Chapter 16

Neutron Monitor Network in Real Time and Space Weather

H. Mavromichalaki[1], V. Yanke[2], L. Dorman[2,3], N. Iucci[4], A. Chilingaryan[5], O. Kryakunova[6]

1. *Physics Department, Athens University, Greece*
2. *IZMIRAN, Russian Academy of Science, Moscow, Russia*
3. *Cosmic Ray Center, affiliated with Tel Aviv University and Israel Space Agency, Israel*
4. *Dipartimento di Fisica "E. Amaldi", 'Roma-Tre' University, Rome, Italy*
5. *Erevan Physical Institute, Armenia*
6. *Institute of Ionosphere, Alma-Ata, Kazakhstan*

Abstract: Relativistic cosmic rays (galactic and solar) registered by neutron monitors at the Earth, bring valuable information on their interaction with interplanetary disturbances. Therefore, they can play a useful role in forecasting space weather storms and in specifying magnetic properties of CME shocks and ejecta. The reconstruction of pitch-angle distribution of high-energy particles may be derived from ground level cosmic ray (CR) observations well in advance of the onset of geomagnetic storm. This can be used for forecasting. High energy solar particle events during powerful solar flares are registered at the Earth well before the main development of particle profiles recorded onboard GOES. This provides a good chance of a preventive prognosis of dangerous particle flux by ground level observations. To produce real-time prediction of the phenomena, only real time data from Neutron Monitor Network (NMN) should be employed. The increased number of NM stations operating in real-time gives a good basis for using NMN as a single multidirectional tool and for improving the definition of the onset of GLEs in powerful SPEs and to give an immediate forecast of the arrival of the interplanetary disturbance at the Earth. The properties of the Neutron Monitor Network and its possibilities for Space Weather tasks are discussed in this paper. Different real time Neutron Monitor Network topologies, different synchronization methods and the ways of collecting data in a central data server accessible to the users, are also discussed.

Keywords Neutron Monitor Network, cosmic rays, space weather, interplanetary disturbance, space environments and effects, predictors.

I.A. Daglis (ed.), Effects of Space Weather on Technology Infrastructure, 301-317.

1. INTRODUCTION

What is the meaning of “bad” space weather? It is a situation in which a complex phenomenon at the Sun causes interplanetary perturbations, essentially influencing the Earth environment and different aspects of the human activity. It is difficult to overestimate the extent of possible loss due to the bad space weather. In any case, it is better to try to prevent the effects of bad space weather than to pay for its consequences. For this purpose an operational space weather monitoring has to be necessary to provide a preventative space weather forecast. Space weather signatures appear in many solar-terrestrial and space environmental parameters. At the Earth’s orbit, on average, a heliospheric storm occurs every 4-5 days, leading to significant changes in solar wind characteristics. Disturbances of the solar wind, magnetosphere and cosmic rays (CR) are closely related, since they caused by the same active processes at the Sun. A large heliospheric storm, as indicated by different space weather parameters, is shown in Figure 1, where significant variations in CR density and in the first harmonic of the CR anisotropy, derived from ground level observations, occur simultaneously with dramatic changes in the interplanetary and geomagnetic parameters.

The effect of the solar wind disturbances on cosmic rays may extend to large distances, and, due to their relativistic velocity, cosmic rays bring information on these disturbances well in advance of their arrival at the Earth. Characteristic signatures in CR behaviour may be selected by special methods from neutron monitor network (NMN) data and input to Space Weather applications. Real time data in combination with developed and tested methods, should be used for successful prediction.

The neutron monitor network is already at a new stage of collecting and processing continuously recorded information. This epoch began in 1997, when Moscow neutron monitor data were the first to appear in real time on the Internet (http://helios.izmiran.rssi.ru/cosray/main.htm). Since that time a number of monitors started to operate in real or quasi-real time, including Apatity, Oulu, Athens, Erevan 2000, Erevan 3000, Tixie Bay, Yakutsk, ESOI, Irkutsk, Norilsk, Lomnitsky Stit, Inuvik, McMurdo, Newark, Nain, Pewanuk, South Pole and Thule. The Athens real-time NM station already records data with 1-second resolution and work has begun to design a system with resolution higher than 1-second. Other neutron monitors plan to be providing real time data in the next few years. This provides a basis for continuous monitoring of Space Weather hazardous effects. For the presentation of data on-line, it is necessary to create special databases, as well as accurate real time synchronization of NMs, This can be achieved through the use of a GPS interface. Preliminary results and models of Space

