On the origin of particle flux enhancements during Winter months at Aragats

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Abstract

We consider particle flux enhancements occurred during Winter months on Aragats. We demonstrate that these events are originated from Rodon and Thoron chain isotopes gamma radiation only. The relativistic runaway electron avalanche is possible on Aragats only in Spring-Autumn seasons. We measure with precise spectrometer the lines of most isotopes participated in the flux enhancement and use multidetector measurements for proving the origin of the particle flux.

Introduction

Since 2000, at the Aragats high-altitude station [1], the Cosmic Ray Department of the Yerevan Physics Institute has been carrying out constant monitoring of almost all species of cosmic rays. The particle detectors were used for monitoring the fluxes of gamma rays, electrons, and neutrons. The main goal of the research was Solar physics and Space Weather. However, after an intense solar flare in January 2005, by which we determined the maximum energy of the solar proton accelerator [2], the activity of the sun has gradually decreased and not a single flare has been recorded on Aragats since then. Therefore, our research shifted mostly to the investigation of modulation effects associated with the passage of cosmic rays through a thunderstorm atmosphere and the influence of the atmospheric electric fields on the natural gamma radiation (NGR). The study of the relationship between the fluxes of elementary particles, lightning discharges of various types, and disturbances of the atmospheric electric field led to the discovery of a number of physical phenomena of both fundamental and applied nature. Using networks of detectors, along with electric field sensors, lightning locators, automatic weather stations, and panoramic cameras, we reach a new quality of research in a new scientific direction, namely in the high energy physics in the atmosphere. The location of our station on the plateau under the southern summit of Mount Aragats near the large mountain lake Kare-lich also was preferable to the occurrence of numerous particle flux enhancements, especially during spring, when thunderstorm clouds descend to the station, originated significant surges in particle fluxes. We call these events thunderstorm ground enhancements (TGEs [3]). TGEs origin is the most powerful natural electron accelerator operated in thunderclouds. In1961 Alex Gurevich [4] recognize that if electron gain from electric field more energy than the loss on ionization, the continuous acceleration and multiplication will lead to avalanches that can reach the earth's surface and significantly enhance more-or-less stable background flux of electrons and gamma rays. Background radiation is formed by numerous extensive air showers (EASs), particle fluxes from interactions of protons and nuclei with atoms of the terrestrial atmosphere. These "primary" cosmic rays are accelerated to ultra-high energies by galactic and extragalactic accelerators at exotic sites, like supernova remnants, neutron stars, and black holes. The avalanches started by an EAS electron (avalanche seed) in the atmospheric electric field is not so large and energetic, however, numerous avalanches from abundant seed electrons also covers a few square kilometers area on the earth's surface, prolongs several minutes, and electron energy can reach 50-60 MeV [5].

Another source of enhanced gamma ray flux is the isotope radiation from the Radon and Thoron chains. Due to the continuous emanation of 222Rn from rocks, the concertation of short-lived daughter isotopes is constantly high near the earth's surface and at basements. Recently discovered at Aragats the radon circulation effect [6], the uplift of charged aerosols with attached isotopes by the near-surface electric field with following return with precipitation, enhance low energy (< 3 MeV) gamma radiation by many tens of percent.

Thus, a comprehensive model explaining natural gamma radiation enhancement describes enhanced particle fluxes as a mixture of two separate processes, both having roots in the electric fields emerging during thunderstorms [7]. The particle flux enhancement in winter months when no thunderstorms are observed on Aragats, and the atmospheric electric field do not exceed the runaway threshold value, sure, comprise only enhanced natural gamma radiation of isotopes mostly from 222Rn chain.

In this letter, on the example of a flux enhancement that occurred in winter 2019, we demonstrate its origination from 222Randon progeny radiation and exclude the possibility of electron-gamma ray avalanches in the atmosphere. We present monthly distribution of TGEs in 2017-2020 showing the most frequent months of RREA process occurrence and again demonstrating that in winter months no TGE took place.

