The new Athens Center applied to Space Weather Forecasting

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Abstract. The Sun provides most of the initial energy driving space weather and modulates the energy input from sources outside the solar system, but this energy undergoes many transformations within the various components of the solar-terrestrial system, which is comprised of the solar wind, magnetosphere and radiation belts, the ionosphere, and the upper and lower atmospheres of Earth. This is the reason why an Earth's based neutron monitor network can be used in order to produce a real time forecasting of space weather phenomena.

Since 2004 a fully functioned new data analysis Center in real-time is in operation in Neutron Monitor Station of Athens University, (ANMODAP Center) suitable for research applications. It provides a multi sided use of twenty three neutron monitor stations distributing in all world and operating in real-time given crucial information on space weather phenomena. In particular, the ANMODAP Center can give a preliminary alert of ground level enhancements (GLEs) of solar cosmic rays which can be registered around 20 to 30 minutes before the main part of lower energy particles. Therefore these energetic solar cosmic rays provide the advantage of forth warning. Moreover, the monitoring of the precursors of cosmic rays gives a forehand estimate on that kind of events should be expected (geomagnetic storms and/or Forbush decreases).

Keywords: Cosmic rays, Neutron Monitors, solar energetic particles, Space weather

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INTRODUCTION

Since 1960 the nucleonic component of the galactic cosmic rays (CR) is recorded in Neutron Monitor (NM) stations [1]. These stations are essential to the detection of low and mid energy particles that arrive at the Earth from solar or/and galactic sources because of the significant monitoring window that these stations open in the atmosphere. The cut-off rigidity of the measured particles varies from zero (0) to fifteen (15) GV, while the energy cut-off applies from 0 value at polar stations, to the value of 20 GeV at the equatorial stations. The technological process made possible

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the construction of very effective and low cost recording systems that could record and provide data of the cosmic ray intensity in real time. The first real time NM station was established in 1997 at Moscow. Nowadays twenty five NM stations provide their data in real or quasi real time and their distribution is presented in Figure 1.

Athens NM station (Super 6NM-64) is operating in the Physics Department at the University of Athens (37.58˚N 23.47˚E, cut-off rigidity 8.53 GV)) since November 2000, and is the 6^{th} station to operate in real time mode. The measurements of the station are being elaborated automatically in order to be compatible to other stations data because of the necessity to compare a number of high rigidity stations in a good quality data that is required for a detailed study of CR variations and space weather conditions. The resolution of the measurements reaches as far as one second – which is uniquely worldwide. Specifically a modern type of atmospheric pressure sensor and registration system which was developed by the Athens Cosmic Ray Group helped a number of NM stations that were out of service to operate again [2].

A number of scientific groups working on the field try to establish a reliable network of neutron monitors operating in real time, because of the necessity to have a large number of recorded activity from as many stations as possible through out the globe. For instance: 'Spaceship Earth' is an effort that combines eleven neutron monitor stations strategically located around the world in order to provide 3-dimensional measurements of the cosmic ray angular distribution [3]. Another operating network of neutron monitors is Aragats Space Environmental Center (ASEC), located in Armenia which consists of two high altitude stations [4]. Those

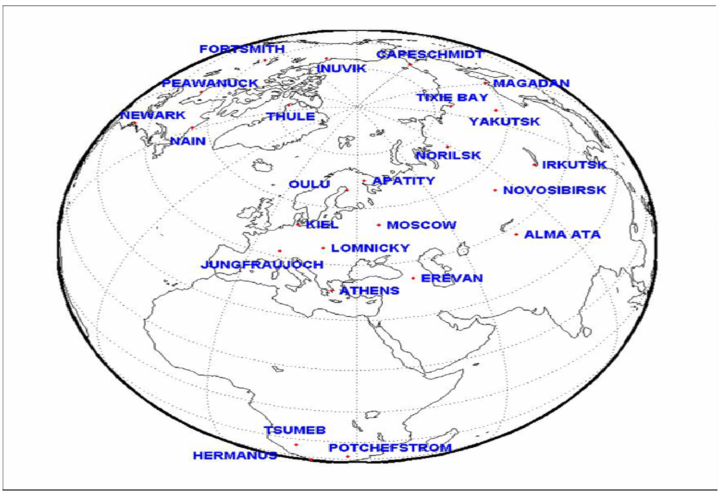

FIGURE 1. A global distribution of NM stations provided data in real time

efforts provide the direction of Space weather forecasting research by cosmic rays [5]. It is of great importance to establish a network of as many neutron monitors as possible combined with satellite data in order to be led into successful prediction.

