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MONITORING AND FORECASTING OF THE GEOMAGNETIC AND RADIATION STORMS DURING THE 23RD SOLAR CYCLE: ARAGATS REGIONAL SPACE WEATHER CENTER

A.A. Chilingarian, V. Babayan, N. Bostanjyan, A. Hovanissyan, G. Hovsepyan, G. Gharagyozyan, N. Gevorgyan, S. Kazaryan, L. Melkumyan, S. Sokhoyan, S. Zarunyan

Cosmic Ray Division, Yerevan Physics Institute, Alikhanian Brothers 2, 375036 Yerevan 36, Armenia

ABSTRACT

The Solar Environment Center located on Mt. Aragats will provide real-time monitoring and forecasting of the extreme Geomagnetic and Radiation Events. Two neutron monitors, a muon telescope and a Solar scintillation telescope operating on Aragats research stations will provide accurate detection of very low fluxes of the most energetic Solar particles and modulation effects of Solar events.

The correlation of the Solar Energetic Phenomena with modulations of the Galactic Cosmic Ray flux and direct detection of the high-energy protons and neutrons emitted during Coronal Mass Ejection provide firm grounds for specification and forecasting of the effects of tremendous explosions on the Solar surface. Consequently ground observation of the variations of Cosmic Ray fluxes make it possible to issue alerts to avoid imminent hazard of upcoming Geomagnetic and Radiation Storms.

INTRODUCTION

Solar Energetic Phenomena (SEP) – pose a serious threat to the performance of working space systems such as satellites, space stations and so on, causing anomalies in their operation. Predictions of solar activity are important for various technologies, including operation of low-Earth orbiting satellites, electric power transmission grids, high-frequency radio communications and radar. The Aragats Space Environment Center (ASEC) initiated in 1999, will provide real-time monitoring and forecasting of the extreme geomagnetic and radiation events.

The center consists of the two interconnected parts, the first dealing with the high energy Galactic Cosmic Rays (CR) and the second - with Solar Cosmic Rays and Solar modulations of Galactic CR. Despite the fact that research in these fields in the last decade is conducted separately numerous ties and correlations exist both from the experimental point of view and from the standpoint of data interpretation and modeling of the very complicated physical processes. The experimental facilities at the stations on Mt. Aragats are and will be used for both data gathering and data interpretation and modeling of the physical processes. A huge amount of the scintillation detectors from our Extensive Air Shower (EAS) installations continuously monitor background radiation for calibration purposes. The neutron monitors measuring the CR variations will be used for the detection of the EAS neutrons to form the multidimensional EAS signature along with the soft and muon component. The Local Area Networks, connecting installations located at the altitudes of 2000m and 3200 m with computing and the space weather forecasting center in Yerevan, along with the precise synchronization of all apparatus triggers will allow us to correlate data from all the monitors, revealing the complicated space-time structure of the investigated phenomena. Multiparameter, multidetector investigation of Cosmic rays will help us understand the origin and acceleration mechanisms of both Solar and Galactic CR, using Solar flares and Coronal mass ejection with originated shock waves as a model of far more energetic Supernova explosions and stochastic acceleration and acceleration by the very strong magnetic fields of neutron stars.

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Table 1. Detectors of CRD

Detector	Altitude, m	Surface, m^2	Threshold(s), MeV	In operation since	Count rate, (min^{-1})
Nor-Amberd Neutron Monitor	2000	18	50	1996	2.7×10^4
Aragats Neutron Monitor	3200	18	50	2000	6.6×10^4
Aragats Solar Neutron Telescope	3200	4	50,100, 150,200	1998	6.7×10^4
Nor-Amberd Muon Telescope*	2000	18	25	...	3.24×10^5
Aragats Muon Array	3200	150	5000	1995	6.2×10^5
Aragats γ/e Array	3200	150	10	1995	3.9×10^6

*Detector is under construction.

