Cosmic rays below 15 GeV and the current rising solar activity phase

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Abstract. The cosmic ray component in the range of energies below 15 GeV is strongly affected by transient phenomena related to solar activity. Cosmic rays and solar particles with energies between 0.5 and 15 GeV can be observed by neutron monitors at ground level. In absence of solar activity, the background counting rate registered by neutron monitors is dominated by the galactic cosmic ray component, showing only long-term variations correlated with the solar cycle. During active periods, short-term temporal variations can be observed in close association with solar activity phenomena such as flares and coronal mass ejections. Most of these transients can produce a strong response in the magnetosphere. The aim of this work is to study the relationship between neutron monitor measurements and the magnetospheric response observed in Dst index, paying special attention to their connection with solar transient phenomena during the current rising solar activity phase.

1. Introduction
Solar activity is organized into eleven year cycles. Magnetosphere echoes solar cycle and its response can be followed using distinct magnetospheric activity indexes. Ground level neutron monitors are able to monitoring the cosmic ray fluxes arriving to the Earth surface with energies between 0.5 to 20 GeV [1]. The geographical location of a neutron monitor determines the cosmic rays minimum energy to reach each station. This is traditionally quantify by mean the geomagnetic cutoff and is expressed in GV. Particles with less magnetic rigidity than the neutron monitor geomagnetic cutoff cannot reach the monitor. The neutron monitor count rate can be strongly affected by solar flare [2] and solar wind structures as interplanetary coronal mass ejections (ICME) [3], interplanetary shocks [4] and interaction regions [5]. While the former produces enhancement in the neutron monitor count rate, this is known as ground level enhancement, the other ones induce decreases named Fosbush decrease (FD). A FD is observed as a decrease in the cosmic ray intensity and was firstly reported by Forbush (1937) [6]. It is characterized by a fast decrease, as much as 20%, in the order of hours and a slow recovery phase that it 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 phenomena restricted to small regions when comparing with the whole heliosphere. These changes can be related with enhancement in solar wind speed, variation in the magnetic field topology, enhancement in the interplanetary magnetic field
magnitude and the presence of magnetic turbulence. ICMEs are huge structures (around 0.1 AU) that propagate at high speed (up to 2000 km/s) and use to produce shocks and magnetic turbulence on solar wind. Moreover, about one third of ICMEs show a closed magnetic topology which is usually known as magnetic cloud (MC). Taking this in mind, a ICME seems to be a good candidate to be a cause of FD.

The magnetosphere is very sensitive to solar wind interaction and solar wind is very depended to solar activity. Fast solar wind, stream interaction regions (SIR), interplanetary shocks and ICME are able to induce changes on magnetosphere conducting to geomagnetic storms, auroras and measurable variations in the global magnetic field. Dst is a measure of the average change in the magnetic field near the equator and is used as an index to determine the strength of magnetic storms. There is no a clear division between moderate or strong storm. If Dst index decreases in more than -75 nT, the geomagnetic storm can be considered as strong one. During magnetic storms, the equatorial magnetic field decreases due to currents flowing in the magnetosphere.

It is generally accepted that physical processes which are responsible of FD and geomagnetic storm have to be different. Nevertheless, the same solar wind phenomenon can, sometimes, produce both FD and geomagnetic storm. The aim of this work is to study what kind of solar wind is able to do this.

![Figure 1](image_url). From top to bottom, EPHIN integral channel, Oulu neutron monitor counts, Dst index and number of strong geomagnetic storms (< -75 nT) and events with a FD higher than 4% and Dst lower than -75 nT (red bars).
2. Data analysis
The Oulu neutron monitor counts (geomagnetic cutoff: 0.81 GV) and the Dst index have been studied from 1996 to 2011. Also measurements from EPHIN-SOHO integral channel (protons and helium > 53 MeV/n), solar wind and interplanetary magnetic field from Wind instruments have been used. During this period 49 events that showed a FD higher than 4% and a Dst index below -75 nT were selected. The solar wind during these events have been also analyzed. The results will be shown in next sections.

![Figure 2. Event detected on August 1998. From top to bottom, solar wind density, thermal speed, solar wind speed, magnetic field components in GSE, magnetic field intensity, Dst index and Oulu neutron monitor counts](image)

2.1. The solar cycle context
As can be seen in Fig. 1, the particles fluxes measured by EPHIN (> 53 MeV/n, upper panel in Fig. 1) and Oulu (> hundreds of MeV, second panel in Fig. 1) show that the last solar minimum was achieved in 2010 (the higher level in cosmic rays below 1 GeV) and the previous one in 1996. It is also observed that the minimum in 2010 was deeper than in 1996 allowing the arrival of a higher cosmic ray flux to the Earth. Following the solar cycle, the Dst index showed the more intense geomagnetic storms in 2001 and 2004 (third panel), nevertheless, the number of intense geomagnetic storms (< -75 nT) was peaked in 2000. On the other hand, the events with a FD higher than 4% and Dst lower than -75 nT were more numerous in 2000 and 2001 and they completely disappear in 1996 (solar minimum) and during the period 2007 to 2010. Nevertheless, some strong geomagnetic storm were recorded in
these years. As a preliminary result, we can say that these kind of events are only present out of the solar minima.

2.2. An example
In August 26, 1998, an event was detected (Fig. 2). The FD started with a strong interplanetary shock to the Earth driven by a fast ICME (700 km/s) with a magnetic cloud (MC) 22 h later. The FD recovery phase started with the MC arrival. In coincidence with the MC, a strong geomagnetic storm (-155 nT) happened. Six days before the shock arrival, another ICME with a MC arrived to the Earth. In this case, only a weak storm was produced. This was a slow MC (300 km/s) without a clear shock ahead. After the MC passage, an increase in the solar wind speed is observed along the two following days what can support the presence of a stream interaction region (SIR). Only a soft decrease in neutron monitor counts was observed. Nothing happened as for Dst index.

3. Preliminary results
Forty nine events with a FD higher than 4% and Dst lower than -75 nT have been detected between 1996 and 2011. They all were observed during the ascending, the maximum and the decreasing solar cycle phases. None of them were recorded in 1996 and the period 2007-2009, i.e. during the solar minima. All the events were associated with shock driven by ICMEs. Neither isolated shocks nor ICMEs were able to produce simultaneously a FD with a geomagnetic storm.

When plotting Dst index against FD percentage (Fig. 3) a proportional relationship is not observed. Stronger storms are not directly related with deeper FD. This seems to confirm that although the same solar wind phenomenon (shock driven by a ICME) is able to induce storms and FD, the physical causes are different and not clearly related.

![Figure 3. Dst index against Oulu neutron monitor counts](image)
Acknowledgments
The authors wish to thank the Wind/MFI, Wind/SWE, SOHO/EPHIN, Oulu neutron monitor and teams for the use of their data. This work is being supported by JCCM PPII10-0150-6529 and AYA2011-29727-C02-01 grants.

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