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TRAcking interplanetary Coronal mass Ejections with foRbush decreases (TRACER)

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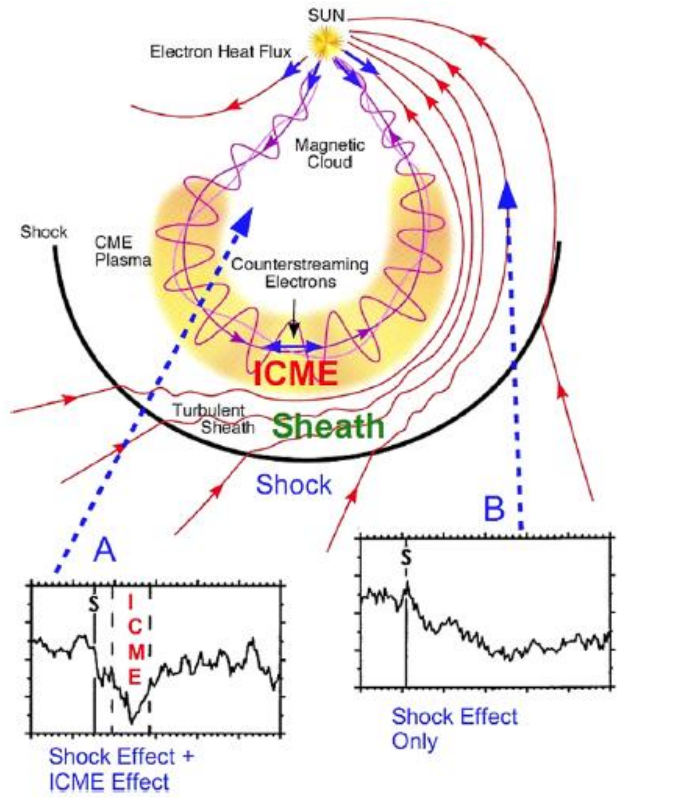
Abstract: During their travel from Sun to Earth, coronal mass ejections (CMEs) interact with Galactic cosmic rays (GCRs) that fill the interplanetary (IP) space. The leading shock wave, when present, and the following CME structure modulate GCRs, which results in a reduction of the cosmic ray (CR) intensity, known as Forbush decrease (FD). CMEs are regularly observed via both remote sensing (coronagraph and heliospheric imaging instruments) and in-situ measurements of plasma and magnetic field. However, this dual approach can be augmented with the identification of FDs in the measurements of GCRs; one may detect interplanetary CMEs passing over the observational site. Thereby, the recordings of FDs at different points within the heliosphere could be used as tracers of the IP evolution of CMEs. In this work, we present FD events recorded at Earth by neutron monitors and in the inner heliosphere by the Helios 1 and 2 spacecraft. Using these FDs as a tracer of the agent CMEs, we identify their kinematics from 0.3 to 1 AU and quantify the effect of the CME physical parameters to the recorded intensity decrease during the FDs.

Motivation



✓ **Forbush Decreases** (**FDs**) are short term (≤ few days) depressions of the **Galactic Cosmic Ray** (**GCR**) intensity.

✓ **FDs** are:
- *not* a local phenomenon but an **interplanetary** one
- of **worldwide scale** (simultaneously measured)
-driven by **Interplanetary Coronal Mass Ejections (ICMEs)** [**Non-recurrent FDs**] or **Co-rotating Regions** [**Recurrent FDs**]

Figure 1. Schematic representation of GCR Variations along trajectories that do (A) or do not (B) encounter the ICME [Richardson & Cane, Solar Physics, 2011]

✓ **Helios** (**A & B**) spacecraft (US-German mission) with an *orbit ~0.3 to ~1.0 AU* was **the first mission to scan the IP space**.
✓ Mission duration
- **Helios A** (1974-12-10 | 1985-02-18)
- **Helios B** (1976-12-15 | 1979-12-23)

Data & Methods

✓ ***Single counter particle data*** from both *Helios A & B* (*Figure 2*) E6: Cosmic Ray Telescope were prepared from the **Christian-Albrecht University of Kiel**. These were used to pinpoint the FDs.
✓ ***Plasma measurements*** from Helios were downloaded from https://heliophysicsdata.sci.gsfc.nasa.gov/.
✓***Shocks** at Helios* spacecraft were further identified by the online database of IPshocks (ipshocks.fi)
✓ **Data for FDs** *at Earth* are obtained from the worldwide network of neutron monitors with the application of the Global Survey Method (GSM) (Belov et al., 2018)
✓***IP conditions*** at the *near Earth space* were collected by the OMNI database IP data
✓***Shocks** at Earth* were taken from the list of sudden storm commencements (SSCs).

