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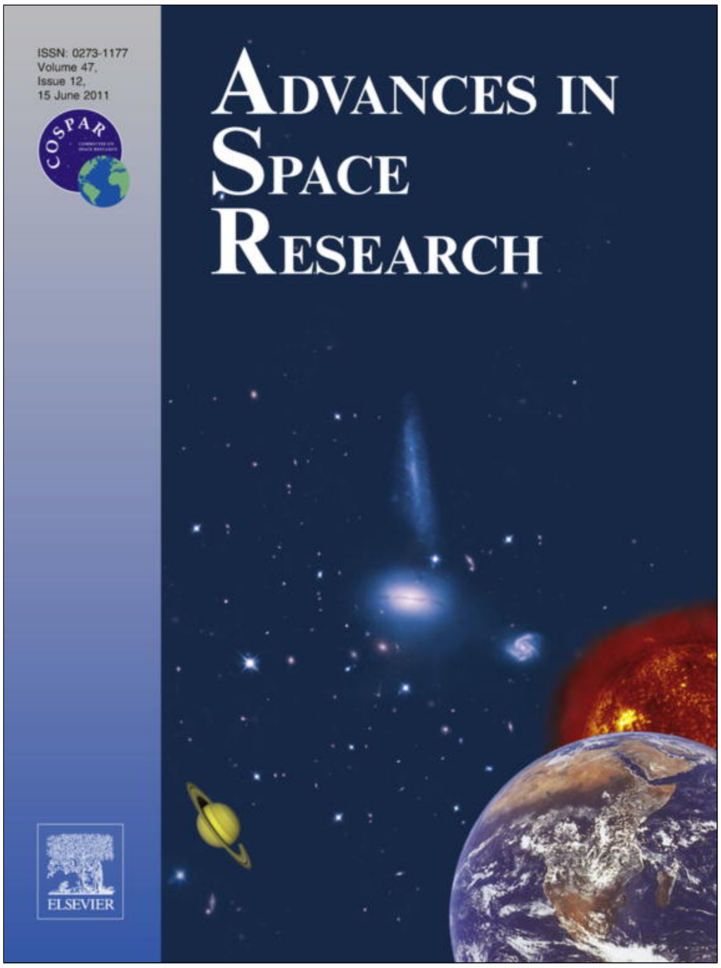

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Applications and usage of the real-time Neutron Monitor Database ☆

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Abstract

A high-time resolution Neutron Monitor Database (NMDB) has started to be realized in the frame of the Seventh Framework Programme of the European Commission. This database will include cosmic ray data from at least 18 neutron monitors distributed around the world and operated in real-time. The implementation of the NMDB will provide the opportunity for several research applications most of which will be realized in real-time mode. An important one will be the establishment of an Alert signal when dangerous solar cosmic ray particles are heading to the Earth, resulting into ground level enhancements effects registered by neutron monitors. Furthermore, on the basis of these events analysis, the mapping of all ground level enhancement features in near real-time mode will provide an overall picture of these phenomena and will be used as an input for the calculation of the ionization of the atmosphere. The latter will be useful together with other contributions to radiation dose calculations within the atmosphere at several altitudes and will reveal the absorbed doses during flights. Moreover, special algorithms for anisotropy and pitch angle distribution of solar cosmic rays, which have been developed over the years, will also be set online offering the advantage to give information about the conditions of the interplanetary space. All of the applications will serve the needs of the modern world which relies at space environment and will use the extensive network of neutron monitors as a multi-directional spectrographic detector. On top of which, the decreases of the cosmic ray intensity – known as Forbush decreases – will also be analyzed and a number of important parameters such as galactic cosmic ray anisotropy will be made available to the users of NMDB. A part of the NMDB project is also dedicated to the creation of a public outreach website with the

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scope to inform about cosmic rays and their possible effects on humans, technological systems and space-terrestrial environment. Therefore, NMDB will also stand as an informative gate on space research through neutron monitor's data usage.
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Keywords: Cosmic rays; Neutron monitors; Space weather; Solar activity; Database

1. Introduction

The Sun dominates interplanetary space, and it is the source of important events such as coronal mass ejections (CMEs), solar flares (SFs) and solar energetic particles (SEPs). It produces solar cosmic rays and modulates the galactic cosmic ray flux, leading to significant changes in the particle populations. Moreover, a series of energetic phenomena such as geomagnetic storms, auroras and particle precipitation near the Earth, can occur in response to solar activities.

The phenomena mentioned above can affect many human activities. Solar X-rays, extreme ultraviolet and radio bursts are responsible for disturbed radio signals, radio interference, etc., SEP events are related to satellite disorientation, false sensor readings, spacecraft damage, etc. and spacecraft charging, power blackouts, radar interference can be due to low-to-medium energy particles. It is obvious that cosmic ray physics relates strongly to solar and geophysics as well as to solar terrestrial physics and therefore Neutron monitors (NMs) are of great importance for space weather monitoring and prognosis (Dorman, 2002, 2004, 2006; Kudela et al., 2000; Storini, 1990, 1997; Storini et al., 2005).

NMs are used for measuring cosmic ray intensity since 1953 (Simpson's type of NM with effective area about 2 m^2) and especially during and after the International Geophysical Year 1957/1958. Directly after International Quiet Sun Year (IQSY, 1964/1965) super neutron monitors with a large effective area (about 18 m^2 for 12 tubes) are widely used in the world (Carmichael, 1964). After approximately 50 years of operation, NMs remain the state-of-the-art instrumentation for measuring cosmic ray intensity variations with rigidity more than 1 GV at high latitudes to more than 15 GV at low latitudes (Moraal et al., 2000). Moreover, NMs are cost effective and reliable registration systems that have been in operation for over 50 years and therefore generate long time series of cosmic ray data. By now a huge amount of valuable data has been collected containing all information for solar and interplanetary events.

