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FORBUSH DECREASES ON NOVEMBER 6-12, 2004 OBSERVED BY THE MUON DETECTOR NETWORK

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ABSTRACT. In this paper we study the relationship between Interplanetary Coronal Mass Ejections (ICMEs) and the muon count rate decreases detected of the Muon Detector Network on November 6-12, 2004. The Muon Detector Network is composed by the detectors installed at Nagoya (Japan), Hobart (Australia) and the prototype detector installed at the "Observatório Espacial do Sul – OES/CRSPE/INPE-MCT", located in São Martinho da Serra, RS, Brazil. With the muon 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 their angle of incidence on 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.

Keywords: interplanetary medium, cosmic rays, Muon Telescope, Forbush decreases, space weather, magnetic storms.

RESUMO. Neste artigo nós estudamos a relação entre as Ejeções Coronais de Massa Interplanetárias (ICMEs) e o decréscimo na contagem de muons observada pela Rede Internacional de Detectores de Muons no período de 6 a 12 de novembro de 2004. A Rede Internacional de Detectores de Muons é composta pelos detectores instalados em Nagoya (Japão), Hobart (Austrália) e o detector protótipo instalado no Observatório Espacial do Sul OES/CRSPE/INPE – MCT, situado em São Martinho da Serra, RS, Brasil. Com o decréscimo na contagem de muons observado pela Rede Internacional de Detectores de Muons podemos determinar a direção em que a ICME se move, e com isso, nós poderemos calcular o ângulo que elas chegam à Terra. Também, com esta rede de detectores de muons, poderemos dar um alerta de até 12 horas antes da chegada de um choque ou uma ICME. O método de previsão do Clima Espacial que usa raios cósmicos será uma ferramenta muito importante porque proporciona uma previsão com boa antecedência.

Palavras-chave: meio interplanetário, raios cósmicos, telescópio cintilador de Muons, decréscimo de "Forbush", clima espacial, tempestades geomagnéticas.

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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 ($B_z \sim -10$ nT) and long-duration ($\Delta t \sim 3$ h) interplanetary magnetic field (IMF) which interconnect with the Earth's magnetic field and allow solar wind energy transport into the Earth's magnetosphere (Dungey, 1961; Bothmer & 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. 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 & Everson, 1998). Geomagnetic storm forecast is made with an antecedence of $\sim$1 hour in the case of in-situ solar wind observations obtained from satellites in the Lagrangian point L_1, 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.

The aim of the present work is to present an analysis of the solar events 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 at the Lagrangian point, L_1, and the decrease of the muon count rate by the Muon Detector Network.

DATA AND METHODOLOGY

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 (1964) and Chapman (1962), great storms are those with Dst peak 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 study where observed by the ACE satellite (Advanced Composition Explorer). Cosmic ray observations from the Muon Detector Network (Munakata et al., 2000) were used to analyze the cosmic ray response to these geomagnetic storms. The objective of this analysis is to show the characteristic of the decrease in the muon count rates related to the ICMEs that caused the geomagnetic storms on November 7 and 9, 2004. This study will be important to help to understand the physical phenomena related to this aspect of the Space Weather.

RESULTS AND DISCUSSION

It is well known that energetic cosmic ray intensities are often subject to modulation effects due to interplanetary disturbances such as shocks and ejecta associated with CMEs (Lockwood, 1971; Cane, 1993). Depression of $>$1 GeV particles intensities, called Forbush decreases, observed by ground detectors, can be of the order of 1-10% downstream these shocks and within the ejecta (Munakata et al., 2000). The cosmic ray intensity is depleted in the region where the IMF magnitude is enhanced, inhibiting particles from entering from outside the region (Munakata, 2000).

Figure 2 shows, 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 on November 7, 2004. One can see a gradual decrease in the Count Rate of the Hobart Muon Detector of approximately 8%, starting before the shock arrival, while for the other detectors, decreases were observed after the shock, more abruptly, probably caused by an intense magnetic field of the magnetic cloud. In the second geomagnetic storm on November 9, 2004, one can see the biggest decrease in Nagoya Muon Detector, of about 18%, while for the other detectors less intense decreases were observed during the shock passage, probably caused by intense magnetic field of the magnetic cloud. Nevertheless the decrease observed in the São Martinho da Serra – Brazil detector was about 4%. The difference in the cosmic ray signals, and consequently in the decreases, observed by different ground detectors may be caused due the difference in the geomagnetic cutoff of the sites location.

