Recovering of the TGE electron and gamma ray energy spectra

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Recovering of the TGE electron and gamma ray energy spectra

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Abstract. Strong electric fields inside thunderclouds give rise to enhanced fluxes of high-energy electrons and, consequently, gamma rays and neutrons. During thunderstorms at Mount Aragats, hundreds of Thunderstorm Ground Enhancements (TGEs) comprising millions of energetic electrons and gamma rays, as well as neutrons, were detected at Aragats Space Environmental Center (ASEC) on 3200 m altitude. Observed large TGE events allow for the first time to measure the energy spectra of electrons and gamma rays well above the cosmic ray background. We describe the methodology of solving cosmic ray physics inverse problem to recover the energy spectra of electrons and gamma rays incident on particle detectors located at mountain altitudes. The energy spectra of the electrons have an exponential shape and extend up to 30-40 MeV. Recovered energy spectra of the gamma rays is also exponential in energy range 5-10 MeV, then turns to power law and is extending up to 100 MeV.

1. Introduction: Thunderstorm ground enhancements (TGEs)

The attempts to discover high-energy phenomena in the atmosphere, so called, Thunderstorm Ground Enhancement (TGE), in spite of a long history since prediction of C.R.T. Wilson in 1916 [1], were discrepant and rare [2-7]. Facilities of the Aragats Space Environment Center (ASEC) [8] observe charged and neutral fluxes of secondary cosmic rays by a variety of particle detectors located in Yerevan and on slopes of Mount Aragats at altitudes 1000, 2000 and 3200 m. ASEC detectors measure particle fluxes with different energy thresholds, as well as, EAS initiated by primary proton or stripped nuclei with energies greater than 50– 100 TeV [9]. TGEs detected during 2008-2011 bring vast amounts of small and very few large TGEs (only 6 TGE events from 243 exceed 20% of cosmic ray background) allowing the detailed analyses and taxonomy of the new high-energy phenomena in the atmosphere. Few very large enhancements can be explained only by invoking the Runaway Breakdown (RB) process [10], also referred as Relativistic Runaway Electron avalanche (RREA), [11, 12]. Proceeding from the measurements of the charged and neutral fluxes, as well as, from the energy deposit of particles in thick scintillators, we recover the energy spectra of TGE electrons and gamma rays for the 2 largest TGE events of September 19, 2009 and October 4, 2010 and considerably smaller event on May 27, 2011.

1.1. The energy spectra of the TGE electrons

Among hundreds of TGE events detected at ASEC only September 19, 2009 and October 4, 2010 TGEs allow the electron energy spectra recovering. In Figure 1, electron spectra of September 19, 2009 and October 4, 2010 TGEs are presented. The spectrum of September 19, 2009 TGE was obtained by additional counts of plastic scintillators with energy threshold of 9,12,15,18 and 25 MeV. The spectrum was approximated with exponential function; corresponding mean energy equals to ~3.3 MeV. Scintillators with thresholds of 2, 7 and 12 MeV were used to recover the October 4, 2010 TGE electron integral spectrum; for this event, the mean energy equal to ~2.3 MeV; both values are significantly smaller than estimates based on simulations of the RREA [13, 14]; however the 7.2 MeV value was obtained for the electrons just exiting electrical field and for rather large electrical field strengths; the particle source of considered measurements at Aragats were located according to our estimates 50-150 m above detectors.

