Interim report of ARAGATS group on NMDB project

Cosmic Ray Division, Yerevan Physics Institute

28.06.2008

NMDB WP3: Guidelines for the data acquisition

For the answering to the online questionnaire, suggested by NKUA, Aragats group performed calculations of the barometric coefficients, mean multiplicity coefficients and daily variations of the Neutron Monitor counts rates. Measurements of these parameters at the start of the 24-th solar activity cycle will provide important benchmark for the further analysis of the solar cycle in progress. Both Aragats neutron monitor are registering simultaneously 3 time series with 18 channels. The dead times of detectors are equal to 0.4, 250 and 1250 microseconds. This option gives additional possibilities both for detector reliability check and for physical analysis of the transient events.
Comparisons of the measured detector parameters with world data were performed and reports were presented to the UN/ESA/NASA/JAXA Workshop on the International Heliophysical Year 2007 and Basic Space Science "First Results from the International Heliophysical Year 2007", Sozopol, Bulgaria, June 2-7, 2008 (http://aragats.am)

NMDB WP4: Development of user tools for submitting neutron monitor data to the database (uploading data) and for accessing the database (downloading data)

Aragats Space Environmental Center (ASEC) presents data from multiple detecting systems, including Neutron Monitors, in the Internet (http://aragats.am/DVIN). The data are gathered from remote CR monitors by so called ADAS-catcher software ; it is a Java application which gets data from the Advanced data acquisition system (ADAS) implemented at all ASEC particle detectors. ADAS-catcher stores time series as XML raw files and also registers them in MySQL database. ADAS-catcher supports several backup links automatically switching to avoid faults in radio network. It also supports Internet proxy mechanisms to make the channels backup organization more flexible.

After registering in MySQL, processing of data started by, so called, presentation processor, which produces 1-minute count rates; performed pressure correction, and other operations and consistency checks. The data in MySQL are described by three tables:

- "DVIN_MONITORS" which describes particle detectors operated at ASEC ,including Neutron Monitors (location, geometry, energy thresholds, efficiency, all changes made during multiyear operation);
- "DVIN_GROUPS" which describes the sub groups for each detector (pressure corrected, pressure uncorrected, directions, coincidences, etc…);

- "DVIN_TIMESERIES" which describes the statistics and meta-information for each of time-series (maximal and minimal values, name, X and Y axes titles, type of time series (neutrons, electrons, muons, dead times, etc…).

All three tables have access rules for presentation to end users and sharing with other DVIN nodes. Particle detector data is stored in MySQL data base at CRD headquarters in Yerevan and also at 2 file servers at Aragats and Nor Amberd research stations. ADAS-catcher and presentation processor subsystems are under redeveloping to be rewritten at the base of PHP. Nonetheless, time series of both Neutron Monitors are available from http://aragats.am/DVIN.

NMDB WP5: Deployment of application and service software to compute key parameters and to implement alert systems from neutron monitor data

We perform analysis of the GLEs detected by ASEC monitors during 23 solar activity cycle to explore possibilities of early forecast of severe radiation storms by the particle detector data. Below is the report of our findings.

Large flux of relativistic particles accelerated in violent solar flares or/and by shock wave expanding in corona unleash Solar Energetic Particle event (SEP), sometimes causing Ground level enhancement (GLE), registered by networks of particle detectors at earth surface

In (Chilingarian et al, 2003, see also ACE news, 2005) based on the subsample of GLE events occurred during 23 rd solar activity cycle (1996 – 2008) and unambiguously detected by the monitors of the Aragats Space Environmental Center (ASEC, Chilingarian et al., 2005) we claimed that relativistic solar ions with GeV energies arrive well before MeV energy ions, thus providing possibility of alerting on upcoming radiation storm. In Table 1 (updated from Gevorgyan et al., 2005), we present the characteristics of these events along with times and statistical significances of peaks detected by ASEC neutron monitors (for 5-minite time series). For comparison in the last column we present the actual time of the S2 alert issued by the Space Environmental Center (SEC) of National Oceanic and Atmospheric Administration (NOAA), based on the enhanced 10 MeV proton flux (I_p (E > 10Mev) > 100/cm^2 * sec*ster), registered by the facilities onboard of GOES satellite. The most important problem of detection of solar modulation effect at middle/low latitudes is proving that observed peak in time series is signal and not background fluctuation only. Assuming Gaussian nature of the count rate fluctuations we can calculate the chance probability to obtain randomly definite enhancement of the count rate. Usually not the chance probability, but the standard Gaussian distribution z-score (σ) is used as a measure of statistical significance. For all 3 events the significance of the peaks detected by surface particle detectors is $\geq 3.5\sigma$, thus the probability that the peak is due to random fluctuation only is rather small, we can expect one such enhancements in 5-minute time series in 3 months.