In Figure 3, the parameters of interplanetary medium are

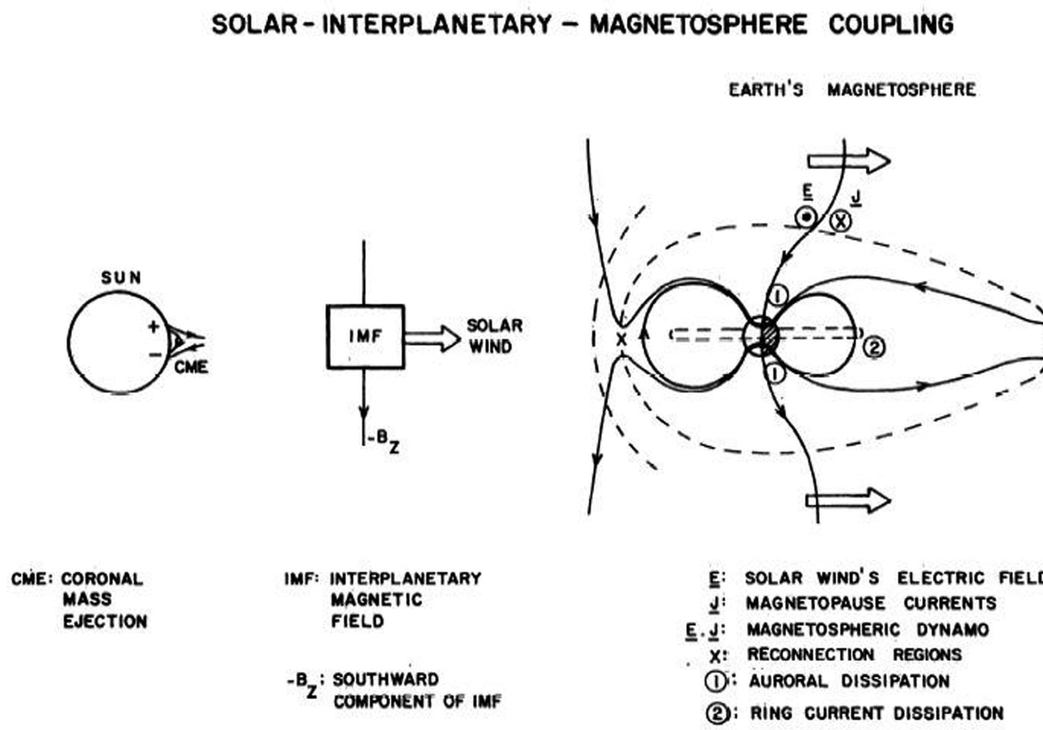

Figure 1 – Diagram of the interplanetary-magnetosphere coupling, showing the reconnection process and energy injection into the nightside magnetosphere, which leads to the formation of the storm-time ring current (Gonzalez & Tsurutani, 1992).

