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On the possibility of location of radiation-emitting region in thundercloud

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Abstract. We present and discuss the modulation effect the large electrical fields within thunderclouds pose on the flux of high-energy muons. This short duration effect, observed by the particle detectors located at Aragats Space Environmental Center (ASEC) can be used for the location of the radiation-emitting region in the thundercloud. The decrease in the count rate of high-energy muons during thunderstorms along with simultaneous large enhancements in the count rates of low energy electrons and gamma rays can be used also for the estimation of the net potential drop in the lower dipole of the thundercloud.

1. Introduction

Thunderstorm ground enhancements (TGEs) observed at mountain altitudes by variety of particle detectors (see for instance [1]) are large impulsive enhancements in intensity of low energy electrons and gamma rays, lasting tens of minutes. These enhancements imply that during thunderstorm special conditions are established inside the clouds, leading to modification of the energy spectra of charged particles (see theory of meteorological effects in [2] as well as to multiplication and acceleration of electrons [3]. It is believed that these conditions are based on the presence of strong electric field, which accelerates/or decelerates electrons, positrons and muons and, if electrical field exceeds the critical value also produce electron – gamma ray avalanches referred as the Runaway breakdown (RB, [4]), and in the recent papers as Relativistic runaway electron avalanches (RREA, [5, 6]). Electrons in RB avalanches create large number of gamma rays via bremstrahlung, so that simultaneous impulsive enhancements in the fluxes of electrons, gamma rays are manifestations of existence of RB/REAA process, see [7]). However, the mechanisms, maintaining the origination of the RB/RREA process are still not clearly understood. The model of RB/RREA process initiating large TGE was discussed in ([7], see Figure 10). The precondition of the TGE is negative near surface electrical field manifesting creation of the positive charged layer in the bottom of the cloud. Thus, the lower dipole originated between middle negative layer and bottom positive layer will accelerate electrons and negative muons and decelerate positrons and positive muons. If the strength of the electrical field will be above critical value and energy gained from the field will be greater that ionization losses the electron – gamma ray avalanche will multiply electron and gamma ray numbers in vast amounts. If electrical field in the cloud will not reach critical value, nonetheless we can expect enhancement of the electron and gamma ray number via muon acceleration process. Accelerated in the lower dipole negative muons will decay nearer to earth surface.

Among the large number of the TGE events detected in 2009-2010 by facilities of the Aragats Space Environmental Center (ASEC, [8, 9]) there were several muon depletion events. Decrease in the flux of high-energy muons was observed also at Baksan [10, 11]. This effect has theoretically analyzed in several papers [12, 13]. The last theoretical model for analyzing these decreases was presented in [14], relating the decreasing muon flux to live time of muons from the generation point at 10-15 km high in the atmosphere. In the presence of layered electric field, muons coming from the altitude of their production need longer time to propagate from the point of generation to the ground level and reach the surface detectors. As a result number of arriving muons decrease due to their decay.

As the required condition for the TGE is the large field, accelerating electrons within the cloud, we expect anti-correlation of the TGE amplitude with muon flux. The positive to negative atmospheric muon flux ratio is measured to be ~1.2 independent of the muon momentum, below 100 GeV/c [15]. Therefore, if TGE conditions fulfilled the overall muon flux can be reduced due to stopping of the positive muons in the electrical field of the cloud.

2. The Detector

Detector assembly measuring particle fluxes originated from protons and ions accelerated on sun and in the Galaxy, as well as in thunderclouds is located on the slopes of the mountain Aragats in Nor Amberd research station on 2000 m above sea level. Geographical coordinates are 40°22'N, 44°15'E. Nor Amberd detecting system consists from Multidirectional muon monitor (NAMMM) measuring low energy charged particles and high energy muons, Neutron monitor (NANM) measuring MeV and more energy muons and 2 proportional counters measuring thermal muons. Upper layer of detector measures low energy charged particles, mostly electrons and muons. NAMMM consists from 24, 5 cm thick 0.9 m^2 area plastic scintillators overviewed by photomultiplier (PM) with large cathode of FEU-49 type arranged above and below NANM (see Fig. 1). The energy threshold of the upper scintillators is determined by the roof matter the sensitivity of PM and by data acquisition electronics DAQ and is equals ~ 10 MeV. The upper scintillator registered charged flux above threshold with very high efficiency reaching 95%; however 5 cm plastic scintillator register also neutral flux (gamma rays and neutrons) with much smaller efficiency - ~10%). The bottom layer of scintillators is located under significant amount of matter including 10 cm of lead and its energy threshold is 350 MeV; therefore the bottom layer scintillators measure high energy muon flux with energies >350 MeV.