Contrary to satellites, the reliability of NMs measurements is not affected by intense events (McDonald, 2000). In the papers of Clem and Dorman (2000), Shea and Smart (2000) and Stoker et al. (2000), the physical and technical properties of NMs together with their data distribution are discussed in great detail. It is noted that NMs continuous measurements have been provided key information regarding the interactions of the galactic cosmic radiation with the plasmas and magnetic fields in the heliosphere and magnetosphere and the acceleration of high-energy particles at the Sun and in space as well (Mavromichalaki et al., 2007). More than 45 NMs are operating worldwide and are shown in Fig. 1.

After the development of real-time technology in NMs, efforts have been made to collect and make high resolution NM data available in one single server. The Moscow cosmic ray station was the first to present cosmic ray (CR) 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 cosmic ray group (Bartol Research Institute – BRI) in the frame of the Spaceship Earth project (http://neutronm.bartol.udel.edu//). A new real-time data collection system was developed by the IZMIRAN cosmic ray group, using the latest networking methods (Belov et al., 2005a).

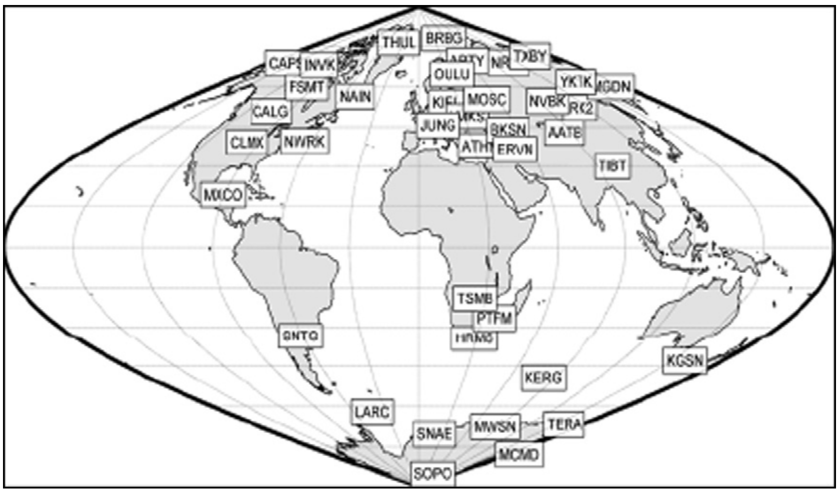

Fig. 1. Neutron monitor stations worldwide.

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As neutron monitor network has been developed and modernized, new centers on the collection and processing data and evolving methods of their use were created: WDCs in USA, Russia and Japan, working Cosmic Ray groups in IZMIRAN, Yakutsk, Irkutsk, Apatity, Rome, Bartol Research Institute. Recently in Athens a Cosmic Ray Data Processing Center (ANMODAP) was initiated with the aim to provide real-time monitoring of cosmic ray intensity variations from NMs widely distributed around the globe (Mavromichalaki et al., 2005a, 2009). The ANMODAP Center enables access to NM network data in real-time and the use of software which monitors the solar activity effects in the terrestrial environment in quasi-real-time (Mavromichalaki et al., 2004; Dorman et al., 2004). The fact that data are obtained from as many stations as possible increased the reliability of further analysis. It should be emphasized that the use of all stations as a unified, multi-directional detector makes the accuracy of the measurements substantially higher.

Recently, in the frame of the Seventh Framework Programme of the European Commission a high-time resolution Neutron Monitor Database (NMDB) has started to be realized. This database will include cosmic ray data from at least 18 neutron monitors distributed around the world and operated in real-time. In the present work, an introduction to this project, focusing on its applications and possible usage, will be furnished. In particular, applications depending on 1-min NM data, such as GLE Alert, GLE Mapping, Radiation dose Mapping within the atmosphere, as well as on 1-h data, such as Forbush decreases precursors, geomagnetic storms, cosmic ray anisotropy etc. will be equally introduced.

2. The Neutron Monitor Database cooperation

The importance of the Neutron Monitor Database (NMDB) project is that eleven different countries have cooperated within the Seventh Framework Programme of the European Commission, in order to create a real-time database with high resolution data (Steigies, 2008a,b). A European digital repository for cosmic ray data by pooling existing data archives and by developing a real-time database collecting observational results in the highest time resolution from as many NM stations as possible operated by European and some neighboring countries is being set up. The central database will comprise all neutron monitor data acquired in the last ~50 years and new continuously updated observations from 17 NMs with 1-min and 1-h resolution, operated by the institutes that constitute the NMDB consortium. The project will also develop some applications of the database to space weather tasks (e.g., estimation of radiation doses, monitoring of the predictors of interplanetary disturbances hitting the Earth and so on). This work will be briefly described in the following. Since the majority of studies in the scientific and applied areas can be realized only by data from widely distributed stations, the incorporation of neutron monitors from outside the NMDB consortium to this database is desirable and welcome.

2.1. Aims and scopes of the cooperation

The key point of this project is to develop a flexible database with important easy to use applications. NMDB had to overcome four important challenges:

(a) Designing a database capable of hosting data of 1-min and 1-h resolution, in real-time, together with historical ones and meta-data, making it a very useful tool characterized by completeness.
(b) Provide fine tuning among all data providers, as most NMs are not synchronized, in the sense that not all have the same resolution or a common time stamp, through the definition of a common format for all neutron monitors.
(c) To develop user tools with which neutron monitor data will be uploaded to the database and by which users will get access to NMDB for downloading data.
(d) To compute comprehensive parameters from the neutron monitor data in near real-time (cosmic ray characteristics in near-Earth space, ionization rate of the atmosphere, radioactive dose rates) for a broad field of applications.

Nevertheless, NMDB also aims at communicating the work done with everyone interested. Primary a web-based system of training courses for students at University level, researchers and engineers from outside the CR community, and public outreach activities will be developed. This will be implemented via the project's website: www.nmdb.eu (Fig. 2).

