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Calculations of the sensitivity of the particle detectors of ASEC and SEVAN networks to galactic and solar cosmic rays

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ABSTRACT

Primary cosmic rays interact with the Earth's atmosphere producing atmospheric showers, thus giving rise to the fluxes of secondary particles. Particle detectors of the Aragats Space Environmental Center (ASEC) and Space Environmental Viewing and Analysis Network (SEVAN) continuously measure neutral and charged fluxes of elementary particles, incident on the Earth's surface. Using CORSIKA code, we have calculated response of ASEC detectors to galactic and solar cosmic rays. The main result of this paper is the estimation of the most probable energy of primary proton generating different secondary fluxes detected on the Earth's surface by a variety of instruments. Results of the paper are applicable to recover the solar proton flux from the surface observations of the ground level enhancements (GLE). In addition, the determination of the most probable energies of the primary proton will help to study energy dependence of solar transient events (Forbush decreases, geomagnetic storms).

1. Introduction

Timely and reliable information on the state of radiation environments in the interplanetary space is of great importance when considering planned manned flights to the Moon and Mars and overall enhancement of space activity of our civilization. For reliable and timely forecast, we need adequate models of the major solar energetic events in progress. The information on the highest energy solar cosmic rays, available from surface based particle detectors can be used to test such models and to obtain thorough knowledge on the particle acceleration in flares and by fast shock blasts.

Neutron monitors and muon detectors are measuring count rates of secondary cosmic rays produced by the interactions of primary cosmic rays with the Earth's atmosphere. The information about primary particle type and energy is mostly smeared during its multiple interactions in the atmosphere. To recover the primary particles fluxes, incident on the Earth's atmosphere, it is necessary to know the relationship between observed count rates of the detectors and the primary particles fluxes, i.e., the most probable primary energy initiating the secondary fluxes detected by neutron monitors and muon telescopes. This relationship can hardly be determined experimentally or analytically, but can be carried out through the modeling process. Of course, the reliability of results depends on the validity of model assumptions and the quality of the simulations.

Several Monte Carlo codes were implemented to simulate the propagation of particles and nuclei through the Earth's atmosphere. One of the first successful attempts in developing simulation code was the work of Debrunner, Fluckiger and co-authors [22,27,38]. Shibata [39] performed extensive calculations to investigate transport of primary neutrons. Several authors [21,37,8] adopted the Monte Carlo particle transport code FLUKA [24] to couple the observed count rate of the detectors with the flux of cosmic rays at the top of atmosphere. Recently, CORSIKA [29] and FLUKA were used to calculate cosmic ray induced ionization in the atmosphere [41] and production of the ^{7}Be in the atmosphere [42]. A new simulation code called ATMOCOSMICS [23] based on GEANT4 [2] was recently developed by the Bern University cosmic ray group.

Our modeling procedure includes the simulation of primary particle propagation through the Earth's atmosphere using CORSIKA package. CORSIKA was originally designed for the simulation of extensive air showers with energy above 10^{14} eV in the context of the KASCADE experiment [5]. CORSIKA code, however, is also widely used for many other experiments by the cosmic ray physics community. It is already successfully used for the interpretation of the data of low energy experiments [34,25,4,35,31,12].

We used CORSIKA code to simulate ground level particle fluxes in order to determine responses of ASEC monitors [14,15] to galactic and solar cosmic rays (GCR and SCR). Various particle detectors are monitoring different species of secondary cosmic rays. ASEC monitors register low energy charged particles (with energies >7 MeV), muons with energies >250 MeV, high-energy muons (>5 GeV) and neutrons. For the analysis of ground level

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enhancements (GLE) it is convenient to relate each detector to the particular (most probable) energy of the primary particle. Of course there cannot be established one-to-one relations of primary energies and count rates of different secondary particles. However, we can outline subsamples of primary energy spectra giving rise to the corresponding particles detected at the Earth's surface. Analyzing these subsamples (energy spectra of primary particles), obtained by simulation of cascade passage through atmosphere and particle detector, we can define representative energy related to various ASEC monitors [43]. Based on the most probable energies, determined for each of the ASEC and SEVAN detectors and measuring count rate enhancements it will be possible to estimate the energy spectra of solar protons initiating GLE at Aragats. A variety of particle detectors at Aragats allow estimating energy spectra at energies from 7 up to 50 GeV (if any).

Another important problem is the energy dependence of transient solar events caused by Interplanetary Coronal Mass Ejections (ICMEs). Flux of GCR is changing (modulated) by disturbed Interplanetary Magnetic Field (IMF) and geomagnetic field. The intensity of the neutron flux measured on the Earth's surface can be depleted up to 20% at a time scale of several hours. Different secondary particle fluxes undergo different changes dependent on the energy of originated primary particles.

The research of energy dependence of Forbush decreases (Fd) and geomagnetic storms (GMS), using the method of most probable energy of primaries which have generated secondary fluxes registered by various particle detectors located in one-and-the-same place, is more effective than the method of using detectors located at different places (see for instance [40].

