

Possibilities of selected space weather and atmospheric studies in JEM-EUSO project?

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The main scientific task of JEM-EUSO is to observe the ultra high energy cosmic rays by looking the atmosphere from space [1, 2, 3, 4]. The detailed description of various sources of the background is important. On the other hand, the study of selected magnetospheric, ionospheric and atmospheric processes related to temporal and spatial variability of UV (ultraviolet) on the orbit where JEM-EUSO is supposed to be situated, could be a useful by-product of the main task of the project (e.g. review [5]). We attempt to summarize selected processes connected with atmospheric electricity and with energetic particles having links to the events as TLE (transient luminous event), TGF (terrestrial gamma-ray flash) and TGE (thunderstorm ground enhancement), recently observed on mountains too. Our groups (in CBK Warsaw, in IEP Košice) have a long track of experience with measurements of waves and particles for magnetospheric/ionospheric research as well as with physical analysis/interpretation of the data obtained. The JEM-EUSO, if the experiment is augmented by a very simple device that monitors energetic particles, and coordinated with other satellite measurements and with ground based observations, may be of relevance for some space weather studies related to the effects in the chain magnetosphere/ionosphere/atmosphere. This can contribute to better understanding of electromagnetic responses of lightning on the Earth and of selected processes at high altitudes in the atmosphere.

*The 34th International Cosmic Ray Conference,
30 July- 6 August, 2015
The Hague, The Netherlands*

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1. Introduction

The atmospheric monitoring system of JEM-EUSO is described recently e.g. in [3]. The slow mode data of JEM-EUSO will allow to monitor also Transient Luminous Events (TLEs). In the following sections we try to survey selected results on space weather-related topics which can be studied in JEM-EUSO mission, if additional simultaneous monitoring of energetic particles and comparison with ground based CR measurements will be done.

2. TLEs and Ionosphere

The ionospheric lightning refers to various short-lived electrical-breakdown phenomena that occur at higher altitudes than *usual lightning* and storm clouds. TLEs generally last from < 1 ms to > 2 s, and are associated with interactions between atmosphere, ionosphere and magnetosphere as well as with strong thunderstorm activity. Sprites, jets, elves, halos and trolls are names of various TLEs differing in altitude, dimensions, type of motions and duration (introduction e.g. in [11] and references therein).

Sprites are known as structured optical emissions in the mesosphere produced by lightning discharges, observed at ≈ 4090 km above thunderstorms (e.g. [28]). Their production is related to quasi-electrostatic heating and ionisation of the lower ionosphere [29]. [48] reports the ionospheric ELF/VLF measurement performed onboard the satellite DEMETER when it was at a distance ≈ 1200 km from a sprite event observed at the top of Śnieżka mountain observatory (1603 m asl) in Poland. A brief history of observations from the Space Shuttle at the beginning of sprite research is in [10].

Contrary to sprites, blue jets project from above a thunderstorm, in narrow structures, to the low ionosphere (40 - 50 km). Elve is the common name for short (< 1 ms in visible and IR light) large extending flashes occurring in the lower ionosphere at ≈ 90 km due to very strong lightning strokes between a thundercloud and the Earth during night. [9] reports a blue jet propagating upwards from a thundercloud to ≈ 70 km. Above ≈ 42 km (upper limit for blue jets and lower altitude for sprites) - the flash exhibited some features normally observed in sprites.

ISUAL, on the Roscat 2 satellite, was a scientific instrument specifically devoted to observation of TLE's [51]. By analyzing sprites and halos paper [52] reports a clear transition at ≈ 75 km altitude from the upper-diffuse to lower -streamer region of sprites. In [53] the global distribution of various types of TLEs obtained by ISUAL during ≈ 3 years of observations is summarized. ISUAL can be used to perform elve survey, to infer the peak current of the elve- producing lightning, and possibly also to check other parameters [17].

Systematic global measurements of UV flashes were done by Tatiana space detectors [15, 16]. In [44] the UV flashes are classified according to the type of their time profiles, and the energy of the flash is estimated. Based on results [31] and experience obtained, project Tatiana-2 [32] improved the system of observation of UV flashes. Data from Tatiana-2 indicated the existence of UV flashes less intense than usual TLEs with a much higher rate than that of UHECR events and having wider latitudinal distribution [40]. The authors stress the importance of such events for the background estimate and for the trigger system. [41] shows two types of atmospheric flashes, namely flashes

with high numbers of photons and those with lower fluxes, the two types differing in geographic distribution: the latter are distributed more uniformly.

