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Athens Neutron Monitor Data Processing Center – ANMODAP Center

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Abstract

Cosmic ray measurements in Athens were initiated in November 2000 with a standard 6NM-64 neutron monitor. Within the last years an effort has been made in order to construct an effective database of neutron monitor (NM) and satellite data in real-time, regarding the necessities of space weather monitoring (Athens Neutron Monitor Data Processing Center – ANMODAP Center). The prospective goal of this network is to make possible the receiving of all data in real-time in close sequence from all servers around the globe. The graphical representation of all these data in real-time is available through the website of the station (http://cosray.phys.uoa.gr). Moreover, a second database that collects data with 1-min resolution operates in a parallel mode. The online services as a special 'Alert' algorithm for Ground Level Enhancements (GLEs) and some models created to analyze aspects of GLEs as the neutron monitor Basic Anisotropic Neutron Ground Level Enhancement (BANGLE) model and the Forbush Decreases (FORD) model as well, are presented. Moreover, a short account on work performed on the possible relationship between the geomagnetic activity level and the biological effects is given.

Keywords: Neutron monitor network; Cosmic rays; Space weather

1. Introduction

During the 1950s and in particular with the International Geophysical Year (IGY), data from neutron monitors (NMs) placed the taxonomy of cosmic ray (CR) temporal variations on a new track, extended the observations of the Sun as a transient source of high-energy particles and laid the foundation of our early concepts regarding the heliosphere (e.g., Bieber et al., 2000). After 50 years of operation, NMs remain the state-of-the-art instrumentation for measuring CR intensity variations of 1–15 GV (Moraal et al., 2000). Moreover, NMs are cost effective and reliable registration systems that hold complete time series of counts for more than 50 years. Contrary to satellites, the functionality of NMs is not influenced by intense events (McDonald, 2000). In the papers by Clem and Dorman (2000), Shea and Smart (2000), Stoker et al. (2000), the physical and technical properties of NMs, together with their data distribution are discussed in great detail. It is, of course, noted that NMs continuous measurements have been providing key information regarding the interactions of the galactic CRs with the plasmas and magnetic fields in the heliosphere and the acceleration of high-energy particles at the Sun (see, among others, Iucci et al., 1979a,b, 1983, 1988; Storini, 1990, 1997; Lockwood et al., 1982, 1991; Nagashima et al., 1994; Storini et al., 1992, 1995, 1997; Kudela et al., 2000; Simpson, 2000; Lockwood and Debrunner, 2002; Usoskin et al., 2002, 2005; Laurenza et al., 2003, 2004; Alanko-Huotari et al., 2007; Mavromichalaki et al., 2007).

The Worldwide NM Network presently includes about 60 standardized IGY and NM64 detectors and spread

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around the globe. Initially, data were stored locally by the Principal Investigators (PIs). Later these data were submitted with a standard format to data collection sites, such as the World Data Centers (WDC). However, only hourly values are often available (e.g., http://www.ngdc.noaa.gov/wdc). This international format is suitable for studies on long-term CR trends. For the investigation of short-time CR intensity variations (as for solar energetic particle events), higher time resolution (1-min or even shorter time intervals) are needed (Moraal et al., 2000; Storini, 2000). This high time resolution format is presently available in many NMs and it can be accessed via internet. In some cases, CR data are available only on request. Thus, the collection of the data can be very time-consuming. A number of past efforts focused on how one could have access to CR data in a more flexible way. This was highly dependent on the development of real-time technology. A great contribution in this direction was made by the IZMIRAN (Russia) CR group as well as other scientific teams. Soon, other groups began to present also continuously their data on line and many new stations were involved in this process. Nowadays about 25 NM stations provide their data in real or quasi-real time, in digital and/or graphical form (Mavromichalaki et al., 2001, 2004).

After the development of the real-time technology in NMs, efforts to collect and make high resolution NM data available in one single server have been made. The Moscow CR station was the first to present NM data on line. The first steps in the process of data collection and analysis from a number of stations in real-time have been made by the Bartol CR group (Bartol Research Institute – BRI) in the frame of the Space Ship Earth project (http://neutronm.bartol.udel.edu//). Then, a new real-time data collection system was developed by the IZMIRAN CR group, using the latest networking methods. Data were obtained from as many stations as possible and, as a result of this; sufficient reliability of further analysis was provided. It should be emphasized that the use of all stations as a unified, multi-directional detector makes the accuracy of the measurements substantially higher (<0.1% for hourly data). All these efforts led to the implementation of a Cosmic Ray Data Processing (ANMODAP for Athens Neutron Monitor Data Processing) Center, that has been realized in Athens with the scope to provide real-time monitoring of CR intensity variations from NMs – widely distributed around the globe – as well as information on the time evolution of several space weather parameters measured by satellites (Mavromichalaki et al., 2005b). The ANMODAP Center was created with the aim to make feasible the use of NM monitor network data in real-time and able to furnish not only the data files but also software to check in near real-time the solar activity effects in the terrestrial environment (Dorman et al., 2004; Mavromichalaki et al., 2004).

