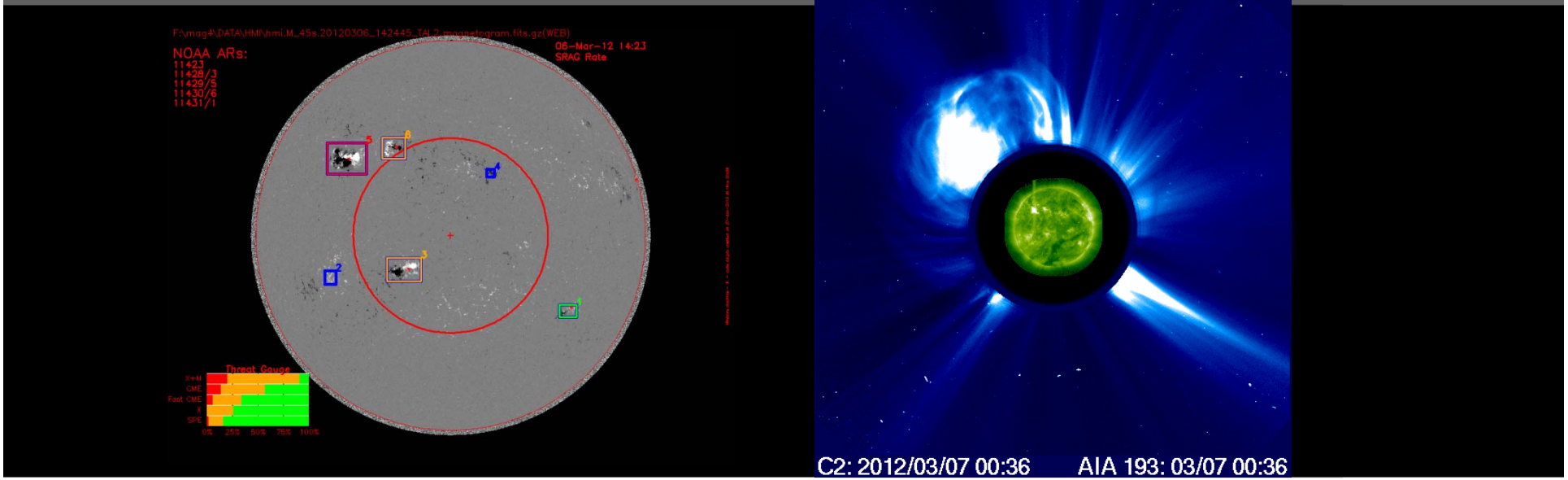
National Aeronautics and Space Administration

MSFC Science & Technology Office



MAG4 versus Alternative Techniques for Forecasting Active-Region Flare Productivity

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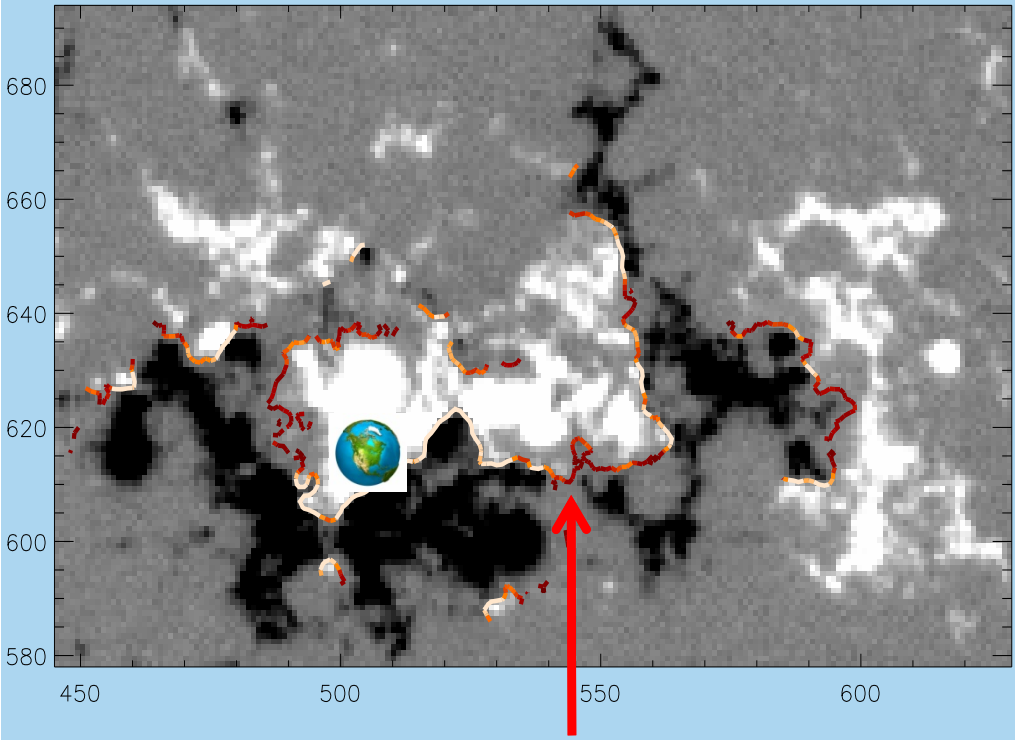
Background

