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Solar activity and Forbush decreases in June 2015

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Abstract: Although the descending phase of the current solar cycle 24 is characterized by low solar activity, a number of intense CMEs and SEPs were recorded in June 2015 leading to two complicated Forbush decreases of the cosmic ray intensity. These decreases were clearly recorded by the ground based neutron monitors of the world wide network. The first one started on June 22 with an amplitude of 8.4% and during its recovery, on June 24, a second one followed with an amplitude of 5.2% at the polar stations. One of the main goals of the present work is to examine the connection between the observable FDs on Earth and the activity on the Sun in the same period. This process requires an analysis of the characteristics of the CMEs such as their size, their proximity to Earth and their magnetic field. Furthermore, hourly cosmic ray intensity data recorded from polar and middle latitude neutron monitor stations around the Earth and obtained from the High Resolution Neutron Monitor Database (NMDB) were used to investigate the rigidity dependence of these events. Interesting results regarding the solar and interplanetary parameters are discussed.

Introduction: Some worth mentioning solar events, such as flares and CMEs, were recorded at the declining phase of the solar cycle 24 between 18/06/15 and 25/06/15. These events were produced at the active region 12371 (Fig. 1) which was the most energetic of the total four active regions at that period. As it is commonly believed, these solar events influence cosmic rays in a dynamic way and can be separated in three basic types; those caused by a shock and ejecta (see Fig. 2), those caused by a shock only and those caused by an ejecta only [1]. An interesting observation of the present event is the unusual form of the Forbush Decrease (FD) [2] since a double FD is observed in less than three days.

Solar Events

Between 18/06 and 22/06 of June 2015, several CMEs were ejected from the Sun disturbing the geomagnetic space. Four of them were of most importance as they were propagating directly towards the Earth ("Halo" CMEs, Table 1). Their linear velocities varied between 584 km/s to 1366 km/s, while all of them were accompanied by a C- or M- class solar flare originating from the active region 12371 (Fig. 1).

The structure of a fast ejecta and the associated shock of a CME is presented on Fig. 2. The upstream solar wind is draped around the ejecta and heated and compressed at the front of the ejecta. Two paths through the ensemble are indicated with differing resultant cosmic ray profiles. The time of shock passage is indicated by a vertical line marked S and the start and end times of ejecta passage are marked T1 and T2. Only if the ejecta is intercepted is a two-step decrease is observed [1]. Based on this schematic, we will try to locate the shock arrival time (and ejecta, if it is possible) of the four CMEs on the CR intensity plots on Fig. 4.

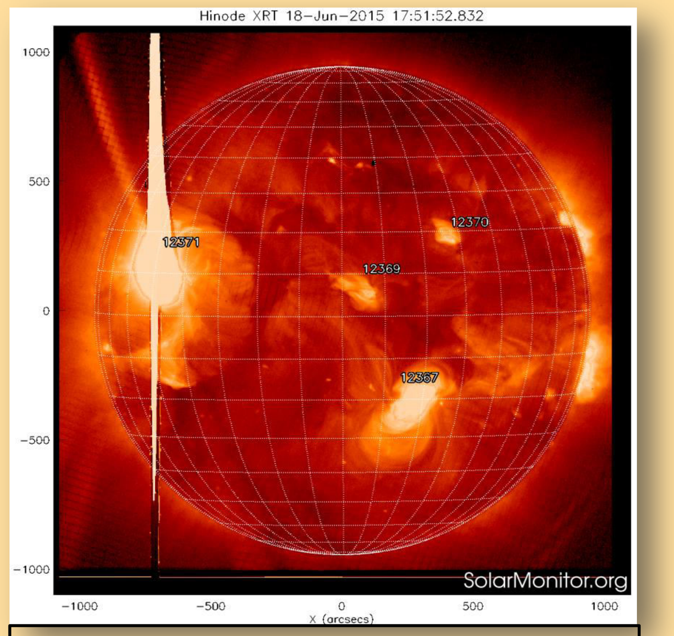


Fig. 1: The active region 12371 that created the event of June 2015 (credit: solarmonitor.org).

