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

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Abstract **– A study of the abnormal features observed during solar extreme events of July 2005 is being presented. Recordings from a number of earthbound receivers (such as the ARTEMIS IV radioheliograph, the Athens Neutron Monitors Data Processing (ANMODAP)Center), space experiments (WIND/WAVES mission)as well as data archives provided new insight, as all solar events and their resulting cosmic ray variation were traced from their sources to the Earth. Time sequence of the events indicated that the initiation of coronal mass ejections (CMEs) were accompanied by type IV radio bursts and intense solar flares (SFs), their effects extended from the low corona to the face of the Earth. As a result, the Athens Neutron Monitor Data Processing (ANMODAP) Center recorded an unusual Forbush decrease with a sharp enhancement of cosmic ray intensity appearing right after the main phase of the Forbush decrease on 16 July 2005, only to be followed by a second decrease within less than 12 hours. This peculiar 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 CMEs in the 13-14 July 2005 period.**

Key Words**—Sun: Coronal Mass Ejections, Sun: Flares, Sun: Activity, Sun: X-Rays Cosmic Rays Forbush decreases**

I. INTRODUCTION

Space weather drivers, such as MHD shocks, CMEs and energetic particles are mostly of Solar origin; these modulate the isotropic flux of galactic cosmic rays in the form of Forbush decreases. In the study of the magnetospheric response to energetic phenomena on the Sun, solar radio bursts offer an extremely efficient diagnostic of the drivers onset in the corona. The type II bursts are the coronal counterparts of the interplanetary MHD shocks; a certain subset of them, the CME driven, manifests the coronal origin of an interplanetary shock. The type IV continua on the other hand 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 manifest the propagation of energetic electrons through the corona and, often, mark the onset of energy release processes.

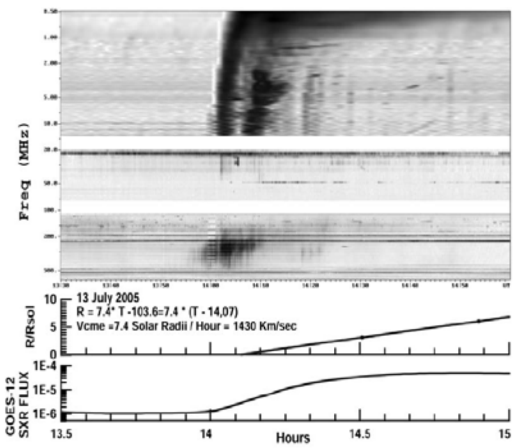

Fig. 1. Top: Composite ARTEMIS–IV/WIND Dynamic Spectrum of the 13 July 2005 Event: A type IV continuum appears from 14:01–14:30 UT while a number of type III electron beams originating in the low corona extends to theWIND/WAVES spectrum. Second Panel: Height Time plot of the CME (The least squares line underlines the CME takeoff at 14:04 UT (14.07) and the plane of the sky speed of 1440Km/sec (7.4 *Rsol*/hour)). Bottom: The corresponding GOES SXR light curve.

In this report, we study, the energetic solar phenomena observed at the Sun in active region 786 (N10*o* W90*o*) on 13-14 July 2005. Their effects are traced at Earths orbit on 16-18 July through neutron monitor measurements. The associated magnetospheric response affected cosmic ray measurements and space weather, marking this activity as the extreme events of July 2005.

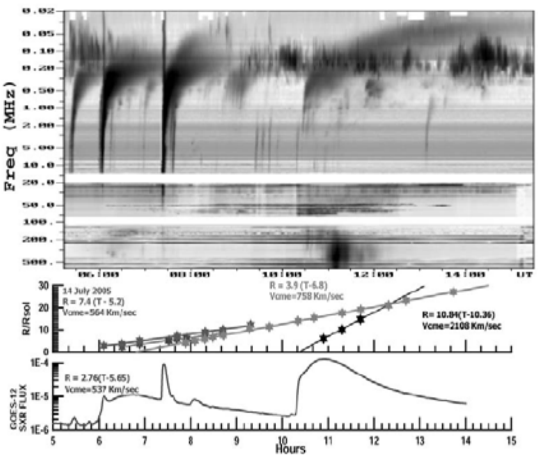

Fig. 2. Top: Composite ARTEMIS–IV/WIND Dynamic Spectrum of the 14 July 2005 Event: Groups of type III bursts extending into the WAVES range; a faint continuum at 06:00–06:30 and a type IV burst at 10:20–12:20 UT (Linear least square fit as in figure 1). Middle: Height Time plot of the fast CME overtaking the slow ones. Bottom: The corresponding GOES SXR light curve.