Multidetector Experiment on Aragats

Analyzing the condition leading to winter flux enhancements authors of [8] absolutely correct mention that "The relatively small amplitude of the disturbance of the surface electric field during the event 2019-01-09 (2 kV/m as compared to 10–30 kV/m at summer TGE) indirectly indicates that the charge of cloud layers during the considered event was significantly less than the characteristic charge of the cloud layer during summer thunderstorms." However, afterward they formulate the wrong conclusion: "Thus, similar to the summer events of surface thunderstorm increases, the increase in the flux of energetic electrons and photons in the cold season occurs as a result of the acceleration and multiplication of electrons in the upward-directed electric field created by the cloud ".

The main cause of the mistake was using data from a few Aragats detectors only. Incorporating information from particle detectors measuring energy spectra of charged and neutral particles give comprehensive information and allow understanding physical mechanisms responsible for such a complicated phenomenon as TGE. To investigate the hour-to-hour variations of radon progeny radiation and for measuring spectral lines, we perform monitoring of the natural gamma radiation on Aragats with NaI(Tl), type 905-4 ORTEC spectrometer. Spectrometer uses 3" × 3" diameter and length crystal, has 1024 channels, and provide relative energy resolution (FWHM

~7%) [9]. Network of large NaI crystal scintillators, overviewed by a large photocathode of PM-49 (15-cm diameter) also monitored particle flux on Aragats. The sensitive area of each NaI crystal is ≈0.032m^2; the efficiency to detect a gamma ray is ≈60%. The energy threshold of two spectrometers is 300 KeV, of 3 other - 4 MeV. Numerous 1 and 3 cm thick molded plastic scintillators arranged in stacks (a network of STAND1 detectors and STAND3 detector) and in cubical structures (CUBE detector) monitor particle fluxes. Light from the scintillators is re-radiated by wavelength shifting optical fibers at larger wavelengths and propagates to photomultipliers of the type PM-115M. The DAQ electronics stores all configurations of the signals in the detector channels, see detector charts with all details in [10]. All particle detectors and spectrometers operate 7/24 and time series are available for comparisons and statistical analysis from databases of cosmic ray division (CRD) of Yerevan physics institute (YerPhI).

In Fig. 1 we show a very long flux enhancement of ≈10 hours duration, that corresponds to the disturbed values of the near-surface electric field. By 1-hour periods we show the episodes of spectral analyses shown in Fig. 2 (4 from 5) and in Table 1.

