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Space storm measurements of the July 2005 solar extreme events from the low corona to the Earth

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Abstract

The Athens Neutron Monitor Data Processing (ANMODAP) Center recorded an unusual Forbush decrease with a sharp enhancement of cosmic ray intensity right after the main phase of the Forbush decrease on 16 July 2005, followed by a second decrease within less than 12 h. This exceptional event is neither a ground level enhancement nor a geomagnetic effect in cosmic rays. It rather appears as the effect of a special structure of interplanetary disturbances originating from a group of coronal mass ejections (CMEs) in the 13–14 July 2005 period. The initiation of the CMEs was accompanied by type IV radio bursts and intense solar flares (SFs) on the west solar limb (AR 786); this group of energetic phenomena appears under the label of *Solar Extreme Events of July 2005*. We study the characteristics of these events using combined data from Earth (the ARTEMIS IV radioheliograph, the Athens Neutron Monitor (ANMODAP)), space (WIND/WAVES) and data archives. We propose an interpretation of the unusual Forbush profile in terms of a magnetic structure and a succession of interplanetary shocks interacting with the magnetosphere.

Keywords: Coronal mass ejections; Flares; Activity; X-rays; Cosmic rays; Forbush decreases

1. Introduction

Space weather drivers, such as coronal mass ejections (CMEs), energetic particles and MHD shocks are mostly of solar origin; these modulate the flux of galactic cosmic rays in the form of Forbush decreases.

Solar radio bursts, on the other hand, provide an extremely efficient diagnostic of the drivers onset in the corona. The type II bursts are MHD shocks; a subset of them is driven by CME and manifests the coronal origin of interplanetary shocks. The type IV continua originate from energetic electrons trapped within plasmoids, magnetic structures or substructures of CMEs (Bastian et al., 2001); those often indicate mass ejection and propagation in the low corona. Lastly, the type III bursts trace the propagation of energetic electrons through the corona and, often, mark the onset of energy release processes.

A group of energetic solar phenomena were observed on the Sun in active region 786 (N10° W90°) on 13–14 July 2005. The associated magnetospheric response affected cosmic ray (Neutron Monitor) measurements and space weather from 16 to 18 July, marking this activity as the *extreme events of July 2005*. On the 16 July, in particular, a sharp decrease in cosmic ray count rate was recorded yet right after the minimum an enhancement followed, distorting the typical profile of a Forbush decrease. The peculiarity of this event and the conditions under which it originated are examined.

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2. Observational data and analysis

2.1. Data sets

The data sources used in our analysis were:

- The Artemis–IV[1] (Caroubalos et al., 2001 also Kontogeorgos et al., 2006, 2008) radiospectrograph at Thermopylae (http://www.cc.uoa.gr/~artemis/); it covers the frequency range from 650 to 20 MHz with time resolution of 0.1 s.
- The WIND/WAVES receivers (Bougeret et al., 1995) in the range 20 kHz–14 MHz, complement the spectral range of ARTEMIS–IV; the combined observations are used in the study of the continuation of solar bursts in the interplanetary space bridging thus the gap between space borne and ground-based radio observations.
- CME data from the LASCO lists on line (http://cdaw.gsfc.nasa.gov/CME_list, Yashiro et al., 2004).
- The Nançay Radio heliograph (Kerdraon and Delouis, 1997) for positional information of radio emission.
- SXR (GOES) on line records (http//www.sel.noaa.gov/ftpmenu/indices).
- The Neutron Monitor Station of Athens University (Mavromichalaki et al., 2001) and the corresponding data analysis center (http://cosray.phys.uoa.gr, Mavromichalaki et al., 2005).
- Solar wind parameters from the OMNI (http://omniweb.gsfc.nasa.gov/) online database.

2.2. Solar activity observations

All solar energetic phenomena studied originated in AR 786 (N10° W90°).