- Major Flares and CMEs are known to be drivers of the most severe space weather
- Most major Flares and CMEs come from Sunspot active regions
- Flares and CMEs are exceptionally large explosive releases of free 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
- **We will demonstrate that our MAG4 forecasting techniques are more accurate than either the McIntosh or Total Magnetic Flux forecasting techniques**

Magnetogram Measures

- When the transverse gradient of the vertical (or line-of-sight) magnetic field is large at the neutral line, 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 AR's free-energy proxy
- The sum of flux from all pixels having more than 100 G is our total magnetic flux.

A magnetogram of an active region



Neutral Line, color coded for gradient

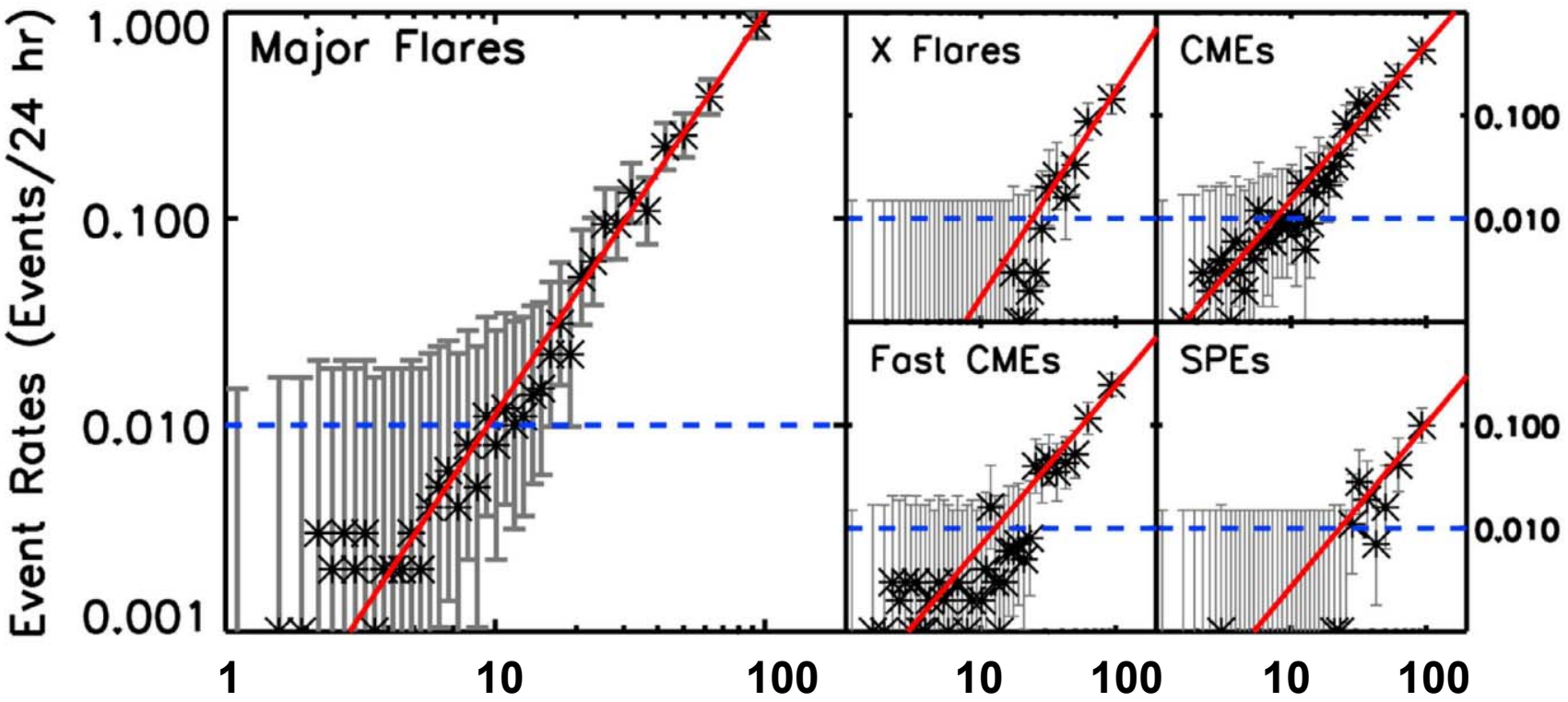
500 G

-500 G

0.1G/km

0 G/km

Converting Free-Energy Proxy to Predicted Event Rates
Present MAG4



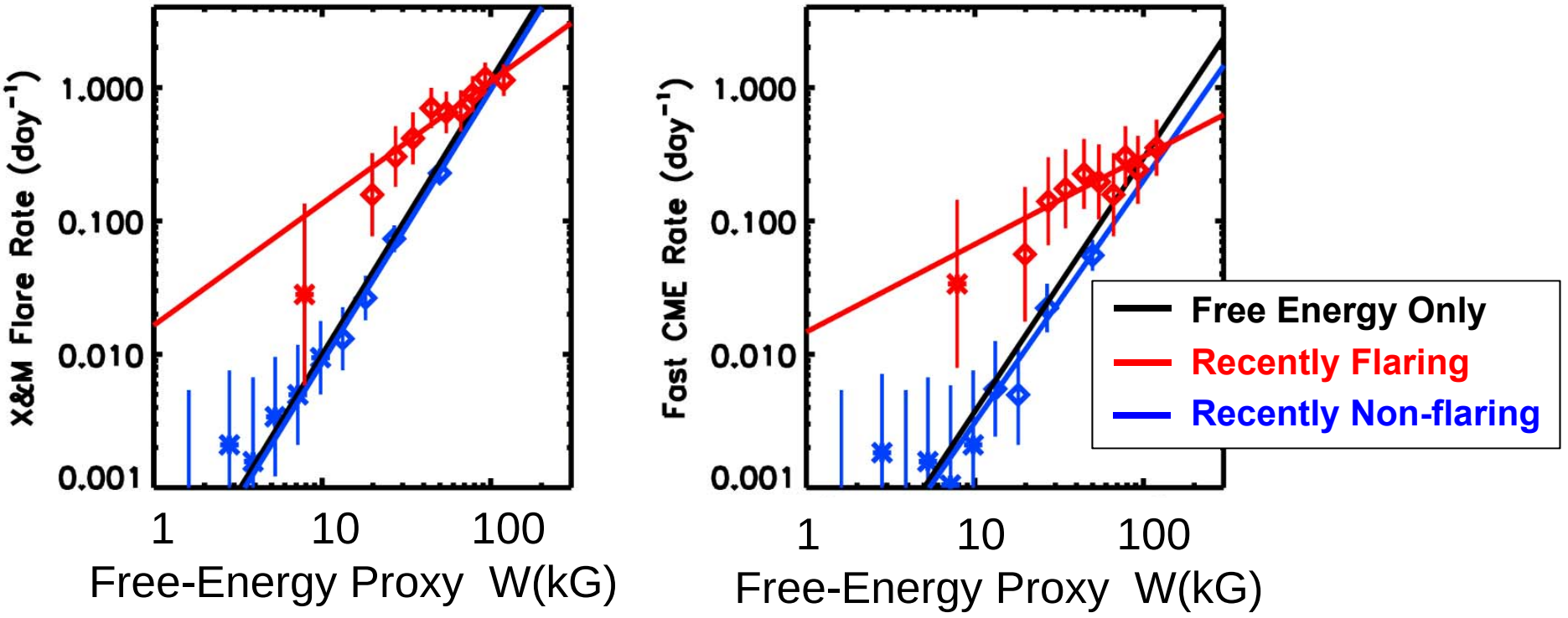
Forecasting Curves

These empirical forecasting 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.