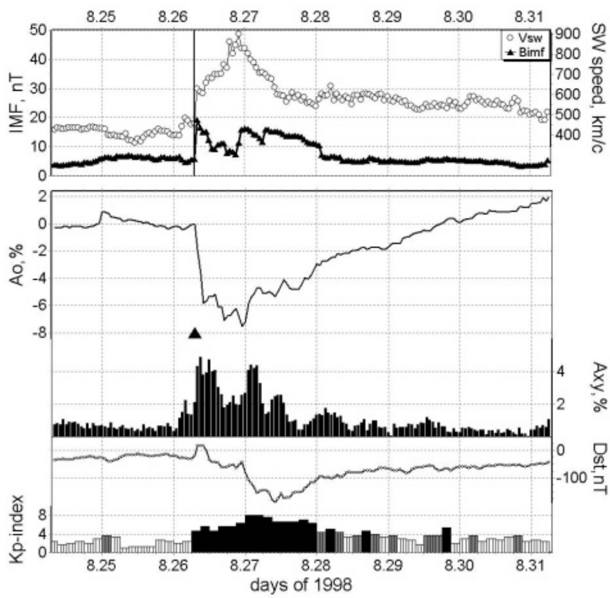

Figure 1. Interplanetary disturbance, a great Forbush effect and a severe magnetic storm during September 1998. A_0 is the 10 GV CR density variations, A_{xy} is the amplitude of the equatorial component of CR vector anisotropy.

Weather forecasting with the use of NMN -measured CRs, have already extensively discussed in a series of reports (Belov et al., 1995; 2001a; b; Bieber et al., 1999; Dorman et al., 2001; Kudela et al., 2000).

2. EXAMPLES OF PRECURSORS IN CR DATA

2.1 Solar Proton Events

One of the hazardous space weather effects is the increase of radiation doses in geo-space during powerful proton events originating on the Sun. Low-energy protons (10-300 MeV) are the most dangerous part of the solar energetic particle (SEP) spectrum for satellite electronics and crew. Maximal flux of such particles can reach the Earth several (sometimes more) hours after the occurrence of the event on the Sun. High energy (> 1 GeV) particles from the solar proton event reach the Earth with a velocity close to that of light. Their flux cannot be recorded on satellites with enough accuracy because of the small detector square, but it is measured by ground-based neutron monitors (NM) with high statistical accuracy (in average, 0.5% for 5 min) as ground level enhancement (GLEs). In Figure 2 the profiles of particles of different energy during the powerful SEP event of 15 April 2001 are presented. One can see that the high-energy particle profiles registered at the Earth had already ended well before the main development of the low-energy particle profiles as recorded onboard GOES. The early detection of an Earth-directed SEP event by NMs gives a good chance of preventive prognosis of dangerous particle flux and can provide an alert with a very low probability of false alarm. The method developed in Villoresi et al. (2000) and Stoker et al. (2000) using 1-minute NM data (Dorman et al., 2001) from a single observatory, was applied to predict the spectrum of the approaching particles. Alternatively, a more feasible and statistically proven method, using total counts from several stations in real time, should be developed and used. Below a short description of this method is given:

Search for a significant increase (greater than 2.5σ, where σ is the statistical error of measurements) in the total counts of the 1, 2, or 5- minute data from several stations. If it is found, go to a state known as "alert-1". If not, continue to search.

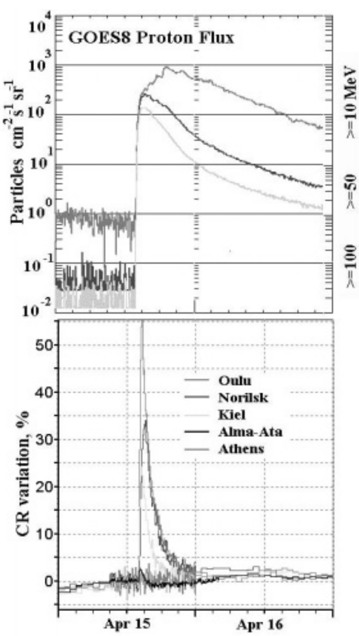

*Figure 2. Be*havior of different energy cosmic rays during the powerful proton event in April 2001.

While in the "alert-1" state: i) Estimate the rigidity spectrum of the SEP event: $\Delta D(R)/D_0(R) = bR^{-\gamma}$, where $D_0(R)$ is the background galactic cosmic ray (GCR) rigidity (R) spectrum, ΔD is spectra augment at any fixed moment and γ is the spectral index.

ii) Calculate spectra parameters b and γ best fitted to the data from at least three different stations (Dorman et al., 2003)

Evaluate the energy-dependent diffusion constant for energetic particle propagation in inter-planetary space using the rigidity spectra calculated from the three preceding one-minute data. This allows the determination of the energy spectrum at the source, by solving the inverse problem.

