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Nor-Amberd multidirectional muon monitor: new detector for the world-wide network

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For early forecasting of possible dangerous impacts of the interplanetary shocks headed toward Earth, the network of the surface cosmic ray detectors are used, measuring the modulation effects of the solar plasma cloud approaching. To measure precisely the directional anisotropy of the cosmic ray intensity enhanced by the modulation effects, the muon detector network should have a wide directional coverage. Nor Amberd multidirectional muon monitor (NAMMM) located on the slope of mountain Aragats in Armenia at 40°30'N, 44°10'E, altitude 2000 m, provides on-line data in 15 asymptotic directions, significantly improving the directional coverage of the pre-existing network and the capability of advance warning on the onset of space weather effects at Earth. Detector is equipped with a modern electronics, allowing various software triggers; microcontroller based electronic units (HV power supply and counting modules) together with optional environmental sensors. The wireless Internet and satellite modems ensure the real-time data transmission rates sufficient for the forecasting within 3 minutes after signal detection.

1. Introduction

The geomagnetic storms are driven by the shocks followed by magnetized plasma clouds, reaching the Earth from 15 hours till several days. During their travel in the interplanetary space the clouds interact with the Galactic Cosmic Rays (GCR) filling the space uniformly and isotropic. As a result the angular distribution and density of GCR with energies up to hundreds of GeV will be modulated. Due to the relativistic speeds of these particles, the information on the upcoming severe disturbance of the Interplanetary Magnetic Field (IMF) is transmitted quickly and can be detected by the world-wide networks of Neutron Monitors (NM), responding to GCR energies ≥ 10 GeV) and Muon detectors (responding to GCR energies ≥ 50 GeV) well before the onset of a major geomagnetic storm [1,2,3].

The strength of the geomagnetic storms depends on the magnitude and space distribution of the cloud's "frozen" magnetic fields. Information on the anisotropy of muons and neutrons generated in the atmosphere by the galactic cosmic rays provides the appropriate tool for "looking" inside the magnetized cloud far before it reaches the Earth and the L1 point, where different measuring facilities, hosted by ACE and SOHO space stations are located.

The changing intensity of the GCR also reflects the large scale structure of the IMF and the diurnal variability of cosmic rays detected by surface monitors and has a rather complicated shape [4]. That is the reason why we need multivariate, multidetector measurements of as many components of the changing secondary cosmic rays as possible. A sudden correlated variation in the flux of neutrons, muons, and electrons, detected by the surface monitors could be an indication of an upcoming severe radiation or geomagnetic storms. Munakata et al. [5] demonstrated that the ''prototype muon detector network''', with nodes located in Nagoya (Japan) , Hobart (Tasmania, Australia)and southern Brazil, can provide a good tool for better understanding space weather in the vicinity of the Earth. However, the network had a serious gap in its directional coverage in European region. The gap made it difficult to precisely estimate the appearance time of precursors preceding the onset of storms. To fill this gap, the Nor Amberd Multidirectional Muon Monitor (NAMMM) is added to the network, as one can see from the Figure 1. NAMMM is equipped with two independent DAQ channels: one FPGA based (installed by group from the *Shinshu University*) , another – microcomputer driven; data is available on line from http://crdlx5.yerphi.am/DVIN.

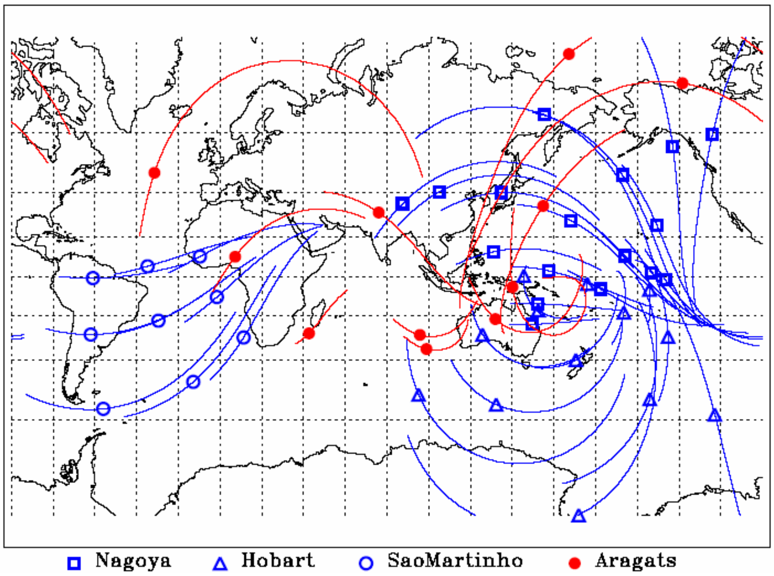

Figure 1 Worldwide network of muon detectors

2. Nor-Amberd Muon Multidirectional Monitor (NAMMM)

The NAMMM, first designed in [7,8], is shown in Figure 2. Detector consists of two layers of plastic scintillators above and below one of the three sections of the Nor Amberd Neutron Monitor.

