

Observable Effects of Interplanetary Coronal Mass Ejections on Ground Level Neutron Monitor Count Rates

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Abstract In this work, non-recurrent Forbush decreases (FDs) triggered by the passage of shock-driving interplanetary coronal mass ejections (ICMEs) have been analyzed. Fifty-nine ICMEs have been studied, but only 25 % of them were associated to a FD. We find that shock-driving magnetic clouds (MCs) produce deeper FDs than shock-driving ejecta. This fact can be explained regarding the observed growing trends between decreases in neutron monitor (NM) count rate and MC/ejecta speed and its associated rigidity. MCs are faster and have higher associated rigidities than ejecta. Also the deceleration of ICMEs seems to be a cause for producing FDs, as can be inferred from the decreasing trend between NM count rate and deceleration. This probably implies that the interaction between the ICME traveling from the corona to the Earth and the solar wind can play an important role in producing deeper FDs. Finally, we conclude that ejecta without flux rope topology are the ones less effective in unchaining FDs.

Keywords ICME · Magnetic cloud · Ejecta · Forbush decrease

1. Introduction

Ground level neutron monitors (NMs) are able to monitor the galactic cosmic ray (GCR) fluxes arriving to the Earth surface with energies between 0.5 to 20 GeV (Simpson, 2000). The geographical location of a NM determines the minimum energy of GCRs that reach each

Flux-Rope Structure of Coronal Mass Ejections

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station. This is traditionally quantified by the geomagnetic cutoff expressed in GV. Particles with less magnetic rigidity than the NM geomagnetic cutoff cannot reach the monitor. The NM count rate can be strongly affected by solar flares (Firoz *et al.*, 2011), coronal mass ejections (CMEs) (Gopalswamy *et al.*, 2012) and solar wind structures such as interplanetary coronal mass ejections (ICMEs) (Jordan *et al.*, 2011), interplanetary shocks (Cane, Richardson, and von Roseninge, 1994), and interaction regions (Richardson, Wibberenz, and Cane, 1996). While the first two can produce a significant increase in the NM count rate, known as ground level enhancement (GLE) (Shea and Smart, 2012), the other three may induce decreases in NM count rate called Forbush decrease (FD). These FDs can be divided into recurrent or non-recurrent, depending on if they are observed along several solar rotations and are associated with corotating stream interaction regions (Richardson, Wibberenz, and Cane, 1996) or if they last for several days and are caused by transient events as interplanetary shocks or ICME passages (Cane, 2000 and Belov, 2008). In this work we focus on non-recurrent decreases and we will refer to them as FDs. A Forbush decrease (FD) is observed as a decrease in the cosmic ray intensity and it was first reported by Forbush (1937). It is characterized by a fast decrease, as much as 20 % in the order of hours, and a slow recovery phase that can last several days. As a first approach, it can be assumed that the decreases in the cosmic ray counts are due to changes in the propagation conditions at the surrounding region where the FD is observed. It can be said that FD is a local phenomenon restricted to a small region when compared with the whole heliosphere. These changes can be related to enhancements in solar wind speed, variation in the magnetic field topology, enhancements in the interplanetary magnetic field magnitude, and the presence of magnetic turbulence. ICMEs are large structures (around 0.1 AU) that propagate at high speeds (up to 2000 km s^{-1}) and produce shocks and magnetic turbulence in the background solar wind. Moreover, about one third of ICMEs show a closed magnetic topology defined by a relatively strong magnetic field and a smooth field rotation which is usually known as magnetic cloud (MC) (Burlaga *et al.*, 1981; Lepping, Jones, and Burlaga, 1990). It is generally accepted that an ICME passage can produce decreases in the count rate of NMs (Cane, 2000; Ifedili, 2004; Papaioannou *et al.*, 2010). These decreases are short-term events with the decreasing phase lasting for about one to two days and the recovery phase over one week of duration.

During a shock-driving ICME passage, the shock may initiate a decrease in NM counts maintained along the sheath region, *i.e.*, the highly turbulent region between the shock and the ICME. This decrement can be steeper at leading edge of the ICME. This scenario is path dependent. This means that depending on the trajectory of the spacecraft or the Earth through the shock/ICME structure one of these two effects might not be observed (Richardson and Cane, 2011).