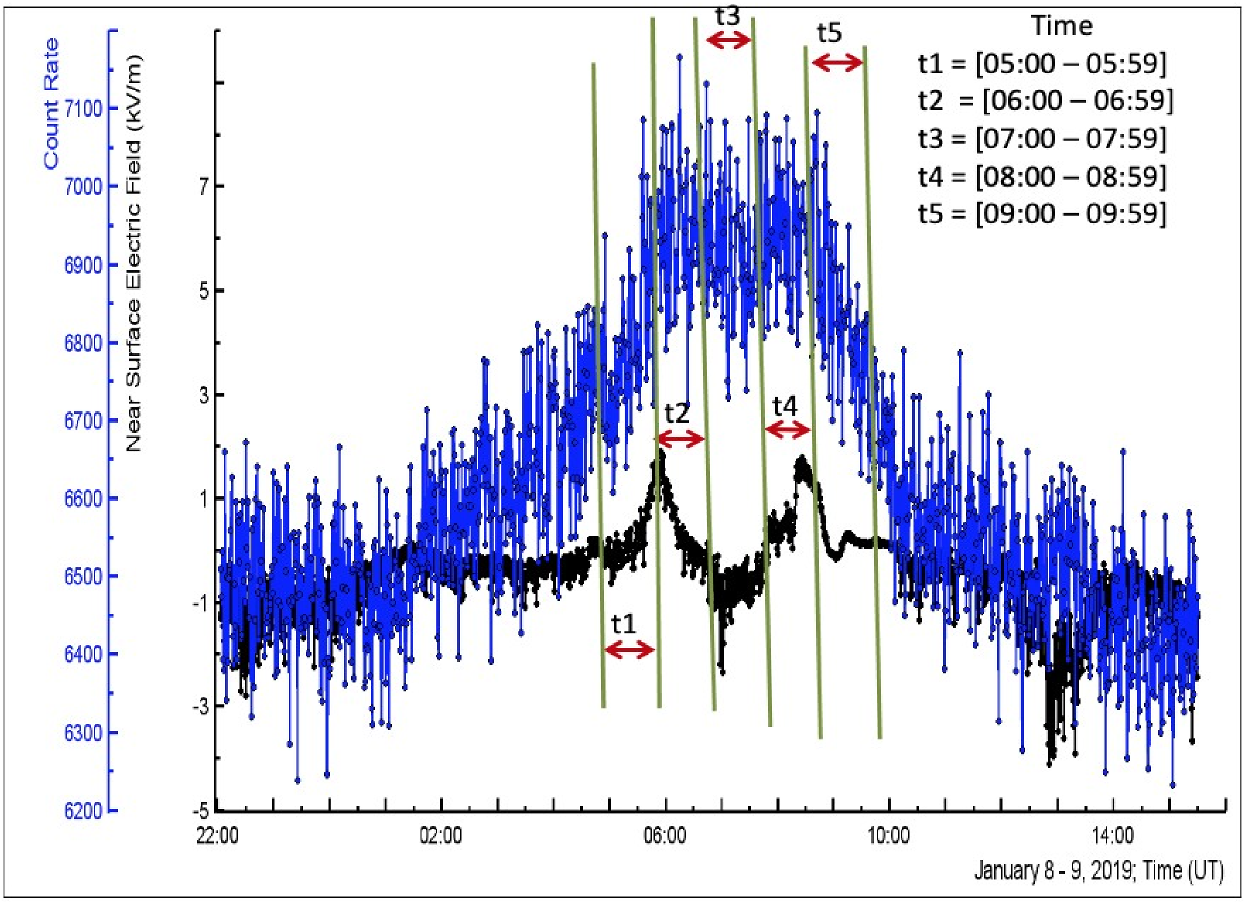

Figure 1. Long-lasting flux enhancement measured by ORTEC spectrometer (blue curve); near-surface electric field measured by the electric mill EFM-100 located on the roof of the MAKET experimental hall. By red arrows, the time spans are shown corresponding to the frames a=d in Fig 2 (besides time span N 5) and shown in Table 1.

In Fig. 2 (a-d) we show energy spectra of 4 successive episodes of very long flux enhancement. Each episode covered 1-hour time; in episodes the spectral line of 214Bi isotope (609 keV) is most abundant; another Bismuth isotope 214Bi (1.12 MeV) also produces smaller peaks.