Figure 2. The orbits of Helios A Helios B and Earth

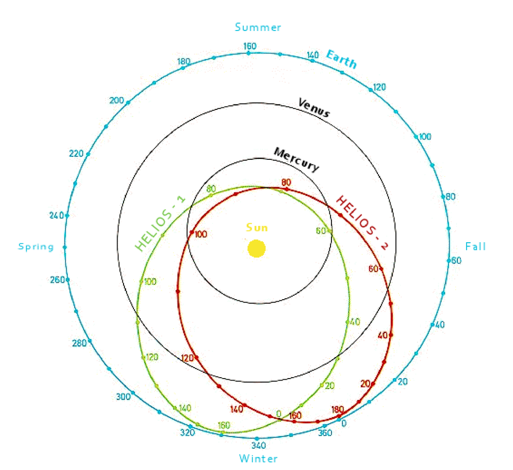
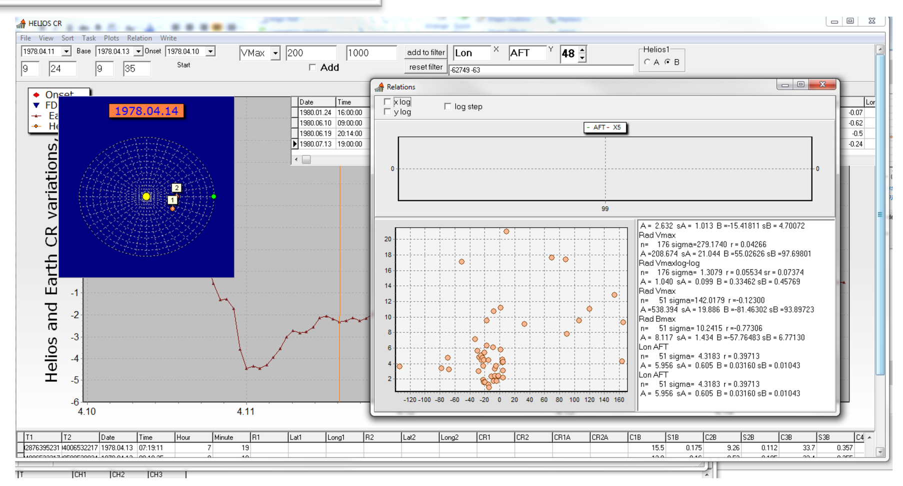


Figure 3. A snapshot of the resulting Helios analysis infrastructure that was implemented in the course of this study.

✓*The data were compiled into a database with an appropriate user interface created for this purpose* (*Figure 3*)