The FD shape may vary from one event to another, especially if complex structures converge on the observation point. Jordan *et al.* (2011) point out that each FD has to be studied separately and that small-scale structures, between shock and ICME, can greatly affect the FD shape and question the two-step FD picture.

To answer the question “do all the CMEs have a flux rope structure?” we proposed to analyze a list of 59 shock-driving ICMEs extracted from Gopalswamy *et al.* (2010) during Solar Cycle 23 during the Living With a Star Coordinate Data Analysis Workshop hosted in San Diego (2010) and Alcalá (2011). This subset (these 59 events) was selected using a CME source region criterion ($E15^\circ \leq \text{source longitude} \leq W15^\circ$). This roughly implies that only CMEs from the central solar disk region were considered. Although the main goal in this workshop was the study of the magnetic structures observed into ICMEs, we investigated the role of these structures in the propagation of cosmic rays, especially during their arrival at Earth.

In this work we analyze the effect of the ICME passage on Oulu NM station count rates with the goal to study which part of an ICME, *i.e.*, shock, MC or flux rope, magnetic field magnitude and induced turbulence plays the most important role in producing observable FDs.

2. Data Analysis

The 59 shock-driving ICMEs selected from the list in Gopalswamy *et al.* (2010) has been studied from January 1997 to September 2006. In 24 of them, clear signatures of MC were found. We considered that an MC has been detected when the solar wind follows the Burlaga criteria (Burlaga *et al.*, 1981; Lepping, Jones, and Burlaga, 1990), *i.e.* low temperature, smooth magnetic field rotation combined with intense magnetic field, and the magnetic field can be fitted with Hidalgo's model (Hidalgo and Nieves-Chinchilla, 2012). The other 35 events did not show clear evidence of an MC, but a depression in solar wind proton temperature is observed with low plasma beta. Generally speaking, we named them ejecta (Ej). If the magnetic field within the Ej is organized as a flux rope that can be fitted by Hidalgo's model, then this Ej is cataloged as ejecta plus (Ej+), and ejecta minus (Ej-) in the opposite case. The ICME pool was separated into MC (24), Ej+ (23) and Ej- (12). The details of this classification can be found in Hidalgo, Nieves-Chinchilla, and Blanco (2013).

Key parameters with a time resolution of 92 s from the *Solar Wind Experiment* (SWE) (Ogilvie *et al.*, 1995), 1 min time resolution data from the *Magnetic Field Instrument* (FMI) (Lepping *et al.*, 1995) on board the *Wind* spacecraft, 64 s time resolution data from the *Solar Wind Electron, Proton, and Alpha Monitor* (SWEPAM) (McComas *et al.*, 1998), and 4-min resolution data from the magnetic field experiment (MAG) (Smith *et al.*, 1998) on board ACE spacecraft have been used. Data have been retrieved from the CDAWeb web page. In this work, it is assumed that an FD is observed when the NM count rate decreases more than 3 % below the GCR background measured before the shock arrival. Because of its relative low geomagnetic cutoff (0.81 GV), cosmic rays arriving with energies higher than some hundreds of MeV are detected by the Oulu (Finland) NM. Counts of 5 min of time resolution from Oulu have been used (Kananen *et al.*, 1991). This station is located at 65.05°N, 25.47°E and at 15 m above sea level. The monitor is made up by 9 NM-64 tubes. The data from this station have been collected from the Neutron Monitor Database (NMDB) (Mavromichalaki *et al.*, 2011) that integrates the readings of many different NM stations located mainly in Europe and Asia. The high-count cadence lets us perform comparable observations with measurements acquired by space-borne instruments with similar temporal resolution to the one used in our analysis of MC magnetic structure. Although using 5-min NM data is not the standard approach to study FDs, where hourly averaged measurements are commonly used (*e.g.* Cane, 2000; Usoskin *et al.*, 2008; Papaioannou *et al.*, 2010; Richardson and Cane, 2011), this high-count cadence is required to make a direct comparison between the results given by Hidalgo's model, *i.e.* MC and/or Ej+ existence and limits, and the role of MCs, Ej+ and Ej- on the depth of FDs.