During the last two years the Athens Neutron Monitor Data processing (ANMODAP CENTER) is being created at Athens University on the basis of the cosmic ray group activity.

DATA COLLECTION SYSTEM

In order to perform a real time prediction of space weather phenomena, only real time data from a neutron monitor network should be employed. The system of the ANMODAP Center collects data in real time from twenty- three widely distributed real time cosmic ray stations using the Internet [6]. The characteristics of these stations (geographic coordinates, altitude, standard pressure, cut-off rigidity) are listed in Table I. The main server in Athens station collects 1-minute, 5-minute and hourly cosmic ray data. The station measurements are processed automatically and converted to a suitable format for forecasting purposes. All programs have been written in an expandable form for easy upgrade of the NM network. Programs that make use of these data for forecasting purposes are already running in experimental mode. The increased number of NM stations operating in real-time gives a good basis for using NM network as a tool of forecasting the arrival of the interplanetary disturbances at the Earth [7].

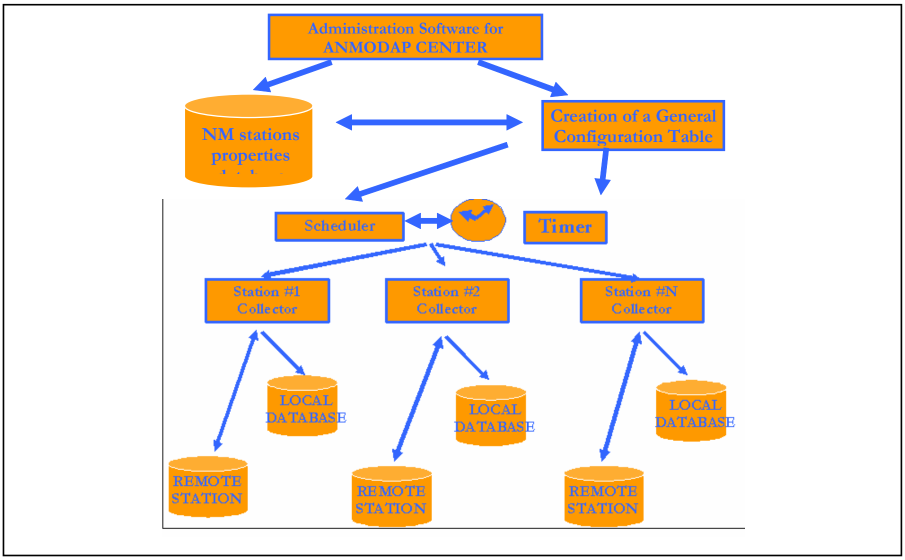

FIGURE 2. A schematic diagram of ANMODAP Center in real time

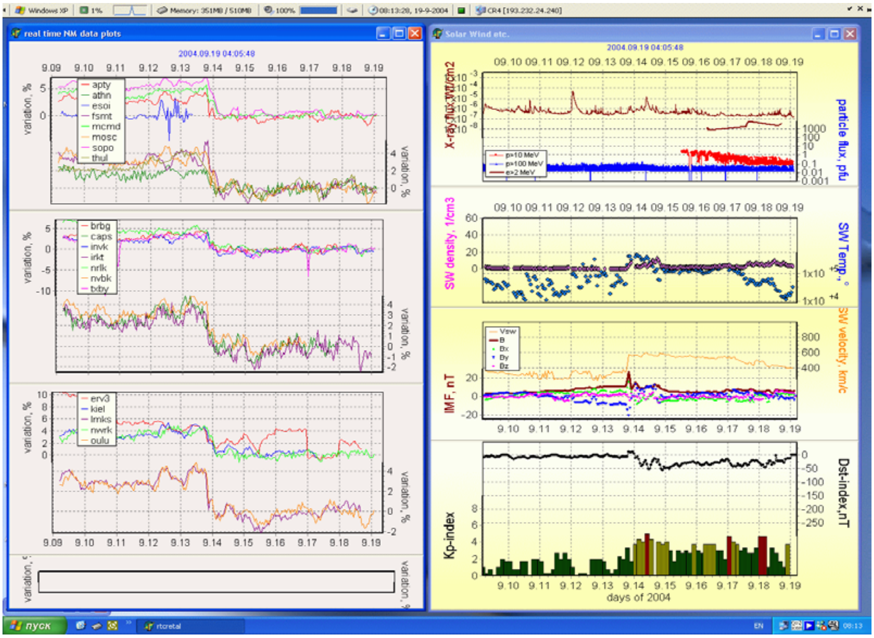

FIGURE 3. An example of the graphical presentation of ANMODAP CENTER data

Stations	Abbrev.	Lat (^{0})	Long(^{0})	Alt (m)	H_0 (mb)	R_C (GV)
APATITY	APTY	67.55	33.33	177	977.80	0.55
ATHENS	ATHN	37.97	23.72	260	974.70	8.53
BAKSAN	BKSN	43.28	42.69	0	818.50	6.91
BARENTSBURG	BRBG	78.12	14.42	0	964.70	0.20
CAPESCHMIDT	CAPS	68.92	180.53	0	1021.30	0.52
EREVAN						
EREVAN-3						
ESOI	ESOI	33.30	35.79	2025	800	10.41
FORTSMITH	FSMT	60.00	-112.00	0	996.10	0.30
INUVIK	INVK	68.35	-133.72	21	1019.10	0.14
IRKUTSK	IRKT	52.47	104.03	433	965	3.49
KIEL	KIEL	54.34	10.13	54	981.40	2.36
LOMNICKY STIT	LMKS	49.20	20.22	2634	733	3.88
McMURDO	MCMD	-77.85	166.72	48	985.10	0.00
MOSCOW	MOSC	55.47	37.32	200	991.90	2.30
NORILSK	NRLK	69.26	88.05	0	1015.30	0.53
NOVOSIBIRSK	NVBK	54.80	83.00	163	999.20	2.69
NEWARK	NWRK	39.68	-75.75	50	1008.60	2.21
OULU	OULU	65.05	25.47	0	990.00	0.77
SOUTH POLE	SOPO	-88.00	210.00	2820	687.70	0.05
THULE	THUL	76.50	-68.70	260	1011.50	0.00
TIXIE BAY						
YAUTSK						

TABLE I. List of real-time Neutron Monitor stations connected to the Athens Center

The properties of each station in the network are input to a database program, the 'Properties Database' (Figure 2). This program includes the characteristics that are described in Table I, the ftp directory of each station, the station operating mode (active or not) and the data update period for each station. A 'Scheduler' program reads the properties of each station and decides whether or not to make a data collection call. Each station has a separate data collection program (triggered by the scheduler) that uploads data from the remote station to the database in Athens. Every station has a recording system and a local database. The data collection program of each station interfaces with the recording system of the remote station and transfers one minute, 5 minute or hourly data to the main server. The main database in Athens can be refreshed with customizable rate (usually every 5min or every hour). For our study not only collecting data but also data presentation is very important. A special program that interfaces with the 'scheduler' program creates a graphical file once per hour which is displayed on the web page of the station presented at the server of Athens Center. An advanced and quick data processing system of 1-, 5-, 15-, and 60-minute refreshes the ANMODAP database providing both graphical and digital form of the measurements (http://cosray.phys.uoa.gr /ANMODAP). On the same page interplanetary space parameters data from GOES and ACE satellite in real time are also presented (Figure 3).

METHOD OF PREDICTION

The early detection of an Earth-directed solar proton event by NMs gives a good chance of preventive prediction of dangerous particle flux and can provide an alert with a very low probability of false alarm [8], [9]. The flux cannot be recorded on satellites with enough accuracy because of their small detecting area. However, it can be measured by ground-based neutron monitors with high statistical accuracy (in average, 0.5% for 5 min) as Ground level enhancement (GLE). The first step towards collecting data from a number of stations and analyzing them in real time have been made by the Bartol cosmic ray group (Bartol Research Institute - BRI) in the frame of the Space Ship Earth project (http://neutronm.bartol.udel.edu//). Subsequently a new real time data collection system was developed by the IZMIRAN cosmic ray group (http://Helios.izmiran.rssi.ru/ cosray/main.htm) using the latest networking methods in order to get data from the maximum possible number of stations to provide sufficiently reliable data of the further analysis. The use of all stations as a unified multidirectional detector substantially improves the measurement accuracy (<0.1% for hourly data).

The Athens Neutron Monitor Data Processing (ANMODAP) Center is being developed by the cosmic ray group of Athens University during the last two years. The prediction is mainly based on a feasible and statistically proven method [10] using total counts from several stations in real time. It consists of the following steps:

GLE onset: Data from at least three NM stations at Earth (two high latitudinal and one/two low latitudinal) and two independent satellite channels, for example X-ray on

GOES10 and GOES12, are processed to search for the start of ground level enhancement. The initiation of a GLE is identified as simultaneous detection of