Similar curves can be derived for **total magnetic flux**

Forecasting Curves based on Free Energy and Prior Flaring

Upgraded MAG4



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

McIntosh AR Classes and Using Them for Forecasting

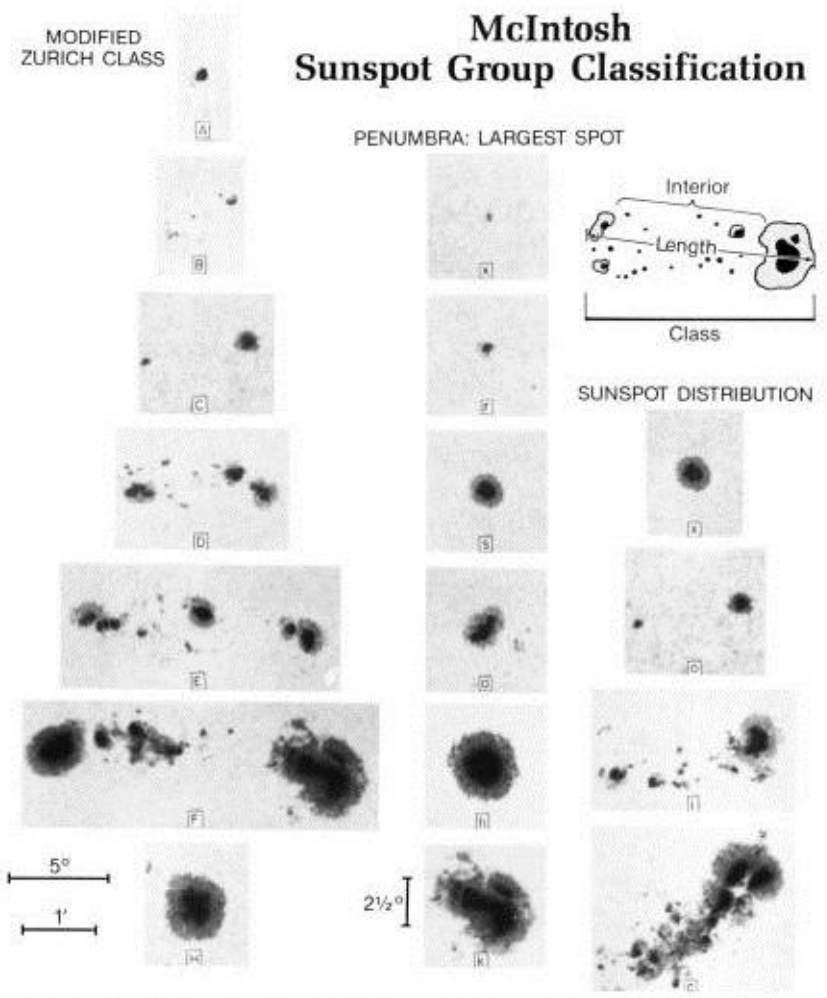


Fig. 1. The 3-component McIntosh classification, with examples of each category.

McIntosh (1990)

Spotclass	AR-Days	M-class	X-class	M & X Rates
FHC	10	11	-	1.10
DHC	3	3	-	1.00
FKC	217	177	32	0.96
EKC	223	112	18	0.58
DKC	82	38	5	0.52
ERO	2	1	-	0.50
FHI	10	5	-	0.50
FKI	184	80	9	0.48
CKI	3	1	-	0.33
DHI	7	2	-	0.29

- There are 60 valid McIntosh classes
- Only 7 of these have M and X-class event rates of greater than 0.5 flares a day
- Any active region in the control sample with one of these seven spot classes, receives a forecast of yes; for all others, the forecast is no.