3. Applications using real-time data

The real-time high resolution database will provide users with the ability to have direct access to many important key parameters of CR variations, via web-based infrastructure, such as CR density and the first harmonic of anisotropy, pitch angle and asymptotic longitude distribution of the CR variations, solar and galactic CR spectra and corresponding radiation doses, information about the imminent arrival of an increased flux of solar CR (Alert signal). Most of these applications are already running at individual institutes as stand alone ones. Through the NMDB project further development as well as the combination of all above applications will be made available in near real-time.

3.1. Applications using minutely data

Minutely data are being used for the determination of ground level enhancements (GLEs) characteristics and their impact within the atmosphere. The sequence of applications provide a warning signal (Alert), mapping of the

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Fig. 2. The website of the NMDB project (http://www.nmdb.eu).

events with reliable output on spectrum derivation, anisotropy and particle's arrival directions and calculation of effective radiation dose for several atmospheric depths. In particular:

3.1.1. GLE Alert system

Ground level enhancements are defined as transient enhancements of the solar cosmic ray intensity observable at Earth. These are extreme events that give a straightforward evidence of a space environment anomaly. Thus they are keys for understanding both space and high altitude environment that react accordingly. The tracing and understanding of solar energetic particles (SEP/GLEs) and the ionization that these events generate in the atmosphere have been an open scientific issue for many years (Bazilevskaya et al., 2008; Usoskin et al., 2009). One of the most important goals of the NMDB project is the creation of a system for high-resolution registration and evaluation of this type of event in real-time.

Several groups (NKUA, IZMIRAN, TAU, ALMATY) participating in the NMDB project run various GLE Alert functions – some of which are of use for real-time applications (Babayan et al., 2001; Dorman and Zukerman, 2003; Dorman et al., 2004; Dorman, 2005a,b; Chillingarian et al., 2007; Souvatzoglou et al., 2009). Within the cooperation of NMDB, these groups work together to provide the best possible Alert system.

The concept of real-time GLE monitoring using a worldwide neutron monitor network has been introduced and operated for some time through the 'Spaceship Earth' project (Bieber et al., 2004), thus the NMDB cooperation aimed at a realistic and reliable application. The physical concept of the Alert software is based on the idea that the early detection of an Earth-directed cosmic ray event by NMs gives a good chance of preventive monitoring SEP-flux rise, providing an Alert with a very low probability of false alarm (Souvatzoglou et al., 2009; Dorman et al., 2004). The cosmic ray flux in the energy range above 500 MeV/nucleon 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). Data from at least three high latitude NM stations on Earth and two independent satellite channels, for example X-ray on GOES series, are processed in order to search for the start of the GLE. The initiation of a GLE is identified as the simultaneous detection of the enhancement in at least two NMs and in an X-ray channel. If these conditions

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are satisfied, data from all other NMs in real-time start to be included in the analysis. For better accuracy, the real-time algorithm takes different kinds of inputs from all available sources.

In order to establish the Alert system, a two-step procedure is followed. Firstly a threshold value is defined by a running mean. When the last measurement exceeds this threshold by more than two (or three) sigma the system marks a pre-alert point. If five pre-alert points are marked, in succession, a Station Alert is defined. Then, a supervision program named 'Check_for_Alert', controls every minute the status of every station. If this program detects at least three stations in 'station alert mode' (Step 1) then it automatically produces a General GLE Alert Signal.

Recently, a statistical analysis of the last 10 successfully recorded GLEs by NMs, from 2001 until 2006 using 1-min data was performed by the Athens NM group (Souvatzoglou et al., 2009). Through this analysis, GLE alarms were produced automatically in the Athens Neutron Monitor Data Processing (ANMODAP) system for nine out of 10 events, while the remaining one was characterized as a non-GLE one. The alarm times compared to satellite data can distinguish them into GLEs or magnetospheric events. The GLE Alert from the Athens system precedes the GOES Alert (>100 MeV or >10 MeV protons) by 4–33 min. When the Alert is definite, an automated e-mail is sent to all the interested users. More detailed information can be found in Mavromichalaki et al. (2005a,b).

At this point it is worth noting that from mid 2006 the GLE Alert system operates in real-time at the Athens NM station, using as input data from the ANMODAP Center. As a result the solar cosmic ray event on December 13, 2006 (GLE70) was the first GLE that was successfully detected in real-time by the Alert system of ANMODAP Center. Graphical results of the Alert are available in real-time at http://cosray.phys.uoa.gr. A reconstructed figure of the GLE70 Alert at the Athens NM webpage can be seen in Fig. 3. It is noticed that three stations, such as Fort Smith, Moscow and Norilsk, provided the General Alert stage.