The chance probability to register random enhancement exceeding 3.5σ simultaneously by several ASEC monitors is rather small. However, we cannot exclude that in some cases magnetospheric or/and atmospheric disturbances influence the count rate of surface particle detectors and enhance fluctuations. Furthermore, by pyre statistical reasons, we can expect large z-scores in continuous multiyear time-series.

Table 1 GLE of 23rd cycle detected by the ASEC particle monitors

GLE number and date	X-Ray Flare	ASEC Monitor	GLE onset	First Peak time	σ	Second Peak time	σ	Time of S2 Alert by SEC/NOAA
GLE 60	X14.4	ANM	13:55	14:00	3.8	14:30	5.3	14:25
4/15/2001		NANM	13:55	14:00	3.5	14:30	4.1	
GLE 65	X17	ANM	11:25	11:45	4.6	12:10	4	12:40
10/28/2003		NANM	11:30	11:35	3.5	12:05	3.6	
GLE 69	X7	ANM	6:55	7:10	5.6			7:01
1/20/2005		NANM	6:55	7:00	4.5			

With the exception of the event on 20 January, when due to very good magnetic connection of the flare site with earth, all relativistic particles seem to come simultaneously, the enhancements of GeV SCR detected by the Neutron Monitors can alert on upcoming severe radiation storm (see also Figures 1 and 2). The alerts from middle and low latitude monitors are even more important compared to high latitude networks, because of lower probability of false alarms. If an enhancement occurs at monitors with large cutoff rigidity it indicates that spectral knee occurs at large enough energy and flux of the MeV ions will be very high. Of course, not all radiation storms will contain particles with GeV energies, but ones having such energies are of utmost hazard and should be reported as soon as possible to satellite operators. ASEC monitors can provide just such alerts. To detect very weak fluxes of highest energy solar ions in 2007 we enlarge the surface of 5 GeV muon detector at Aragats up to 100 m^2, to achieve the relative accuracy of signal detection of 0.07% (for 5 minute time series).

On 2003 October 28 one of the biggest solar flares of the 23^{rd} cycle occurs (X17.2 according to the NOAA scale, X-ray flux maximum at 11:10). It was a remarkable event not only because of its strength, but for many associated physical phenomena. Extended GLE event was registered by world-wide networks of Neutron Monitors (Panasyuk et al. 2004); some of monitors (Bieber et al., 2005) and satellite detectors (K. Watanabe et al., 2006) detect solar neutrons. The record cosmic ray depletion (Forbush decrease) was detected by the middle-latitude particle detectors (Chilingarian et al., 2005). The radiation storm (S4, according to the NOAA scale) was fourth largest in history since NOAA began keeping records in 1976. Due to this storm many satellites experience extensive surface charging, problems with orientation, uplink/downlink and tracking. Instruments on SOHO space station were shut down for safety reasons. Astronauts at Space station hide themselves in Russian module Zvezda, having best shielding against space radiation. Sever over-polar flights were rescheduled. The Geomagnetic Storm (GMS) triggered by the interplanetary coronal mass ejection reached earth 19 hours after flare. GMS also interfere with satellite communications; power grids in the northern United States and Canada are feeling the effects of the extreme geomagnetic storm and are experiencing power surges, voltage control problems and protective system problems. Event influence on the Earth's Atmosphere, the Ionospheric and Magnetospheric responses (see details in Gopalswamy et al., 2005) make this event unique in terms of the free energy available at the Sun and the geospace and heliospheric consequences. Therefore, it is of special interest compare the forecasts issued by Space Environment Center in Boulder, Colorado with possible alerts from the

ASEC particle detectors. Of course, ASEC provides only post-event analysis, because in 2003 there was not operational Space Weather service established at ASEC.