Forbush decreases @ Earth and @ Helios

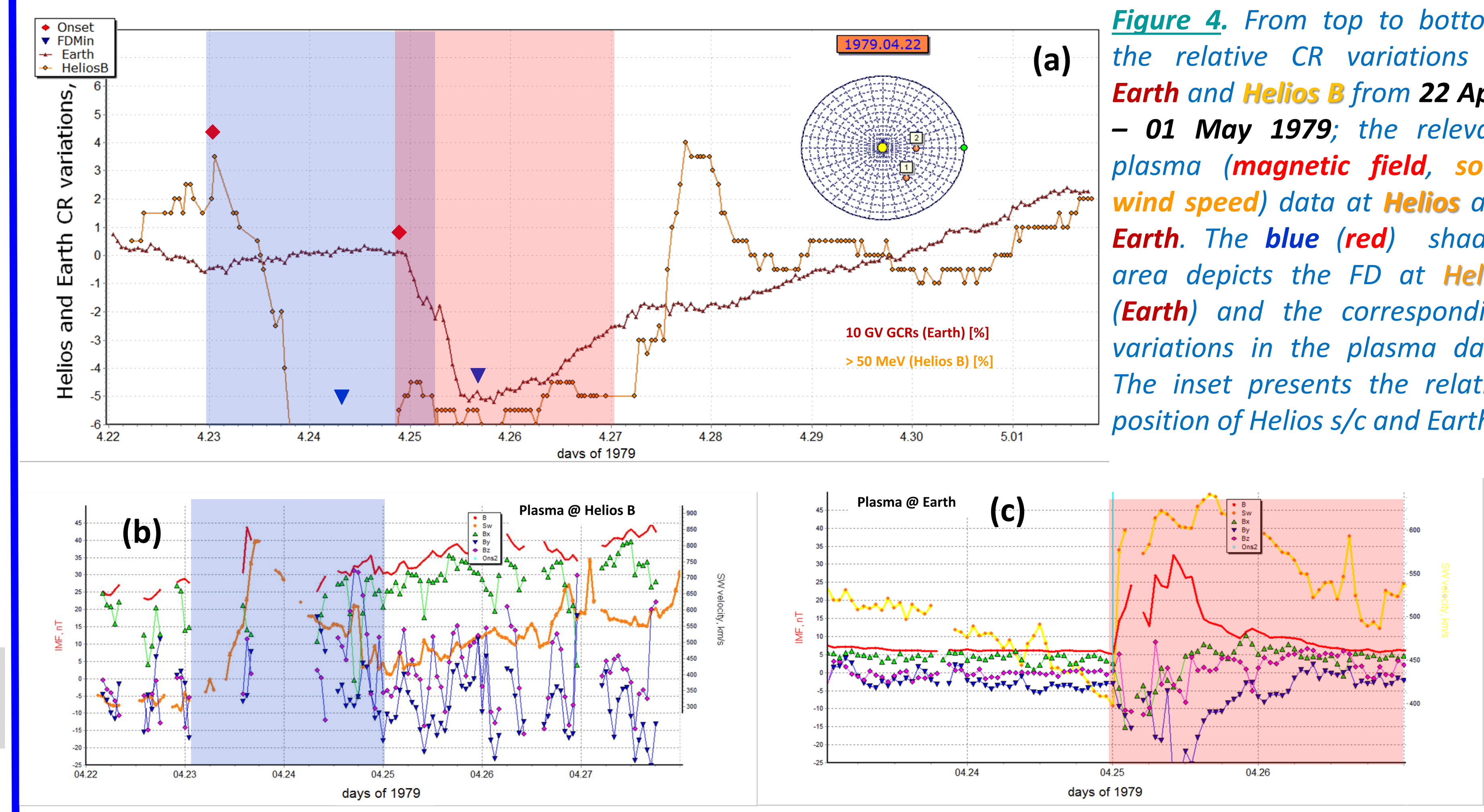
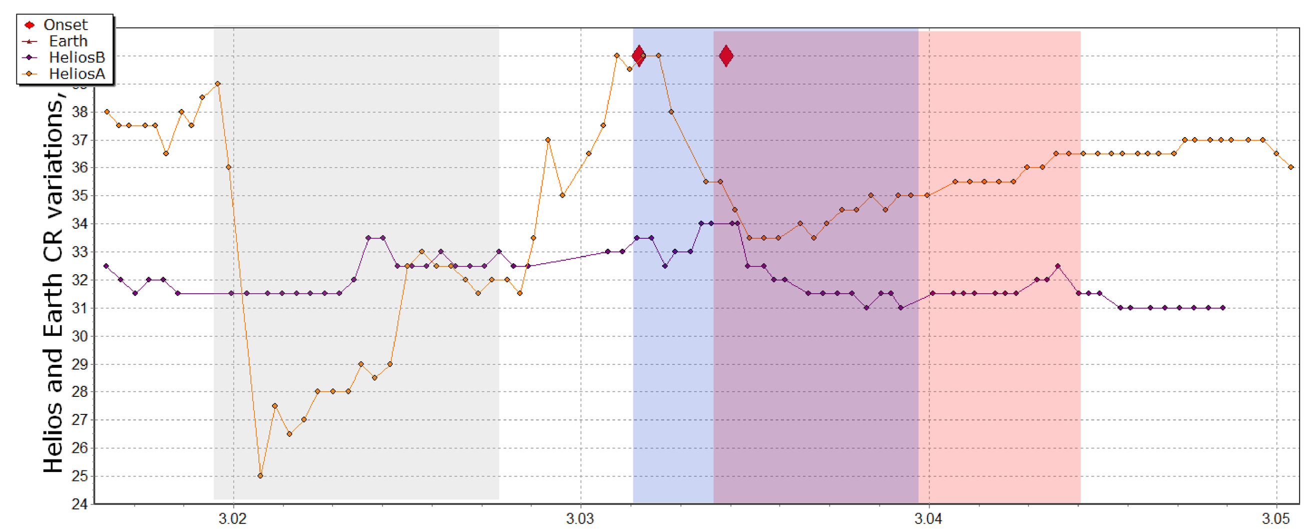


