Neutron production during thunderstorms

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Abstract. We have analyzed the neutron fluxes correlated with thunderstorm activity recently measured at mountain altitudes by Tien-Shan, Tibet and Aragats groups. We perform simulations of the photonuclear reactions of gamma rays born in the electron-gamma ray avalanches in the thunderstorm atmosphere and calculate expected count rates of the neutron counters used by 3 groups. Our analysis supported the Tibet group conclusion on the photonuclear nature of thunderstorm-correlated neutrons. The photonuclear reactions of the gamma rays born in the electron-photon avalanches in the thunderstorm atmospheres interacting in the lead producer of a Neutron monitor can provide neutron yield compatible with additional count of NM at least for the largest Thunderstorm Ground Enhancements (TGEs).

1. Introduction: Neutron production simulations

Recently 3 papers were published ([1], Aragats, 3200 m; [2], Tien-Shan, 3340m, [3], Tibet, 4300 m) on the measuring sizable neutron flux from the thunderclouds. All 3 measurements were done at high altitudes with Neutron Monitors (NMs,[4]).

Aragats and Tibet groups measure coinciding in time with neutrons gamma ray fluxes; although Tibet group with a very high threshold of 40 MeV. Plastic scintillators (60 cm and 40 cm thick) were used to detect gamma rays.

Aragats and Tien Shan groups in addition to NMs also use detectors sensitive to thermal neutrons (energy range - 0.025 – 1 eV).

In all 3 experiments the near surface electric field was monitored; at Tien-Shan and Aragats the atmospheric discharges were monitored as well.

All 3 groups drastically differ in explanation of the origin of neutron flux. The Tien-Shan group reports large flux of thermal neutrons correlated with atmospheric discharges; Aragats and Tibet groups do not relate the neutron flux to lightning occurrences, rather to photonuclear reactions of the bremstrahlung gamma rays born in the Relativistic Runaway Electron Avalanches (RREA, [5], also referred as Runaway Breakdown, RB, [6]) in the thunderstorm atmospheres. However, Tibet group assumes that gamma rays born in the avalanche directly initiate NM counts by photonuclear reactions with lead producer of NM [3]; Aragats group accepts the photonuclear reaction of the RREA gamma rays with the atmosphere as a source of neutrons [1].

Tien-Shan group hypothesis on origin of neutrons is based on the large thermal neutron flux detected by outdoors and indoor neutron detectors correlated in time with atmospheric discharges; no gamma ray flux was reported. Tibet and Aragats groups along with presenting the measured neutron fluxes also perform the GEANT-4 simulations of the neutron production.

To resolve apparent ambiguity and to clarify neutron production mechanisms we analyze the models of neutron production used for predicting the neutron yield and perform additional simulations with adequate model.

[7] start to simulate the neutron production by placing the photon source at the fixed height in the atmosphere: 5, 7.5, 10, 15, and 20 km. Photons energies were drawn from the bremstrahlung spectrum initiated by the electrons in the atmosphere regions where electrical field is above the RREA threshold value. For these heights and used gamma ray spectrum the neutron yield relative to gamma ray flux above the photonuclear reaction cutoff (~10 MeV) was estimated to be ~0.6%.

[8] also simulate a homogeneous gamma ray source in the form of a disk located at the fixed altitude. The universal spectrum of relativistic runaway electron avalanche bremsstrahlung was used. The neutron yield relative to 10 MeV photon flux was estimated to be ~0.43%. The authors conclude, that most likely, the photonuclear reactions account for the neutron flux increases observed at mountain altitudes.

The model used by Aragats group for neutron yield estimation was the same as described above. The relative yield of neutrons was estimated to be 0.3-0.6 %, depending on simulation conditions [9].

Detailed simulation performed by [3], confirmed presented above estimates of relative neutron yield. Combining neutron and photon fluxes with an efficiency of NM to register gamma rays with energies above 10 MeV and neutrons above 1 KeV (Fig. 1 of [3]) Tibet group found that bremsstrahlung gamma rays interacting with lead producer of NM largely attribute the signal obtained by YBJ NM and neutrons born in photonuclear reactions in the atmosphere give only a small fraction of the signal.

The authors of [3] conclude finally that "Consequently, not neutrons but gamma rays may possibly dominate enhancements detected by the Aragats neutron monitor".