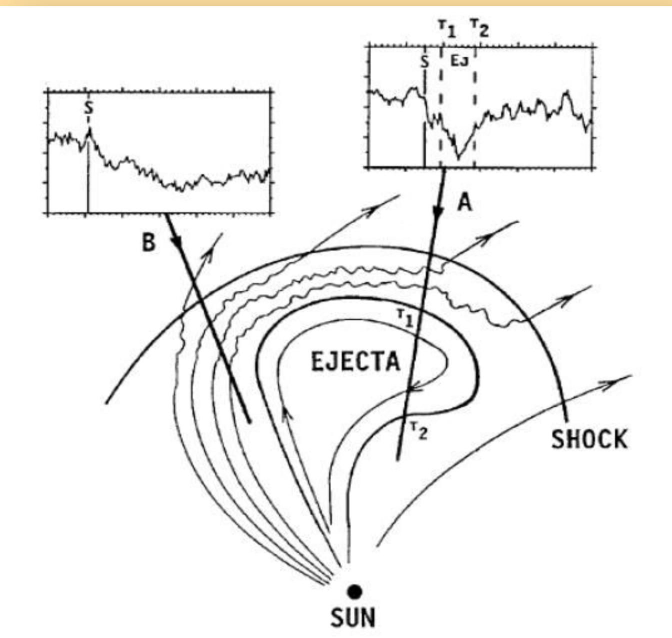


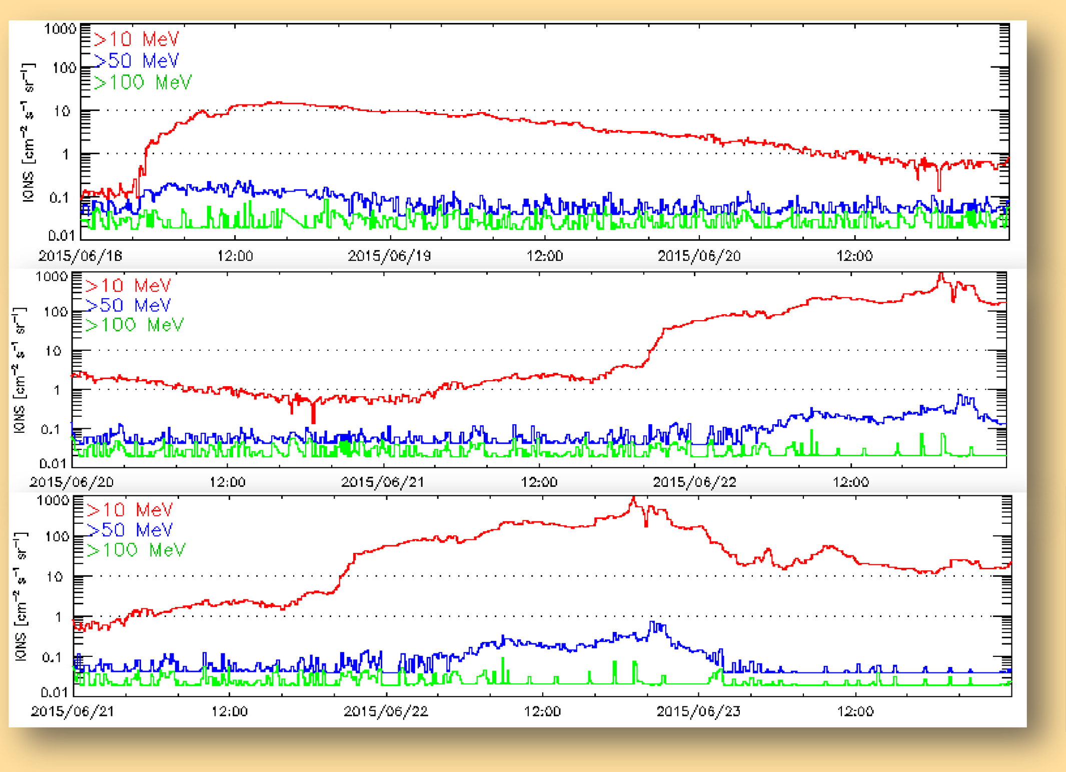
Fig. 2: The large-scale structure of a fast ejecta and associated shock.

