A Space Weather Service for Solar Flare Forecasting

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Introduction: A solar flare forecasting method based on a Bayesian analysis of past event statistics (refer to ESWW10 invited talk by M. Wheatland) has been re-implement to develop an automated service for daily predictions of M-X and ≥ X-class flares. The latest GOES X-ray measurements are used to make whole-sun predictions, and the reliability of the method is quantified for the current solar cycle. The possibility of extending the prediction technique to Solar Energetic Proton (SEP) events is investigated, and the initial results are presented.

The Wheatland statistical solar flare forecast method (Wheatland, ApJ. 609, 2004) has been implemented to provide a mock-up for a new Space Weather service (figure 1). Automated IDL code and scripts are run daily on a RHEA server to provide 24 hour forecast probabilities for C to X-class flare events. Reliability is quantified by comparing the forecast probability with the observed probability, defined to be equal to (R+1)/(S+2), where R is the number of days for which at least one event is recorded, and S is the total number of days with a particular forecast probability. Figure 2 shows a reliability plot using data from the current solar cycle. The straight diagonal line represents perfect prediction, and points lying above and below indicate under- and over-prediction, respectively.

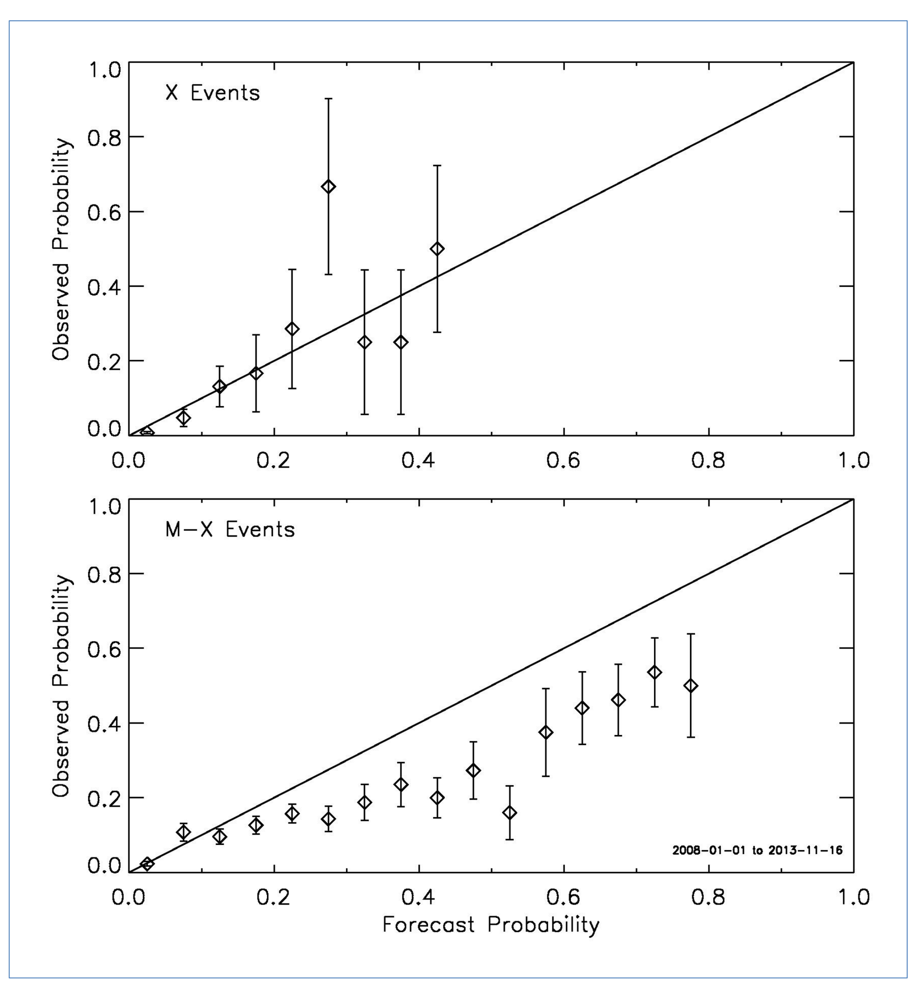
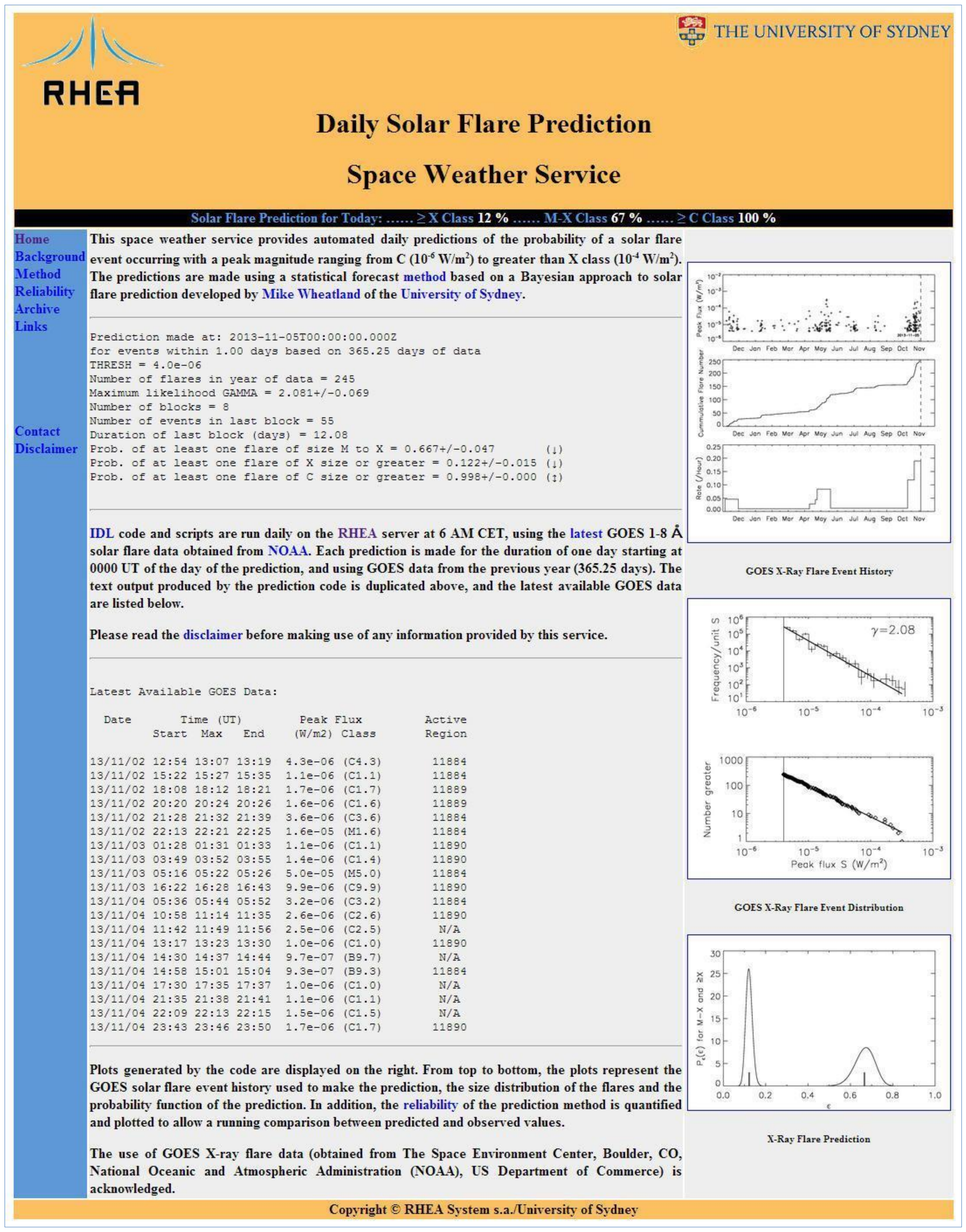


Figure 2: Reliability plots for X (top panel) and M-X (lower panel) events during the current solar cycle.