In this work a short description of this data collection and analysis center in Athens and the operated space weather applications are discussed.

2. The Athens Cosmic Ray Station and its on-line services

(a) *The Neutron Monitor Station:* CR station of the Athens University (37.58°N, 23.47°E) initiated in November 2000 with a standard Super 6NM-64 at an altitude of 260 m above sea level (Fig. 1) and a vertical cut-off rigidity of 8.53 GV evaluated for the year 1995 by Shea and Smart (2001). The Athens station was the sixth one to present both graphical and digital data in real-time with 1-h and 1-min resolution.(http://cosray.phys.uoa.gr). This station is important for the estimation of the maximum particle energy during great proton events due to the fact that frequently the maximum energy of these particles, ranges within 5–10 GeV, i.e., very close to the minimal energy of particles recorded in Athens (Mavromichalaki et al., 2001). The measurements of the station are being processed automatically in order to be compatible with data from other stations. This is significant because in order to study in detail CR variations and space weather conditions, it is necessary to compare a number of high rigidity stations with good quality data. The resolution of the measurements reaches values as low as one second – which is unique worldwide with a counting rate $\sim 55 \pm 10$ counts/s.

(b) *The ANMODAP Center:* As NMs step into a new era, it is necessary to combine as many CR detectors as possible, in order to maximize their abilities and corresponding usage. Taking this into account, a new fully functional real-time data analysis center operates in the Athens NM Station for research applications, since 2003 (Mavromichalaki et al., 2004, 2005a,b). A suite of NMs, consisting of 23 stations operating in real-time, provides crucial information on space weather phenomena. The ANMODAP Center is capable of issuing preliminary alert for Ground Level Enhancements (GLEs) of high energy solar CRs, providing a pre-warning of the low-energy particles potentially harmful to space-borne and ground-based technological systems. Moreover, the monitoring of the precursors of CRs offers a prior estimation of the expected solar-terrestrial event type, geomagnetic storms and/or Forbush decreases (Belov et al., 1995). In other words, the network of NMs is a unified multidirectional spectrometer/detector characterized by considerable accuracy, providing an important tool of forecasting the arrival of interplanetary disturbances at the Earth. The main server, located in Athens, collects 5-min and hourly CR data in real-time. The measurements of each station are processed automatically and stored in special user-friendly format for possible future research applications. The presentation of the data is also being realized in real-time via internet. A special algorithm, included in a scheduler, creates a graphical file once per hour which is displaced on the web site of the ANMODAP Center. An advanced and quick data processing system refreshes the ANMODAP database providing both graphical and digital form of the measurements (http://cosray.phys.uoa.gr), as can be seen in Fig. 2, where satellite data from GOES and ACE are also being presented.

Fig. 1. Athens Neutron Monitor Station: view from the building of the Physics Department of the University of Athens (left panel) and inside (right panel).

(c) *GLE Alert system:* The preliminary alert of ground level enhancements in forth warning was the first project that used data from the ANMODAP Center. The Alert software is based on the idea that 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 (Dorman et al., 2004; Mavromichalaki et al., 2004). This flux cannot be recorded by satellites with enough accuracy because of their small detecting area. However, it can be measured by ground-based NMs with high statistical accuracy (on average, 0.5% for 5 min) as GLE. Data from at least three NM stations on Earth (two high latitudinal and one/two low latitudinal) and two independent satellite channels, for example X-ray on GOES10 and GOES12, are processed in order to search for the start of the GLE. The initiation of a GLE is identified as simultaneous detection of enhancement in at least two NMs and in an X-ray channel. If these conditions are satisfied, data are collected from all other NMs. In order to be accurate, the real-time algorithm takes different kind of inputs from all the available sources. A statistical analysis of the last 10 GLEs recorded by NMs from 2001 till 2006 using 1-min data, produced GLE alarms in our system for the nine events, while the rest one was characterized as non-GLE event. The alarm times comparing with the satellite data can distinguish them into GLEs or magnetospheric ones. The GLE alert from the Athens system precedes the GOES alert (>100 or >10 MeV protons) by 4–33 min. When the alert is final then an automated e-mail is sent to all the interested users (see, for more details, Mavromichalaki et al., 2005a,b).