Only 15 ICMEs from the selected sample of 59 triggered the detection of an FD in the Oulu NM. Eight of them were MC and other six Ej+. Only one Ej- was able to induce an observable FD at Oulu. The latter Ej was preceded by a strong interplanetary shock. It is clear that flux ropes (MC or Ej+) within ICMEs play a crucial role in producing FD (94 % of FD associated with flux ropes). The decrease percentage of the resulting FD ranged between 5.2 % and 26.1 %, those related to MCs being deeper (Table 1). The transit time, *i.e.* the time that it takes a CME to arrive at Earth, has been calculated using the onset times from the

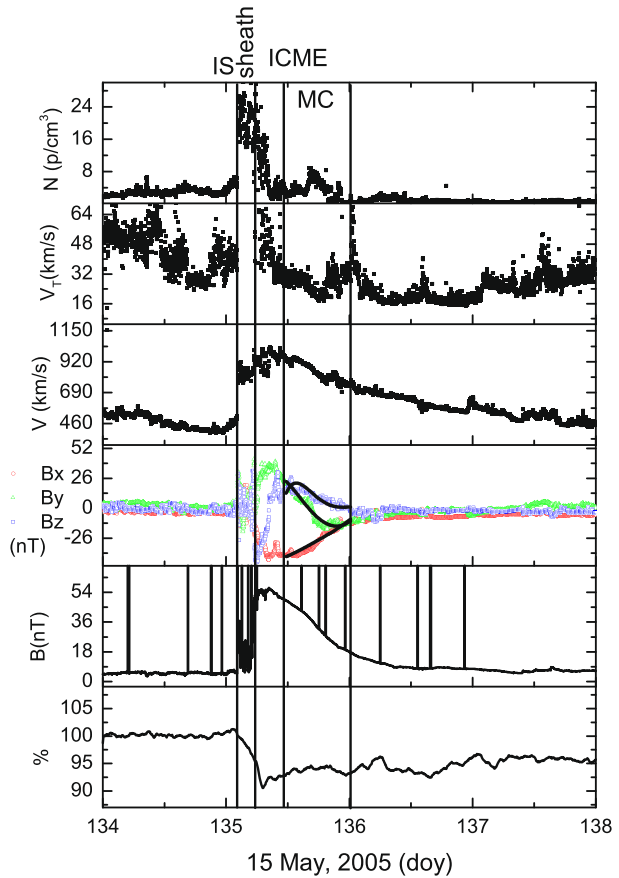
Table 1 ICME associated with FD. The columns give the year, time interval between the MC nose and its rear as estimated by Hidalgo's model, CME transit time, magnetic rigidity cut off associated with the flux rope, FD percentage, and FD location within the ICME. The asterisk in MC* means a complex event where two consecutive MCs were observed but the FD is not resolved into two separate events.

Year	ICME interval (doy)	Type	Travel time (day)	Rigidity (GV)	FD (%)	FD location
1998	124.442 → 125.234	Ej−	1.95	167	7.5	Ejecta
1999	178.942 → 179.108	Ej+	3.38	27	6.24	Sheath
2000	197.911 → 198.298	MC	1.46	419	16.00	Ejecta
2000	261.221 → 262.599	MC	1.77	283	8.86	Ejecta
2000	311.964 → 312.74	MC	3.2	215	6.96	Ejecta
2000	332.458 → 333.131	Ej+	3.23	80	9.01	behind Ej+
2001	102.367 → 103.279	MC*	2.14	139	12.63	Ejecta
2001	118.892 → 119.662	MC	2.37	106	8.17	Sheath
2001	285.205 → 285.360	Ej+	2.73	24	7.67	Sheath
2003	302.554 → 303.151	MC*	1.07	162	26.13	Ejecta
2004	22.558 → 23.282	Ej+	2.55	142	10.09	Sheath
2004	315.195 → 315.705	MC*	4.11	188	12.42	Sheath
2005	135.464 → 136.004	MC	1.75	354	11.89	Sheath
2005	149.495 → 149.638	Ej+	2.6	27	6.10	Ejecta
2006	232.630 → 233.625	Ej+	3.94	80	5.24	Ejecta