Figure 4. From top to bottom: the relative CR variations at Earth and Helios B from 22 April – 01 May 1979; the relevant plasma (magnetic field, solar wind speed) data at Helios and Earth. The blue (red) shaded area depicts the FD at Helios (Earth) and the corresponding variations in the plasma data. The inset presents the relative position of Helios s/c and Earth

✓ *Figure 4* presents the **FD** on *23 April 1979* at **Helios B** – which was located at **~0.4 AU** (***a***) and its corresponding plasma measurements (***b***). Despite the data gaps, *the arrival of the disturbance* at **Helios** is **clear**. The **magnetic field** increases from **25 to 45 nT** and the **solar wind speed** reaches **800 km/s** quite steeply. The ***CME agent then expands and propagates out*** to 1 AU, reaching the **Earth** (***c***) and creating a **significant FD** on *25 April 1979*.



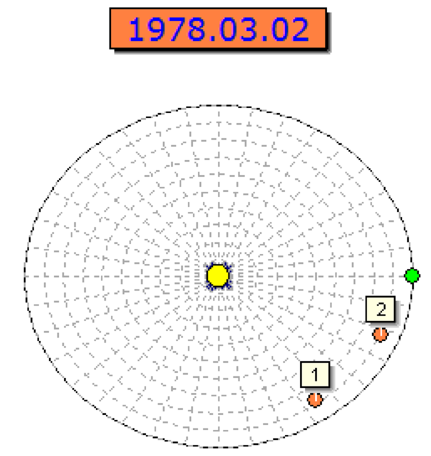


Figure 5. The relative CR variations at Helios B and Helios A from ***02 – 05 March 1978****. The gray shaded area depicts a* ***classical two-step FD*** *[Cane, 2000] at Helios A. The blue (red) shaded areas depict the FD at Helios A (Helios B), respectively. The red diamonds denote the start of the FD at each Helios s/c.*

✓ The relative positions of **Helios A** (**1**); **Helios B** (**2**) and **Earth** (**green circle**) with respect to the Sun on **02 March 1978**.

Statistical results:

Preliminary

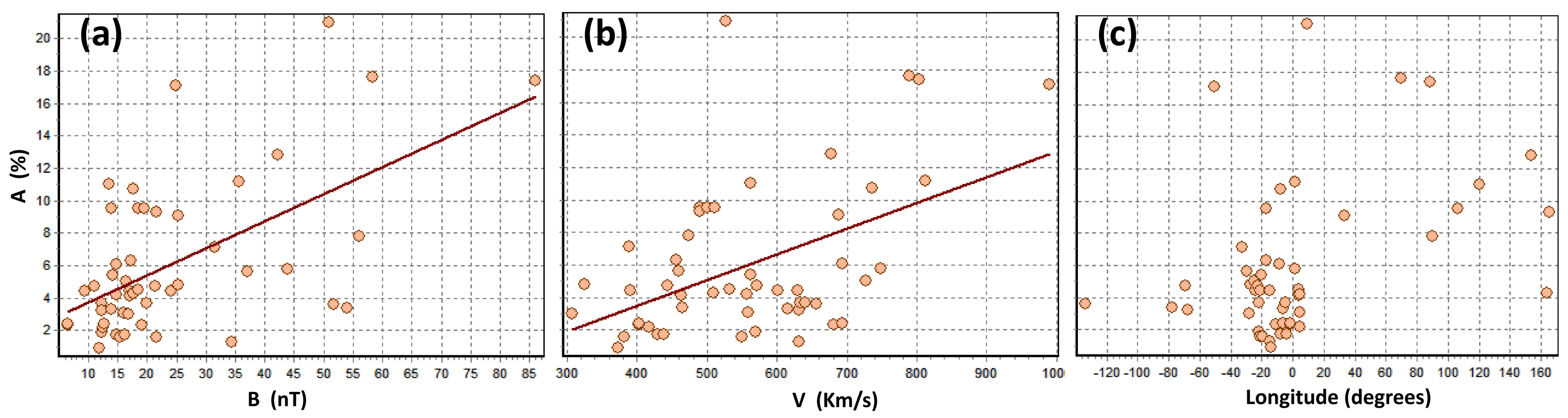
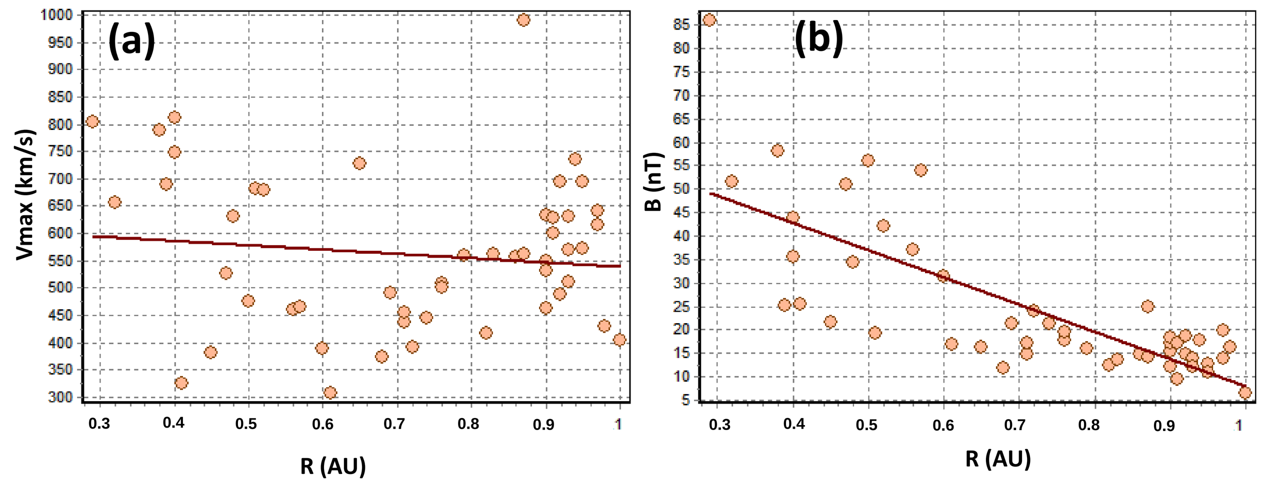