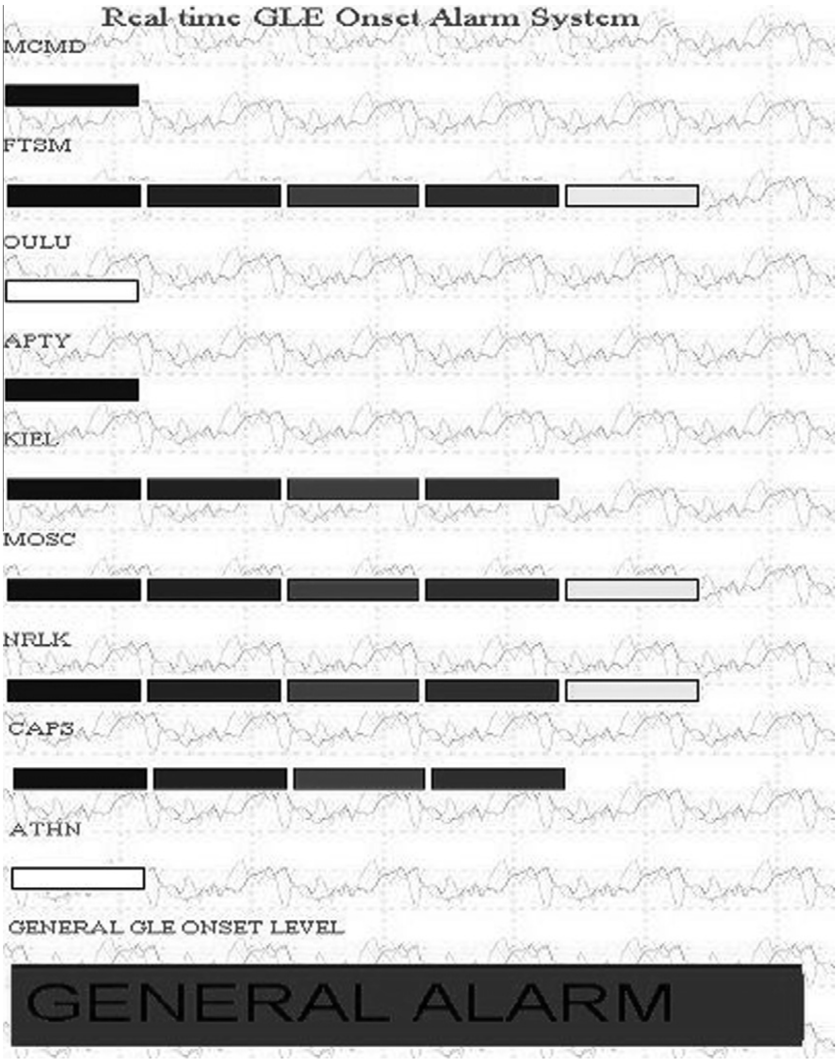

Fig. 3. Alert signal for December 2006 (GLE70) at the Athens NM station.

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3.1.2. Ground level enhancement modelling

In order to understand the physics of the processes that take place under extreme solar conditions such as those producing relativistic solar cosmic rays (GLEs), accurate and reliable models should be used. The NM-BANGLE model is a new cosmic ray model which couples primary solar cosmic rays at the top of the Earth's atmosphere with the secondary ones detected at ground level by NMs during GLEs. It is based on the Coupling Coefficient Method, firstly introduced by Dorman (2004). The NM-BANGLE model calculates the evolution of several GLE parameters such as the solar cosmic ray spectrum derivation and anisotropy, revealing crucial information on the energetic particle propagation and distribution in the region at the top of the Earth's atmosphere, including the arrival direction of solar cosmic rays with respect to Earth's magnetic field. The total output of the NM-BANGLE model is a multi-dimensional GLE picture that gives an important contribution to revealing the characteristics of solar energetic particle events recorded at ground level (Fig. 4). This 'multi-dimensional' picture provided by the actual model, consists of the following outputs: (a) spectral index of the solar CR rigidity spectrum, assumed to be a power-law in its current version, (b) position of the CR anisotropy direction (latitude and longitude), (c) a parameter characterizing the form of the anisotropic CR flux and (d) the amplitude of the solar cosmic ray intensity. It should be mentioned that the analytic description of the NM-BANGLE model as well as the physical meaning and usefulness of its outputs is reported by Plainaki et al. (2007).

Extensive and analytical study of GLEs applying the NM-BANGLE model has already been realized. The outstanding event on January 20, 2005 (GLE69) (Bieber et al., 2005; Moraal et al., 2005; Simnett, 2006; McCracken and Moraal, 2008; Buetikofer et al., 2009; Grechnev et al., 2008) and the intense GLE on December 13, 2006 (GLE70) (Bieber et al., 2008; Storini et al., 2008; Grigoryev et al., 2008), were investigated in detail on the basis of the NM-BANGLE model (Plainaki et al., 2007; Plainaki, 2008). In order to analyze and interpret the peculiarities of the solar energetic particle events, the NM-BANGLE model considers an angular solar cosmic ray distribution in the form of a beam. After fitting the GLE data from a great number of NMs and optimizing the ground level responses to a primary anisotropic cosmic ray flux, important results on the evolution of solar parameters can be derived. Specifically, for GLE69 (Plainaki et al., 2007), the derived results include the following:

- the event had a complex structure with two maxima;
- the time evolution of the rigidity spectrum had a rather complicated behaviour;
- 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 at 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.

In a series of papers (Shea and Smart, 1982; Humble et al., 1991; Cramp et al., 1997; Vashenyuk et al., 2003; Perez-Peraza et al., 2006), an identification of the primary relativistic solar proton parameters during ground level enhancements have been performed. This led to the implementation of another model which was based on the

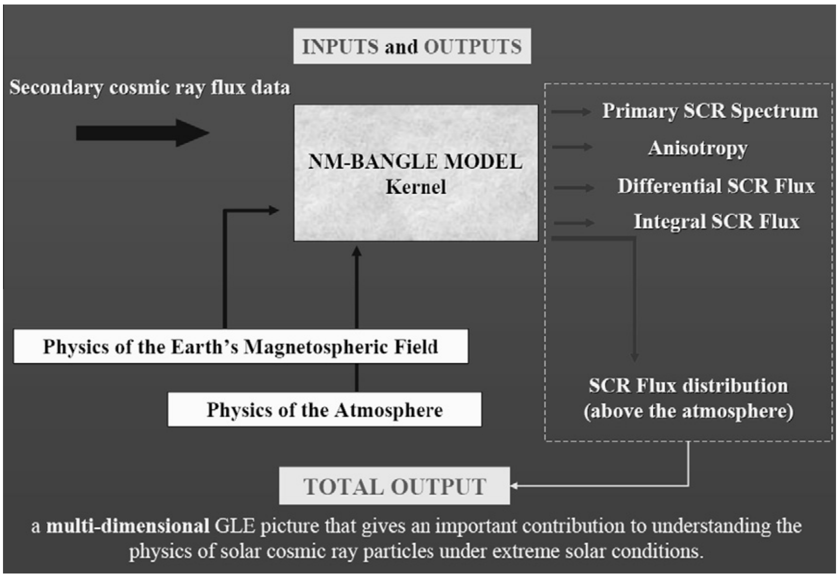

Fig. 4. Inputs and outputs of the NM-BANGLE model.