LASCO CME list (http://cdaw.gsfc.nasa.gov/CME_list/) and the ICME *in-situ* times using measurements from instruments on board the *Wind* and ACE spacecraft. From Table 1, it seems that the shorter the travel time, the deeper the FD. This will be discussed in the next section. In our list of 15 ICMEs connected to CMEs from the central region of solar disk, the deepest GCR decrease rate was measured in eight events during the ejecta's passage, in six events during the ICME sheath's and one behind the ejecta's passage. Only in three events, 12 April 2001, 29 October 2003 and 10 November 2004, the FDs could have been affected by other structures. The former two during their recovery phases, because of the presence of a subsequent interaction region and a later ICME, respectively, and the third during its main phase due to a previous ICME which reduced the GCR level before the 10 November MC's arrival. Five events produced decreases higher than 10 %. All of them were ICMEs with MC and in three of them some interaction with previous or subsequent structures might have happened, as has been explained above.

For every event, the shock strength, the Ej size, its mean speed and mean magnetic field have been computed. As an example, the analysis of two events is shown in detail. On 15 May 2005 a shock arrived at *Wind*'s location ($X_{GSE} = 200 R_E$, near L1) followed by a sheath and three hours later by an ICME with an MC structure. The ICME front is marked by a jump higher than 30 nT and a fast field rotation (less than 4 h) characterized by an elevated thermal speed. This region coincides with the deepest point in the FD measured by the Oulu NM. At the MC nose, *i.e.* when the field begins to rotate due to the MC passage, a magnetic field intensity of 55 nT and a speed of 990 km s^{-1} were observed. Under these conditions, the ICME reached the Earth 23 min later. The arrival of the shock at Earth was observed in coincidence with a steep decrease in the counts measured at Oulu, triggering a clear FD (Figure 1, bottom panel, where 5-min Oulu NM data have been smoothed using a

Figure 1 Example of an ICME with an MC. Data from the *Wind* spacecraft and the Oulu neutron monitor have been used.

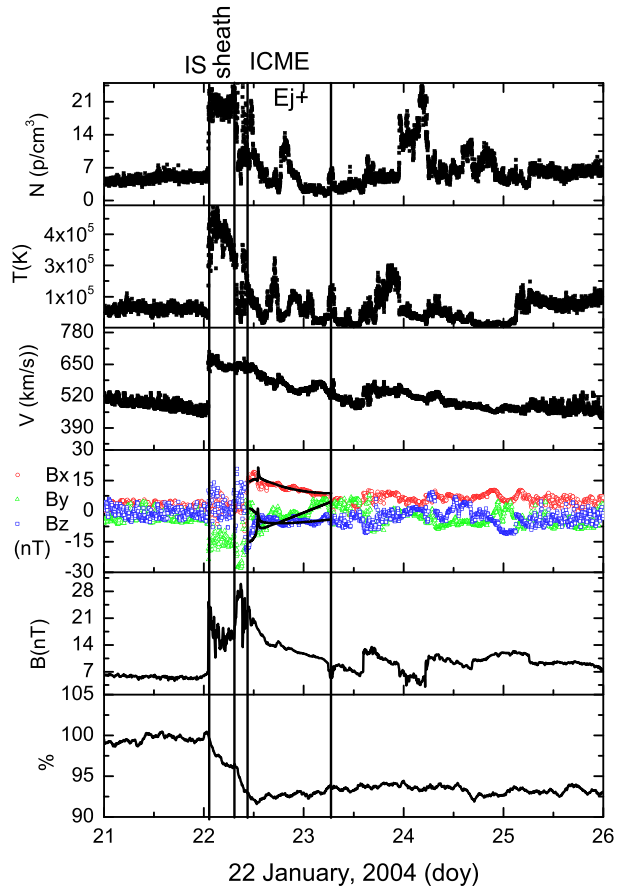


1-h running average). At ICME front arrival, the FD slope changed, clearly being the second step in this particular FD. In the figure, divided into panels, we show from top to bottom:

- i) solar wind density,
- ii) thermal velocity,
- iii) solar wind speed,
- iv) magnetic field components in GSE system (red circles B_x , green triangles B_y and blue squares B_z) over plotted with continuous lines, which are Hidalgo's model results,
- v) the magnetic field strength, and
- vi) the percentage of the normalized NM count rate.

