NOAA/SWPC Proton Forecast Skill and Assessment of WSA-ENLIL + SEPMOD Model

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Abstract

At the NOAA Space Weather Prediction Center (NOAA/SWPC) forecasts are issued for solar radiation storms, which consist of mainly energetic protons. These events can be hazardous to astronauts and passengers & crew on polar flights, and they can damage satellite electronics. We present the current SWPC proton event forecast skill, assessed over two decades in the time period from 1997 through 2017.

Introduction

- Coronal Mass Ejections (CMEs) are large eruptions of plasma and magnetic field from the Sun. As they propagate, they can develop a shock in front of them.
- Often ions can get swept up in these shocks and protons can be accelerated to much higher energies.
- Once the CMEs become magnetically connected to Earth protons can stream along the field lines to Earth, where they are observed as a proton event (Bain et al. 2016)[1].
- In some cases protons can arrive at Earth in tens of minutes after the CME erupts, making them a challenge to forecast.

SWPC Forecast Products

- The SWPC Solar Radiation Storm S-scale (Fig. 1), is used to categorize proton events.
- SWPC forecast warnings are issued for 10MeV protons reaching a threshold of 10 protons/sr/cm^2/s and for 100MeV protons reaching a threshold of 1 proton/sr/cm^2/s
- We analyzed SWPC 10 MeV forecast warnings between 1997 and 2017 in order to determine the SWPC forecast skill.

Fig. 1: SWPC Solar Radiation Storm Scale

Forecast Metrics

SEP events and warnings were classified using the metrics in Table 1 and were used to calculate a probability of detection (POD) and false alarm ratio (FAR)

Table 1: Forecast metrics

True Positive (TP)	Warning was issued before alert [Hit]
False Negative (FN)	Warning wasn't issued or issued after alert [Miss]
False Positive (FP)	Warning issued without alert [False Alarm]

$$Probability\ of\ Detection = \frac{TP}{(TP+FN)} \qquad False\ Alarm\ Ratio = \frac{FP}{(TP+FP)}$$

Solar Cycle 23 **Solar Cycle 24**

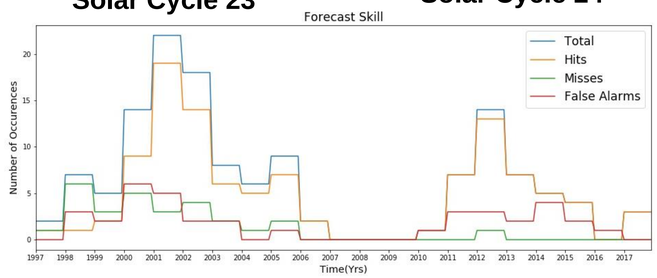

Fig. 2: Forecast outcomes from 1997 through 2017

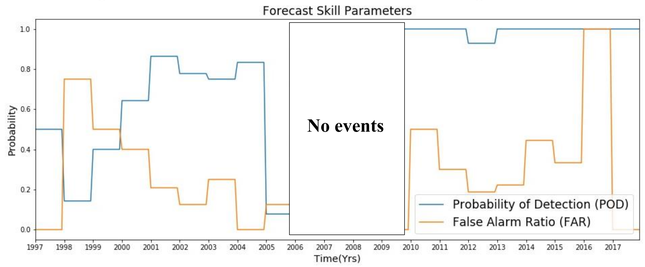

Fig. 3: Forecast POD and FAR from 1997 through 2017

- The forecast skill has improved between solar cycles 23 and 24 as less SEP events were missed, Fig. 2.
- Fig. 3 shows the POD and the FAR forecast metrics.
- In 2016 the FAR looks high, however this results from a single false alarm that year.

Forecast Lead Time

- Lead time is defined as the amount of time between the forecast warning issue time and the event onset time.
- Hits have positive lead times while misses have negative lead times
- In Fig 4 you can see that despite the difficulty in forecasting these events, SWPC still has large lead times.
- An example of a long lead time is shown in Fig. 5

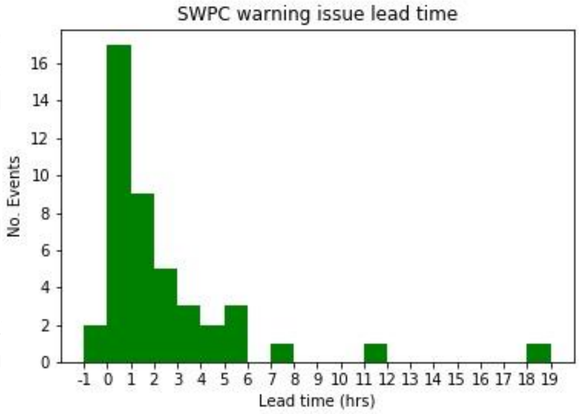

Fig 4: Lead time of warnings from 2008 through 2017

Forecast Skill

10 MeV Warning Start	Dark Red Solid Line
10 MeV Warning End	Dark Red Dotted Line
10 MeV Warning Duration	Dark Red Bar
10 MeV Alert	Light Red Solid Line
100 MeV Alert	Light Green Solid Line

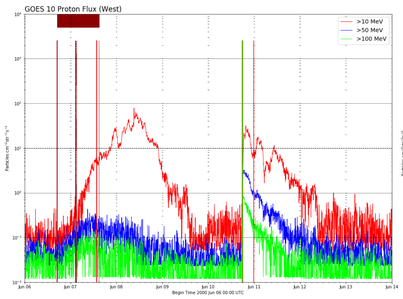

Fig 5: GOES Proton Flux: Examples of a large lead time and a miss

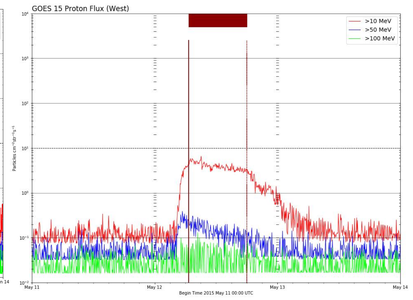

Fig 6: GOES Proton Flux: Example of a False Alarm

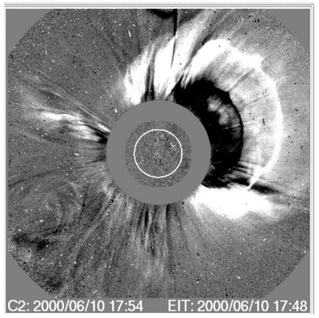

Fig. 7: CME on June 10th, associated with the miss

- Fig. 5 shows a warning with a long lead time of 10 hours and 49 minutes on June 6th followed by a missed event on the 10th despite that event being associated with a fast CME (1108 km/s) and an M-class flare.
- Fig. 6 shows a false alarm where the proton flux did not cross the SWPC event threshold.

Conclusions

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.

	POD	FAR	CSI
Solar Cycle 23	0.71	0.18	0.58
Solar Cycle 24	0.98	0.28	0.70

$$CSI = \frac{TP}{TP+FN+FP}$$

Ref: (1) Bain et al.(2016) 2016ApJ...825....1B apj, 825, 1
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