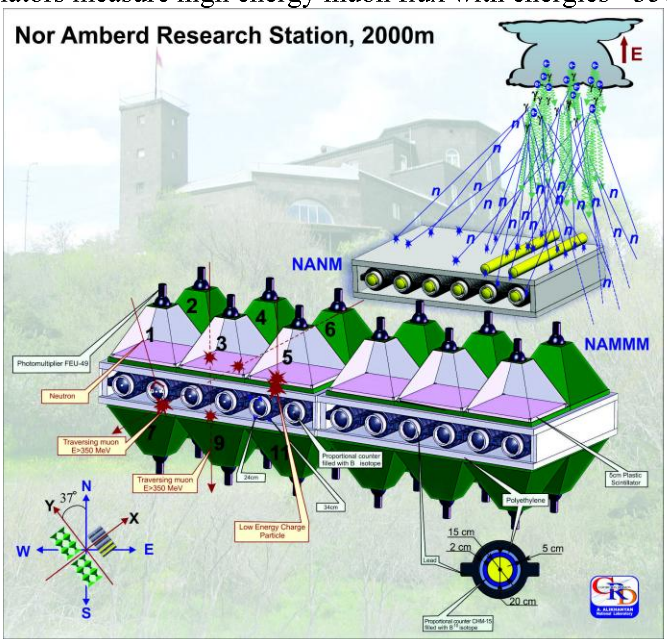

Figure 1 Nor Amberd multidirectional muon monitor (NAMMM) arranged above and below 2 sections of the Nor Amberd Neutron Monitor (NANM); on the third section of NANM 2 “bare” proportional counters are located

DAQ electronics calculates all possible coincidences of detector operation as well as count rates of each detector and total count rates of upper and bottom detectors of both sections of NAMMM. By counting one-to-one coincidences of upper and bottom scintillators it is possible to monitor muons fluxes for 12 directions: from vertical till 74 degrees inclined.

3. Estimation of the size of radiating region in thundercloud

In Fig.2 we post detected at 28 March 2009 time series of 1-minute count rates of NAMMM top and bottom layer combinations. Combination 10 (signal only in top layers selects mostly gamma rays; due to cloud height of 100-200 m very few electrons can reach detector); combination 11 selects high-energy muons capable to traverse 10 cm of lead. We see a large enhancement of the counts in the upper layer of NAMMM conditioned on absence of signal in the lower layer (we assume that most of them are gamma rays); and depletion of counts of high energy muons.

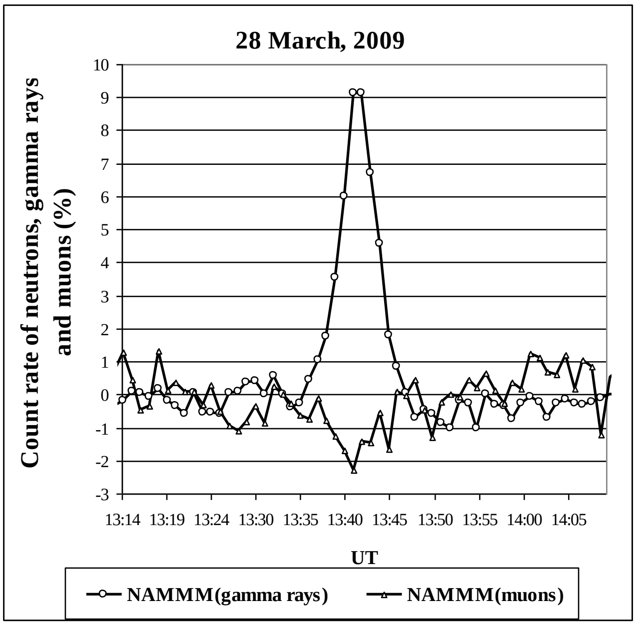

Figure 2 The 1-minute time series of count rates of top (10) and bottom (11) layer combinations of NAMMM

In Table 1 we post deficits of muons measured in different horizontal coordinates by the coincidences of upper and bottom scintillators. In first clolumn of Table 1 we post the examined directions of muon arrival with corresponding measured muon deficits. In Columns 2-4 we post the expected sizes of the electrical field within thundercloud conditioned on the cloud height. At 28 March we detect sizeble anisotropy in different muon arrival directions; the largest deficit was detected from the (W-E) and (S-N) directions, 7 and 6% correspondingly; i.e. from the west-sough.

Table 1 The deficit of muons coming from different spatial directions

Muon deficits for different angular openings and directions	The size of radiation-emitting region if height of cloud is 100m	The size of radiation-emitting region if height of cloud is 200m	The size of radiation-emitting region if height of cloud is 300m
(-66^0 - + 66^0) (WS-NE) (-3.2%) (NE-WS) (-1.5%) (WN-SE) (-3%) (SE-WN) (-2.5%)	(225*2)m	(450*2)m	(675*2)m
(-72.5^0 - + 72.5^0) (W-E) (-7%) (E-W) (0%) (WN-SE) (-3.7%) (S-N) (-6%)	(320*2)m	(650*2)m	(970*2)m
(-74^0 to $+74^0$) (1-11)(2-12) (0%) (5-7)(6-8) (0%)	(340*2)	(675*2)m	(1000*2)m

3. Discussion, Conclusions

The only group reported muon deficit during thunderstorm (Baksan Astrophysical observatory, [13]) reported at 24 Sept 2000 and 24 Sept 2007 the deficit of >100MeV muon flux correspondingly -0.5% and -1% during ~1hour.

Count rate decreases, detected by ASEC monitors have amplitude up -6% and short (several minutes) duration, whereas the decreases measured by facilities located at Baksan neutrino observatory have amplitude less than -2% and long (up to 1.5hour) duration.

Using the map of the deficits in muon flux coming from different directions we estimate the most probable emitting region not greater than 700 m.

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