Forecasting Safe or Dangerous Space Weather from HMI Magnetograms

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We have developed a space-weather forecasting tool using an active-region free-energy proxy that was measured from MDI line-of-sight magnetograms. To develop this forecasting tool (Falconer et al 2011, Space Weather Journal, in press), we used a database of 40,000 MDI magnetograms of 1300 active regions observed by MDI during the previous solar cycle (cycle 23). From each magnetogram we measured our free-energy proxy and for each active region we determined its history of major flare, CME and Solar Particle Event (SPE) production. This database determines from the value of an active region's free-energy proxy the active region's expected rate of production of 1) major flares, 2) CMEs, 3) fast CMEs, and 4) SPEs during the next few days. This tool was delivered to NASA/SRAG in 2010. With MDI observations ending, we have to be able to use HMI magnetograms instead of MDI magnetograms. One of the difficulties is that the measured value of the free-energy proxy is sensitive to the spatial resolution of the measured magnetogram: the 0.5"/pixel resolution of HMI gives a different value for the free-energy proxy than the 2"/pixels resolution of MDI. To use our MDI-database forecasting curves until a comparably large HMI database is accumulated, we smooth HMI line-of-sight magnetograms to MDI resolution, so that we can use HMI to find the value of the free-energy proxy that MDI would have measured, and then use the forecasting curves given by the MDI database. The new version for use with HMI magnetograms was delivered to NASA/SRAG (March 2011). It can also use GONG magnetograms, as a backup.

Acknowledgments: The development of the MDI database and MDI-based tool was supported by funding from NASA's Office of Chief Engineer Technical Excellence Initiative. The science that went into development of this tool was supported by funding from the NASA Heliophysics Division, from NSF's Division of Atmospheric Sciences, and from AFOSR'S MURI Program. We wish to acknowledge the use of both Chris Balch's flare/CME data sets as well as the CME catalog generated and maintained at the CDAW Data Center by NASA and The Catholic University of America in cooperation with the Naval Research Laboratory.

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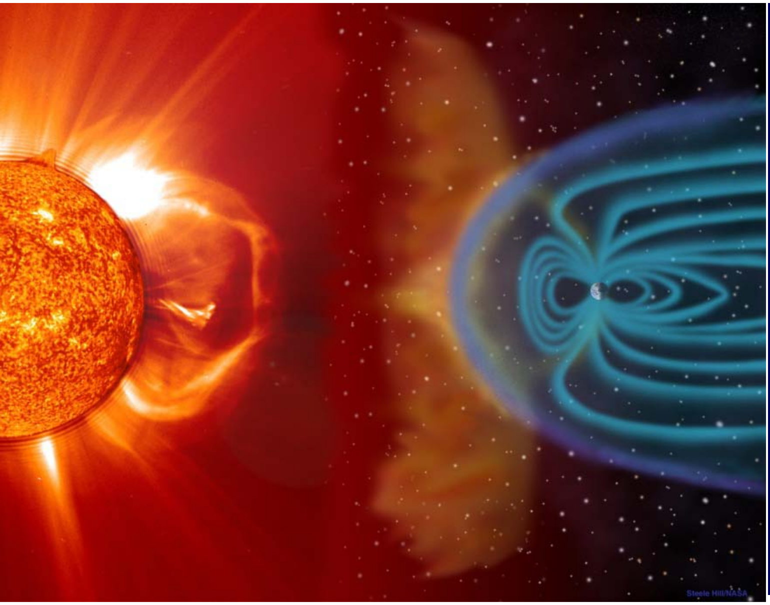
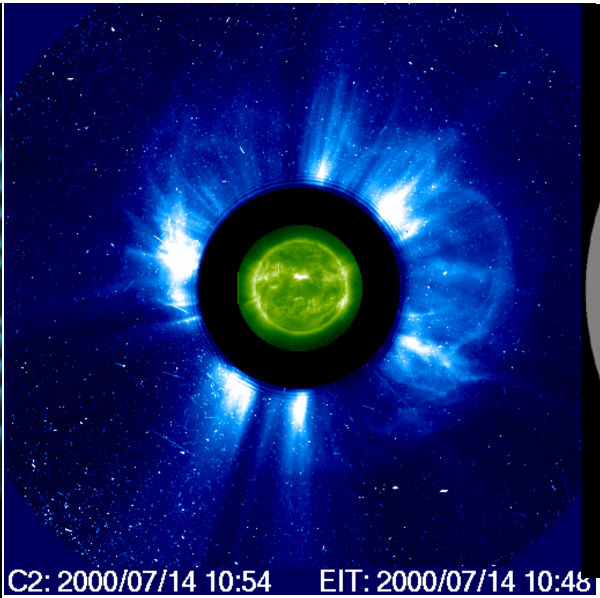
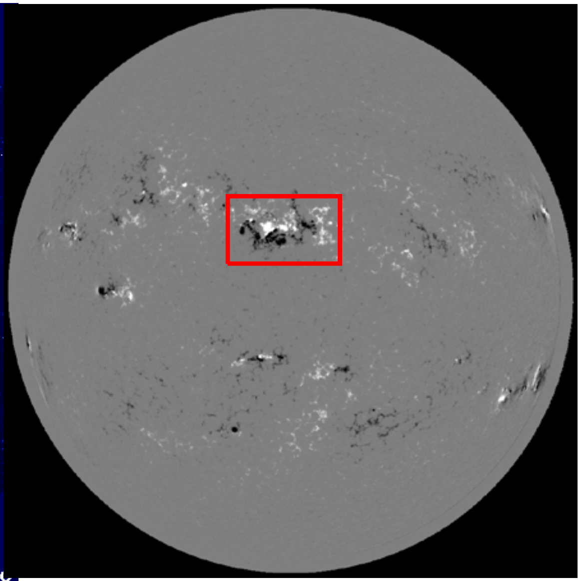






