

## Upgrade of the Brazilian Southern Space Observatory Multidirectional Muon Detector

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**Abstract:** A multilateral collaborative effort was carried out to upgrade the Multidirectional Muon Detector (MMD) installed at the Brazilian Southern Space Observatory (SSO/INPE), located at São Martinho da Serra (SMS), (Latitude 29° 26' 24''S, Longitude 53° 48' 38''W, 492m above sea level), south of Brazil. An increase detection area was possible with the addition of two layers of 4 m<sup>2</sup> each. The current configuration of the instrument is 2 layers of 4 × 8 m<sup>2</sup>. The MMD is part of the Global Muon Detector Network (GMDN), which is composed by four detectors: Nagoya, Sao Martinho da Serra, Hobart and Kuwait. At the National Institute for Space Research (INPE), the MMD is part of the institutional Space Weather Program, which started since 2008 and aims to provide a comprehensive set of observations to researchers and the general community regarding all solar-terrestrial physics phenomena. The upgrade was sponsored by Shinshu University, Australian Antarctic Division, the Brazilian CNPq funding agency, the National Institute for Space Research (INPE) and its Space Geophysics Graduate Program. A status report of the SMS detector, as well as preliminary observations are presented.

**Keywords:** muon detector, GMDN, space weather

### 1 Introduction

Since 1992, an international muon detector network has been established, with detectors in Nagoya (Japan) and Hobart (Australia), with detection areas of 36 m<sup>2</sup> and 9 m<sup>2</sup>, respectively. In order to fill an observation gap over the Atlantic Ocean and Europe ([1]), a prototype muon detector was installed in São Martinho da Serra (SMS), Brazil, in 2001. The initial configuration of the prototype was 2 layers of 4 m<sup>2</sup> each ([2]). In 2005, an expansion of the SMS detector took place, increasing the detection area from 4 m<sup>2</sup> to 28 m<sup>2</sup>.

With the addition of a fourth detector in Kuwait in 2006, the Global Muon Detector Network (GMDN) was established ([3]). A second upgrade in the SMS detector was possible in July 2012. The current configuration of the instrument is 2 layers of 4 × 8 m<sup>2</sup> (32 m<sup>2</sup>). The upgrade was sponsored by Shinshu University, Australian Antarctic Division, the Brazilian CNPq funding agency, the National Institute for Space Research (INPE) and its Space Geophysics Graduate Program. We present a status report of the current SMS Multidirectional Muon Detector in operation at the SSO, Brazil. Some preliminary observations after the upgrade are presented.

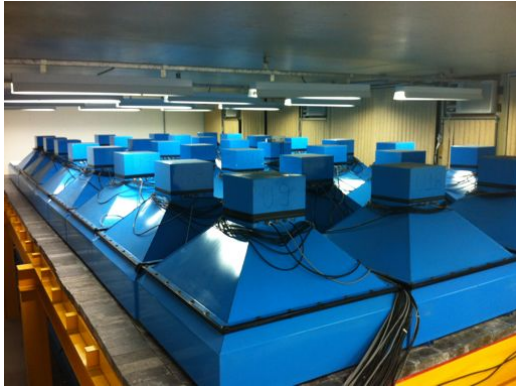
### 2 Upgrade

In order to derive the cosmic ray streaming from the GMDN observations, a least-square best-fit calculation is necessary. In the calculation, some parameters are derived, including the amplitude and orientation of the streaming. The SMS detector optimum detection area is the same as its conjugate detector in Nagoya (36 m<sup>2</sup>), in order to diminish best fitting bias. After the last upgrade, the area of the SMS detector became only ~ 11% smaller than the area of the Nagoya detector. A final upgrade is planned for the near future, with the inclusion of 2 layers of 4 m<sup>2</sup>.

### 3 Current status of the SMS detector

The SMS multidirectional muon detector has been upgraded to a configuration of 2 layers of 4 × 8 m<sup>2</sup> (32 m<sup>2</sup>) in July 2012. Figure 1 shows a picture of the upper layer of the upgraded instrument.

The detector has 17 directional channels, which combine simultaneous detections on the upper and lower layers. Table 1 presents the hourly count rates and estimated errors for the 17 directional channels before and after the upgrade.



**Figure 1:** Upgraded SMS multidirectional muon detector in operation in the Southern Space Observatory (SSO/INPE), at Sao Martinho da Serra city, (Latitude 29°, 26', 24''S, Longitude 53°, 48', 38''W, 492m above sea level), south of Brazil.

#### 4 Muon observations and Space Weather

Since 2008, the National Institute for Space Research has started a Space Weather program (<http://www2.inpe.br/climaespacial/en/index>). Its aim is to provide a comprehensive set of observations to researchers and the general community regarding solar-terrestrial physics phenomena.