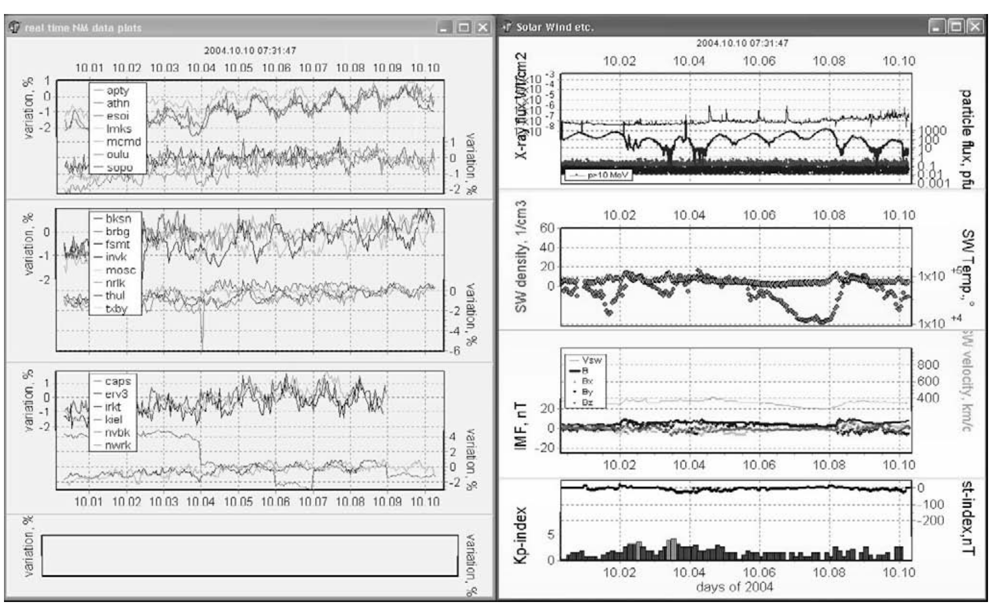

Fig. 2. Graphical representation of the data provided by the ANMODAP Center: cosmic ray intensity data from the NM stations APTY-Apatity, ATHNS-Athens, ESOI-Tel Aviv, LMKS-Lomnicky stit, MCMD-McMurdo, OULU-Oulu, SOPO-South Pole, BKSN-Bakstan, BRBG-Barensburg, FRSH-FortSmith, INVK-Inuvik, MSCW-Moscow, NRLK-Norilsk, THUL-Thule, TXTY-TixieBay, CPSH-Cape Sshmidt, ERV3-Erevan, IRKT-Irkutsk, KIEL-Kiel, NSBK-Novosibik, NWRK-Newark (left panel) and satellite data, as solar wind temperature (K), solar wind density (cm^{-1}), solar wind velocity (km/s), Interplanetary Magnetic Field B (nT), IMF Bx, By, Bz components (nT), Dst (nT), Particle Flux (pfu), X-ray flux ($\mu W/m^2$) (right panel).

Real-time Alert on December 2006: From mid 2006 the GLE Alert system operates in real-time, using as input the data from the ANMODAP Center. Graphical results of the Alert are available in real-time at http://cosray.phys.uoa.gr. On December 13, 2006 the mentioned above criteria were realized and thus for the first time, a real-time signal was produced (Souvatzoglou et al., 2009). In Fig. 3, one can see the actual Alert as it was displayed on the webpage of the Athens NM station (right panel) together with the special scripts that read data from different NM stations and produce the Alert signal (left panel).

3. Research activities of the Athens CR group

As it is well known the interaction of CRs with interplanetary disturbances play a useful role in space weather monitoring and analysis, as well as in specifying magnetic properties of coronal mass ejections (CMEs), interplanetary shocks and GLEs (Kudela et al., 2000; Mavromichalaki et al., 2004; Kudela and Storini, 2006). In this direction the main goal of the ANMODAP Center is to use the existing NM network as a multidimensional device in order to study solar-terrestrial and CR physics and to give contribution to the resolving of crucial problems concerning space weather forecasting. The main research applications of the Athens CR Group are described in the following sessions.

3.1. The NM-BANGLE model

In order to understand the physics of the processes that take place under extreme solar conditions such as those producing GLEs, it is important to use accurate and reliable models. The NM-BANGLE model is a new CR model which couples primary solar CRs at the top of the Earth's atmosphere with the secondary ones detected at ground level by NMs. It is based on the Coupling Coefficient Method, firstly introduced by Dorman (2004). The NM-BANGLE model calculates the evolution of several GLE parameters revealing crucial information on the energetic particle propagation and distribution. In specific, the values of the following GLE parameters can be obtained for each phase of the event: (a) spectral index of the solar CR spectrum, assumed as power-law according to the model's current version, (b) position (latitude and longitude) and spatial extent of the solar CR anisotropy source, and (c) amplitude of the solar CR intensity. It should be mentioned that the analytic description of the NM-BANGLE model, as well as of the physical meaning and usefulness of its outputs, is reported by Plainaki et al. (2007a).

