SPACE WEATHER FORECASTING BY USING A PROTOTYPE NETWORK OF MUON DETECTOR

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Abstract

In order to observe cosmic ray precursors of geomagnetic storms a prototype detector of cosmic ray muons was installed at Observatório Espacial do Sul - OES, located at São Martinho da Serra (29°S, 53°W) Brazil. The system has been operating since March 2001 and was it obtained under an agreement of scientific cooperation between Brazil and Japan. This detector plays an important role in the network of muon observations together with two other larger detectors operating in Japan and Australia. The planned extension of the detector in its full size will complete the global coverage of our muon detector network allowing to a more accurate forecasting of geomagnetic storms precursors. The prototype network has already observed cosmic ray precursors of several magnetic storms, such as those reported by Munakata et al. (2000, 2001). We have also observed Forbush Decreases (FD's) events, as well as the precursory enhancements of cosmic ray anisotropy preceding the onsets of geomagnetic storms. This report presents a description of the network and some of the first results obtained with the detector implementation.

Introduction

Large geomagnetic storms are primarily caused by interplanetary disturbances occurring during high solar activity. Energetic cosmic rays intensities observed by ground level detectors are also subject to modulation effects due to interplanetary disturbances such as shocks and coronal mass ejection (CMEs). Such events affect the pre-existing population of galactic cosmic rays in a number of ways. For instance, the cosmic rays intensities of > 1 GeV particles are normally suppressed by ~1-10% downstream shock and within ejecta (CME) following the shock (Gosling et. al 1999, 1993). These energetic particles are of great interest from a space weather perspective for several reasons. First, these particles travel nearly at the speed of light. Such particles interact with a shock or CME getting out of the downstream region and race ahead of the slower shock, providing advance warning of a disturbance approaching to the earth. Second, they have large mean free paths in the Solar Wind, which is important since precursory signatures of the an approaching disturbance would be extinguished due to the scattering in larger scales than the free medium path.

The prediction of solar structures arriving in Earth depends on the simulation of interplanetary propagation, for instance, by using data available through space probes. However, space weather researchers and the space industry need accurate forecasts of the arrival times at earth. This is only possible if the CMEs and shocks waves are observed as early as possible during interplanetary propagation after they are outside of such probes viewing field. Ground level cosmic rays detectors cover various directions in space (including the sun). Daily variations in counting rates of ground bases cosmic rays detectors can reflect the anisotropic intensity distribution of cosmic rays. Such cosmic rays anisotropies can indicate with hours in advance the sudden commencement of geomagnetic storms.

In March 2001, a prototype muon detector was installed in São Martinho da Serra, at Observatório Espacial do Sul (OES/RSU/INPE-MCT). It has been operating in order to get basic information on the performance of the full-scale network together with telescopes located in Nagoya (Japan) and Hobart (Australia).

The project of the muons detection will provide forecasts on solar structures that can produce geoeffective magnetic storms, whose effects over the earth atmosphere are expressive, producing strong electromagnetic fields and high induced currents capable to damage electro-eletronic devices, inclusive in terrestrial bases. At the moment, the monitoring of the cosmic rays precursors of geomagnetic storms have been carried out by a network of ground level muons telescopes.

Method

Since the detectors with large volume can be installed at ground-based stations, neutron monitors (*Simpson et al.*, *1953*) and muon detectors (*Fujimoto et al*., *1976; 1984*) are the preferred instruments for measuring anisotropies of >1 GeV cosmic rays. Typical neutron monitor has maximum response to ~10 GeV primary cosmic rays, while muon detector responds to ~50 GeV cosmic rays. Hence, earth directed CMEs and shocks waves are detectable with ground level muons detectors earlier than with neutron monitors. In general the detectors observe a reduced flux of particles moving away from the shock with small pitch angles due to a cosmic ray depleted region behind the shock. This depletion is measured by the cosmic rays telescopes as a intensity deficits of cosmic rays (1-2%) at the ground. As presents higher energy, muons travel straight in the atmosphere keeping the information of the incident direction of primary cosmic rays. It is possible to make the directional measurement of cosmic ray intensity by installing multidirectional muon telescopes at a single station. However, the current muon detector network is hampered by a lack of station(s) in the western hemisphere. The symbols (squares, triangles and diamonds), displayed in Figure 1, show the asymptotic viewing directions (after correction for geomagnetic bending) of cosmic ray particles incident to each directional telescope, (*Munakata et al.*, 2000), in the network before installing the prototype detector in Brazil.

