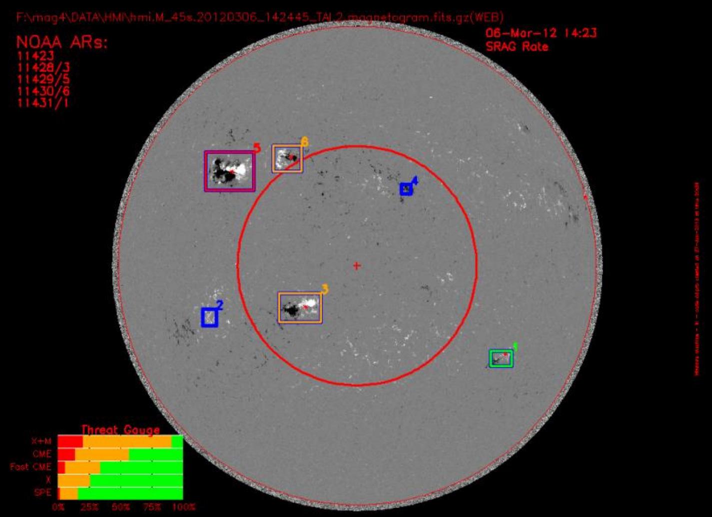
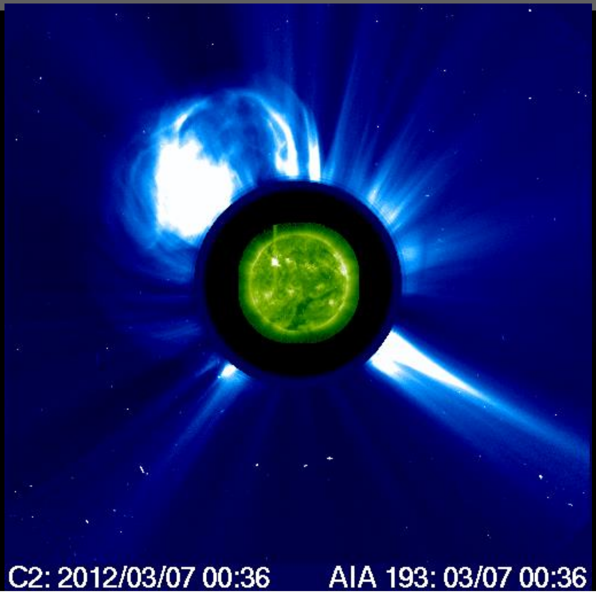
National Aeronautics and Space Administration

SCIENCE & TECHNOLOGY OFFICE





Mag4: SEP Prediction

David Falconer, Igor Khazanov, Nasser Barghouty

Presentation, Sept 30, 2015

MAG4 Automated Processes

Download HMI Magnetogram
LOS or Vector

↓

Identify Active Regions LOS
Use SHARPS for vector

↓

Calculates Free-Energy Proxy

↓

Predicted Event Rate

↓

Make Forecasts

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

What is MAG4?

- 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 that a flare will occur at a particular time in the next 24 or 48 hours; rather the **probability of one occurring!**

- 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** (60 minutesfo CCMC)
  Vector magnetogram actual cadence: **12 minutes**

MAG4 Background

- 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 the magnitude of the free-energy proxies

R2O Timeline of MAG4

- *1973* The MSFC (Marshall Space Flight Center) vector magnetograph was built to support Skylab
- *2000-present* MSFC used vector magnetograms to study CME correlation with free-energy proxy
- *2007-12* A DOD/Multidisciplinary University Research Initiative/Neutral Atmosphere Density Interdisciplinary Research helped support funding of the basic research
- *2008* Partnered with JSC/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 <u>NRT (Near-Real-Time) forecasting tool</u>, 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**
- *2015* Transition to HMI line-of-sight to vector magnetograms