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responses of neutron monitors of the worldwide network. The modelling comprised an optimization procedure as well as proton trajectory calculations in the up-to-date magnetosphere model Tsyganenko (1987, 1989).

The modelling technique of the neutron monitor response to an anisotropic solar proton flux included definition of asymptotic viewing cones of neutron monitor stations by particle trajectory computations in the Earth's magnetosphere modelled by Tsyganenko's algorithm. Trajectory calculations have been an open fascinating issue (Cooke et al., 1991; Flückiger and Kobel, 1990; Boberg et al., 1995) and provided many interesting results over the years. Determination of the anisotropic solar proton flux parameters outside the magnetosphere was carried out by optimization methods based on the comparison of computed neutron monitor responses with observations.

3.1.3. Computation of the effective radiation dose rate

The effective dose rates caused by CRs will be calculated for selected atmospheric depths at specified grid points from the secondary particle flux in the atmosphere by using the flux to dose conversion factors based on FLUKA calculations by Pelliccioni (2000). In order to implement this task a two-step procedure is necessary, considering: (i) CR particle trajectories in the geomagnetosphere and (ii) the transportation of these particles through Earth's atmosphere.

In particular:

(i) CR trajectories through geomagnetosphere will be calculated with the Geant4 software (Allison et al., 2006) MAGNETOCOSMICS (http://cosray.unibe.ch/~laurent/magnetocosmics/) which has been developed by the University of Bern (Desorgher, 2004). Due to the geometry of the geomagnetic field, the rigidities of primary cosmic ray particles responsible for the counting rates registered at ground level have values bigger than the respective cut-off rigidity of the specific site. Moreover, due to the particle motion inside the geomagnetic field, each ground level detector is capable of recording particles produced by primaries originating from a limited set of directions in space, which is called asymptotic cone of viewing. The problem of defining these asymptotic directions of viewing for a specific neutron monitor has been always of great interest and therefore several efforts for calculating the cut-off rigidities as well as the particle trajectories and the asymptotic cones of viewing have been made over the years (McCracken et al., 1962, 1968; Shea et al., 1965; Smart and Shea, 2003; Bobik et al., 2003; Desorgher, 2005; Desorgher et al., 2009). In the code, the magnetic field is specified by the IGRF model (http://www.ngdc.noaa.gov/IAGA/vmod/igrf.html) for the internal field and by the Tsyganenko89 magnetic field model (Tsyganenko, 1989) for the magnetic field caused by external sources. The trajectory calculations are made for vertical incidence at the top of the atmosphere and at the grid points of network with mesh size $5° \times 5°$ in latitude and longitude at the same time.

(ii) The interactions of the GCR and the SCR with the Earth's atmosphere will be calculated by using yield functions that were computed with the Geant4 PLANETOCOSMICS (Desorgher, 2005) code. The flux of the different secondary particle species and the resulting ionization of the atoms and molecules in the Earth's atmosphere are evaluated for the $5° \times 5°$ grid in geographic coordinates and as a function of the atmospheric depth.

All of the forth mentioned steps have been illustrated via a flow chart (Fig. 5) and contour plots of computed effective dose rates at several atmospheric depths have been produced (Fig. 6). More details on the computations regarding the ionization within the atmosphere can be found at Buetikofer and Flückiger (2009).

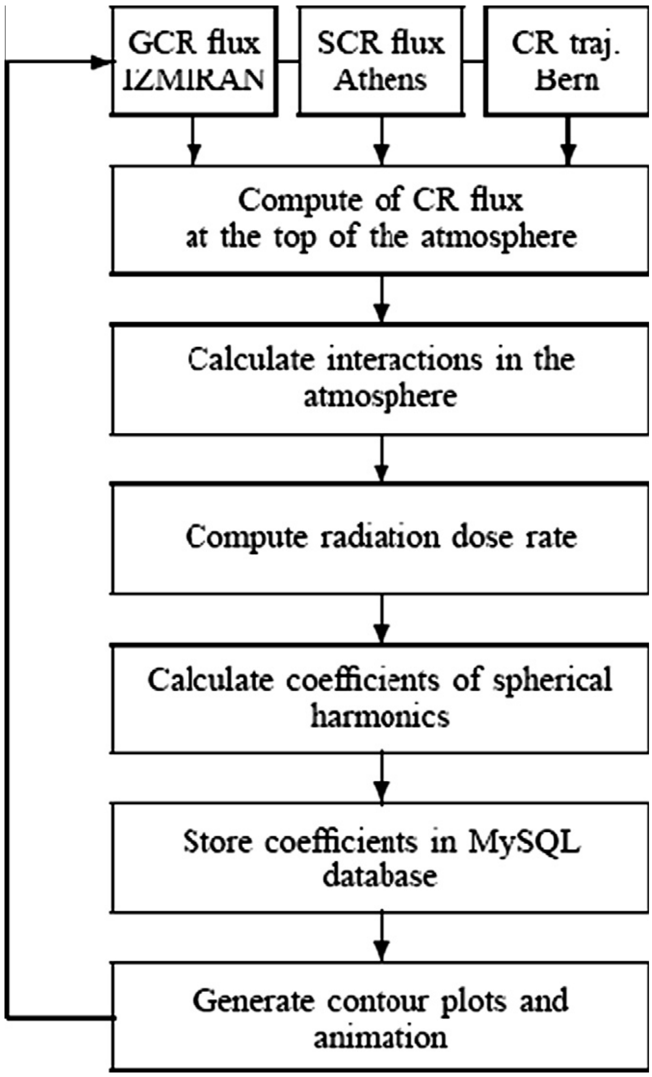

Fig. 5. Flow chart of the computations of the ionization and radiation dose rates. For details see Section 3.

