmospheric boundary of the radiation belt, $B_0$ was calculated in the framework of the IGRF geomagnetic field model and MSISE residual atmosphere model).

In principle, all detected particle bursts can be divided into 2 groups. The first one contains most of the bursts of particles and corresponds to the observation of GKV wave away from the place of the local disturbance of the radiation belt. In earlier works, presented in references [2-6], bursts of particles from this group have been studied (see also Introduction). The second group of particle bursts is associated with their registration directly in the region of the local disturbance of the radiation belt. Search for bursts of particles from this group is the purpose of the work.

3.1. Particle bursts of seismic origin
Figure 1 shows the geographical position of the particle bursts detected in the ARINA and VSPLESK experiments and satisfying the criteria above mentioned. In this figure the tectonic faults are plotted as the lines. Part of the particle bursts (boxes with black dot) are grouped along the faults. There are three such faults: Mid-Atlantic, the Kurile-Aleutian, Indo-European.
3.2. Particle bursts of lightning origin

Some zones with the increased frequency of appearance of the particle bursts have been analyzed in [6]. In particular, the region of the Himalayas, where level of thunderstorm activity is high, was identified.

The analysis of seasonal changes of the frequency of observations of particle bursts and thunderstorms revealed the existence of such changes and showed the correlation between particle bursts and lightning [6].

Detail study of the geographical distribution of particle bursts, observed in ARINA and VSPLESK experiments, showed two new regions where particle bursts are grouped (Figure 2, top, open circles). These regions coincide with zones of high thunderstorm activity: the island of Madagascar, the coast of Australia (Figure 2, bottom). Other particle bursts (black circles) are possibly associated with propagation of GKV waves. Thunderstorm activity regions in South America and South Africa were rejected from the analysis by criteria of burst selection, when radiation belt was excluded.

4. Particle burst observation during the period of seismic events in Japan in March 2011

ARINA and VSPLESK experiments ensure practically continuous measurements of fluxes of high-energy protons and electrons. Nevertheless, there are gaps of missing in the information in the VSPLESK experiment, associated with low transfer rate of onboard telemetry system. In particular, it led to the losses of information related to the observation of particle fluxes during the March 2011 for Japan region. So, the experimental results, presented below, have been obtained with ARINA instrument.

Powerful seismic event in Japan started on March 11, 2011 with the earthquake with magnitude M~9, followed by an unusually high aftershock activity with the number of earthquakes (M> 4) to
about 140 per day. For analysis of this seismic event in a whole (including main shock and aftershocks) and particle burst activity the following approach was used [14]. The region of Japan with the geographical coordinates in the range of longitudes 140°-155° and latitudes 33°-45° has been chosen. Further in this region (in near-Earth space above it) the temporal profile of the particle burst count rate \( N_b/t \) (the number of bursts per day) was determined in the time interval before and during the seismic event. Then \( N_b/t \) was compared with the behavior of the daily number of earthquakes \( N_e/t \) with \( M>4 \) (it was used the catalogue ANSS: http://www.ncedc.org/anss/catalog-search.html).

The behavior of \( N_b/t \) and \( N_e/t \) in the period from March, 1 to March, 18 is shown in Figure 3. One can see sharp increase in the number of particle bursts several times since March 11, 2011, which correlates with the sharp increase in the number of earthquakes in the selected region. The increase of particle bursts were also observed in the zone, magnetically conjugated to the Japan region.

Figure 3. \( N_e \) the number of earthquakes (\( M>4 \)), \( N_b \) the number of particle bursts, ARINA experiment.

5. Conclusion

Results on high-energy charged particle bursts in ARINA and VSPLESK satellite experiments, presented in this paper, show that, along with bursts of particles observed at various longitudes of disturbed L-shell, there are bursts of particles, grouped directly in the regions of local disturbances of the radiation belt (seismic and lightning activity zones).

The results of observations of dynamics of flux of high-energy electrons in the near-Earth space during the development of seismic event in Japan in March 2011, once again confirm the existence of seismo-magnetosphere interrelation and demonstrate the possibility of using this phenomenon for satellite monitoring of earthquakes.

6. References

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