Aragats group is initiating a world-wide network of particle detectors measuring simultaneously three components of secondary cosmic rays. It gives definite advantages in solar physics and Space Weather research and determination of the most probable energies for different secondary particles located at various sites are of upmost importance (see, for instance, [18,20].

The paper is organized in the following way:

- in the second section the ASEC monitors are briefly described;
- the third section is devoted to the simulation, including CORSIKA options used in the simulations, validation of simulations, determination of the energy spectra of primary protons generating different secondary fluxes and illustration of the robustness of the simulation results relative to the change of strong interaction model;
- in the forth section the possibility to study the solar modulation effects is demonstrated;
- in the fifth section we investigate the disturbances of the Earth's magnetic field during the magnetic storms;
- the sixth section is devoted to the estimation of the power index of GLE N69 on January 20, 2005;
- the seventh section describes the most probable energies of the primary protons having initiated secondaries detected by the new particle detector network named SEVAN.

2. ASEC particle detectors

Particle detectors of the Aragats Space Environmental Center (ASEC, [14,15] are located on the slope of Mount Aragats and in Yerevan, Armenia; geographic coordinates: 40°30′*N*, 44°10′*E*, altitudes – 3200, 2000, and 1000 m asl. Various ASEC detectors, measuring fluxes of various secondary cosmic rays, are sensitive to different energetic populations of primary cosmic rays. Two neutron monitors (18NM-64) operating at the Nor-Amberd and Aragats research stations detect secondary neutrons. The Nor-Amberd muon multidirectional monitor (NAMMM) detects low energy charged particles and muons. The threshold energy of the detected muons is estimated to be 350 MeV. The Aragats Multidirectional Muon Monitor (AMMM) registers high energy muon flux (threshold energy −5 GeV). The Aragats Solar Neutron Telescope (ASNT) measures neutrons and charged particles. ASNT is a part of the world-wide network coordinated by the Solar-Terrestrial Laboratory of the Nagoya University. Another monitoring system based on the scintillation detectors of the Extensive Air Shower (EAS) surface arrays, MAKET-ANI [16] and GAMMA [28], detects low energy charged particles. The particle detectors of the new world-wide networked named SEVAN [18]; Chilingarian et al. [19] are in operation on the slope of Mount Aragats at altitudes 3200, 2000, and 1000 meter and in Bulgaria and Croatia at altitudes 2925 m. and 130 m, respectively. SEVAN detectors also measure low energy charged particles, neutral particles (gammas and neutrons), muons (>250 MeV). NAMMM and ASNT measuring channels are equipped with Amplitude-to-Digital (ADC) convertors and microcontroller based advanced electronics. Data Acquisition (DAQ) electronics and flexible software triggers allows to register not only the count rates of the detector channels, but also histograms of energy releases; correlations of the charged and neutral fluxes and many other important parameters. Details of the detector operation can be found in [17,6].

3. Simulations

3.1. CORSIKA package options used in simulation

Atmospheric shower production and propagation through the atmosphere has been performed using CORSIKA package with the following options:

- primary cosmic ray particles: protons, helium nuclei;
- zenith angles of incidence $0 < \theta < 70^{\circ}$;
- geomagnetic field corresponding to the location of Aragats Bx = 25.5 μT, Bz = 41.2μT;
- low energy thresholds for secondary particles:
  for hadrons: 50 MeV;
  for muons: 10 MeV;
  for electromagnetic particles: 3 MeV;
- interactions of the low energy primary protons ($E_0 < 80$ GeV) was modeled by: GHEISHA2002 [26] and FLUKA2006 [24];
- interactions of the high-energy primary protons ($E_0 >$ 80 GeV) – by: QGSJET01 [30];
- CORSIKA version: 6.720;
- observation levels:
  Aragats – 3200 m above sea level;
  Nor-Amberd – 2000 m above sea level;
  Yerevan – 1000 m above sea level;
- flat atmosphere model, where the density of the air decreases with the height, is used.

3.2. Validation of simulation results

Most important stage of any simulation is the validation of simulation results. Any model performs a reduction of a sophisticated physical process. Due to many simplifications, we cannot expect that results of simulations will exactly coincide with measurements. Nonetheless, the basic features of simulated phenomenon should coincide within definite limits with measurements. To validate CORSIKA simulation, we choose count rates of ASEC particle detectors and muon spectra measured at mountain altitude.

3.2.1. Count rates of ASEC particle detectors

The threshold energies for the incident particles correspond to the cut-off rigidity of the location −7.0 GV. All secondary particles are followed until they are below the threshold energies or reach the Earth surface.

The total number of particles entering the atmosphere within the solid angle $\Delta\Omega$ during the time interval Δt has been estimated according to the equation:

$$N_{\mathrm{tot}} = I(>E)\Delta\Omega\ \Delta \mathrm{t}, \tag{1}$$

where $I(>E)$ is the integral energy spectrum.