Science & Technology Office

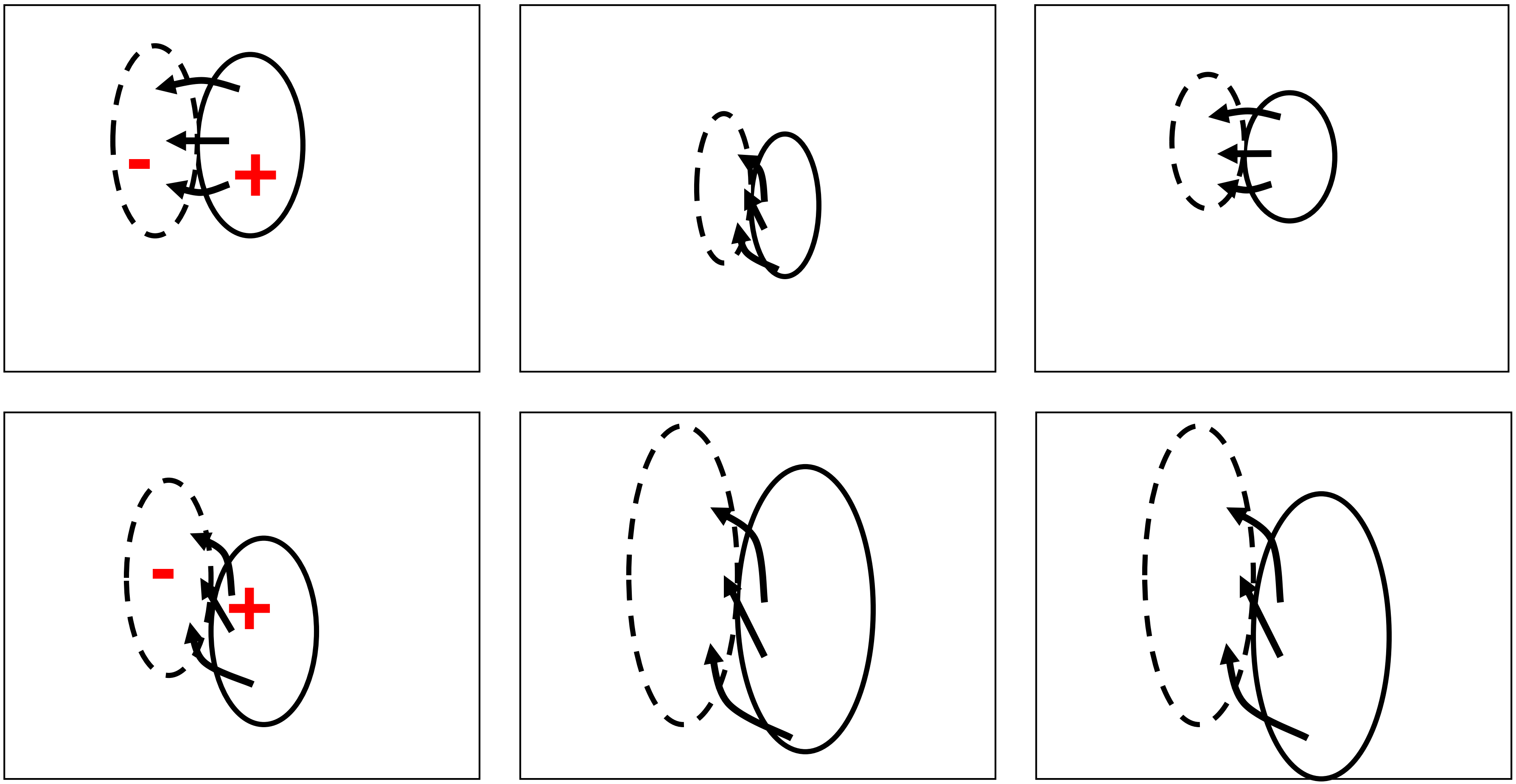
Free-Magnetic Energy

Contours Vertical Magnetic Field
Arrows Transverse Magnetic Field

Currents ~10^{12} Amps

Less

More



Twist

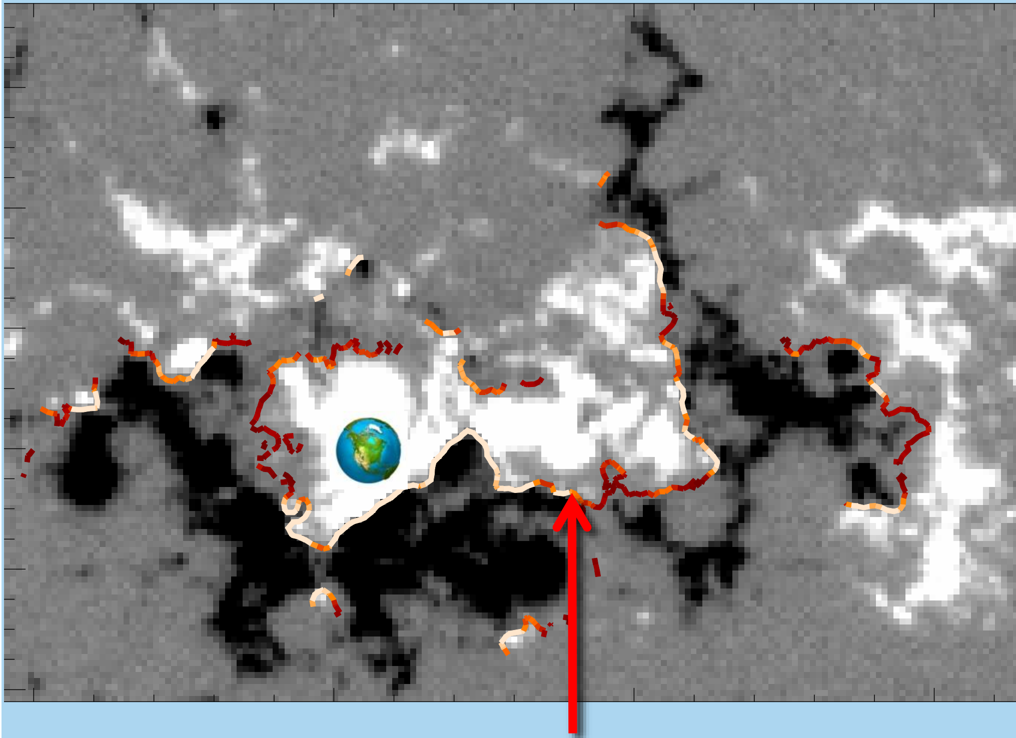
Size

Free Magnetic Energy Or Nonpotentiality

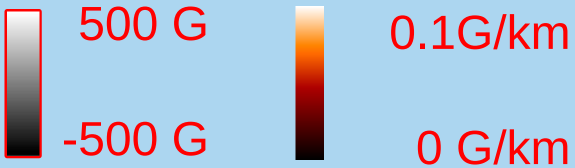
Process 2: Calculating the Free-Energy Proxy

- When 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



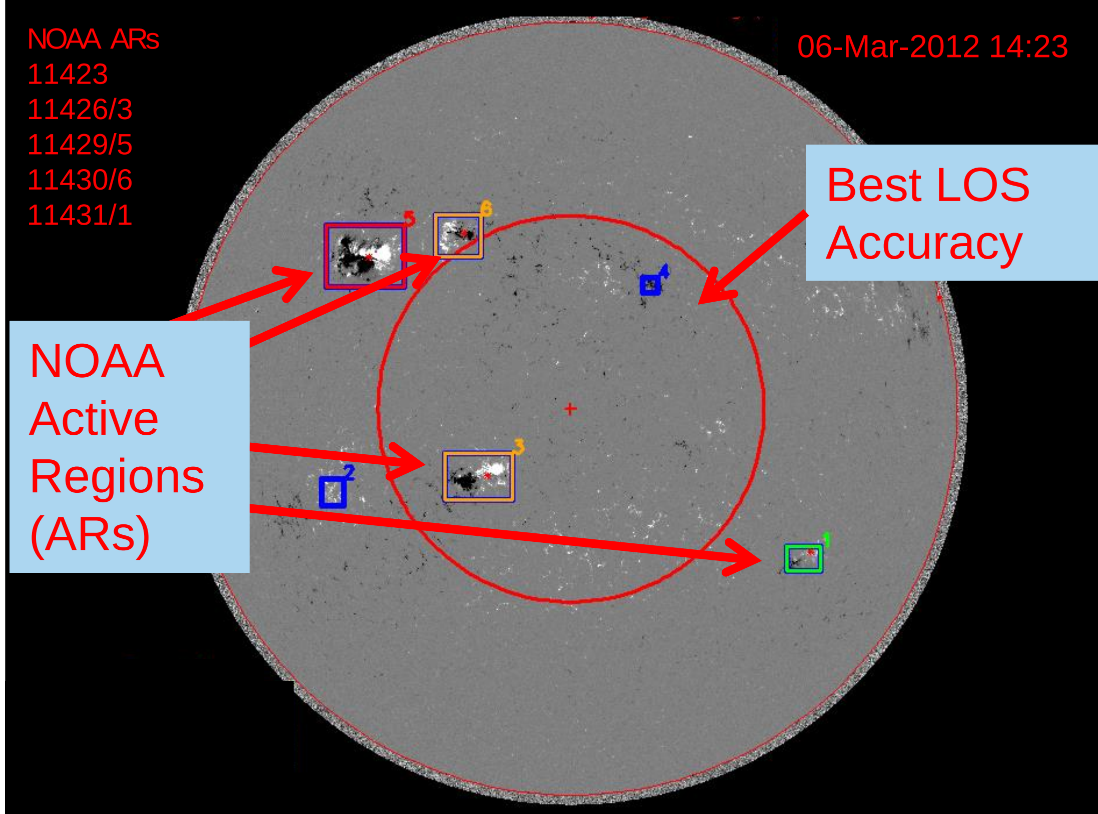
Neutral Line, color coded for gradient



Process 1: Identifying Active Regions

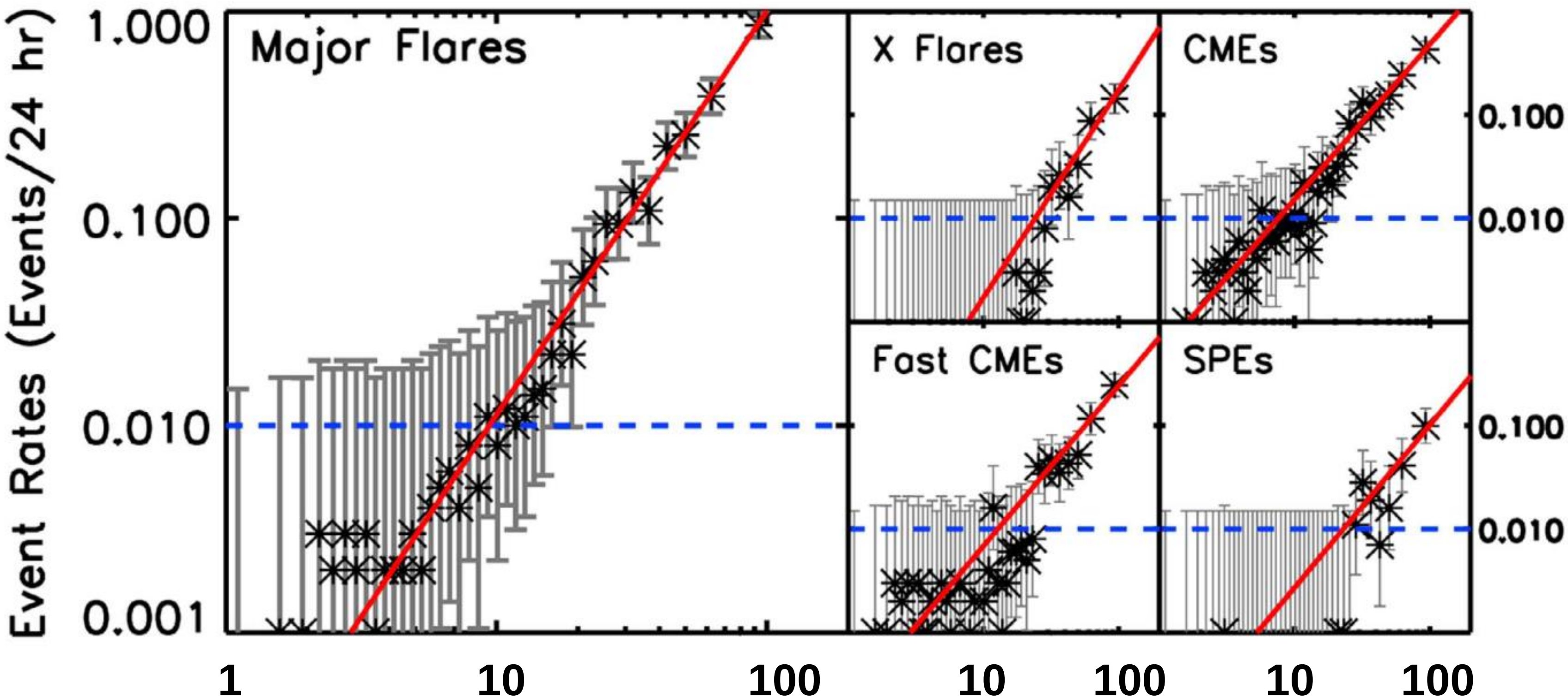
- Magnetograms are spatial maps of the magnetic field strengths
- They come in two basic types
  - line-of-sight (right)
  - vector magnetograms
- Free-energy proxies can be measured for Active Regions (areas with sunspots) from either type of magnetogram
- Line-of-sight magnetograms suffer reduced accuracy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