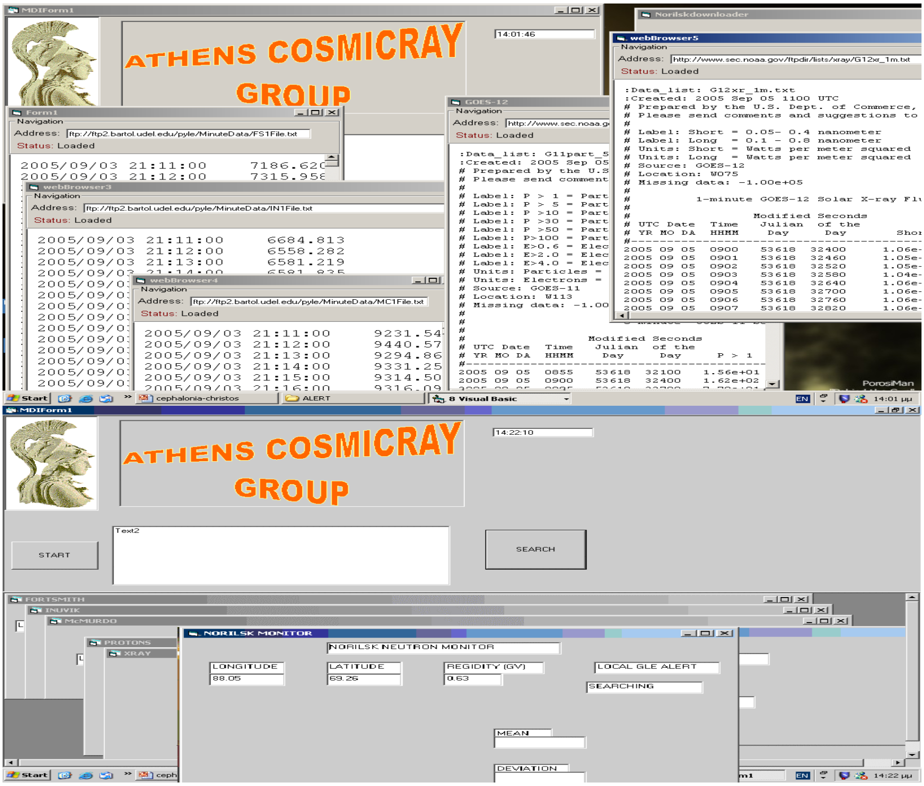

FIGURE 4. The operation of the Alert program at ANMODAP Center

enhancement in at least two neutron monitors and in an X-ray channel. If these conditions are met, data is collected from all other NMs. The real time algorithm in order to be accurate takes different kind of inputs from all the available sources. For large events the Alert stage is envisaged to be of about 99 % accuracy. Our statistic is still poor because of the continuous upgrades of the input data source code in the program. It is possible that very soon we will present a full analysis of all the old available GLE data. It is well known that GLEs accompany only small fractions of the strong solar proton events and also that not all proton events result in ground enhancements. However, a technique of calculating the relative flux increases using the data of high latitude stations eliminates the possibility from loosing an event.

An improved version of the ALERT program [11] will soon be available via a link from the main page of the Athens NM station visualizing all the forecasted events in real time (Figure 4). Also, it calculates spectra and other parameters for the estimation of the expected CR profiles for lower energies at different altitudes, several hours ahead. After the alert is obtained by the procedure described in the previous paragraph, the forecasting is sent by e-mail to the whole NM network in order to activate a system of minute data collection. During the last two years GLEs Alerts were also estimated using this program. Taking into consideration that in the analysis the data from high latitude stations are included and also the fact that our program uses 5min-averages and X-ray data from GOES for a comparison, the probability that the observed increase is not associated with GLE is very low. Preliminary results of the Alert program for the events of October 28, 2003, August 24, 2002 and January 20, 2005 are presented in Tables IIa, IIb and IIc.

Geomagnetic storms: According to the proposed method [8] , [9] , [11] for the analysis of geomagnetic storms the system collects hourly data from at least fifteen stations. An analysis based on the global survey method (GSM) results in the derivation of certain parameters such as CR density, the spectral parameters of density, and the three components of CR anisotropy vector (in x, y, and z axes), the amplitude of isotropic variation and the characteristics of the CR anisotropy at this current hour. In summary, a first analysis of the current heliospheric situation is being performed. To carry out more reliable analysis it would be desirable to use these results together with other data on solar and solar wind measurements.