The thin lines through the symbols encompass 80% of the total energy response of each directional channel (*Bieber et al*., *2001*). This illustration emphasizes the necessity of a new muon detector for filling the big gap over the European and Atlantic area. In early March 2001, a small prototype muon detector was installed at São Martinho da Serra (29°,26',24"S, 53°,48',38"W, above 500 m sea level), at the Southern Space Observatory in order to fill the gap illustrated in Figure 1.
The telescope is composed by a frame of two levels with 4 detectors each, occupying a total area of 4 m^2. It possesses 16 different combination ways among the detectors taken 2 by 2, providing 9 directional channels of the cosmic ray intensity observation. Each detector has a box with a dense plastic scintillator and a phototube fixed in the top of the system. The pulses of the phototube are amplified and a pre-established tension of discrimination differentiates them from the gamma rays pulses. The width of the common high voltage is regulated to compensate both the sensibility difference and the scintillation efficiency of the detectors, maintaining the linear count rate of all channels. A coincidence circuit identifies the direction of the muons. The muons periodic count is displayed in a PC on-line. The observed count rate in the vertical channel is 390,000 count per hour (cph). The detector is identical to the detector which is operating in Nagoya, Japan, except for its smaller detection area (Nagoya muon detector has a total detection area of 36 m^2 and a vertical count rate of 2,760,000 cph).
The muon detector is multidirectional, i.e. it detects the muon intensity in every channel of incident direction of muons. The detector at São Martinho da Serra has 9 directional channels: Vertical, North, South, East, West, North-East, North-West, South-East and South-West respectively represented by the symbols: V, N, S, E, W, NE, NW, SE, SW. Table 1 summarizes characteristics of directional telescopes in São Martinho da Serra, (*Munakata et al. , 2000*).

Telescope Name	Hourly Count, 10^4 cph	Count Error %
V	39	0.16
N	11	0.30
S	11	0.30
E	11	0.30
W	11	0.30
NE	4.7	0.46
NW	5.4	0.43
SE	5.3	0.43
SW	5.5	0.43

Table 1. Characteristics of the muon detector at SSO

We have been planning to expand the 2x2 array of 1 m^2 detectors at São Martinho da Serra to a 6 x 6 array. This expansion will increase the number of directional channels of cosmic ray intensity to 17 (from 9 at present), as well as the count rate in each channel (the vertical count rate, for instance, is expected to be 2,860,000 cph). Such expansion will provide a great improvement in the directional correlation of the equipment, increasing from 16 to 992 different combinations ways in 17 channels.
Figure 2 shows the directional coverage of the full-scale network with the expanded detector at São Martinho da Serra. The open circles show the viewing directions of the present prototype detector at São Martinho da Serra, while the solid circles show new directions to be added by the proposed expansion. The count rates in all directional channels at São Martinho da Serra would also increase dramatically.
After the amplification, together with Nagoya (Japan) and Hobart (Australia) Telescopes, it will be covered the big gap in the global coverage of the muons detection network over the Atlantic and European areas. The full network will allow an effective and reliable forecast on the solar structures leading to a better understanding of the space weather studies.

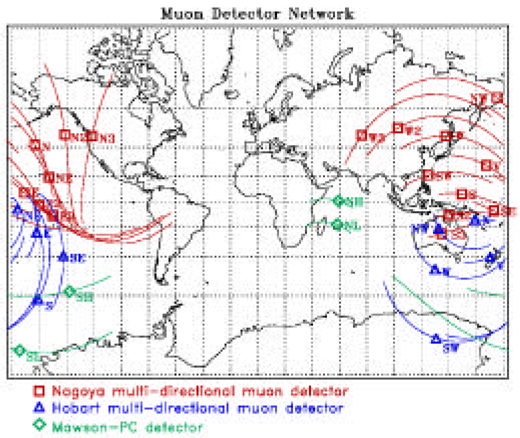

Figure 1 - The big gap before the prototype muon detector implementation at SSO.

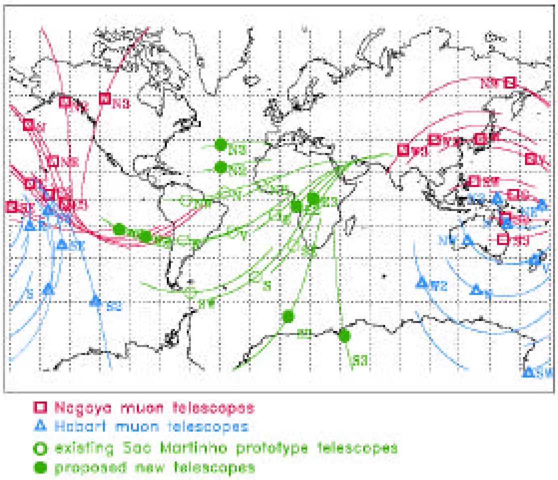

Figure 2. Proposed expanded muon detector network.

Observation Site

High energy cosmic rays intensities, observed by the ground level prototype muon detector, have been continuously carried out at Southern Space observatory (OES/CRSPE/INPE), coordinates: 29º26'24"S, 53º48'38"W, which is located in São Martinho da Serra - RS, in the southern region of Brazil. This Observatory support several experiments for higher and lower atmosphere monitoring. The telescopes are installed at the main building of the SSO, as illustrate in Figure 3. A viewing of the system can been seen in Figure 4.

Figure 3 - Viewing of the main building of the SSO.

Figure 4 - Viewing of the system implemented at SSO.