Magnetograms & identify ARs



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

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



Forecast Curves

Free-Energy Proxy W(kG)

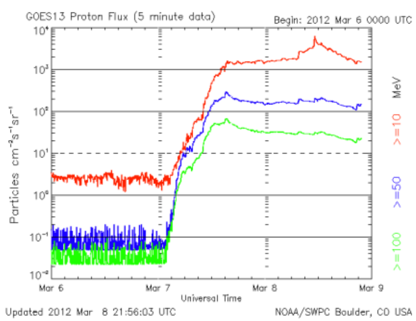
These empirical forecast curves are used to convert our free-energy proxy into predicted event rates. Curves are derived from a sample of 40,000 magnetograms, from 1300 active regions observed between 1996-2004.

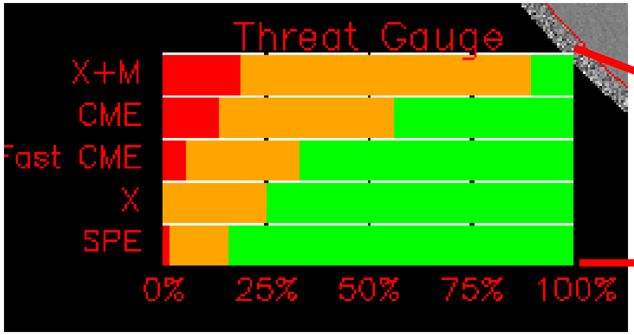
Process 4: Forecast

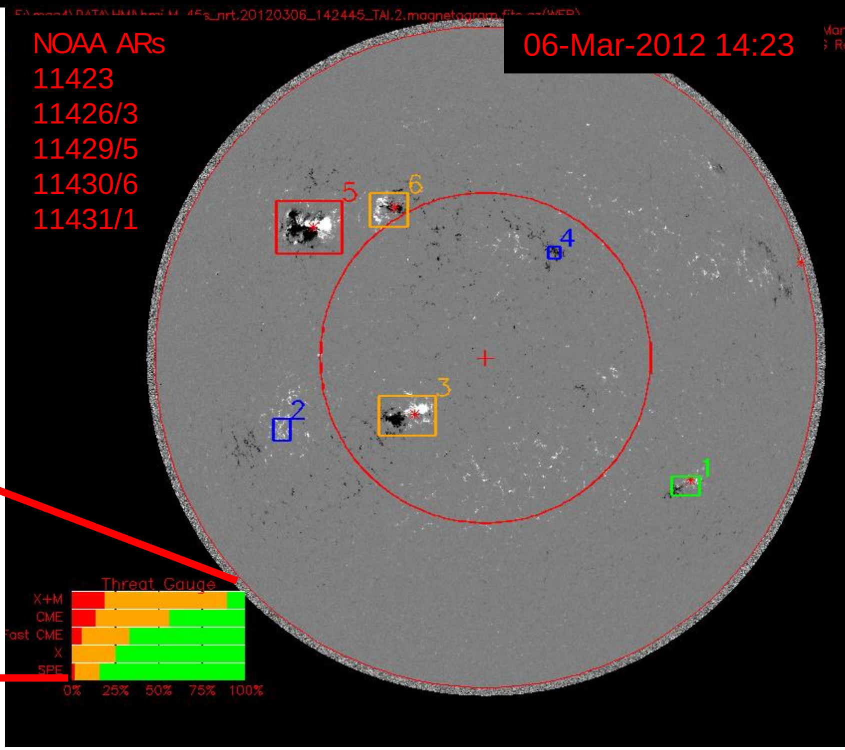
Multiplicative uncertainty example

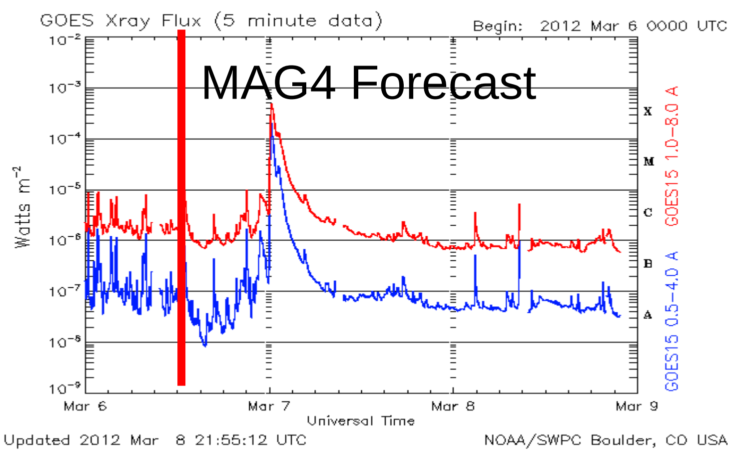
Rate Events/day	1 sigma 66% Confidence	Probability
0.02	0.01-0.05	0.7-5%
0.7	0.3-1.9	20-80%

For a Multiplicative Uncertainty of 2.7x









2012/03/06 14:23

#	AR#	WL!DSG!N (kG)	Lng	Lat (deg)	M&X	CME	FCME	X	SPE	Dist (deg)
					24 Hour Event Rate					
3	11428	9	-21	-17	0.020	0.020	0.009	0.002	0.003	27
5	11429	65	-41	17	0.700	0.400	0.200	0.100	0.080	44!
6	11430	11	-25	20	0.020	0.030	0.010	0.004	0.005	32!
1	11431	1	36	-27	0.000	0.001	0.001	0.000	0.000	45!
Disk Forecast Rates					0.800	0.400	0.200	0.100	0.090	
Multiplicative Uncertainties					2.7x	2.1x	2.2x	3.0x	2.4x	
Disk All-Clear Forecast Probabilities					50.00%	70.00%	80.00%	90.00%	92.00%	
Uncertainties					40.00%	20.00%	10.00%	10.00%	7.00%	

