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Multivariate correlation analysis of transient solar events by the facilities of Aragats Space Environmental Center (ASEC)

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Starting from autumn 2002 ASEC detectors perform monitoring of different species of secondary cosmic rays at two altitudes and with different energy thresholds. We present results on sensitivity of secondary cosmic ray flux to geophysical conditions, taking as examples the solar extreme events of 2003-2005.
We introduce multivariate correlation analysis of the different components of registered time-series as a tool for the classification of the geoeffective events, i.e. Ground Level Enhancements (GLE), Forbush decreases (Fd) and effective reductions of the geomagnetic cutoff rigidity.

1.Introduction

The 2003-2005 solar extreme events demonstrated violent and unexpected nature of solar eruptions and provide fundamental insights into the behavior of the Sun and its influence on the space environment of Earth. In [1,2] based on the four GLE events from of 23-rd cycle we claimed that relativistic solar ions with energies above Neutron Monitor (NM) cutoff rigidity arrive well before 50 MeV protons, thus providing possibility of alerting on upcoming radiation storm. But not all solar events are alike these ones. For example, protons of all energies accelerated during the X7.9 flare of January 20, came and was detected by NOAA's GOES-11 spacecraft detectors simultaneously, giving no room for alerting and mitigation actions. This event was also very dangerous from Space Weather point of view because of very hard energy spectra and very fast rise of >100 MeV protons intensity to its maximum very fast. The rapid onset can be explained by good magnetic connection with the Earth (event originated at W67°). Another extreme event from 28 October 2003 was associated with an X17.2 solar flare located at E08, reached maximum soft X-ray intensity at 11:10 UT. This event has several unusual features; the most intriguing is the mysterious spike from the anti-Sunward direction [4].
Solar particle beams are superimposed on the uniform and isotropic Cosmic Ray (CR) background from galactic and extracalactic sources. Space born spectrometers are measuring the time series of the changing fluxes with excellent energy and charge resolution. Surface detectors measure time series of secondary particles, born in cascades originated in atmosphere by primary ions. Information about energy and type of primary is smeared, nevertheless the time stamps allows to correlate secondary and primary fluxes and estimate the arrival times of solar ions at 1 AU and injection place in sun corona [5]. These studies shed light on high-energy particles acceleration associated with solar flares. Particles can be generated either directly in the coronal flare site with subsequent escape into interplanetary space, or they can be accelerated in Coronal Mass Ejection (CME) associated shocks that propagate through corona and interplanetary space [6].
Time series of intensities of high energy particles can provide highly cost-effective information on the key characteristics of the interplanetary disturbances (interplanetary coronal mass ejections (ICMEs)). Because cosmic rays are fast and have large scattering mean free paths in the solar wind, this information travels rapidly and may prove useful for space weather forecasting [7].
Size and occurrence of southward B_z in an ICME are correlated with modulation effects ICME poses on the ambient population of the galactic cosmic rays during its propagation till 1 AU.
In statistical study [8] the relation of CR variability/anisotropy with the geospace disturbances was investigated. It was demonstrated that the parameters changing CR time series are potentially useful for

geomagnetical activity forecasts. In present report, proceeding from the various secondary CR fluxes, measured by particle detectors at Aragats Space-Environmental Center (ASEC) [9], we discuss possibilities of using multivariate correlated information on neutron and muon fluxes to classify geomagnetic disturbances according their strength and type.

2. Multivariate Correlation analysis of ASEC monitors data.

The relative values of flux attenuation in different components of the secondary cosmic ray flux can be used as a characteristic of the Fd magnitude. For the investigation of parameters of secondary fluxes, which are the most sensitive to the geoeffectiveness of the event, we select 4 distinct test cases: one corresponds to the silent phase of the geomagnetic disturbance, and others corresponding to the Fd of different magnitudes - from modest, to strongest. The selected cases are: 25 January 2004, 20 November 2003, 27 July 2004, 29 October 2003. We are looking for the correlations between fluxes of neutrons (Aragats and NMs – ArNM, NANM); the mixture of charged and neutron component (different thresholds of the SNT – from 10 MeV till ~GeV) and high energy muons (with threshold >5 GeV). The details of ASEC monitor operation could be found in references [9,10].

Table 1. Correlations between different ASEC monitor recordings for the Forbush decrease of October 29, 2003 event (from 6:00 UT to 14:40 UT).

	ArNM	NANM	SNT Thr 0	SNT Thr 1	SNT Thr 2	SNT Thr 3	SNT Thr 4	Muons > 5Gev
ArNM	1							
NANM	1.00	1						
SNT Thr 0	0.99	0.99	1					
SNT Thr 1	0.99	0.99	1.00	1				
SNT Thr 2	0.99	0.99	0.99	1.00	1			
SNT Thr 3	0.98	0.98	0.99	0.99	0.99	1		
SNT Thr 4	0.98	0.98	0.99	0.99	0.99	0.99	1	
Muons > 5Gev	0.97	0.97	0.97	0.97	0.97	0.96	0.95	1

There are no correlations between different particle fluxes calculated for 25 January 2003, when no geomagnetic activity was present. Opposite to it, very strong correlations between all monitors are seen For 29 October 2003 Fd (Table 1), which indicates that the upcoming ICME has enormous size and frozen magnetic field and influenced primary energies up to several hundred of GeV. For smaller Fd of 27 July 2004 and 20 November 2003 the correlations between monitor count rates are large for the low energy particles and they are decreasing with increasing of threshold energy. As a geoeffectivess characteristic we choose the Disturbance storm time (Dst). In Table 2 we present the correlation coefficients of above-mentioned four events with corresponding detected minimal values of the Dst. From Table is apparent that a strong association exists between selected correlation coefficients and corresponding values of Dstmin:

Table 2. Correlation coefficients and minimal values of Dst for different event

Event	CC ArNM & AMMM	CC ArNM & SNT_0	Dstmin (nT)
25 January 2004	0.03	0.02	-20
20 November 2003 -Fd	0.38	0.75	-84
27 July 2004	0.85	0.92	-236
29 October 2003	0.97	0.99	-360

the higher correlation coefficient between ArNM and AMMM, and between ArNM and SNT, the stronger is the geomagnetic disturbance. We performed also correlation analysis of 20 November 2003 huge geomagnetic storm (see Table 3).

