Forbush decreases in November 6-20, 2004 observed by the Muon Detector Network

Jairo F. Savian[1,2], Marlos R. da Silva[3], Vânia F. Andrioli[1,2], Alisson Dal Lago[3], Ezequiel Echer[3], Luis E. Antunes Vieira[3], Kazuoki Munakata[4], Galina I. Pugacheva[2], John W. Bieber[5], Walter D. Gonzalez Alarcon[3], Nelson J. Schuch[2].

[1] Santa Maria Space Science Laboratory, UFSM, Santa Maria, Brazil,
[2] Southern Regional Space Research Center – INPE/MCT, Santa Maria, Brazil,
[3] National Institute for Space Research, São José dos Campos, Brazil,
[4] Physics Department, Faculty of Science, Shinshu University, Matsumoto, Japan,
[5] Bartol Research Institute, University o Dalawere, Newark, USA.

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Abstract

In this paper we study the relationship between Interplanetary Coronal Mass Ejections (ICMEs) and the count rate muon decrease detected by the muon detector network in November 6-20, 2004. The Muon Detector Network is composed by the detectors installed in Nagoya (Japan), Hobart (Australian) and the prototype detector installed in the "Observatório Espacial do Sul – OES/CRSPE/INPE-MCT", located in São Martinho da Serra, RS, Brazil. With the muons count rate observed by the Muon Detector Network, we will be able to observe, in the future,the direction in which a given ICME moves, and with that, we will be able to calculate the angle which they reach the Earth. Also, with this muon network, we will be able to send alerts of up to 12 hours before the arrival of a shock or an ICME. The Space Weather forecast method using cosmic rays will be a very important tool because it provides a forecast with good antecedence.

Introduction

Around solar maximum, the dominant interplanetary phenomena causing Intense Magnetic Storms (Dst < -100 nT) are the interplanetary manifestations of fast Coronal Mass Ejections (ICMEs). The primary cause of magnetic storms is associated with interplanetary structures with intense (B_z ~ -10 nT) and long-duration (Δt ~ 3 h) southward magnetic fields (IMF) which interconnect with the Earth's magnetic field and allow Solar Wind energy transport into the Earth's magnetosphere (Dungey, 1961; Bothmer and Schwenn, 1995; Gonzalez et al., 1994). This is schematically shown in Figure 1.
Energetic cosmic rays observed in ground-level detectors are also subject to modulation effects due to interplanetary disturbances such as shocks and ejecta associated with CMEs (Lockwood, 1971; Cane, 1993). A solar disturbance propagating away from the sun affects the pre-existing population of galactic cosmic rays in a number of ways. Figure 2 displays the large-scale structure of a fast ejecta and its associated shock. The CME shields the passage of cosmic rays. Analysis of cosmic rays anisotropy ($\vec{B}\times\vec{\nabla}n$) with the IMF ($\vec{B}$) data measured by space probe yields the cosmic ray gradient vector ($\vec{\nabla}n$), which contains valuable information about the large-scale structure and geometry of the ICME (Bieber and Everson, 1998). Geomagnetic Storm forecast is made with an antecedence of ~1 hour in the case of in-situ solar wind observations obtained from satellites in the Lagrangean point L1, and from 8 to 12 hours using the muon detector network (Munakata et al. 2000). The study of the parameters of the Interplanetary Medium and cosmic rays are important tools for the study of the Space Weather.

Data and Methodology of Analysis

The present work has as objective to present an analysis of the solar event of November 7, 2004 and November 9, 2004, studying data from the Interplanetary Medium to identify the interplanetary structures responsible for this intense Geomagnetic storm, where the Dst index reached peak negative values of -383 nT and -296 nT, respectively. we compared the observations done by the satellites located in the Lagrangian point, L_1, and the decrease of the muons count rate by the Muon Detector Network.
The ring current Dst index was introduced in 1964 and it measures primarily the ring current magnetic field. It is based on hourly averages of the horizontal component recorded at four low-latitude observatories (Sugiura, 1964). Following the terminology of Sugiura and Chapman, great storms are those with peak Dst of -100 nT or less, moderate storms fall between -50 nT and -100 nT, and weak storms are those between -30 nT and -50 nT. All interplanetary and geomagnetic data were obtained via the internet, through the ISTP data services, Coordinated Data Analysis Web and WDC-C2, Kyoto.
Interplanetary magnetic field (B, B_x, B_y, B_z) and plasma (solar wind velocity, proton density, proton temperature) data used in this studywere observed by the ACE satellite (Advanced Composition Explorer), to analyze the cosmic ray response to these Geomagnetic Storms, cosmic rays observations from the Muon Detector Network (Munakata et al., 2000) were used. The objective is to show the characteristic of the decrease in the muon count rates related to the ICMEs that caused the Geomagnetic Storms of 7 and 9 November, 2004. This study will be important to help to understand the physical phenomena related to this aspect of the Space Weather.