Comparison of Safe and Not Safe Days

June 26, 2013

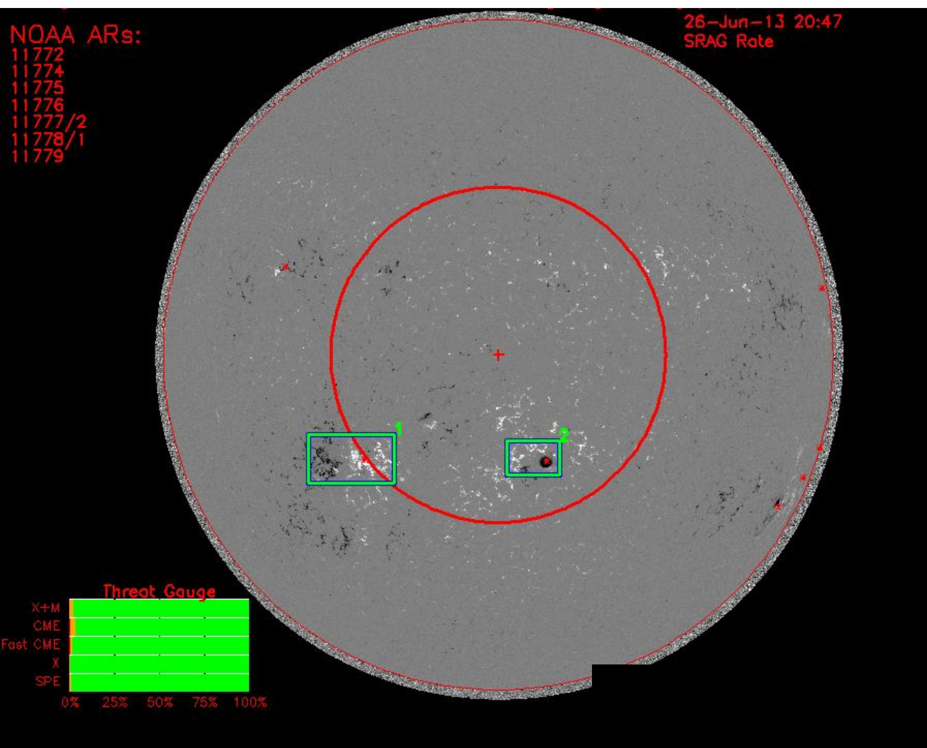
C1, C1.5 flares

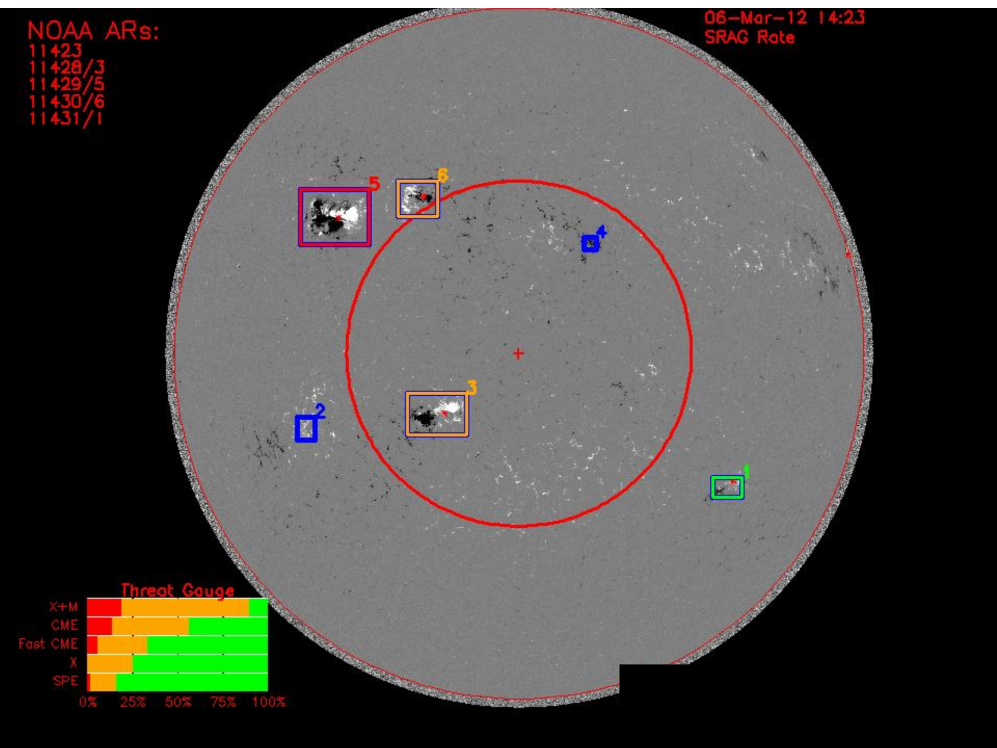
March 7, 2012

X5.4, X1.3, C1.6

CME 2684, 1825 km/sec,

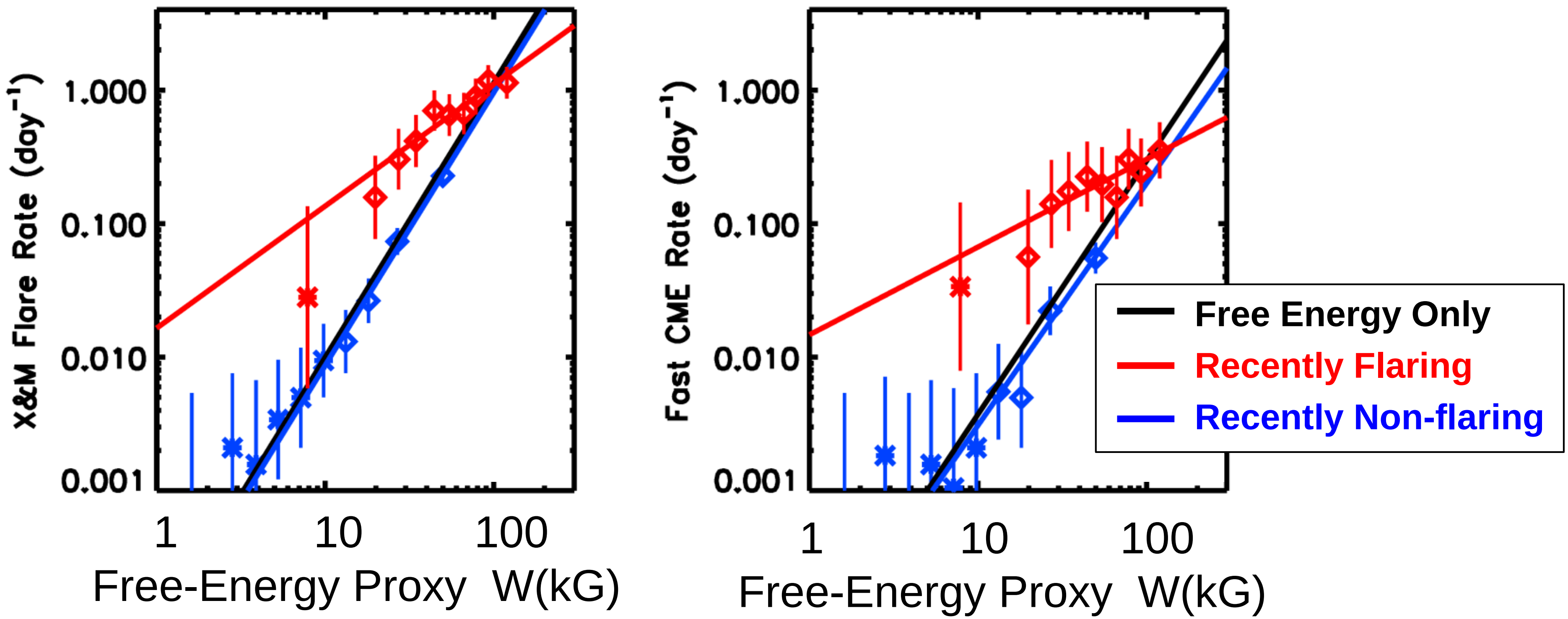
Solar Energetic Proton Event reaches 6530 particle flux unit >10MeV





Improving the Forecasts:

1. Recent Flare History



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

How Well Does MAG4 Forecast:

2. Skill Metrics

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

PC	Percent Correct (0 to 100%)
POD	Probability of Detection (0 to 1)
FAR	False Alarm Rate (1 to 0)
HSS	Heidke Skill Score (-1 to 1)
TSS	True Skill Score (-1 to 1)

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	273	284	618	18830	95.5	0.31	0.50	0.35	0.47
Free-energy proxy and previous flare activity	340	317	551	18797	**95.7**	**0.38**	**0.48**	**0.42**	**0.49**
Best	890	0	0	19114	100	1	0	1	1

Science & Technology Office

How Well Does MAG4 Forecast:

2. Skill Metrics Significance of Upgrade

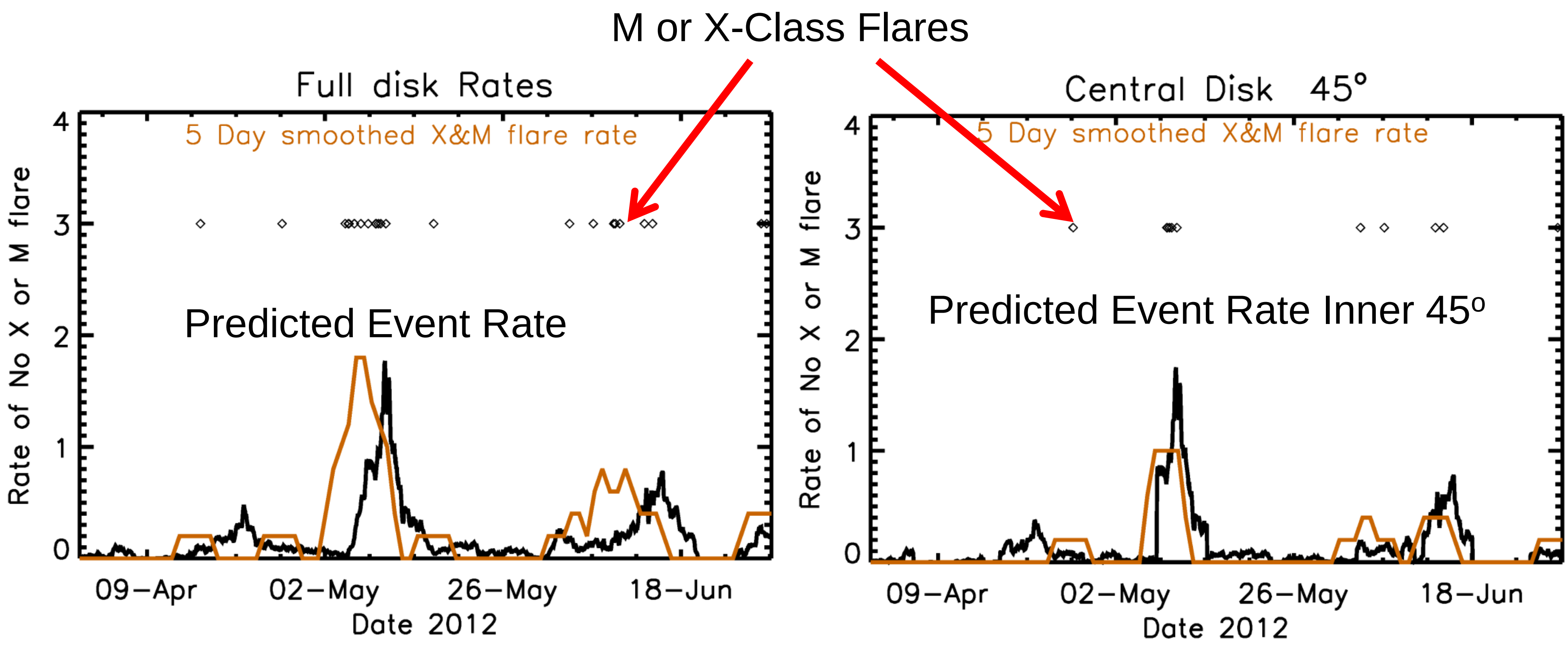
Forecast Method	YY	YN	NY	NN	PC(%)	POD	FAR	HSS	TSS
McIntosh/**NOAA**	259	638	631	18476	93.7	0.29	0.71	0.26	0.26
Free-Energy Proxy **Present MAG4**	273	284	618	18830	95.5	0.31	0.50	0.35	0.47
Free-energy proxy and previous flare activity **Upgraded MAG4**	340	317	551	18797	**95.7**	**0.38**	**0.48**	**0.42**	**0.49**
Best	890	0	0	1911 4	100	1	0	1	1

Improvement in Metric	PC(%)	POD	FAR	HSS	TSS
McIntosh/**NOAA** **Present MAG4**	1.8±0.5 **(4σ)**	0.03±0.05 **(0.3σ)**	0.21±0.07 **(3σ)**	0.10±0.04 **(2σ)**	0.21±0.07 **(3σ)**
Present MAG4 **Upgraded MAG4**	0.2±0.2 **(0.7σ)**	0.08±0.03 **(2σ)**	0.02±0.05 **(0.5σ)**	0.06±0.03 **(2σ)**	0.03±0.05 **(0.5σ)**

How Well Does MAG4 Forecast:

1. Situational Awareness

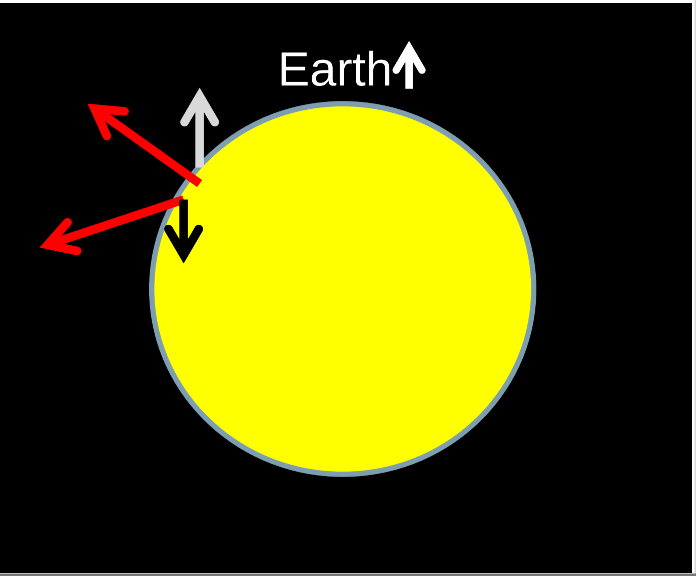
- During periods when flare-productive active regions cross the disk, the predicted rate and actual rate both increase, providing situational awareness
- The results are best when flares and predicted rates are limited to inner 45 degree circle (Right)



Science & Technology Office

MAG4 Improvements: Vector Magnetograms

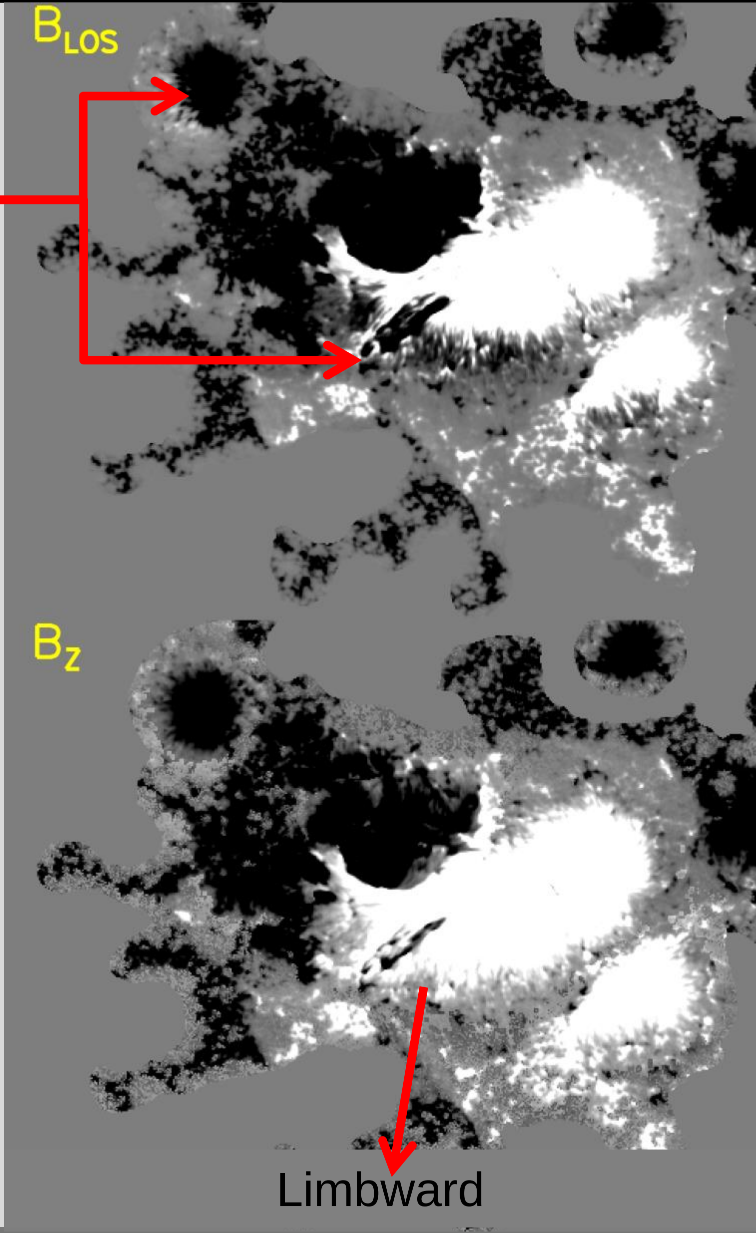
- Both vectors shown in red have positive B_z (magnetic field out of the sun), but have opposite sign B_{LOS} and thus a false (unphysical) neutral line in the line-of-sight (LOS) field.