CME#	Start date	Start time	Arrival date	Arrival time	Type	Lin. Speed (km/s)	Flare	Flare Coord.
CME 1	18/06/15	01:25	N/A	N/A	Part. Halo	1714	M1.2	N/A
CME 2	18/06/15	17:24	21/06/15	15:40	Halo	1305	C3.5	N12E47
CME 3	19/06/15	06:42	22/06/15	04:51	Halo	584	N/A	N/A
CME 4	21/06/15	02:36/02:48	22/06/15	17:59	Halo	1366	M2.7	N12E16
CME 5	22/06/15	18:36	24/06/15	12.57	Halo	1209	M6.5	N12W08
CME 6	25/06/15	08:36	27/06/15	03:30	Halo	1627	M7.9	N09W42
CME 7	26/06/15	13.25	N/A	N/A	Part. Halo	563	N/A	N/A

Table 1: Characteristics of the CMEs ejected between 18/06/15 and 26/06/15 with the type and the coordinates of the associated flares from the active region 12371 (credit:ftp.ngdc.noaa.gov/STP/space-weather/solar-data/ and cdaw.gsfc.nasa.gov/CME_list).

SEPs

At the same period, the flux of the solar energetic particles (SEPs) was increased due to the solar eruptions (Fig. 3).



SEPs can derive either from a solar flare or from the shock-wave driven by a CME [3]. In our case, we believe that the two ion increases recorded on 18/06/15 and late on 21/06/15 are mostly due to the existed flares because no CME has arrived on Earth around these specific hours. Nevertheless, it seems to be a contribution due to the shock-waves after the 22/06.

Fig. 3: The proton flux from 18/06/15 to 24/06/15 as recorded by SOHO/LASCO. The >50 MeV proton flux component is clearly increasing especially after 22/06/15, when the magnetosphere was hit by the CME 2 and 3 within a time window of 12 h.

