Current NOAA/SWPC Proton Forecast Skill and Assessment of Future Improvements With the WSA-ENLIL + SEPMOD Model

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SPACE WEATHER PREDICTION CENTER
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University of Colorado Boulder

CIRES

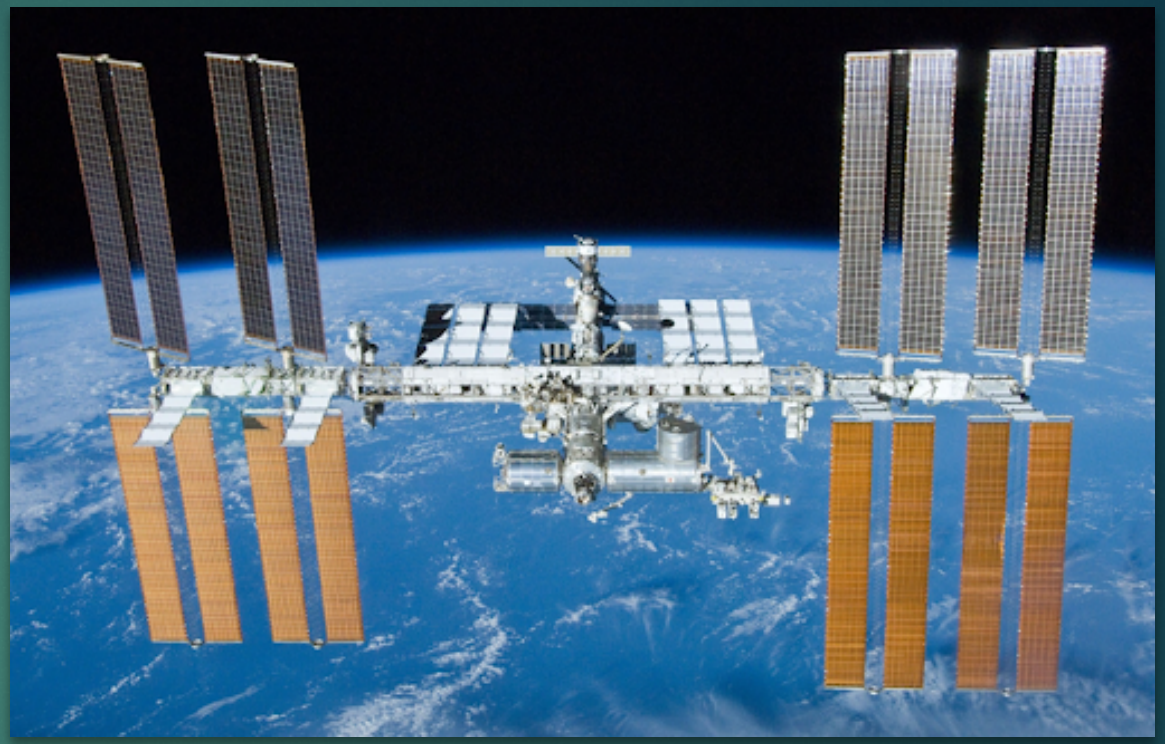
Boulder Solar Alliance
Research Experience for Undergrads

Millersville University

Solar Radiation Storms

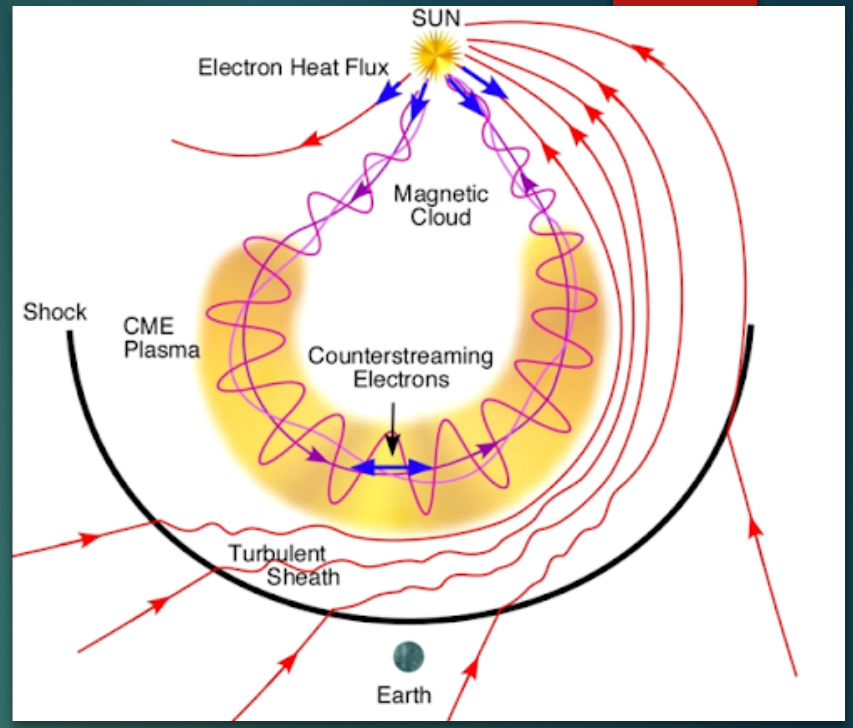
- NOAA Space Weather Prediction Center issues forecasts for solar radiation storms, predominantly consisting of energetic protons.

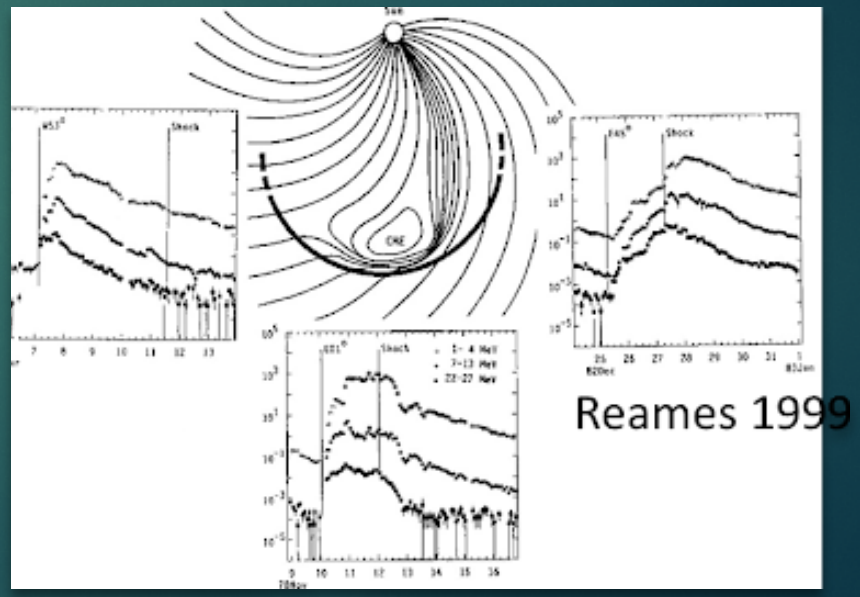
- These events can be hazardous to:
  - the health of astronauts
  - The health of passengers and crew on polar flights
  - satellite electronics
  - HF radio communication at the poles