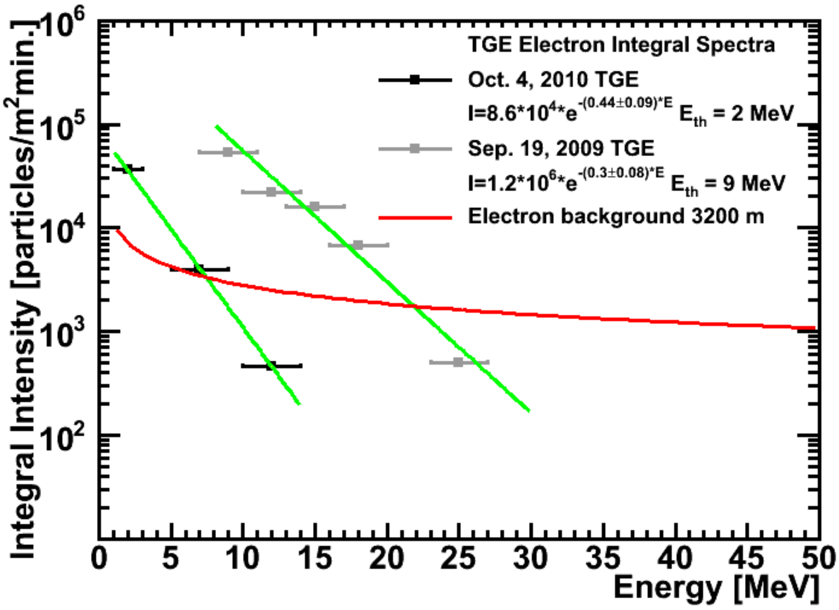

Figure 1. Electron integral energy spectra of the September 19, 2009 and October 4, 2010 TGEs measured at 3200 m compared with the background energy spectrum

1.2. The energy spectra of the TGE gamma rays

The energy spectra of September 19, 2009 and October 4, 2010 TGE gamma rays are recovered based on the energy deposit spectra measured by Cube and ASNT detectors (see details of detector operation in [9]). Both Cube and ASNT detectors are measuring the energy deposit spectra and store them each minute. These histograms reproduce the energy spectrum of gamma rays, however they are folded by the detector response very different for Cube and ASNT detector assemblies. Recovering the energy spectrum by the energy deposit histograms, i.e. solving the inverse problem of cosmic ray physics is rather complicated task and we use multiple trial spectra for solving it. For October 4, 2010 TGE, we recover the gamma ray energy spectrum in the range of 5-10 MeV. The spectrum was approximated by both exponential and power law functions. Exponential function with mean energy of ~4 MeV provides slightly better approximation of the measured energy deposit with simulated one.

We use the energy deposit spectra measured by Cube detector for the calibration of ASNT detector. Above 10 MeV, the energy spectra are better approximated with power law. The spectral indices of gamma ray differential energy spectra were estimated to be 3.3±0.7 and 3.4±0.8.

The recovered gamma ray energy spectra posted in Figure 2 have no error bars due to the spectra recovering method; we chose a particular power index (the power was found to be the best model), which provides simulated energy deposit histogram (obtained by simulation of the detector response) closest to the experimentally measured one. The uncertainties of the procedure, including the possible errors in estimating detector response are included in the errors of the estimated power law indices.

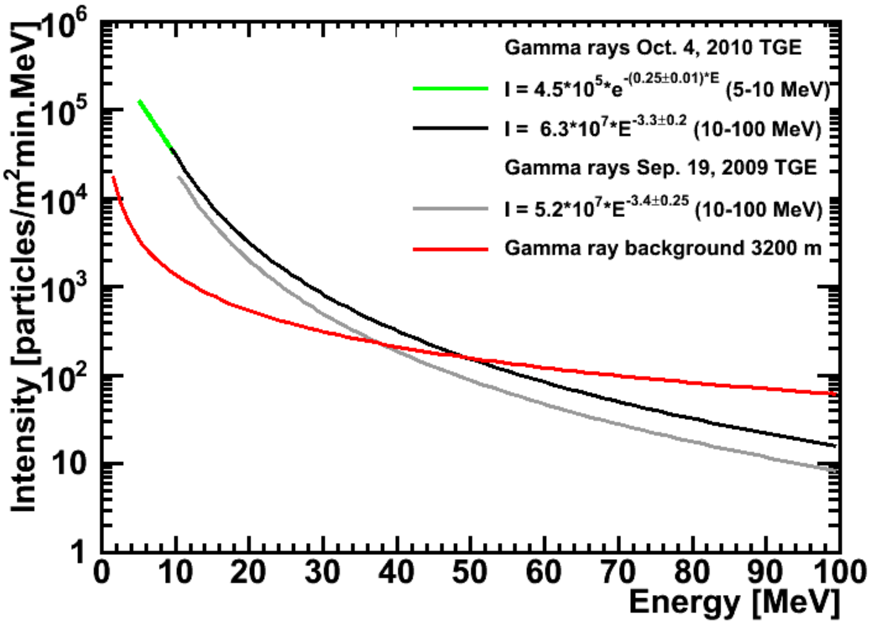

Figure 2. The Differential energy spectra of the gamma rays detected on September 19, 2009 and October 4, 2010