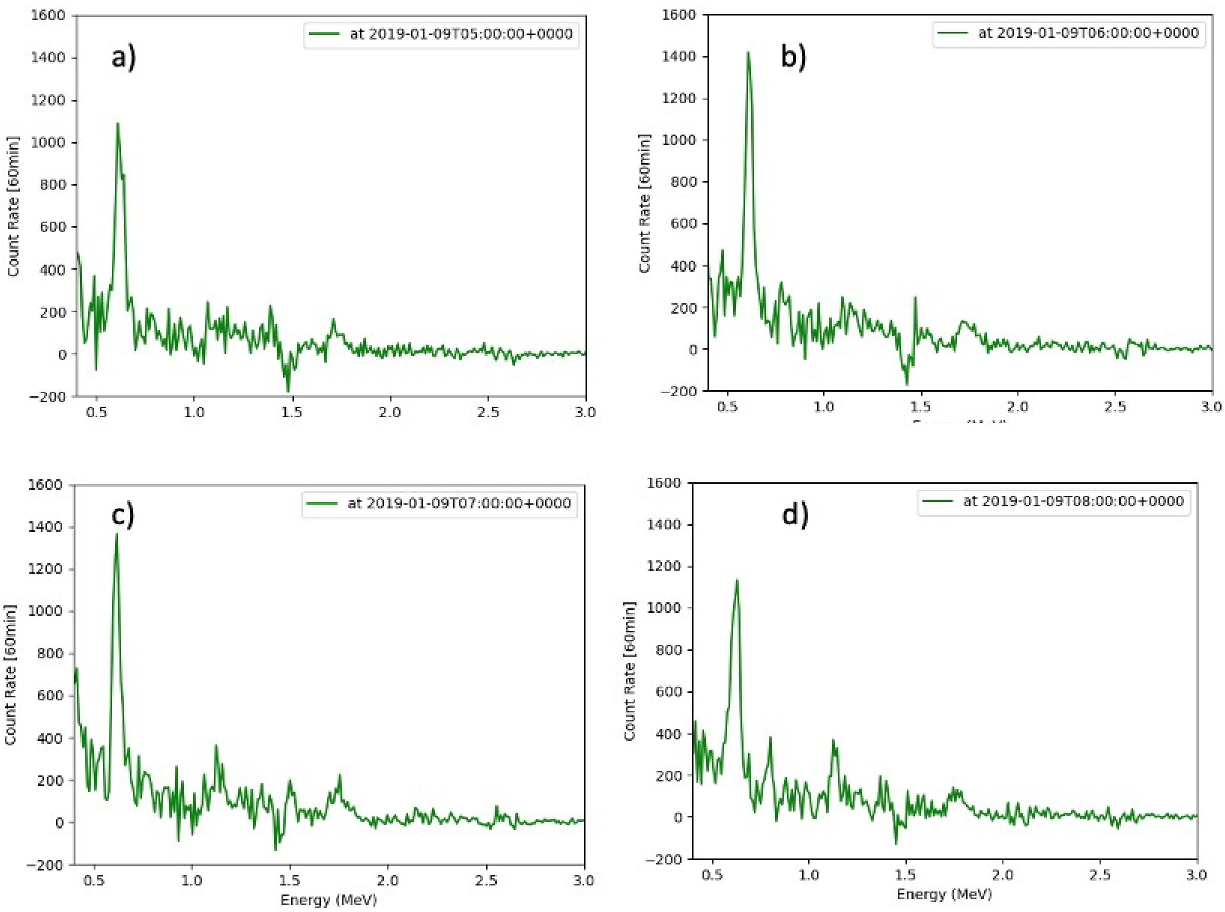

Figure 2. Spectrograms of the natural gamma radiation responsible for the enhancement of the count rate at low energies. The spectrograms are observed by an ORTEC precise spectrometer with high resolution (FWHH ~7.7%).

In the second column of Table I, we show the enhancement of radiation relative to background radiation measured at fair weather before and after the event. In the following columns we show the enhancement for each identified spectral line and its percent relative to overall enhancement.. In the last two columns, we summarize the characteristics of the NGR enhancement: the share of the continuous spectrum (CR +Compton scattered) and the sum of the peaks correspondent to radio-nuclides spectral lines. Energies of most of the NGR emitters measured by the NaI spectrometer are below 1.2 MeV (85%). And most of the gamma radiation below 1.2 MeV comes from Radon and Thoron chain isotopes (75%).