To check this statement and to decide on the nature of peaks in NMs we perform detailed simulation of the RREA process in thunderstorm atmosphere above the Aragats detectors. The electron and gamma ray content of RREA as well as neutrons born in the photonuclear reactions were traced till ground level and stored. The main difference of this simulation compared with described above ones is that we do not locate gamma ray source in the thunderstorm atmosphere, we direct simulate the RREA process, using the seed electrons from the ambient cosmic rays and following the unleashed electron-gamma-ray avalanches till their attenuation. Also we inject electrons not from one point, but from an extended area; according to estimates done in [9, 10] the gamma ray emitting area has dimensions less than 700 m. The locality of the particle emitting region is explained by the small sizes of the Lower Positive Charge region (LPCR, see for instance [11]). LPCR forms with main negatively charged region above in the thundercloud the, so called, lower dipole, which accelerates electrons downward. Therefore, the size of the particle-emitting region should be less than the size of LPCR.

From the survived particles rates we calculated the neutron and photon fluxes reaching the detector location on 3200 m a.s.l. Due to much broader neutron angular distribution compared with photon ones the maximal neutron relative yield will be on the periphery of the projection of LPCR on the ground. The gamma rays are illuminating in narrow cones around vertically accelerated electrons and neutrons emitted by the exciting nucleolus can be distributed on broader surface beneath LPCR, thus the neutron/photon ration tends to enlarge with distance from the projection of LPCR center.

2. Explaining Neutron Monitor counts: photonuclear reactions in air or in lead?

To calculate the yield of neutrons from the photonuclear reactions of the gamma ray flux in the lead we need to recover the gamma ray flux fallen on the neutron monitor. The shape of the gamma ray flux will not differ from the shape above the roof of the building we recover and publish in [12] for the 2 largest Thunderstorm ground enhancements (TGE) detected on 19 September 2009 and 4 October 2010.

Aggregate (folded) efficiency of ASNT to register power low flux fallen on the detector equals 8%. Taking into account the registration efficiency, and proceeding from the count rate enhancement at 4 October 2010 of 10,280 at maximal flux minute, we come to gamma ray flux incident the neutron monitor of 10,280/0.08 ~ 130,000 per minute/per m.sq. To estimate how many Neutron Monitor (NM) counts this flux will generate we adopt from Figure 1 of [3] the energy dependence of the NM efficiency to detect photons.

The aggregate efficiency of registration of gamma rays equals to 0.095%. The expected NM count rate we obtain by multiplying the incident gamma ray flux on the aggregate detection efficiency 130,000 * 0.00095 ~ 120 counts per minute per m.sq.; the number of additional counts measured by Aragats NM at 14 October (ANM) was 124, see Table 2 of [1]. The number of photonuclear neutrons above the roof of the building where NM is located we can estimate from the neutron/photon ratio obtained in simulations. The gamma ray flux above 10 MeV on 4 October 2010 on 3200 m height was estimated to be 150,000 per minute per m.sq. Therefore, even taking the maximal neutron/photon ratio of the 0.25% we come with ~ 400 neutron above the roof, an order of magnitude less than required for generating 124 counts of the NM.

The estimate of expected NM counts from another “super-TGE” on 19 September 2009 (see [13]) gives again values close to measured:

Number of additional gamma rays detected by ASNT at 19 September was 7,452; recovered gamma ray flux above NM – 7,452/0.08 ~ 93,000; number of expected ANM – 93,000 * 0.00095 ~ 88, compatible with 63 measured.

For the smaller by gamma ray content other 10 events of Table 2 of [1] we do not recover the energy spectra due to scarcity of energy release histograms. If we assume the power law index equal to -2 for energy spectra of all these 10 “small” events we will get number of expected ANM counts 3-8 times less than measured.

3. Conclusion

We consider the data on recently reported neutron fluxes correlated with thunderstorms. The Tibet group explains the detected count rate enhancement in the neutron monitor by the previously neglected direct registration of gamma ray photons by NM. According to their estimates the gamma ray channel overperformed the contribution of the neutrons born in the photonuclear reactions in the atmosphere by an order of magnitude.

A new realistic simulation of the RREA process in the thunderstorm atmosphere checked the situation. We found that the explanation of Tibet group is supported by new simulation and our explanation – not. Therefore, we confirm the conclusion of Tibet group that NM counts are due to photonuclear reactions of the TGE photons in the lead of NM. Also we find that the simulations of neutron yield with gamma ray source located on the fixed altitude above detector gives optimistically biased (at least one order of magnitude larger) relative neutron yield.

Aragats and Tibet measurements also do not support the hypothesis of particle fluxes directly related to the atmospheric discharges, accepted by Tien-Shan group. Accordingly during the developed Lower positive charge region in the thundercloud (necessary condition of the creation of lower dipole accelerated electrons downward) the flash rate is quite low [11].

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