STRUCTURE OF THE ARAGATS SOLAR ENVIRONMENT CENTER

Cosmic Ray Division (CRD) of Yerevan Physics Institute runs 2 high altitude stations Nor-Amberd (2000m a.s.l.) and Aragats (3200m a.s.l.) on the slope of mountain Aragats in Armenia (cutoff rigidity $\sim 7.6GV$). Two 18NM-64 neutron monitors (NM) are in operation, one at Nor-Amberd, another at Aragats research station[1].

Solar neutron telescope[2] (SNT) at Aragats station consists of $4m^2$ 60cm thick scintillation detectors with anti-coincidence shielding vetoing near vertical charged flux. SNT is part of world network, coordinated by Solar-Terrestrial laboratory of the Nagoya University (Y. Matsubara, Y.Muraki, et al., 1999).

Forth detector is multidirectional muon telescope, now under construction at Nor-Amberd research station.

At Aragats high altitude station two surface arrays (S.H. Sokhoyan et al.,1999 and A.P. Garyaka et al., 1999) are operating with main purpose to detect Extensive Air Showers (EAS) initiated by very high energy primaries ($> 10^{14}eV$). Simultaneously for detector calibration purposes the charged flux of the secondary particles (background flux) is continuously measured. The high frequency of charged background on mountain altitude ($> 400Hz/m^2$) and huge surfaces of detectors ($300m^2$) provide better relative accuracy of flux measurements comparing with standard neutron monitors. Of course, the absolute intensity of CR muons (majority of background) are influenced by the unknown temperature profile above installation and, consequently, longterm variations couldn't be studied by this technique, even though short term variances of intensity could point on the approaching shock and upcoming geomagnetic storm.

Joint analysis of multidimensional information from all ASEC detectors (see Table 1), will provide information for timely and reliable forecasting of hazardous high-energy particles and geomagnetic storms.

DATA ACQUISITION AND TRANSFER

To increase reliability and stability of data acquisition systems, we use i486 PC's running Linux with PC-CAMAC interface as registration devices. This flexible solution will provide remote control and on-line debugging possibilities.

For the time synchronization at least 3 Global Positioning Satellite (GPS) receivers will be installed, one for each subnetwork (i.e. Yerevan, Aragats, Nor-Amberd). The GPS's will be attached to the Linux-servers, and by using Network Time Protocol we will be able to synchronize time of any computer up to millisecond.

CRD Local Area Network (LAN) is part of Yerevan Physics Institute LAN connected via 128 kbps satellite channel to the Internet. YerPhI LAN connects few hundred of computers located in 7 buildings using 10 and 100 Mbps cable links.

Nor-Amberd and Aragats research stations are connected to CRD LAN through radio-modems. Aragats

[1] `http://crdlx5.yerphi.am/neutron/index.html`
[2] `http://crdlx5.yerphi.am/solar.html`

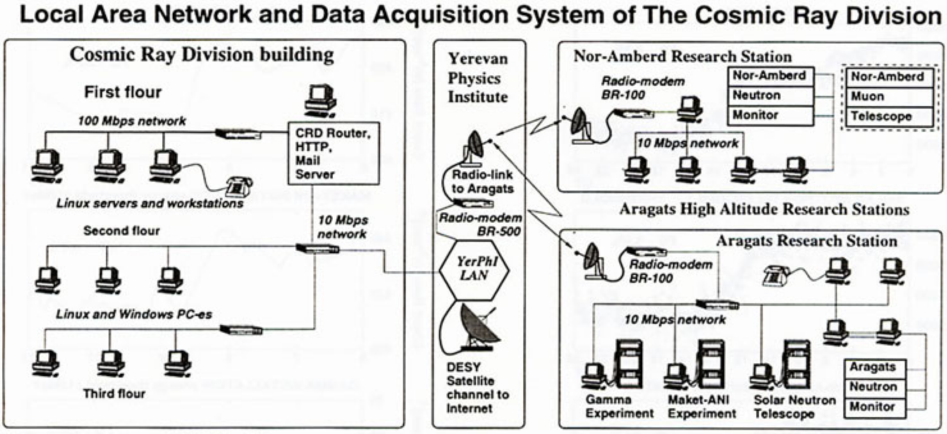

Fig. 1. Structure of CRD LAN.