Actual Examples

False Neutral Lines occur on limbward sides of sunspots.

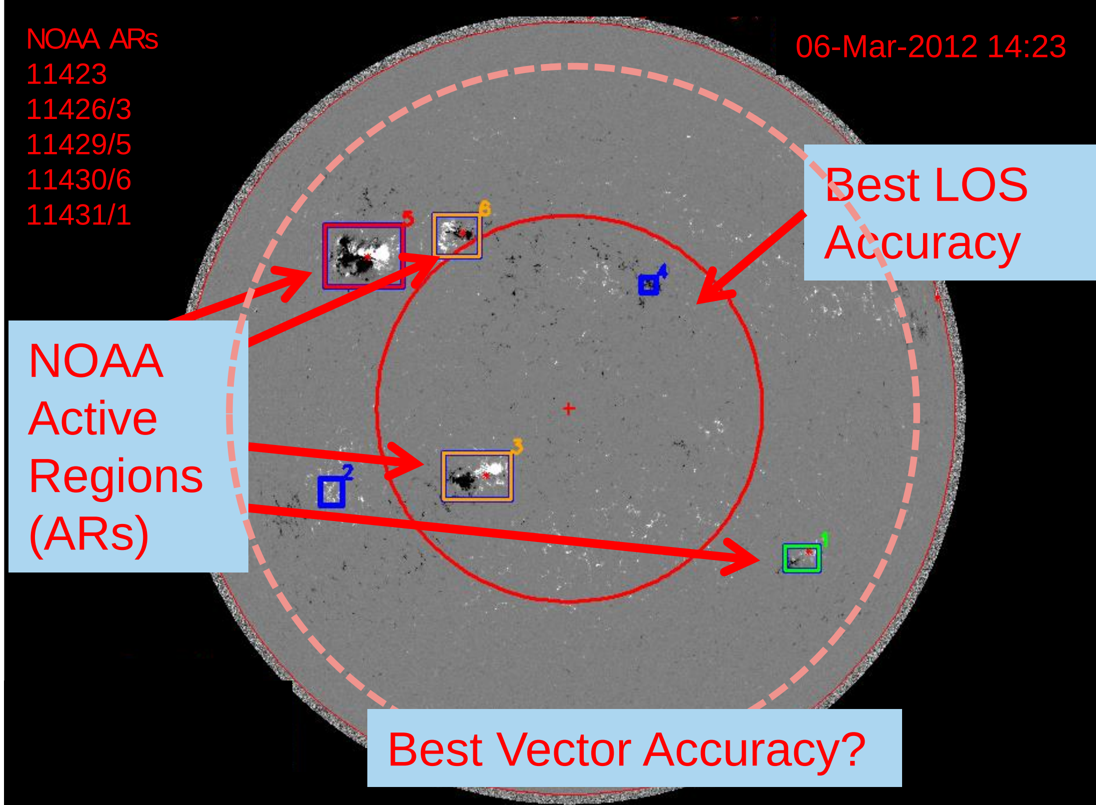
Problem fixed by converting from B_{LOS} and $B_{Transverse}$ to B_Z and $B_{Horizontal}$



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

Magnetograms & identify ARs



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

Vector Version

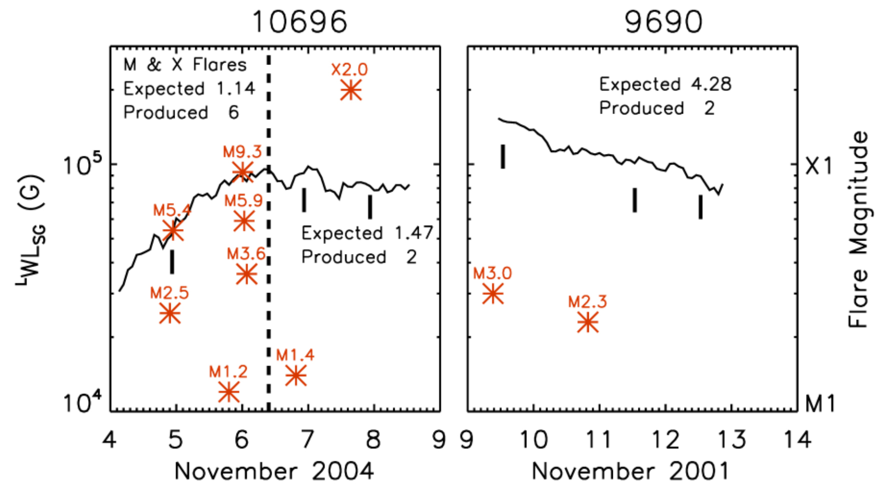
Improvements with Vector MAG4

- Correct for systemic errors in measurements due to radial dependence of transverse field noise and foreshortening.
- Access skill scores relative to present LOS
- Investigate if a vector measure is better than LOS measure
- Investigate if change of measure is important
- Investigate if combination produces better measure
- Correct SPE forecasts based on Longitude of source region
- Partner with heliosphere modeling to better forecast where the particles would go.
- Twin CME

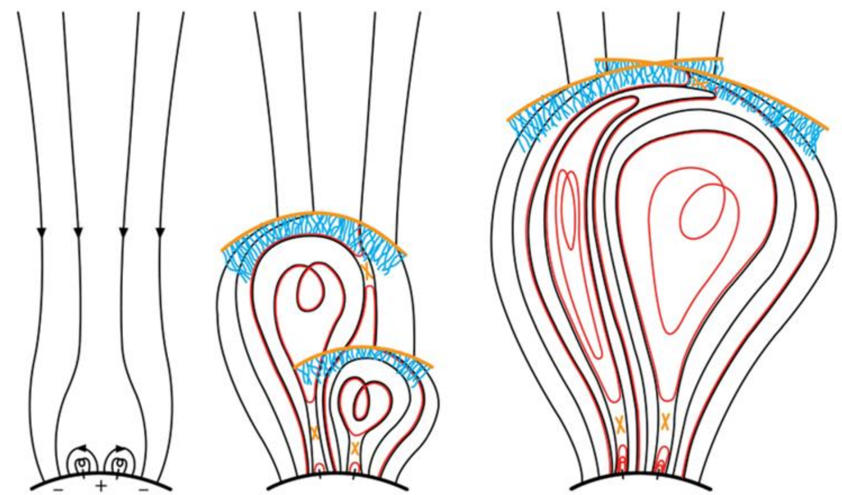
BACKUP

Basic Research to do for later R20

- Determine if growth/decay phase of an active region has additional prediction ability



- Determine if looking at twin-CME or single-CME can produce improved SEP forecasts



How Well Does MAG4 Forecast:

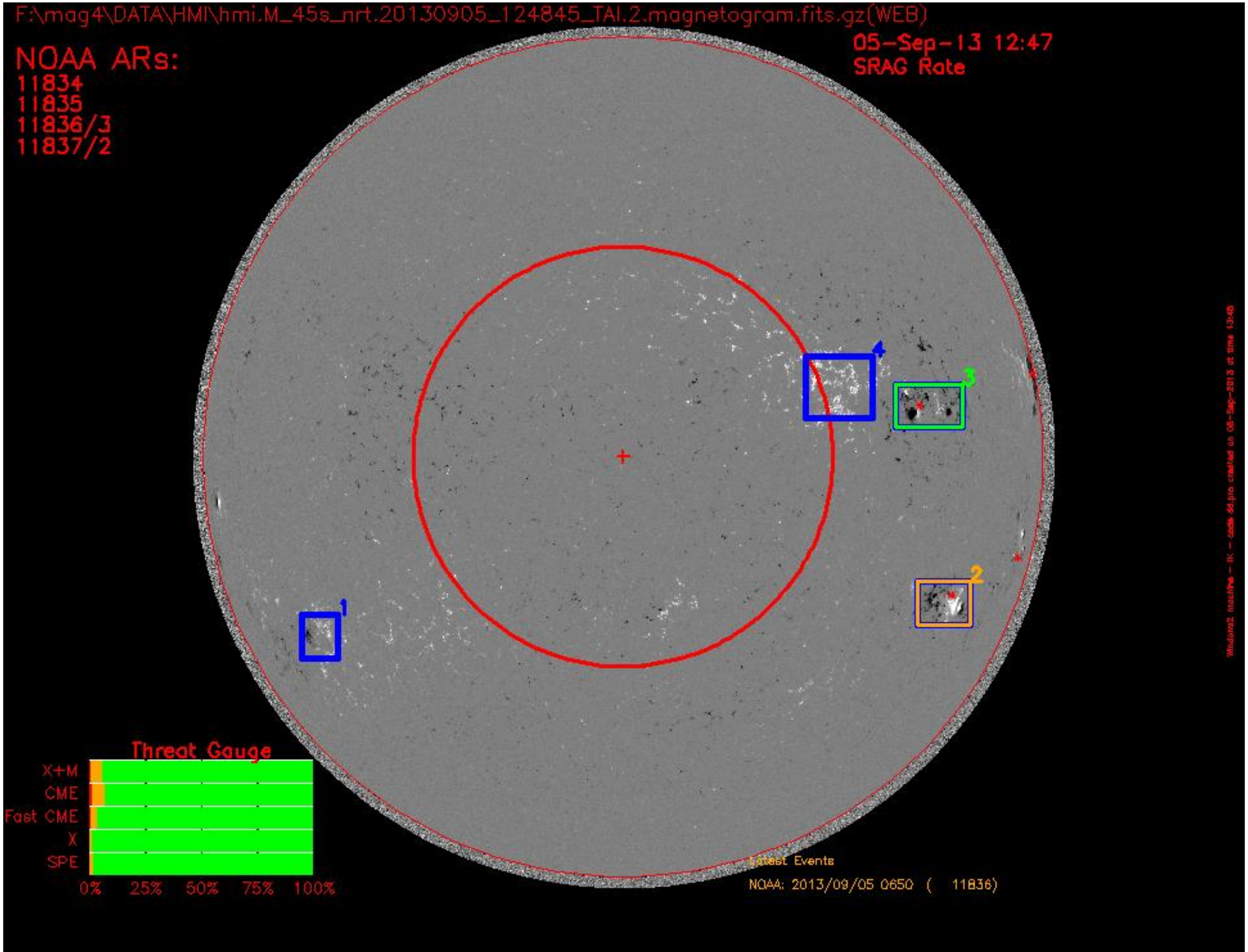
2. Skill Metrics Equations

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

Metric Equations

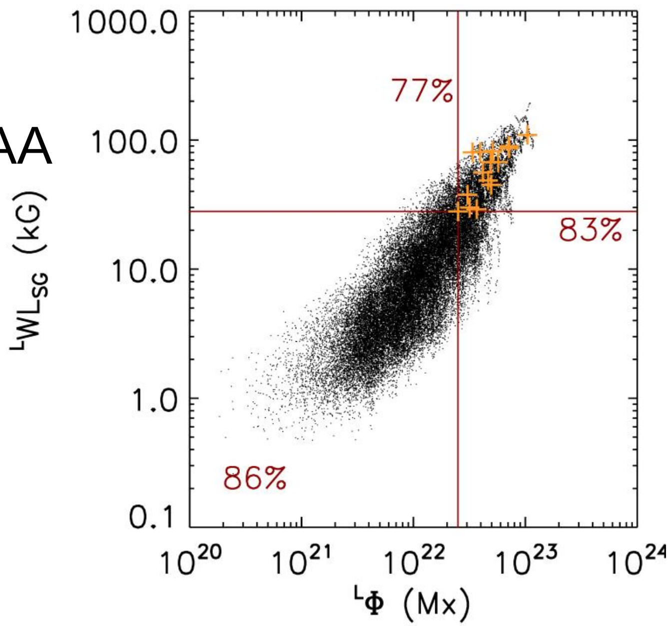
Percent Correct	PC=(YY+NN)/(YY+YN+NY+YY)
Probability of Detection	POD=YY/(YY+NY)
False Alarm Rate	FAR=YN/(YY+YN)
Heidke Skill Score	HSS=2*(YY*NN-YN*NY)/[(YY+NY)*(NY+NN)+(YY+YN)*(YN+NN)]
True Skill Score	TSS=(YY*NN-NY*YN)/((YY+NY)*(YN+NN))

Today's Forecast Questions

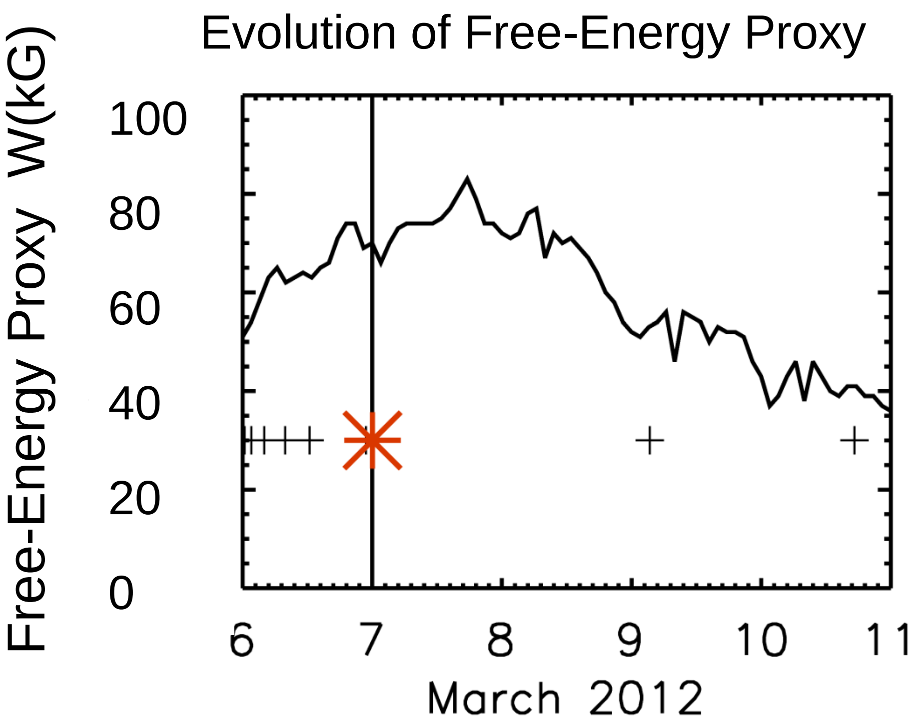


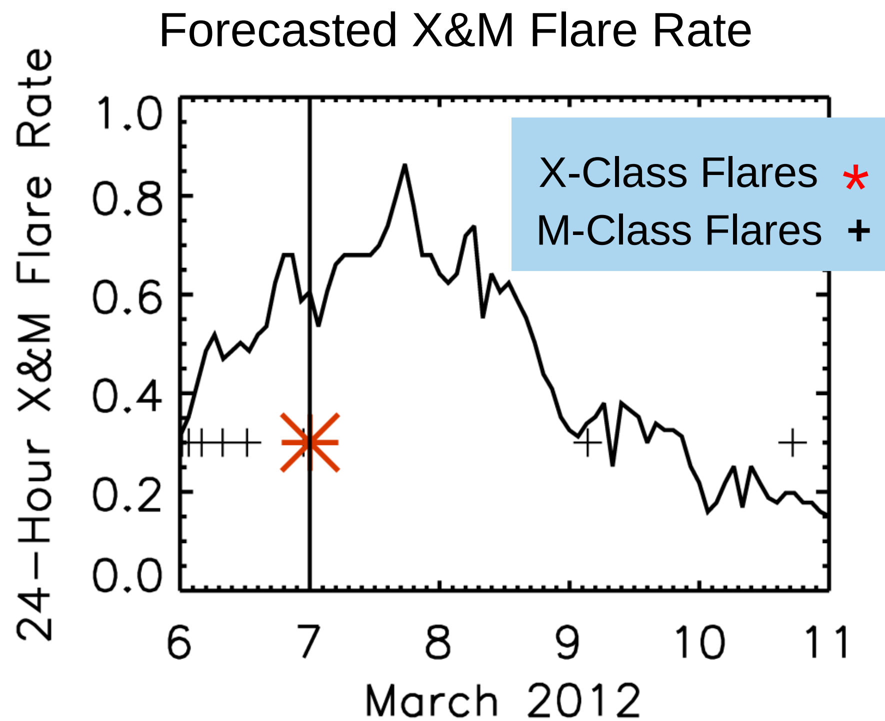
Research to Operations and Operations for FY14