The decrease was even steeper when the ICME leading edge hit the Earth. The FD's deepest point was measured within the fast rotating region before the MC nose arrival, and a soft recovery phase started during the MC passage (marked with vertical lines in Figure 1). The FD lasted more than five days until the previous neutron monitor count rate was recovered (day 140, not shown in Figure 1). The MC showed a well-organized magnetic flux rope. This is clear when comparing to the over plotted continuous lines which show Hidalgo's model results. During this FD, the count rate dropped to 12 % with respect to the GCR background before the shock arrival, following, in our opinion, a two-step FD shape. This event has been analyzed by Dasso *et al.* (2009) in terms of the magnetospheric response. They argue for the

Figure 2 Example of an ICME with Ej^+ . Data from the ACE spacecraft and the Oulu neutron monitor have been used.



presence of two consecutive MCs. The first one in coincidence with the fast-rotating region mentioned above and the second one with the MC presented in Figure 1. In our opinion, the temperature is too high to be sure that such a rotation may result from a small MC.

On 22 January 2004 a shock arrived at *Wind*'s location in $(-210, 42, -2)$ Earth radii in GSE coordinate system, *i.e.* on the night side of the Earth. To avoid possible interactions with the magnetotail, data from the ACE spacecraft have been used to analyze this event. ACE was located at L1. This event is shown in Figure 2. Plots are organized as in Figure 1. There is one difference though. In the second panel from the top the proton temperature appears instead of the thermal speed. As in Figure 1, the Oulu count rate has been smoothed using a running average of 1 h to get a clearer structure of the FD. The FD started with the interplanetary shock arrival. During the sheath between the shock and the ICME front the NM counts were reduced by 4 %. Six hours later, when the ICME arrived, a change in the FD slope was detected. Two hours later the flux rope nose, confirmed by Hidalgo's model (continuous lines in Figure 2), was observed. The FD minimum and the beginning of the recovery phase occurred within the flux rope. The Ej were characterized by a mean magnetic field of about 10 nT with a smooth field rotation that lasted almost one day and a solar wind speed of 600 km s^{-1} in the low solar wind temperature region. As for the FD shape, it showed a two-step behavior with a harder slope in coincidence with the ICME leading edge passage. The recovery phase was slower than that seen in Figure 1, lasting up

to 10 days. The neutron monitor registered a decrease of 10 % of its counts compared to the GCR background on 21 January.

3. Results

The FD depth can be influenced by various ICME properties. One of the possible causes of an FD can be the size of the magnetic structure and the intensity of its magnetic field. Cane (1993) found a clear correlation between the percentage decrease of GCRs and the magnetic field strength in the ICME. The effect of these two elements can be evaluated by the expression $R = Brc$, which gives the magnetic rigidity in GV, B being the magnetic field intensity, r the particle gyroradii and c the light speed. We assume the value of B to be the mean value inside the ICME and r the size of the ICME section because the particle gyroradius has to be in the order of this size to be affected in its normal movement. In a recent paper, Kubo and Shimazu (2010) analyzed the effect of a finite Larmor radius on GCR penetration into flux ropes, concluding that it can be relevant at 1 AU. The mean B and the structure size have been computed using Hidalgo's model both for MCs and Ej+. As for the only Ej-, its size was assumed to be equal to the size of the ICME. The resulting plot of the FD minimum *versus* the estimated rigidity is presented in Figure 3a. Red circles represent MCs, blue triangles Ej+, and the green square Ej-. The growing trend of GCR count rate percentage with rigidity is clear, ICMEs with MC being more effective than Ej+ and Ej- in producing FDs. This can be understood, as larger MC sizes and more intense magnetic fields imply higher associated rigidity. One of the MCs (the 29 October 2003 event) showed a percentage decrease higher than 25 %. Nevertheless, its rigidity was relatively low. This event had a sheath with a magnetic field as high as 50 nT and an MC mean field of only 12 nT. In this event, the role of the sheath seems to be more important than that of the MC in terms of reducing the Oulu NM count rate.