Results and Discussion

In Figure 3 it is shown, from top to bottom, the Dst index and Count Rate of Muon Detector Network. Two severe Geomagnetic Storms were observed during the period. The first one reached – 373 nT and the second one -289 nT in the Dst index. The start of the first Geomagnetic Storm was in November 7th, 2004. One can see a gradual decrease in the Count Rate of the Robart Muon Detector of approximately 8%, starting before the shock arrival, while in the other detectors, decreases were observed after the shock, more abruptly, probably caused for a intense magnetic field of the magnetic cloud. In the second Geomagnetic Storm in November 9, 2004, one can see the biggest decrease in Nagoya Muon Detector, of about 18%, while in the other detectors less intense decreases were observed during the shock passage, probably caused for intense magnetic field of the magnetic cloud. Nevertheless the decrease observed in the Sao Martinho detector was about 4%. In Figure 4,,the parameters of interplanetary medium are shown, where one can identify the signature of the geomagnetic storm: B_z in south direction of -50 nT, in the first Geomagnetic Storm; and B_z equal – 30 nT in second Geomagnetic Storm.

Summary

In this work we studied the count rate decreases observed by the muon detector network during two November 2004 magnetic storms. These decreases probably occur due to intense magnetic field of magnetic cloud structures within the ICMEs, or within the turbulent magnetic field between the shock and the magnetic cloud, also known as sheath field. The Muon Detector Network covers nearly all meridians and is efficient for detecting different decrease responses in different logitudes in the count rate of the muons of high energy (~ 50 GeV). In the near future, the muon detector network will be a very important tool for Space Weather forecasting.

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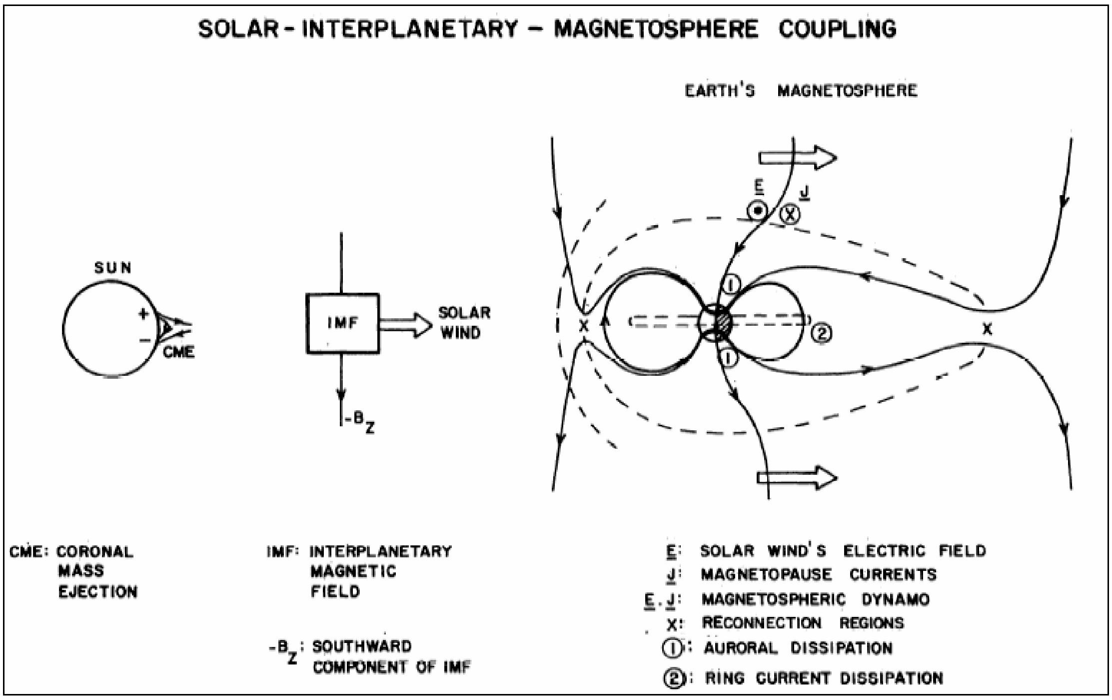