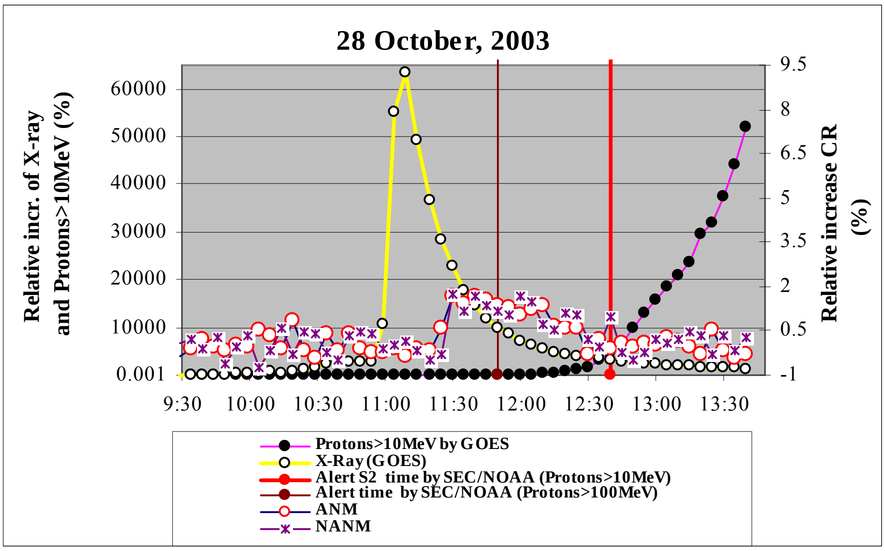

Figure 1 Radiation from 28 October 2003 X14.4 flare. X-ray count rate is multiply by 2 (flux maximum at 11:10). SEC/NOAA alerts enhancement of 100 MeV protons at 11:50 and S2 alert for 10 MeV protons at12:40. Enhancement of the Aragats Neutron Monitor (ANM) and Nor Amberd Neutron Monitor (NANM) reaches ~1.7% and reaches maximum at ~11:30.

In Figure 1 we can see that abrupt enhancement of the ASEC monitors count rates started at least 20 minutes earlier than 100 MeV protons alert and more than 1 hour earlier than S2 alert, both issued by SEC. In Figure 2 we can see that at 11:20 correlations between particle fluxes on 2 research stations of ASEC as well as “delayed” correlations of both fluxes with X-ray flux are reaching peaked at 0.7-0.8.

Correlation information along with information on the GLE makes the false alarm probability extremely small. Information only on the GLE isn’t enough due to not very big enhancement at middle-low latitudes (usually 1.5-2%) and rather large fluctuations of count rates. The relative accuracy of neutron monitor 5-minute count rate is at ASEC 0.3-0.4%, therefore, significance of 1.5-2% enhancement corresponds to 3.5 - 5σ, and related false alarm probability to $10^{-4} – 10^{-5}$, i.e. occurs randomly several times in year by chance. The “delayed” correlations are calculated by the “memorization” of the X-ray flux enhancement (available on-line from SEC) and continuous (moving) calculations of the correlations with surface particle detector data.

