Thunderstorm correlated enhancements of Cosmic Ray flux, detected at mt. Aragats

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Abstract. **The cosmic rays ionize enough the atmosphere to be questioned as possible triggers of the thunderstorms. A mechanism proposed by A. Gurevich and his collaborators suggest that showers of energetic particles produced by high-energy cosmic rays in the terrestrial atmosphere might provide a conductive path that initiates lightning. Because cosmic-ray air showers do not produce enough particles for the electrical discharge by themselves, Gurevich postulated that the thunderstorm gave the cosmic-ray shower a boost by increasing the number of energetic electrons through an exotic process called "runaway breakdown". The Monte Carlo transport calculations of the cosmic-ray muons and associated particles (e.g. knock-on electrons and bremsstrahlung photons) in thunderstorm electric fields, using GEANT4 code indicate that the production of energetic electrons by cosmic ray muons plays an important role in the enhancement of electron and photon fluxes in the thunderstorm electric fields. The Aragats Space Environment Center (ASEC) facilities allow measurements of the charged particles energy from 5 up to 120 MeV. In May – June 2008 we detect short count rate enhancements of low energy charged component of secondary cosmic rays. In the same time there were no peaks in time series of high energy muons. We present first attempt to calculate the energy spectra of the detected additional charged particles, possibly runaway electrons connected with thunderstorm activity.**

***Keywords*: Cosmic ray variations, Atmospheric effects, Secondary cosmic rays**

I. INTRODUCTION

The short-and long-term cosmic ray influences on terrestrial weather is a commonly accepted idea currently tested for the several meteorological phenomena. However, physical links connected CR intensity and frequency of rains have not yet been put on firm basis. An interesting example is the bombardment of the terrestrial atmosphere by solar cosmic rays. The cosmic rays and the secondary particles ionize enough the atmosphere to disturb the entire planetary current ring systems; it seems there are correlations between cosmic rays and thunderstorm activity. Plots of global thunderstorm activity peak strongly about three days after any maximum in solar cosmic rays [1].

A mechanism proposed in [2] suggests that large showers of energetic particles produced by high-energy cosmic rays in the terrestrial atmosphere might provide a conductive path that initiates lightning. There are indeed types of particle detectors called spark chambers that exploit this principle. In a spark chamber, a very large voltage is applied across a small gap filled with a gas. The resulting electric field is large enough to cause discharge following the path of elementary particle.

On the other hand, the case of thunderstorms and lightning is slightly different. Unlike the spark chamber, the electric fields inside the thunderstorm do not appear to be big enough to initiate a spark, so in order for Gurevich's mechanism to do the job, he had to suppose that there were many, many charged particles passing through the storm at once. Because cosmic-ray air showers do not produce enough particles by themselves, Gurevich postulated that the thunderstorm gave the cosmic-ray shower a boost by increasing the number of energetic electrons through an exotic process called "runaway breakdown".

"Runaway breakdown" is a theoretical process in which the liberated electron ionizes nearby air molecules. These molecules become accelerated in the very high electric fields inside a thundercloud, which can reach up to ten million volts in strength. A group of fast electrons is then formed, which can emit gamma rays as they are gradually slowed down by contact with surrounding air molecules. In such cases, the electrons will "run away," gaining very large amounts of energy. As the runaway electrons collide with air molecules, they generate other runaway electrons plus x−rays and gamma rays, resulting in an avalanche of high-energy particles. According to the Gurevich model, this conductive path is what causes lightning [3].

Runaway breakdown can create large amounts of high-energy electrons, as well as x-rays and gamma rays. Interestingly, we know that runaway breakdown works for the low electric fields already seen inside thunderstorms. We also know that it does sometimes happen right before lightning, because we can see big bursts of x−rays and gamma rays shooting out of thunderstorms. In fact, these gamma rays are so energetic and so bright that they have been observed from outer space, 600 kilometers above Earth's surface. Experimental evidence of gamma rays production was recently reported [4]. Gamma bursts which had been previously measured to last less than a second, could occur for almost a minute and started some 70 seconds before a lightning strike.

