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THE HVAR OBSERVATORY CME-EFFECTIVENESS FORECAST TOOLS

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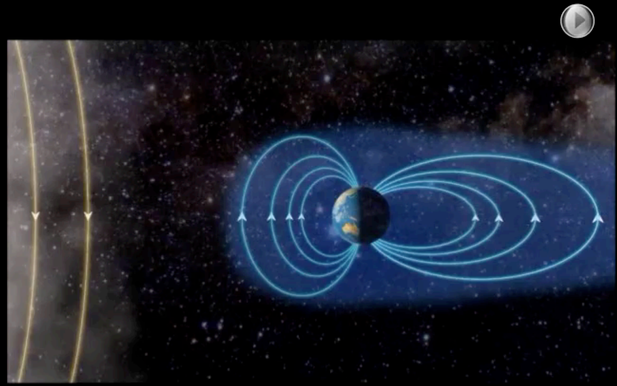
GEOMAGNETIC STORMS

Geomagnetic disturbances (detected by magnetometers at Earth)

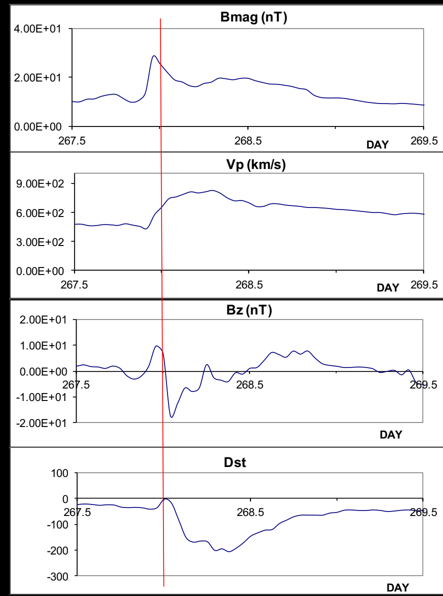
Currents induced by charged particles injected due to magnetic reconnection between ICME & geomagnetic field

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

Dungey (1961), Koskinen&Huttunen (2006), Verbanac et al (2013)



Animation: www.forskning.no (University of Oslo)



In situ/ACE + Dst indeks/Kyoto

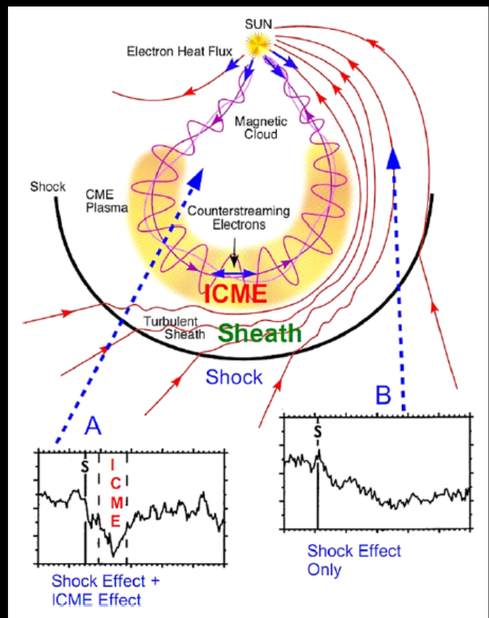
FORBUSH DECREASES

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

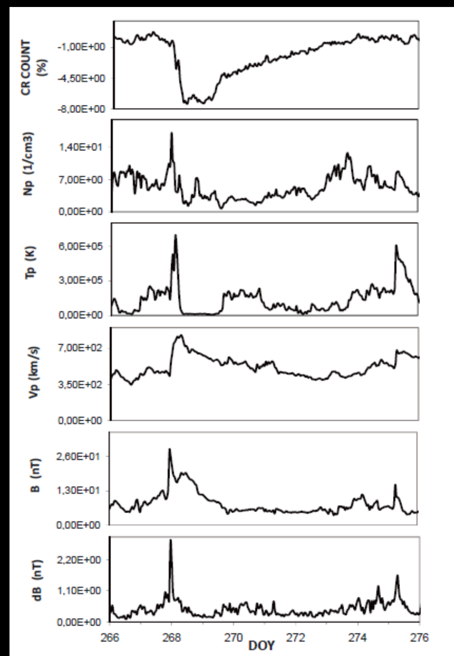
Due to interaction of GCRs with shock/sheath region and CME/ejecta region (different mechanisms)

Increased B and v crucial!

Dumbović et al (2011), Richardson & Cane (2011), Dumbović et al (2012), Belov et al (2014)

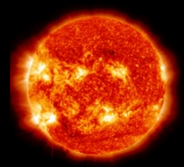


Richardson & Cane (2011)



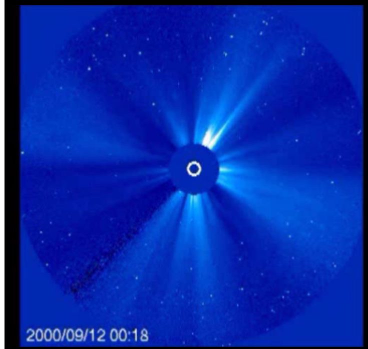
Dumbović et al (2012)

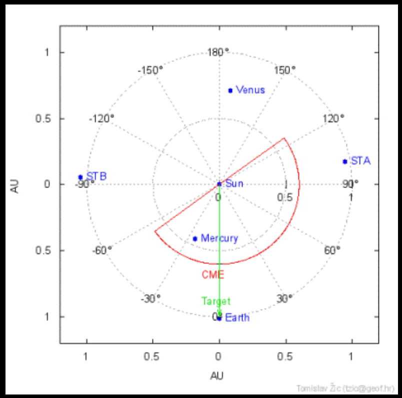
How to predict CME space weather effects?