Table 1. Characteristics of the natural gamma radiation measured in 5 episodes of Winter TGE

Date on 9 January 2019	Sum 0.39- 3 MeV	511 KeV	214Bi 609 KeV	214Bi 768 KeV	228AC 911KeV	214Bi 1.12 MeV	214Bi 1.76 MeV	214Bi 2.2 MeV	CR+Compt. scattered	Sum Radio-Nukl.
05:00-06:00	19206	2750	6547	1760	1160	2113	1421	371	3084	13372
%		14,3	34,1	9,2	6,0	11,0	7,4	1,9	16,1	69,6
06:00– 07:00	24947	3022	7878	2304	1407	2463	1615	488	5770	16155
%		12,1	31,6	9,2	5,6	9,9	6,5	2,0	23,1	64,8
07:00-08:00	26585	2349	7032	2691	1536	2748	1818	445	7966	16270
%		8,8	26,5	10,1	5,8	10,3	6,8	1,7	30,0	61,2
08:00– 09:00	23286	2871	7447	2214	1536	2653	1407	266	4892	15523
%		12,3	32,0	9,5	6,6	11,4	6,0	1,1	21,0	66,7
09:00 – 10:00	13821	1448	4290	1266	342	987	945	102	4441	7932
%		10,5	31,0	9,2	2,5	7,1	6,8	0,7	32,1	57,4
Mean	21569	2488	6638,8	2047	1196,2	2192,8	1441,2	334,4	5230,6	13850,4
Mean (%)		11,5	30,8	9,5	5,5	10,2	6,7	1,6	24,3	64,2

In Table 2 we summarize the information from Table 1 to demonstrate that all enhancement is explained by isotope radiation only and no RREA process is unleashed above detectors.

Table 2. Summary table of radiation origin measured during winter TGE

	511 KeV	CR + Compton scatter	Sum radionuclide [Ir]
t1	14,3	16,1	69,6
t2	12,1	23,1	64,8
t3	8,8	30,0	61,2
t4	12,3	21,0	66,7
t5	10,5	32,1	57,4
Mean	11,6	24,5	63,9