Proton Events

- After the eruption of a Coronal Mass Ejection (CME), the CME can develop a shock
- Protons in the solar atmosphere and solar wind can get swept up into these shocks and accelerated to higher energies
- When these CMEs become connected to Earth magnetically, these protons begin to stream down the magnetic field line straight to Earth
- Due to this the timing of the proton event does not just depend on when the CME leaves the sun, but when it becomes magnetically connected to Earth
- CMEs behave differently depending on if the erupt from the sun's eastern or western limb





SWPC Solar Radiation Scale (S-scale)

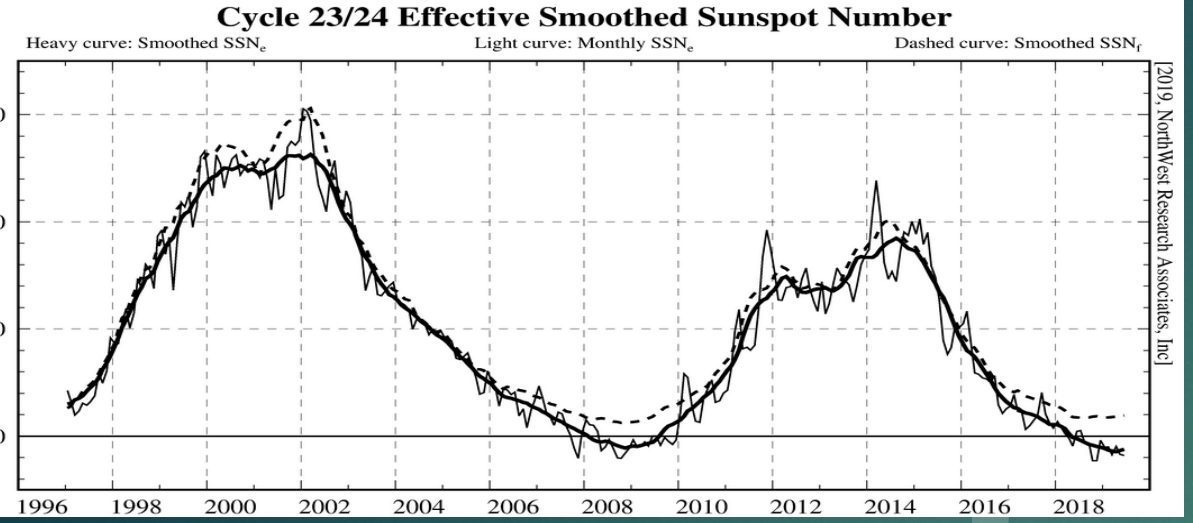
- SWPC issues forecast warnings for the expected onset of S1 events, defined as the time when 10 MeV protons exceed 10 Proton Flux Units (pfu). Pfu is protons/sr/cm^2/s
- Warnings are also issued for 100 MeV protons exceeding 1 p.f.u.
- In addition, SWPC forecast alerts are issued when these thresholds are crossed

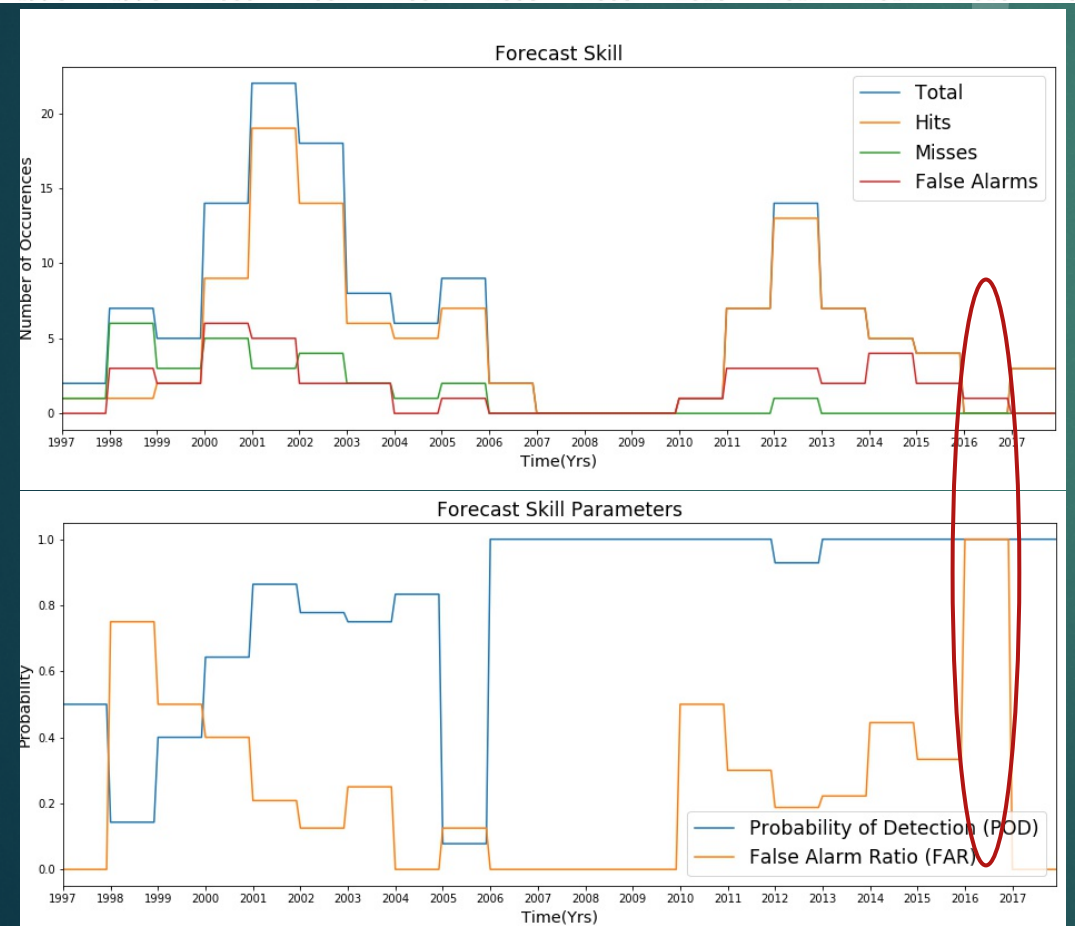
Scale	Description	Effect	**Physical measure** (Flux level of >= 10 MeV particles)	**Average Frequency** (1 cycle = 11 years)
S 5	**Extreme**	**Biological:** Unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. **Other systems:** Complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	**Severe**	**Biological:** Unavoidable radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** May experience memory device problems and noise on imaging systems; star-tracker problems may cause orientation problems, and solar panel efficiency can be degraded. **Other systems:** Blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.	10^4	3 per cycle
S 3	**Strong**	**Biological:** Radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** Single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. **Other systems:** Degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	**Moderate**	**Biological:** Passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk. **Satellite operations:** Infrequent single-event upsets possible. **Other systems:** Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	**Minor**	**Biological:** None. **Satellite operations:** None. **Other systems:** Minor impacts on HF radio in the polar regions.	10	50 per cycle