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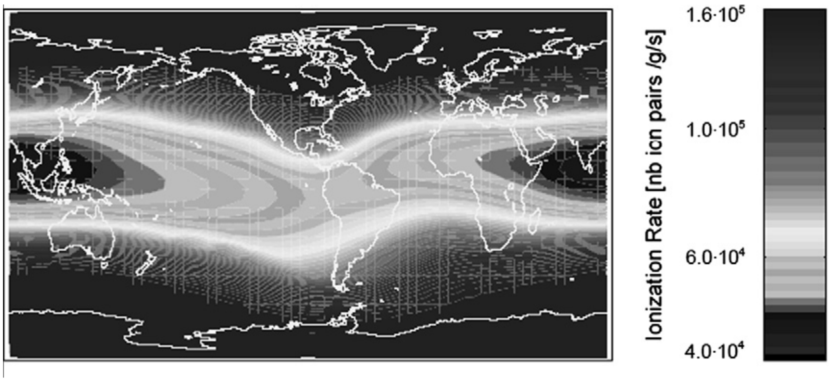

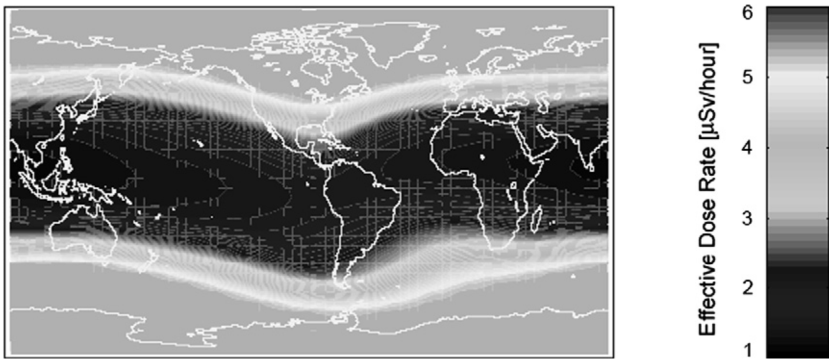

Fig. 6. Contour plots of effective radiation dose calculated by NMDB. For details see Section 3.

3.2. Applications using hourly data

Hourly data have been used by the scientific community for more than 50 years providing solid physical answers to significant problems. Highlighted cases and corresponding applications have been developed over the years, including geomagnetic storms, Forbush decreases, and precursors of CR intensity, as well as CR anisotropy and CR periodicities. In specific:

3.2.1. Geomagnetic storms

The most highlighted case is the geomagnetic storms, defined as a temporary disturbance of the Earth's magnetosphere associated with extreme solar phenomena, such as coronal mass ejections and solar flares. The geomagnetic storm is the result of the solar wind/magnetospheric coupling during the passage at the Earth of an interplanetary macro-perturbation, often initiated by an interplanetary shock (SSC in the Dst parameter) reaching the Earth ~1–4 days after the solar event. Solar wind pressures on the magnetosphere resulting at extreme electric currents that surround the Earth. This leads to a decrease of the cut-off rigidity of the galactic cosmic rays and permits the registration of more particles by a NM detector. So, regarding NM count rate, when a geomagnetic storm occurs NMs detectors record a small increase (much smaller than GLEs) which lasts a couple of hours. A good example of the cosmic ray rigidity variations obtained from November 20, 2003 magnetospheric event is given in Fig. 7 (Kudela and Usoskin, 2004; Belov et al., 2005b; Desorgher et al., 2009).

3.2.2. Forbush decreases (FDs)

A special kind of cosmic ray (CR) variations, called Forbush decrease (FD) or in a wider sense, Forbush effect (FE), was discovered Forbush (1937). It is a result of influence of the interplanetary disturbances (coronal mass ejections – CME or ICME, and/or high speed streams of the solar wind from the coronal holes) on the background cosmic rays. Forbush effect is a storm in cosmic rays, which is a part of heliospheric storm and very often observed simultaneously with a geomagnetic storm. FEs have been extensively studied over the years (Lockwood, 1971; Iucci et al., 1979a,b; 1988; Cane, 2000; Belov et al., 2003; Storini, 1991; Storini et al., 1997; Usoskin et al., 2002, 2005; Kudela and Storini, 2006; Munakata et al., 2000; Belov, 2009; Papaioannou et al., 2009a; Kuwabara et al., 2004, 2006; 2008; 2009).

The FE is the response of cosmic rays to the propagating disturbance including precursors (pre-increase and predecrease in CR variations before the main phase), CR intensity decrease as the main phase, and the recovery phase, while the Earth exits a disturbance area (Belov et al., 2001, 2003).

3.2.3. Precursory decreases and increases at CR intensity

Precursory decreases (pre-decrease) apparently results from a "loss-cone" effect, in which a neutron monitor station is magnetically connected to the cosmic ray-depleted region downstream the shock (Leerungnavarat et al., 2003 and references there in). Pre-increase is usually caused by particles reflecting from the approaching shock. The longitudinal distribution of the CR variations in asymptotic