Forecasting X-class, M-class, CMEs, and SPEs from active region magnetograms.

Overview

•Last year we delivered to NASA/SRAG a solar major-event forecasting tool based on a free-energy proxy that can be measured from a SOHO/MDI magnetogram. **Slides 3-8**

•Since then, the higher-resolution, higher-cadence, SDO/HMI vector magnetograph has replaced SOHO/MDI. **Slide 9**

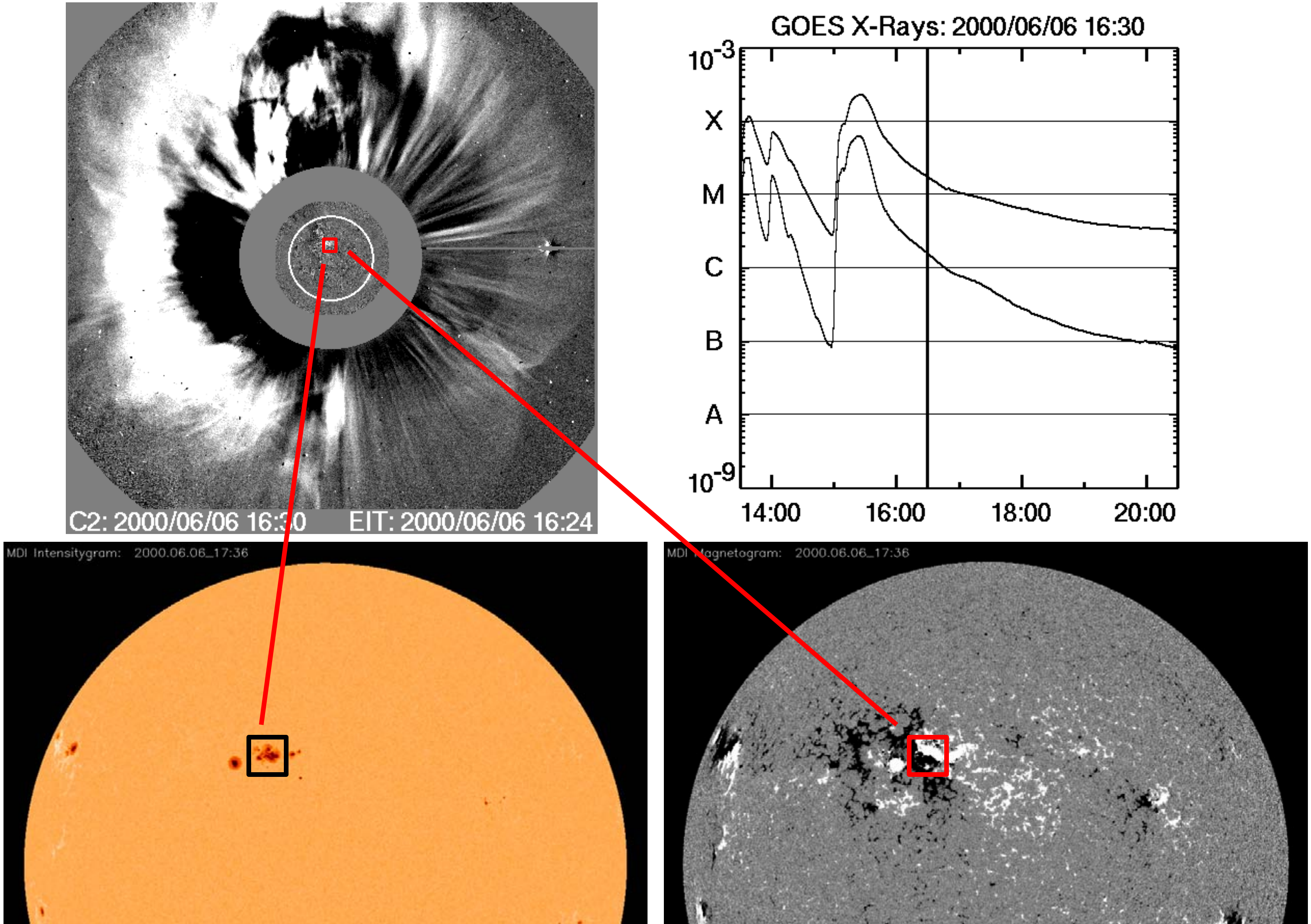
•In March, we installed a modified forecasting tool that uses SDO/HMI line-of-sight magnetograms. **Slides 10-14**

•Modified tool can use GONG as backup.