It can be argued that the shocks observed ahead of some ICMEs play an important role in the FD depth themselves, but what we observed in Figure 3b is that those shocks associated with MCs are related to deeper FD. The shock strength is defined here as the ratio of the difference between the downward and the upward magnetic field at shock passage. It is important to point out that the shock driven by the Ej- (green square) was the third more intense, but it only caused a modest FD of 7 %. The conclusion that can be extracted from Figure 3 is that an MC strengthens the shock effect on the neutron monitor count rate. A red continuous line and a blue dashed line are the linear fits to MCs and Ej+ with slopes of 13.6 and 4.7 and Pearson's coefficients (Pc) of 0.76 and 0.66, respectively. The shock triggers the FD but the MC makes it deeper. This result is in agreement with Richardson and Cane (2011) concerning the role that MCs may play in producing FD. Also the observed relationship between Ej rigidity and FDs could support the argument of MCs being closed magnetic structures.

Another important parameter that deserves to be studied focusing on the causes of FDs is the speed of the ICME. There are three different speeds that can be associated with the ICME propagation. We have the CME emergence speed that is calculated from coronagraph images, the ICME transit speed that can be estimated from the CME onset time and the ICME arrival time at the spacecraft location and the solar wind speed measured within the ICME. A common conclusion inferred from the three speeds is that the faster CME or ICME, the deeper the FD (Figure 4). This result agrees with those by Richardson and Cane (2011) who used a pool of more than 300 ICMEs. As they affirm in their paper, the dependence of the decrease on the CME/ICME/MC speed can be explained arguing that in faster-propagating

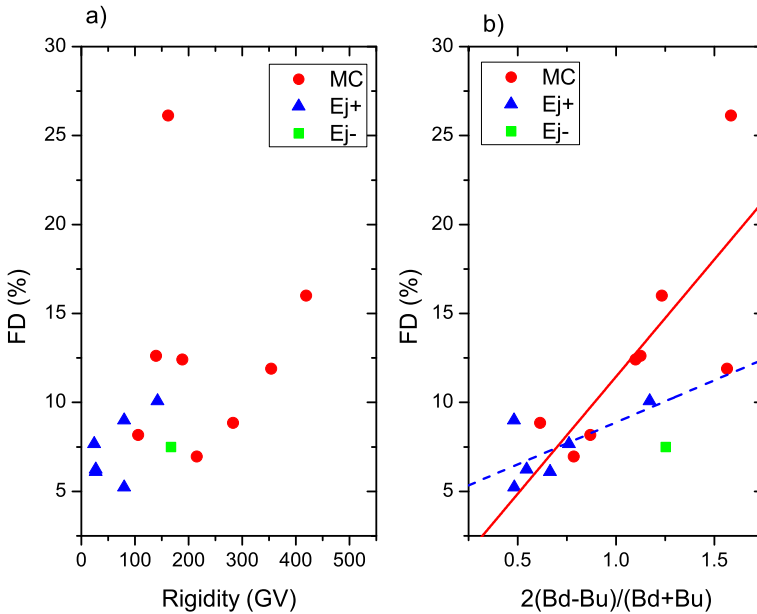


Figure 3 FD dependence on rigidity (a) and shock strength (b).

events GCRs have less time to fill up the closed magnetic structure of an MC. On the other hand, the range of values of the three speeds is different. The CME speed ranges between 300 and 3000 km s^{-1} (Figure 4a), the transit speed between 500 and 2000 km s^{-1} (Figure 4b), and the solar wind speed between 300 and 1300 km s^{-1} (Figure 4c). Again, MCs are, generally speaking, faster than Ej events. On the other hand, taking a closer look at Figure 4c, it is clear that Ej velocities are in a narrow range of 500 km s^{-1} (250 to 750 km s^{-1}) without a clear linear relationship (blue dashed line) with the associated FD ($P_c = 0.33$). Nevertheless, the FDs produced by MCs show a good linear correlation (red continuous line) and a clear growing trend with the MC speed at 1 AU ($P_c = 0.71$).

