33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
THE ASTROPARTICLE PHYSICS CONFERENCE

The Global Muon Detector Network - GMDN. The Brazilian Contribution for Space Weather Forecasting

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Abstract: The GMDN, is a Global Muon Detector Network (GMDN) of ground based multi-directional detectors, and an international collaboration consisting of 10 institutions from 6 countries, with real time data generated by the GMDN, which was developed at Shinshu University, Japan. The Brazilian GMDN's contribution was the installation in 2001, of a Multi-Directional Muon Detector prototype (MMD) for detection of high-energy galactic cosmic rays (GCRs), through an international cooperation between Brazil, Japan and USA, and has been in operation since then at the Southern Space Observatory - SSO/CRS/INPE - MCTI, (Latitude 29^o, 26', 24"S, Longitude 53^o, 48', 38"W, 492m above sea level), São Martinho da Serra, RS, in southern Brazil. The SSO-MMD detector's capability and sensitivity were twice upgraded, in 2005 and 2012. The Brazilian contribution for Space Weather forecasting is through the observations conducted by the SSO-MMD which are used for forecasting the arrival of the geomagnetic storm and their Interplanetary Coronal Mass Ejection (ICME) drivers in the near-Earth geospace. The detector measures GCRs by detecting secondary muons produced from the hadronic interactions of primary GCRs (mostly protons) with atmospheric nuclei. Since muons have a relatively short life-time (about 2.2 microseconds at rest), it can reach the ground level due to the relativistic effect, and can preserving the incident direction of primary particles, because its high energy, the SSO-MMD detector can measure the GCRs intensity in 17 directions as a multidirectional detector at a single location, the SSO in southern Brazil.

Keywords: Galactic cosmic rays, muon, coronal mass ejection, space weather

1 Introduction

A Multi-Directional Muon Detector for the detection of Secondary High Energy Cosmic Rays (Muons) was installed and became operational in 2001, in the Southern Space Observatory - SSO (29^o 26'24"S, 53^o 48'38" W, 492 meters above sea level) in São Martinho da Serra, southern Brazil. The prototype, simpler and cheaper, was tested in the S-SO from 2001 to 2005, allowing all the intense magnetic storms of the period - quite frequently - were detected. This fact led our Japanese and Americans collaborating partners to propose an expansion of the telescope prototype with the installation of a new equipment, larger and more sophisticated (see Figure 2). As a consequence of this fact, in 2005, the Federal University of Santa Maria received from the Janpanese Shinshu University a giving of a new set of equipment systems (with estimated market value of approximately 1.6 million dollars) to replace the prototype for a new Multi-Directional Muons Detector (MMD). This equipment was installed in 2005 in SSO. Since then, the dimensions of the MMD were 7 $\times$ 4 meters, arranged in two layers (see Figure 2). In 2012, the detection area was further expanded, for size 4 $\times$ 8 meters, arranged in two layers. Thereby, increasing the detection area, the accuracy of the experiment increases too.

2 Physics Background

The relationship between Coronal Mass Ejections and the decrease of the cosmic rays count is well known by scientists [1], [2]. When a Coronal Mass Ejections happens, a decrease in the Muon count is observed in the MMD system, because the strong magnetic field of the solar structure shields the passage of cosmic ray particles. This decrease is called Forbush decrease in honor of the discoverer of this physical mechanism [3].

The observations of Muons are used to predict the

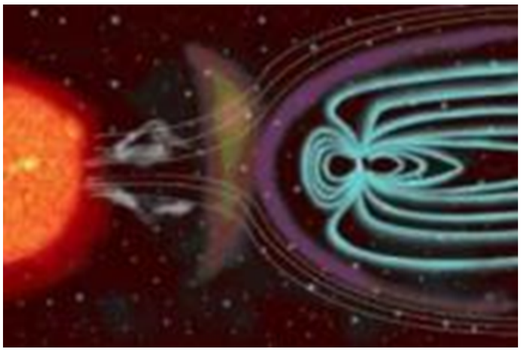

Fig. 1: Artistic representation of Sun - Earth relationship, now called Space Weather. The solar variability is the main source of disturbances in vicinity of Earth. Source: `http://www.estec.esa.nl/wmwww/wma/spweather/index.html`

occurrence of disturbances in Geospace around the Earth and thus, provides the prediction of Geoeffective Magnetic Storms [4, 5, 6, 7, 9].

3 Space Weather Forecast by observations of Cosmic Rays

It is a known fact that Cosmic Rays observations on Earth's surface are modulated by solar disturbances that are approaching the Earth. These disturbances, usually caused by Solar Mass Ejections, shields cosmic rays like magnetic shields, causing depressions on the order of 1% to 10% in cosmic rays count. Based on this principle, it is possible to predict the arrival of a solar disturbance with up to 10 hours in advance, since there is a network of detectors around the Planet [4, 5, 6, 9]. Therefore, in 2001 Brazil became part of the International Network of High Energy Cosmic Rays Detectors, using the MMD installed in SSO.

4 The Brazilian Contribution for Space Weather Forecasting

The MMD installed in SSO, along with two other detector systems, located in Hobart (Australia) and Nagoya (Japan), allow the study and performing the prediction of geoeffective magnetic storms [8]. These storms are consequences of plasma ejections from Sun's eruptions. When they reach our planet, can cause great damage to satellites, communications, power distribution by high voltage networks, among others. Even, a few years ago a magnetic storm caused a fire in a power plant in Quebec, Canada, causing a blackout that left six million people without electricity for ten hours.