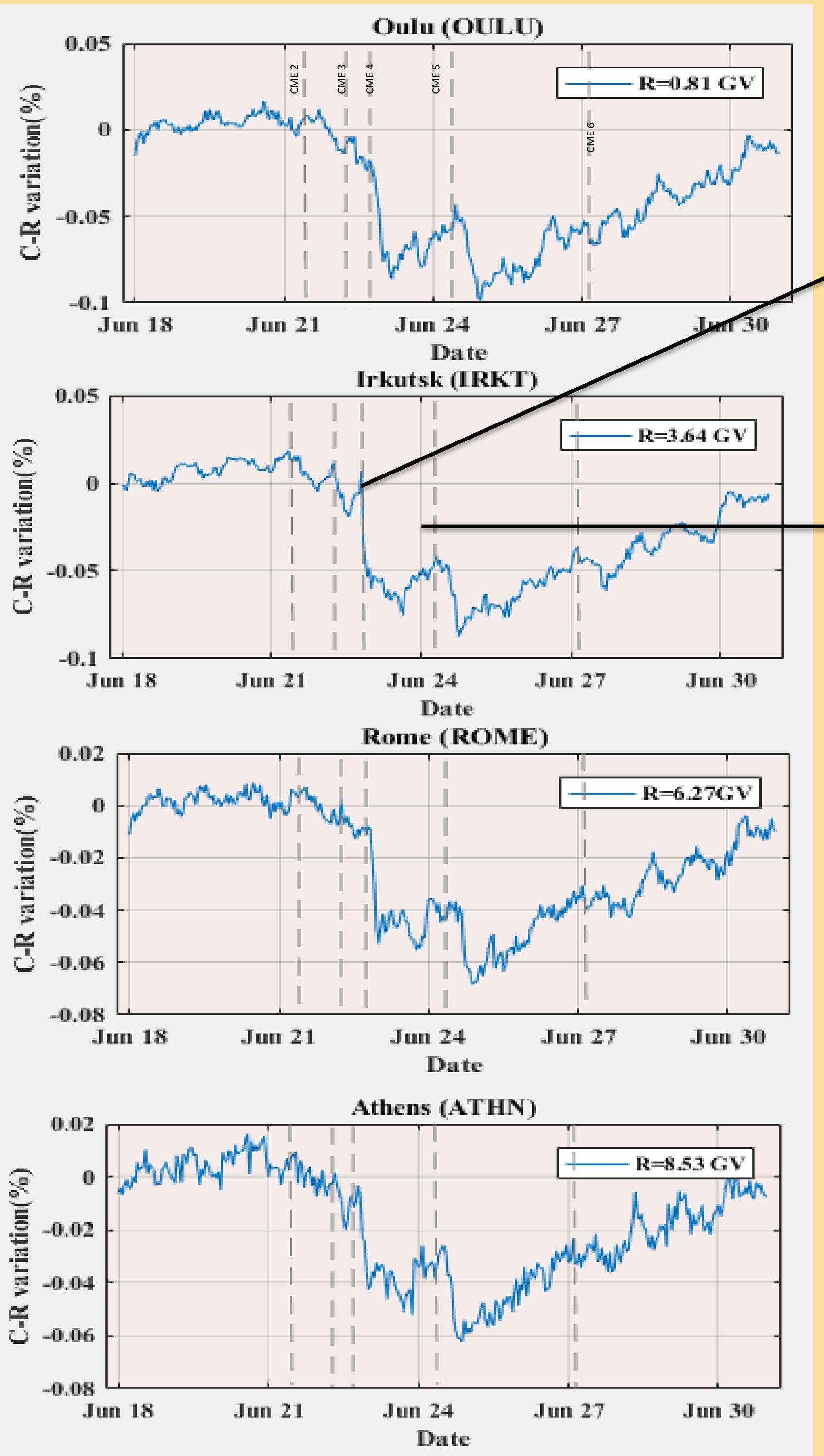


Fig. 4: The behavior of the CR intensity as recorded from the neutron monitors of Oulu, Irkutsk, Rome and Athens.

During a FD we expect a decrease of the CR intensity with amplitude inversely proportional to the rigidity related to the location of the cosmic ray station. Setting zero amplitude as the point of reference we have an exponential fit of the above relation. The second FD is depending on the preceding decrease setting the latter as a reference point.

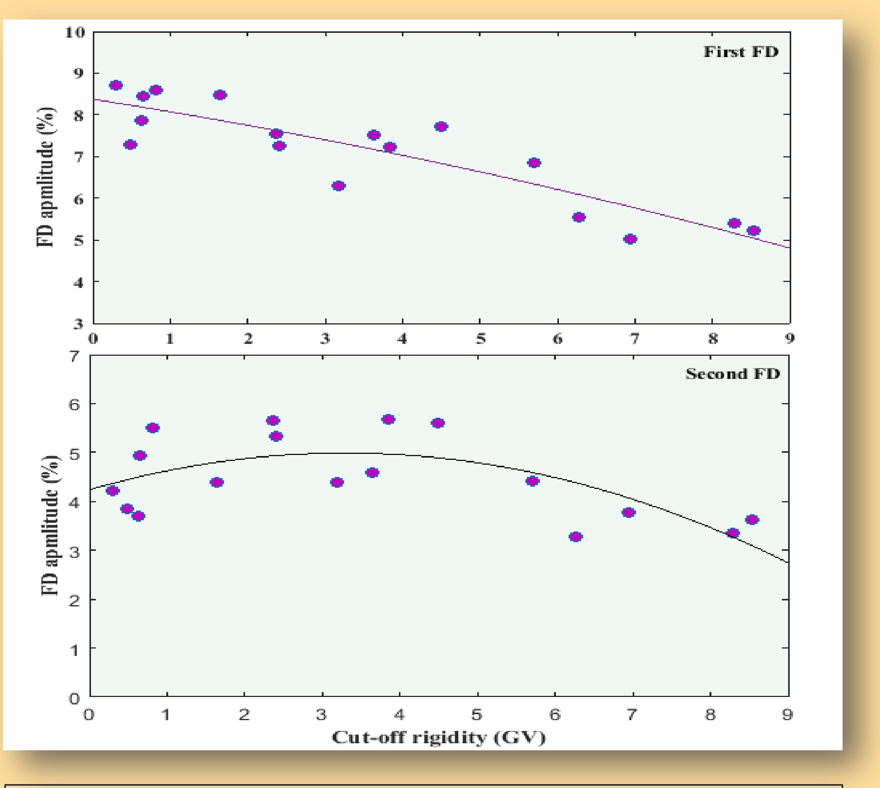


Fig. 6: FD amplitude as a function of the rigidity of different stations for the first (upper panel) and the second (lower panel) FDs.