By using the source spectrum and the diffusion constants, predict the near Earth spectrum for a time window of ~ 1 hour. Compare on-line GOES measurements for the last several minutes (if available) with previous predictions, in order to refine subsequent predictions.

If the predicted flux at 100 MeV exceeds a pre-determined threshold, issue an "alert-2".

Repeat steps 2-5, until the total count returns to background level.

2.2 Geomagnetic storms

Another Space Weather effect on the Earth's environment is associated with propagation of interplanetary disturbances and their interaction with the Earth's magnetosphere. There are many direct and indirect data on the origin of coronal transient and the start of their propagation. However, CME observations become rather difficult after the initial stage; cosmic rays can provide an important tool for the study of their structure and the propagation from the source to the Earth.

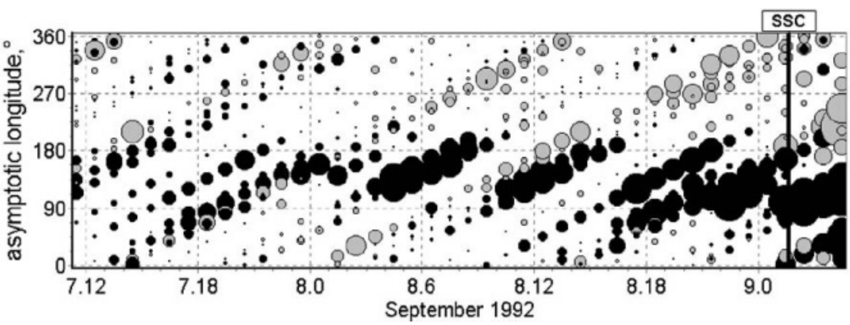

Figure 3. Angle distribution of the cosmic ray intensity on September 7-9, 1992, derived from the high latitude neutron monitors. Vertical incident asymptotic directions calculated for 9.5 GV rigidity, define asymptotic longitudes. 180° correspond to the stations looking Sunward. Gray circles indicate an increase and black ones a decrease of CR intensity. Size of the circle is proportional to the magnitude of variation. Isotropic intensity has been subtracted out.

The most significant near-Earth manifestation of large disturbances is the shock arrival, followed by the passage past the Earth of associated magnetic cloud. CR density and anisotropy vary significantly during these special times, as we can see in Figure 1. These changes may be used for short time prognosis, especially at the earliest moments of the disturbance development. The Forbush effect, as a heliospheric phenomenon, starts simultaneously with the disturbance emergence, well in advance of the geomagnetic storm onset. Due to their high speed and large mean free paths, relativistic CRs bring information on interactions, such as “loss cone” distribution and shock reflected populations to the Earth in advance of the disturbance itself. In Figure 3 an example of changes in CR pitch-angle distribution before shock arrival is presented. In such cases a precursory flux decrease may result from a “loss cone” effect, where the CR monitoring station is magnetically connected to the cosmic ray depleted region behind the shock. Precursory increases may result from accelerated particles being reflected by the approaching shock. This anomalous pitch-angle distribution has very specific features: a decrease of the CR intensity within a narrow range of pitch-angles (as a rule < 50-60°) close to the IMF direction (usually sunward, more rarely antisunward); a large, sometimes > 1%, difference between the CR intensity from these and from other directions; a sharp transition between the regions with different intensities; a pitch-angle distribution which cannot be fitted by the sum of only the first two spherical harmonics (Belov et al., 1999; 2001b). This distribution, which is unusual for quiet periods, is rather typical of periods just before the Forbush effect. They can therefore be used as an early indicator of an approaching disturbance and as a predictor of a magnetic storm.

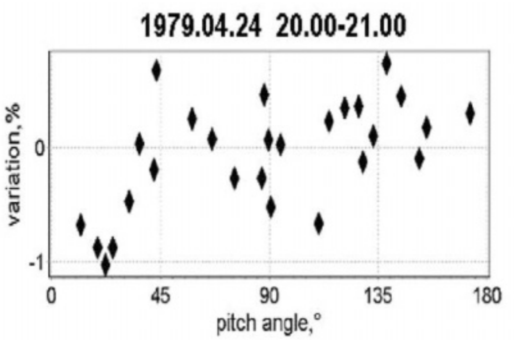

Figure 4a. Pitch-angle distribution of cosmic rays measured by different NMs (each diamond represents a different NMs) at 21:00UT on April 24,1979.

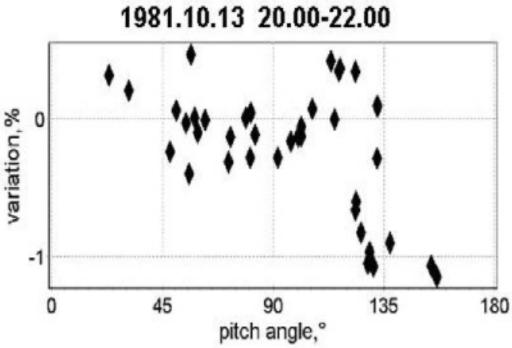

Figure 4b. Pitch-angle distribution of cosmic rays as measured by different NMs (diamonds) at 20-22 UT on 13 October 1981.