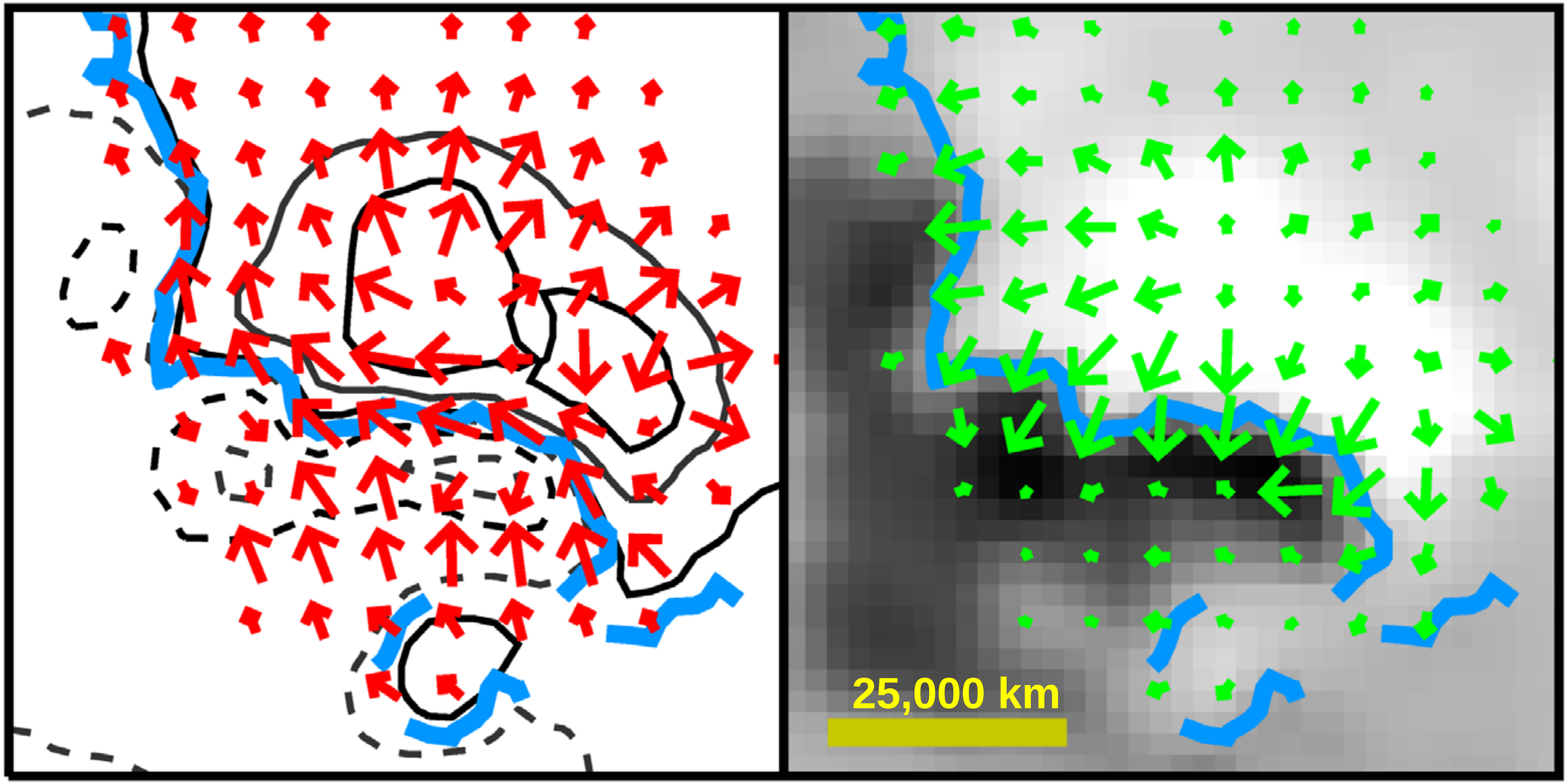
Science behind Forecast

- Active regions (ARs) with large free energy are more able and more likely to produce large flares and CMEs than active regions with little free energy (See example AR in slides 4-5).
- It is reasonable to expect AR free energy to be strongly correlated with AR CME/flare rate.
- Present observations do not allow us to directly measure the free energy of an active region, but there are a variety of free-energy proxies that should be strongily correlated with flare/CME event rates.
- These correlations can be determined empirically.