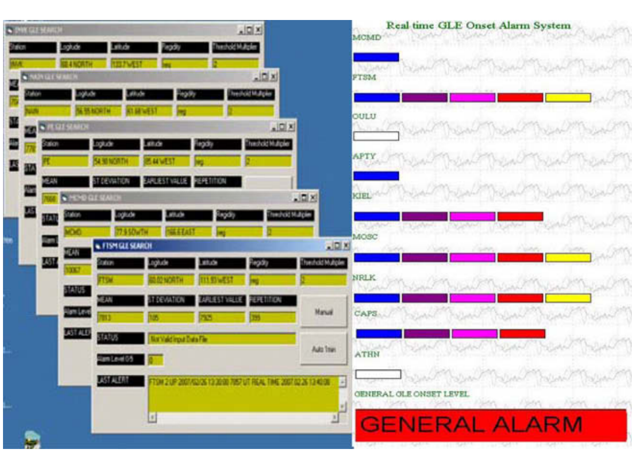

Fig. 3. The scripts that read data from NM stations (left panel) and the actual Alert signal displayed at the Athens NM station webpage (right panel).

Extensive and analytical study of GLEs applying the NM-BANGLE model has been realized already. The outstanding event of 20 January 2005 (GLE69) and the intense ground level enhancement of 13 December 2006 (GLE70), were studied in detail on the basis of the NM-BANGLE model (Plainaki et al., 2007a,b). In order to analyze and interpret the peculiarities of the solar energetic particle events, the NM-BANGLE model considers an angular solar CR ray flux distribution in the form of a narrow beam (Plainaki et al., 2007a). After fitting the GLE data from a great number of NMs and optimizing the ground level responses to a primary anisotropic CR flux, important results on the evolution of solar parameters can arise. Specifically, for GLE69, some derived results are:

- the event had a complex structure with two maxima,
- the time evolution of the rigidity spectrum had a rather complicated behavior,
- an extremely intensive narrow beam of solar relativistic particles arriving at the Earth during the initial time interval of the event had a width that did not exceed 10–40°,
- anisotropy remained in relatively high levels during the first hour of the event,
- the estimation of the integral flux for particles with energy >100 MeV on the basis of our model is in good agreement with the satellite observations (Figs. 4 and 6, left panel).

Moreover, application of the NM-BANGLE model to GLE70 showed that:

- solar particles seem to have started propagating, forming also a narrow beam, sensed initially by those NMs with the most favorable positions,
- the narrow beam effect, however, was more intense in case of GLE69 than in case of GLE70 (the angular parameter had larger values in the former case),
- the solar CR rigidity spectrum appeared hard in the beginning but it softened during later phases, and
- integral proton fluxes for low-energy particles calculated on the basis of the NM-BANGLE model lead to reliable results, verified by the satellite data (Figs. 5 and 6, right panel).

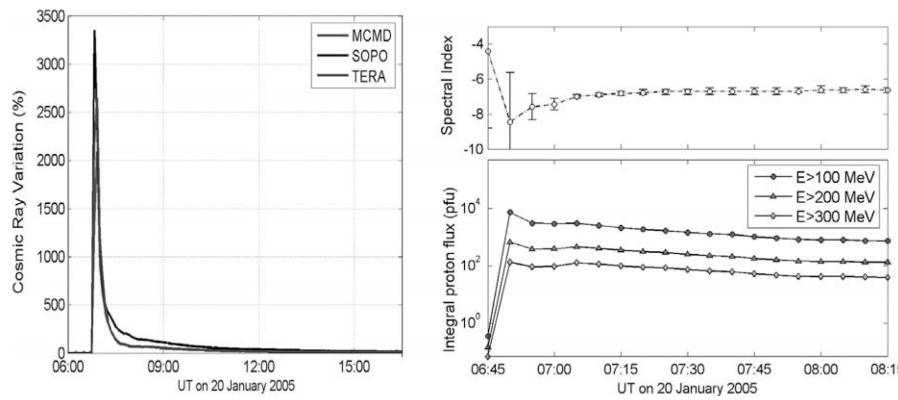

Fig. 4. GLE69 on January 20, 2005. Results from NM-BANGLE model applied to the NM stations: MCMD: McMurdo, SOPO-South Pole, TERA-Terra Adelie.