Discussion

The first results obtained with the prototype muon telescopes have show a good agreement with those available in previous studies. *Munakata et al. (2000)* have previously identified cosmic ray precursors with lead times ranging from 6 to 9 hours prior to the storm sudden commencement (SSC) and demonstrated that the muon detector network may provide useful information for space weather forecasting. Figure 5 exemplifies an observation for a period covering the onset of a geomagnetic storm event (Munakata et. al 2000). The distribution in the pitch angle values show the type of the precursory anisotropy, for this case a "Loss Cone" (LC) structure can be observed. The open and solid circles represent an excess and a deficit of cosmic ray intensity relative to the average, and the diameter of each circle is proportional to the magnitude of deficit or excess. About 7 hours before the SSC an intensity excess in the sunward IMF direction became evident, indicating with hours in advance the arrival of an effective structure which produced a geomagnetic storm event.
In order to provide, in real time, information about cosmic ray precursors, the muon intensity data can been exchanged among the stations by using the INTERNET.
Precursory anisotropy of geomagnetic storms have been observed by our prototype allowing to studies of the behavior of the muon count rate data during geomagnetic storms. Some examples of the first events observed with our detector are displayed in Figure 6, which shows (on the top panel) the percentile variation of muon hourly count rate. Also shown in the figure are: the Dst index data (the second panel from the top), obtained through Kyoto web page; the IMF components, B_z and B_t (third panel) and the solar wind speed (last panel) measured by the ACE satellite. The Dst index have been used to study the development of geomagnetic storms, while the IMF and solar wind data are used to identify the shock arrival at the earth. In the Figure 5 we can observe the sudden decrease of the cosmic ray intensity. These signatures are well know as Forbush Decreases (FDs) events. The FDs was first discovered at the beginning of cosmic ray studies and has been studied for more than 60 years

(Forbush, 1937). This phenomenon is primarily defined as a decrease of cosmic ray intensity during geomagnetic storms *(Dorman, 1963)*. However it is also known that the FDs are often observed under quiet geomagnetic conditions as well. Figure 7 shows an example of FDs observed by our network during quiet geomagnetic activity.

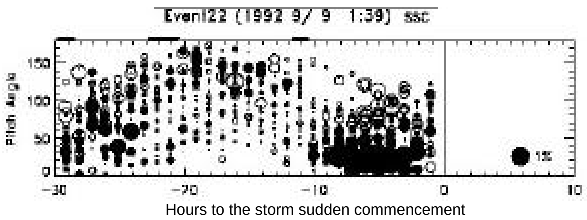

Figure 5 - Pitch angle distribution observed during a Loss Cone anisotropy (LC) event occurred in September 09, 1992. The LC appear about 8 hours in advance to the SSC.

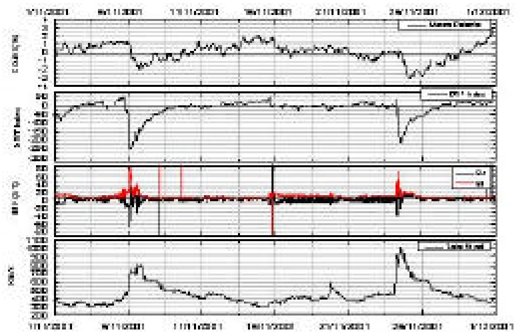

Figure 6. Example of the first event recorded by São Martinho da Serra muon detector. The top panel indicates the muon count rate; the second panel indicates Dst index; third panel the IMF components and in the last panel is represented the solar wind speed. Two events of Forbush Decreases can be identified by sharp decreases in the cosmic ray intensity.

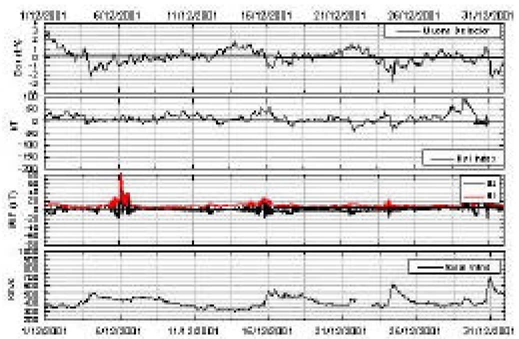

Figure 7. Example of a FD event observed during quiet geomagnetic conditions. A Forbush Decrease of ~2 %, associated with Dst levels of about -10 nT, is observed in December 3, 2001.

Conclusion

We have observed the cosmic ray response to geomagnetic storms by analyzing the data recorded by a ground level prototype muon detector installed at the Southern Space Observatory - SSO. Such analysis is important since it can provide information about the parameters which reflects the nature of interplanetary disturbances. Previous studies have shown that the network is able to observe cosmic ray precursors from 6 to 9 hours prior to the storm onset, making possible more accurate forecasts about the arrival of energetic particles. Even a single prototype muon detector installed in the southern Brazil provided a large improvement in the sky coverage over the Atlantic region. However, the present muon detector network still has a gap in directional coverage over the Atlantic and European regions. This gap disabled us from precisely evaluating the appearance time of long lasting precursors.
The expansion of the detector in its full size will be important and is therefore required for both better understanding of the cosmic ray precursors and for space weather forecasting.

Acknowledgments

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