SWPC Forecasting Skill

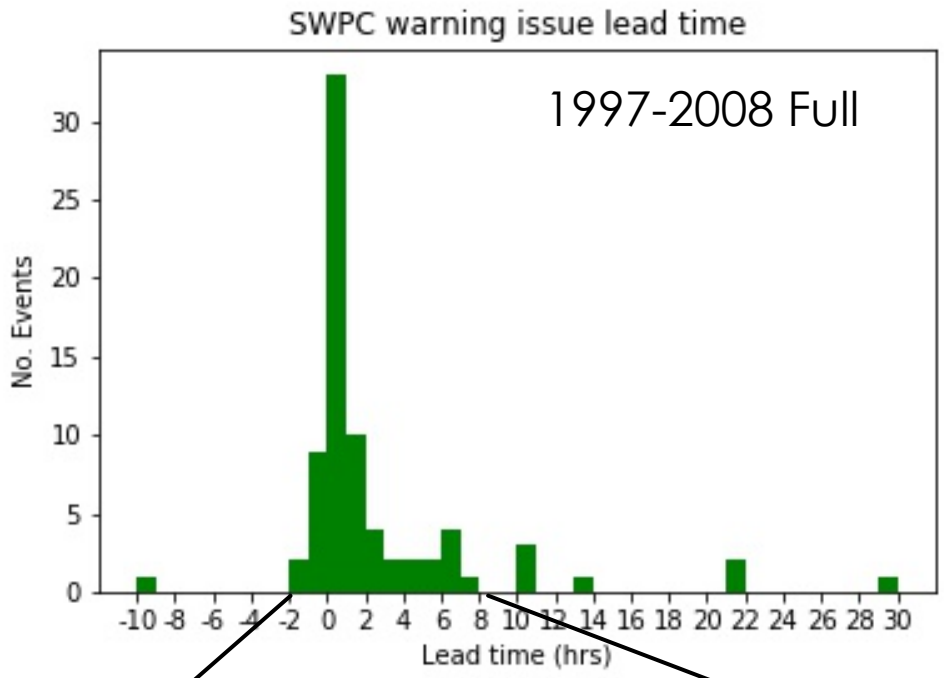
- Currently SWPC uses the PROTONS model to support proton event forecasting, however newer models could add value
- Before attempting to assess the usefulness of other models in the future, it is important to first assess how well the current forecasters perform using the tools and models already available to them.
- To do this we analyzed two decades of forecast data between 1997 and 2017 in order to determine the forecast skill of the SWPC forecasters.