Figure 4(a, b) shows examples of such specific CR distributions for different events at the times before a shock arrival. Figure 4a displays an intensity deficit of about 1% near the sunward IMF direction, and a sudden jump from low to high intensity around 35-50°. For this event, the available monitoring stations were distributed uniformly in pitch angle. The shock arrived 3 hours later (23:58 UT), and a severe magnetic storm started immediately. The pitch-angle distribution plotted for the 20:00-22:00 period combined (Figure 4b) is like a mirror image of the distribution discussed above. This seems to be a case where the loss cone is in the antisolar direction. An antisolar predecrease is more rarely observed. Some examples were discussed in Belov et al. (1995; 1999), where such cases were associated with interplanetary disturbances originating from eastern solar longitudes. In this case, despite of leading part of disturbance went out the Earth’s orbit at the time of predictor observation, the Earth still can get this disturbance later. Another possible cause of predecrease is that the disturbed interplanetary field is in a complicated loop-like configuration. Cosmic ray preincreases, caused by reflection and acceleration of ambient galactic CR from approaching shock, are also frequently observed prior to Forbush decreases (and magnetic storms). However, the anomalies in CR distributions discussed above (a narrow predecrease) are more unusual. The regularity of this behavior enhances the value of using the preincrease effect for prediction purposes. Therefore, in addition to improving basic knowledge of particle interactions with shocks, studies of precursors also suggest that ground level cosmic ray observations may be useful for space weather forecasting. A critical issue is whether these precursors can be reliably detected sufficiently in advance of the associated geomagnetic disturbance, to furnish a practical benefit. This depends on the reliability of the neutron monitor network and on the use of data in real time.

3. NEUTRON MONITOR NETWORK AND DATA PRESENTATION

Currently, the worldwide network (Shea and Smart, 2000; Moraal et al., 2000) consists of about 45 operational neutron monitors (see Figure 5) with different specific space-energy characteristics and responses to primary CRs.

The monitors are standard devices located at different points on the globe, recording secondary cosmic rays which associated with primaries in the energy range from hundreds MeV to hundreds GeV. These high energies represent an extension of the low-energy ranges measured on spacecraft. On the map of Figure 5 the globe distribution of neutron monitors (NMN) is shown together with isolines of different cut-off rigidities. NMs at different locations are suitable for studying different phenomena. For example, the high latitude network is essential for measuring anisotropies related to transient CR events, such as solar CR and Forbush effects. The homogenous energy response at high latitudes is utilized by placing NMs at high latitudes in such a way as to cover uniformly asymptotic directions on the celestial sphere.

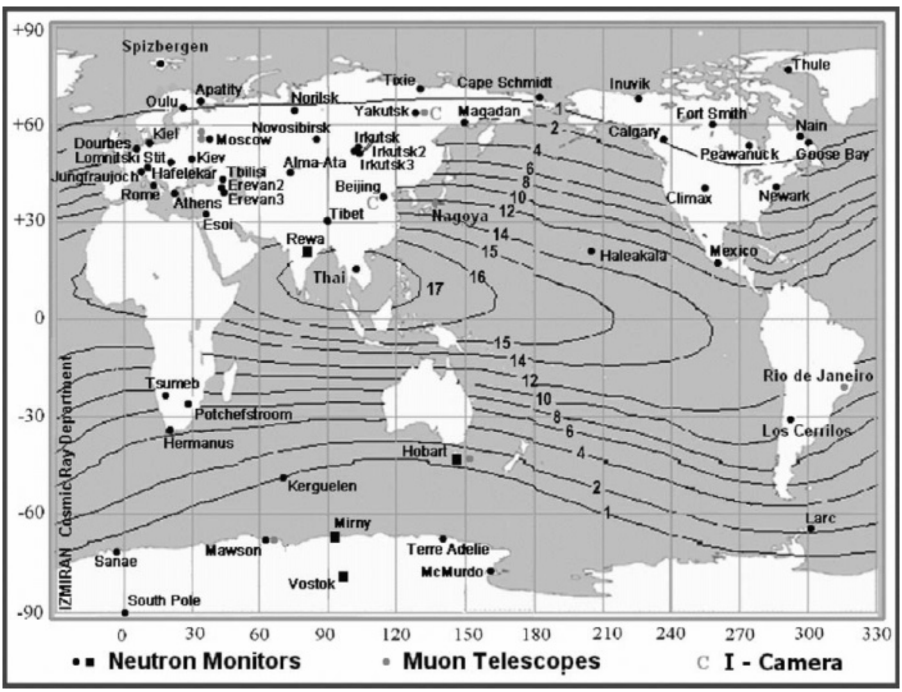

Figure 5. The global distribution of ground level cosmic ray detectors: neutron monitors and muon telescopes. CR cut-off rigidities at different points on the Earth are indicated on the isolines.

