THE HVAR OBSERVATORY CME-EFFECTIVENESS FORECAST TOOLS

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GEOMAGNETIC STORMS

Geomagnetic disturbances (detected by magnetometers at Earth)

Currents induced by charged particles injected due to magnetic reconnection between ICME & geomagnetic field

ICME $B_s$ and $v$ crucial! ($E = B_s v$)


FORBUSH DECREASES

Short term decreases in galactic cosmic ray (GCR) flux (typical duration several days, typical magnitude several %)

Due to interaction of GCRs with shock/sheath region and CME/ejecta region (different mechanisms)

Increased $B$ and $v$ crucial!

How to predict CME space weather effects?

CME detection: Initial conditions → Modeling of CME propagation & evolution → Prediction of ICME arrival and near-Earth properties → Modeling of geomagnetic storms and Forbush decreases

~ 1 day  ~ 1 h
How to predict CME space weather effects?

CME detection: Initial conditions

Statistical relations

Empirical probabilistic model

~ 1 day

Modeling of geomagnetic storms and Forbush decreases
METHOD OVERVIEW:

Make a sample of events

Select CMEs and associated flares

Associate geomagnetic storms (GMS)

Associate Forbush decreases (FD)
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Statistical analysis

Select key CME properties

 Associated flare X-ray flux peak and source position

CME speed

CME apparent width

CME-CME interaction parameter (likelihood of CME-CME interaction)

Guided by previous studies:
- Zhang et al. (2003)
- Srivastava (2005)
- Gopalswamy et al. (2007)
- Zhang et al. (2007)
- Richardson & Cane (2011)
- Kim et al. (2012)
METHOD OVERVIEW:

Make a sample of events

Select CMEs and associated flares

Associate geomagnetic storms (GMS)

Associate Forbush decreases (FD)

Statistical analysis

Select key CME properties

Find CME-GMS relations

STRONGER STORMS ARE CAUSED BY:
- faster CMEs
- wider CMEs
- interacting CMEs
- central CME/flares
- stronger flares

Adapted from: Dumbović et al (2015a)
METHOD OVERVIEW:

Make a sample of events

- Select CMEs and associated flares
- Associate geomagnetic storms (GMS)
- Associate Forbush decreases (FD)

Statistical analysis

- Select key CME properties
- Find CME-GMS relations
- Find CME-FD relations

DEEPER FDs ARE CAUSED BY:
- faster CMEs
- wider CMEs
- interacting CMEs
- central CME/flares
- stronger flares

Dumbović et al (2015b)
METHOD OVERVIEW:

Make a sample of events

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Statistical analysis

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Model

Employ the results of the statistical analysis

1) Construct probability distribution which changes from one event to another depending on the input parameters

2) Estimate the expected level based on the probability distribution
CME Geo-effectiveness Forecast Tool (CGeFT)

Model input

CME speed, \(v\) (in km/s):
CME/flare source position radius, \(R_s\) (in solar radii):
CME apparent width, \(w\):
Solar flare x-ray class, \(f\):
CME-CME interaction level, \(i\):

Documentation

not available
not available
not available
not available

Calculate  Reset

CME geo-effectiveness forecast tool has performed 285 successful calculations (since 10.3.2014).

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CME Geo-effectiveness Forecast Tool (CGeFT)

http://oh.geof.unizg.hr/CGEFT/cgeft.php

Probability distribution and expected |Dstl| level

INPUT:
- $v = 400.00$ km/s
- $r = 0.80$ Reun
- $w = \text{non-halo}$
- $f = \text{B or C-class flare}$
- $i = \text{no interaction}$

Probability distribution and expected |Dstl| level

INPUT:
- $v = 1000.00$ km/s
- $r = 0.35$ Reun
- $w = \text{partial halo}$
- $f = \text{M-class flare}$
- $i = \text{probable interaction}$

Probability distribution and expected |Dstl| level

INPUT:
- $v = 1500.00$ km/s
- $r = 0.10$ Reun
- $w = \text{halo}$
- $f = \text{X-class flare}$
- $i = \text{interaction highly probable}$
Forbush Decrease Forecast Tool (FDFT)

http://oh.geof.unizg.hr/FDFT/fdft.php

**INPUT:**
- $v = 500.00 \text{ km/s}$
- $r = 0.95 \text{ Rsun}$
- $w = 100.00 \text{ deg}$
- $f = 100.00 \times 10^{-7} \text{Wm}^{-2}$
- $i = \text{no interaction}$

**Probability distribution and expected FD range**

- **Input:** $v = 800.00 \text{ km/s}$
  - $r = 0.45 \text{ Rsun}$
  - $w = 150.00 \text{ deg}$
  - $f = 300.00 \times 10^{-7} \text{Wm}^{-2}$
  - $i = \text{interaction not likely}$

**Input:** $v = 1000.00 \text{ km/s}$
- $r = 0.25 \text{ Rsun}$
- $w = 200.00 \text{ deg}$
- $f = 500.00 \times 10^{-7} \text{Wm}^{-2}$
- $i = \text{probable interaction}$

**Probability distribution and expected FD range**

- **Input:** $v = 2000.00 \text{ km/s}$
  - $r = 0.05 \text{ Rsun}$
  - $w = 360.00 \text{ deg}$
  - $f = 5000.00 \times 10^{-7} \text{Wm}^{-2}$
  - $i = \text{interaction highly probable}$
EVALUATION MEASURE – HEIDKE SKILL SCORE (meteorology!):
$-\infty < \text{HSS} < 1$

- HSS=0 as good as a random guess
- HSS<0 worse than a random guess
- HSS>0 better than a random guess
- HSS=1 perfect forecast

<table>
<thead>
<tr>
<th>Effect</th>
<th>FD</th>
<th>HSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>no intense effect</td>
<td>$\text{FD} &lt; 6%$</td>
<td>0.31</td>
</tr>
<tr>
<td>no strong or intense effect</td>
<td>$\text{FD} &gt; 3%$</td>
<td>0.5</td>
</tr>
<tr>
<td>any effect</td>
<td>$\text{FD} &gt; 1%$</td>
<td>0.24</td>
</tr>
</tbody>
</table>

e.g. human forecast (SIDC*) whether or not there will be storm, HSS=0.34

Devos et al (2014); Solar Influences Data Center (at ROB, BEL)
The work leading to this research was (partly) funded by:

- EU FP7 project COMESEP (Coronal Mass Ejections and Solar Energetic Particles)
- HRZZ project SOLSTEL (Solar and Stellar variability)
- HEP (national) project “Predviđanje učinaka Sunčevih koroninih izbačaja na Zemljino magnetsko polje”
- Research grant at the Royal Observatory of Belgium “Testing and improvement of the CME Geomagnetic Forecast Tool (CGFT)”
- ESF funding program “Increase of the competitiveness through development of researchers in Solar Physics” (PoKRet)

Publication:
Dumbović et al. (2015a), Sol.Phys.  
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