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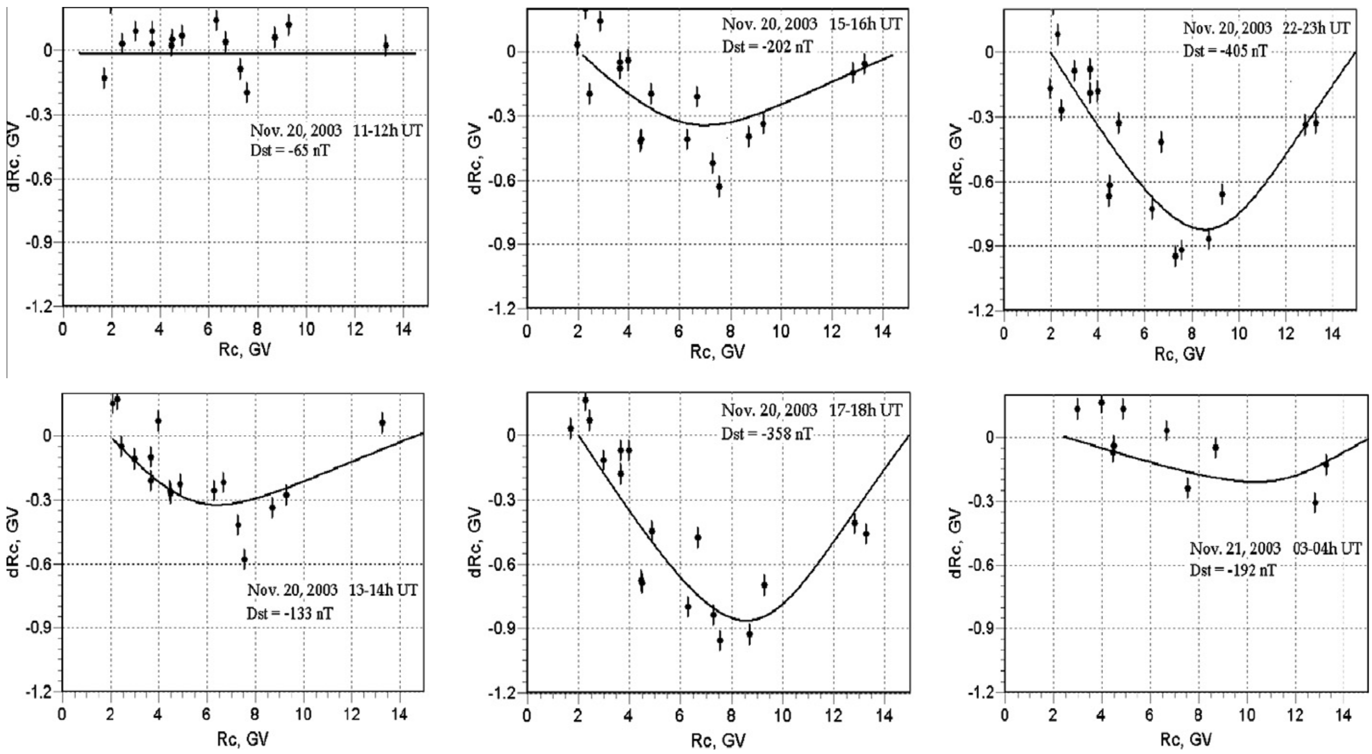

Fig. 7. Variations of cut-off rigidities during the severe magnetic storm observed during November 20, 2003 at different latitudes (and longitudes).

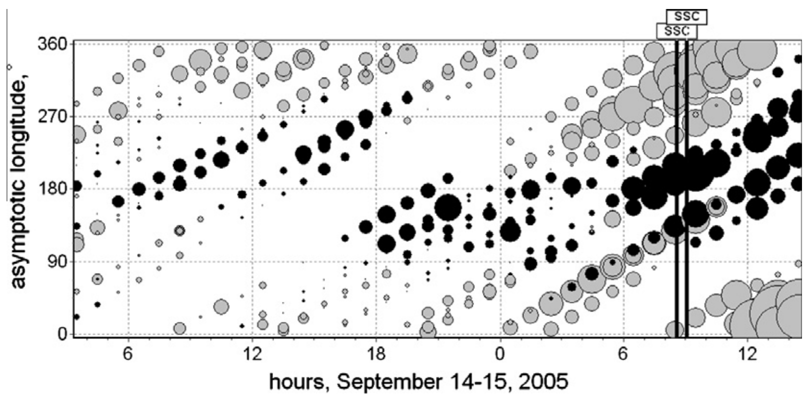

Fig. 8. Forbush effect on September 15, 2005: distribution of the CR variations by asymptotic longitudes after reduction of the isotropic part. Black circles signify a decrease of intensity and gray circles an increase relatively to the base value before the FE. The size of the circle is proportional to the amplitude of CR variation. Vertical lines indicate the timing of the shocks (8:35 UT and 9:04 UT).

longitudes obtained by the "ring station" method for September 14–15, 2005 is presented in Fig. 8. It is worth mentioned that around 03:00 UT on September 15 the narrow region of longitudes (in a sector 90–180°) with low CR intensity stands out against the background of increases in CR variations. This peculiarity became especially well pronounced from ~06:00 UT (3 h prior to the SSC incoming). So, pitch angle and asymptotic longitude distribution of the CR hourly variations obtained from the neutron monitor network data may give the characteristic pictures for a real-time diagnostics of the interplanetary and near-Earth space.

3.2.4. Anisotropy

Cosmic rays are an integral part of our vital environment and provide the valuable information on processes on the Sun and interplanetary space (Asipenka et al., 2009a). The anisotropy of cosmic rays (CR) in the energy range of 1–100 GeV is capable to provide information regarding the conditions of interplanetary space (Dorman, 2004; Krymsky et al., 2003 and references within). Structural features and processes in solar wind within the wide spatial (10^9–10^{15} cm) and time (10^3–10^8 s) scales, are reflected in the CR anisotropy observable at Earth. The resulting anisotropy, derived from ground level CR

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observations, might be considered as a reliable tool for interplanetary space diagnostics (Belov, 1987; Chen and Bieber, 1993), since it reflects a more detailed structure of the interplanetary disturbance which caused the FE than CR intensity variations. In particular, in its evolution the Earth's entrance into and exit from the magnetic cloud is normally clearly seen and allows a definition of a two-step structure of the Forbush decrease (Wibberenz et al., 1997). Belov et al. (2008) have recently shown that on average the anisotropy directly before the sudden storm commencement (SSC) has a perceptible increase which is proportional to the magnitude of the following Forbush decrease.

The method used for obtaining CR anisotropy from ground based CR observations is the Global Survey Method (GSM) (Krymsky, 1966; Nagashima, 1977; Yasue, 1982), the latest version of which is described in Asipenka et al. (2009a). With this method it is possible to derive all components of the anisotropy's vector at the magnetosphere's frontier (Papaioannou et al., 2009b). The following parameters of CR are being calculated: A – isotropic part of CR variations (density – zero harmonic) with its spectral characteristics; Ax, Ay, Az – three components of the anisotropy's first harmonic (for 10 GV particles) at the Geocentric Coordinate System (GCS), Axy – the amplitude of the equatorial component of CR anisotropy and Az – the North–South anisotropy. CR density variations, obtained for 10 GV rigidity, have high accuracy and reflect all solar wind changes responsible for CR disturbances.