- Continue to supply support, and upgrades to NASA/SRAG
- Finish and evaluate using vector magnetograms
- Fully implement in consultation with SRAG using combined free-energy proxy and previous flare activity
- Improve All Clear Forecast for SEP
- Partner with Air Force, and through them NOAA



How Free Energy Proxy Evolves and Clustering of Flares



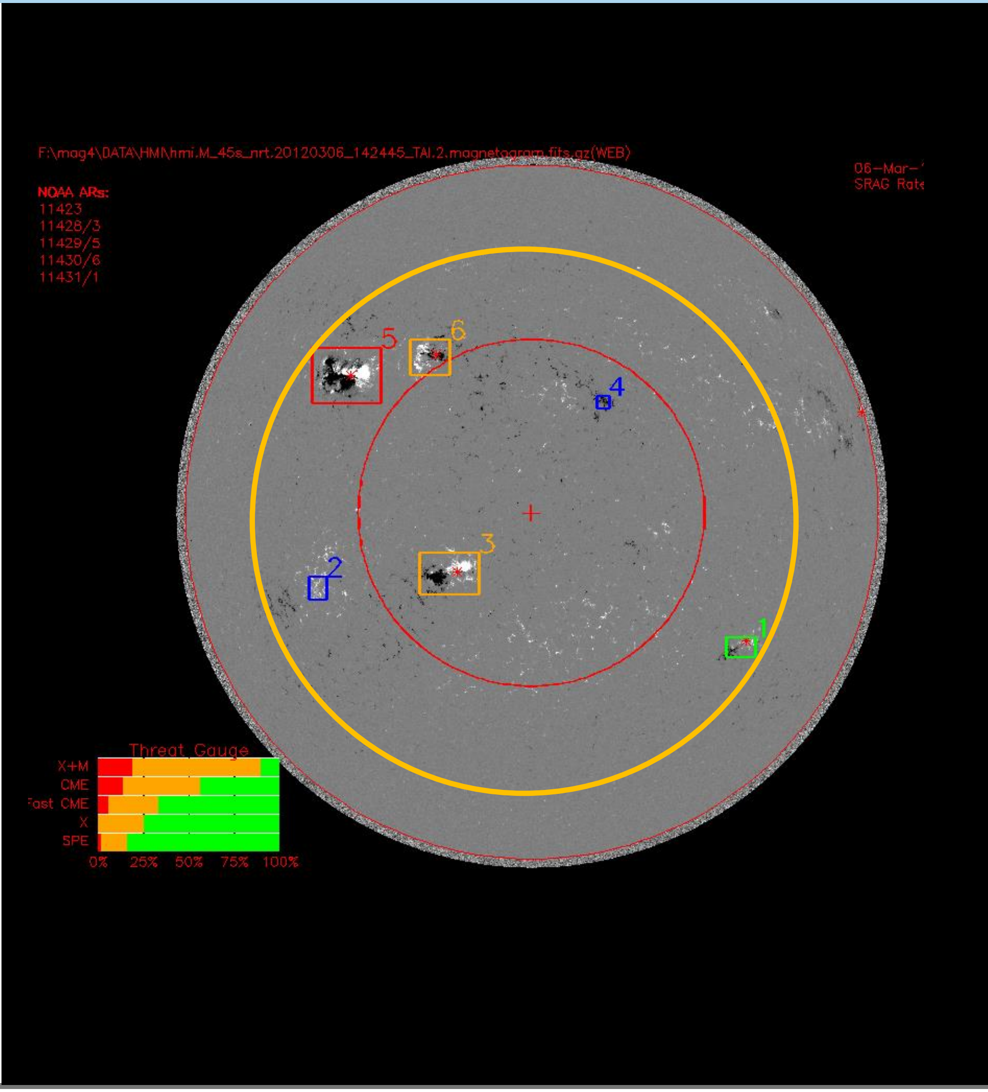


The free-energy proxy evolves on time periods of days =>
the forecast is on those time scales

Improving the Forecasts:

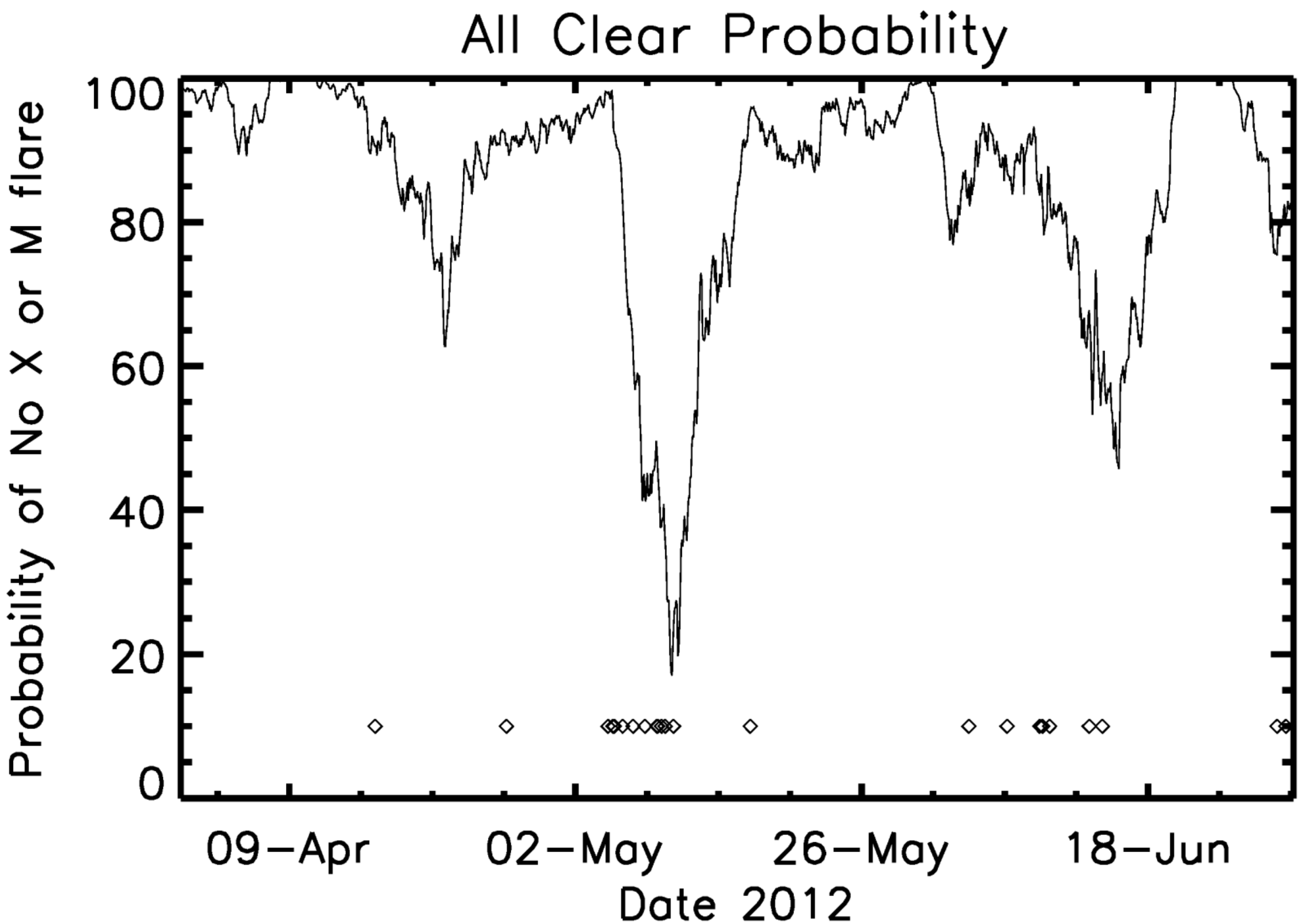
2. Vector Magnetograms (In Progress)

- 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



How well it works (All-Clear)

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



Times of X or M Flares