Example Halo CME, X-Flare, and δ-Sunspot Source Region



MSFC Vector Magnetogram of δ-Sunspot Source Region of Example CME/Flare Eruption



An active-region field's horizontal shear is concentrated along neutral lines where the field's horizontal component is strong and the vertical component's horizontal gradient is steep.

Observed-field upward (downward) vert. comp. is shown by solid contours or light shading (dashed contours or dark shading); red arrows show observed hor. comp. ; green arrows show hor. comp. of pot. field computed from obs. vert. comp. ; strong-observed-field (>150G) intervals of neutral lines are blue.

Free-energy proxy from vertical-field component of vector magnetogram or from line-of-sight magnetogram:

- Active regions that have large magnetic shear along neutral lines (where the observed field is nearly perpendicular to the potential field, and thus a large free energy content) also develop large transverse gradients along the neutral line (see example AR in slides 4-5).

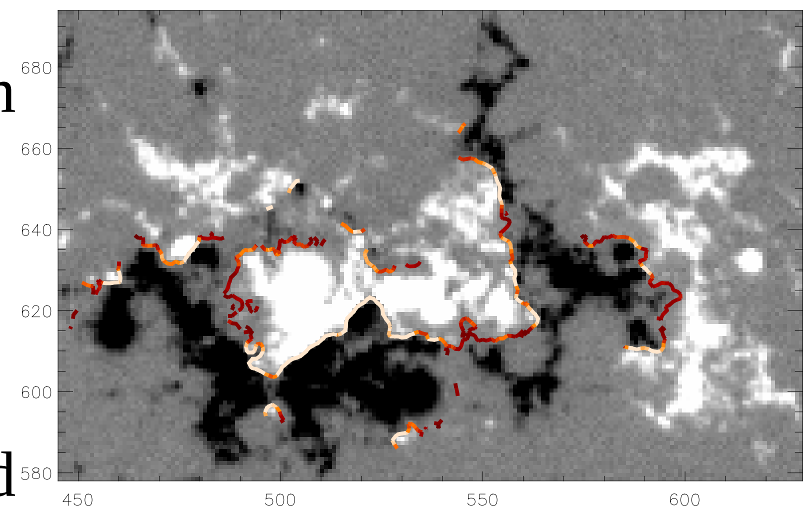
Deprojected vector magnetogram version

$$WL_{SG}=\int(\nabla B_Z)dl$$

or line-of-sight approximation

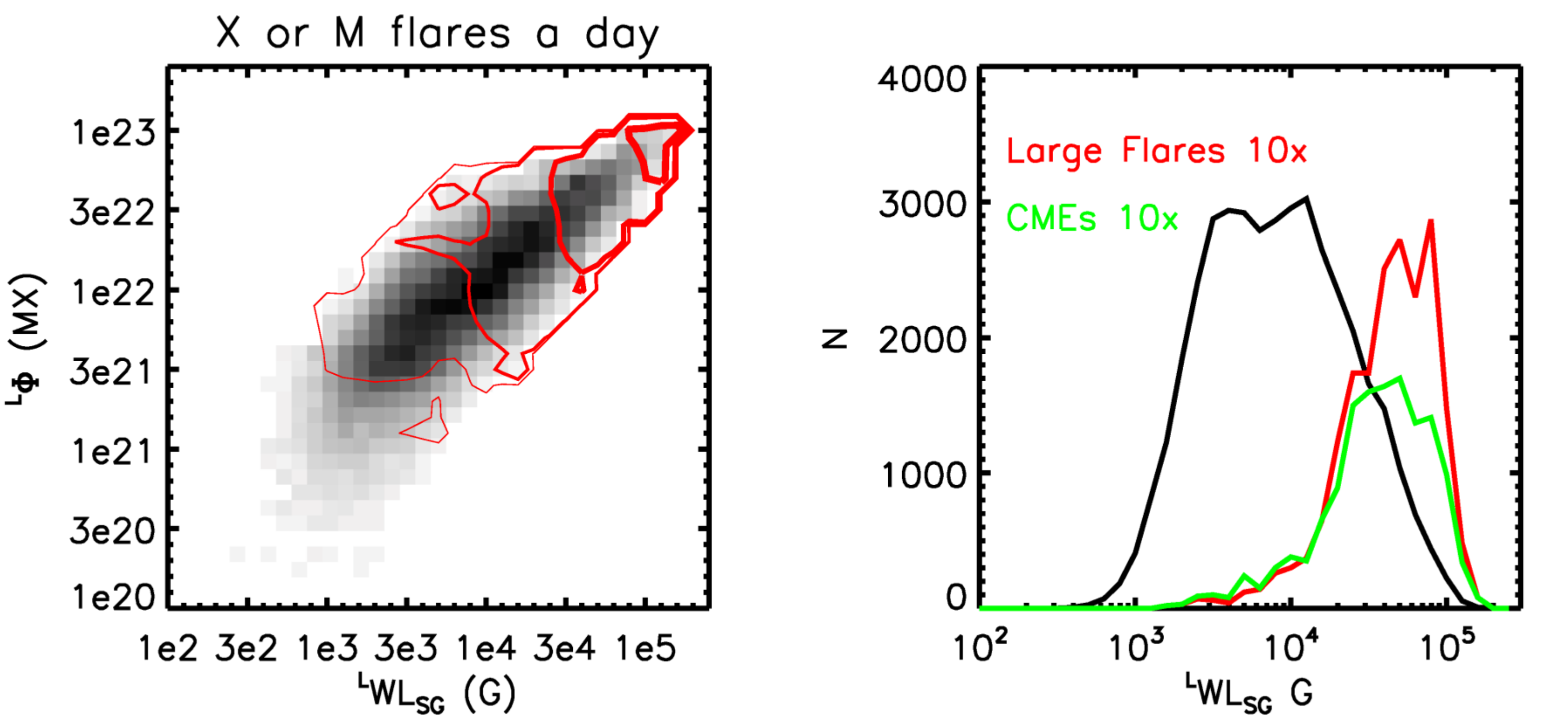
$$^{L}WL_{SG}=\int(\nabla B_{LOS})dl.$$

Integration is along strong-field intervals of the AR neutral lines.

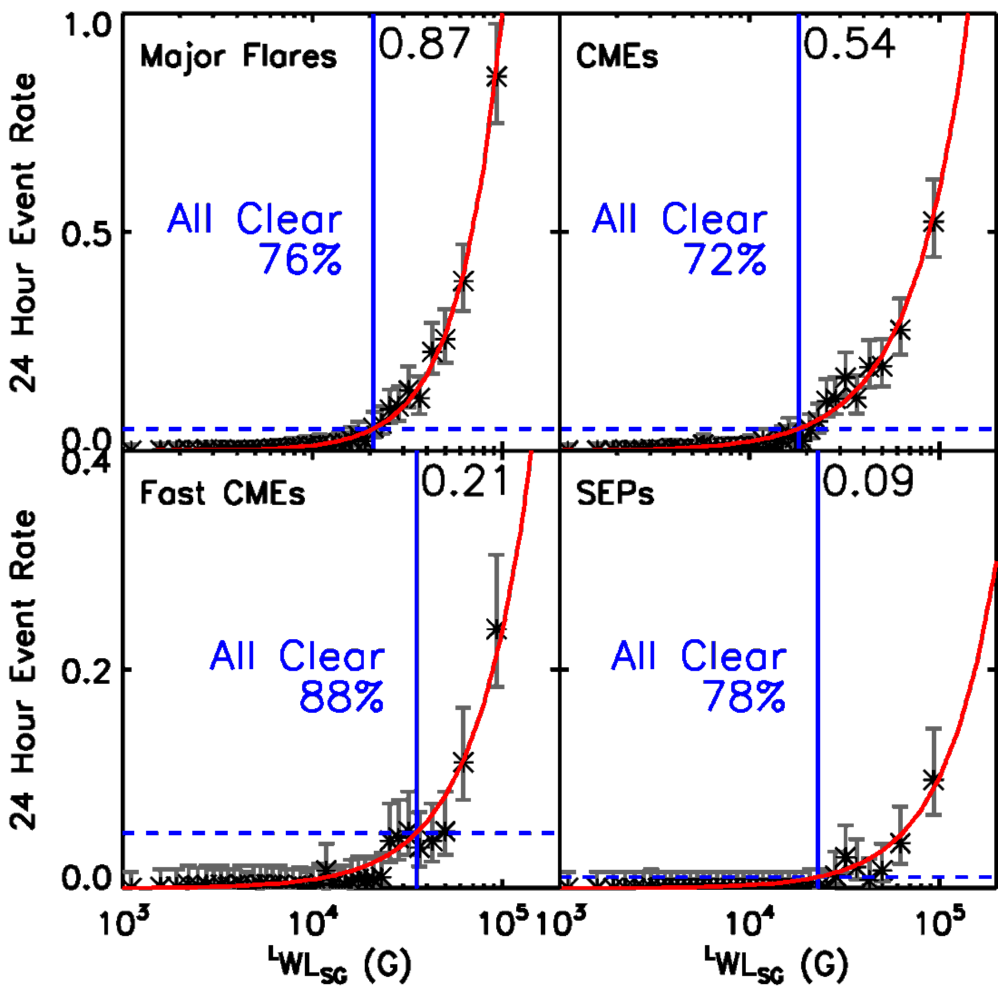


Correlation of AR Production of Major Solar Events with Free-Energy Proxy

- **Left:** Gray scale plot shows free-energy/magnetic size distribution of 40,000 magnetograms of 1,300 active regions. Red contours are 0.001, 0.01, and 0.1, and 0.5 event/day levels.
- **Right:** Free-energy proxy histogram of all active regions(black curve), and those that produce an X or M flare or CME in the next 24 hours.