The results for January 2005 and December 2006 GLEs are satisfactory enough, as it can be verified by the actual spacecraft measurements registered during those periods. In specific, at the time that the GLE69 took place, the GOES satellites registered intense proton fluxes that reached the value of almost 10^3 pfu, for protons of energy >100 MeV (Fig. 6, left panel). The GOES measured proton flux value, corresponding to particles in the higher energy spectral range, suffers the so called 'streaming limit' effect (Reames and Ng, 1998, 2004). This means that the source intensity rises above that required to reach the streaming limit and as a consequence additional particles are diffusively trapped near the expanding shock source. Thus, added acceleration does not serve to increase the intensity on the early plateau region, which is of course modulated by the geometric effect of the connection longitude of the observer relative to the solar particle source (e.g., Reames, 1997). According to Reames and Ng (1998), the analysis of proton data (>10 MeV) from the GOES spacecraft for the period 1986 January 1 to 1997 September 1, showed that the streaming limit is placed at 200 $(\text{cm}^2\,\text{sr s MeV})^{-1}$, a value that is in reasonable agreement with the streaming limit of ~300 $(\text{cm}^2\,\text{sr s MeV})^{-1}$ at 1.0 AU found by Ng and Reames (1994) in the ~1 MeV region. Nevertheless, the integral flux value measured at GOES is of the same order of magnitude with the proton fluxes extracted from the NM-BANGLE model application to GLE69, for the majority of the 5-min time intervals inside the first hour of the event. One should note, however, two major issues extracted from the comparison of Figs. 4 and 6, left panel: (a) the NM-BANGLE modeled proton fluxes are slightly higher than the observed ones and (b) during the second time interval of the event (6:50–6:55 UT) the NM-BANGLE modeled proton flux value exceeds the observed one by ~1 order of magnitude (10^4 versus 10^4 pfu, 10^3 pfu, respectively). These differences between modeled and observed solar fluxes are reasonable, since the NM-BANGLE model functionality is based on the use of NM data. Ground-based NM data correspond to the higher energy range of the primary solar CR spectrum (>500 MeV/particle), hence their extrapolation to the lower energy particle range induces a 'visual' increase in the corresponding modeled particle flux. Similar conclusions can be derived also for the case of GLE70, comparing the right panel of Fig. 6 with the right panel of Fig. 5.

The NM-BANGLE modeled proton flux results could be utilized in means of space weather monitoring and/or prognosis, keeping in mind, however, that they constitute only a first approximation. It is of great importance to apply this model to as many GLEs as possible in order

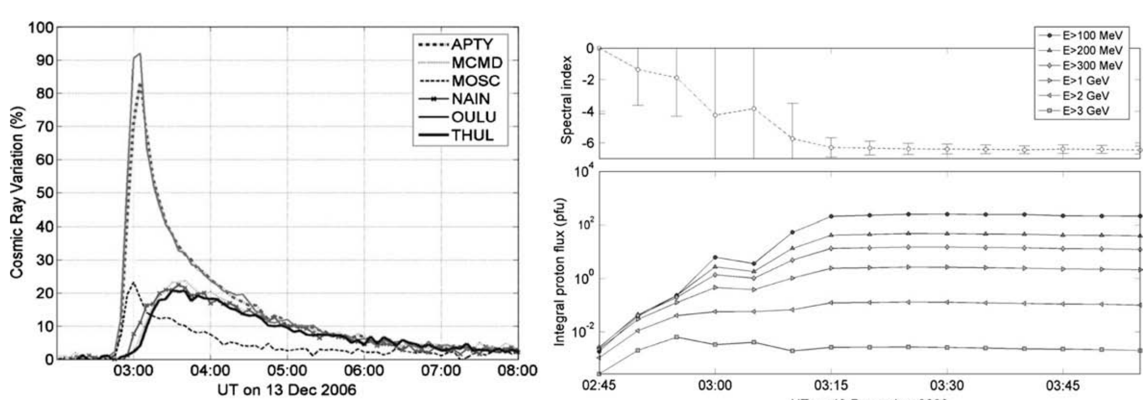

Fig. 5. GLE 70 on December 13, 2006. Results from NM-BANGLE model refereed to the NM stations: APTY-Apatity, BRBG-Barentsburg, CAPS: Cape Schmidt, NRLK-Norilsk, OULU-Oulu, TXBY-Tixie Bay.

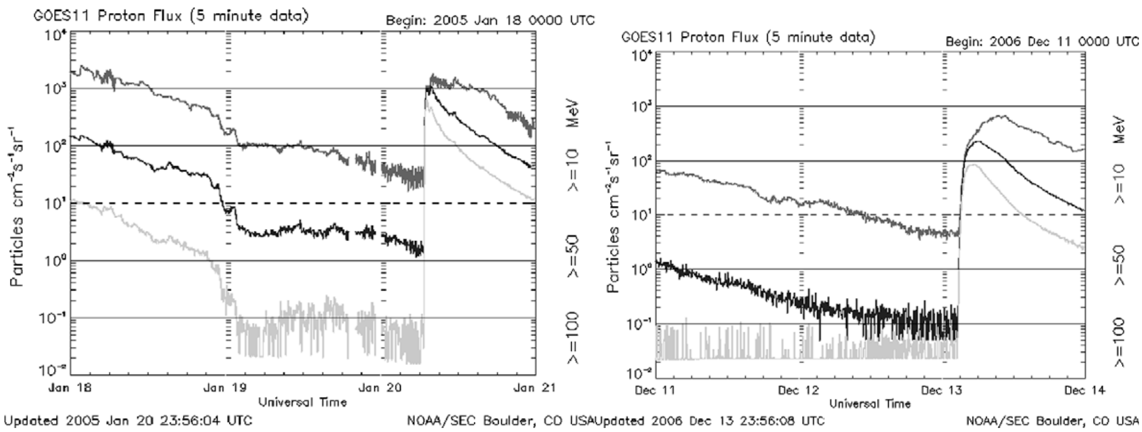

Fig. 6. Proton fluxes registered at GOES during the time of GLE69 (left panel) and GLE 70 (right panel) (http://www.swpc.noaa.gov/ftpdir/).