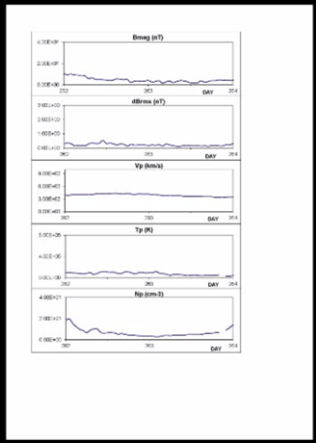


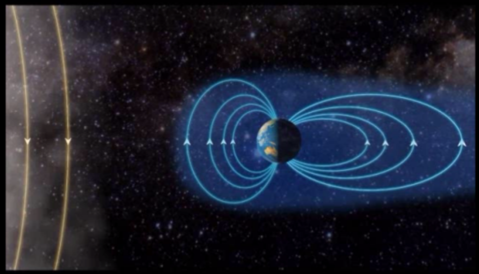
1500 000 km

150 000 000 km







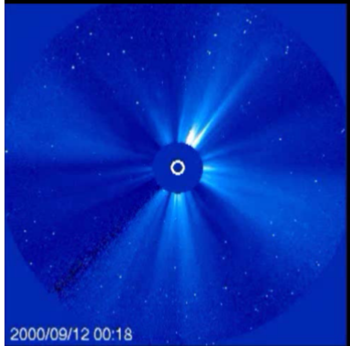


CME detection: Initial conditions → Modeling of CME propagation & evolution → Prediction of ICME arrival and near-Earth properties → Modeling of geomagnetic storms and Forbush decreases

~ 1 day

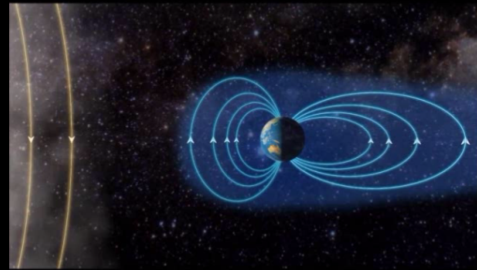
~ 1 h

How to predict CME space weather effects?



Statistical relations

Empirical probabilistic model



CME detection:
Initial conditions

Modeling of
geomagnetic storms
and Forbush
decreases

~ 1 day

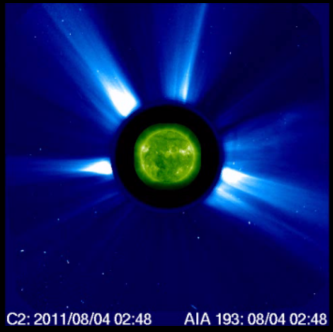
METHOD OVERVIEW:

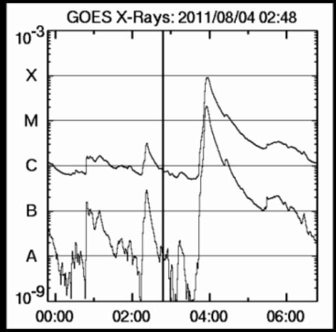
Make a sample of events

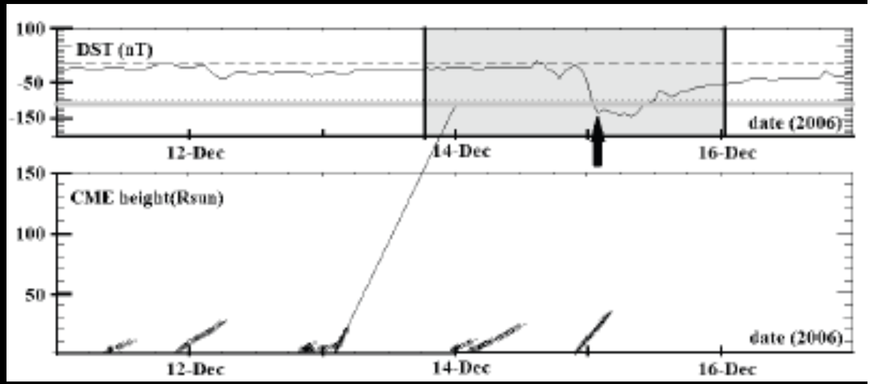
Select CMEs and associated flares

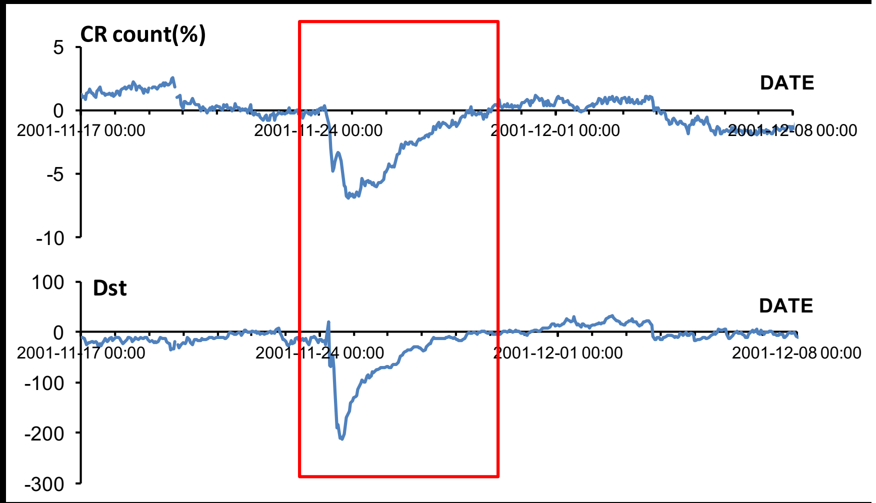
Associate geomagnetic storms (GMS)

Associate Forbush decreases (FD)









METHOD OVERVIEW:

Make a sample of events

Select CMEs and associated flares

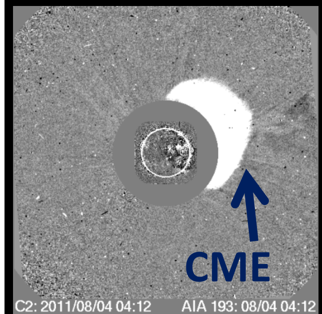
Associate geomagnetic storms (GMS)

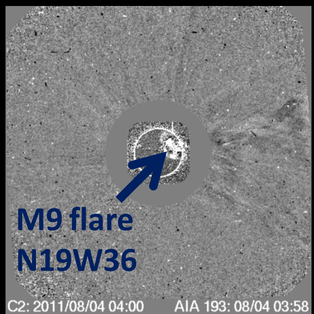
Associate Forbush decreases (FD)

Statistical analysis

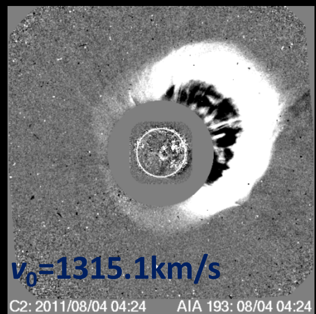
Select key CME properties

guided by previous studies:
e.g. Zhang et al. (2003), Srivastava & Venkatakrishnan (2004), Srivastava (2005), Gopalswamy et al. (2007), Zhang et al. (2007), Richardson & Cane (2011), Kim et al. (2012)

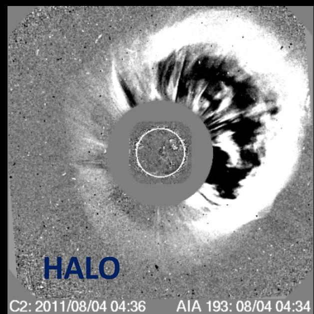




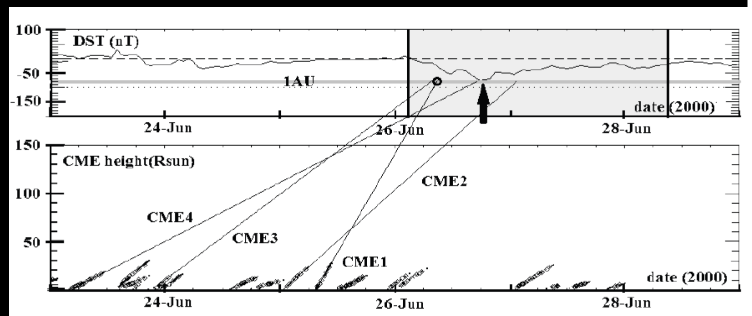
Associated flare X-ray flux peak and source position



CME speed



CME apparent width



CME-CME interaction parameter (likeliness of CME-CME interaction

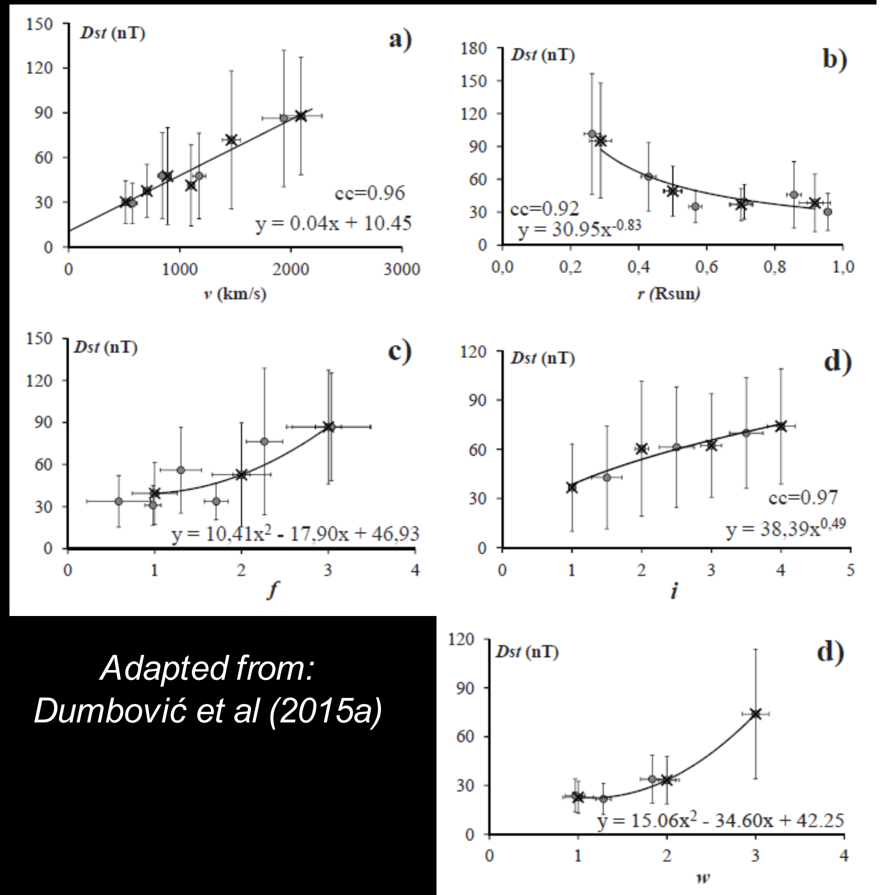
METHOD OVERVIEW:

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



Adapted from: Dumbović et al (2015a)

STRONGER STORMS ARE CAUSED BY:

- faster CMEs
- wider CMEs
- interacting CMEs
- central CME/flares
- stronger flares