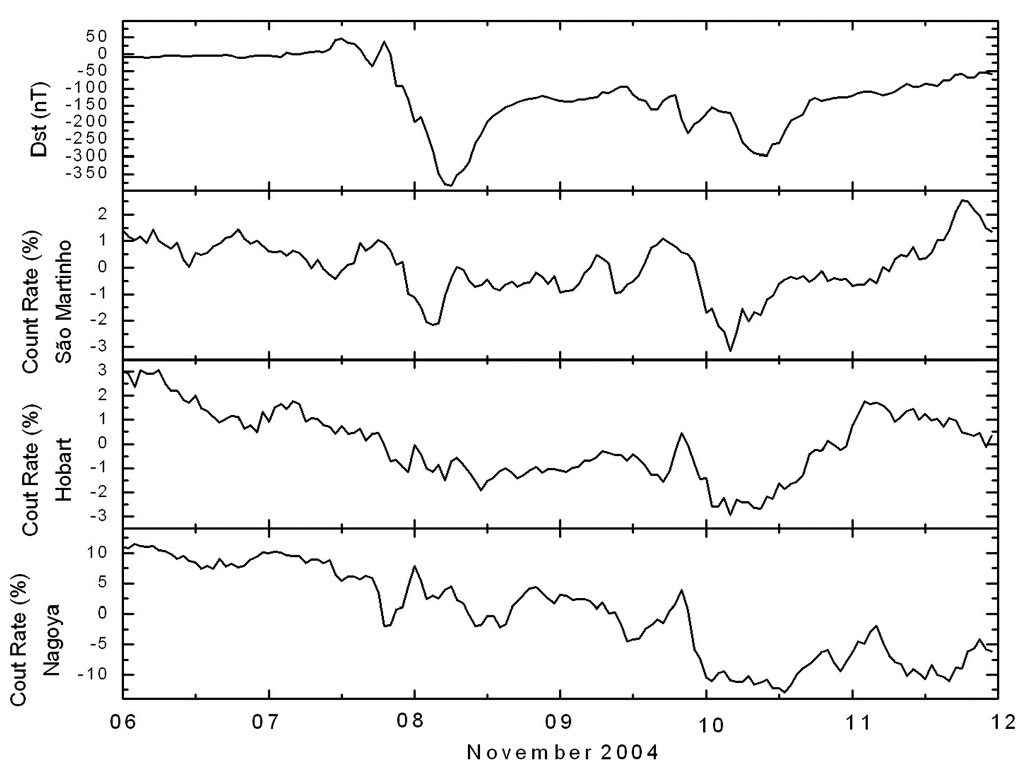

Figure 2 – Dst index and Count Rate of three Muon Detector Network stations: São Martinho da Serra, Hobart and Nagoya.

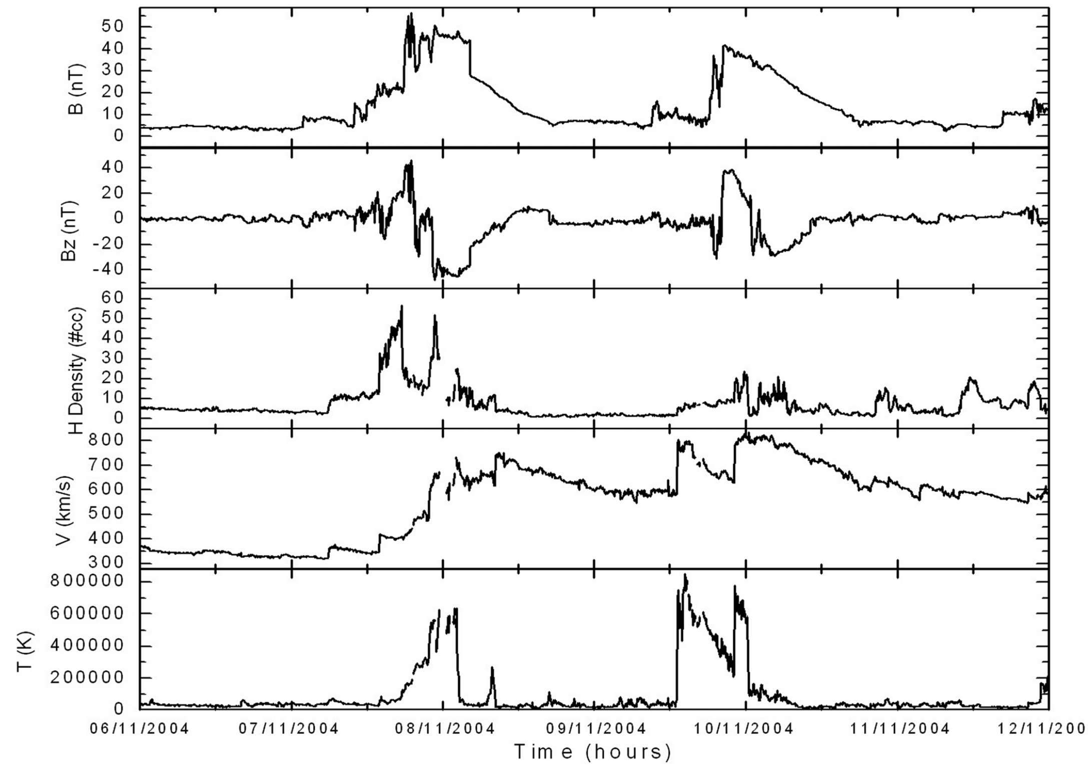

Figure 3 – Interplanetary magnetic field intensity and its B_z component, and plasma parameters observed by the ACE satellite from 6 to 12 November 2004.

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 of –30 nT in second geomagnetic storm.

SUMMARY

In this work we studied the count rate decreases observed by the Muon Detector Network during two magnetic storms in November 2004. 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 longitudes in the count rate of the muons of the high energy muons (∼50 GeV). In the near future, the Muon Detector Network will be a very important tool for Space Weather forecasting.

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