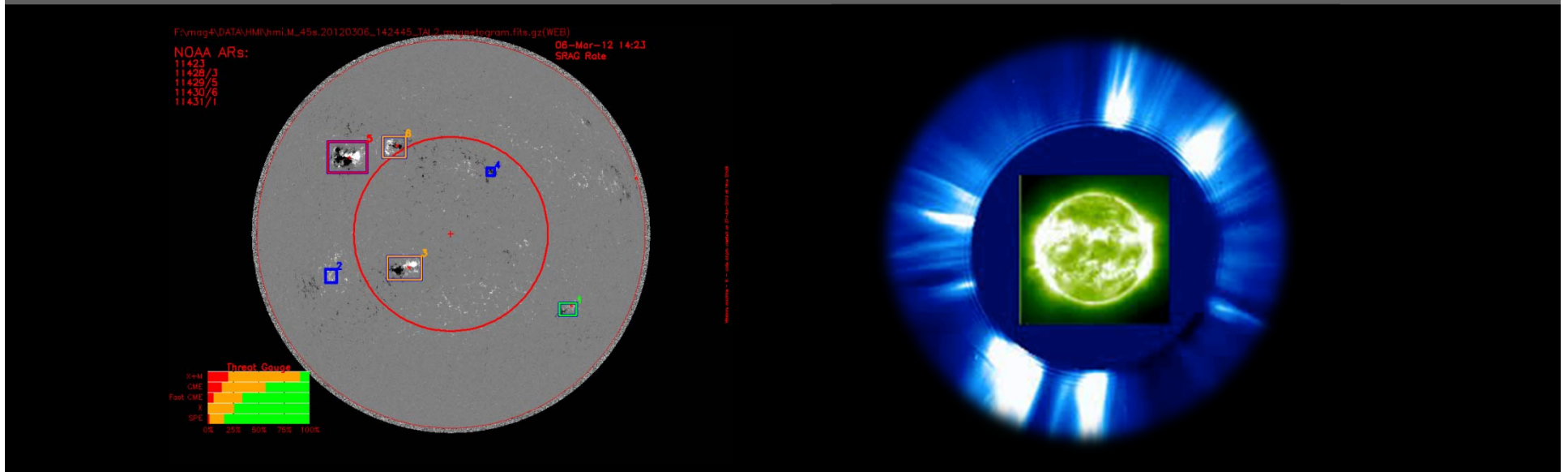




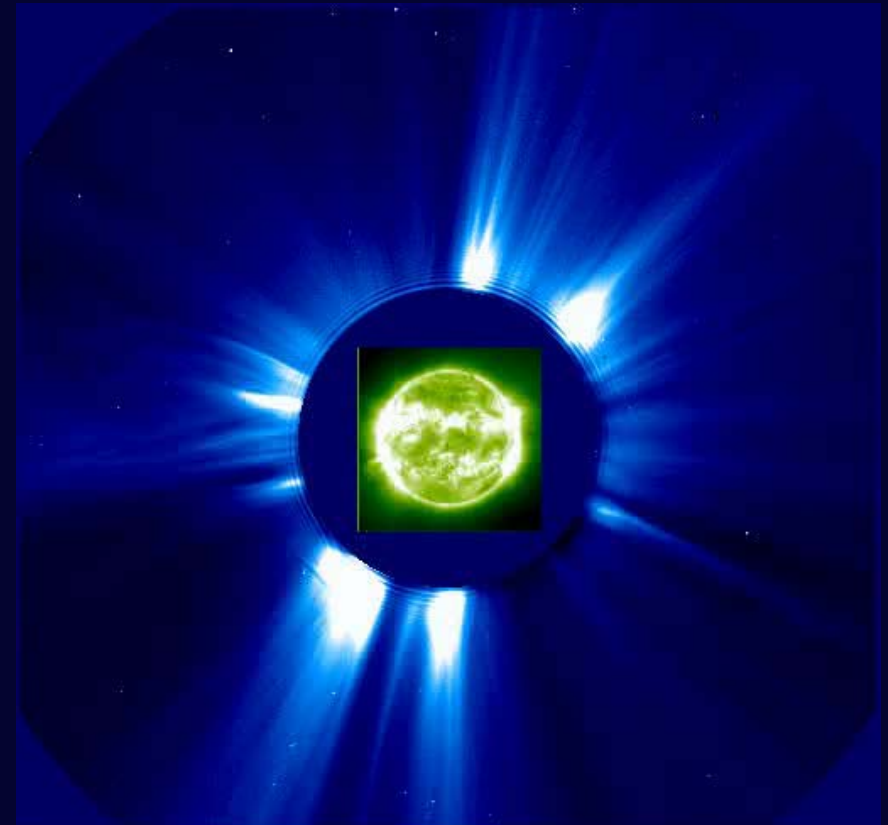
SCIENCE & TECHNOLOGY OFFICE



How MAG4 Improves Space Weather Forecasting

David Falconer
Igor Khazanov
Nasser Barghouty

1. Space Weather Background
2. MAG4 (Magnetogram Forecast)
 - a. What it is
 - b. Brief Background
 - c. History of R2O
3. MAG4 Automatic Process
4. Demo by Igor Khazanov
5. Improvements in the Pipeline
 - a. Recent Flare History
 - b. Vector Magnetograms
6. How Effective
 - a. Situational Awareness
 - b. 2x2 Contingence Table Metrics
7. Suggested Collaborations with AFWA

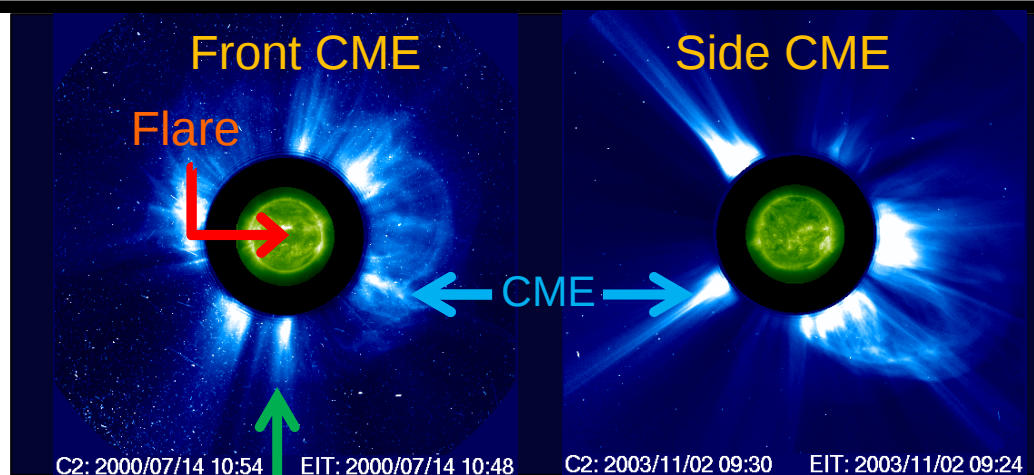


C2: 2000/07/14 09:30:05 EIT: 07/14 09:24:10

Bastille Day (2000 July 14) Flare, Coronal Mass Ejection and Solar Energetic Particle Event

Dangerous space weather is driven by solar flares and Coronal Mass Ejection (CMEs).

Forecasting flares and CMEs is the first step to forecasting either dangerous space weather or All Clear.