In order to investigate the generation of energetic photons which originate in thunderstorm electric fields, by authors of [5] have been calculated the behavior of secondary cosmic ray electrons and photons in electric fields. In the calculation, the electron and photon fluxes have increased greatly in the region where the field strength exceeds about 280 P(z) kV/m−atm, and these energy spectra show a large increase in the energy region up to several MeV [5]. The Monte Carlo transport calculations of the cosmic-ray muons and associated particles (e.g. knock-on electrons and bremsstrahlung photons) in thunderstorm electric fields, using GEANT4 code [6] indicates that the production of energetic electrons by cosmic ray muons plays an important role in the enhancement of electron and photon fluxes in thunderstorm electric fields. Muons form a large part of the secondary cosmic-rays and directly reach the regions of strong electric fields owing to their high penetrability in the atmosphere. Therefore, they can serve as the source of a considerable amount of runaway electrons, through their ionization process with air molecules, and their decay into energetic electrons. The electron and photon fluxes show notable increases in the strong electric field, while the muon flux does not fluctuate significantly. From the calculation results, authors of [5] estimate that the irradiation of muon beams rapidly increases energy deposition in the region of strong electric fields, and produce numerous electron - ion pairs. These productions may induce the lightning discharge by the runaway breakdown process [2].

In experiments at Baksan cosmic ray station of the Institute of Nuclear Physics of Russian academy of sciences the spectrum of cosmic rays are continuously measured along with precise measurements of the electric field and monitoring of thunderstorms [7]. Characteristic enhancements of soft cosmic rays (below 30 MeV) and hard cosmic rays (30−90 MeV) were studied. The detected enhancements of the soft component of cosmic rays are interpreted as runaway electrons. Events with fast exponential increase of intensity are interpreted as a feedback effect for runaway particles. It was shown that the critical field and particle energy for this process are 300 kV/m and 10 MeV, respectively [7].

It is very important to establish correct theory of lightening; thunderclouds may be a natural particle accelerator and could provide a nearby hidden prototype for other energetic cosmic accelerators.

II. Low energy charged particle calorimeter at Aragats

At Aragats Space Environment Center [8],[9],[10] since 1997 is operated the Aragats Solar Neutron Telescope (see Fig. 1) as a part of the world-wide network of same type detectors coordinated by the group from Nagoya University [11]. In 2006 with installing of new Data Acquisition electronics [12] facility was turned to a precise calorimeter for charged particles with energies up to 120 MeV.

Fluxes of particles with energies from 10 to 120 MeV under angles of incidence from 0 to 40 degree can be monitored with energy resolution not worse than 5 MeV. Histograms of Energy releases are taken and stored each minute providing exact pattern of changing fluxes of 10−120 MeV electrons & muons during solar transient events and also, during thunderstorms that are very often and strong at Aragats, 3200 m above sea level.

In Fig. 2 the 1− minute histograms of energy releases in 5 and 60 cm scintillators. Examining histograms that are measured and stored each minute it is possible to determine the energy of particle forming enhancement and finally establish the energy spectrum of the "additional" particles. If particle have energy less than 120 MeV it will release whole energy in thick scintillator. By integrating within definite codes (energies) we can obtain intensities of particles of different energies with resolution equivalent to one code of ADC. The ADC provides linearity in the code interval of [0<K<∼80].

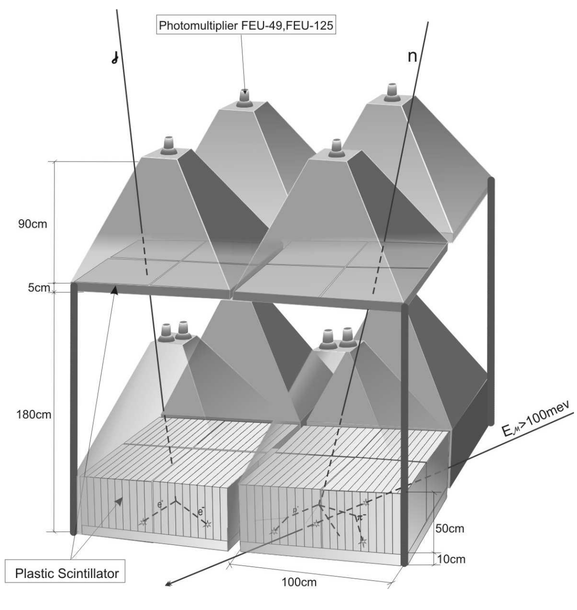

Fig. 1. Aragats Solar Neutron Telescope (ASNT)