The input spectra for the simulation were selected to follow the observed proton and helium spectra of CAPRICE98 balloon-borne experiment [10]. We have transformed the CAPRICE98 kinetic energy spectra into the total energy spectra, which can be represented by

$$I(E_0) = 1.1 \cdot 10^4 \cdot E_0^{-2.69} \quad \text{particles } (\mathrm{m}^2\ \mathrm{GeV\ sr\ s})^{-1} \tag{2}$$

for protons in the energy range 6.5–100 GeV and

$$I(E_0) = 7.07 \cdot 10^3 \cdot \mathrm{E}_0^{-2.73} \text{ particles } (\mathrm{m}^2\ \mathrm{GeV\ sr\ s})^{-1} \tag{3}$$

for helium nuclei in the energy range 13.5–200 GeV. E_0 is the energy of primary particle. The simulated ground level particles (downward flux) were stored and used to estimate ASEC monitors count rates. Due to high efficiency of the 5 cm thick plastic scintillators to register charged particles (see for instance [16]) with energy greater than 7 MeV we assume 100% efficiency of detectors measuring fluxes of muons and electrons on the Earth's surface and in the underground hall. To calculate Aragats and Nor-Amberd neutron monitors count rates we used NM-64 neutron monitor detection efficiency as a function of rigidity from the report of [21]. As far as neutron monitor responds mostly to neutrons and protons, only these secondary particles are taken into account.

The mean count rates with the statistical errors calculated from five independent simulated samples for primary protons and helium nuclei are presented in Tables 1 and 2. For comparison, experimentally measured count rates of ASEC monitors on a quiet day (minimal solar modulation) are presented as well (given errors are statistical ones). Of course, the experimental values are changing with the phase of solar cycle and other solar modulation effects, but one can conclude that there is a reasonable agreement (5–15%) between the simulated and the measured count rates of ASEC monitors.

3.2.2. Differential muon flux

Muon measurements [32] at Mt. Aragats can be used to check modeling of atmospheric cascade. Experimental results were obtained during the low solar activity period, 1953–1956. The spectrometer accepted particles in the near-vertical direction ($0^\circ < \theta < 20^\circ$). Muons with energies $E > 2$ GeV were detected.

The corresponding muon flux was computed with CORSIKA for the mixture of primary protons (87%) and helium nuclei (13%). One can see in Fig. 1 that the experimentally measured flux is a little higher than the simulated one, perhaps, because of the missing heavier nuclei or because no adequate primary particles spectra were used in the simulation. Nonetheless, agreement of both curves is apparent.

3.3. Primary energies responsible for different secondary fluxes

To relate each ASEC detector to the primary proton energy the fluxes of secondary cosmic rays were computed on three observation levels. The number of generated showers was 300,000 for each simulation. Parameters of primary protons (energy, angle of incidence, number of secondaries, etc.), producing certain secondary flux (low energy charged particles, muons with energies greater than 250 MeV, high-energy muons with energies greater than 5 GeV and neutrons) were stored. In this way the energy spectra of protons (subsamples of overall energy spectra) responsible for generation of different secondary fluxes were obtained. Partial energy spectra obtained in this way depend on the power-law index used in simulation and on the observation level and geographic coordinates. In this study simulations were performed for four spectral indexes $\gamma = 2.7$ (galactic cosmic rays) and 4, 5, 6 (solar cosmic rays) and 3 observation levels. The comparison of the spectra of GCR and SCR generating high-energy muons at Aragats are presented in Fig. 2.

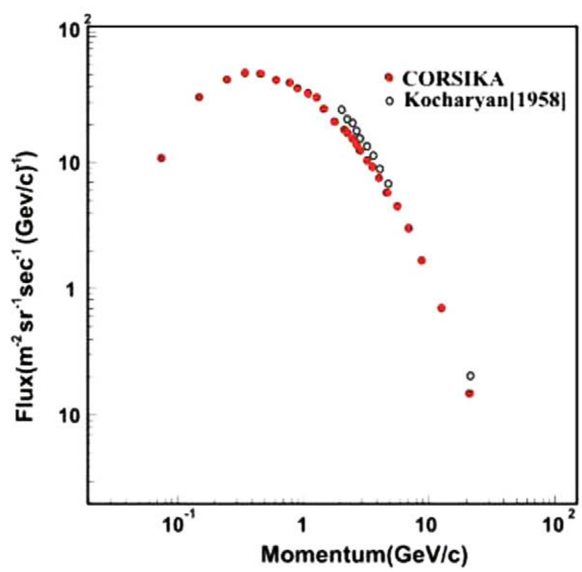

Fig. 1. Experimental (Mt. Aragats, 3200, [32]) and simulated (CORSIKA) near-vertical muon spectra.

Table 1
The ASEC monitors' count rates at Aragats level (3200 m asl) due to secondary galactic cosmic rays (cts/m^2 min).

	Neutrons, protons	Low energy charged particles	Muons (>350 MeV)	Muons (>5 GeV)
Simulated	2.919 ± 33	23.378 ± 214	12.479 ± 92	3.223 ± 239
Experimental	3.218 ± 22	24.985 ± 320	–	3.688 ± 35

Table 2
ASEC monitors' count rates at Nor-Amberd level (2000 m asl) due to secondary galactic cosmic rays (cts/m^2 min).