Flare

Solar Energetic Particle Event (SPE or SEP Event)

CME

ELECTROMAGNETIC RADIATION
(IMMEDIATE: **TIME 8 MIN**)

X-EUV

ULTRA-VIOLET

VISIBLE LIGHT

RADIO WAVES

SIMULTANEOUS EFFECTS

INCREASED D-LAYER IONIZATION

GEOMAGNETIC DISTURBANCE

ANOMALOUS RADIO PROPAGATION

OUTBURST OF RADIO NOISE

RADIO INTERFERENCE

HIGH ENERGY PARTICLES
(DELAYED **< HOUR**)

ATOMIC NUCLEI

ENHANCED SOLAR WIND
(DELAYED **~3 Days**)

IONS AND ELECTRONS

DELAYED EFFECTS

ENHANCED ENERGETIC PARTICLES

MANNED FLIGHT RADIATION HAZARD(I)

SPACECRAFT RADIATION HAZARD (C³)

IONIZATION

ANOMALOUS RADIO PROPAGATION

RADAR CLUTTER

GEOMAGNETIC STORM

IONOSPHERIC STORM AND

INDUCED CURRENTS

RADIO EFFECTS

SATELLITE DRAG

AURORA

Space Weather

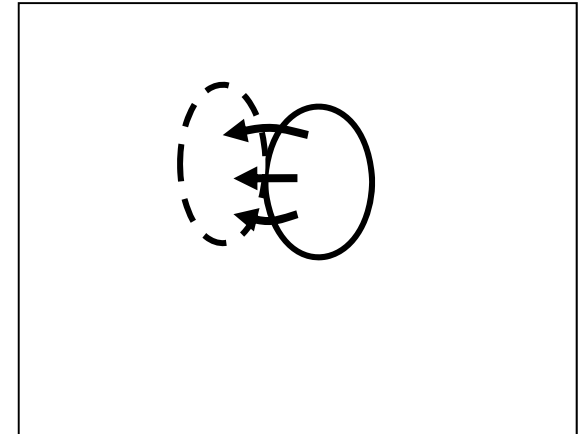
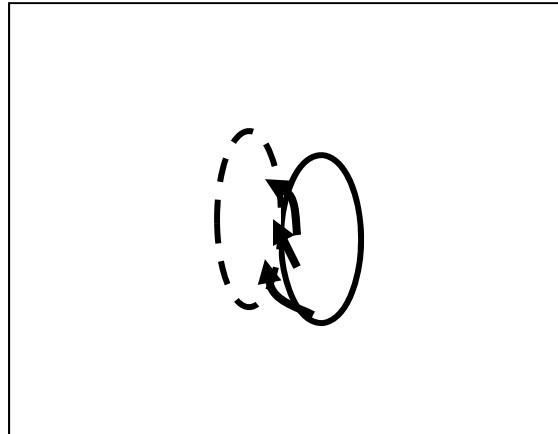
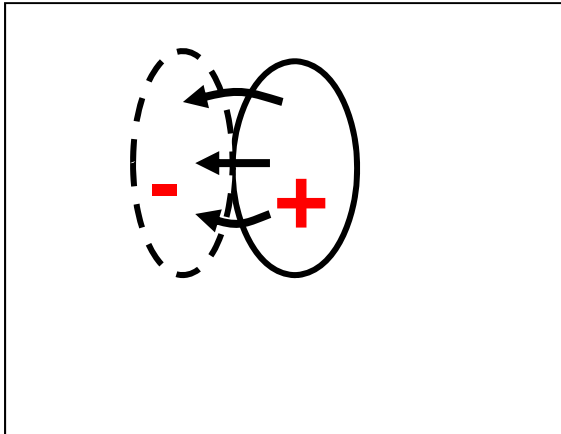
- MAG4 (Magnetogram Forecast), developed originally for NASA/SRAG (Space Radiation Analysis Group), is an automated program that analyzes magnetograms from the HMI (Helioseismic and Magnetic Imager) instrument on NASA SDO (Solar Dynamics Observatory), and automatically converts the rate (or probability) of major flares (M- and X-class), Coronal Mass Ejections (CMEs), and Solar Energetic Particle Events.
- MAG4 does not forecast a flare will occur at 12:02 tomorrow, but the probability of one occurring tomorrow.
- GONG ([Global Oscillations Network Group](#)) magnetograms, can be used instead as a **backup** but at a lower forecast accuracy.
- Present cadence of new forecasts: **96 minutes**.
Vector magnetogram actual cadence: **12 minutes**.

- Flares and CMEs are known to be drivers of the most severe space weather
- Flares and CMEs typically originate in active regions (aka sunspots)
- Flares and CMEs are examples of exceptionally large explosive releases of magnetic energy stored in the corona
- While the amount of free energy cannot be measured directly, free-energy proxies can be measured
- Event rates have been shown to be correlated with values of free-energy proxies

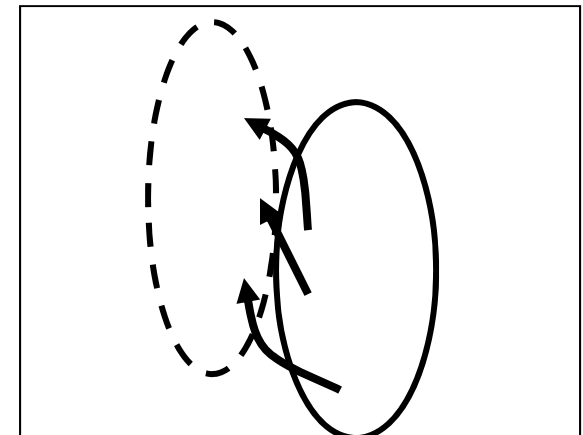
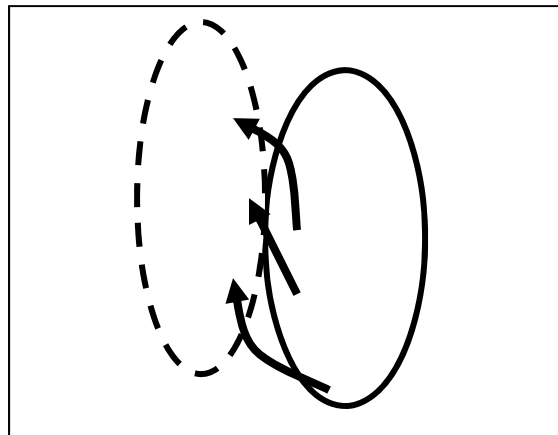
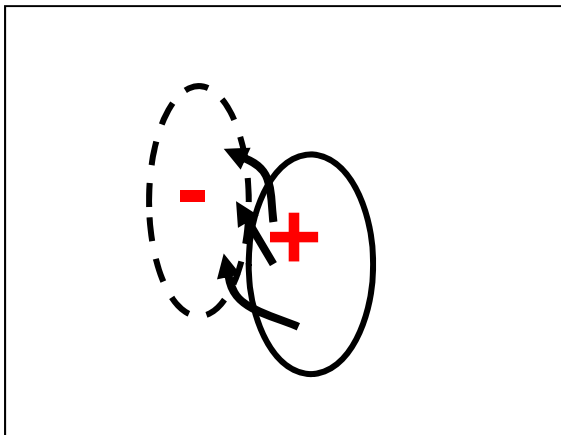
Contours Vertical Magnetic Field
Arrows Transverse Magnetic Field