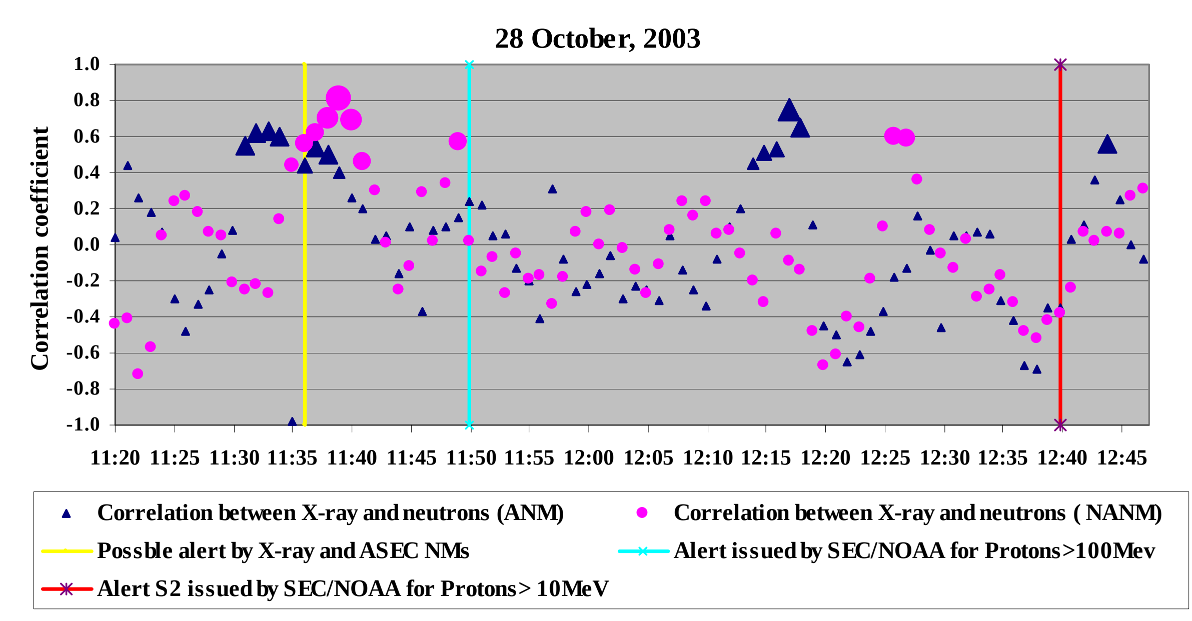

Figure 2 Pattern of correlations between neutron fluxes measured by surface particle detectors and measured by GOES satellite X-ray flux. Correlations are calculated with 1-minute count rates, by memorizing the X-ray 10 minute peak and moving 10 minute intervals of surface particle detector count rates. The triangles, circles and diamonds are denoted the correlation coefficient between changing fluxes of particle detectors and X-rays.

In Figures 1 and 2 we can see that X-ray flare maximum was at 11:10 and dangerous flux of abundant 10-MeV protons reach Earth more than1 hour later. 100 MeV protons alert was issued by SEC/NOAA 40 minutes after flare and surface monitors at ASEC can alert on GLE 20 minutes earlier and 1 hour in advance of SEC S2 alert. The correlation analysis of multiple ASEC monitors make ASEC alert reliable and confident. Correlation of X-ray peak and Neutron monitors peaks reach values 0.6-0.8 at 10:35, 25 minutes after X-ray maximum. In Figure 3 we can see that correlation of X-ray peak and rising charged component of secondary cosmic rays (mostly electrons and muons, measured by scintillators) reach values 0.6-0.8 even earlier at 10:26, 15 minutes after X-ray maximum. Time difference between neutron peak and charged secondary particle peak can be explained by difference in primary energy of protons giving rise to both types of secondaries; the most probable energy of "parent" protons is bigger for secondary charged particles comparing with neutrons (the time history of proton detection apparent in Figure 1 supported hypothesis that arrival time is inversely proportional to the proton energy). Correlations between X-ray radiation and particle fluxes unambiguously prove genetic relation between flare and surface particles and can be used for construction of an alert on most violent radiation storms. Continuous monitoring of the abrupt enhancement of monitors count rate and "moving" correlations calculation after severe solar flare will surely point on upcoming severe radiation storm. False alarm probability of such alerts will be negligible, efficiency for most violent storm – high.

Detected radiation from 28 October 2003 flare demonstrates power of combining information from space born spectrometers and surface particle detectors for constructing reliable and timely Space Weather forecasting services. Another example of the time history of radiation connected with violent solar flare is posted in Figures 4 and 5.