	Neutrons, protons	Low energy charged particles	Muons (>350 MeV)	Muons (>5 GeV)
Simulated	1.196 ± 19	15.320 ± 138	9.997 ± 89	2.839 ± 20
Experimental	1.325 ± 12	14.540 ± 130	9.600 ± 150	–

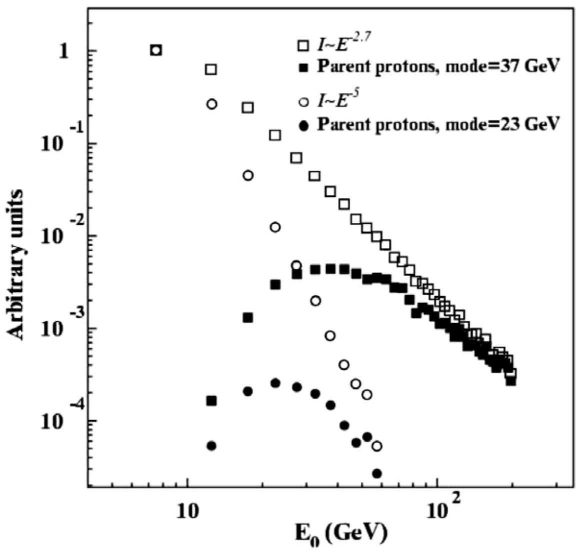

Fig. 2. Energy spectra of primary protons and protons responsible for the flux of secondary high-energy muons obtained by QGSJET01 + GHEISHA2002 at Aragats level for two cases – GCR and SCR.

It is possible to describe the energy spectra by different characteristics, for instance, by 10% quantile (1st decile cut), 90% quantile (9th decile cut), median and mode of distributions (see Fig. 3, where the statistical distributions of the primary protons are posted for the secondary charged particles detected on Aragats level).

In Fig. 4 we posted efficiencies of the primary proton incident on the Earth's atmosphere to yield neutron and muon with energy greater than 5 GeV being registered by the appropriate detectors located at Aragts geographical coordinates (the probability that primary particle will yield a secondary particle).

As an optimal characteristic describing the energy spectra we chose the mode, because it represents the most probable energy of primary particle. This characteristic is stable, as we will see in the next sections, against change of the model (both strong interaction and primary spectra), robust against random fluctuations and robust against occasional very large energies encountered in simulations (outliers).

3.4. Comparison of two codes: FLUKA and GHEISHA

Another check of simulation is its robustness relative to alternative strong interaction model. The energy interval in simulation was 7–350 GeV. Because of the steep primary energy spectrum the low energy interval (below 80 GeV) is more important for our analysis. To check the robustness of the obtained statistical parameters of the primary distributions against the change of strong interaction model the comparison of the results obtained by two low energy codes (FLUKA and GHEISHA) was performed. The outputs from both codes are in good agreement (see Fig. 5).

4. Solar modulation of galactic cosmic rays

Fluxes of the elementary particles on the Earth's surface are highly dependent on the energy spectra of primary protons and nuclei. Highly isotropic flux of GCR can be described by power law, $dN/dEo \sim E_0^{\gamma}$, with a rather stable power index, $\gamma \sim -2.7$. However, GCR fluxes with energies up to few tens of GeV are modulated by the solar wind. During the active sun years, the strong solar wind blows out from solar system significant fraction of the low energy protons and nuclei. Therefore, an energy spectrum of lowest energy range is changing and should be described by another functional dependence.

The primary particle generator in CORSIKA uses power-law spectra. For the accurate description of the gradually softening shape of proton spectrum the original CORSIKA has to be extended by parameterization of the solar modulation. For our analysis we just tried to roughly reproduce low energy curvature and model the deficit of lower energy protons at year of active sun approximating primary proton spectrum by a *broken power law* with $\gamma = -2$, in the energy range 7 GeV < E_0 < 15 GeV and $\gamma = -2.7$ for E_0 > 15 GeV.

As we can see in Table 3 the influence of changing energy spectra is apparent and most probable energies of primary protons are shifted to the right. Effect is energy dependent and at highest energies almost no noticeable.

5. Variations of cosmic rays caused by cut-off rigidity changes during geomagnetic storm

Disturbances of the Earth's magnetic field during the magnetic storms can cause changes of effective cut-off rigidity. These changes may be sufficiently large to change essentially cosmic ray intensity measured by ground-based detectors. We have studied the CR intensity dependences on cut-off rigidity. The count rates for the ASEC monitors for the four different values of rigidity cut-off are calculated. The relative increases of count rate $\Delta N_{cnts}/N_{cnts}$ due to the decreases of rigidity cut-off are presented in Table 4. One can see that the neutron flux is much more influenced by the cut-off rigidity decrease than the charged particle flux.