Currents $\sim 10^{12}$ Amps

Less



More

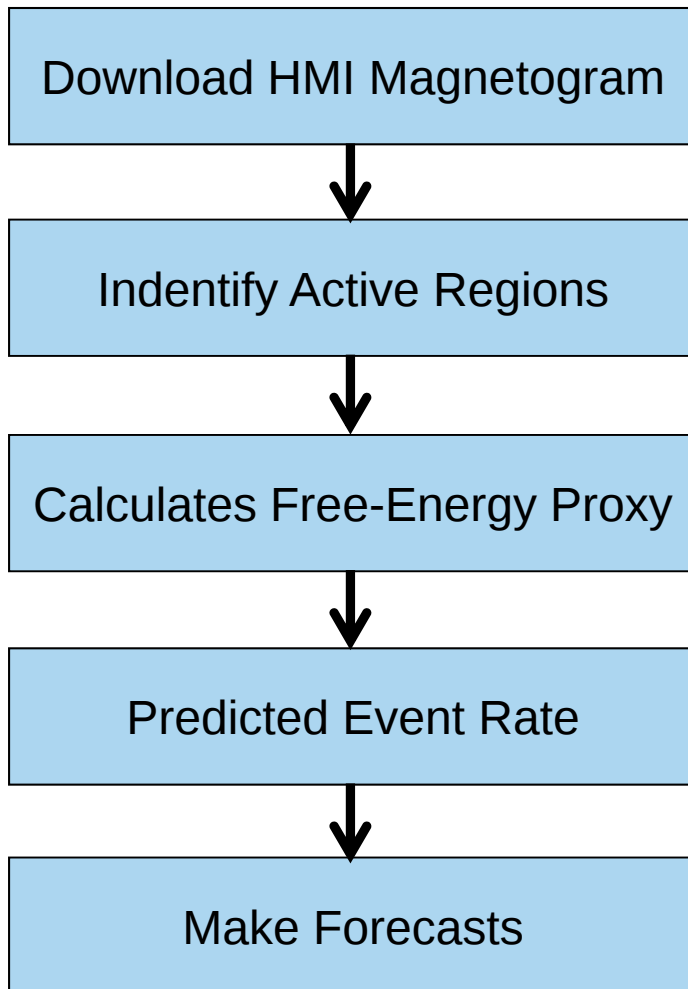


Twist

Size

**Free Magnetic
Energy**

- **1973** The MSFC (Marshall Space Flight Center) Vector Magnetograph was made to support Skylab.
- **2000-present** MSFC analyzed vector magnetograms to study CME correlation with free-energy proxy.
- **2007-12** Co-I in a Multidisciplinary University Research Initiative/Neutral Atmosphere Density Interdisciplinary Research
- **2008** Partnered with SRAG (Space Radiation Analysis Group) and won an R20 NASA/Technical Excellence Initiative grant: Began building a database that grew to ~40,000 magnetograms of ~1,300 active region, covering years 1996-2004 with event catalog from SOHO/MDI (Solar and Heliospheric Observatory/Michelson Doppler Imager) observations.
- **2010-present** NASA's HEOMD (Human Exploration and Operations Mission Directorate) support.
- **2010** SDO is launched began transitioning from MDI to HMI line-of-sight magnetograms.
- **2011** **MAG4 installed at SRAG a NRT (Near-Real-Time) forecasting tool, and SRAG began pre-operations testing.**
- **2012** Provided NOAA web access to MAG4 NRT forecasts.
- **2013** Improve MAG4 so that it can use a combination of **free-energy proxy** and previous **flare activity**.
- **2013** Transition to HMI line-of-sight to vector magnetograms.



MAG4 is completely automated, from downloading magnetograms to outputting forecast products.

Process 1: Identifying Active Regions



- Magnetograms are spatial maps of the magnetic field strengths.
- They come in two basic types
 - line-of-sight (right)
 - vector magnetograms
- Free-energy proxies can be measured for Active Regions (areas with sunspots) from either type of magnetogram.
- Line-of-sight magnetograms suffer reduced accuracy further from disk center.

Introduce Magnetogram,
identify ARs.

NOAA ARs
11423
11426/3
11429/5
11430/6
11431/1

06-Mar-2012 14:23

Best
Accuracy

NOAA
Active
Regions
(ARs)

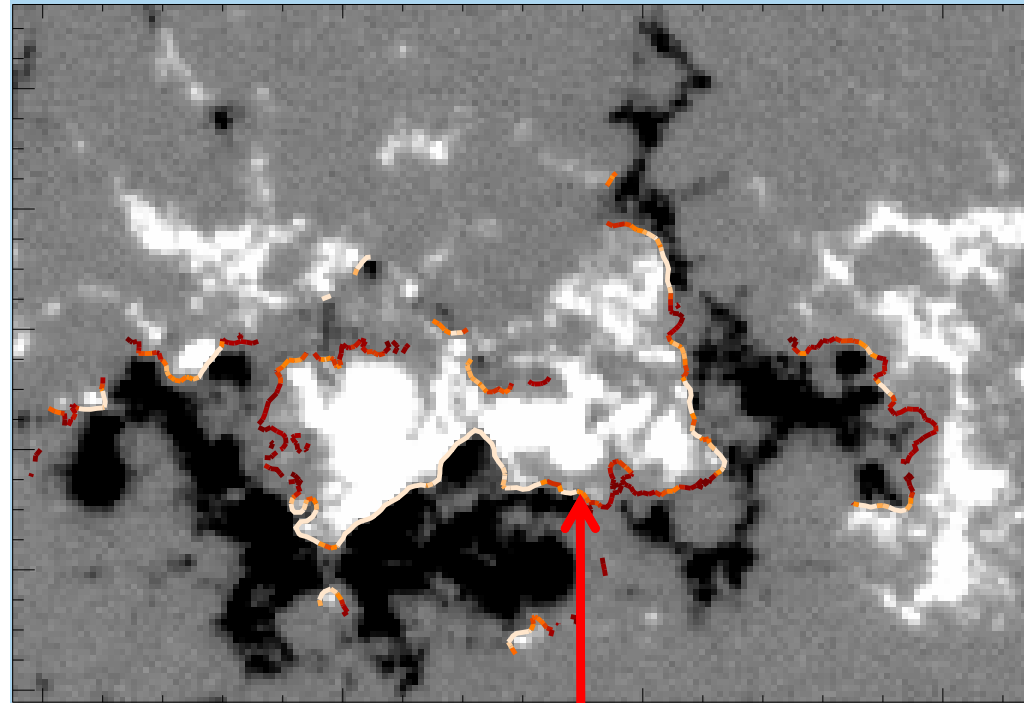
*A full-disk line-of-sight magnetogram of
the Sun, from SDO/HMI.*

Process 2: Calculating the Free-Energy Proxy



- Where the transverse gradient of the vertical (or line-of-sight) magnetic field is large, there is more free-energy stored in the magnetic field
- For **each Active Region**:
The integral of the gradient along the neutral line is the free-energy proxy