Non-recurrent FDs are observed by NMs at ground level as local phenomena related to solar wind conditions around Earth, given that most of them can be directly related to the passage of an ICME. No relationship of CME speed, transit speed and FD should be expected other than the dependence between these two velocities on the solar wind speed. Nevertheless, important variations in the speed from the CME onset to the ICME arrival at the Earth are depicted in Figure 4. This can be explained by assuming that an effective interaction between ICMEs and solar wind occurs during the ICME's travel in the interplanetary space (Vršnak, 2001). In almost all the events a deceleration is observed. This deceleration can be due to an effective kinetic energy exchange between the ICME and the solar wind. This exchange can produce intense shock waves and turbulence ahead (sheath) the ICME and therefore make the ICME able to change the propagation conditions of GCRs with energies from hundreds to thousands of MeV. This is expected for propagating diffusive barriers (Wibberenz *et al.*, 1998). The ICME acceleration can be estimated from the difference between the solar wind speed and the CME speed divided by the travel time. In Figure 5, this acceleration is plotted against the percentage decrease of GCRs displaying a clear negative slope. Those ICMEs that are more intensively decelerated produce deeper FDs. Only two of 15 ICMEs show a positive acceleration. Although acceleration could produce an effective

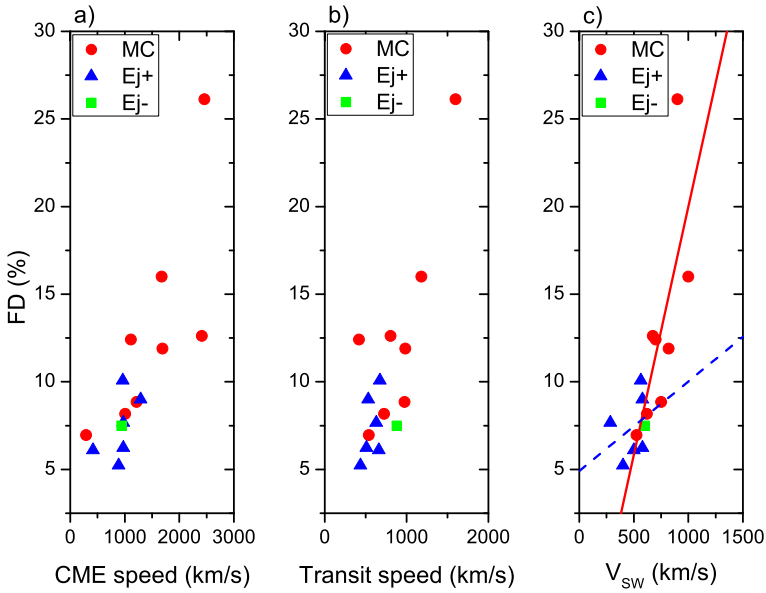


Figure 4 FD dependence on CME speed (a), transit speed (b) and solar wind speed measured during an ICME passage (c).

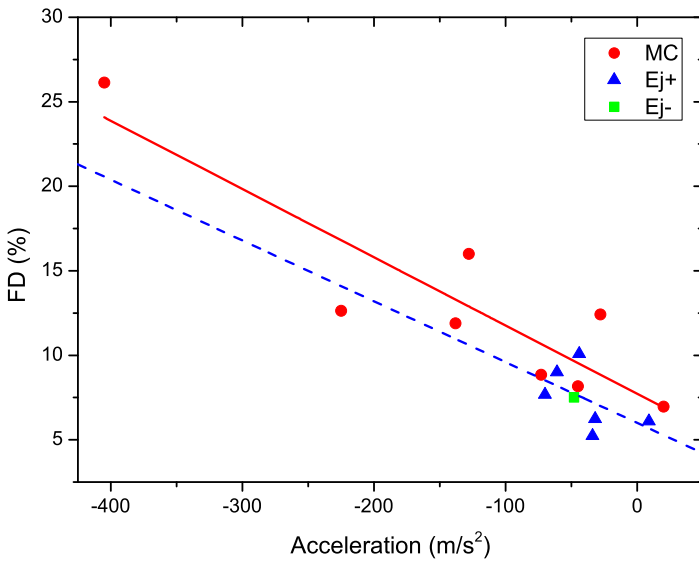


Figure 5 FD dependence on ICME acceleration. This acceleration has been estimated by means of the expression $(V_{SW} - V_{CME}) \times$ ICME travel time.

interaction with the solar wind, two events provide little statistical evidence to affirm that a change in the acceleration slope appears. Moreover, this cannot be considered as a conclusive result because of the uncertainty in CMEs speed estimations. MCs and Ej+ events have

similar slopes (red continuous and blue dashed lines, respectively) of 0.04 and 0.035 but different Pcs , -0.89 for MCs and -0.53 for Ej+. MCs are more efficiently decelerated. This may be due to their larger size, more intense magnetic field and higher speed. Moreover, the FD depth is better correlated with MC acceleration than with any other physical quantities considered in this work (rigidity, shock strength, and speed). The deceleration/acceleration of ICMEs plays a very important role in the development of FDs. Intense accelerations imply strong interaction between ICME and solar wind. This interaction drives stronger shocks and makes the solar wind more turbulent. These two features greatly affect the propagation of cosmic rays in the range of the detectable energies by the neutron monitors.