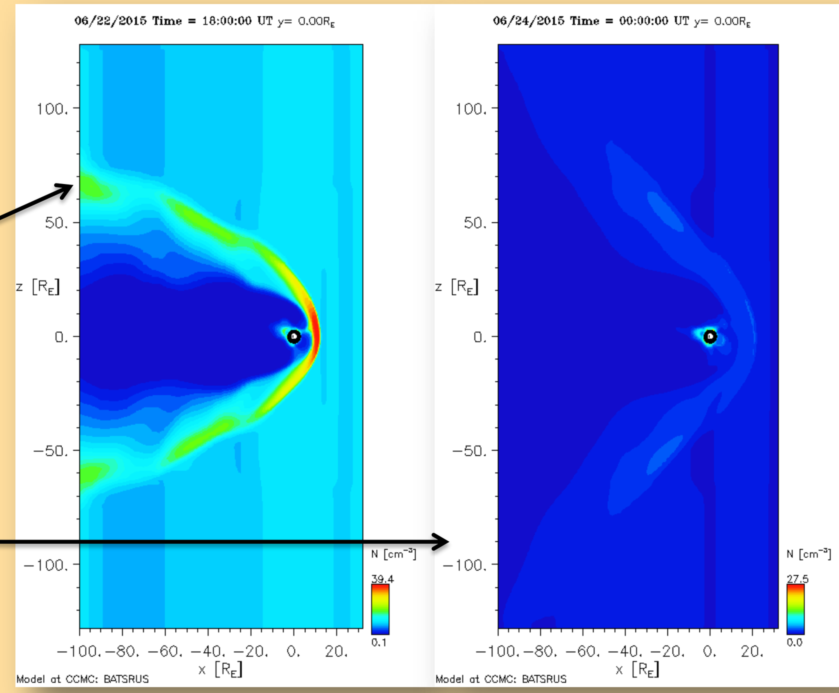


Fig. 5: The compression of the magnetosphere and the particles density increase on 22/06/15 (left) at 18:00 compared with the magnetosphere two days later, on 24/0615, 00:00 at the recovery phase of the first FD (credit: ccmc.gsfc.nasa.gov).

Forbush Decrease

For the Cosmic Ray (CR) analysis, pressure & efficiency corrected hourly data from the European Neutron Monitor Database (NMDB) (www.nmdb.eu) have been used. Specifically, the first FD started in the middle of June 22 and, within almost one day, reached the value of 8.4% at the polar stations while it was followed by a short and slow recovery. Two days after the first FD, on June 24 at around 12 UT, a second one characterized by a decrease in the CR intensity of 5.2%, began. Finally the classical FD recovery followed. Fig. 4 depicts the behavior of the CR intensity as recorded by neutron monitor stations of different rigidities (Oulu, Irkutsk, Rome, Athens). This classification has been used in order to be apparent that the event has been clearly recorded from almost all the stations. Also, an effort has been made to locate the arrival of the CME-shocks based on [1] and on Table 1. The grey-dashed lines indicate this arrival as recorded from each station. Finally, on Fig. 5 the difference between a compressed (due to the arrival of the CME 4-shock, on 22/06) and a non-compressed magnetosphere (at the end of the recovery phase of the first FD is presented.

	Neutron Monitor Stations	Rigidity (GV)
1	McMurdo (MCMU)	0.3
2	Tixie Bay (TXBY)	0.48
3	Norilsk (NRLK)	0.63
4	Apatity (APTY)	0.65
5	Oulu (OULU)	0.81
6	Yakutsk (YKTK)	1.65
7	Kiel (KIEL2)	2.36
8	Newark (NEWK)	2.40
9	Dourbes (DRBS)	3.18
10	Irkutsk (IRKT)	3.64
11	Lomnickystit (LMKS)	3.84
12	Jungfraujoch (JUNG)	4.49
13	Baksan (BKSN)	5.70
14	Rome (ROME)	6.27
15	Guadalajara (CALM)	6.95
16	Mexico (MXCO)	8.28
17	Athens (ATHN)	8.53

Table 2: Neutron Monitor stations used in this work and their correspondent cut-off rigidities (GV).

Conclusions

- The cosmic ray events of June 2015 constitute a significant FD in solar cycle 24.
- A first effort has been made to match the shocks of the recorded CMEs with the peak areas of the cosmic ray variations during these events. A more extensive study has to be made in order to identify these shocks more accurately.
- An important double FD was recorded by all the neutron monitor stations with an amplitude of 8.4% and 5.2% at the polar stations.
- An increase of the >50 MeV proton flux component was recorded confirming that a solar flare has accompanied a CME when it left the Sun.

References
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