Date	Time (UT) Start	Max	End	Peak Flux (W/m2)	Class	Active Region
13/11/02	12:54	13:07	13:19	4.3e-06	(C4.3)	11884
13/11/02	15:22	15:27	15:35	1.1e-06	(C1.1)	11884
13/11/02	18:08	18:12	18:21	1.7e-06	(C1.7)	11889
13/11/02	20:20	20:24	20:26	1.6e-06	(C1.6)	11889
13/11/02	21:28	21:32	21:39	3.6e-06	(C3.6)	11884
13/11/02	22:13	22:21	22:25	1.6e-05	(M1.6)	11884
13/11/03	01:28	01:31	01:33	1.1e-06	(C1.1)	11890
13/11/03	03:49	03:52	03:55	1.4e-06	(C1.4)	11890
13/11/03	05:16	05:22	05:26	5.0e-05	(M5.0)	11884
13/11/03	16:22	16:28	16:43	9.9e-06	(C9.9)	11890
13/11/04	05:36	05:44	05:52	3.2e-06	(C3.2)	11884
13/11/04	10:58	11:14	11:35	2.6e-06	(C2.6)	11890
13/11/04	11:42	11:49	11:56	2.5e-06	(C2.5)	N/A
13/11/04	13:17	13:23	13:30	1.0e-06	(C1.0)	11890
13/11/04	14:30	14:37	14:44	9.7e-07	(B9.7)	N/A
13/11/04	14:58	15:01	15:04	9.3e-07	(B9.3)	11884
13/11/04	17:30	17:35	17:37	1.0e-06	(C1.0)	N/A
13/11/04	21:35	21:38	21:41	1.1e-06	(C1.1)	N/A
13/11/04	22:09	22:13	22:15	1.5e-06	(C1.5)	N/A
13/11/04	23:43	23:46	23:50	1.7e-06	(C1.7)	11890

Figure 1: Homepage for the solar flare prediction website (under development).

Peak GOES 1-8 Angstrom X-ray flux measurements are obtained daily using FTP from the public NOAA/SWPC website. The preceding year of data is used to provide the past event statistics necessary to perform the current prediction. A power-law behaviour is assumed for the peak flux distribution for event sizes above a lower threshold equivalent to C4. Optimal Bayesian blocks are defined according to the most recent Scargle algorithm (Scargle et al., ApJ. 764, 2013). The last Bayesian block provides information about the current rate of flare occurrence, and previous blocks Indicate the associated variation. This information (see diagrams in figure 1) is used to provide probability distributions for the occurrence of M-X and ≥ X class solar flare events (Wheatland, Space Weather Vol. 3/7, 2005).