II. OBSERVATIONAL RESULTS & ANALYSIS

2.1 Data

The data sourses used in our analysis were taken from:

• The Artemis–IV [1] (Caroubalos et al. (2001) also Kontogeorgos et al. (2006)) solar radio–spectrograph 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.

• TheWIND/WAVES receivers (Bougeret et al. (1995)) in the range 14 MHz–20 kHz, complement the 650–20 MHz 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 NańEcay Radio heliograph (Kerdraon and Delouis (1997)) for positional information of radio emission.

• SXR (GOES) light curves and 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.

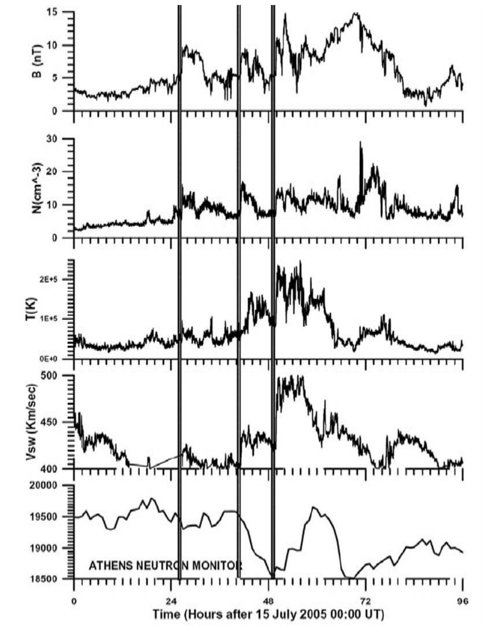

Fig. 3. Solar wind parameters from the OMNI data base; From Top to Bottom: Total magnetic field strength, proton density, proton temperature and Solar Wind Speed. Three weak shocks are marked, where the magnetic field increases (5.8 to 8.0 nT, 5.2 to 8.0 nT and 5.6 to 9.3 respectively); proton density and temperature increase also but the solar wind speed shows rather small changes. Bottom Panel: The Athens Neutron Monitor Recordings of an irregular Forbush decrease, interrupted by a sudden enhancement.

2.2 Solar Activity Observations

Solar activity on the 13 July 2005 starts at 14:01 UT with an M5.0 long duration SXR flare in AR 786 on the west limb (N10*o* W90*o*) which ends at 15:38 UT. A fast halo CME, with speed 1430 km/sec 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; from the NańEcay Radio heliograph images the position of the continuum appears over AR 786. In figure 1 we present a composite ARTEMIS–IV/WIND Dynamic Spectrum combined with the height – time plot of the CME and the associated SXR flare light curve. The active phenomena of the 14 July 2005 originate in AR 786; they 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 & 758 Km/sec; a sharp SXR peak associated with a group of type III and an SF H*α* flare (Lear) appears at about 7:59–8:12 UT although is not included in the GOES SXR flare lists. All CMEs start with almost the same position angle (252*o*–282*o*) and with increasing width (14*o*, 60*o*, 103*o*); 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 06:00–06:30 UT in the 500–100 MHz range. The latter flare is associated with a fast CME (2108 Km/sec) 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 figure 2 we present a composite ARTEMIS–IV/WIND Dynamic Spectrum combined with the height – time plot of the CME and the associated SXR flare light curve.