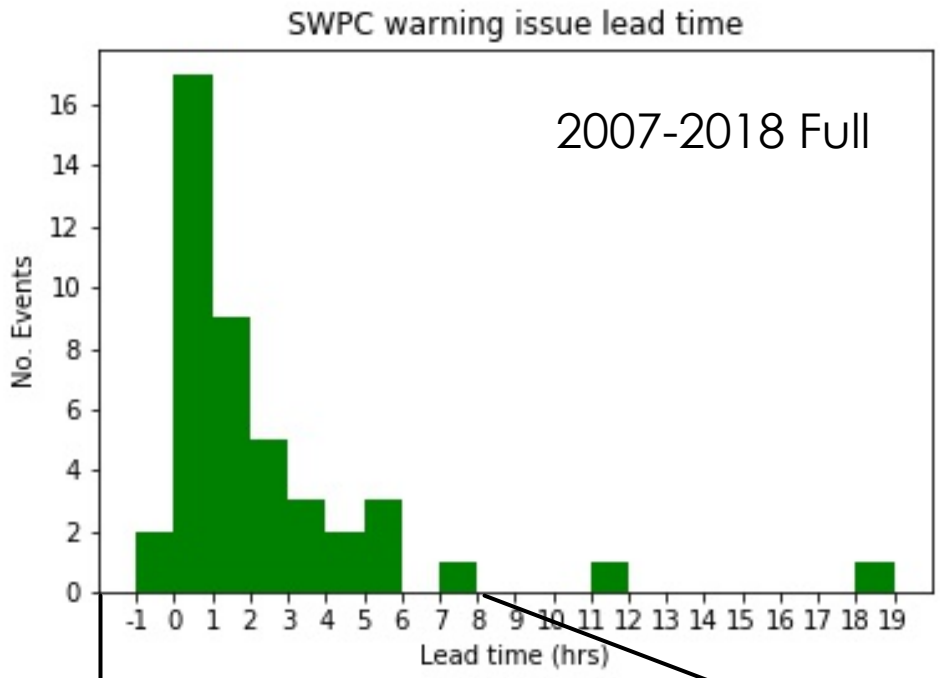
SWPC Forecast Skill

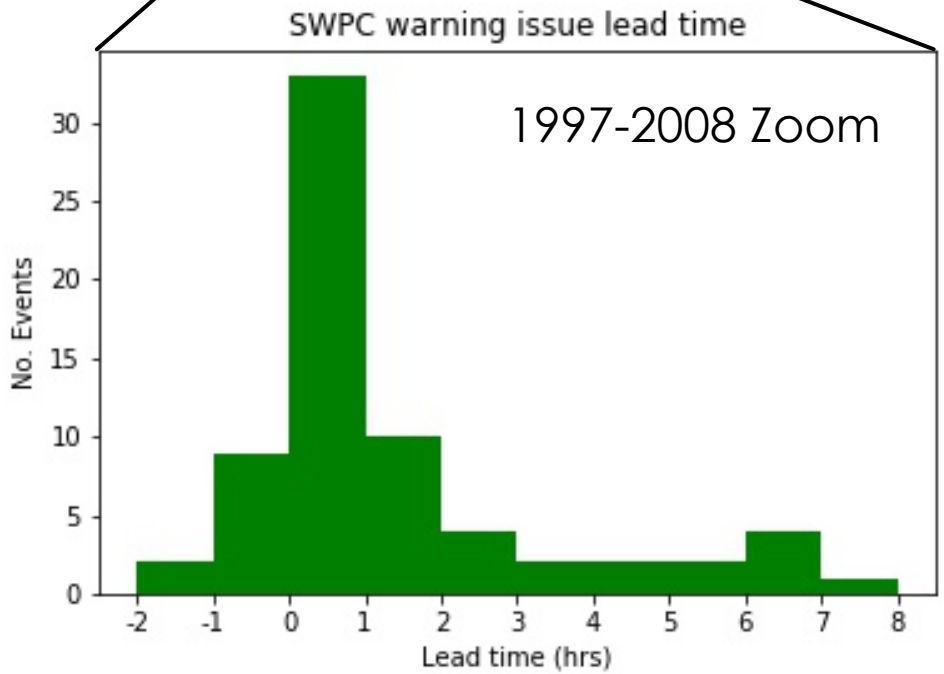


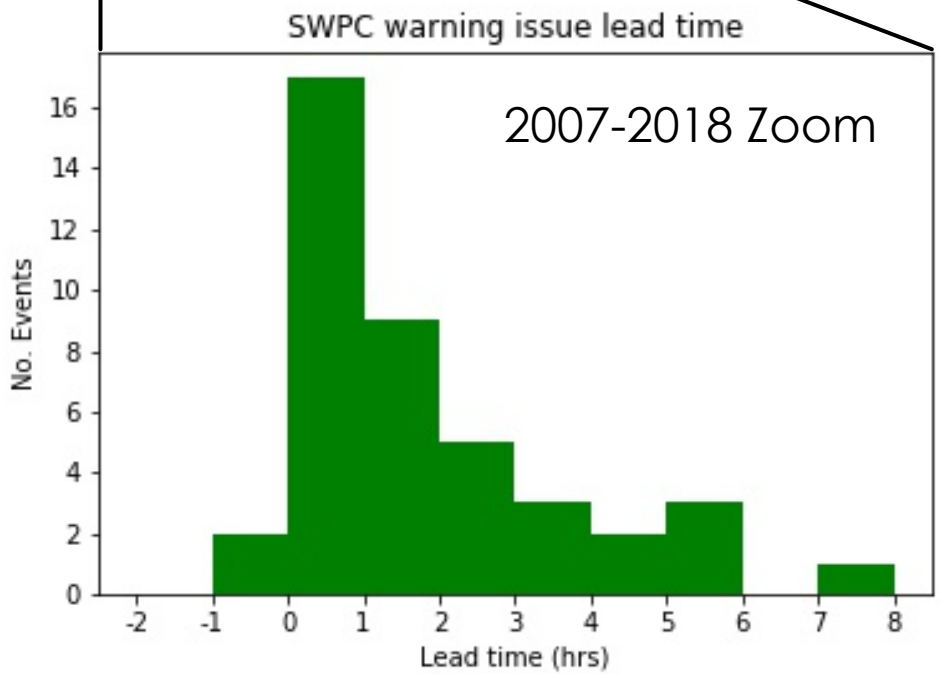


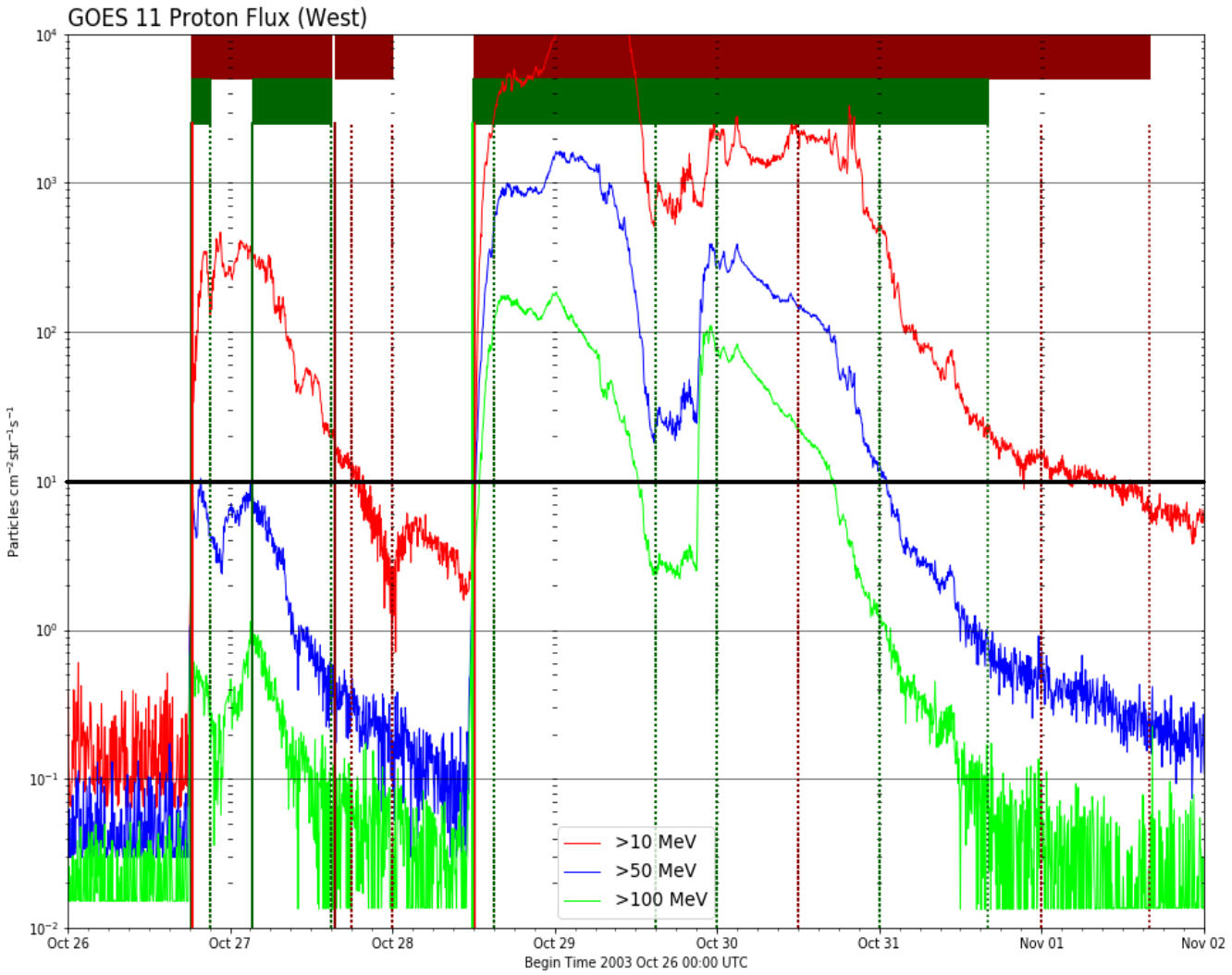
- Hit – Warning was issued before alert – Also called True Positive (TP)
- Miss – Warning either wasn't issued or issued after alert – Also called False Negative (FN)
- False Alarm – Warning issued when there was no event – Also called False Positive (FP)
- $Probability\ of\ Detection = \frac{TP}{(TP+FN)}$
- $False\ Alarm\ Ratio = \frac{FP}{(TP+FP)}$