III. Detection of the characteristic changes of intensities by ASNT

In the time series of the ASEC monitor count rates in May June 2008 were detected few count rate enhancements possibly connected with thunderstorm activity. The most significant one was recorded at May 4, 2008. The count rate enhancement was observed by all ASEC detectors measuring low energy charged particles of secondary cosmic rays (see Fig. 3− 4). The shape of the enhancement was the same for ASNT and

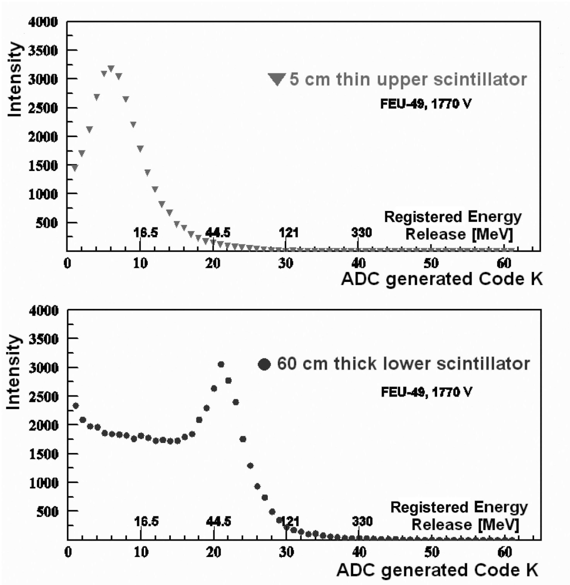

Fig. 2. One-minute histograms of energy releases in thick and thick scintillators of ASNT

for particle detectors of Aragats Multichannel Muon Monitor (low energy particles; detectors on the surface), located on the distance 700 m. from ASNT (see Fig. 3 and 4).

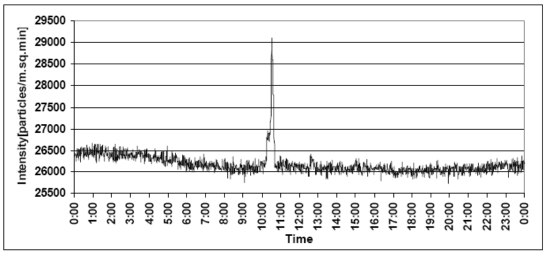

Fig. 3. The 1 minute time series of ASNT at 4 May

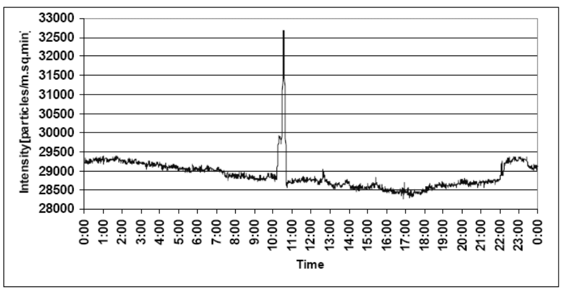

Fig. 4. The 1 minute time series of AMMM surface detectors at 4 May 2008

After locating the enhancement and proving that it is not an artifact due to failure of one detector we examine this event in more details. In Fig. 5 we can see the enhancement in more details: 4% constant enhancement lasting $\sim$10 minutes followed by the abrupt peak ($\sim$e$^{0.25}$) and consequent decay ($\sim$e$^{-0.17}$) lasting another 15 minutes. The exponential behavior of intensity increase and decay is in agreement with Baksan group results [7]. The peak enhancement was $\sim$12%; the accuracy of ASNT is $\sim$0.6%, therefore the peak enhancement corresponds to 20 standard deviations!

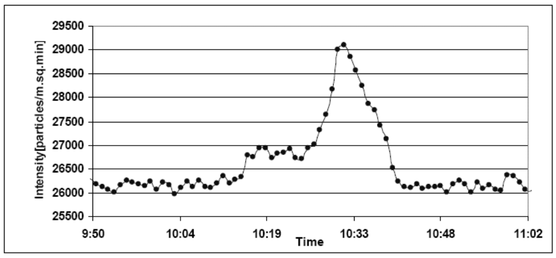

Fig. 5. Count rate of ASNT at May 4

In Fig. 6 we can see that whole enhancement can be attributed to low energy particles; high energy particles do not demonstrate any enhancement.
In Fig. 7 we present the energy spectra of enhancement (runaway electrons & photons) fitted rather well by the exponential function according to the expectations of Gurevich theory [13].