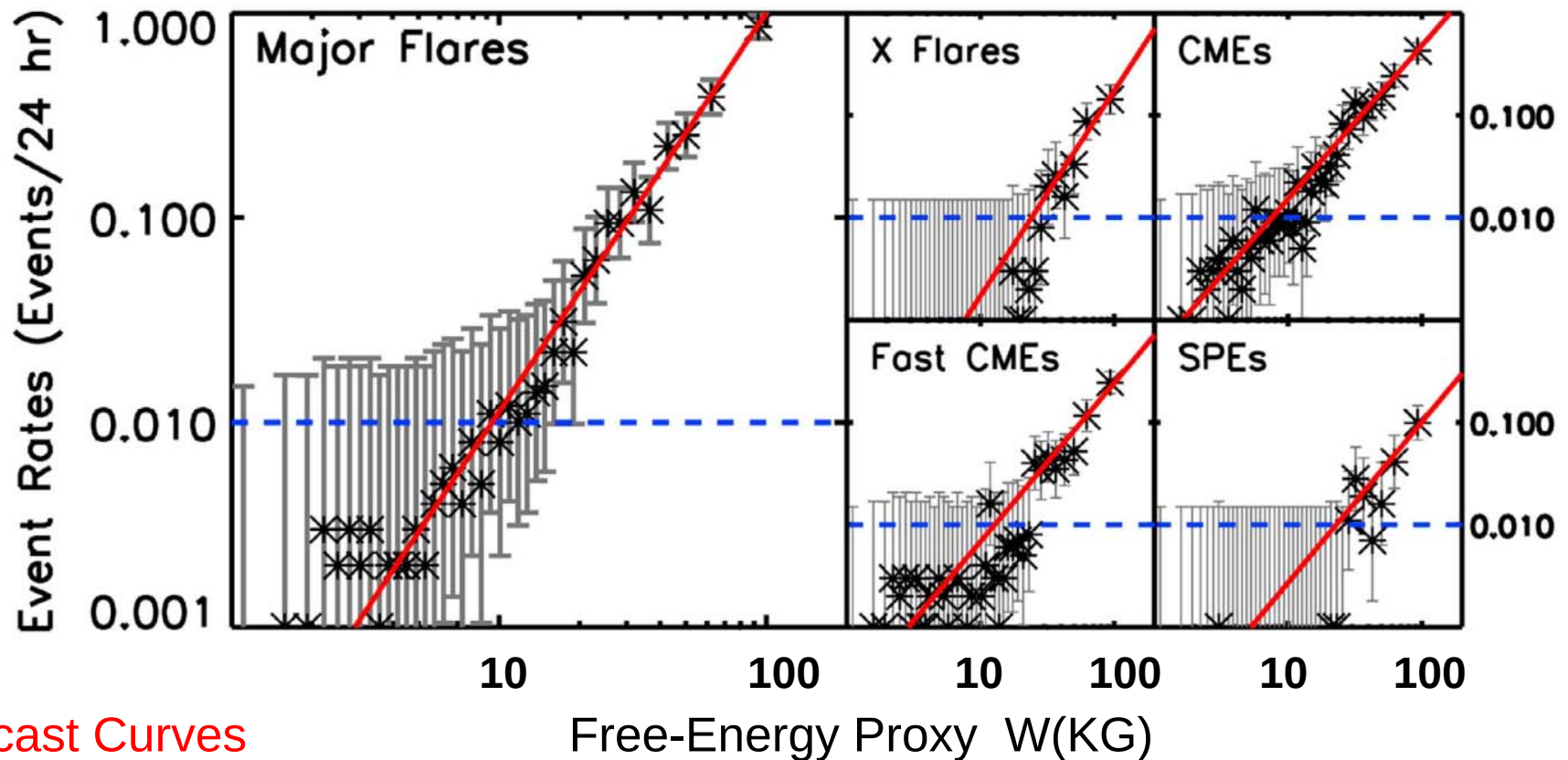
A magnetogram of an active region



Neutral Line, color coded for gradient



Process 3: Converting Free-Energy Proxy to Predicted Event Rates



Forecast Curves

These empirical forecast curves are used to convert our free-energy proxy into predicted event rates. Curves are derived from a sample of 40,000 magnetograms, from 1300 active regions observed between 1996-2004.

Process 4: Forecast

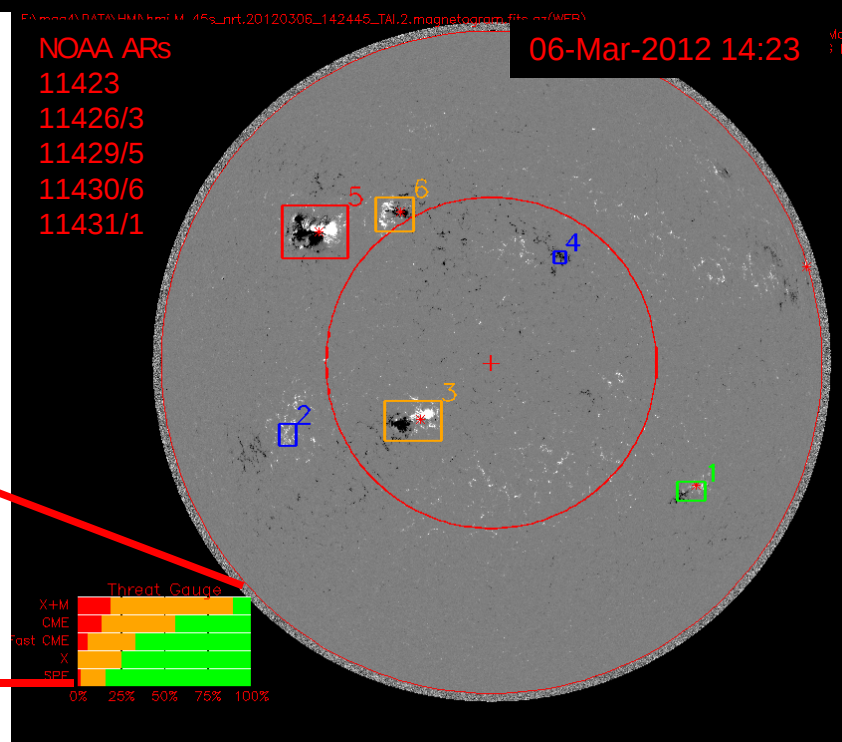
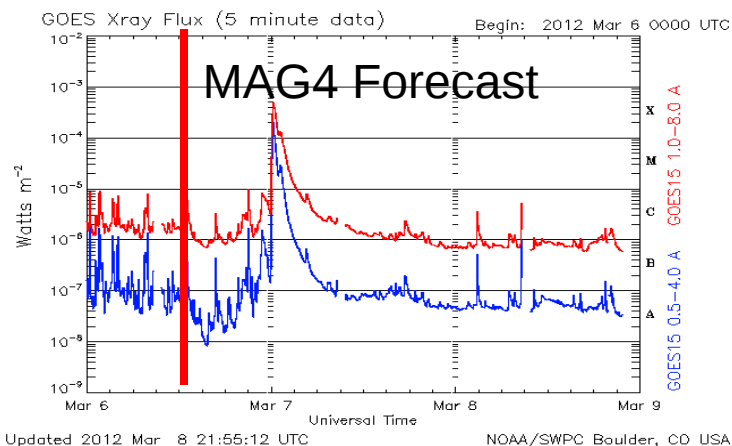
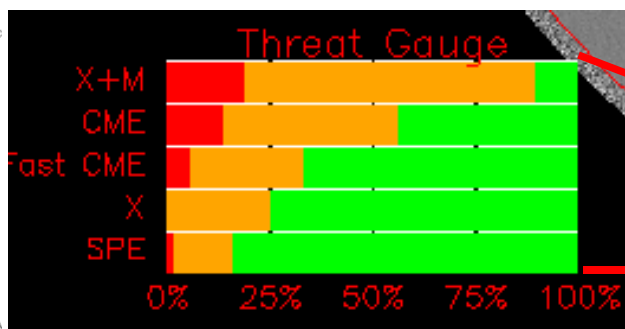
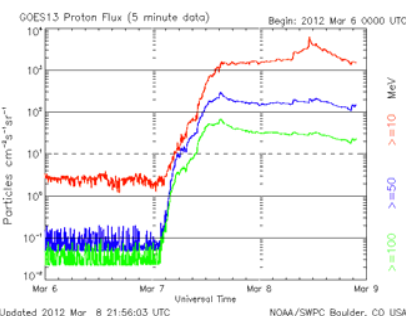
lots of layers on this page – not sure what you wanted showing