The solar activity on the 13 July 2005 starts at 14:01 UT with an M5.0 long duration SXR flare ending at 15:38 UT. A fast halo CME, with speed 1430 km/s takes off at 14:12 UT. From the ARTEMIS/WIND recordings we establish that a type IV burst (14:01–14:30 UT) overlaps in time with the flare onset and the estimated CME lift-off (cf. Fig. 1); from the Nançay Radio heliograph images the position of the continuum appears over AR 786.

The active phenomena of the 14 July 2005 commence with an M9.1 (05:57–07:43 UT) flare followed by an X1.2 (10:16–11:29 UT). The former is associated with type III groups and the lift-off of three slow CMEs, with estimated take off at 05:32 UT, 06:01 UT and 07:02 UT and corresponding speeds 514, 573 and 758 km/s; a sharp SXR peak associated with a group of type III bursts and an SF Hα flare (reported by LEARMONTH) appears at about 07:59–08:12 UT although is not included in the GOES SXR flare lists.

All CMEs start with almost the same position angle (252–282°) and with increasing width (14°, 60°, 103°); those appear as successive ejections from AR 786 which eventually merge as the faster overtake the slower. This activity is accompanied by a faint continuum from 06:00 UT to 06:30 UT in the 500–100 MHz range. The X1.2 flare is associated with a fast CME (2108 km/s) which takes off at 10:27 UT overtaking the three slow CMEs at about 12:20 UT. It is also accompanied by type III bursts and a type IV continuum (10:20–12:20 UT).

In Fig. 2 an overview of the active phenomena of the 14 July 2005 is presented.

2.3. Solar wind parameters analysis – effects on cosmic ray modulation

A large Forbush decrease (9% – at south polar stations) and sharp changes of the anisotropy occurred on 16–17 July 2005; these more or less coincide with medium level disturbances in the interplanetary space (Fig. 3) which, in turn, correspond to weak interplanetary shocks without coronal counterparts.

The shocks were recorded in the OMNI data base (July 16, 02:35 UT, 17:06 and July 17 01:41 UT) and appeared at the near-Earth space 2–2.5 days after the fast CME onsets of the 13–14 July, therefore they are expected to be driven by them; we note that their time difference is about 23 h while the interval between successive fast CMEs was about 20. The passage of each interplanetary shock was marked by an increase in magnetic field strength (5.8–8.0 nT, 5.2–8.0 nT and 5.6–9.3 nT, respectively), an increase in proton density (6.7–11.10 cm^{-3}, 6.7–13.7 cm^{-3} and 6.7–11.10 cm^{-3}) and temperature (48,000–63,000 K and subsequently to 165,000 K). The variation in the solar wind speed shows rather small changes (Fig. 3), implying that only a small part of the mass ejection interacted with the Earth's magnetosphere as the CME was launched from the limb. The shock speeds were computed at the Earth's orbit from $v := (n_2v_2 - n_1v_1)/(n_2 - n_1)$, where n_1, v_1 and n_2, v_2 the upstream and downstream plasma density and velocity, respectively, and v the shock velocity. The calculated speeds were found to be 509, 434 and 557 km/s exceeding the solar wind speed values reported in OMNI data base which were 420, 411, 483 km/s respectively.

The direction of B as reported in the OMNI data base is found to be south ($Bz < 0$) for the first and in part the third IP shock; this is consistent with a small variation of the geomagnetic field (Kp index) and a double sub storm of −60 and −76 nT (Dst index) which were also recorded in the same data set. This event cannot be classified as strong; were this the case the Dst index should be lower than −100 nT (Loewe and Prolss, 1997) resulting in a strong geomagnetic storm according to the NOAA Space Weather Scales (http://www.swpc.noaa.gov/NOAAscales/).

An intensive Forbush decrease of cosmic rays, recorded on the 16th of July, was observed by the majority of the neutron monitors worldwide. After the main phase of the

[1] Appareil de Routine pour le Traitement et l' Enregistrement Magnetique de l' Information Spectral.