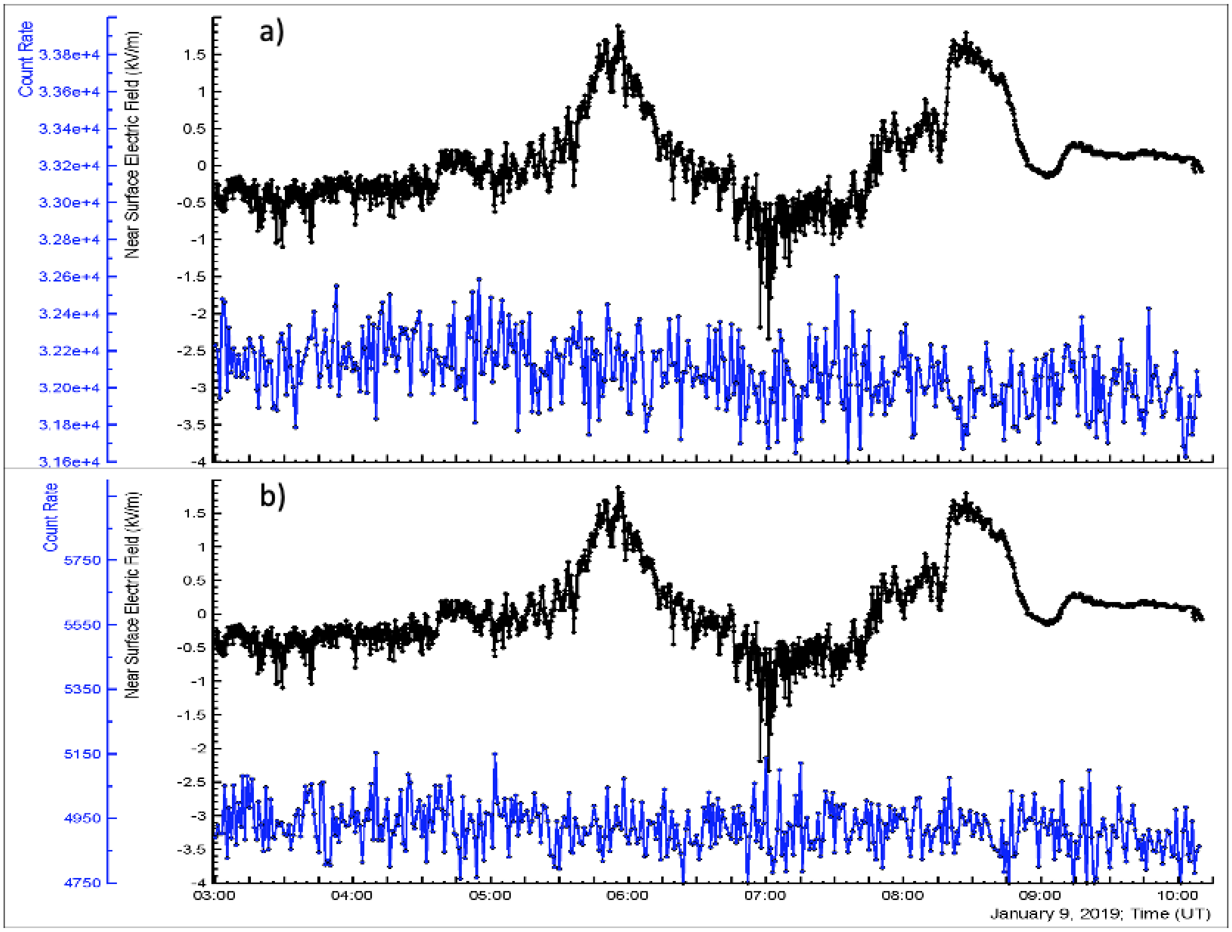

Figure 3. Time series of count rates of 3 cm thick and 1 m^2 area upper plastic scintillator of STAN3 array (energy threshold 2 MeV, a) and of NaI spectrometer with energy threshold 4 MeV (b). By black curve, we show disturbances of the near-surface electric field during long lasting flux enhancement.

As we can see In Fig. 3 the time series of particle detectors with an energy threshold above 2 MeV do not show any flux enhancement, thus, proving that the enhancement was originated only by isotope radiation, no electron acceleration in the atmosphere above detectors took place.

In Fig.4 we demonstrate the monthly distribution of TGE events originated by the RREA process in the atmosphere above detectors. The energy threshold of the used detector is above 4 MeV; in this way we exclude flux enhancement events originated by the isotope radiation only. As we can see in Figure no RREA occurred in 2017-2020 in the Winter months. Also, as we can see in the Figure in last 2 years the number of TGEs in April-May months abruptly diminished and total number of TGEs reduced ≈3 times in 2019-2020 compering with 2017 (the typic year for the TGE abundance in the previous 8 years).