Multiplicative uncertainty example

Rate	1 sigma	Probability
Events/day	66% Confidence	
0.02	0.01-0.05	0.7-5%
0.7	0.3-1.9	20-80%

For a Multiplicative Uncertainty of 2.7x



2012/03/06 14:23

#	AR#	WL!DSG!N	Lng	Lat
			(kG)	(deg)
3	11428	9	-21	-17
5	11429	65	-41	17
6	11430	11	-25	20
1	11431	1	36	-27

Disk Forecast Rates
Multiplicative Uncertainties
Disk All-Clear Forecast Probabilities
Uncertainties

24 Hour Event Rate					Dist
M&X	CME	FCME	X	SPE	(deg)
0.020	0.020	0.009	0.002	0.003	27
0.700	0.400	0.200	0.100	0.080	44!
0.020	0.030	0.010	0.004	0.005	32!
0.000	0.001	0.001	0.000	0.000	45!
0.800	0.400	0.200	0.100	0.090	
2.7x	2.1x	2.2x	3.0x	2.4x	
50.00%	70.00%	80.00%	90.00%	92.00%	
40.00%	20.00%	10.00%	10.00%	7.00%	

Comparison of Safe and Not Safe Days

June 26, 2013

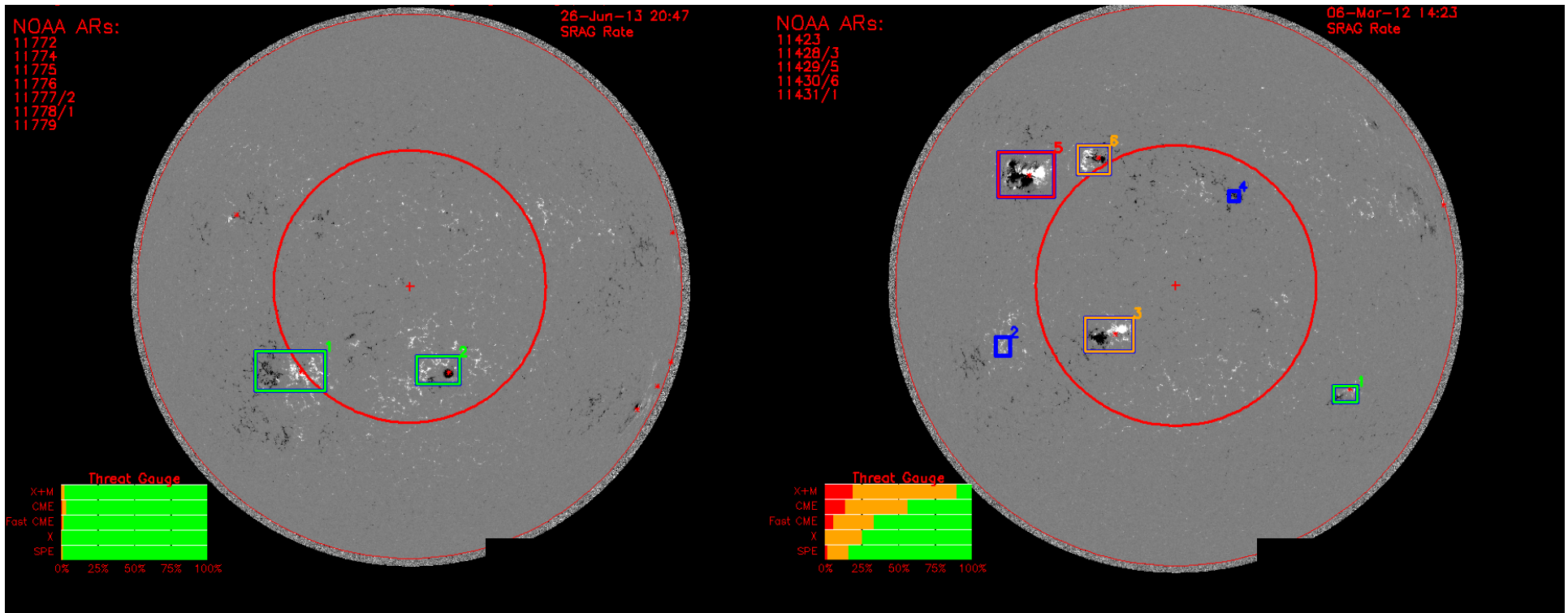
C1, C1.5 flares

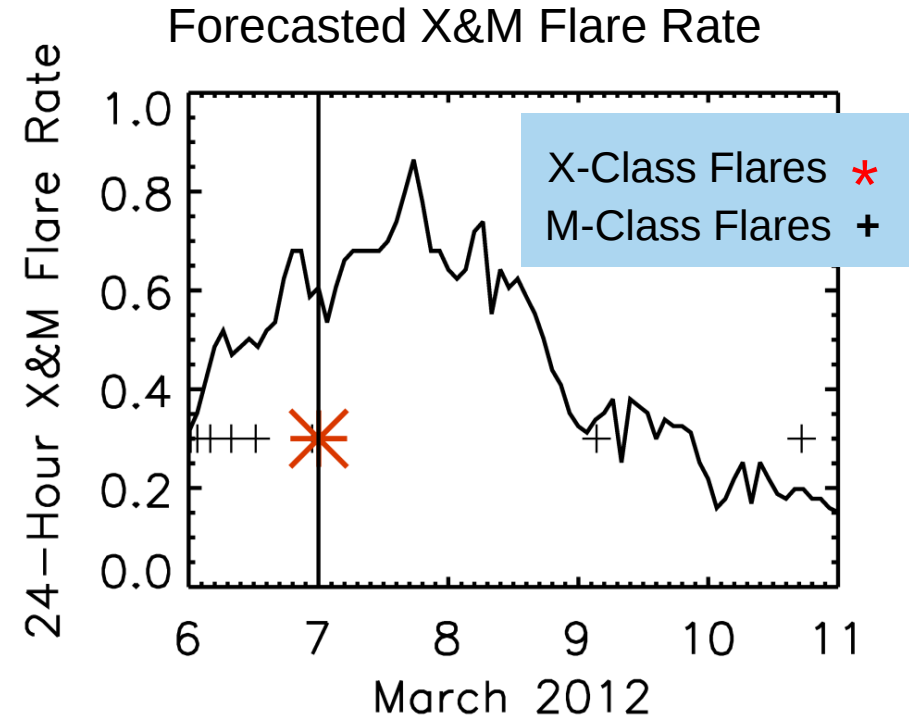
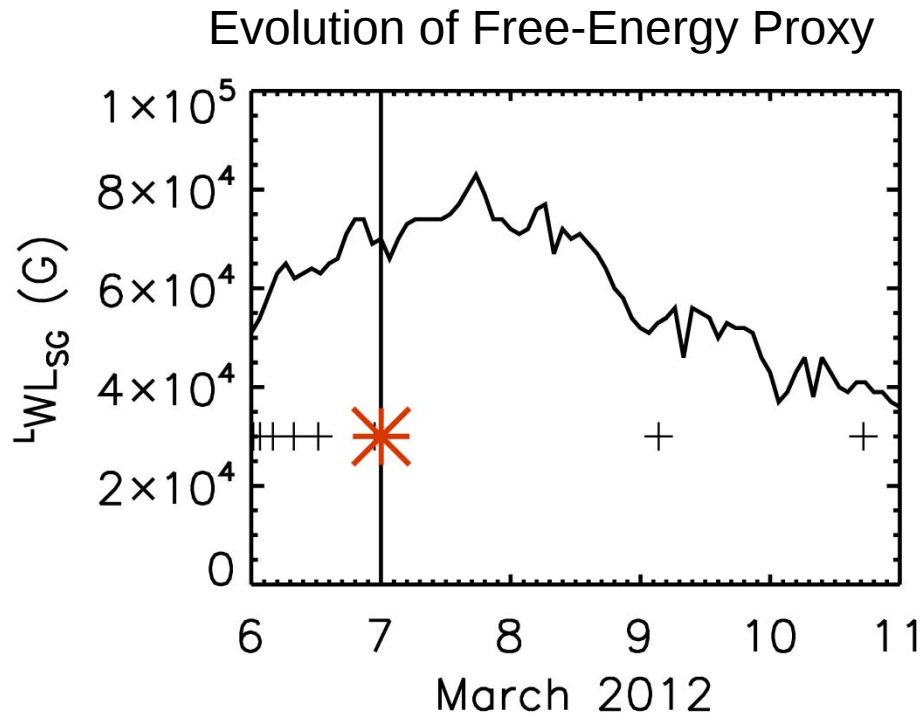
March 7, 2012