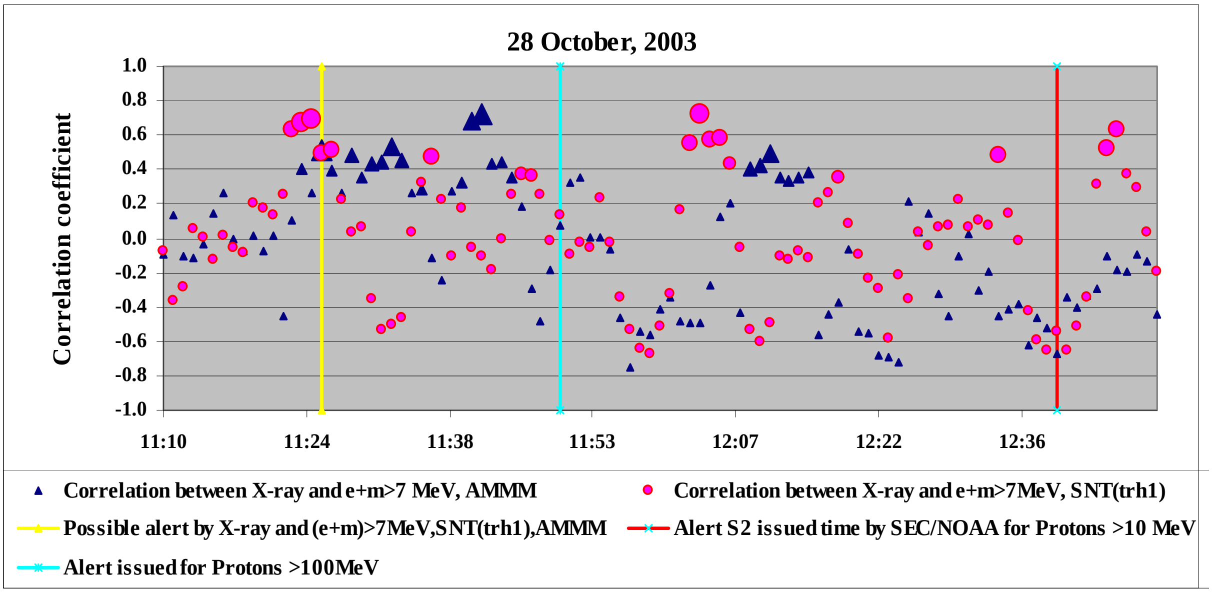

Figure 3 Pattern of correlations between rising charged species of secondary cosmic rays and measured by GOES satellite X-ray flux at 28 October 2003. Correlations are calculated with 1-minute count rates, by memorizing the X-ray 10 minute peak and moving 10 minute intervals of surface particle detector count rates. The triangles, circles and diamonds are denoted the correlation coefficient between changing fluxes of particle detectors and X-rays.

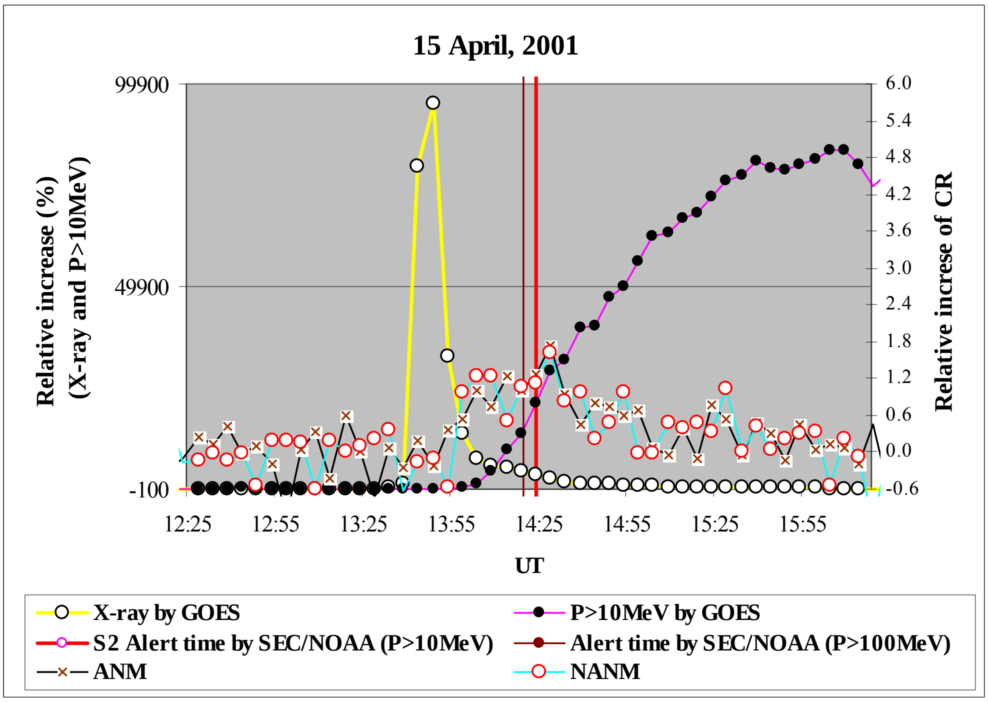

Figure 4 Radiation from 15 April 2005 X17.2 flare. SEC/NOAA alerts enhancement of 100 MeV protons at 14:21 and S2 alert for 10 MeV protons at 14:25. Enhancement of the Aragats Neutron Monitor (ANM) and Nor Amberd Neutron Monitor (NANM) reaches ~1.4% and reaches maximum at ~14:00.