Table 3. Correlations between different ASEC monitors recordings for the geomagnetic storm of November 20, 2003 event (from 14:40 UT to 6:00 UT 21 November)

	ArNM	NANM	SNT thr0	SNT thr1	SNT thr2	SNT thr 3	SNT thr4	Muons >5Gev
ArNM	1							
NANM	0.89	1						
SNT thr0	0.47	0.44	1					
SNT thr1	0.81	0.79	0.64	1				
SNT thr2	0.85	0.83	0.34	0.82	1			
SNT thr3	0.67	0.65	0.44	0.70	0.76	1		
SNT thr4	0.38	0.35	0.34	0.43	0.43	0.67	1	
Muons>5Gev	-0.01	-0.04	0.44	0.14	-0.04	0.13	0.13	1

To characterize the magnitude of the geoeffectiveness of the event, we again use the Dst index. During this storm the Dst index decreased up to a record value –472 nT. Note, that there is no correlation between fluxes of high energy muons and neutrons as well as between high energy muons and low energy muons&electrons. It means that significant reduction of geomagnetic cutoff at the Mt. Aragats latitude during the storm, enhanced the flux of low energy primaries, meanwhile the flux of much higher energy primaries, which produce >5GeV muons, didn't change.

3. Ground Level Enhancement (GLE) from January 20, 2005

Recent GLE event, named "very special" and "mysterious", "shaking foundations of space weather theory", was detected by all ASEC monitors. In Figure 1 we present one-minute data of ASEC monitor's time series. The amplitudes of "peaks" are measured in "number of standard deviations"; the standard deviations were calculated for all monitors during "calm" time interval before GLE.

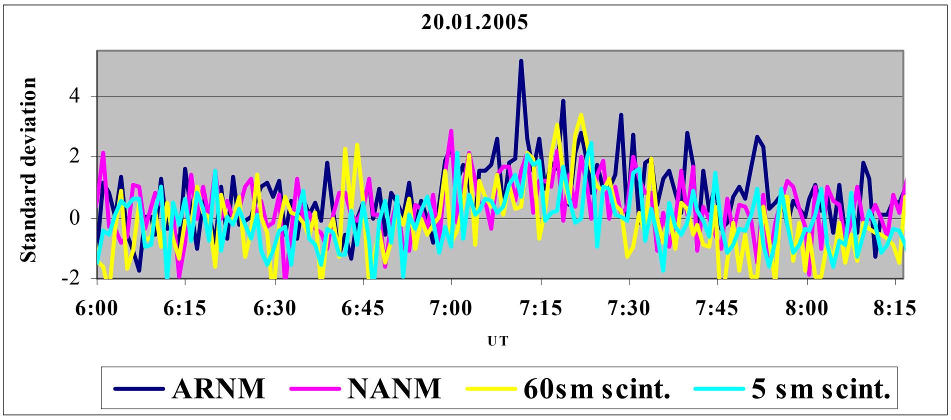

Figure 1. Multiple detection of GLE by ASEC monitors

Sure, some of peaks can be fluctuations only; nevertheless, the 1-2 minute coincidences of such peaks for all 4 detectors make peak evidence stronger. Note, that we are measuring fluxes of various particles by located at different altitudes monitors. Comparison of the temporal pattern of GLE measured by surface monitors and exact times of first ions arrival, measured by space-born spectrometers are posted in the Table 4. We can detect correlations between time patterns of Solar Energetic Particles (SEP) arrival and one-minute monitor peaks. We did not claim that ions registered by SIS/ACE spectrometer are responsible for peaks in time series of ASEC monitors; however we point out on similarity of the time-sequence of detected SEP GLE events. Monte Carlo simulation of ASEC monitors time series is underway and we plan to determine parameters sensitive to type of primary nuclei for the classification of peaks according to primary type[11].

Table 4. Comparison of ion arrival times and times of ASEC detector peaks

Arrival time of ions to 1 AU	NANM UT	ARNM UT	SNT(5sm) UT	SNT(60 cm) UT
Mg, 7:00	7:00	7:00	7:01	6:59
O, 7:07	7:13	7:12	7:13	7:13
C, 7:17	7:19	7:18	7:19	7:18
-	7:22	7:22	7:23	7:22

4. Conclusion

Big variety of solar transient events is reflecting in different patterns of particle fluxes in vicinity of Earth. We have demonstrated the sensitivity of correlation analysis to the different types of events caused by strong geomagnetic disturbances. We conclude that the correlations between different ASEC monitors recording could be used for the identification of geo effectiveness of events according to their type and severity. The possibility of the early diagnostic of the expected hazard of geomagnetic or/and radiation storms using the correlation information on the changing fluxes of the ASEC monitors is under investigation now.

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