Besides the three detectors mentioned previously, two another systems were installed in City of Kuwait (Kuwait) and Greifswald (Germany), which together allow the coverage of the celestial sphere of the Earth. The goal is to organize a highly efficient global alert system. Currently, the geoeffective geomagnetic storms forecast can only be done with just an hour in advance, since for this prediction are used data from satellites located in the vicinity of the Planet. With the new data, provided by the International Network of Multidirectional Muon Detectors, or GMDN - the Global Muon Detector Network (see Figure 3) the detection of distribution of Muons will allow the prediction from six to

Fig. 2: Multidirectional Muons Detector (MMD) of Cooperation Japan-USA-Brazil, installed in the Southern Space Observatory, in São Martinho da Serra, Southern Brazil.

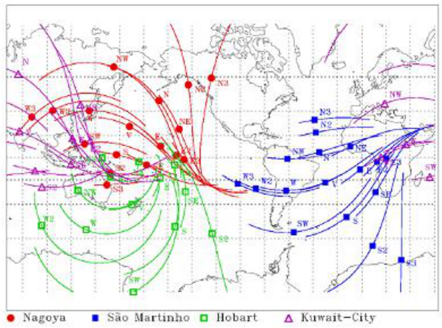

Fig. 3: The complete coverage of the GMDN - Global Muon Detector Network with the directions for each MMD?s: Nagoya, Japan 17 directions; Hobart, Australia 13; Kuwait, Kuwai 13; So Martinho da Serra, RS, Brazil 17 (V, N, S, E, W, NE, NW, SE, SW, N2, S2, E2, W2, N3, S3, E3, W3).

twelve hours before magnetic storms occur. In Figure 3 it is presented the GMDN geographic location (big star) of each muon detector. The symbols (squares, triangles and circles) shows the existing asymptotic viewing direction of a particle incident to each Multi-Directional Muons Detector (MMD) with the median primary rigidity, after correction for geomagnetic bending of cosmic ray orbits. The track through each symbol represents the spread of viewing directions corresponding to the central 80% of each MMD's energy response. . This makes it possible to organize preventive strategic defenses, such as the shutdown of instrument and satellite systems that may be affected, to protect humans and their properties.

Today, the expanded system of the MMD, consists of two layers of 32 detectors. These layers are separated by 1.73 meters high, intermediated by a layer of 5 centimeters thick lead blocks, used to absorb the low energy cosmic rays the components. At the bottom of a 1.6 millimeters thick metallic box are installed blocks of scintillating plastic (with dimensions $1 \times 1 \times 0.1$ meter) which release photons - UV to be pierced by muons. The photons are captured in the top of the box by a photomultiplier tube whose diameter is 12.7 centimeter, generating electrical pulses. These detectors are arranged in the shape of a rectangle (4×8 meters) in each layer, where one side is aligned geographically in the north-south direction.

During the SSO's MMD expansion mission in 2005, about 10 people attended the installation, including researchers and especially graduate and undergraduate students, from Brazil and Japan. The equipment operates automatically 24 hours / day, being remotely monitored from

Santa Maria, United States, Japan and Germany. The team responsible for the expansion was coordinated by Japanese researcher, Prof. Dr. Kazuoki Munakata, the major international researcher and the Head of international project (PI), Dr. Takao Kuwabara (Visiting Researcher from Bartol Research Institute, University of Dalawere U.S.A.); and Brazilians researchers, Dr. Alisson Dal Lago (National Institute for Space Research); and locally Dr. Nelson Jorge Schuch (National Institute for Space Research). The installation had the collaboration and support of the undergraduate students of Physics and Electrical Engineering courses of the Federal University of Santa Maria.

In 2012 occurred the third partial upgrade of the MMD, which has been successfully completed. The detector now has an area 14% larger and should improve the measurements / observations quality. The partial upgrade of 2012 (equivalent is planned for the near future) was made possible by:

1. the donation of 29 scintillator plastics by the Shinshu University (Japan) and the Australian Antarctic Division (Australia); providing amplifiers by the Shinshu University;

2. the purchase of photomultiplier tubes by INPE/MCTI, through the Space Weather Program (EMBRACE CEA / INPE-MCTI);

3. financial support funded by CNPq (Proc. 481368/2010-8) to transport donated stuff, from Australia to Brazil;

4. INPE's graduate students of Space Geophysics and undergraduate students from Federal University of Santa Maria, which provided an active participation in the work of the assembly.

It is necessary to be pointed out the great opportunities of discussions occurred during the technical visits to the SSO for the implementation of the third partial upgrade of the MMD, in particular for the students, that besides to learning about the functioning of scientific instrument and participate in its assembly, attended seminars on scientific issues related to the observations being carried out in the SSO.

5 Summary and Conclusions

1. Since 2001 Brazil is a member of the International Network of High Energy Cosmic Rays Detectors, using the MMD installed on the Southern Space Observatory, in São Martinho da Serra, RS, Southern Brazil.

2. In 2012 the third upgrade of Multidirectional Muon Detector has been successfully completed. The new MMD now has an area 14% larger, which is improving the quality of the measurements and the resolutions of the observations.

Acknowledgment: The NJS acknowledge the Brazilian CNPq agency contract number 313865/2009-4. The authors acknowledge for donation of plastics scintillators by the Shinshu University (Japan), the Australian Antarctic Division (Australia) which provided the amplifiers with the Shinshu University. The financial support funded by CNPq, contract number 481368/2010-8, to transport donated stuff, from Australia to Brazil. The authors acknowledge the INPE's Space Weather Program - EMBRACE from CEA/INPE-MCTI for the purchase of photomultiplier tubes by INPE/MCTI. M. Rockenbach thanks FAPESP and CNPq for financial support under the projects 2011/11581-9 and 300300/2012-3. A. Dal Lago thaks CNPq for grants 305351/2011-7 and 481368/2010-8. E. Echer ackowledge the Brazilian CNPq agency contract number 301233/2011-0 and FAPESP agency contract number 2012/066734 for support for this work.

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