LAN is connected to Yerevan via Aironet BR100 radio-modems (transfer rate at 1 Mbps). Nor-Amberd LAN is connected with Arlan 655 radio-modem (planed to be replaced with Aironet BR500 modems). Aironet's BR100, BR500 series bridges uses Direct Sequence Spread Spectrum radio transmission type. These bridges supports several types of the radio modulation technique, which are different implementations of the phase shift keying. They have ability to support a reliable connection at $2Mbps$ up to 40km.

As shown in the scheme of LAN (see Figure) radio-modems are connected to CRD LAN via YerPhI LAN. Cause of existing internal traffic among computers of CRD, CRD LAN's will be separated from YerPhI LAN, to reduce the load of traffic and will be connected to YerPhI LAN via gateway of CRD.

DATA ANALYSIS

The modulation effects of the huge magnetized clouds of Solar plasma, erupted during CME's started far before cloud reach Earth (usually in 2 days). The modulated relativistic GCR's reach Earth in 10-15 minutes and fluctuations of their intensity are registering by all 6 CRD installations. From the Figures 2-5 one can see recent huge Forbush decreases detected by ground arrays. This variety of information on intensity and anisotropy fluctuations form basis for establishing forecasting service center.

The main goal is to utilize short range (15 min - 3 hours) fluctuations of the galactic Cosmic Rays during the Fd for forecasting purposes. This fluctuations could be associated with large-scale disturbances of interplanetary magnetic field. This disturbances suppress intensities of GCR from some trajectories, those generating precursors of severe geomagnetic storms.

It is believed that this disturbances are generated during the decay of the large-scale structures of magnetic field of the Sun (V.I. Kozlov and V.V. Markov, 1997).

We want to investigate scale invariance of the CR intensity oscillations, by calculating the correlation dimension of the GCR time series, detected by ASEC facilities. The advanced methods of fractal dimensionality calculation will be used (A.A. Chilingarian, 1992).

We'll try to identify the fractal structures in the nonlinear dynamic of the GCR fluctuations and connect them with possible creation of the turbulent region beyond the coming shock wave.

Besides the fractal dimensionality calculation also the cross-correlation coefficients with *lag k* are used for comparing intensity variations measured by different installations as well as for comparisons of ground and space born sensors:

$$r_k(x,y) = \frac{\sum_{i=1}^{N}(x_i-\mu_x)(y_{i+k}-\mu_y)}{(N-1)\sigma_x\sigma_y}$$

where x_i and y_i are the N point intervals of the NM, SNT and satellite detectors (GOES 8, GOES 10, ACE,

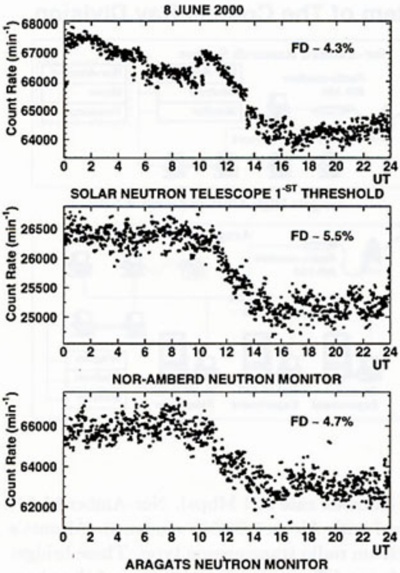

Fig. 2. Forbush decrease registered by neutron monitors and solar neutron telescope.