The Heart of the Forecasting Tool: The Forecast Curves



- Only active regions that have a large free energy are likely to produce major events in the next 24 hours. Most active regions have a negligible (All Clear) chance of producing an event.

Advantages of HMI over MDI

	MDI	HMI
pixels	2”	0.5”
Cadence	96 minutes	45 sec LOS, 90 sec Vector
Latency	Approximately a day	tens of minutes
Magnetograph Type	Line-of-sight	Vector
Operational	1996-Jan 2011 **Now Turned off**	May 2010 to present **Now Operating**

Forecasting from HMI in the Near Term

- **Ideal Method:** Develop database similar to MDI database (40,000 magnetograms of 1,300 ARs with known event history) spanning most of a solar cycle. Measure various free-energy proxies that can be measured from deprojected HMI vector magnetograms. Determine free-energy proxy that has strongest correlation with AR major-event production, and develop forecast curves.
- **Problem:** Need system now, but accumulating an HMI database that is as large as the MDI database will likely take the entire present solar cycle, or more.
- **Solution:** Use HMI to measure free-energy proxy, and use MDI forecast curves to convert free-energy proxy to predicted event rate.

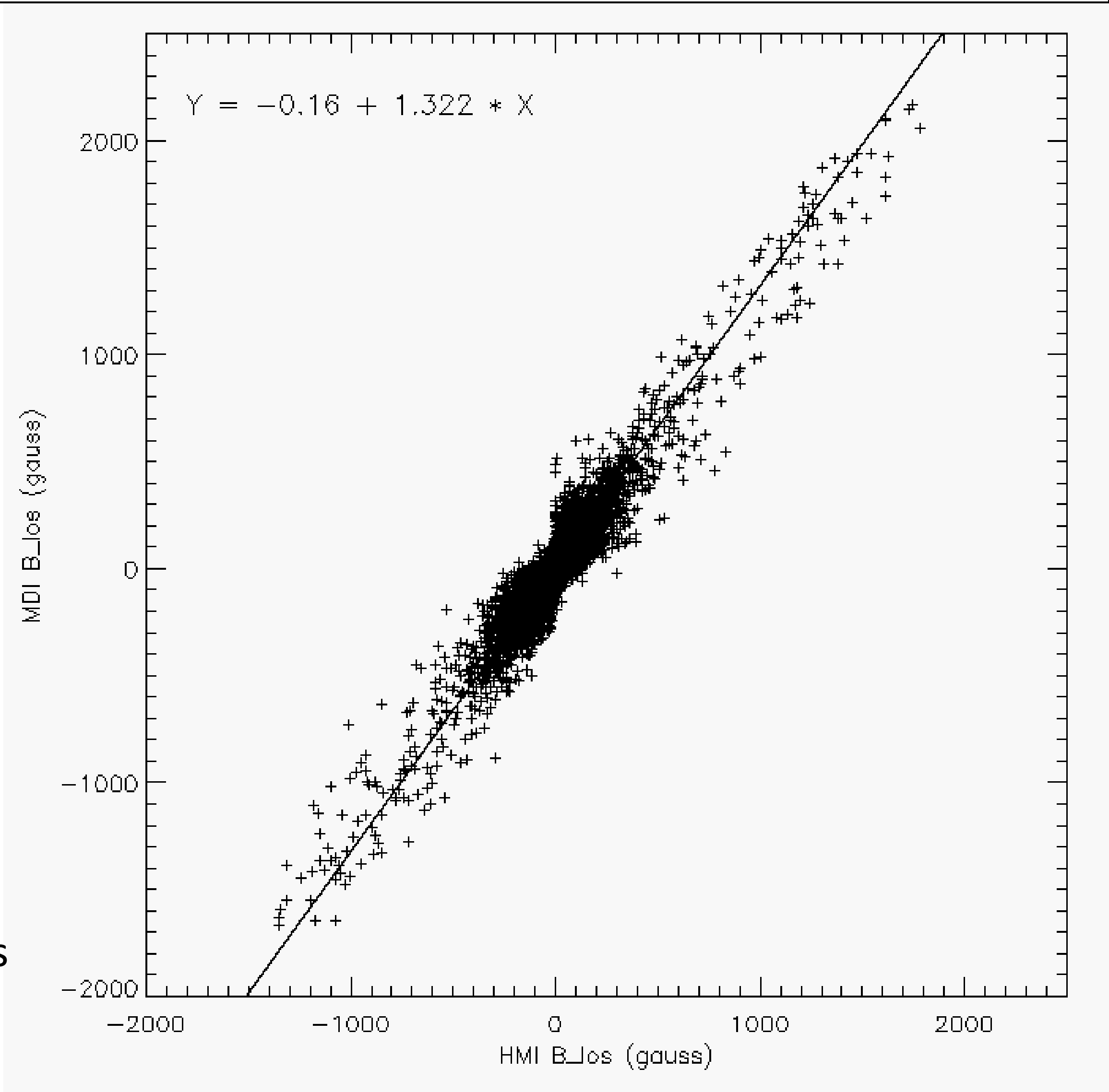
Implemented Solution

- Measure free-energy proxy with HMI, use MDI forecast curves to convert HMI measurement to forecasted rate.
- **Problem:** Our free energy proxy **(**$WL_{SG}=\int|\nabla B_Z|dl$) has both $|\nabla B_Z|$ and dl, which are resolution dependent, so the two magnetographs give different WL_{SG} values.
- **Solution:** Modify a HMI magnetogram to be MDI-like by converting to MDI magnetic field strength (Slide 12), apply MDI point spread function to HMI and re-bin to MDI pixels (Slide 13) before calibrating and measuring WL_{SG}.

HMI vs MDI Blos Comparison

Empirical conversion of HMI magnetic field strength to MDI magnetic field strength

Hoeksema and the HMI team has done this work.



Early HMI Magnetic Field Observations
Hoeksema et al

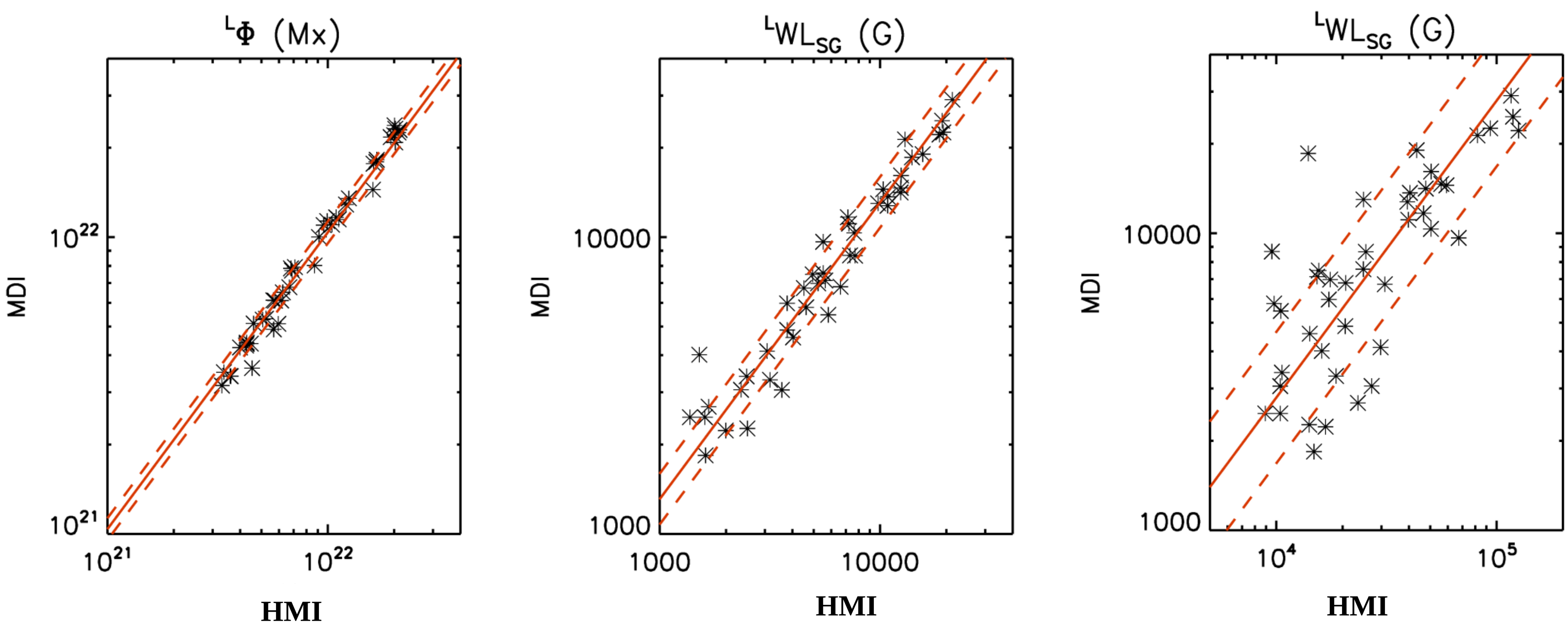
Estimating from HMI the value of $^{L}WL_{SG}$ MDI would have measured in order to use MDI forecast curves

Multiplicative uncertainty due to different instruments and their spatial resolutions			
Event Type	MDI	**HMI-lowres**	HMI-full res
X and M Flares	1.07	**1.48**	2.71
X Flares	1.29	**1.60**	2.86
CMEs	1.10	**1.36**	2.16
Fast CMEs	1.17	**1.41**	2.24
SPEs	1.32	**1.51**	2.33