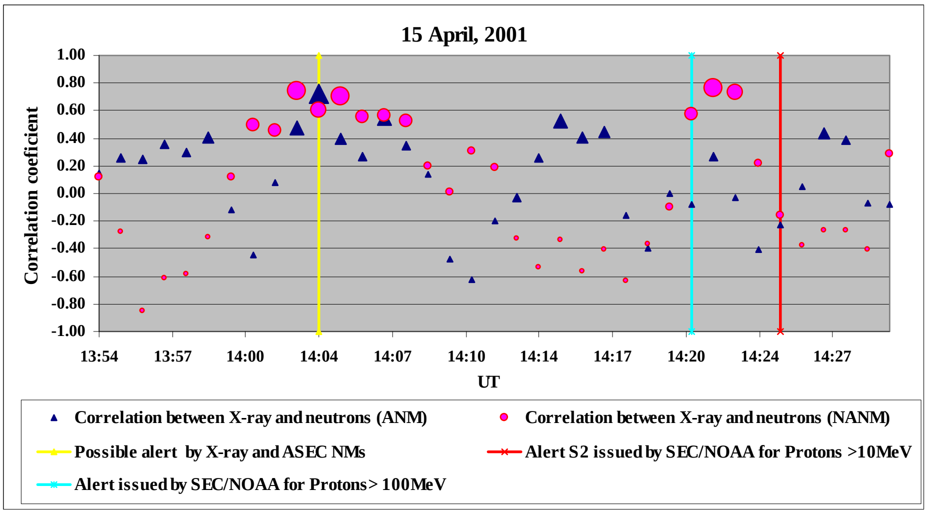

Figure 5 Pattern of correlations between neutron fluxes measured by surface particle detectors and measured by GOES satellite X-ray flux at 15 April 2001. Correlation between X-ray and Neutrons peaks reach values 0.6-0.8 at 14:04, 20 minutes after X-ray maximum.

In Figures 4 and 5 we can see that X-ray flare maximum was at 13:50 and dangerous flux of abundant 10-MeV protons reach Earth at 14:25, 35 minutes later. 100 MeV protons alert was issued by SEC/NOAA 31 minutes after flare and surface monitors at ASEC can alert on GLE ~20 minutes earlier. However, as we can see from the Figure 6, the most intense GLE of 20 January, 2005 leave very small time span (if any) for the forecasting by the surface particle detector data.