Detectors on Tatiana-2 with a higher trigger rate observed a series of flashes not connected with lightning [45]. A review of several Russian missions with the experimental goal to investigate the origin of the high-energy electrons (e) and γ ray quanta for specific TLEs and their role in the ionosphere-magnetosphere system, namely Tatiana-2, CHIBIS, RELEC and TUS, is in [39].

3. Atmospheric electricity and Terrestrial Gamma Flashes (TGFs)

Wilson in 1924 predicted existence of short-lived light flashes over large thunderstorm clouds [12]. Reviews on planetary atmospheric electricity can be found e.g. in [50]. First observations of short pulses of γ rays with hard energy spectra consistent with bremsstrahlung and related to atmospheric electrical discharges, have been reported from BATSE mission [24] by analysis of ≈ 2 years of measurements. The authors indicated that the corresponding flashes originate at altitude above ≈ 30 km and proposed an idea, namely that energetic e are related to rare types of high-altitude discharges above thunderstorm regions. TGFs started to be associated with phenomena of that type.

Dwyer [25] on the basis of TGF observations by RHESSI mission proposed that the observed γ ray bursts from the atmosphere originate deeper (< 21 km), and that the relativistic runaway e avalanches or EAS alone do not produce TGFs. Instead, the energetic seed particle production most likely involves either relativistic feedback or runaway e production in the strong electric field associated with lightning leaders or streamers, similar to the energetic radiation observed on the ground.

Runaway breakdown in air (RB) is stimulated by the presence of a high energy secondary CR. EAS are accompanied by an effective local growth of the number of secondary CR with strong influence on the RB process [19, 20]. The existence nowadays of satellite and ground based systems which obtain regularly a large amount of observational radio frequency (RF) data could allow to use them in combination with other methods for effective study of high energy CR. The improved sensitivity and absolute timing accuracy of Gamma-ray burst monitor (GBM) at Fermi brought new information about TGFs. A study associating RF discharges with e in the showers of particles that produce TGFs, based on Fermi measurements, is in [30].

A concept of an avalanche type increase of a number of runaway e in air under the action of the thunderstorm electric field which could take place during a thunderstorm, stimulated by CR secondaries was proposed in [21]. Authors of [22] found strong 511 keV e^+ annihilation lines, demonstrating that these TGFs also contain substantial e^+ components. Pair production occurs in conjunction with some terrestrial lightning and most likely all TGFs are injecting $e^+ e^-$ beams into the near Earth environment. [23] analyzed 30 kHz RF emissions (sferics - broadband electromagnetic pulse occurring due to natural atmospheric discharges) from lightning discharges associated with TGFs recorded by the RHESSI satellite. Brief increases of dose at aircraft due to lightning discharge or a TGF event are estimated in [8]. Papers [42, 43] discuss (among other subjects) the experimental evidences of the relationships between CR flux and atmospheric current and lightning. Review of TGF studies is e.g. in [14].

4. Energetic electrons and UV flux

Fluxes of suprathermal e as well as e accelerated to relativistic energies, present in the magnetosphere, are highly variable both in temporal as well as in spatial sense, especially during magnetospheric substorms, which leads to variable flux precipitating to the atmosphere (e.g. [33, 34]) and remain of interest in the research of sources, acceleration, losses and transport processes within the magnetosphere (e.g. [35]). The e have a specific link to the status of the ionosphere as well as to atmospheric electricity processes and thus also to UV emissions.

UV emissions of the nightside atmosphere have been simultaneously studied with e fluxes > 70 keV by the Universitetskii-Tatiana satellite. The analysis led to the conclusion that the mean intensity of UV radiation at high latitudes is correlated with the e fluxes (UV increases observed at higher latitudes than those of e), but it is not the case with the SAA [36]. Statistical analysis found three latitudinal regions of enhanced UV emission [37]. While at high geomagnetic latitudes ($L > 4$) the UV emission observed can be explained by e precipitation, at low geomagnetic latitudes ($L < 2.5$) the UV enhancements are higher than those expected just from e precipitation - other mechanism is needed for explanation. [37] concludes that the origin of UV enhancements at middle latitudes ($2 < L < 4$) is still unclear and requires further studies. Simultaneous measurement of UV, energetic e and other high energy particles on Tatiana 1 and 2 satellites allowed to obtain several results important also for understanding the energetic particle dynamics in near-Earth space [39]. Review of the results including those obtained in study of transient events in the atmosphere can be found e.g. in [38] and in references therein.

