A simple model of Forbush decreases caused by sheathless magnetic clouds

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INTRODUCTION
Forbush decreases (FDs) are short term depressions in the galactic cosmic ray (CR) flux observed at Earth and in the interplanetary space, caused by interplanetary counterparts of coronal mass ejections (ICMEs). In a general case, when ICME drives a shock, a two-step FD is observed, the first decrease caused by the shock-sheath region, whereas the second decrease is caused by the ejecta (ICME). These two regions have different characteristics and presumably modulate cosmic rays in different ways. The ejecta-modulation can be studied separately in ICMEs which do not drive shocks/sheaths.

We study ejecta modulated FDs for a special subset of ejecta that have a smooth rotation in an enhanced magnetic field, low proton temperatures and low plasma beta parameter – MAGNETIC CLOUDS (MCs). The magnetic structure of the MC is presumably of a flux rope, where it's local magnetic configuration can be modeled using a cylindrical geometry. In order to model FD we assume a simple cylindrical structure of the MC.

MODEL
The MC is represented by a cylinder consisting of a uniform magnetic field. We consider 2D circular region (MC cross-sectional area) in polar coordinates.

\[ N = \int n dA \]

The number of particles within the surface element dA is \( N \), and \( n \) is particle density, a function of particle energy, \( E \).

A particle that gyrates along its guiding center field line at a distance \( r \) will stay in the flux rope if \( cr_{cg} < r \), where \( r_{cg} \) is Larmor radius of the particle. This condition defines the weight function, \( g \).

\[ g(E, r, v) = g(\xi, \xi < r, \xi \geq r, \text{ elsewhere}) \]

For a given energy the magnitude of the FD can be calculated, where \( n_{0} \) is the particle density when magnetic field is not present and \( n(r) \) is the particular density in the presence of magnetic field. We define the number of particles modulated/excluded by the occurrence of the MC assuming it corresponds to the number of confined particles in our model, when magnetic field is “switched on”.

\[ \phi(E, r, v) = \frac{1}{\sqrt{2\pi}} \int g(E, r, v) \phi(E, r, v) dE \]

The weighted sum (black) of series of modeled FDs (colored) at different energies using a force field approach, gives an estimation of FD which can be compared to observation. (Heber et al., 2015)

SUMMARY & OUTLOOK
This simple model predicts that the number of CRs will decrease towards the center of the MC, the profile of the amplitude depend on the magnetic field strength and spatial extent of the MC, and qualitatively describes observations. However, the model tends to underestimate the amplitude of the shape of the FD strongly depends on CR trajectory of the spacecraft through the MC, we don't expect a match between the model and observations. Future improvements should include the analysis on a larger sample as well as using more realistic magnetic field in the modeling.

REFERENCES
Usoškin et al. (2011), JGR, 116, 2104
Heber et al. (2015), submitted to CEAS

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ANALYSIS & RESULTS
IN SITU MEASUREMENTS
MCs were identified using in situ measurements of solar wind plasma density, temperature, speed, and plasma beta parameter (SWEPAM/MIN) and analysis using magnetic field components, strengths, and fluctuations (MAG/ACE). Solid black lines mark the beginning and the end of the MC in analyzed events (event 1 and 2).

COSMIC RAY MEASUREMENTS
FDs are identified using EPHIN/SOHO measurements of CR count, normalized to the CR count at the start of the MC. The lowest panel displays the measured and modeled FD (black and red lines, respectively). Taking into account the simplicity of our model we find a reasonable agreement.

EVENT 1

EVENT 2

EVENT 1 – MODEL INPUT:
start - end day: 261.15 – 262.35
Duration: 28.8 h
R=0.172 AU
(MC expansion included)
B=11 nT

EVENT 1 – MODEL OUTPUT:
Tmin = the time of the FD minimum
Tmin(obs) day: 261.6
Tmin(model) day: 261.77
\( \Delta T = 4 \) h
Amin = FD minimum amplitude
Amin(obs) = 2.5 %
Amin(model) = 1.9 %
\( \Delta Amin = 0.6 % \)

EVENT 2 – MODEL INPUT:
start - end day: 359.15 – 359.75
Duration: 13.2 h
R=0.055 AU
(MC expansion included)
B=11 nT

EVENT 2 – MODEL OUTPUT:
Tmin = the time of the FD minimum
Tmin(obs) day: 359.8
Tmin(model) day: 359.43
\( \Delta T = 4 \) h
Amin = FD minimum amplitude
Amin(obs) = 25 %
Amin(model) = 1.1 %
\( \Delta Amin = 0.1 % \)

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This simple model of FDs can be used to predict the amplitude and duration of FDs in the interplanetary space. The model can provide a useful tool for predicting the occurrence of FDs and their impact on space weather.