Cosmic Ray Intensity variations detected by ASEC monitors during the 23^{rd} solar activity cycle in correlation with Solar Transient events

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***Abstract*. Huge magnetized plasma clouds and shocks initiated by Coronal Mass Ejections (CME) emitted by Sun are travelling in the interplanetary space with mean velocities up to 2500 km/sec (the so called Interplanetary Coronal Mass Ejection (ICME)), are known as major drivers of severe geomagnetic storms when arriving at Earth. On the way to the Earth ICMEs also modulate the flux of Galactic Cosmic Rays (GCRs), introducing anisotropy and changing energy (rigidity) spectra of the previously isotropic population of protons and stripped nuclei accelerated in the numerous galactic sources. Changes in the rather stable flux of GCR are detected by space-born spectrometers (rigidities up to $\sim$1GV) and by world-wide networks of particle detectors (rigidities up to $\sim$100GV) located at different latitudes, longitudes and altitudes. Therefore, measurements of secondary fluxes can be used for probing ICMEs, providing highly cost-effective information on the key characteristics of these interplanetary disturbances. In this paper we present analysis of the transient solar events (Forbush decreases and geomagnetic effects) detected by the particle detectors of the Aragats Space Environmental center during 23^{rd} solar activity cycle.**

***Keywords*: Coronal mass ejections, Geomagnetic storms, Secondary cosmic rays**

I. Interplanetary coronal mass ejection

The size and magnetic field strength of ICMEs are correlated with the ICME modulation effects on the energy spectra and direction of GCRs. At the same time the presence of strong and long-duration southward magnetic field (-B_z) in ICMEs is the primary requirement for their geoeffectiveness ([1] and references therein). Thus, strong magnet field frozen in ICMEs is both modulation agent of GCR and driver of GMS.

Although there is no one-to-one dependence between the variations of the GCR and the strength of GMS [2] and there exist other drivers of storms and modulation agents of GCRs, the large B_z value associated with approaching ICMEs is best known diagnostics of GMS strength. Appropriate observations of the variations of the primary and secondary cosmic rays can be a proxy of B_z value available long before IMCEs reach the L1 libration point where B_z is measured directly (see e.g., [3]).

II. Forbush decrease

The attenuation of the Galactic Cosmic Ray (GCR) flux due to passing Interplanetary ICME (Forbush decrease - FD) is dependent on the speed and size of the ICME, the magnetic field strength and orientation of the ICME and pre-shock conditions of Interplanetary Magnetic Field (IMF). All these parameters are rather difficult to measure; therefore, the explanation of the FD mechanisms still lacking many details. To improve physical understanding of the FD and to explore the Space Weather drivers, we need to measure as geospace parameters as possible, including the changing fluxes of secondary cosmic rays. At ASEC we measure neutral and charged fluxes coming from different directions by particle detectors located at 3 different altitudes. Each species has different most probable energy of primary parent proton/nuclei. New particle detectors now starting to operate at ASEC will extend this energy range from 7 to 200 GeV. Therefore, from ASEC monitor data we can estimate the GCR energy range affected by ICME and reconstruct actual spectra of the galactic cosmic rays incident terrestrial atmosphere. The FD magnitude measured at ASEC during the 23^{rd} solar activity cycle ranges from about 1.5% to 20% in the secondary neutron flux, 1-15% in the charged low-energy particle flux and 0.6-6% in the $>$5 GeV muon flux. The modulation strength of the ICMEs is highly correlated with the speed and size of ICMEs, but not with its density.

Muon rate variations during some of the FDs of the 23^{rd} solar were registered by muon detectors DECOR, TEMP and URAGAN operated in the experimental complex NEVOD [4]. MEPhI data can path the gap between low energy charged particles and more than high energy muons ($>$ 5 GeV) measured by ASEC. In Fig. 1 we present the data on a FD, which occurred on 15 May 2005. Because MEPhI group publish data corresponding to median energies of primary flux, we also present ASEC data accordingly. In Fig. 1 we see good agreement for data obtained by detectors located at different latitudes and altitudes. It is evidence that FD magnitude in the high energy muon flux measured on Earths surface is global characteristic, approximately the same for different detector locations.