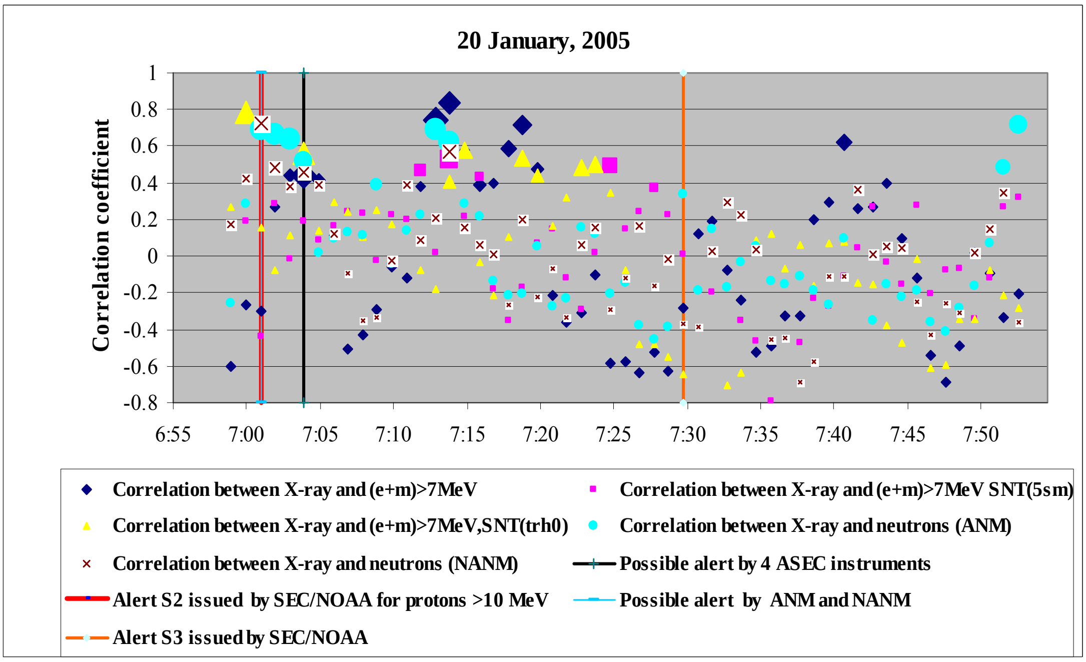

Figure 6 Pattern of correlations between neutron fluxes measured by surface particle detectors and measured by GOES satellite X-ray flux at 15 20 January 2005. Correlation between X-ray and ASEC monitors reach values 0.6-0.8 at 7:01, 20 minutes after X-ray maximum.

The reliable alert service, exploiting information from both surface particle detectors and space-born facilities, for warning on upcoming SEP event can be established as follows. As soon as strong flare (X-class according to the NOAA scale) is reported by the GOES satellites (available on-line from SEC/NOAA) the alert programs started:

1. The first one is examining the enhancement of count rates in all channels of neutron and muon monitor routinely calculated by the Aragats Data Acquisition System (ADAS); Enhancements and corresponding statistical significances are calculated each minute by twelve 5-second count rates. Examining of the inter-channel correlation matrix, also calculated by ADAS, will help to prove that enhancement is not failure of one of channels, but consistent enhancement.
2. The time history of the X-ray flux (from start till maximum, usually ten 1-minute numbers) is memorized and a "delayed correlation routine start to calculate correlation of X-ray peak with also 10 counts of ASEC monitors. Counts are shifted and map of moving correlations is constructed.
3. Dependent on the values of peak statistical significance and value of the correlation between X-ray flux enhancements and enhancements of neutral and charged fluxes, measured by surface particle detectors different warnings and alerts are issued.

Described scheme of alert service will be highly reliable, because it uses different particle fluxes measured at 3 altitudes (1000, 2000, 3200 m. A.S.L.) and X-ray flux measured by satellite facilities.

References

1. *Bieber, J. W., Clem, J., Evenson, P., Pyle, R., Ruffolo, D., & Sarïz, A. 2005, Geophys. Res. Lett., 32, L03S02.*
2. *Chilingarian, A., Avakyan, K., Babayan, V., et al.: Aragats Space – Environmental Center: status and SEP forecasting possibilities, J. Phys. G: Nucl. Part. Phys., Vol. 29, 939 – 952, 2003.*
3. *Chilingarian, A., Arakelyan, K. Avakyan, K., et al.: Correlated measurements of secondary cosmic ray fluxes by the Aragats Space – Environmental Center monitors, Nucl. Instrum. Methods Phys. Res., Sect. A, 483-496, 2005.*
4. *N.Gevorgyan for the ASEC team, (2005) Test Alert Service Against Very Large SEP Events, Advances in Space Research (ASR), Vol. 36, issue 12, 2351-2356.*
5. *N. Gopalswamy, G. Barbieri, et al. (2005), Introduction to the special section: Violent Sun-Earth connection events of October–November 2003, Geophys. Res. Lett., 32, L03S01*
6. *Panasyuk, M. I., et al. 2004, Cosmic Res., 42, 489*
7. *Watanabe, K., Gros, M., Stoker, P.H., et al.: Solar neutron events of 2003 October–November, Astrophysical Journal, 636, 1135–1144, 2006.*

NMDB WP6: Training courses and public outreach

We start development of the "Space Education" WEB site which will serve as a convenient and effective way for education and outreach purposes. The website will perform as a virtual mentoring platform for students of the Physics Department of Yerevan State University, providing comprehensive listing of all of CRD activities, projects, workshops, scientific news, as well as offer the lectures and courses held at CRD, allow to pass preliminary on-line examinations, submit their research papers and generally familiarize with the opportunities and programs developed by CRD. An on-line library will also be available at the website. Having registered and acquired their personal account the students will receive virtual guidance and take part in a wide range of training sessions, pass through e-testing, solve problems for students, etc…

The aim of the website is to become an educational guide for the students throughout the academic year as well as perform as a more convenient way to manage the students' works and performance for the educators.