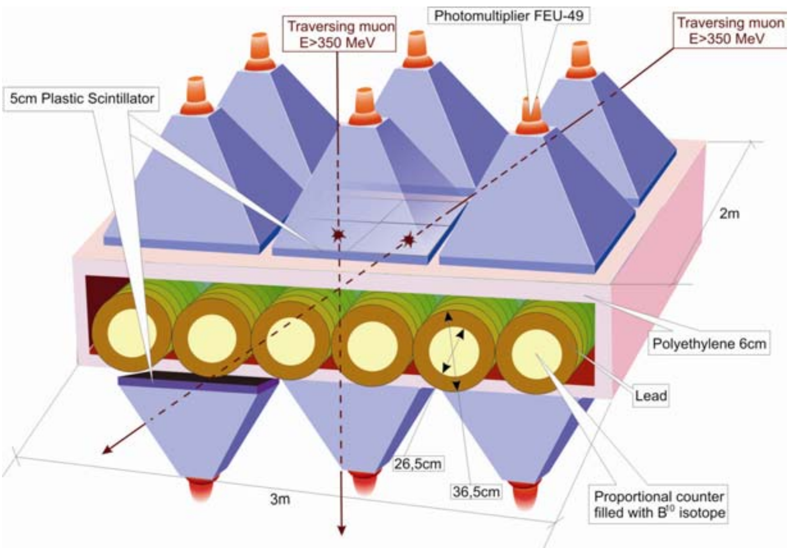

Figure 2 Nor Amberd Multidirectional Muon Monitor (NAMMM)

The lead (Pb) filter of the NM absorbs electrons and low energy muons. The threshold energy of the detected muons is estimated to be 350 MeV. The distance between layers is ~ 1 m. The data acquisition system of the NAMMM can register all coincidences of detector signals from the upper and lower layers, thus, enabling measurements of the arrival of the muons from different directions. The signals ranging from 5 mV to 5 V, from each of 12 photomultipliers, are passed to the programmable threshold discriminators. The discriminator output signals are fed in parallel to the 12-channel OR gate triggering device and to a buffer.

Two 6 bit length words are stored in the buffer, reflecting the trigger status from the 12 registering channels: the first word is for the upper set and the second word is for the lower set. The ones correspond to "fired" channels and zeros to channels that were not fired during a program selectable duration gate in the range 100-1000 nsec. The NAMMM triggered condition is defined by detecting at least one signal in the 12 data channels. There are 43 different possibilities of so called "basic states" of detector triggers. 36 of them carry information about the direction of the incident muon. For example, trigger word configuration "001000" for the upper layer and "001000" for the lower layer corresponds to the muon traversal through third upper and third lower scintillators (zenith angle between 0 and 45º), as demonstrated in Figure 2 Upper and lower layer trigger word configuration of "001000" and "100000" respectively corresponds to the traversal through the third upper and the first lower scintillator (zenith angle between 45 and 65º). The other 7 possibilities, for example, more than one trigger in upper and lower layers such as "111100" and 110000" respectively, or one in the upper layer and many in the lower layer, can be analyzed in terms of the various physical processes, such as the extensive air shower hitting the detector setup, or particle generation in the lead (Pb) layer of the neutron detector system, neutron bursts [9], etc.

Events corresponding to each of the 43 basic states, described above, are independently summed over a 10-second data collection period. Then the string of the 10-second averaged 43 numbers is passed to the analysis software and another cycle of 10-second summation is started.