The relative increases of the measured count rates for two geomagnetic storms detected by ASEC monitors are presented in Table 5. The experimental increases are estimated above pre-event background, calculated by 1-h data prior shock arrival. The comparison of simulated and experimental increases in count rates shows that the November 20, 2003 event could be associated with the cut-off rigidity changes of ~ 1 GV. This is in a good agreement with the cut-off rigidity variation obtained by the global survey method (~ 1.2 GV for Aragats station) calculated by [7]; in their calculations value of 7.6 GV was used as the cut-off rigidity for Aragats location, now it is estimated to be ~ 7.0 GV.

From Tables 4 and 5 one can conclude as well that the decrease of cut-off rigidity on September 7, 2002 is less than 0.5 GV.

6. Estimation of the power index of GLE N 69 on January 20, 2005

A traditional method for determining energy spectra is to employ GLE observations from the world-wide network of neutron monitors with different cut-off rigidities. An example of such model is the NM-BANGLE model which couples primary solar cosmic rays at the top of the Earth's atmosphere with the secondary ones detected at ground level by the world-wide network of neutron monitors, characterized by the rigidity range from 0.5 until 12 GeV [36]. However, the usage of the model function separable in energy and anisotropy for the GLE fitting can introduce a bias in the recovered spectra (see discussion in [1]) and it is difficult to follow the time-history of spectral indices. ASEC monitors access wide range of primary energies and allow recovering of the energy spectra by the particle data measured at one and the same location. Sure, only from ASEC data we cannot measure the anisotropy of the event; however, the observations from the growing SEVAN network [18,20] along with existent particle detector networks will allow accessing also information of the anisotropy of the GLE event.

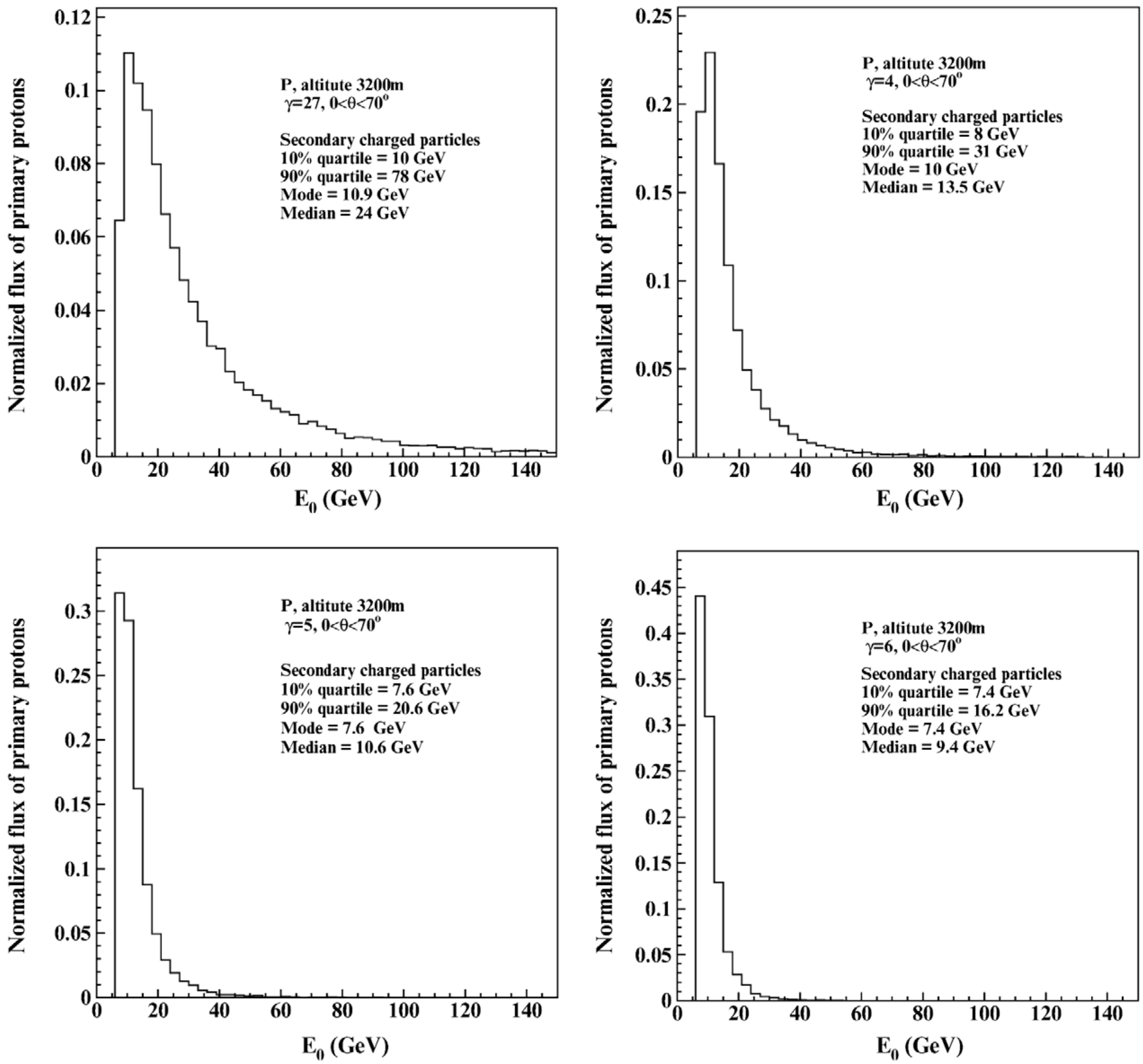

Fig. 3. Energy distributions of primary protons responsible for the secondary charged particles flux obtained by QGSJET01 + GHEISHA2002 at Aragats level for four spectral indexes.