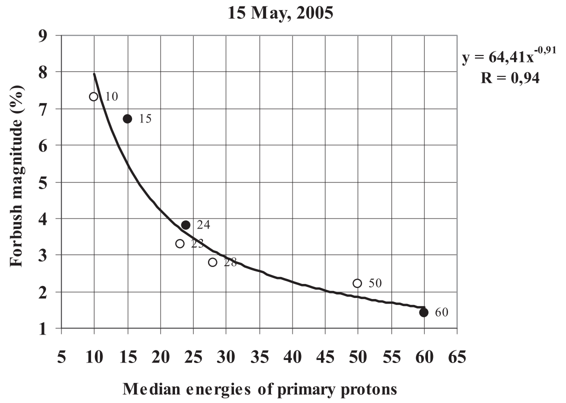

Fig. 1. Observation of the FD from 15 May 2005 by MEPhI (for ASEC monitors we use medians of primary proton energy distributions). Open symbols MEPhI data, close symbols ASEC data.

III. Geomagnetic effects

Our observations of the another class of the Solar transient events, the Geomagnetic Effects (GME) demonstrates that the particle detector count rate increase occurs coherently (or up to one hour in advance) with development of the Geomagnetic Storm (GMS).
We demonstrate that the ratio between the increases of neutron and charged fluxes is approximately constant in a large diapason of GMS severity. The neutron flux always undergoes larger changes comparing with the charged component. The difference in peak amplitude can be explained by the lower energy of the primary particles initiated neutrons comparing with primaries generated electrons and muons reaching Earths surface. Also we demonstrate that the main driver of GMS is southward component of magnetic field of ICME (B_z). Thus, the information on the flux changes for different secondary particles helps to "test" the Interplanetary Magnetic Field (IMF) and the magnetosphere for understanding of the level of disturbance and the specific mechanisms leading to cutoff rigidity reduction. Severe geomagnetic storms are known to be triggered by prolonged periods of negative B_z (when the later reconnects with the terrestrial magnetic field), thus the Dst index can be predicted from the solar wind and interplanetary magnetic field conditions. Cosmic Ray flux also change due to approaching ICMEs. Therefore, the changing fluxes of secondary cosmic rays measured at Earths surface can be used as proxies of ICME parameters when measurements at L1 Lagrange point are not feasible due to severe radiation storms.
Information on the simultaneous detection of GMS in neutral and charged fluxes gives clues on the disturbance of the IMF and the magnetosphere. The ratio between increases of neutral and charged fluxes is approximately constant in a large diapason of GMS severity and neutral flux always undergoes larger changes compared to the charged component. The maximal enhancement of the neutron flux during the GMS (the GME) was ~7.5% and the low energy charged particles ~3% during the 23^{rd} solar cycle.

IV. Colliding ICMEs

The most severe GMS of the 23rd cycle occurred at 20 November, 2003 is well investigated and published in several papers (see for instance [5], [6]). In both papers assumed that the immediate cause of the GMS is the CME launched on 18 November, at 08:50 UT. After abrupt jump of solar wind at 7:28 20 November, 2.5 hours ACE spacecraft facilities detect large changes of temperature, density and velocity of solar wind (transition of the ICME sheath). The time span from 10:00 until 24:00 characterized by the low proton temperature is treated as magnetic cloud passage (see Figure 1 in [5]).
Our approach to this event consists in assumption of 2 colliding ICMEs.
In Table I we can see that the first CME was started at 8:06 with initial speed of 1223 km/sec; second CME launched after 44 minutes with initial speed of 1660 km/sec. Both CMEs have approximately the same heliocoordinates, therefore 08:50 CME is likely to collide with the 08:06 CME because both are from the same active region AR 501. The faster CME overtakes the first one after at a distance of ~17 Rsun. Third CME at 9:50 were from the eastern limb and could not interact with the central CMEs. If both ICMEs not mixed up and move together as a composite ICME with different magnetic structures at arrival to ACE spacecraft we expect to detect severe disturbance of IMF strength. Indeed, in Fig. 2 we can see that sign of B_z component abrupt varies from plus 36 nT up to a minus 49 nT; in the same time B_y component of IMF is abruptly decrease.
Simultaneously we detect pronounced (although not very large) jumps of solar wind velocity, density and temperature). All these features indicate complicated structure of arrived ICME.