This special part of the network, with its separation of asymptotic directions, is named "Space Ship Earth" (Bieber et al., 1995) and it is presented in Figure 6, together with an indication of asymptotic directions for solar CRs at each station. All stations in Figure 6 have very high angular resolution (22o-57o) and receive median rigidity particles within a 22o nearly equatorial range. The regions of median energy directions in space are separated by less than 62o in longitude. Thus, this network provides a high angular resolution of particle equatorial distributions during solar proton events, exceeding the corresponding accuracy of measurements onboard satellites. This set of stations, together with some others at rigidity <4.5 GV, may be successfully used in the "ring station method" to monitor precursors of geomagnetic storms, as shown by Belov et al. (2001a). High rigidity (>5 GV) stations, such as Athens, Beijing, Rome, ESOI, Mexico, Tibet and many others, are necessary for the global survey method, to derive CR density, and anisotropy components, which exhibit anomalous behaviour before the arrival of an interplanetary disturbance at the Earth (Belov and Eroshenko, 2002). These high rigidity stations are also important to estimate spectra of solar cosmic rays during solar proton events. They can give information on the upper energy limit of solar particles in these events. In other words, the era when a single or a few NMs were used to analyse solar-terrestrial phenomenon, has passed. The NM network should be now considered as a unique multidirectional spectrograph. The development of special programs (Global Survey Method-GSM, Ring Station Method-RSM) allow the derivation at any moment of the CR density, anisotropy and CR pitch-angle distribution, by using as many neutron monitor stations as possible. Naturally, parts of the network may be

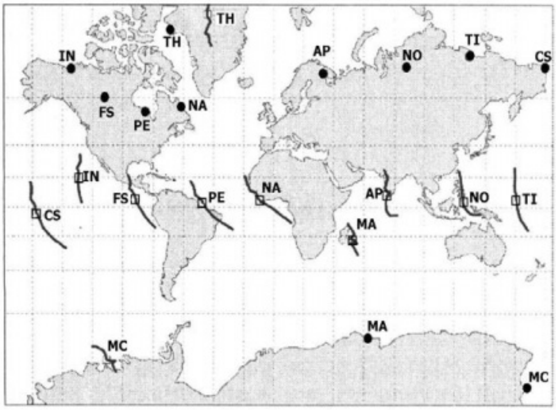

Figure 6. **Spaceship Earth stations** Circles are the geographic positions, squares-asymptotic cones of the stations:
IN–Inuvik **NO**–Norilsk **FS**-Fort Smith **TI**–Tixie Bay
PE–Peawanuck **CS**–Cape Shmidt **NA**–Nain **AP**–Apatity
MC–McMurdo **TH**–Thule **MA**- Mawson

still used for some selected tasks. The evolution of the number of neutron monitors since 1952 is presented in Fig. 7.

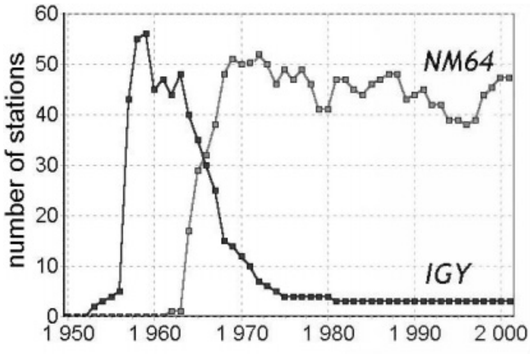

Figure 7. Number of IGY and NM64 neutron monitors over the history of CR observations.

The first version of the neutron monitor (the Simpson NM) was based on small counters, with low statistical accuracy. Their number increased abruptly after the famous flare of 23.02.1956 during the International Geophysical Year 1957 (IGY NM). At the beginning of 60's new counters and a new geometry for NMs were developed. Gradually these super neutron monitors (NM64) of high statistical accuracy replaced the old ones over the whole globe. It is clear that, even for the IGY neutron monitor or a single counter of the NM64, the accuracy is higher than that of CR observations on spacecraft. The use of all stations as a unified multidirectional detector, makes the accuracy substantially higher (<0.1% for hourly data).