Figure 1 – Schematic of interplanetary-magnetosphere coupling, showing the reconnection process and energy injection into the nightside magnetosphere, which leads to the formation of the storm-time ring current (Gonzalez and Tsurutani, 1992).

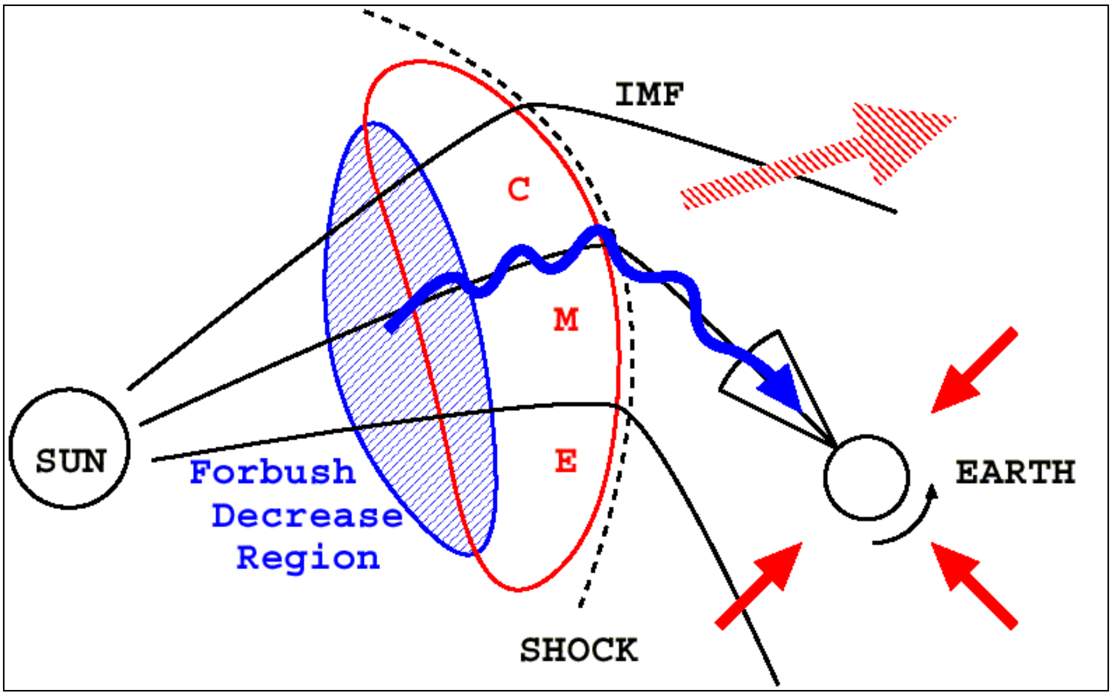

Figure 2 – Schematic figure illustrating the cosmic ray shielding effect (Ruffolo and Nagashima, 1999).