to reveal the characteristics of the solar proton flux distribution and magnitude in the vicinity of the Earth. Future improvements of the model regarding the form of the anisotropy and/or the spectrum, as well as model application to more GLEs, may give results that will enrich our current knowledge on solar extreme events.

3.2. Solar proton enhancements analysis

A new catalog of 1265 solar proton enhancements (SPE) covering the time period from 1975 to May 2006 and based on all available data, has been created (Belov et al., 2005; Gerontidou et al., 2006). Unlike to the NOAA definition, the term SPE refers to those solar proton enhancements having energy >10 MeV and proton flux >0.1 pfu at the Earth's orbit. The term SPE is introduced in order to emphasize the point that a broad range of near-Earth proton flux is being investigated, including fluxes well below that of the NOAA standard (Belov et al., 2005).

A broad range of phenomena relates proton events to flares with some references to related interplanetary disturbances. Correlations of occurrence, intensity, duration and timing of both the particle event and the flare as well as the role of the heliographic location of the designated active region are investigated. The statistical analysis indicates that the probability and the magnitude of the near-Earth proton enhancements depend critically on the flare's importance and its heliolongitude (see for instance Van Hollebeke et al., 1975). The existence of a high correlation between the number of SPE and major flares with importance ⩾M4–M5 may provide a reasonable proxy index for SPE production rate on a scale of months and years (Belov et al., 2005, 2007). The heliolongitude dependence of protons with energies from 10 MeV to relativistic values reveals that many SPE associate with flares which are located westward of 70°W, i.e., west of the predominant 45°W–70°W sector.

On top of this, the SPE probability of occurrence, increases with the SXR flare duration. This is especially true for flares of low importance. This correlation becomes less important for more powerful flares, on the prima facie basis that strong flares trend to long duration anyway. Additionally, the SPE probability of occurrence appears to be inversely related to the maximum temperature and directly related to the loop length of the X-ray flare (Garcia, 1994). In a recent work (Gerontidou et al., 2009) it is showed that SPEs are also associated with fast CMEs, as Reames (1999), Kahler et al. (2001) and Gopalswamy et al. (2002) have firstly promoted.

3.3. Radiation simulations

Natural space radiation consists of two particle populations: (a) those that are trapped by planetary magnetospheres in 'belts', namely protons, electrons and heavy ions and (b) particles, including protons and heavy ions from all elements of the periodic table, coming from outside of the planet. Basic research provides the necessary understanding of radiation effects for developing models useful for designing radiation hardened systems. Due to increasing sensitivity of microelectronics to radiation and increasing complexity of spacecraft systems it is more difficult to completely avoid the risk of radiation effects on systems. In order to reduce such risk, a second but still crucial level of defence is the monitoring of every parameter of the radiation environment (Leveson, 2004).

The need of interpreting the properties of galactic CR environment existed for a long time. The fact that CRs were held responsible for causing single event effects (SEEs) on spacecraft, made this need even more intense. Moreover, the microelectronics community benefited from work in the CR research field. A galactic CR model predicts energy flux spectra for all the elements of the periodic table. The energy spectra is converted into linear energy transfer (LET) spectra, which is a crucial metric to understand the level of space environment hazards to microelectronics as well as the important key step in order to calculate Single Event Upsets (SEUs). Considering SPEs, those are the main aspect of near-Earth ionization hazard. As it is now known, the high energy long duration particle events – which are important for spacecraft design – are caused by shocks, driven by fast CMEs (Reames, 1999; Spurny et al., 2004).

The analysis of the complex space environment and its impact on space systems led to the developing of empirical or quasi-empirical models by different organizations, often independently of one another. Regarding CRs the most well known and used operating model is the Cosmic Ray Effects on Micro-Electronics (CREME), developed by NASA, which also lies inside the Space Environment Information System (SPENVIS) interlink, developed by BIRA under an ESA contract. Both are provided with user-friendly interfaces and can be used via internet (http://www.spenvis.oma.be/spenvis/). An extended report on these issues can be found in Mavromichalaki et al. (2007) and references within, as well as examples from SPENVIS simulations (Fig. 7).