All NMs operate continually with 1- or 5- minute intervals of data collection. Several recent results on the use of the prognostic properties of ground level CR observations suggest the need to provide continuous data in real time. Starting in July 1997, the Moscow NM64 was the first in the world to present data on the Internet in real time. After Moscow, several other stations became involved in this process, and now 23 stations present their data in real time, in digital and/or graphical form (Mavromichalaki et al., 2001). The main problem now is to make it possible to get all these data in real time in close sequence from all servers in order to make a real time monitoring of space weather conditions.

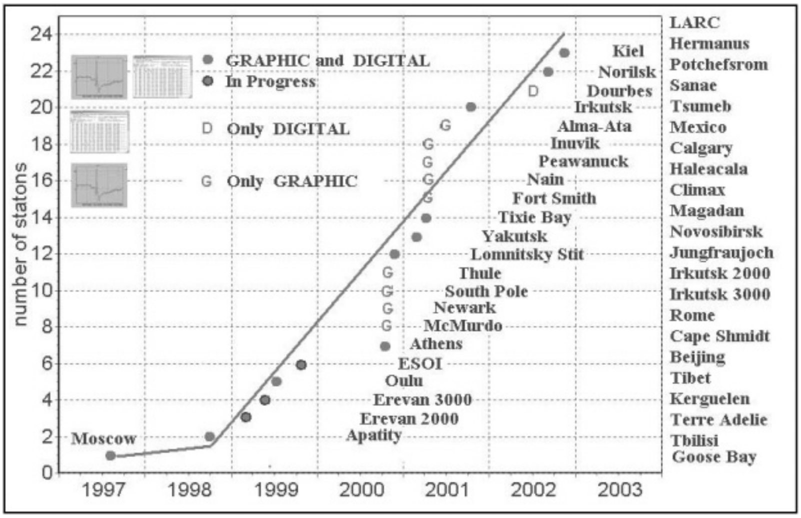

Figure 8. Diagram of the stations presenting data in real time (in the inner frame) and ready to present in a near future (list on the right side).

3.1 Data presentation

The most acceptable way for data publication on the Internet is via a standard interactive WWW-interface, providing access to the local databases of the CR stations, which altogether can be considered as and example of distributed database. The neutron monitor recording system, transfers one minute and hourly data to a server and refreshes this database, every hour. A special program included in a scheduler creates a graphical file once per hour, which is displayed on the web page. Standard access to the database is managed by FTP.

More modern processing systems have been established in Apatity and Oulu stations, in which the database is refreshed every 10 minutes. On request, a graphical file is produced by ISAPI technology on the server, and then displayed on the web page. The result is resent by HTTP protocol both in graphic and ASCII format. Standard access to the database from outside for the one-minute and hourly data (refreshed every 10 minutes) is via http protocol requests.

An improved version of 1-5-15-60-minute refreshed database system is operating at the stations of Athens, Kiel, Moscow and Irkutsk. Standard access to the database is http protocol request as well as FTP. Data may be retrieved both in graphical and digital form.

4. HOW TO GET DATA FROM THE NETWORK

4.1 Synchronization problem

To use data from the network stations in real time it is necessary to have high time precision in the NM registration systems. At present, the NM stations use PC clocks for timekeeping, but its timing uncertainty depends on the stability of the interrupt requests and any change in the interrupt request rate causes the clock to gain or loose time. So another way for the right timekeeping of NM stations must be found to obtain the best synchronization of the stations.

What accuracy is necessary to keep the clock precise? If the statistical accuracy of 1-minute data is about 1%, then the accuracy of 1-minute interval should not be worse than 1 sec. If the maximum change in the CR intensity during a GLE is about 30% per minute, the required time accuracy will be nearly 5 sec. These are not very strong requirements, and may be easily realized. The situation is more complicated when the data accumulation interval is 20 sec (Apatity), 10 sec (South Pole), or 1 sec (Athens). The timekeeping in these cases takes more efforts and some other approaches. We propose two different ways for correct timekeeping and NM stations synchronization.

1) Internet time synchronization

Computers can synchronize their clocks to an Internet timeserver. Special client software is needed in this case, linked to each of the three major Internet timing protocols: Time Protocol, Daytime Protocol, and Network Time Protocol. Timeservers are continuously “listening” for timing requests and will send them by using any of these three protocols. When the server receives a request, it sends the time to the NMN computers in the appropriate format. This timekeeping method has a number of advantages (it is cheap and easy to establish) and disadvantages, such as requirement for special software, dependence of the server-client time latency on the time of day and network health, the occasional loss of synchronization. If the Athens NM server was to act as the central timekeeper, the following time latencies (t_{AV}), observed on March 5/3/2003 at 18:00 U.T., give an indication of the performance:

Table I

Servers	t_{AV} (ms)
Apatity	866
Emilio Segre	225
Erevan	130
Kiel	121
Lomnicky Stit	495
Moscow	261
Roma	136

2) GPS synchronization

GPS can be used to determine precise time, time intervals, and frequency. GPS satellites carry highly accurate atomic clocks on board. For the system to work, GPS receivers on the ground synchronize themselves to this clock, what means every GPS receiver is, in essence, a clock with atomic accuracy. GPS can be used to synchronize clocks to tens of nanoseconds over large distances. The advantages of using GPS are the precision, the same time latency for all NM stations, the reliability and very fast synchronization. The disadvantages are the requirement for modern fast electronics, the need for special software and high prices.