X5.4, X1.3, C1.6

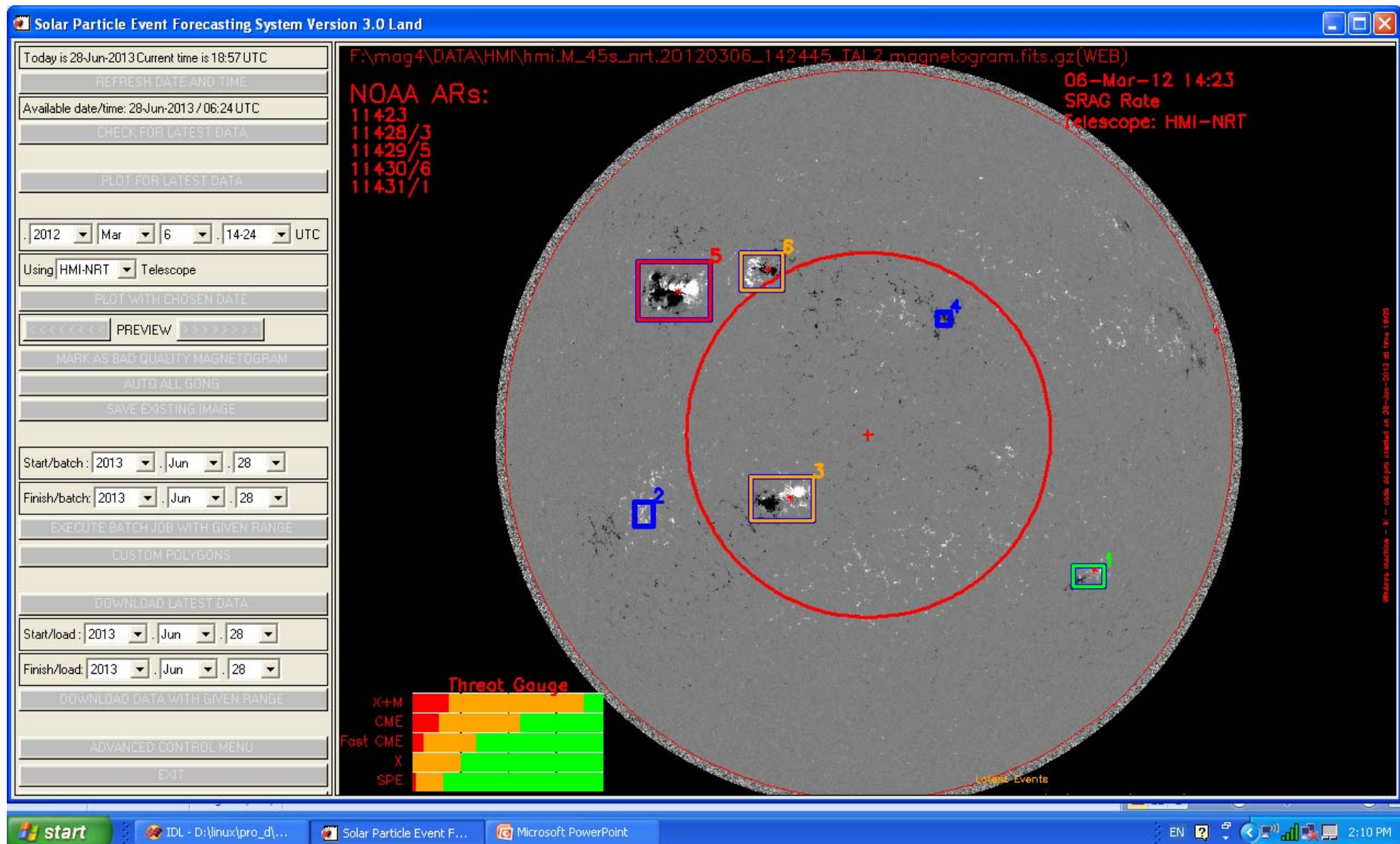
CME 2684, 1825 km/sec,

Solar Energetic Proton Event reaches
6530 particle flux unit >10MeV

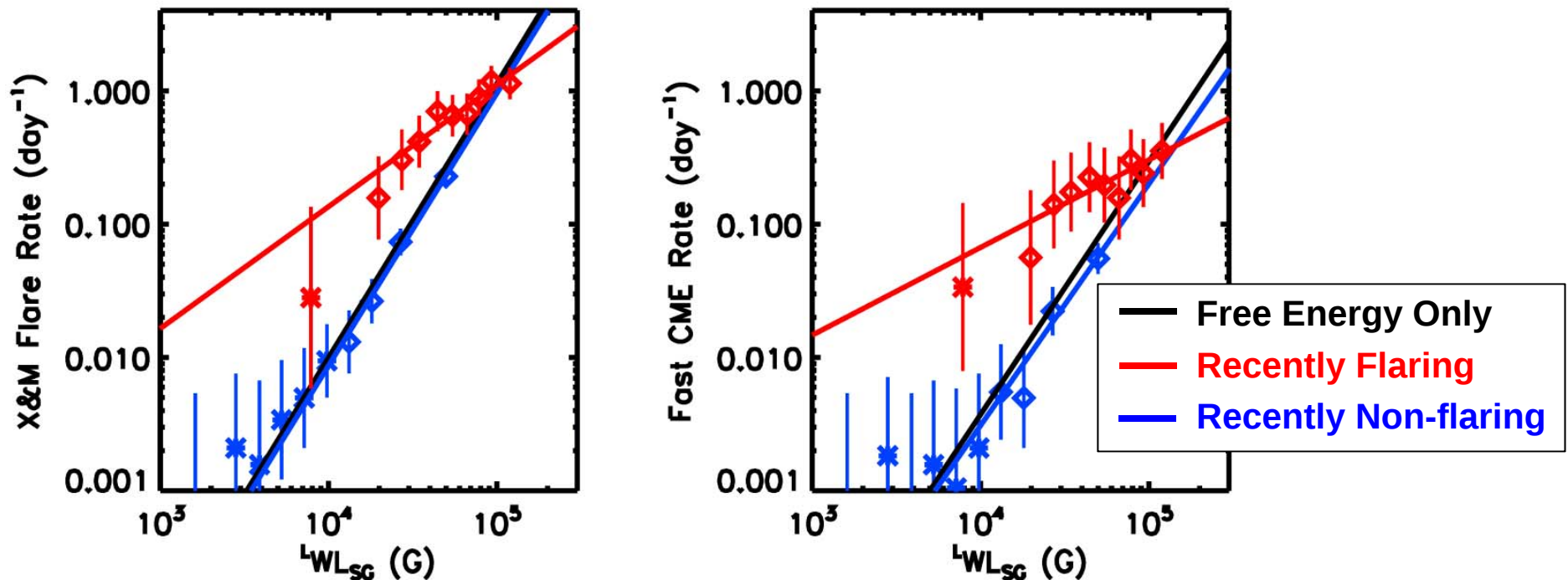




The Free-Energy Proxy evolves on time periods of days,
and the forecast is on those time scales.



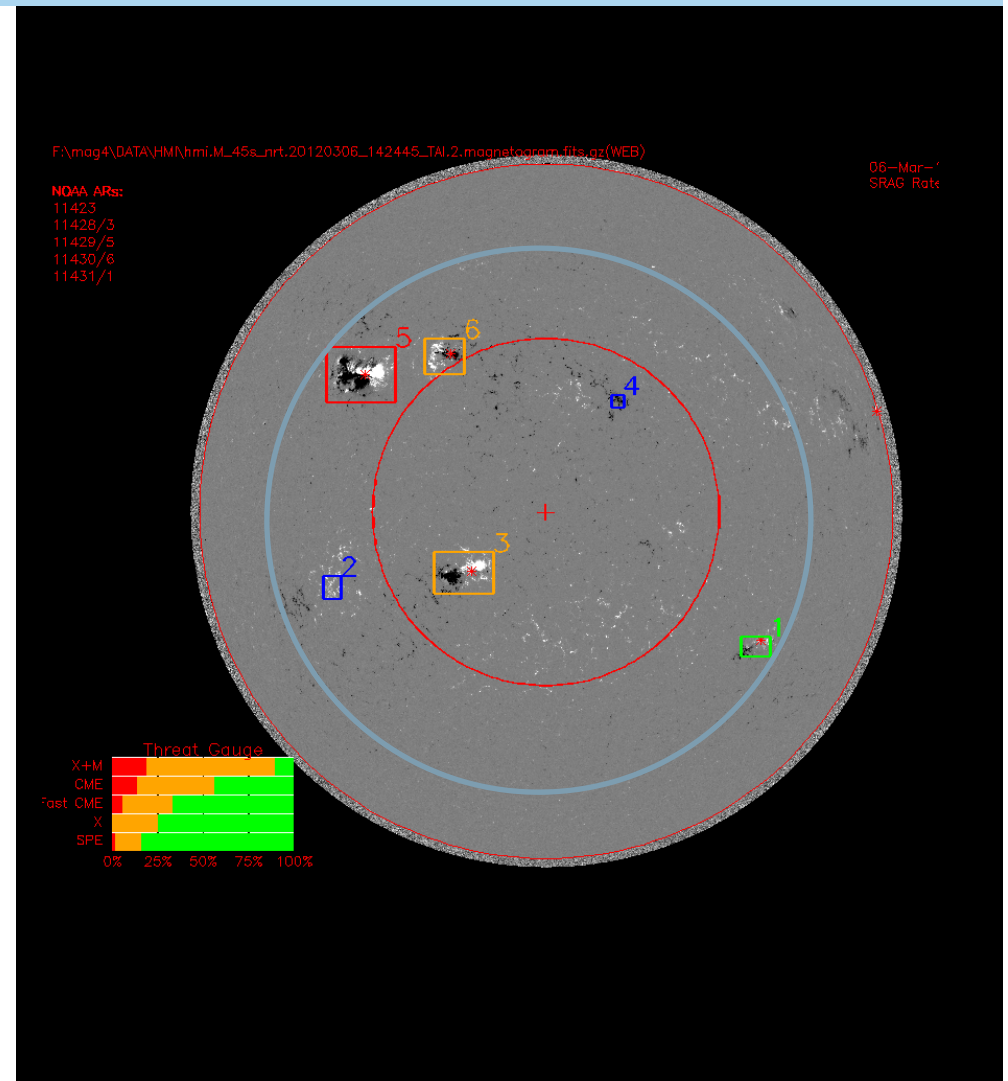
1. Recent Flare History (In Progress)