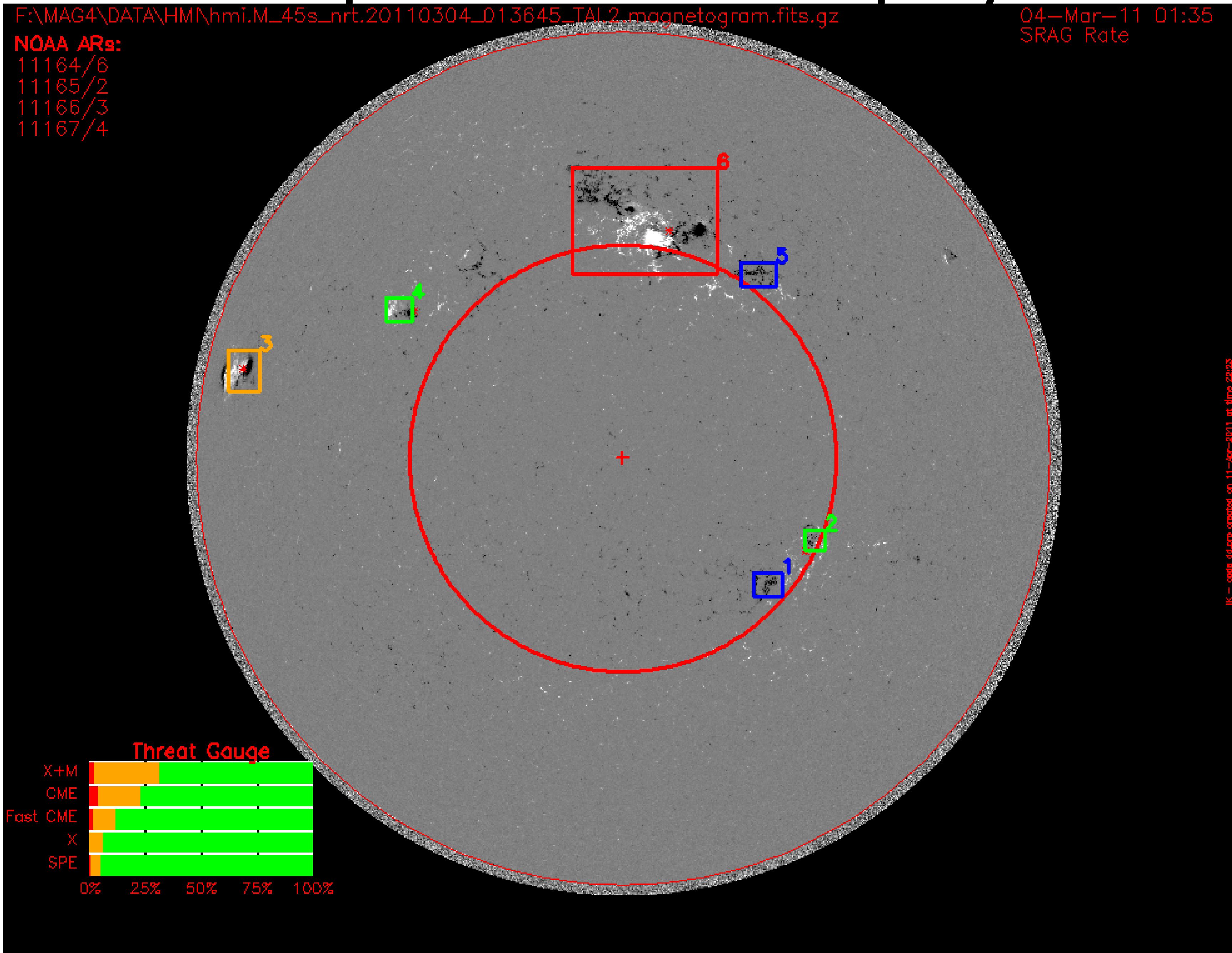
For MDI resolution

- $^{L}WL_{SG}(MDI)=1.31*{}^{L}WL_{SG}(HMI)$
- Multiplicative uncertainty is 1.22

HMI Smoothed to MDI Resolution Unsmoothed



Example Forecast Display



Future Work:
Tool upgrades to be done using HMI

- **Use deprojected vector magnetograms to measure WL_{SG}**
  - Waiting for automated ambiguity resolution
  - Will incorporate de-projecting of ambiguity-resolved active-region tiles
- **Determine whether any vector free-energy proxies are more strongly correlated with AR production of major events than WL_{SG}**
- **Does HMI's higher resolution give WL_{SG} values that are more strongly correlated with AR major-event production than does the lower resolution of MDI?**

Last two need a large HMI database to determine. As of March 16, 2011 there have been 40 M and 2 X-class flares; most of these (30 M and 2 X) in 2011. This means that preliminary results are likely possible by year end.