Space weather phenomena can modulate cosmic rays in a variety of ways. It is known that the passage of an interplanetary counterpart of a solar coronal mass ejection (ICME) through the earth can cause an isotropic decrease of ground cosmic ray counts ([4]). Figure 2 presents, from top to bottom, the interplanetary magnetic field ( $B$ ), its  $z$  component ( $B_z$ ), proton speed and temperature, measured by the Advanced Composition Explorer satellite at L1 point, just outside the earth's Magnetosphere. Bottom panel shows the percentage variation of the vertical (V) direction of the upgraded SMS multidirectional muon detector. These observations from the SMS detector are preliminary (not pressure or temperature corrected). In the figure it is possible to identify an interplanetary shock on November 12th, at 22:08 UT. Behind this shock, an ICME-magnetic cloud is present. This event was a source of relatively intense out-of-the-ecliptic interplanetary magnetic field, and it was responsible for an intense geomagnetic storm, with peak Disturbance Storm time index  $Dst = -108nT$ . On November 13th, a decrease in the count rate of the SMS vertical channel is possibly related to the passage of this interplanetary event through the earth.

#### 5 Summary

An increase detection area of the Multidirectional Muon Detector (MMD) installed at the Brazilian Southern Space Observatory (SSO/INPE), Brazil, with the addition of two layers of  $4 m^2$  each was done. The current configuration of the instrument is 2 layers of  $4 \times 8 m^2$ . The purpose of the upgrade is to improve the estimation of the cosmic ray streaming derived from the GMDN observations. Participated in this upgrade the following institutions: Shinshu University, Australian Antarctic Division, Brazilian CNPq funding agency, the National Institute for Space Research (INPE) and its Space Geophysics Graduate Program. Pre-

	Jan/2012		Jan/2013	
	counts ( $\times 10^3$ )	error (%)	counts ( $\times 10^3$ )	error (%)
V	2337	0.065	2650	0.061
N	888	0.106	1006	0.100
S	915	0.105	1035	0.098
E	1030	0.099	1190	0.092
W	1028	0.099	1188	0.092
NE	419	0.154	484	0.144
NW	421	0.154	487	0.143
SE	434	0.152	500	0.141
SW	432	0.152	495	0.142
N2	290	0.186	332	0.174
S2	300	0.182	342	0.171
E2	368	0.165	433	0.152
W2	367	0.165	428	0.153
N3	33	0.543	39	0.503
S3	35	0.532	41	0.493
E3	75	0.364	94	0.325
W3	77	0.360	95	0.324

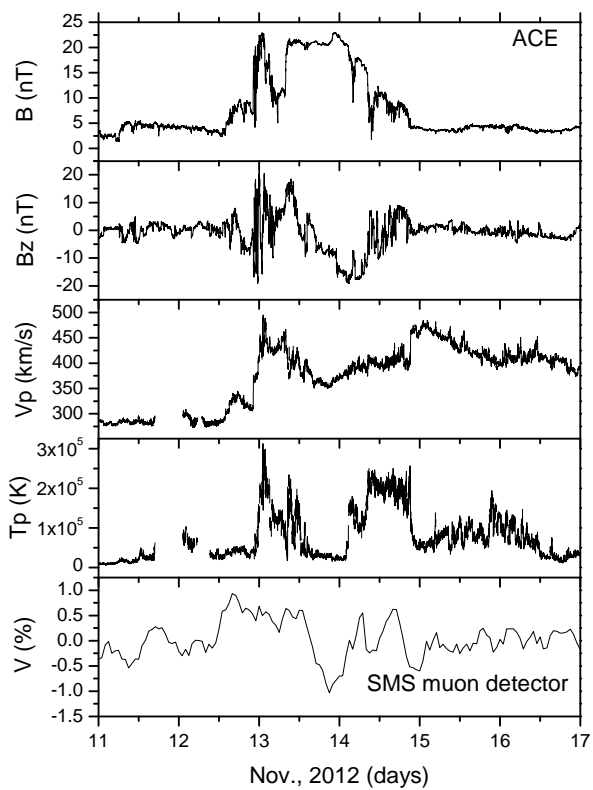
**Table 1:** Hourly count rates and estimated errors of SMS detector before and after the upgrade.

liminary observations of the upgraded instrument was presented.

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**Figure 2:** From top to bottom: the interplanetary magnetic field ( $B$ ), its  $z$  component ( $B_z$ ), proton speed ( $V_p$ ), proton temperature ( $T_p$ ), measured by the ACE satellite. Bottom panel: percentage variation of the vertical ( $V$ ) channel of the upgraded SMS multidirectional muon detector (not pressure or temperature corrected).