The analysis of the CR vector anisotropy, derived from the data of the worldwide NM network during Forbush effects, is able to provide information regarding approaching shock waves. In particular, CR anisotropy changes may be seen not only directly before the shock but rather earlier as well, as indicated in Fig. 9, where the variations of CR density and Axy component of anisotropy, averaged by the superposed epoch method, are depicted relatively to the SSC onset (Asipenka et al., 2009b). The approach of a shock wave begins to affect cosmic ray anisotropy and density almost 5 h prior to the shock's arrival at Earth. Changes of the anisotropy direction, especially for sources of Forbush effects in the western solar hemisphere, are sufficiently large and become noticeable more than a day before the shock arrival at Earth. This should not be surprising if one remembers that Forbush effects are heliospheric phenomena which start well before the interplanetary disturbance reaches the Earth, right after its formation near the Sun.

3.2.5. Periodicities

The modulation leading to variability of cosmic ray flux and the quasi-periodicities related to that effect are still studied through the analysis of neutron monitor data (Kudela et al., 2009; Zarrouk, 2009). The description of cosmic rays variability is important regarding its influence on the atmosphere. Modulation effect is important for cosmic ray particles with energies <50 GeV and its ionization is predominant in atmospheric layers already above a few kilometers (De Jager, 2005). A current hypothesis is that the variable ionization may affect the degree of cloudiness and the discussion on that is continuing (Sloan and Wolfendale, 2008). Cosmic ray flux at energies to which neutron monitors are sensitive is modulated by complex physical mechanisms in the heliosphere, driven mainly from solar phenomena (CMEs; SFs). Thus comparison of the temporal profiles of quasi-periodic characteristics (namely ~27 days, 1 year and ~1.7 years) representing solar activity with those of cosmic rays is very important and can lead to the clarification of casual relations between solar modulation effects and cosmic ray fluxes on long and short term basis (Mavromichalaki et al., 2003; Kudela et al., 2009).

Therefore, NMDB will be in place to provide potential users with all of the above listed scientific results. In specific, geomagnetic storms monitoring will be performed through Forbush decreases analysis together with precursory appearance and CR anisotropy calculations. This will be an online service that will take into consideration – for the initial approach – only the NMDB related cosmic ray stations. More than that, several periodicities leading to solar modulation characteristics is envisaged to be provided in a quasi-real-time mode through NMDB webpage.

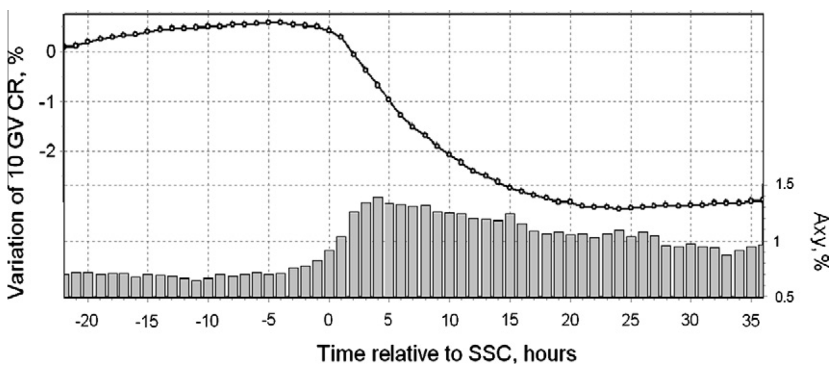

Fig. 9. Variations of the CR density (points) and the amplitude of the equatorial component Axy of the first harmonic of anisotropy (columns) for the periods before and after the SSC obtained from a number of 332 FEs.

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4. Conclusions

Today the impact of space science on every day life is well perceivable. Communication, space satellites, air travels at high altitudes, power supply factories and many other daily activities depend on space conditions. This is a major motivation for NMDB: combine knowledge and explore space environment. Neutron monitors are the only registration equipments that detect every significant event and cannot be scrambled, in any case. NMDB's prime aim is the construction of one easy to use database. In order to do so, all neutron monitors that take part in this effort will be updated with the technological advantages of nowadays. Also, from the scientific viewpoint, NMDB will be the connector of many stand alone applications that several participating groups own but never before the initiation of this project had used as one. This will of course demand time and extensive testing in order to achieve fine tuning between different applications written in different codes.

From all the above it is clear that the NMDB project is realistic and will lead NMs into new usage. All participating groups will upgrade their stations and will provide access to good quality neutron monitor data and applications meta-data (results). The following applications of NMDB will be of major help for the understanding of the space environment and for the protection of people and systems that depend on space technology. It is important to note that 12 months after the initiation of the project, six significant steps of the overall NMDB work plan have been realized:

(a) To set up preliminary database – validation is underway.
(b) To have a functional project website, where all information on the NMDB project can be found.
(c) To test all Alert approaches using historical data, in order to choose the best features from all contributions.
(d) To make an executable of the NM-BANGLE model. This will be used by any user in real-time.
(e) To determine the cosmic ray flux at the top of the Earth's atmosphere by a computer code which will be used to calculate the ionization and radiation dose rates in the atmosphere based on yield functions computed by PLANETOCOMISCS (Desorgher, 2005).
(f) To acquire data at high resolution and update the database: up to now 11 NM stations are able to send 1-min NM data to the database updated every 1 min. Another five NM stations are being upgraded in order to provide 1-min data to NMDB.

When NMDB database will be ready, using at least 16 NM stations in real-time, all applications will be adjusted as a service for scientists and other users. An extension of this effort including all neutron monitor stations of the worldwide network in this database is desirable.

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