PROCEEDINGS OF SCIENCE

The Forbush Decreases of October 2003 as Measured by a Muon Detector at Mid-Latitude Site

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Forbush decreases (FD) are one of the most important cosmic ray time variations occurring during the active phases of the solar cycle. They are associated with geomagnetic storms caused by solar flares or coronal mass ejections.
On October 28, 2003 the Sun experienced one of its strongest activities during the 23rd solar cycle. The geomagnetic activity experienced by the Earth because of this activity caused a strong FD. Data from a KACST muon detector, Rc =14.4 GV, were analyzed to study the effect of this event on the cosmic ray counting rate. Interplanetary conditions causing this event were briefly discussed. The magnitudes of this FD from 27 cosmic ray stations were calculated and compared with KACST data.

The 34th International Cosmic Ray Conference
30 July- 6 August, 2015
The Hague, The Netherlands

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1. Introduction

During solar activity periods, extensive variations to the interplanetary magnetic field and heliospheric structure usually occur because of the geomagnetic storms produced by solar flares and/or coronal mass ejections (CME) [1-3]. As a result of these disturbances, cosmic ray intensities are reduced for short periods of time, causing what is known as a Forbush decrease (FD). FD decreases are defined as a sharp and sudden decrease in the cosmic ray count rate, reaching the maximum within one day and recovering to background level within five to ten days [1, 4-5]. This phenomenon is a global one and is considered as one of the most important cosmic ray time variations [2, 6]. The magnitude of FDs depends on several factors such as the strength of the magnetic field in the interplanetary space, the conditions of the magnetosphere, the physical properties of the solar flare and/or the CME, and the nature of the detection system and its cutoff rigidity [7-9].

On October 28, 2003 an X17 solar flare erupted in association with earthward-directed CME. The geomagnetic activity experienced by the Earth because of these events caused one of the strongest FD in the 23rd solar cycle [10-12]. The event caused considerable interest among the scientific community. In this paper data from a KACST muon detector during this FD are discussed and compared with data from 29 cosmic ray monitors with different cutoff rigidities.

2. Observational Data

Figure 1 shows the behavior of some of the interplanetary parameters recorded by GOES 10 for the month of October 2003[13].

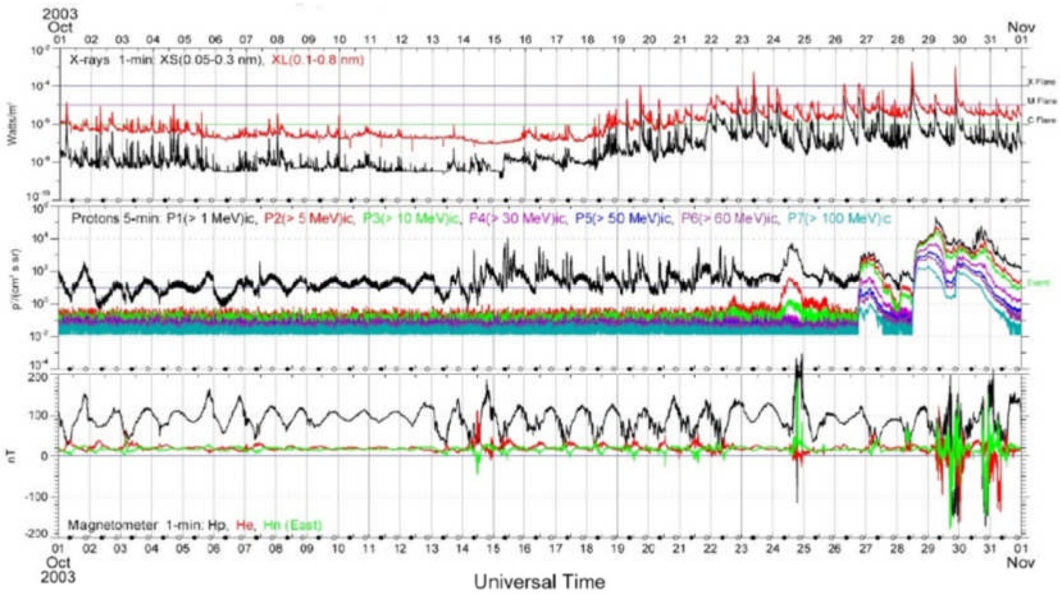

Figure 1: Sumurizes the behaviour of X-ray fluxes (top panel); proton intensities between 1 and 100 MeV (second panel); and magnetic field intensity. This figure obtained from http://www.ngdc.noaa.gov.