4.2 Bases and ways of the data collection

For data collection by a central system (CS-Client) from all real-time neutron monitor stations (peripheral systems PS), different network configurations may be assumed. The basic network topology must be a "star-type", but the means of data collection may be different. The network should run independently of the quality level of the operation of each PS; the data collection must be as fast as possible and the data must arrive at the CS simultaneously from all the stations. Here we discuss three data collection models, their benefits and drawbacks. One way, presented in Figure 9, is based on the use of the star topology, in such a way that the central system collects data via FTP from peripheral stations (PS). Each PS records the last measurement locally in an FTP server with read-only access properties, so that the system is more secure.

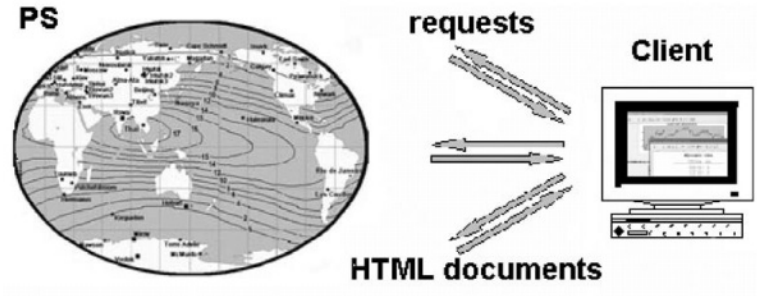

Figure 9. An example of real-time data collecting in the Central database (CS) of the NMN by a HTML request is given.

The CS requests and downloads the data one by one or simultaneously in a multithreading process, and provides the reference time. A problem of this system is that if a peripheral station fails, this will probably affect the central system, which would therefore need a timeout function while processing data from a peripheral station. In this case every PS must be an FTP server serving the CS. The management of so many servers can cause problems on the network.

A second way is based on the same star topology, but the PSs send their data to the CS at a specific time. In this model each PS will have a username and a password in CS and will send their data via the FTP protocol. The data will consist of a file with the latest measurements. In this topology, the system is "strong" because the failure of one PS does not affect the CS. If good enough synchronisation is provided, the data will reach the CS simultaneously. A possible drawback of the above method is the security of the central system, and extra security control will be needed. In any case, the management of the FTP process is easier because it has to be configured on only one FTP server, the central server. The main drawback of this method is that there is no way of the CS collecting data on request from the PS.

The third method is based on the second with some improvements taken from the first. In this case, the PS periodically sends data to the CS, but the CS has also the ability to request data from PS at any time. Such an approach is realized in the project RECORD (Real time Cosmic Ray Database), proposed by the Russian-European collaboration (Yakutsk, Moscow, Oulu, Lomnitsky Stit). Two or several regional databases (RS) should be managed (see Figure 10). One of the regional servers has the status of central data base, all others have a status of "mirrors". Comparison and balancing of regional databases is done by replication. The updating of regional databases uses many different sources, providing data by different ways (in particular, it can occur by the two ways mentioned above).

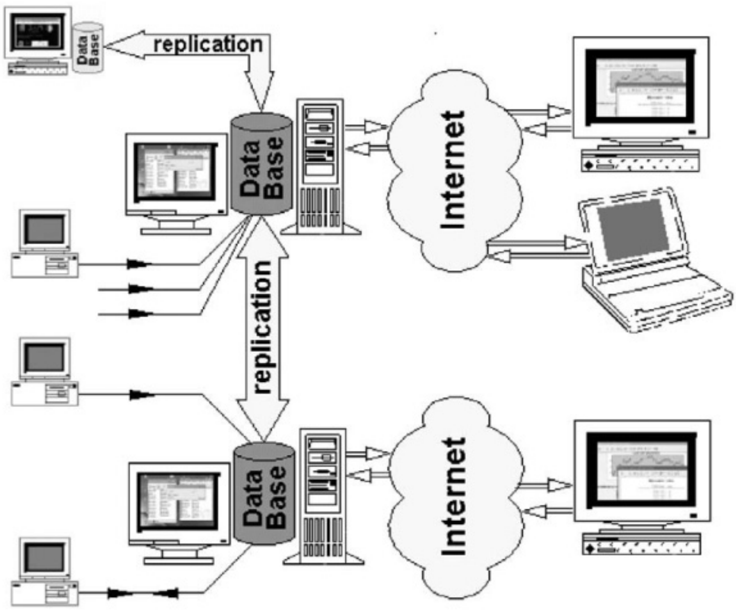

Figure 10. Schematic presentation of RECORD project.