SWPC warning issue lead time
1997-2008 Full
No. Events
Lead time (hrs)


SWPC warning issue lead time
2007-2018 Full
No. Events
Lead time (hrs)


SWPC warning issue lead time
1997-2008 Zoom
No. Events
Lead time (hrs)


SWPC warning issue lead time
2007-2018 Zoom
No. Events
Lead time (hrs)



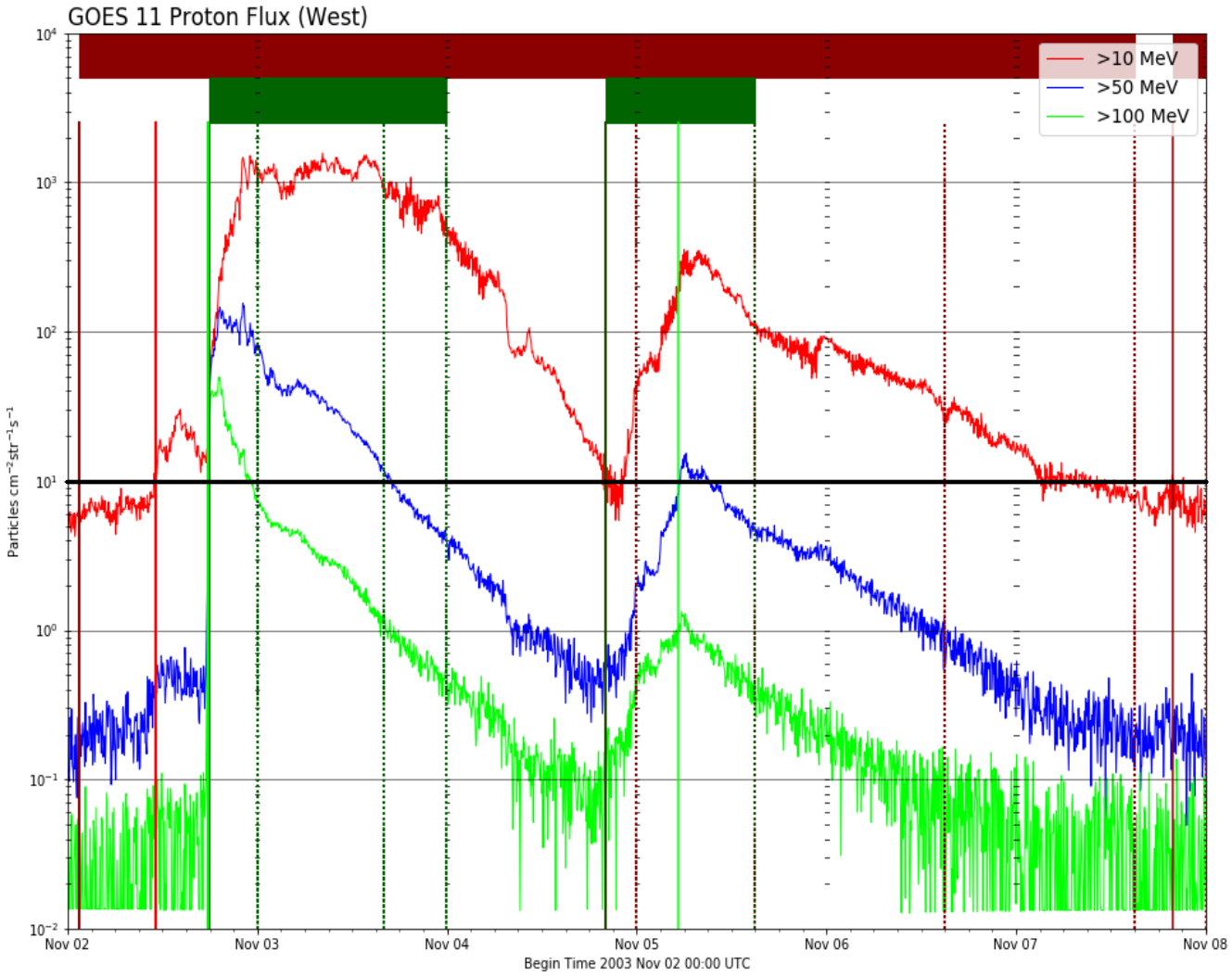
October 27-November 2, 2003

Alert

Warning Begin

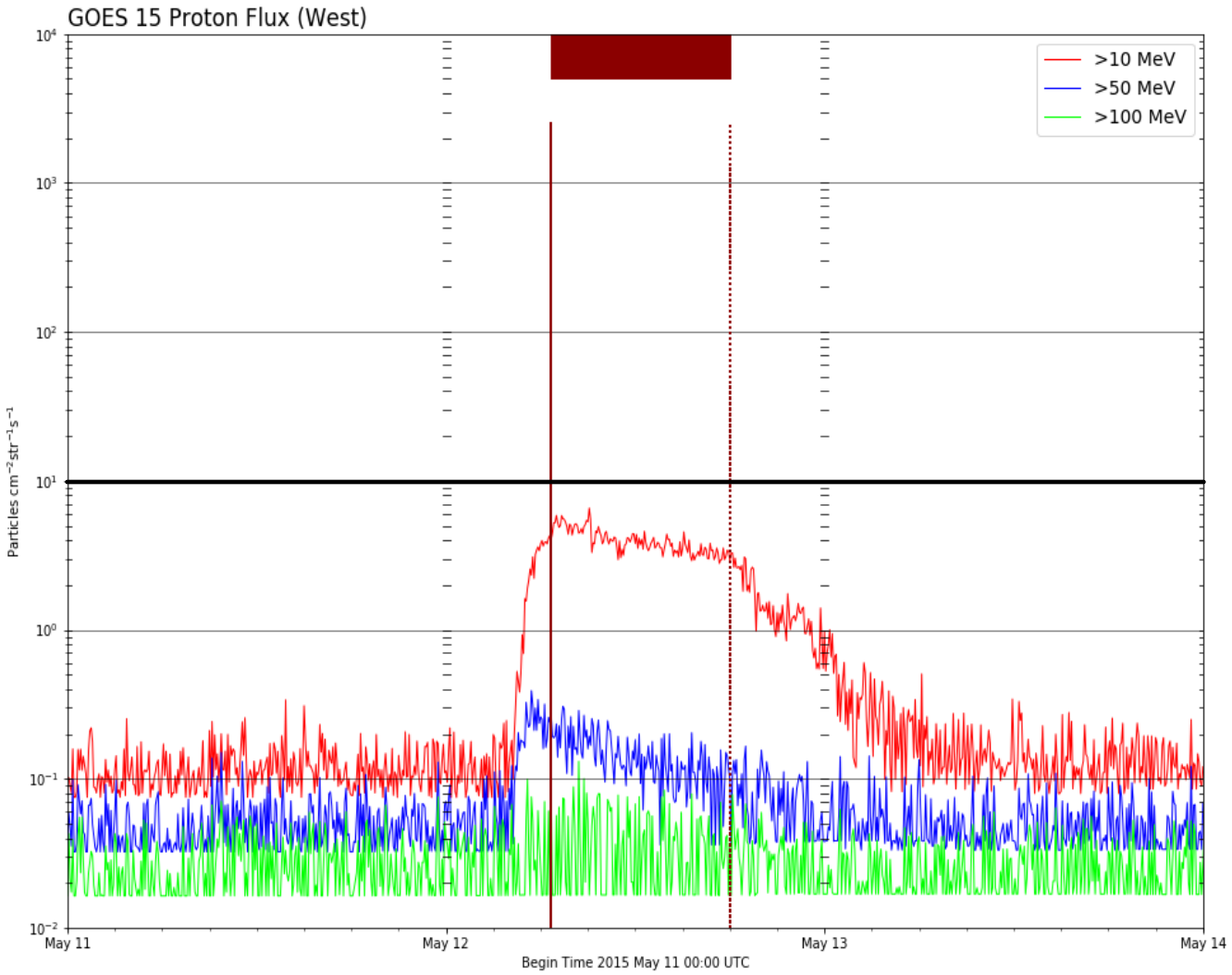
Warning End

Warning Duration



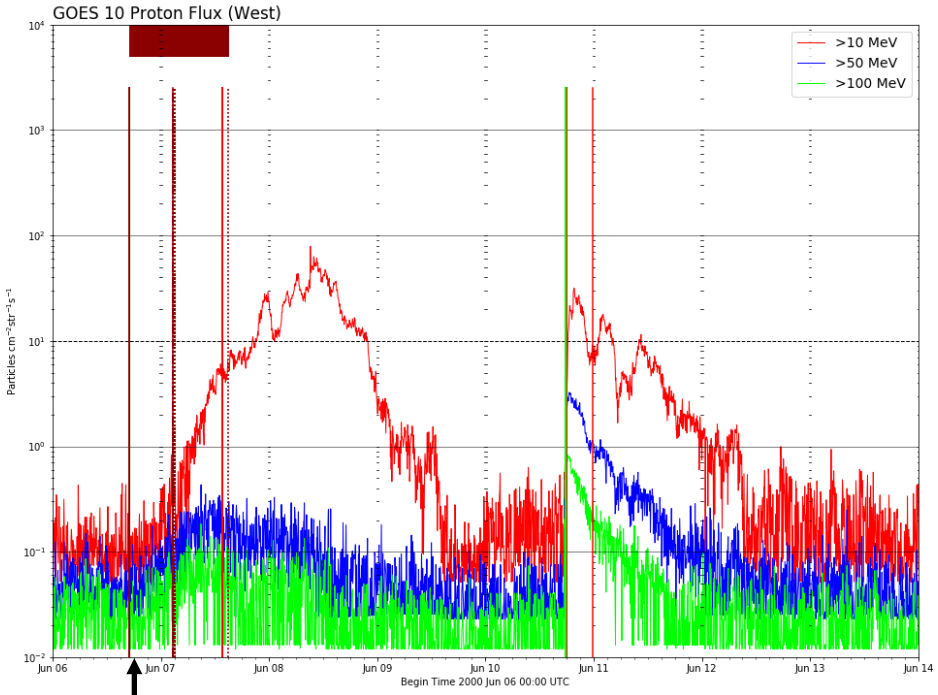
November 2-8, 2003

"Free Hit"