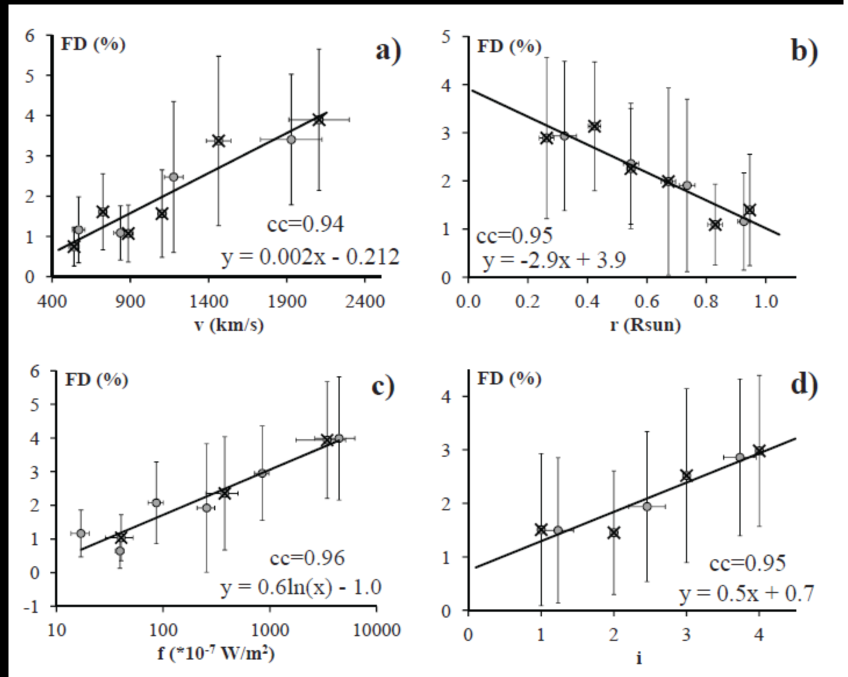
METHOD OVERVIEW:

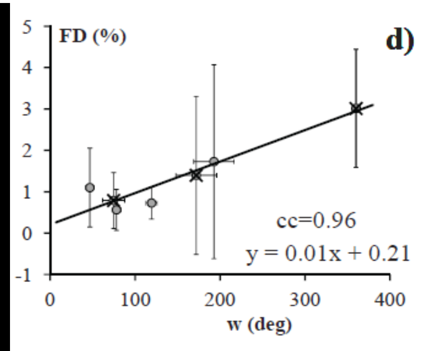
Make a sample of events

- 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





Dumbović et al (2015b)

DEEPER FDs ARE CAUSED BY:

faster CMEs
wider CMEs
interacting CMEs
central CME/flares
stronger flares

METHOD OVERVIEW:

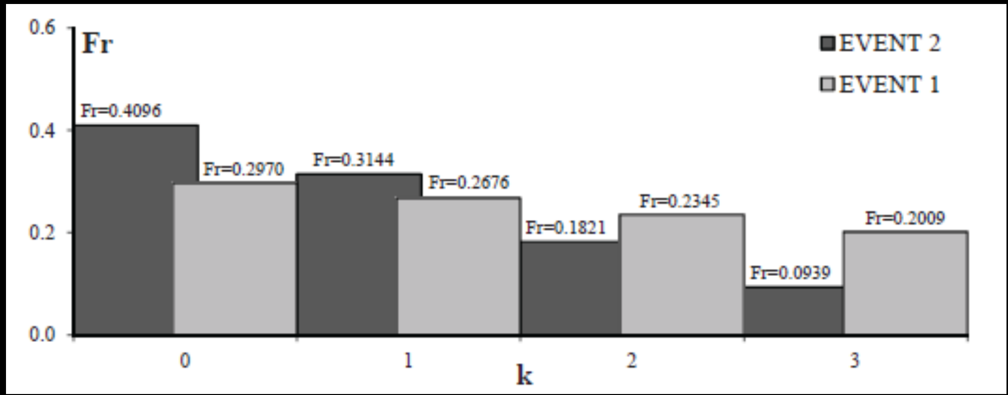
Make a sample of events

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

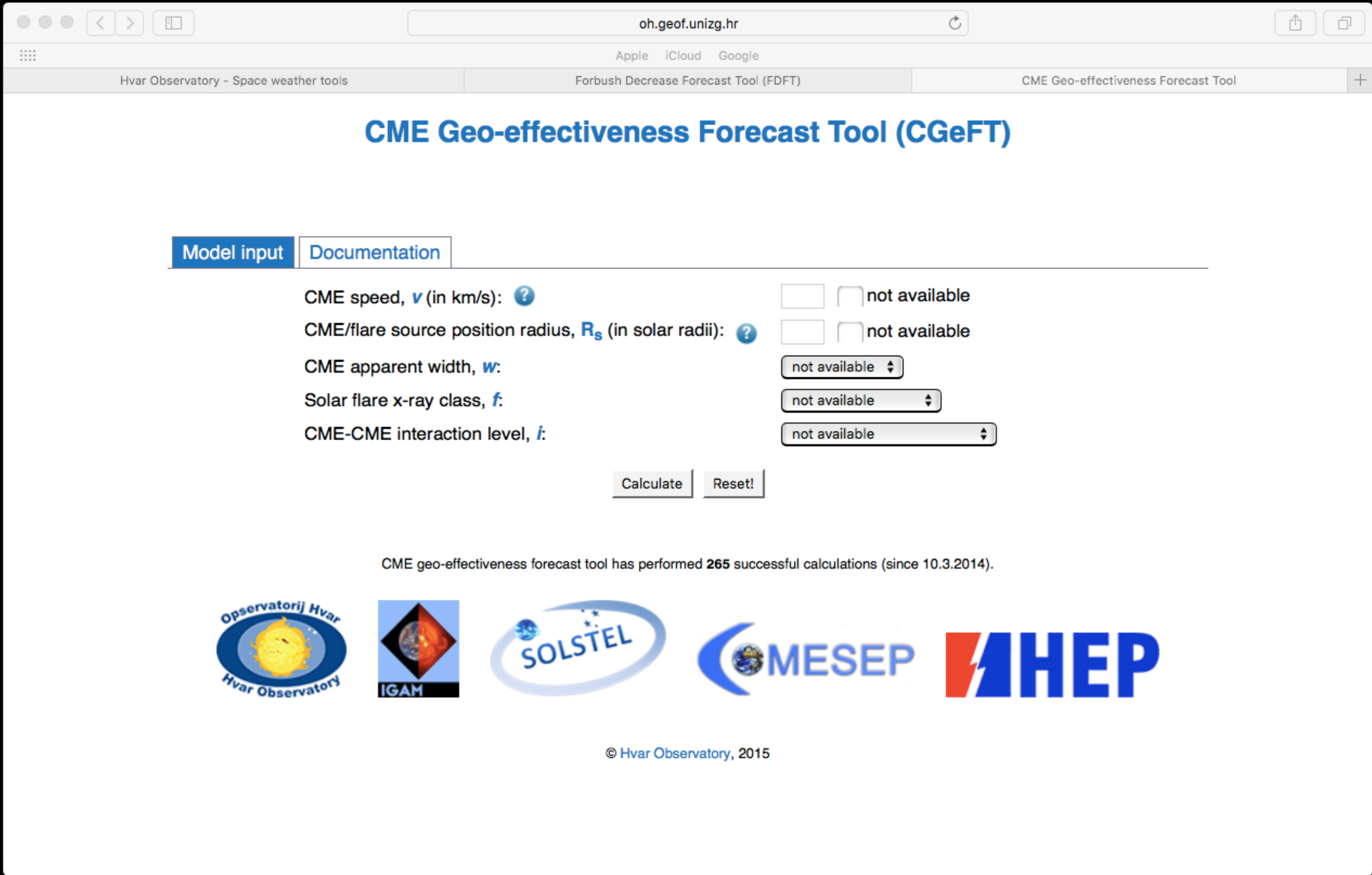
1) Construct probability distribution which changes from one event to another depending on the input parameters