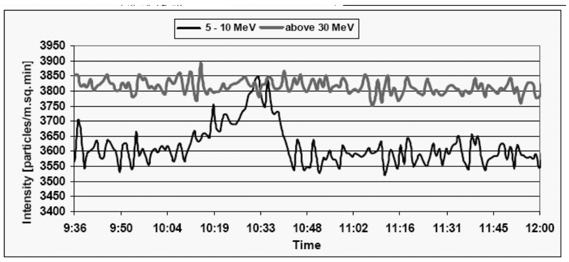

Fig. 6. Intensity enhancement for low and high energy releases (5−10 MeV and > 30 MeV) measured by ASNT at May 4

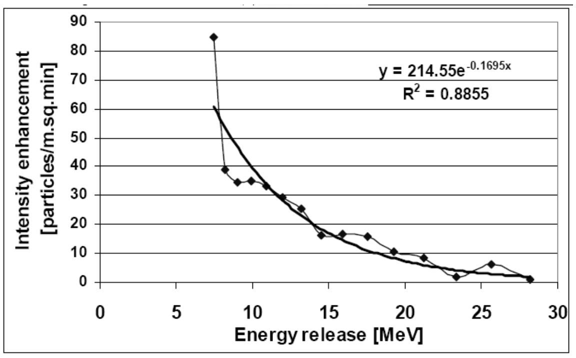

Fig. 7. Energy release spectrum of additional particles

IV. Conclusion

ASNT has advanced possibilities to detect thunderstorm-cosmic ray correlations. First results of estimating energy spectra of runaway electrons confirm expectations of Gurevich theory, however, of course additional work is needed to confirm our findings (underway):

- Detect additional thunderstorms with detailed time history;
- Install precise detector to measure electrical field on the Earth's surface to locate in time the exact thunderstorm discharge time;
- Perform monitoring in different radio frequencies for multivariate evidence of thunderstorm evolution.

REFERENCES

[1] Lethbridge, M.D. , *Cosmic Rays and Thunderstorm Frequency. Geophysical Research Letters*, 8:521, 1981.
[2] Gurevich A.V., Milikh G.M., and Roussel-Dupre R., Phys. Lett. A, 165, 463, 1992.
[3] Dwyer J.R. *A Bolt out of the Blue,* April issue of Scientific American, 2005.
[4] Enoto T., and Tsuchiya H., PRL, 2007
[5] Torii,T., Nishijima,T., Sugita,T., Kawasaki,Z., *Generation of Runaway Electrons Induced by Cosmic-Ray Muons in Thunderstorm Electric Fields.* Geophys. Res. Lett.,, 2004.
[6] Agostinelli A., Allison J., et al., *GEANT-4 code.* Nucl. Instrum. Meth. A 506, 250, 2003.
[7] Khaerdinov N.S., Lidvansky A.S., and Petkov V.B., *Electric Field of Thunderclouds and Cosmic Rays: Evidence for Acceleration of Particles (Runaway Electrons).* Atmospheric Research, 76, pp. 346-354, 2005.
[8] Chilingarian A.A., Avagyan K., Babayan V. et al. *Aragats Space-Environmental Center: status and SEP forecasting possibilities.* J.Phys. G:Nucl.Part.Phys. 29, pp. 939-952, 2003.
[9] Chilingarian A.A., Arakelyan K., Avagyan K., et al. *Correlated measurements of secondary cosmic ray fluxes by the Aragats Space Environmental Center monitors.* NIM, A543, pp. 483-496, 2005.
[10] Chilingarian A.A. and Reymers A.E. *Particle detectors in Solar Physics and Space Weather Research,* Astropart. Phys., 27, pp. 465-472, 2007.
[11] Chilingarian, L. Melkumyan, G. Hovsepyan, A. Reymers, *The response function of the Aragats Solar Neutron Telescope,* Nuclear Instruments and Methods in Physics Research A 574, 255-263, 2007.
[12] Arakelyan K., Abovyan S.,Avetisyan A., et al., *New electronics for the Aragats Space-Environmental Center (ASEC) particle detectors,* JASR, in press, 2008.
[13] Gurevich A. and Zibin K. *Runaway breakdown and electrical discharge in thunderstorms,* Success in Physical Science 171, N 11, 1178 1199, 2001, in russian.