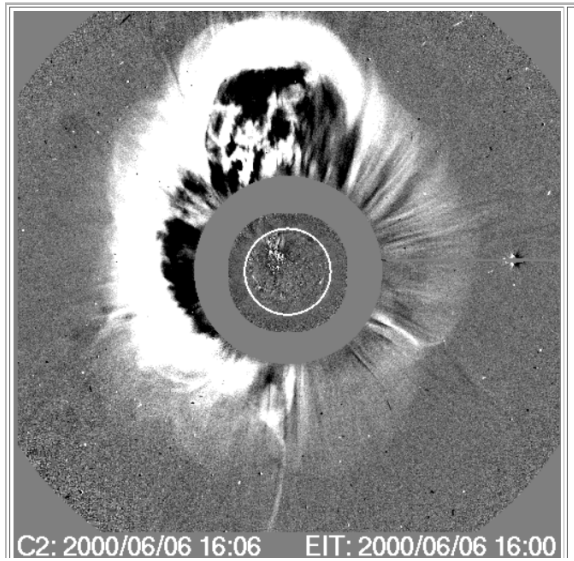


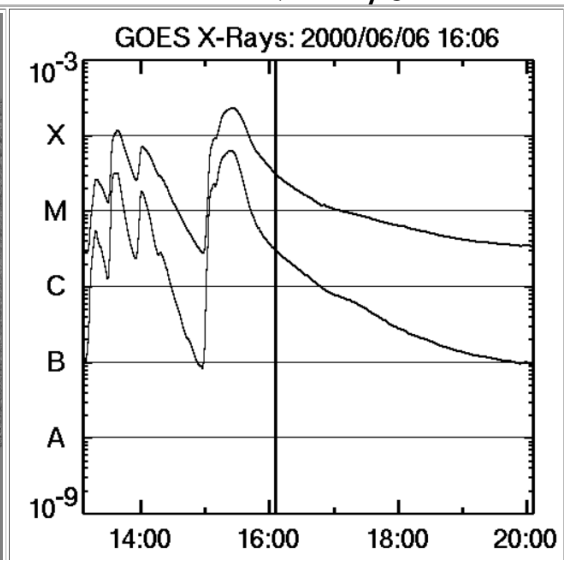
May 12, 2015

False Alarm



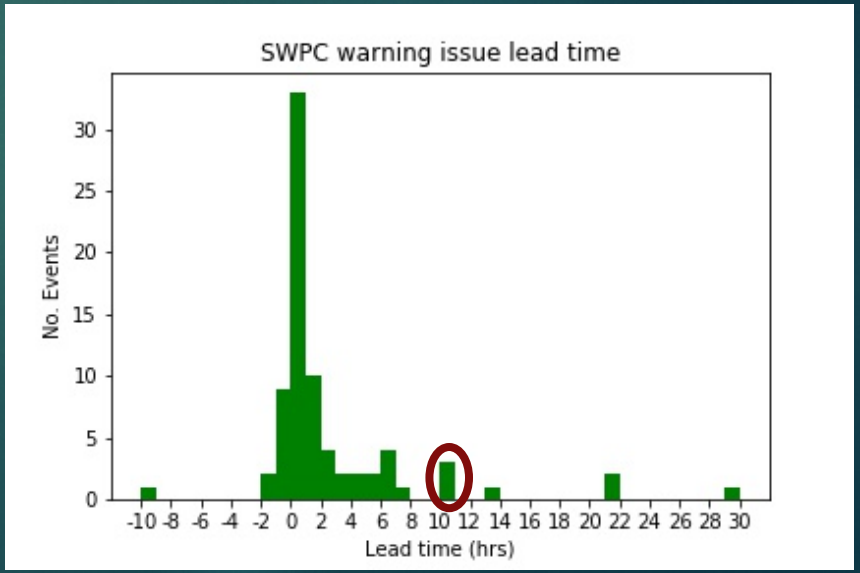
1119km/s

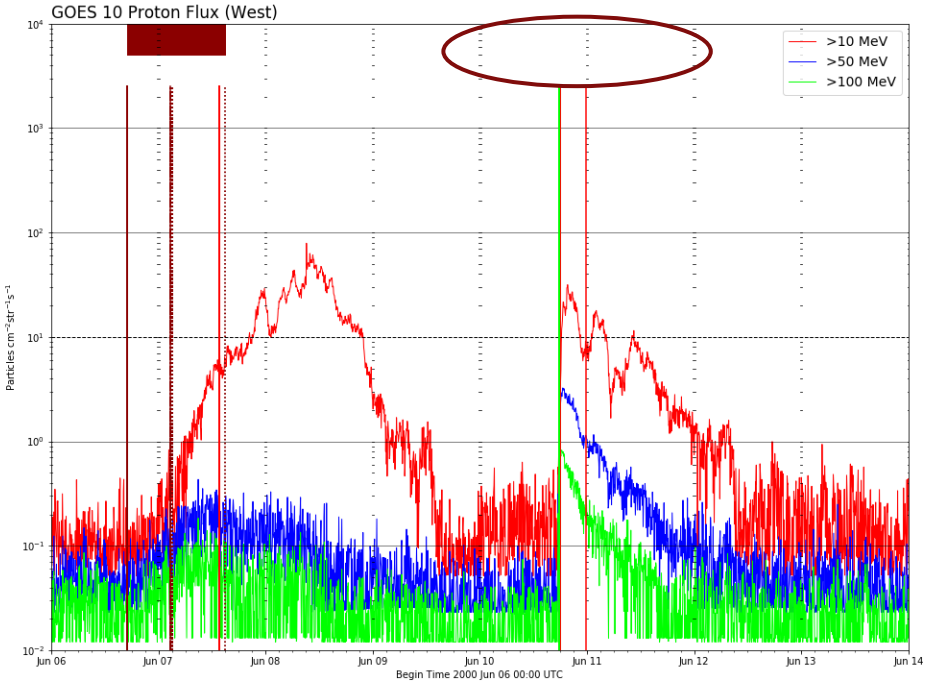




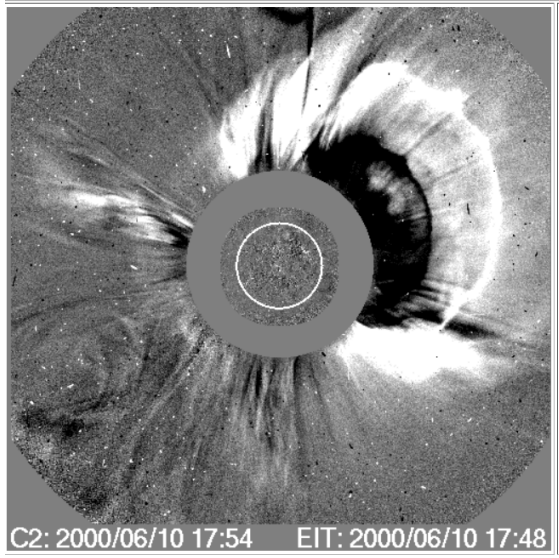
June 6-10, 2000

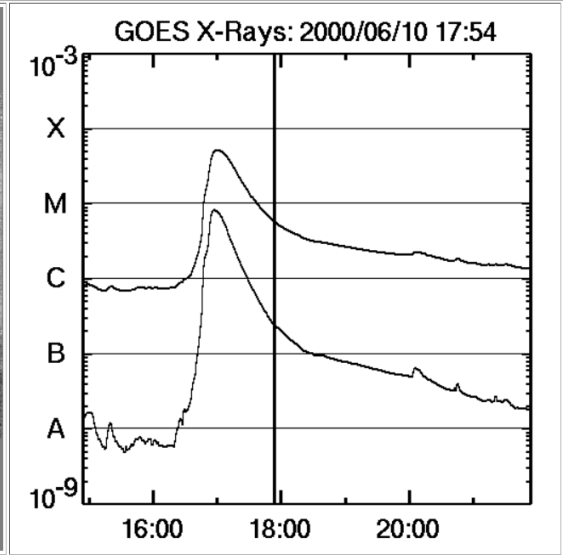
Large Lead Time: 10:49





1108 km/s



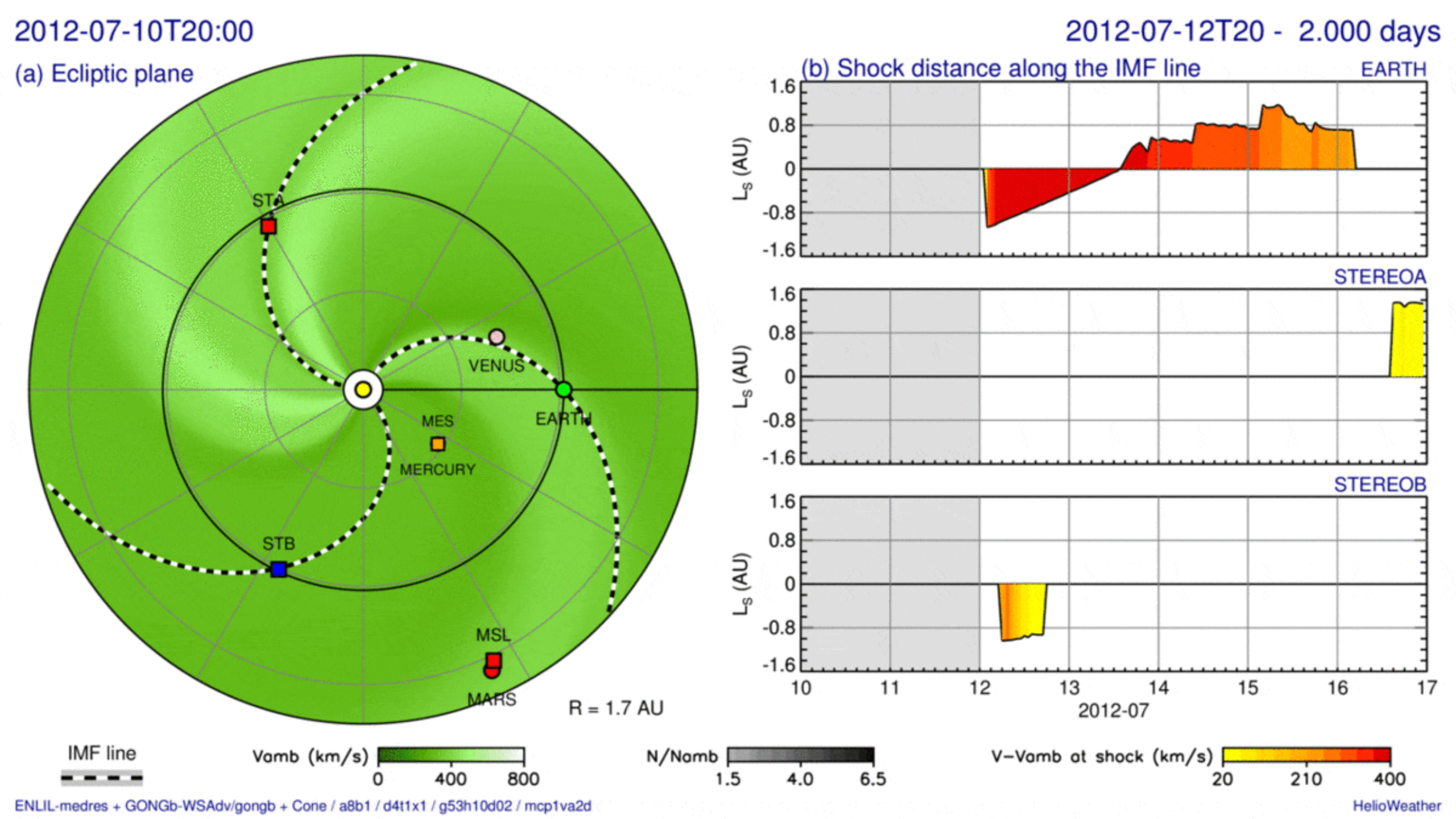


June 10-13, 2000

Total Miss

WSA-ENLIL

- We looked at several case study events coming from the eastern limb of the sun
- For each event we ran WSA-ENLIL with the CMEs within a week of the event itself
- For the input we used the historical SWPC fits for the CMEs
  - This allowed us to assess how this model would help in a real time environment


2012-07-10T20:00
2012-07-12T20 - 2.000 days
(a) Ecliptic plane
(b) Shock distance along the IMF line
EARTH
STEREOA
STEREOB
STA
STB
VENUS
EARTH
MES
MERCURY
MSL
MARS
R = 1.7 AU
L_S (AU)
1.6
0.8
0
-0.8
-1.6
10
11
12
13
14
15
16
17
2012-07
IMF line
Vamb (km/s)
0
400
800
N/Namb
1.5
4.0
6.5
V−Vamb at shock (km/s)
20
210
400
ENLIL-medres + GONGb-WSAdv/gongb + Cone / a8b1 / d4t1x1 / g53h10d02 / mcp1va2d
HelioWeather

SEPMOD

- WSA-ENLIL was used to assess when the event became magnetically connected to Earth.
- This output was then used by SEPMOD to simulate the proton events that would be observed at Earth.

Conclusions

- $Probability\ of\ Detection = \frac{TP}{(TP+FN)}$
- $False\ Alarm\ Ratio = \frac{FP}{(TP+FP)}$
- $Critical\ Success\ Index = \frac{TP}{(TP+FN+FP)}$

	POD	FAR	CSI
Solar Cycle 23	.71	.18	.58
Solar Cycle 24	.98	.28	.70

Conclusions Cont. and Future Work

- SWPC forecasts are improving over time likely due to improved solar observations
- In between solar cycles 23 and 24 the Probability of Detection has improved from 71% to 98% and the Critical Success Index (CSI) has improved from 0.58 to 0.70
- Next will be comparing the results from SEPMOD to proton data for accuracy