Cosmic ray measurements were obtained from a single channel muon detector installed at the King Abdulaziz City for Science and Technology (KACST), Riyadh, Saudi Arabia (24 43; 46 40; Rc =14.4 GV). It consisted of 4×250 mm^2 of plastic scintillator viewed by a photomultiplier tube (PMT) with a diameter of 120 mm. After amplifications, the outputs from the photomultiplier were digitized using an A/D converter linked to a PC card. Data were acquired every 15 minutes; corresponding atmospheric pressure and room temperature were also recorded. The detector has been in operation since July 2002, and more details of the detection system are given in [14-16].

3. Results

On 28 October, 2003 an X17 solar flare, the strongest recorded in the past 30 years, erupted in the NOAA10486 solar region. This flare began at 09:51 UT and had an X-ray peak at 11:10 (top panel Figure 1) [13]. At that time X-ray fluxes increased (both 0.05-0.3 nm bands and 0.1-0.8 bands) by a magnitude of six or seven in comparison with the background fluxes. Solar protons (second panel) between 1 and 100 MeV increased dramatically with the onset of the flare. Low to medium energy protons lasted longer and decreased slowly to their background level. Higher energy fluxes, on the other hand, increased more slowly and decayed faster to their normal level. This flare was accompanied by a CME traveling at approximately 2000 km/s and took about 19 hours to reach the Earth [17]. At 06:13 on October 29, the near Earth's magnetic field increased dramatically because of the effect of this CME (last panel, Figure 1), which caused a drop in the ground-based cosmic ray count rates.

Figure 2 shows the pressure-corrected cosmic ray muons [18] observed by the KACST detector for the period between October 23 and November 12, 2003. Daily variations of about 0.5 % with a maximum around 13 UT and minimum around 20 UT were observed prior to the occurrence of FD. An increase of 1 % was recorded at 08:00 on the 29th immediately before the FD. This unexplained increase was also reported by some monitors [8]. At 08:15, cosmic ray muon counts started to decline until they reached the maximum reduction around 20:15.

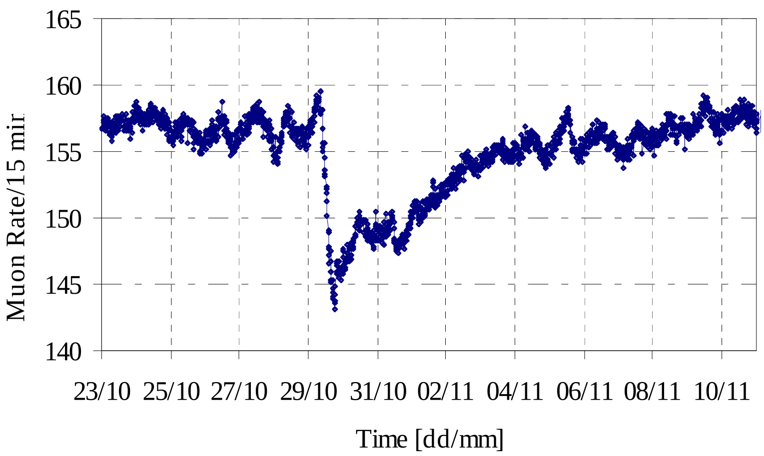

Figure 2: The 15-min cosmic ray muon rate recorded by the KACST detector for the period October 23 to November 12, 2003. The size of the ± 1σ error is smaller than the size of the cross plotted.