2) Estimate the expected level based on the probability distribution

Model

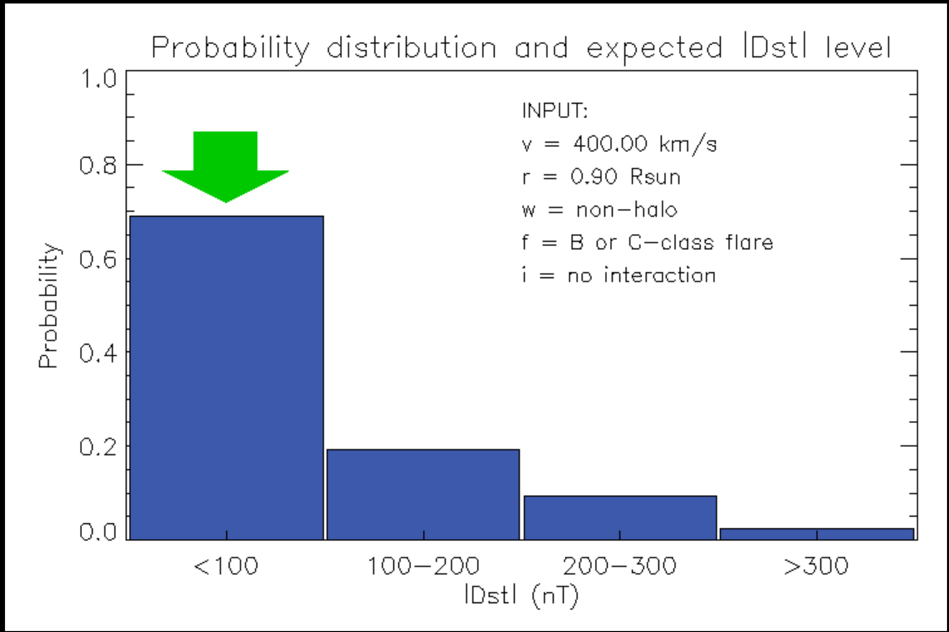
Employ the results of the statistical analysis