2. May 27, 2011 TGE measured by NaI detectors

In 2011, several TGEs were detected by newly installed NaI crystals network and also by Cube detector providing veto signal for charged particles and by STAND assembly allowing detection of charged flux with various energy thresholds. These detectors enabling us to disentangle charged and neutral fluxes and recover energy spectra of TGE gamma rays and electrons. Since NaI gamma ray registration efficiency is much higher than one for the plastic scintillators, the measured energy deposit is closer to the energy spectra above the detector. Therefore, for obtaining gamma ray energy spectra we use simpler method that was used for the energy recovering by the measured energy release histograms in plastic scintillators [15]. Proceeding from the simulation of the energy release in NaI crystals we calculated corrections to be applied to measured energy release spectrum in each histogram bin. These corrections are dependent on assumed in simulation energy spectrum of gamma rays (power law with different indices); however corrections corresponding to indices -1.5, -2 and -3 are very close to each other. Moreover, after corrections for the efficiency, the shape and index of energy deposit spectrum doesn't change much and the differences are within the errors bars. The energy deposit spectrum of the gamma rays registered on May 27, 2011 by the NaI crystal of thickness 13.5 x 13.5 x 21 cm in aluminum case of 0.7 mm is shown in Figure 3. In the same figure, one also can see the "corrected" spectrum. According to the calculations, there were ~130,000 particles/m^2/min at the energy range 3-20 MeV on May 27, 2011. The power spectrum index of these gamma rays is ~2.8±0.1. It is worth mentioning, that Stand detector's data show the absence of electrons > 7 MeV and presence of electrons of 4-7 MeV, which can contaminate gamma ray flux observed by NaI crystals, however, by our estimates the electron fraction can not exceed 5 % of the gamma ray flux.

3. Conclusions

We present electron and gamma ray energy spectra of 2 large events observed by facilities of Aragats Space Environmental Center (ASEC) in 2009 and 2010, and considerably smaller event (without electrons above 7 MeV) detected by NaI crystals in 2011. Integral energy spectra of the TGE electrons of super events on September 19, 2009 and October 4, 2010 have exponential shape with mean energy

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~3.3 and ~2.3 MeV respectively. The gamma ray differential energy spectrum also is better fitted by an exponential function at energies below 10 MeV with mean energy ~4 MeV; in the energy range 10–100 MeV spectra are fitted by power law function with indices -3.3 and -3.4. The spectral index of the May 27 2011 event (energy range 3-20 MeV) equal to approximately -2.8.

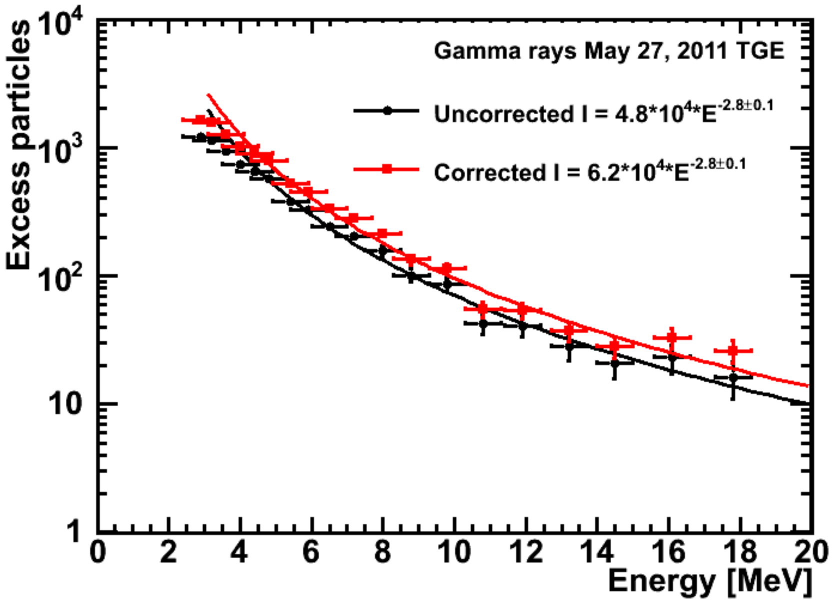

Figure 3. The gamma ray energy spectra of the NaI detector, corrected and uncorrected for efficiency

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