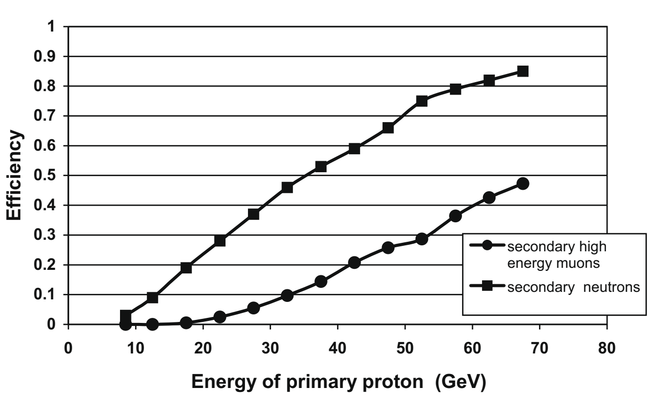

Fig. 4. Efficiency of primary proton incident the Earth's atmosphere to yield at least one secondary neutron and high-energy muon at Aragats level.

The largest GLE of the space era was detected by particle detectors worldwide on January 20, 2005 [9,13]. All Aragats particle detectors registered significant intensity increases. The most important result was obtained with the Aragats Multichannel Muon Monitor (AMMM), establishing flux of >20 GeV muons at 7:01–7:03 UT, 20 January 2005 [11,19]. In addition neutron monitors located at Aragats detected significant enhancement of neutron intensity, several minutes later at $\sim 7:15$ UT.

The analysis presented in this paper is based on the Aragats and Nor-Amberd neutron monitors count rates. These two neutron monitors are located on different altitudes, but at the same geographical coordinates.

The idea to deduce the spectra of solar flare protons using two neutron monitors located close by at the same vertical cut-off rigidity, but at different altitudes above sea level was proposed by Lockwood et al. [33]. Using Mt. Washington and Durham neutron monitors' count rates, coupled with the knowledge of the proton specific yield functions, they have derived the rigidity spectra, $AR^{-\gamma}$, for selected solar flare events since 1960.

Our method is based on the modeling of the responses of Aragats and Nor-Amberd neutrons monitors to solar proton flux [44]. We use some trial spectrum of solar protons for CORSIKA simulation. Based on data from ACE, SAMPEX and GOES11 spacecraft