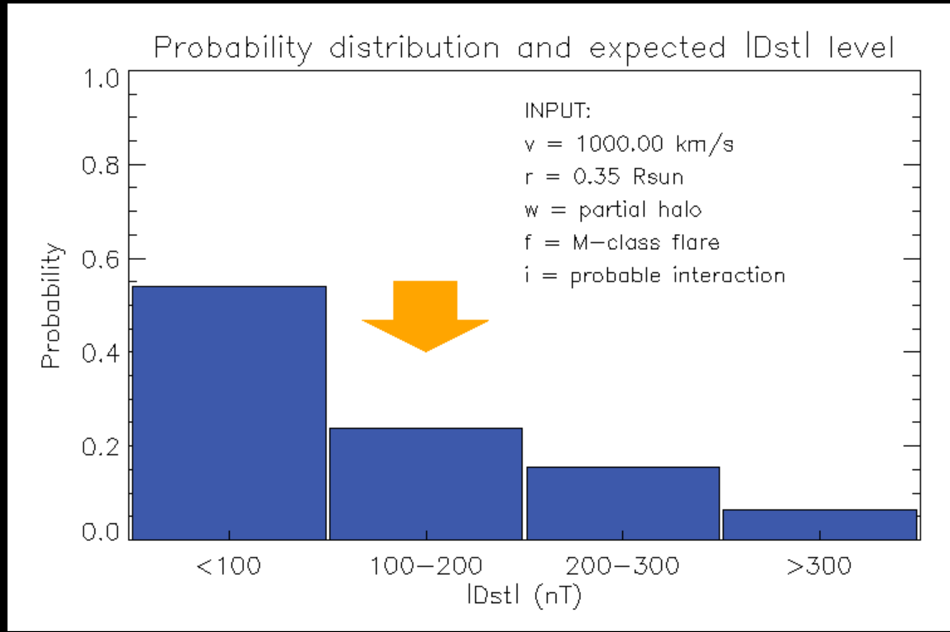
www.oh.geof.unizg.hr

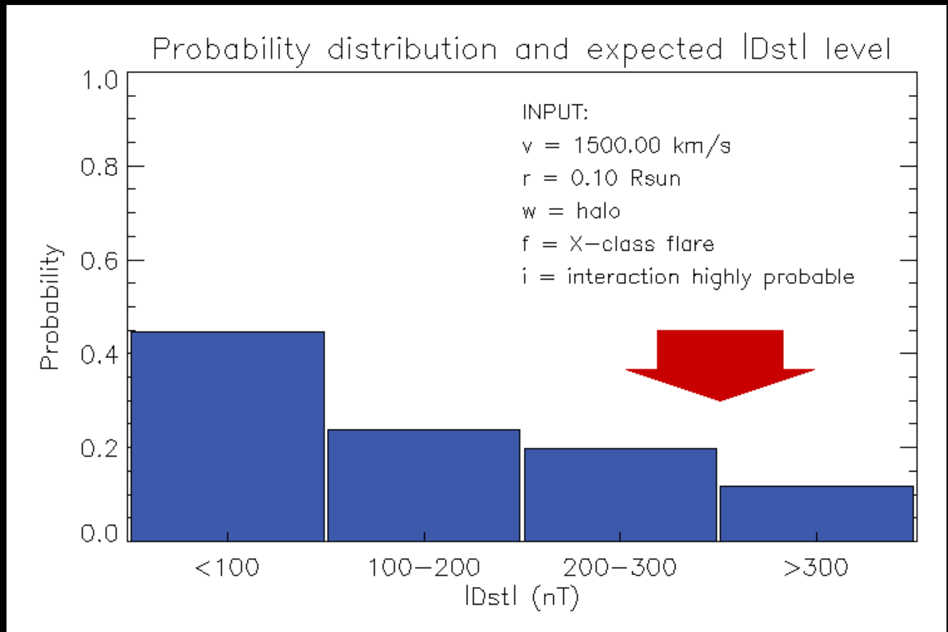


CME Geo-effectiveness Forecast Tool (CGeFT)