Lightning is related to whistler waves. The first satellite with simultaneous in-situ observations of whistlers and lightning-induced energetic particle bursts, namely DEMETER, brought new information about e bursts related to the lightnings and whistlers (e.g. [46]). Enhancement of hard X-rays (bremsstrahlung by energetic e) was observed in regions geomagnetically conjugated to the site of thunderstorm activity on CORONAS-I satellite [47].

Detection of high energy e , if added to the concept of JEM EUSO, is important not only for correlative studies with various types of optical flashes. Different orbit of ISS compared e.g. to that of Tatiana-type provides different parts in (L,B) space. Importance of e below radiation belts (quasi-trapped - drifting azimuthally before entering the SAA - named also as *forbidden*) for total electron content (TEC), was shown e.g. in [55]. There are known relations of seismic events to ELF/VLF waves (e.g. [56]), but also changes of high energy e flux is reported to be related to seismicity (e.g. [57, 58] among others).

5. Ground based CR / other particle observations related to atmospheric electricity

In past years, response to atmospheric electricity is reported from ground based observations of secondary CR and from thermal neutron (n) detection. [26] reports short and sharp increases in low energy n count rate simultaneous with a lightning discharge occurring in vicinity of the detector. Measurements with high time resolution at Tian Shan indicate highly correlated short n signals (bursts $\approx 200 - 400 \mu s$) observed by three types of detectors placed at different positions: He3 counters (with and without polyethylene moderator) and neutron monitor (NM) in time coincidence

with thunderstorms [27]. This implies n of various energies, temporary/spatially correlated, are generated during thunderstorm discharges.

Simultaneous enhancements of γ ray and n fluxes during thunderstorm ground enhancements at ≈ 3200 m in Aragats Space Environmental Center (ASEC) are reported in [18]. Photonuclear reactions of the γ rays born in the RB (now referred to as relativistic runaway e avalanche, RREA) process with the air were considered as the main process responsible for the copious n production. The authors of [18] consider also the mesoatom nuclei decay as a possible source of additional n observed by NM due to increase of μ -accelerated in the thunderclouds. A huge event observed at ASEC by several detectors supports the existence of long-lasting particle multiplication and acceleration mechanisms in the thunderstorm atmosphere [13]. Authors present the energy spectra of e and γ rays from particle avalanches.

Nowadays there are operating several systems/networks of lightning observations, some of them described e.g. in [6, 7]. At Lomnický štít (2634 m asl), in addition to measurements by NM, since February 2014 there is in operation detector system SEVAN [49]. Short spikes in the channel 1 not accompanied with increases in second and third channel (this corresponds mainly to e^- or e^+ impact) are observed sometimes in time coincidence with strong thunderstorms as deduced from LINET data and/or from the direct observations at the mountain.

6. Concluding remarks

Characteristics of TLE's have been described by different groups working with detectors on the orbit and on the ground. JEM EUSO is unique in its time and spatial resolution that allows it to see time evolution of the subtle structure (filamentation) of TLE's. There will be two more experiments dedicated to measuring of TLEs in orbit soon (ASIM and TARANIS [61], [62]). Data sets produced by all these experiments may create an exceptional chance to further investigate the physical nature of the TLEs.

Since [24] the intense γ ray flashes of atmospheric origin are observed. Energetic e are probably precipitating also in geomagnetically conjugated point to strong lightning. TGFs must be created > 30 km to escape absorption in atmosphere. Few past years there are observations of counterparts? of lightning induced TGFs at high altitudes - the TGEs on the ground [54]. There are links between atmospheric processes and secondary CR. These processes, however, occur at lower altitudes and are observed on the ground.

In addition to the main JEM-EUSO physical tasks it may be of interest to check the possibility of putting additional energetic e (e.g. that based on [59] with high flexibility) and γ ray monitoring detector (using e.g. experience from CORONAS-F [60]) and to coordinate the JEM-EUSO observations with other satellites targeted to ionospheric/magnetospheric phenomena research as well as with ground based CR measurements, especially on mountains.

Acknowledgment: KK wishes to acknowledge VEGA agency project 2/0040/13 and SAV for support, JB has been supported by grant NCN 2014/13/B/ST10/01285. Corresponding authors acknowledge Dr. Valerie Connaughton for important information about TGFs results obtained from Fermi mission.

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