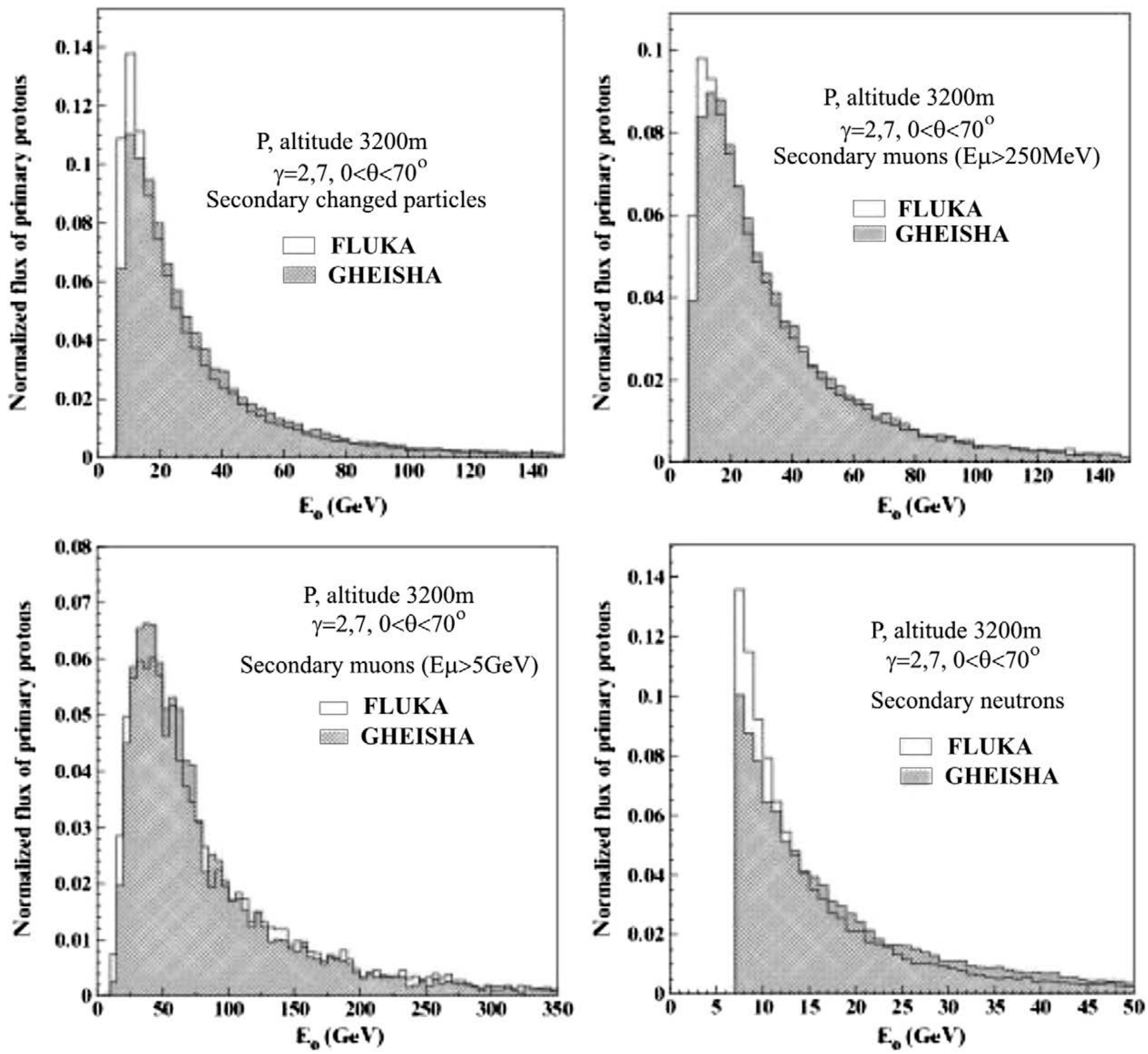

Fig. 5. Comparison of energy distributions of primary protons responsible for different secondary fluxes obtained by GHEISHA and FLUKA codes at Aragats level.

Table 3
The most probable energy of GCR primary protons producing secondary fluxes at Aragats level for two phases of the solar activity.

Secondary flux	$\gamma = 2.7$	$\gamma = 2$ for 7 GeV < E_0 < 15 GeV and $\gamma = 2.7$ for E_0 > 15 GeV
Charged particles (GeV)	10.5 ± 0.2	13.4 ± 0.3
Muons (E > 250 MeV) (GeV)	14.0 ± 0.2	15.2 ± 0.4
Muons (E > 5 GeV) (GeV)	36.2 ± 0.7	37.7 ± 1.3
Neutrons (GeV)	7.1 ± 0.04	8.1 ± 0.2

Table 4
The simulated increase $\Delta N_{cnts}/N_{cnts}$ in the 5-minute count rates of ASEC monitors due to the changes of rigidity cut-off.

R_c decreases (GV)	Neutrons, protons (%)	Low energy charged particles (%)	Muons (>350 MeV) (%)
From 7.56 to 7.00	3.1	0.74	0.43
From 7.56 to 6.50	6.0	1.34	0.74
From 7.56 to 6.00	9.2	1.93	1.00

[3] the intensity of protons with kinetic energy $E_k < 1$ GeV was found to be

Table 5
The experimental increases $\Delta N_{cnts}/N_{cnts}$ (5-min count rates).

Event	Neutrons, protons (%)	Low energy charged particles (%)	Muons (>350 MeV) (%)
November 20, 2003	6.2	0.8	0.5
September 7, 2002	2	0.5	0

$$I(E_k) \sim 4.07 \times 10^5\ E_k^{-2.15}\ \text{part}/(\text{m}^2\ \text{sr s GeV}). \quad (4)$$

Taking into account that ground-based instruments observed much softer spectra and assuming that there is a knee around ~ 1 GeV, a trial spectrum at higher energy was adopted in the form:

$$I(E_k) \sim 4.07 \times 10^5\ E_k^{-\gamma}\ \text{part}/(\text{m}^2\ \text{sr s GeV}). \quad (5)$$

The total number of solar protons of kinetic energy corresponding to rigidity cut-off of the location was calculated according to Eq. (1) for different spectral indexes. Particle fluxes at ground level were simulated, and the count rates were determined for Aragats and Nor-Amberd neutron monitors.

Table 6
Simulated and experimental count rate relative increases of the Aragats and Nor-Amberd neutron monitors at 7:15UT on January 20, 2005.

γ	Aragats NM (%)	Nor-Amberd NM (%)
4	105	88
5	10.5	8.5
6	1.4	1.1
7	0.15	0.12
Exp.	1.52	1.23

Table 7
Simulated and experimental ratios of count rate relative increases of Aragats and Nor-Amberd neutron monitors at 7:15UT.