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

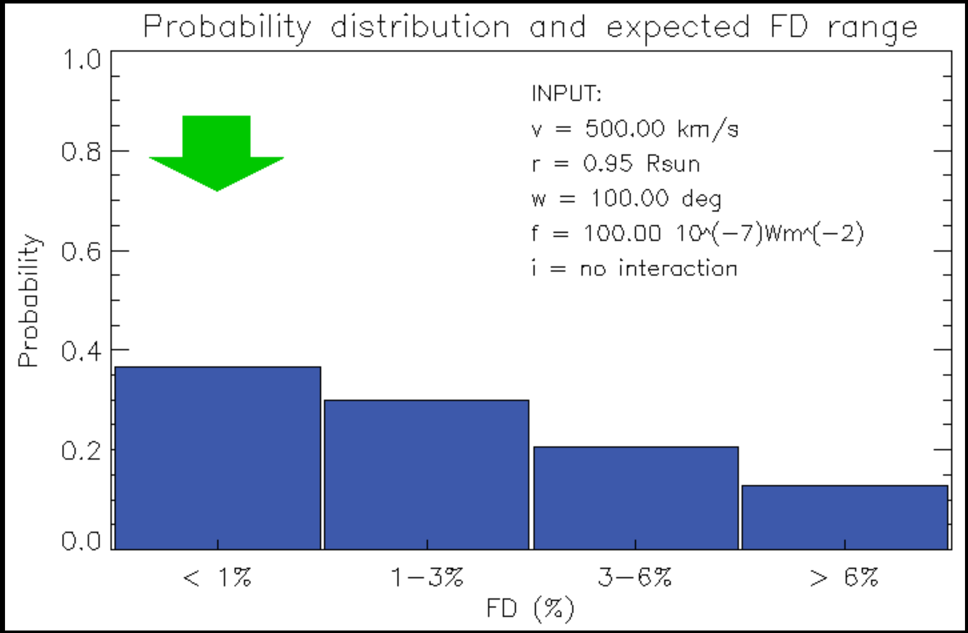


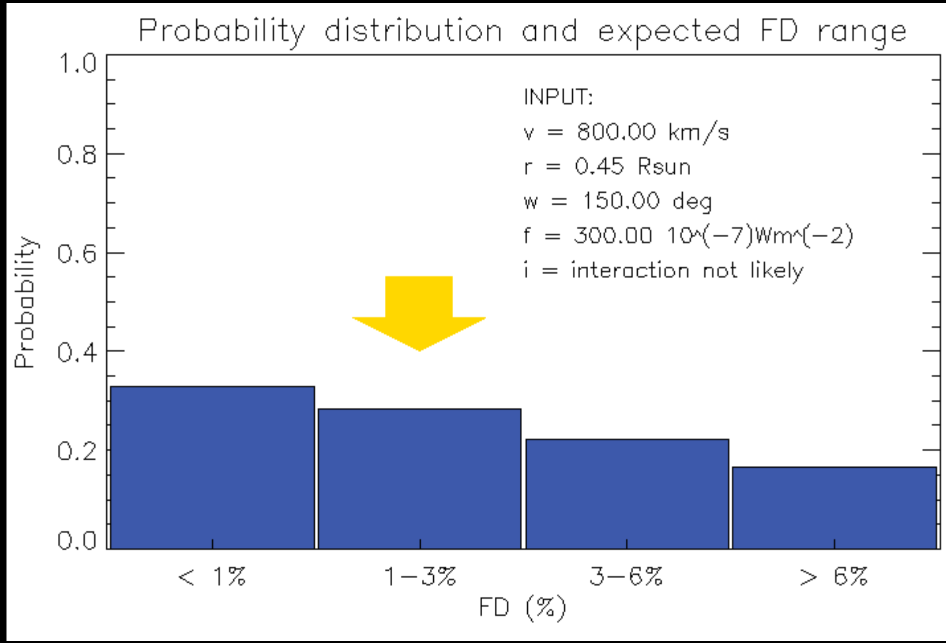


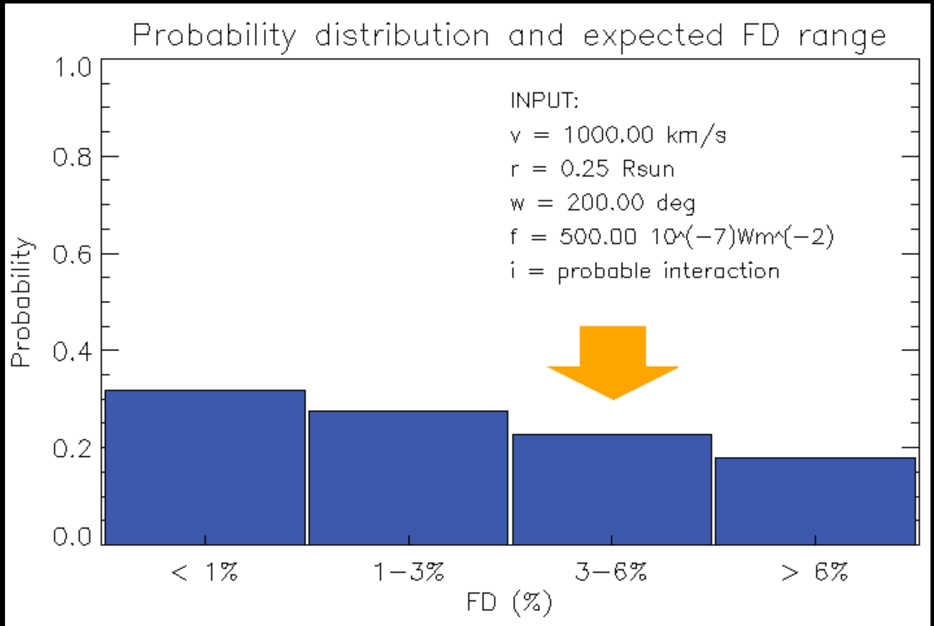


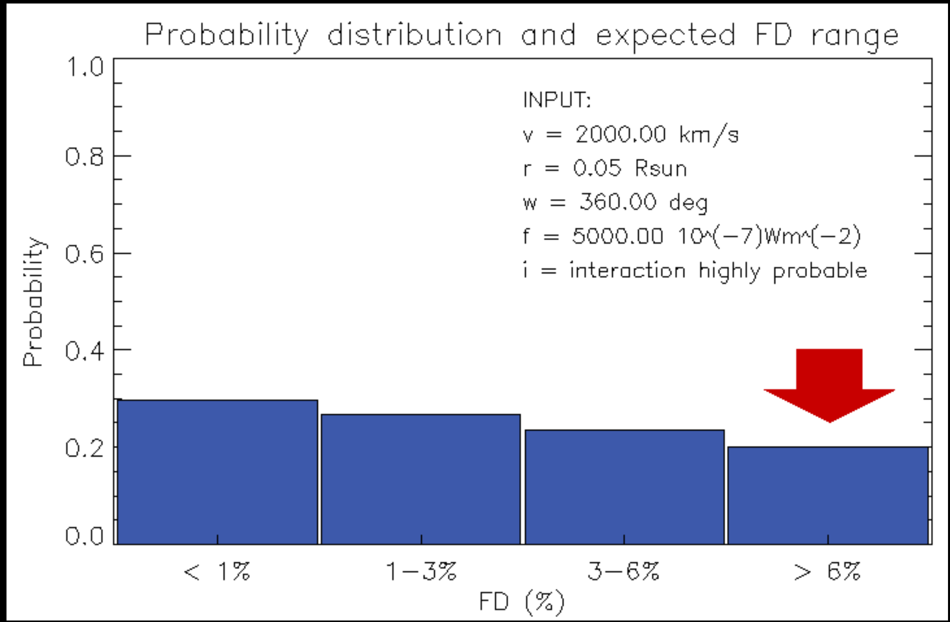
Forbush Decrease Forecast Tool (FDFT)

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









evaluation

EVALUATION MEASURE – HEIDKE SKILL SCORE (meteorology!):