TABLE IIa. Event of the 20th January 2005

NM Stations	Event started at (UT)	Established Alert signal at (UT)	Maximum of the event (UT)
Moscow	6:51	6:55	7:05
Kiel	6:51	6:55	7:05
Oulu	6:52	6:56	7:00
Norilsik	6:31	6:35	6:41

TABLE IIb. Event of the 24th August 2002

NM Stations	Event started at (UT)	Established Alert signal at (UT)	Maximum of the event (UT)
Norslik	1:29	1:33	1:44
Oulu	1:28	1:32	1:49
Cape Smidt	1:27	1:31	1:41

TABLE IIc. Event of the 28th October 2003

NM Stations	Event started at (UT)	Established Alert signal at (UT)	Maximum of the event (UT)
Cape Smidt	11:46	11:50	12:07
Irkutsk	11:40	11:44	11:54
Oulu	11:44	11:48	11:51

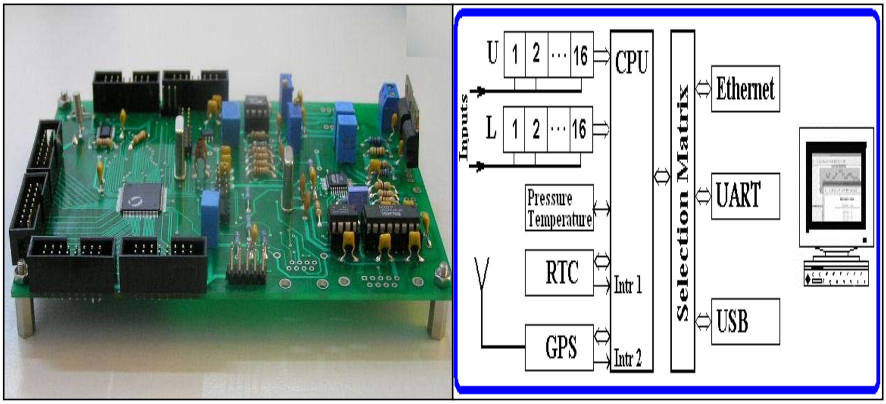

FIGURE 5. A new electronic pad is in development at the ANMODAP CENTER

DISCUSSION- CONCLUSIONS

The new Athens Neutron Monitor Data processing Center r based on the activity of the cosmic ray group of Athens University provides real time monitoring of cosmic ray variations. It is created also with the aim to make feasible the use of the neutron monitor network data in real time for the space weather tasks. The Athens Center at the same time with some other Centers (IZMIRAN, BARTOL University) gathers data to detect possible abrupt changes in the cosmic rays associated with the real solar wind and geomagnetic disturbances. This Center put the basis of a world wide data collection system in a real time from the network and elaborates adjusted software capable of the real time data processing and forecasting.

It is interesting to note that the Athens Center except of the possibility of successful prediction of the behaviour of the low energy part of the solar energetic events near Earth, it is proposed to be suitable also for other applications. A system of data accumulation for multidirectional muon telescopes and neutron monitor stations is in development (Figure 5) [12]. This electronic pad will provide hard real time implementation, GPS synchronization and time stamping, Ethernet connectivity, accuracy of μsec of event recording, low power consumption, portability and analog parameters measurement and recording. Such construction is very important due to the fact that a complete monitoring in mid, high and low energies in synchronization will be in place to indicate extreme phenomena well in advance providing an alert signal.

Moreover a study of a light unmanned aerial vehicle(UAV) carrying a linear energy transfer (let) radiation spectrometer and networked to the new Athens Neutron

Monitor data Processing Center applied to space weather events forecasting is carried out (Figure 6) the ANMODAP CENTER capability will be increased from high

FIGURE 6. The Unmanned Aerial Vehicle (UAV)

altitudes of Greek area with the LET radiation spectrometer carried by a special designed UAV [13].

In the near future this ANMODAP center is managing to improve the data collecting process, the resolution of the measurements and the data timestamp drift. Furthermore more measurement parameters like multiplicity and more sensor like multidirectional muon telescopes In order to succeed these the ANMODAP CENTER needs a implementation of a new data acquisition system that meet the needs of compact design, high performance, low cost and easy setup in any Real or non Real time NM station. The new type of this registration system is under development and it fulfill hard real time processing and acquisition needs. Typical board characteristics are GPS synchronization and time stamping, Ethernet connectivity, μsec accuracy of event recording, low power consumption, portability and analog parameters measurement and recording. The new type of registration system for NM and muon telescopes is very important due to the fact that a complete monitoring in mid, high and low energies in synchronization will be in place to indicate extreme phenomena well in advance providing an alert signal and best data for research combine measurements that recorded first time with so high resolution.

Concluding we can say that the joint multidimensional analysis of the relevant information from space borne and ground based detectors and from other sources as well, will minimize the number of false alarms and will maximize the reliability and the timely forecasting of the arrival of dangerous fluxes and disturbances from the space.

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