2.3 Solar Wind Parameters Analysis - Effects on Cosmic Ray Modulation

A large Forbush decrease (8% - at 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 (cf. Figure 3). The disturbances correspond to weak interplanetary shocks without coronal counterparts; these shocks were recorded in the OMNI data base (July 16, 02:35 UT, 17:06 & 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 hours while the interval between successive fast CMEs was about 20. The passage of the interplanetary shock was marked by an increase in magnetic field strength (5.8 to 8.0 nT, 5.2 to 8.0 nT and 5.6 to 9.3 respectively), an increase in proton density (6.7 to 11.10 cm^{-3}, 6.7 to 13.7 cm^{-3} & 6.7 to 11.10 cm^{-3}) and temperature (47800 K to 63100K and subsequently to 165300 K). The variation in the solar wind speed shows rather small changes (cf. Figure 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:=(n2v2-n1v1)/(n2-n2), where n1, v1 and n2, v2 the upstream and downstream plasma density and velocity respectively and v the shock velocity, (cf. for example Burlaga (1995)). The calculated speeds were found to be 509, 434 and 557 Km/sec exceeding the solar wind speed values reported in OMNI data base which were 420, 411, 483 Km/sec 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. An intensive Forbush decrease of cosmic rays, recorded on the 16th of July, was observed by the majority of the neutron monitors worldwide (cf. Figure 4).

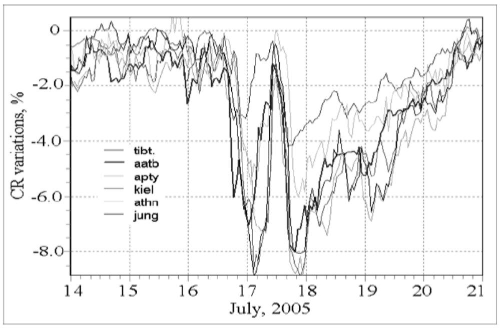

Fig. 4. Cosmic ray variations from 14-18 July 2005 from various stations at diffeent cut-off rigidities: Aatb- Alma-Ata, Apty- Apatity, Athn- Athens, Jung- Jungfraujoch, Kiel- Kiel, Tibt- Tibet.

Right after the main phase of the FD at the 17th of July, a sharp enhancement of cosmic ray intensity occurred and was followed by a second decrease, within 8 hours (cf. Figure3, bottom panel). The peculiarity of this event is due to the fact that it does neither comprise a ground level enhancement of solar cosmic rays nor a geomagnetic effect in galactic cosmic rays due to the fact that this was the result of solar modulation of galactic cosmic rays, which were recorded under quiet geomagnetic conditions. In order to concider such event as a strong geomagnetic one the Dst index should be lower then - 100 nT (Loewe and Prolss (1997)), which would resulted into a strong geomagnetic storm (http://www.swpc.noaa.gov/NOAAscales/). The recorded data on Kp and Dst showed that this was not the case for the event under consideration. Nevertheless, the event was also characterized by unusually high anisotropy of cosmic rays (7-8 %) especially of the equatorial component, with a direction to the western source (Mavromichalaki et al. (2007)). It seems that the sequence of the CMEs and the corresponding interplanetary shocks have produced the above cosmic ray decrease with the two distinct deep minima; the time between them is approximately 20 hours, as is the time interval between successive interplanetary shocks, and between the fast CME lift–of on the 13 & 14 July respectively. Moreover, this cosmic ray enhancement can not be considered as a Rogue event (Kallenrode and Cliver (2001)) due to the fact that this was the result of galactic cosmic ray modulation and not solar cosmic ray manifestesion.

III. DISCUSSION & CONCLUSIONS

In this report the Solar Extreme Events on the 13 and 14 July 2005 and the associated Forbush decrease has been studied. The observed time sequence of events of this time period indicates that the initiation of CMEs is closely related to the appearance of type IV radio bursts and strong solar flares. Their effects were traced from the base of the solar corona to the near Earth vicinity; they included complex radio bursts and variations in cosmic ray fluxes and space weather. Three interplanetary shocks were observed about 48 hours from the CMEs take off; their time intervals in both cases were similar (about 20 hours) yet they were not accompanied by significant change of the solar wind parameters, the solar wind speed in particular, probably due to the origin of the CMEs on the west limb. A sub storm (Dst double minima of -60 and -76 nT) and a Forbush decrease (double minima with a time interval of 20 hours between then) were recorded; minima is almost the same with the time distance between the IP shocks. It is not unprobable to propose that a closed magnetic structure, of which the Earth felt only a minor part, travelled through interplanetary medium and resulted into this abnormal cosmic ray events that were recorded at this time. It seems that the Earth was influenced by the first shock which resulted to the FD on the 16th-17th of July. Right after the minimum of the decrease, the Earth got outside the closed magnetic structure and thus galactic cosmic rays could register by ground based detectors. On the same day (17th of July), the third shock resulted in the second part of this irregular FD.

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