This 10-hour FD had a magnitude of about 8.51 %. This was calculated as follows: FD

(%) = 100 (N_o–N_F)/N_o, where N_o and N_F were the moun counts from the detector before the decrease and during the maximum depression of the cosmic ray rates respectively.
The slope of the FD, with a correlation coefficient of 0.98, showed a reduction in the cosmic ray muons by about 1.06 % per one hour. Cosmic ray intensities took 12 days to return to their normal rate. Another sign of the solar activity on October 28 in the KACST data was a sharp increase by about 1.3 % detected at 12:15; Figure 3.Ground level enhancement (GLE-65) was observed by several cosmic ray stations [9-11,17]. This GLE had a magnitude ranging from 10 % at the South Pole to about 0.1 % at Tsumeb, Namibia (lat.-19.5) [10]. Kane [19] reported the detection of this GLE by low-latitude stations. Because of its high cutoff rigidity, we could not be certain that the increase observed by the KACST detector was GLE-65.

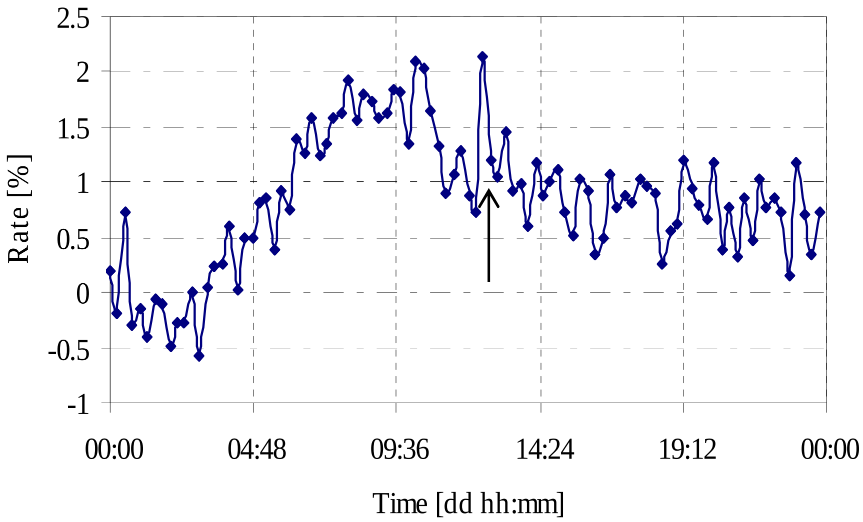

Figure 3: KACST cosmic ray muon rate for October 28, 2003. The arrow points to the plausible GLE.

To compare the response of the FD of October 29 with other cosmic ray detectors, data from 21 neutron monitors were obtained (from the Neutron Monitor Database, NMDB) and used to calculate the magnitude of the FD [20]. Data from the Adelaide muon detector (which was similar to our detector) were also obtained from the detector's website [21]. Furthermore, the magnitude of this FD for Karlsruhe (MT), Nagoya V, and GRAND (MT) muon detectors was obtained from [8][9][19] respectively. Table (1) presents the stations, their rigidities, and the amplitude of the FD. Neutron monitors reported a reduction in their count rates between 24 % for Terre Adelie (TERA), a high-latitude station, and 17 % for low-latitude stations in Italy, Greece and Israel.

On the other hand, muon telescopes showed a reduction in the count rate range between 8.6 and 11 %. The differences in the magnitude between the muon and neutron detectors are owed to the cutoff rigidity of the station and the physical mechanism that produces neutrons and muons. The KACST detector and GRAND telescope showed almost the same reduction, although the latter had lower rigidity. Moreover, KACST and Adelaide detectors employ the same detection system but vary greatly in their magnitude.