Figure 6. Amplitude of the decrease [A(%)] versus: (a) ICME magnetic field intensity [B (nT)]; (b) ICME speed [V(km/s)] and (c) longitude of the CME agent.

✓ We selected **a sample of 66 FD events** recorded *at both Helios spacecraft* with an amplitude **A ≤ 20%**. For this sample we identified *a trend of decreasing amplitude A with increasing ICME magnetic field strength*. The continuous line represents the linear fit and the correlation coefficient (**cc**) is **0.61**. → **The magnetic field strength determines (relative) well the expected amplitude of the FD and vise versa**. [Cane, 1993; Blanco et al., 2013] (*Figure 6a*)
✓ We then examined the role of the ICME speed in producing a significant (in terms of amplitude) FD. The continuous line represents the linear fit and **cc = 0.46**. → **The ICME speed does not determine well the expected amplitude of the FD and vise versa**. [Richardson & Cane, 2011; Blanco et al., 2013] (*Figure 6b*)
✓Finally, A was plotted versus longitude → **There seems to be no relation between the location of the agent CME (from the associated flare) and the resulting magnitude of the FD** (*Figure 6c*)



✓ **Radial dependence of the ICME parameters** at 0.3-1.0 AU (*Helios A & B*) (*Figure 7*)

Figure 7. Radial dependence of the ICME parameters at 0.3-1 AU (Helios A & B)

Conclusions

Preliminary

✓ The depth of the FD [**A(%)**]is *linearly* **strongly** (cc = 0.61) **related to the magnetic field strength** [B(nT)] and *weakly* (cc=0.46) *related to the speed* [V(km/s)] of the ICME (*Figure 6*).

✓ Nearby spacecraft may observe different magnetic field structures within (possibly) the same ICME (*Figure 4 , 5*)
→ **the amplitude of the FD can provide answers with respect to the characteristics of the agent CME**

✓ The ICME speed does not show a clear dependence on the distance to the Sun (*Figure 7a*). → **there seems to be large variation from event to event**

✓The ICME magnetic flux decreases with the distance to the Sun (*Figure 7b*) → **expansion mode of the agent CME**

References:
Cane, J. Geophys. Res., 1993
Cane, Space Scie. Rev., 2000
Richardson & Cane, Solar Physics, 2011
Blanco et al., Astron. Astrophys., 2013

url: **http://members.noa.gr/atpapaio/tracer.html**

Contact: **atpapaio@astro.noa.gr**

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