Lately, the MAGNETOCOSMICS Geant4 application, which was developed by the University of Bern (Desorgher, 2004) enabled the computation of the propagation of charged CRs through different magnetic field models of the Earth's magnetosphere. It permits also the computation of cut-off rigidities and asymptotic directions of incidence. Efforts on this direction were performed by the scientific community from long ago (see, for reviews, Desorgher et al., 2009; Smart and Shea, 2009; Stoker, 2009).

The NM data can be used for the calculation of radiation at space environment and at different altitudes within the atmosphere. Moreover, NMs provide key information about the interactions of the CRs with the plasma and magnetic fields in the heliosphere and contrary to satellites, the functionality of them is not influenced by intense events.

3.4. Forbush decreases analysis

A FORbush Decrease (FORD) model based on the Coupling Coefficient Method has been also developed

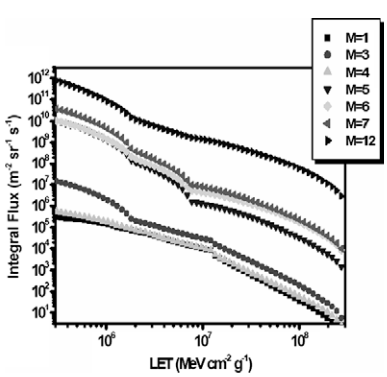

Fig. 7. An example of using the SPENVIS interface's utility of LET spectra to represent the space environment and to calculate the SEU rates for a GEO orbit that lasts from the 14th–18th of July 2005 and considering the cases of GCR ($M = 1$), 90% worst case cosmic ray level ($M = 3$), GCR and singly ionized anomalous component ($M = 4$), ordinary flare flux and mean composition ($M = 5$), ordinary flare flux and worst case composition ($M = 6$), 10% worst case flare flux and mean composition ($M = 7$) and worst case flare flux and worst case composition ($M = 12$), is given.

(e.g., Dorman, 2004). In its present preliminary version, the model considers an isotropic galactic CR flux at the top of the atmosphere. The interactions of CRs with the Earth's magnetospheric field and atmosphere are taken into account by the FORD model integrating the Tsyganenko 1989 model (Tsyganenko, 1989) as well as the Dorman's coupling functions. Ground level data of the worldwide network are incorporated in order to fit the basic model equations. The overall result is a detailed picture of the Forbush effect extracted by the use of ground level data. The FORD model has already been used in order to analyze CR events such as the one on November 26, 2000. The preliminary results show a variation of the CR spectrum during that period. In specific, as it can be seen in Fig. 8 the spectrum becomes harder, during this Forbush Decrease event. This result is reasonable if one adopts an interpretation based on the magnetic bottle model (Gold, 1959), possibly occurring during a FD. Low-energy particles can no longer penetrate inside the magnetic bottle area and therefore the only CR particles modulating the rigidity spectrum are those of higher energy. The future goal is to develop a more reliable FORD model that will have the possibility to be applied in real-time, using the utilities of the ANMODAP Center. Moreover, detailed comparison of this model with others being realized in the past (e.g., Nishida, 1983; Clem et al., 1993), is intended.

3.5. Geomagnetic storm analysis/relation to human health

There is an increasing amount of evidence linking biological effects to solar and geomagnetic conditions (Stoupel, 2002). A series of studies is published referring to the changes in normal human physical responses at different levels of daily and monthly geomagnetic activity.

Human physiological status is influenced by environmental factor changes requiring from the organism and its nervous system a large range of adaptation reactions, which are decreased in case of different diseases (Dimitrova, 2006). It has been revealed that cardiovascular circulatory, nervous and other functional systems react under changes of geophysical factors (Cornelissen et al., 2002). It is shown that the monthly number of acute myocardial infarction correlates with solar, geomagnetic and cosmic ray activity (Stoupel et al., 2005, 2007). This relationship is 2–3 times stronger for women (Stoupel et al., 2005). Some evidence has also been accumulated on the association between geomagnetic disturbances and increases in work and traffic accidents (Dorman et al., 2001). Forbush decreases could be considered as sensitive indicators of association between geomagnetic field disturbances and health parameters, as incidence of myocardial infarction, brain stroke and vehicular traffic accidents (Dorman et al., 1999).