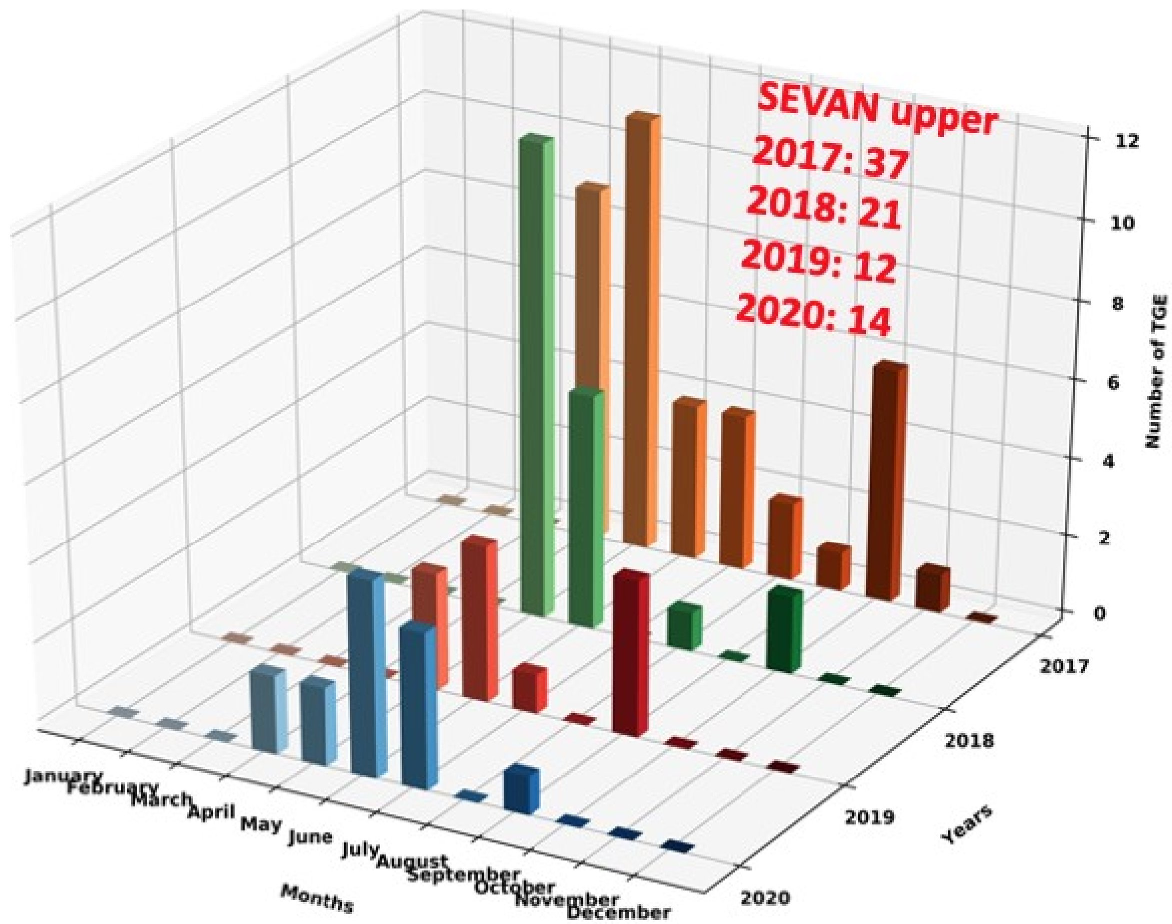

Figure 4. Monthly distribution of TGE activity in 2017–2020 by SEVAN detectors upper scintillator (energy threshold 4 MeV).

Conclusions

We analyzed a winter flux enhancement and its relation to RREA and radon progeny radiation. We demonstrate that flux enhancement observed on 9 January 2019 is due to 222Rn progeny radiation only and no RREA process occurred in the atmosphere. Precise measurement of radiation lines and continuum spectrum in the energy domain 0.3-3 MeV demonstrate that the enhanced isotope line radiation (63.9%), related do it continuum radiation of Compton scattered gamma photons in the body of NaI spectrometer (24.5%), and positron annihilation 511 KeV line (11.6%) are responsible for the flux enhancement. The large peaks and large energies of TGE particles originating from the particle avalanches cannot be observed if the electric field inside the cloud does not exceed the runaway threshold. In winter the shape of the flux enhancement is a Gaussian-like with a long, exponentially decaying tail. The near-surface electric field of a few kV/m is another indicator that the intracloud electric field is below the avalanche initiation threshold (≈1.8 kV/cm at 5-6 km height). The count rate of NaI spectrometer with energy threshold 4 MeV and STAND3 detector with energy threshold ≈2MeV show no enhancement at the time when NaI spectrometer with energy threshold 300 KeV demonstrate large peaks. Thus, as we present in Fig. 4, no RREA can occur on Aragats in winter, all observed flux enhancements are due to the isotope enhanced radiation only.

ACKNOWLEDGMENTS

We thank the staff of the Aragats Space Environmental Center for the operation of the NaI network on Mount Aragats. The authors thank S. Chilingaryan for his continuous efforts at maintaining and improving Web-based data analysis facilities for a large stream of data coming online from the Mount Aragats research station. The data for this article are available by accessing the multivariate visualization software ADEI in numerical and graphical type on the website of the Cosmic Ray Division of the Yerevan Physics Institute [11].

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