Station	Rate	Rc	Station	Rate	Rc
Rome, (ROME)	17.4	6.32	Dourbes, (DRBS)	21.9	4.6
Athens , (ATHN)	16.9	8.53	Newark (NEWK)	21.4	2.4
Kiel, (KIEL,)	21.4	2.36	MAGADAN (MGDN)	20.8	2.09
Oulu, (OULU)	22.4	0.81	Kerguelen (KERG)	22.2	1.14
MOSCOW (MOSC)	22.3	2.34	Inuvik (INVK)	20.8	0.3
APATITY (APTY)	22.4	0.65	McMurdo (MCMU)	22.8	0.3
Climax (CLMX)	21.1	1.09	Peawanuck (PWNK)	21.2	0.3
Adelaide (MT)	9.9	4.2	Thule (THUL)	21.3	0.3
Karlsruhe (MT)	11.3	3.8	Terre Adelie (TERA)	24.4	0
Jungfraujoch	23.2	4.5	ESOI-TAU, (ESOI)	17.3	10.75
Nagoya V	10.0	11.5	Almaty, (AATB)	21.2	6.69
GRAND (MT)	8.0	7.1	Lomnicky stit, (LMKS)	23.6	3.8
KACST (MT)	8.6	14.4	AKUTSK (YKTK)	19.7	1.65
TIXIE (TXBY)	21.1	0.43	Fort Smith (FSMT)	22.1	0.3

Table (1) Amplitude of 29th FD obtained by stations with different rigidities, Rc. Stations in bold are muon detectors.

Figure 4 shows the relationship between the cutoff rigidity and the magnitude of the FD of October 29, 2003. It is noticeable that the magnitude of the decrease is anti-correlated with the rigidity. Also, KACST muon data extend the rigidity range to higher values which can be used to complement other cosmic ray stations located at lower rigidities.

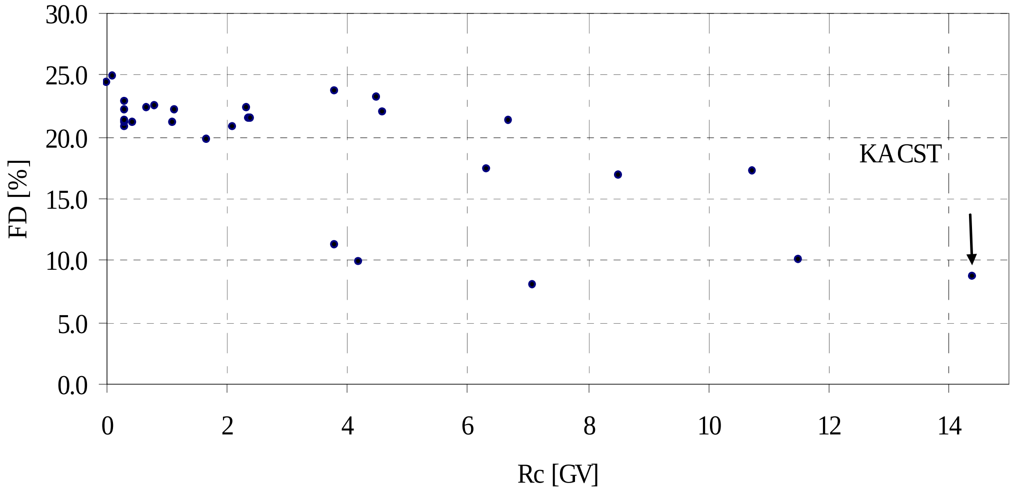

Figure (4) Dependence of the FD of October 29 on the rigidity of Rc. The arrow points to KACST data.

4. Conclusion

In this study, the FD of October 29, 2003 was studied using data from the KACST muon detector. The 10-hour decrease had a magnitude of 8.6 %. Interplanetary conditions causing this event were briefly discussed. The magnitudes of this FD from 27 cosmic ray stations were calculated and compared with KACST data. A 1.3 % increase in the muon rate was detected by the KACST detector at 12:15 on October 28, 2003. This coincides with the occurrence of the GLE-65 as reported by several investigators. However, we cannot guarantee that this increase is the KACST's response to the GLE-65.

Acknowledgments

The authors would like to thank King Abdulaziz City for Science and Technology (KACST) for supporting this work. The NMDB and High Energy Astrophysics group at the University of Adelaide Australia researchers and administration are highly acknowledged for making the neutron monitors and muon detector data available.

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