γ	R(ArNM/NANM)
4	1.19 ± 0.02
5	1.26 ± 0.05
6	1.29 ± 0.07
7	1.30 ± 0.14
Exp.	1.24

The expected increases in the count rates, calculated for possible spectral indices, as well as detected increases of Aragats and Nor-Amberd neutron monitors are presented in Table 6. We conclude that the spectral index $\gamma \sim 6$.

However, we realize that the results of simulation depends also on the value of the second spectral parameter, the constant A in the power-law energy spectrum $I(E_k) = AE_k^{-\gamma}$. To avoid this dependence, we consider the ratio of count rate increases of two monitors:

$$R(\text{ArNM}/\text{NANM}) = (\Delta N/N)_{\text{ArNM}}/(\Delta N/N)_{\text{NANM}} \quad (6)$$

which is a function on spectral index only.

The ratios of the count rate relative increases for Aragats and Nor-Amberd neutron monitors simulated for different spectral indexes and the calculated from measured count rates are presented in Table 7.

From the comparison of the computed and observed ratios we estimated γ at 7:15 to be equal or greater than 5.

Thus, based on our analysis we conclude that $\gamma \sim 6$ is a reasonable choice for the spectral index at the time of maximum flux increase (7:15 UT).

7. SEVAN particle detector network

Networks of particle detectors on the Earth's surface are an important element of planetary Space Weather warning services. The big advantage of ground-based particle detectors upon space-based facilities is their consistency, 24-h coverage, and multi-year operation. In contrast, the planned life of the satellites and spacecraft is only a few years, the same solar blast that they should alert can destroy them, and space-born facilities instead of sending warnings are usually set in the stand-by mode.

The SEVAN multi-particle detectors [18,20] will probe different populations of primary cosmic rays. The basic detector of the SEVAN network measure fluxes of neutrons and gammas, of low energy charged particles and high-energy muons. The rich information obtained from the SEVAN network located mostly at low and middle latitudes will allow estimating the energy spectra of the highest energy SCR. The SEVAN network will be sensitive to very weak fluxes of SCR above 10 GeV, a very poorly explored region of the highest energy. To understand the sensitivity of the new type of particle detectors to high-energy solar ions we calculate most probable energies of primary protons to which the SEVAN basic units, located at different latitudes, longitudes and altitudes are sensitive (see Table 8). Construction of the SEVAN network started in the framework of the International Heliophysical Year and United Nations Basic Space Science (UNBSS) program focusing on deployment of arrays of small inexpensive instruments around the world. The Cosmic Ray Division of the Alikhanyan Physics Institute donates scintillators, photomultipliers, and Data Acquisition electronics to donor countries. Six SEVAN detectors starting from 2008 are monitoring cosmic ray fluxes at research high mountain stations in Armenia and Bulgaria, at the Yerevan CRD headquarters and at Zagreb observatory (supported by European Office of Aerospace Research and Development).

8. Summary

Based on the detailed analysis of distributions obtained for different observation levels and different spectral indexes of initial energy ($\gamma = 2.7, 4, 5, 6$) the range of the most probable energy of primary protons producing different secondary fluxes were calculated. These results can be used for recovering of the solar proton flux from the GLE and to investigate energy dependence of the transient solar events (Forbush decreases, geomagnetic storms) in energy range from 4 to 50 GeV.

Results of the simulations were validated in two ways: by comparing the experimentally measured count rates of the neutron monitors located on the slope of Mount Aragats and by comparing simulated and experimentally measured muon energy spectra. We also check the robustness of simulation results relative to strong interaction model and the adequateness of treatment of the solar modulation effects. In this way, we demonstrate that CORSIKA code allows relating the primary cosmic ray flux on the top of the atmosphere to observed ground level fluxes.

In addition, we recommend using as most probable energy not the median of the distribution of the "parent protons", but the mode of the same distribution.

Table 8
The range of most probable energies (in GeV) of primary protons producing secondary fluxes at different SEVAN sites.

Station	GCR ($\gamma = 2.7$)				SCR ($\gamma = 4, 5, 6$)			
	Charged particles	Muons ($E > 250$ MeV)	Muons ($E > 5$ GeV)	Neutrons	Charged particles	Muons ($E > 250$ MeV)	Muons ($E > 5$ GeV)	Neutrons
Yerevan (Armenia)	14.6	18.4	38.4	7.1	8.2–1.2	10–11.6	21.2 -31.9	7.1
Nor-Amberd (Armenia)	13.1	14.9	41.2	7.1	7.6–10.6	9.7–11.3	20.5–31.3	7.1
Aragats (Armenia)	10.9	14.3	37	7.1	7.4–10	7.6–10.6	21.2–27	7.1
Mussala (Bulgaria)	10.6	13.3	–	7.4	6.6–7.4	7.1–9.5	–	7.6–9.4
Zagreb (Croatia)	17.4	17.3	–	7.6	9.4–12.9	9.1–13.4	–	5.1–5.7
Lomnisky Stit (Slovakia)	11.5	14.5	–	4.1	4.1 –6.5	5.2–8.3	–	4
Delhi (India)	18.1	18.1	–	16.5	14.2–15.1	14.3–15.3	–	14.3–14.4

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