A study towards the direction of analyzing the relation between CRs and human physiological parameters has been conducted at the Athens NM station (Petropoulos

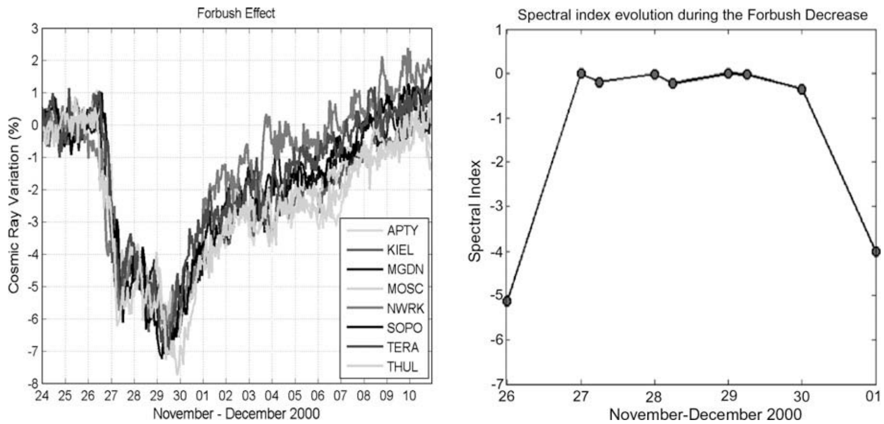

Fig. 8. Results from FORD model. CR variations on November 26, 2000 from the NM stations APTY-Apatity, KIEL-Kiel, MGDN-Magadan, MOSC-Moscow, NWRK-Newark, SOPO-South Pole, TERA-: Terra Adelie, THUL-Thule (left panel): and the estimated spectral index (right panel).

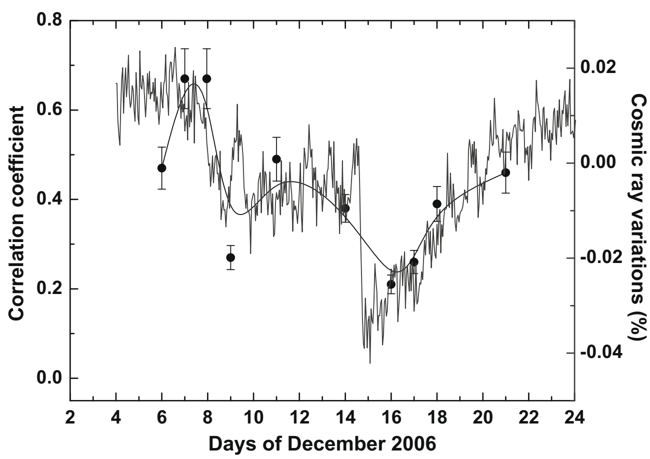

Fig. 9. Comparative analysis of the correlation coefficient between the heart rate and the cosmic ray intensity (continuous line) to the cosmic ray variations (dashed line) for the extreme events of December 2006.

et al., 2006). The possible relation between the daily variations of CR intensity, measured by NMs, and the average daily and hourly heart rate of persons, with no symptoms or hospital admission, monitored by Holter electrocardiogram is investigated (Fig. 9). We are mostly interested in how CR variations may relate to heart rate variations and the effect they may have on different cardiovascular diseases and with the capabilities offered from the ANMODAP Center, we can establish specific and accurate criteria on this relation.

4. Discussion and conclusions

Galactic CRs are a part of the interplanetary medium and the human environment and their variations reflect all large effects of solar activity and solar wind disturbances. Real-time CR measurements by ground-based NM stations combined to a worldwide network, can provide reliable and complete information on galactic CR variations. The time series of NM data extended over a long time period can additionally provide large scale estimations of the physics behind CR propagation. Until 1997 CR measurements were accumulated on hourly basis only in the World Data Centers: WDC-A (USA, Boulder), WDC-B2 (Russia, Moscow) and WDC-C (Japan, Ibaraki) and were not presented in the internet. Hence, with the real-time presentation of the CR data, the picture of the space weather, related to the solar-terrestrial phenomena, is more complete.

During the last years the quality and the abilities of the real-time NM network increased significantly by the development of a new information system. Nowadays this new real-time data collection system uses the latest networking methods in order to achieve maximum data collection reliability through the best synchronization and expandability. The new IP-based network lays the foundation of a worldwide data collection system with the specification to join all neutron monitor stations in a common real-time network, capable of real-time data processing and forecasting.

The new Athens Neutron Monitor Data Processing Center, based on the activity of the CR group at Athens University, provides real-time monitoring of cosmic ray variations enabling the use of the neutron monitor network data for the space weather related services. The modern methods applied to these data give the possibility for forecasting the arrival at the Earth of the powerful disturbances from the Sun. At present, 25 NM stations are operating continuously at different locations on the Earth and presenting their data in the Internet. The ANMODAP Center also accumulates experience and tested methods, and tries to elaborate the more modern methods, in order to carry out a timely and feasible prognosis of the geomagnetic storms deriving precursors from the worldwide NM network. It is clear that the joint complex analysis of the relevant information from space-borne and ground-based detectors 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 space. Nevertheless, as it is revealed in this report, it is clear that this kind of NM data processing center also provides the opportunity to develop sophisticated algorithms capable of space weather monitoring and forecasts, as well as extensive scientific analyses on CR and space weather related phenomena, both on small and large time scale.

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