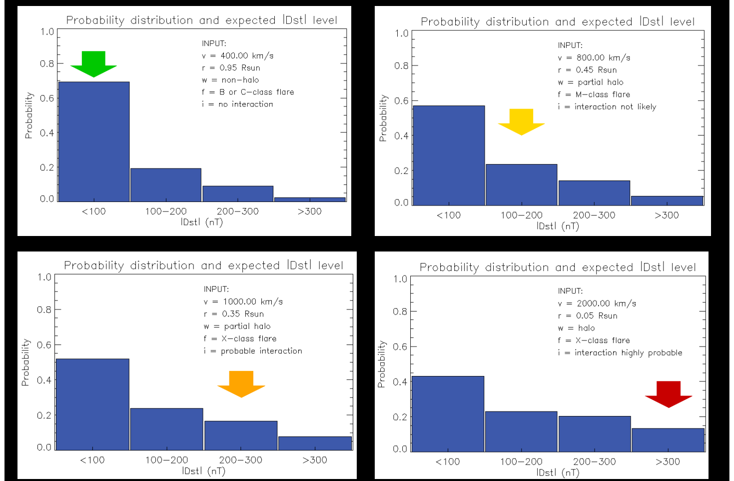
$-\infty < HSS < 1$

HSS=0 as good as a random guess

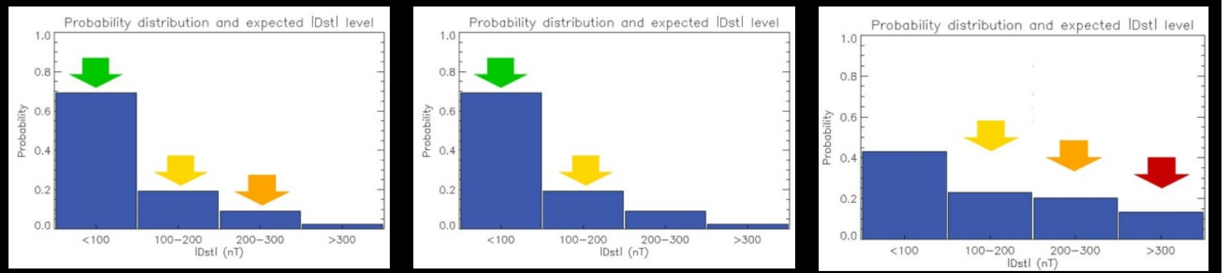
HSS<0 worse than a random guess

HSS>0 better than a random guess

HSS=1 perfect forecast



<table>
<tr><th></th><th>storm</th><th>FD</th></tr>
<tr><td>no effect</td><td>0.2</td><td>0.24</td></tr>
<tr><td>medium</td><td>0.08</td><td>0.08</td></tr>
<tr><td>strong</td><td rowspan="2">0.36</td><td>0.16</td></tr>
<tr><td>intense</td><td>0.31</td></tr>
</table>



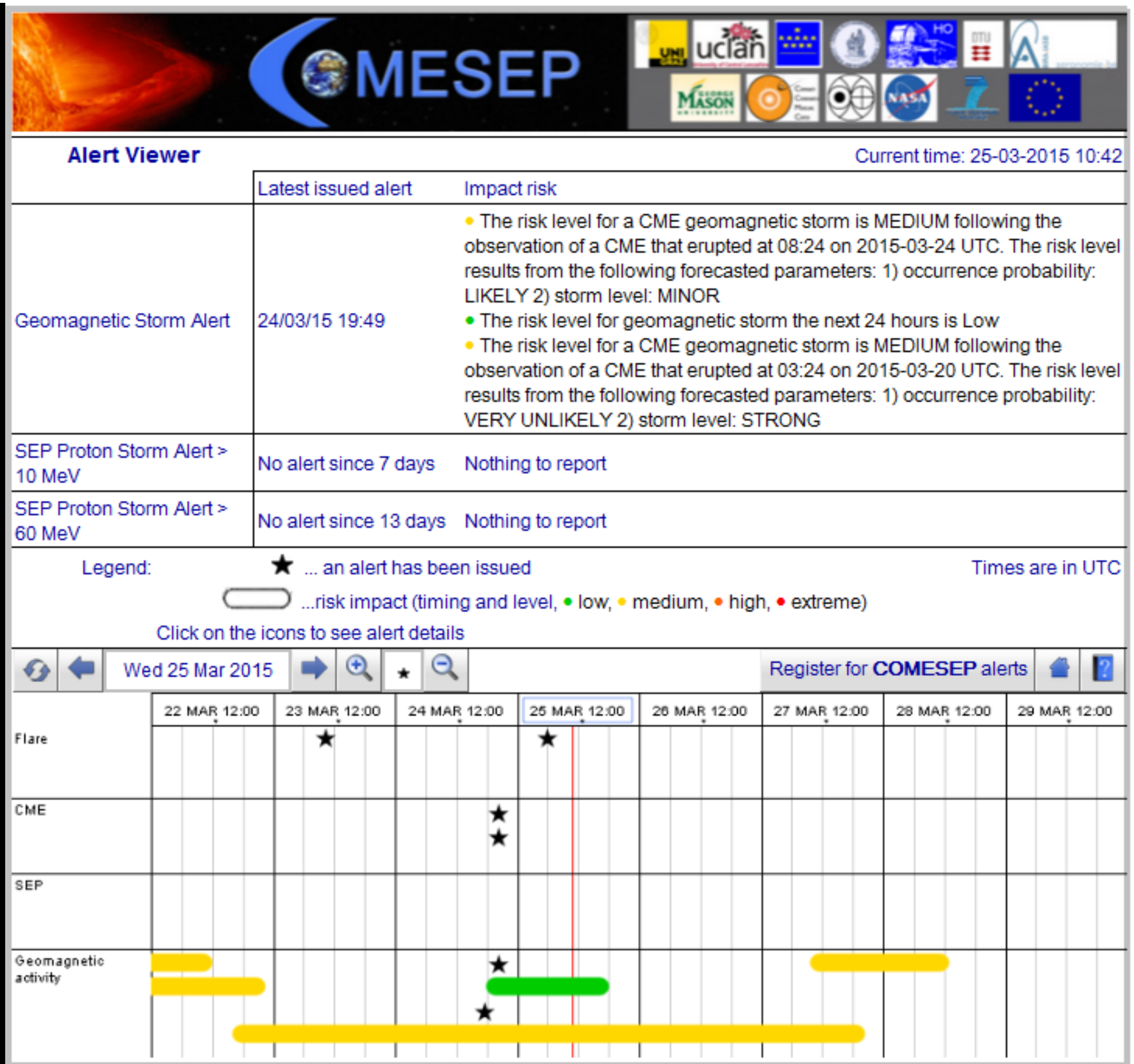
no intense effect	FD < 6%	0.31
no strong or intense effect	FD > 3%	0.5
anny effect	FD > 1%	0.24

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 1st version of CGeFT implemented in the COMESEP alert system

(check out the poster by Srivastava et al: "Validation of the CME Arrival Time and Geomagnetic forecast alerts under COMESEP")



Publication:

Dumbović et al. (2015a), Sol.Phys.
Dumbović et al (2015b), Sol. Phys.
Dumbović PhD thesis (2015)

Available at: *oh.geof.unizg.hr*

Ackgnowledgements:

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EU FP7 project COMESEP (Coronal Mass Ejections and Solar Energetic Particles)
HRZZ project SOLSTEL (Solar and Stelar 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)

Thank you for your attention!

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