If a station implements its own database on the same platform as in CS, the process of transferring data to the Central Database is simply by replication. In a second method, when a station sends data to the Regional database, the data transfer by TCP/IP Protocol should be established on the server of the station itself. In a third case the station is a passive element and only publishes data on its own server. The Regional Database gets data by a request to this server via http. It provides independence with respect to apparatus and programs. Users have an access to the Central DB via WWW, FTP and SQL interfaces.

5. CONCLUSIONS

Early detection of Earth-directed SEP events by NMs gives a good chance of preventive prognosis of dangerous particle fluxes in space and can provide an alert of an SEP with reasonable accuracy.

The worldwide neutron monitor network is a good tool for detecting anomalies in the CR pitch-angle distribution especially prior to the arrival of the interplanetary disturbance at the Earth. This can be used to give a good space-weather forecast.

At present, data from >15 neutron monitors are accessible in real time, and this provides a good basis for attempts to search for precursors of geomagnetic activity and to organize alerts of SEP events in real time.

The main task in the use of CR variations for space weather forecasting is to manage a real-time data presentation from as many neutron monitors as possible, collecting these data in real time on suitable databases accessible via Internet.

6. ACKNOWLEDGEMENTS

This work is partly supported by RFFR Grants 01-02-17580 and 03-07-90389 and by PENED 01EP87 and ENTER 01EΔ87 grants. We thank a lot for the useful discussion and great help with the preparing of this paper to Drs A. Belov, E. Eroshenko, L. Pustiljnik and also to postgraduate students C. Sarlanis and G. Souvatzoglou from Athens University. We are grateful to the Organizing Committee of ESPRIT for the chance to publish this paper.

7. REFERENCES

Belov A.V., L. Dorman, E. Eroshenko, N. Iucci, G. Villoresi and V.Yanke: Search for predictors of Forbush decreases, Proc. 24-th ICRC, **4**, 888-991, 1995.

Belov A.V., E.A.Eroshenko and V.G.Yanke: Cosmic Ray Effects Caused by Great Disturbances of the Interplanetary Medium in 1990-1996. Proc. 26th ICRC, 6, 431-434, 1999.

Belov A.V., E.A. Eroshenko, V.A. Oleneva and V.G Yanke: Relation of the Forbush effects to the interplanetary and geomagnetic parameters, Proc. 27-h ICRC, **9**, 3552-3355, 2001a.

Belov A.V., J.W. Bieber, E.A. Eroshenko, P. Evenson, R. Pyle and V.G. Yanke: Pitch-angle features in cosmic rays in advance of severe magnetic storms: Neutron monitor observations, Proc. 27-th ICRC, 9, 3507-3510, 2001b.

Belov A.V. and E. A. Eroshenko: Cosmic Ray Observations for Space Weather, Proc. for the 22nd ISTC Japan Workshop on Space Weather Forecast, Nagoya University, Japan, 129-146, 2002.

Bieber J.W., and P. Evenson: Spaceship Earth- An Optimized Network of Neutron Monitors, Proc. 24-th ICRC, v. 4, 1316-1319, 1995.

Dorman L.I., L.A. Pustil'nik, A. Sternlieb, and I. Zukerman: Using ground-level cosmic ray observations for automatically generating predictors of hazardous energetic particles levels. Adv. Space Res., 2001.

Kudela K., M. Storini, M. Hoffer, and A. Belov. Cosmic rays in relation to space weather. Space Sci. Rev., 93, 153-174, 2000.

Mavromichalaki, H., C. Sarlanis, G. Souvatzoglou, S. Tatsis, A. Belov, E. Eroshenko, V. Yanke and A. Pchelkin: Athens Neutron Monitor and its aspects in the cosmic-ray variations studies. Proc. 27th ICRC 2001, 4099.

Shea M. A. and D. Smart: Fifty years of Cosmic ray Radiation Data. Space Sci. Rev., 93, 229-262, 2000.

Stoker P. H., L. I. Dorman and J.M. Clem: Neutron monitor design improvements. Space Sci. Rev., 93, 361-380, 2000.

Villoresi G., L.I. Dorman, N. Iucci, and N.G. Ptitsyna: Cosmic ray survey to Antarctica and coupling functions for neutron component near solar minimum (1996-1997), 1. Methodology and data quality assurance. JGR, 105,. A9, 21025-21034, 2000.