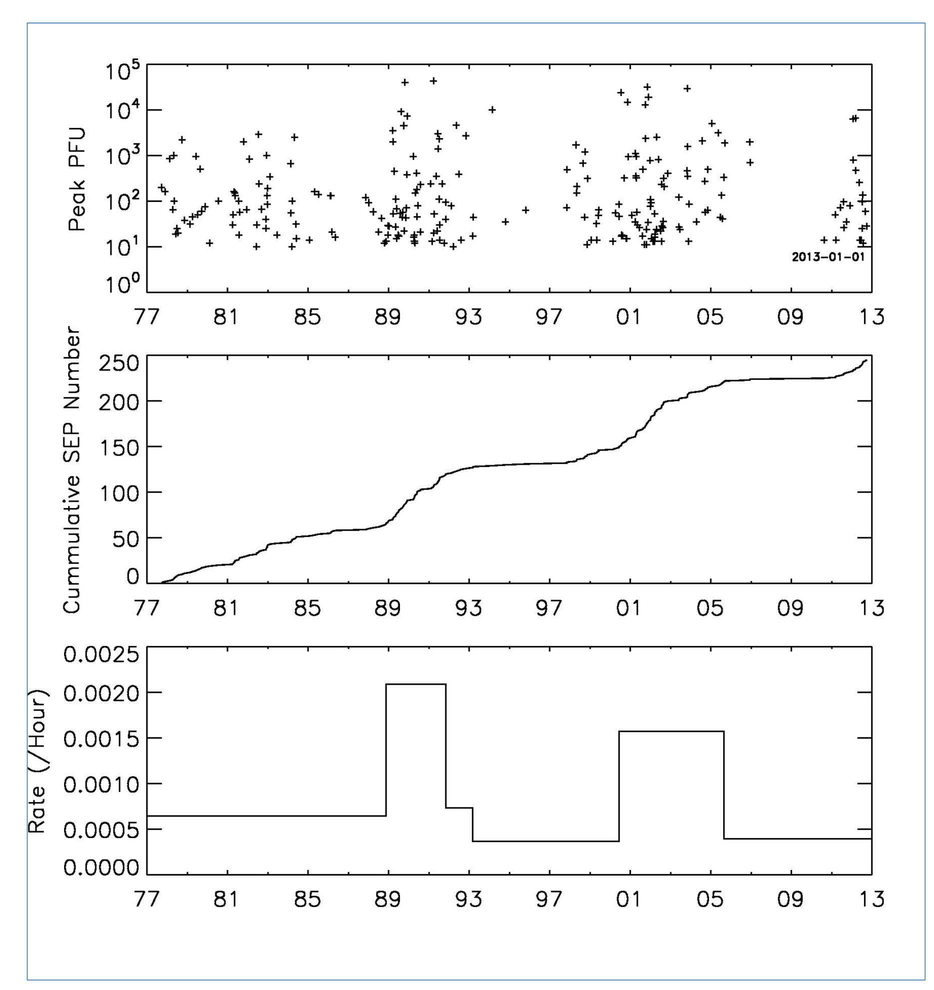


Figure3: The top panel shows the GOES >10 MeV SEP event history (since solar cycle 21). The middle panel plots the cummulative number of events, and the bottom panel shows the blocks defined using the optimal Bayesian block algorithm.

An attempt to extend the statistical forecast model to SEP events has been investigated using measurements of peak fluxes (in peak flux units, PFU) from the GOES >10 MeV proton event list (figure 3). The SEP event frequency is greatly reduced compared to that of solar X-ray flare events. First results show that there are too few events for the forecast method to be effective for time dependent predictions, but long term predictions during phases of the solar cycle may be feasible. Future work will consider using alternative solar proton data sets (for example from SEPEM, SEPServer, etc.).

Conclusions: A Space Weather Service is being implemented to provide automated daily predictions of solar flare occurrence based on a Bayesian analysis of GOES solar X-ray event statistics (courtesy of NOAA). Predictions made in the current solar activity cycle have been used to quantify the reliability of the forecast method, with emphasis on the recent increase in the number of the largest flares. The possibility of extending the forecasting technique to SEP events has been investigated, although the relatively low number of useable proton events may prove to be a limiting factor for making short-term predictions. Future development of the flare (and potentially SEP) prediction service will be considered after public release and an assessment of the initial user response.

Reference List:

- Wheatland M.S., A Bayesian Approach to Solar Flare Prediction, ApJ. 609, 1134-1139, 2004.
- Wheatland M.S., A Statistical Solar Flare Forecast Method, Space Weather Vol. 3 No. 7, S07003, 2005.
- Scargle J.D. et al., Studies in Astronomical Time Series Analysis. VI Bayesian Block Representations, ApJ. 764, 167-192, 2013.
- Wheatland M.S., Exploting Solar Flare Statistics for Flare Prediction, invited talk, ESWW10, 2013.