Active regions that have recently produced an X- or M-Class flare are more likely to produce flares in the near future

2. Vector Magnetograms (In Progress)

- MAG4 presently uses SDO/HMI line-of-sight magnetograms
- Near-real-time Ambiguity-Resolved SDO/HMI vector-magnetograms have recently become available
- We are transitioning to using these new data from SDO
- Implementation just started

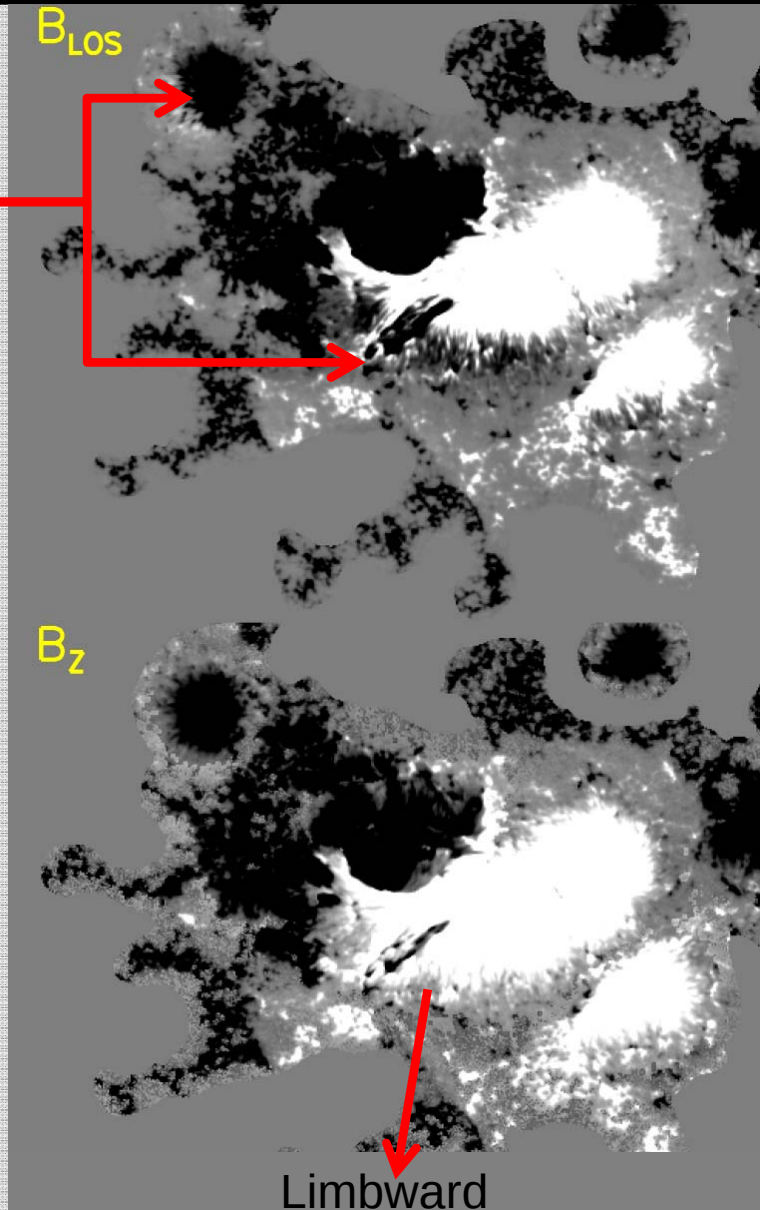
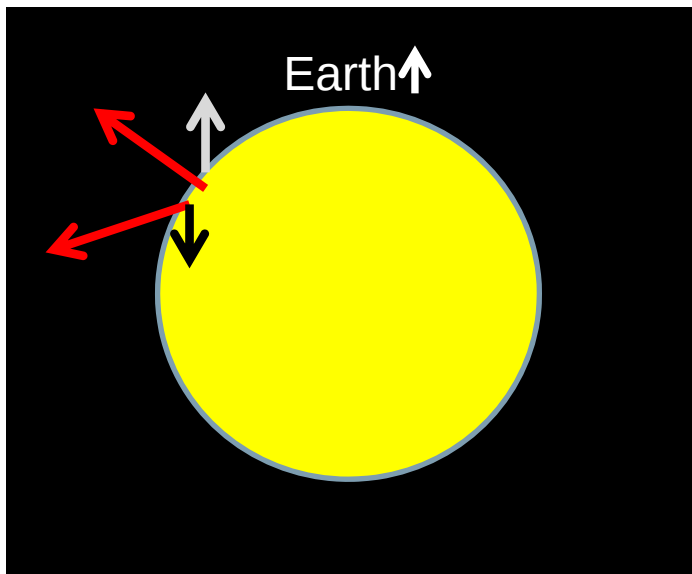