4. Conclusions

The role of CMEs originating from near the center of the solar disk and their associated ICME on FDs detected by the Oulu NM have been analyzed. Cosmic rays with energies higher than a few hundreds of MeV are the main component of the energetic particle population detected by this NM. A pool of 59 shock-driving ICMEs has been classified into three groups, MC (24), ejecta with flux rope (23) and ejecta without apparent flux rope structure (12). Only around 25 % of them were able to produce decreases in the NM count rate higher than 3 %, eight MC, six Ej+ and one Ej-. This result seems to show that an isolated shock is rarely able to produce FD. Moreover, similar shocks may induce stronger FDs if they are driven by an MC or an Ej+. Therefore a closed magnetic structure such as MC or flux rope strengthens the effect of shocks on FDs. Richardson and Cane (2011) reached the same conclusion.

The rigidity associated with MCs and Ej events affects the CGR propagation into ICMEs. This rigidity has been compared with the GCR decreases concluding that higher rigidities are related to deeper FDs. The higher rigidities correspond to MCs because they are larger and their magnetic fields are more intense than those of the Ej events.

The shock strength and its relationship with FD have also been analyzed. Stronger shocks produce higher decreases in the GCR count rate, but when considering similar shocks, those driven by MC are more effective (almost three times more effective) in shielding the Earth from the arriving GCRs. This can be explained assuming that MCs interact more strongly with the underlying solar wind than Ej events driving turbulence into the sheath region and therefore, affecting in a more efficient way the propagation of the GCRs into the ICME.

Another analyzed aspect is the effect of ICME speed on GCR count rates. The observations show that faster structures (MC or Ej) are more efficient to produce FDs, and at least in the sample analyzed, MCs are faster than Ej events. Moreover, FDs associated with ejecta show an increasing trend with CME speed and transit speed but the relation is not so clear with their measured speed at 1 AU ($Pc = 0.33$). As for MCs these three velocities show similar increasing trends with the FD depth and a good correlation between MC speed and FD depth ($Pc = 0.71$). This result is also in agreement with the conclusion by Richardson and Cane (2011).

Finally, we have observed that the deceleration/acceleration of ICME between the Sun and the Earth can play an important role in the development of FDs. Higher decelerations induce deeper FDs. This can be explained in terms of effective energy exchange between the ICME and solar wind. This interaction can lead to the formation of a stronger shock ahead of the ICME. MCs decelerate stronger. Closed magnetic structures as MCs with stronger magnetic field and larger size than those observed in Ej events seem to be more effective in interacting with the solar wind. Moreover, we find the best correlation between deeper

FDs and the MC acceleration. The linear correlation gives a Pc equal to -0.89 . This value implies that the interaction between MC and solar wind is very important in the shielding effect that an ICME has over GCRs.

Richardson and Cane (2011) propose that MCs are effective in excluding GCRs because they are closed magnetic structures. Our results support this conclusion but also the importance of MC/solar wind interaction on GCR decreases as can be inferred from the clear relationship between MC acceleration and GCR count rates.

Hidalgo, Nieves-Chinchilla, and Blanco (2013) have found that most of the ejecta from the initial list of 59 shock-driving ICMEs showed axes close to the Sun–Earth line. This implies that the passage of the spacecraft through the corresponding ejecta event was probably by its flank and this may be seen as support for the idea of MCs and Ej events being observed at different parts of a flux rope. According to this picture and the results showed in this work we conclude that the effect of shock-driving ICMEs on GCR count rates may also depend on which region of the flux rope hits the Earth.

In conclusion, shock-driving MCs produce deeper FDs than $Ej+$ and $Ej-$ events, because the MCs have higher rigidity, higher speed, and higher deceleration, and they interact more effectively with the solar wind.

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