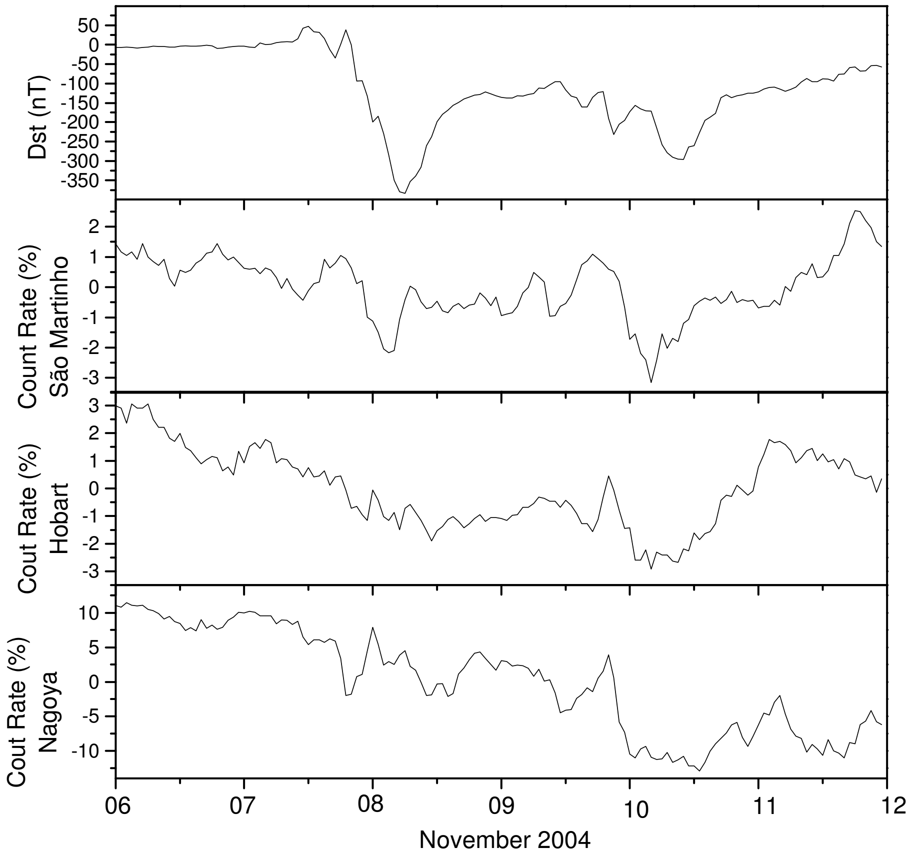

Figure 3 – Dst index and Count Rate of three Muon Detector Network stations: São Martinho da Serra, Hobart, and Nagoya.

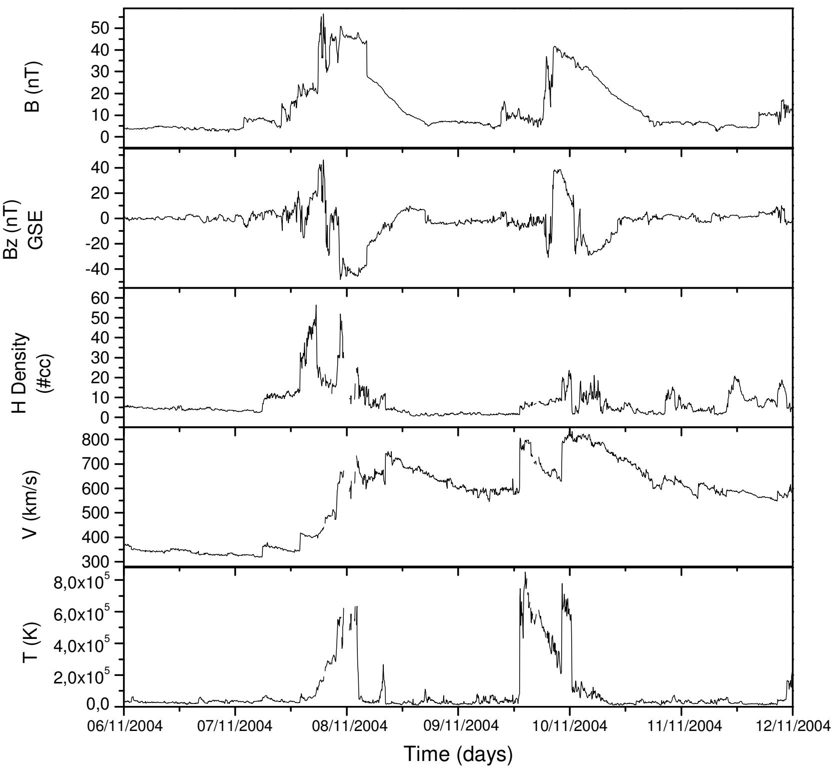

Figure 4 – Interplanetary magnetic field intensity and its Bz component, and plasma parameters observed by the ACE satellite from 6 to 12 of November 2004.