The collision of two ICMEs is rather complicated phenomena, depended on the polarity and orientation of the magnetic field of colliding ICMEs. We still are lacking observational information (unfortunately STEREO was launched too late) to form realistic models of ICME interactions. Only information we have is the time history of the solar wind passage of L1 libration point where ACE and SOHO space stations are located. Existences of two ICMEs confirm the particle data: start of the Fd associated with first ICME arrival (B_z oriented anti-southward) and after 6 hours arrives another ICME with B_z oriented southward triggers GME.

V. Conclusion: Classification of the Solar Transient events

Our studies of the particle time series variations during 23^{rd} solar activity cycle with particle detectors

TABLE I
DAILY VARIATIONS OF NEUTRON DATA FROM NMDB

Date	Time [UT]	Heliocoordinates	Angular depth [deg]	CME velocity [Km/sec]
18-11-2003	8:06	N01E19	>104	1223
18-11-2003	8:50	N02E18	360	1660
18-11-2003	9:50	S13E89	>197	1824

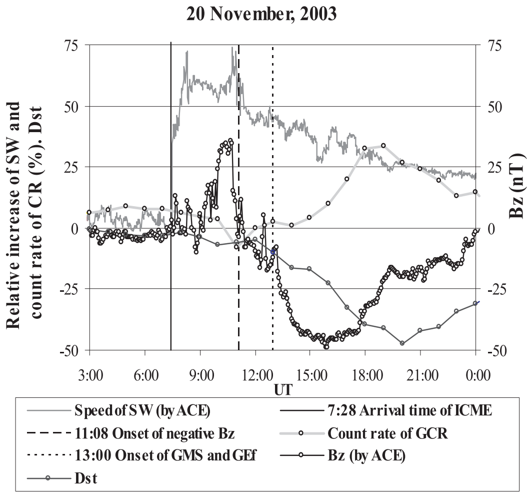

Fig. 2. The time history of the disturbances of the major geomagnetic and Solar Wind parameters at arrival of the ICME to 1 AU at November 20, 2003. The CR count rate enhancement is multiplied by 5 to be noticeable relative SW speed changes. Dst values are divided by 10.

of the ASEC, confirm that the major modulation agent influences both particle fluxes and geomagnetic parameters is the Interplanetary Coronal Mass Ejection. Particle flux variations due to ICME arrival at 1 AU can be broadly distributed into 3 main categories:

1) Sudden, lasting few hours abrupt decrease of the particle detector count rate (Classical Forbush decrease, Fd);
2) Count rate increase (so called Geomagnetic Effect, GME), continued with decrease;
3) Count rate decrease analogical to described in point 1; following with abrupt count rate increase (GME); producing a peak up to 5-7 % (on middle latitudes) lasting 2-10 hours.

Detection of the parameters of Solar Wind, at ACE and SOHO space stations allows connecting particle flux variations with ICME parameters. As the main trigger of magnetospheric disturbances is southward component of the Interplanetary Magnetic Field (IMF), the causes of the mentioned three categories are as follows:

$a)$ The B_z component of IMF is randomly oriented at arrival to 1 AU (B_z is fast changing with mean value near to zero);
$b)$ B_z component of magnetic field of the ICME is oriented southward at arrival to 1 AU;
$c)$ Magnetic field of ICME has composite structure or rotates.

Count rate increases, mentioned in the points 2 and 3 strongly anti-correlate with Dst index changes, i.e. with Geomagnetic Storm (GMS) severity.

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