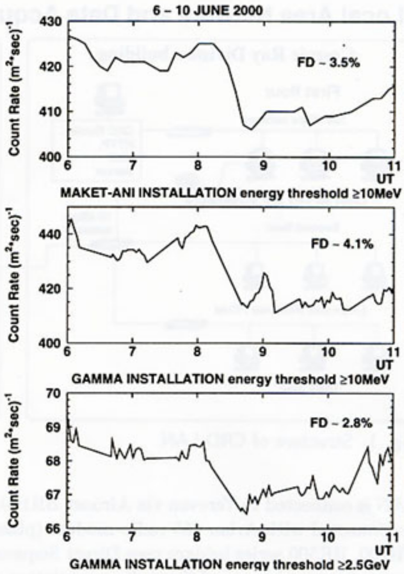

Fig. 3. Forbush decrease registered by ϵ/γ and μ detectors of EAS installations.

etc...) one-minute Time Series (TS). The quantities μ_x, σ_x and μ_y, σ_y are the correspondent mean values and variances of chosen TS intervals, comprising N counts. The k value of the *lag* is optimized to give maximal correlation. For all energetic events calculated value of lag $k \approx 0$ and correlation between TS are rather big.

This is prove that ASEC installations are detecting CR variations at the same time. In contrast, data from satellite sensors usually have a lag about several hours (A.Chilingarian, et.al., 1999), proving that CR variations can be used as precursors of high geomagnetic activity.

Another example of our attempts to utilize GCR modulation for magnetic storm forecasting was made by A.A. Chilingarian et al. (2000). On the last 3 year data from Nor-Amberd NM it was illustrated that majority of GCR modulation events started before the shock wave reach ACE satellite. Of course all detected correlations are *a posteriori* detected.

For establishing forecasting service we need reliable methodology for early detection of upcoming storm, based on the analysis of GCR intensity time series. Such analysis could be made exploiting neural information technologies – a leading approach for solving analytically intractable multidimensional nonlinear problems. The historical data on Forbush decreases accompanied with severe Geomagnetic storms will be used for network training. Stochastic algorithms of net training developed in CRD (A.Chilingarian, 1998) along with powerful Linux servers will provide timely alerts and warnings on up coming radiation and geomagnetic storms.

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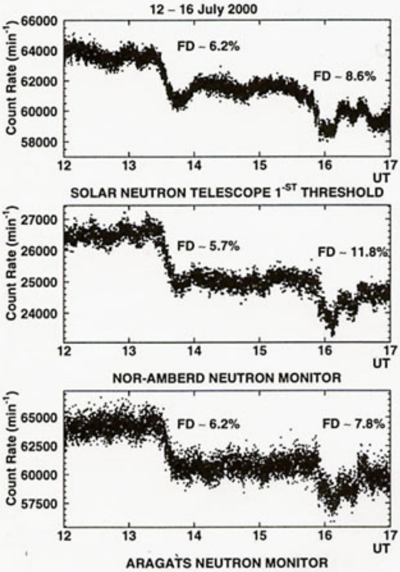

Fig. 4. Forbush decrease registered by neutron monitors and solar neutron telescope.

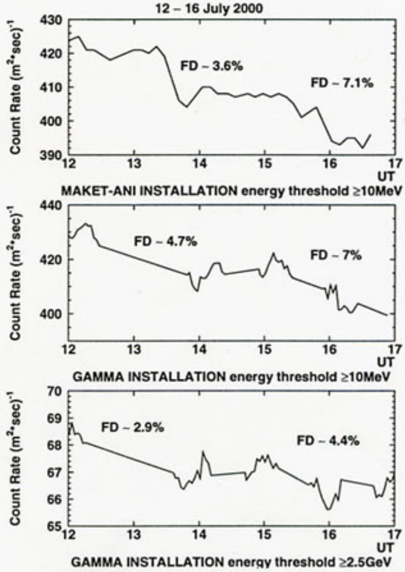

Fig. 5. Forbush decrease registered by ϵ/γ and μ detectors of EAS installations.

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