- Both vectors shown in red have positive B_z (magnetic field out of the sun), but have opposite sign B_{LOS} and thus a false (unphysical) neutral line in the line-of-sight (LOS) field.

Actual Examples

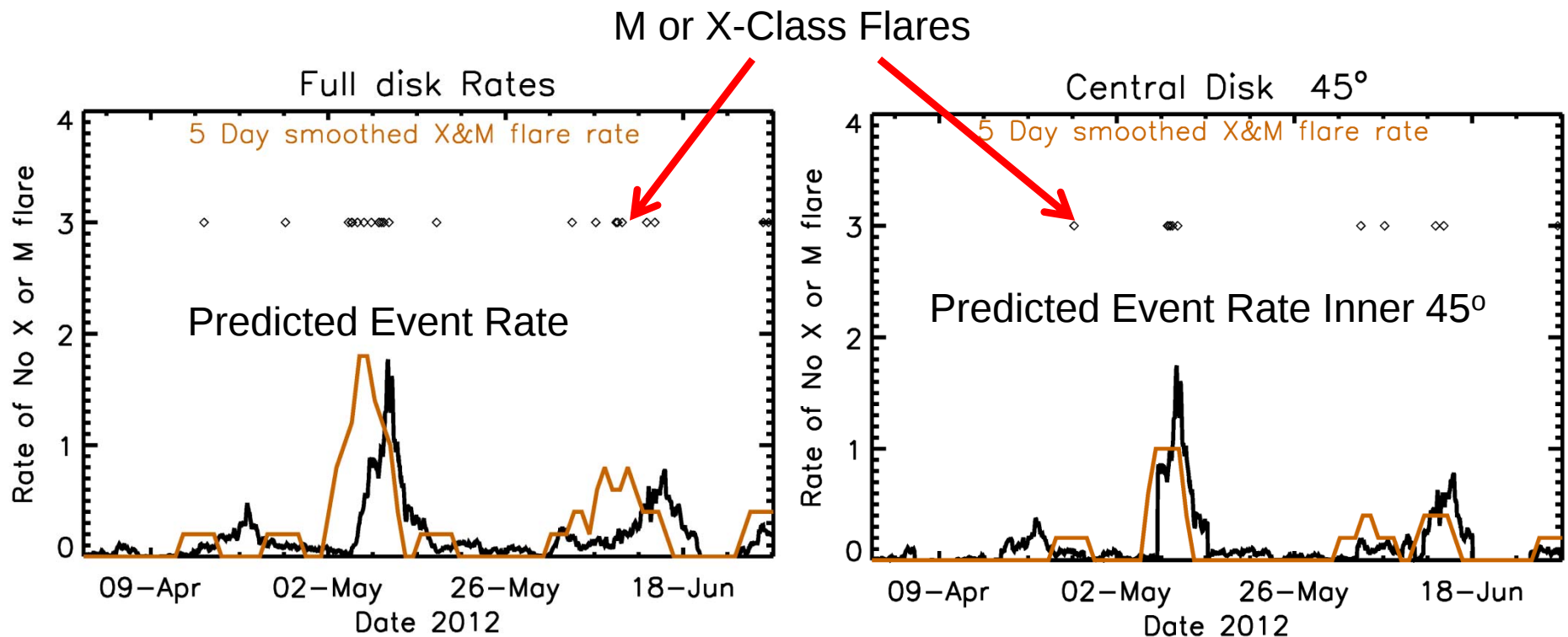
False Neutral Lines occur on limbward sides of sunspots.

Problem fixed by converting from B_{LOS} and $B_{Transverse}$ to B_z and $B_{Horizontal}$



1. Situational Awareness

- During periods when flare-productive active regions cross the disk, the predicted rate and actual rate both increase, providing situational awareness
- The results are best when flares and predicted rates are limited to inner 45 degree circle (Right)



2. Skill Metrics

Truth Table	Actual Yes	Actual No
Predict Yes	YY	YN
Predict No	NY	NN

PC Percent Correct
 POD Probability of Detection
 FAR False Alarm Rate
 HSS Heidke Skill Score
 TSS True Skill Score

Forecast Method	YY	YN	NY	NN	PC	POD	FAR	HSS	TSS
McIntosh/NOAA	259	638	631	18476	93.7	0.29	0.71	0.26	0.26
Free-Energy Proxy Present MAG4	273	284	618	18830	95.5	0.31	0.50	0.35	0.47
Free-energy proxy and previous flare activity Upgraded MAG4	340	317	551	18797	95.7	0.38	0.48	0.42	0.49
Best	890	0	0	19114	100	1	0	1	1

- Customizing MAG4 to AFWA needs
- Further development of MAG4
 - R2O: use time series, Heliosphere propagation of CME, Helioseimology, Improve forecasts as with flare history
 - Operational Tool: Robustness, usability, interface
- Independent Verification Tests



Backup Slides



2. Skill Metrics Equations

	Actual Yes	Actual No
Predict Yes	YY	YN
Predict No	NY	NN

Metric Equations

Percent Correct	$PC = (YY + NN) / (YY + YN + NY + YY)$
Probability of Detection	$POD = YY / (YY + NY)$
False Alarm Rate	$FAR = YN / (YY + YN)$
Heidke Skill Score	$HSS = 2 * (YY * NN - YN * NY) / [(YY + NY) * (NY + NN) + (YY + YN) * (YN + NN)]$
True Skill Score	$TSS = (YY * NN - NY * YN) / ((YY + NY) * (YN + NN))$

Flares occur when high free-energy proxy active regions crossing disk.