All electronics are of original design, according to modern very compact and high reliable technologies, oriented for easy maintenance and production. To minimize data transmission rate, the raw data is partially processed in microcontroller before sending it to the main computer. A newly designed readout is based on the concept of full software control of the detector parameters and maximum utilization of all detector data. Each photomultiplier has its own local programmable high voltage (HV) power supply and buffer preamplifier to condition the pulses in preparation for sending them via long coaxial cables without degrading the dynamic range and signal-to-noise ratio. Counting modules are located in the counter room. They have buffer preamplifiers and programmable threshold comparators (discriminators) at the inputs. All electronics modules are based on using modern 8-bit and 32-bit microcontrollers, for the detector control system (HV programming and measurement) and for the main data acquisition respectively. Currently the Atmel 8-bit and Fujitsu FR 32-bit controllers are used.

Two modules of ANMMM are in operation now. Detector is measuring low energy charged component (upper layer), 350 MeV muons (coincidences of scintillators in upper and down layers), and neutrons (section of NANM). Photomultipliers will be equipped with ADCs to select Extensive Air Shower events (by coincidences of high particle densities in upper and down layers) and correlate such events with neutron multiplicities.

3. Forbush decrease from 15 May 2005

First "geoeffective" event detected by NAMMM occurred at 15 May 2005. The Coronal Mass Ejecta (CME) left the sun on May 13th at 16:57UT, propelled in our direction by an M8-class explosion near sunspot 759. CME hit Earth's magnetic field. At May 15th at 02:30 UT and unleashed severe geomagnetic storm with $B_{z\,r}$ reaching -40 nT and Dst decreasing down to -300 nT. Southward direction of B_z effectively decrease the Earth magnetic field and, consequently, cut-off rigidity at Aragats location at ~10:00. Therefore, all ASEC monitors detect well pronounced 2 hour peak during the restoration phase of Forbush decrease (Fd). In Figure 3 we see that charged particle monitors with threshold ~10 MeV ($SNT_{e,\mu}$, SNT_0, $NAMMM_1$) and threshold 350 MeV ($NAMMM_2$) demonstrate very similar behavior (flux is decreasing ~4% in first phase of Fd and decreases ~2% during cut=oo rigidity decrease) reacting on changing parameters of geo-space. Particle detector with much higher threshold (5 GeV, AMMM) is selecting primaries with higher energies, not affected very much by geomagnetic disturbances (flux is decreasing only ~1%).

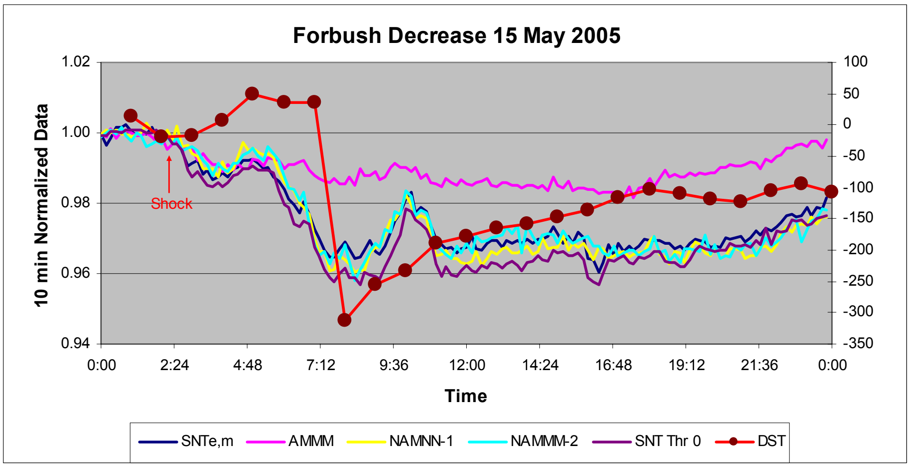

Figure 3 Fd from 15 May 2005 as detected by the ASEC monitors (charged particles detectors)

Correlation coefficients between changing particle fluxes posted in the **Table 1**, also illustrate coherent operation of the ASEC monitors. Directional information from the NAMMM is under analysis mow.

Table 1 Correlation matrix of ASEC monitors – Decreasing phase of Fd
2:10 – 8:30, May 15, 2005

	ArNM	NANM	AMMM	SNTe,m	SNT Thr 0	NA MMM-1	NA MMM-2
ArNM	**1**						
NANM	0.86	**1**					
AMMM	0.85	0.69	**1**				
SNTe,m	0.96	0.90	0.83	**1**			
SNTThr 0	0.96	0.91	0.83	0.99	**1**		
NAMMM-1	0.95	0.91	0.83	0.99	0.99	**1**	
NAMMM-2	0.94	0.89	0.83	0.98	0.98	0.99	**1**

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