Statistical Measurement of the Difference in Performance of Alternative Forecasting Techniques

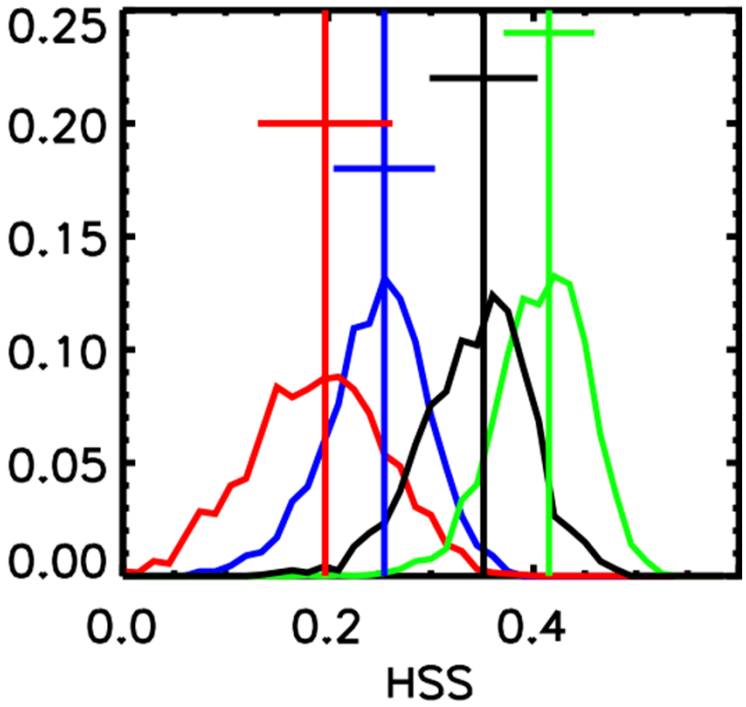
How we evaluate which forecasting technique is best

- Randomly divide sample by AR into control and experimental halves
- Derive forecasting curves from control half
- For each technique make forecasts for the experimental half
  - For McIntosh we use NOAA's tables
  - For all others we use the forecasting curves derived from the control half on the experimental half
  - If predicted event rate is above 0.5 major flares a day, we forecast yes, else forecast no (we tried other thresholds and got similar results)
- Determine the Two-by-Two Contingency Table for each forecasting technique, and
  - Obtain values of five performance metrics for each technique.
  - For each technique obtain the difference in the value of each metric and the value of that metric for the **Present MAG4** forecast
- Repeat Random division 2000 times

MSFC
UAH

Two Methods of Evaluating which Forecasting Technique is Best using the same Perfromance Metric

Good



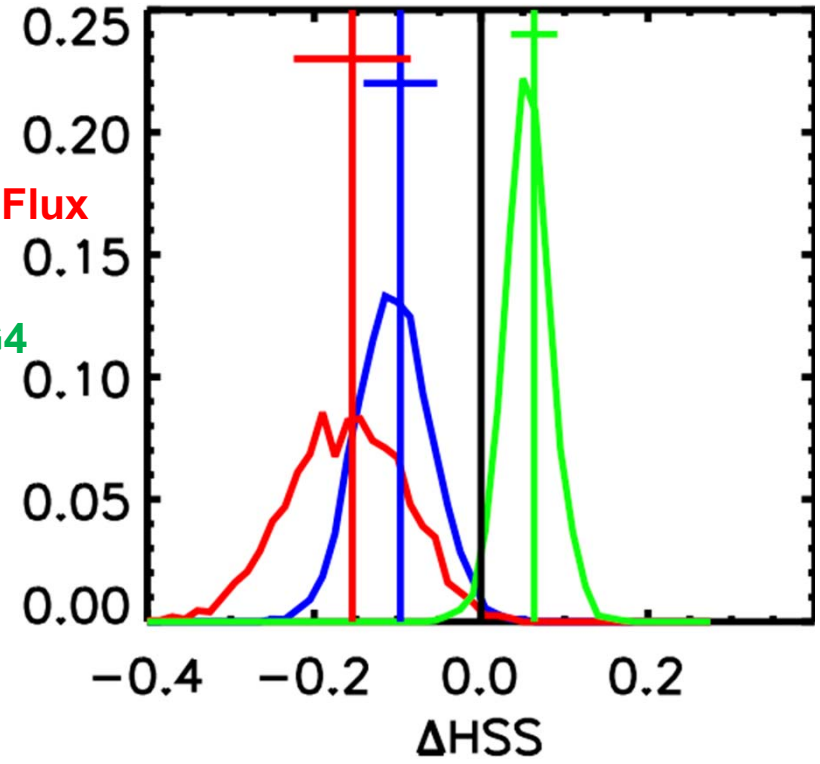
McIntosh

Total Magnetic Flux

Present MAG4

Upgraded MAG4

Better



Contingency Table

	Event Observed	
Event Forecast	**Yes**	**No**
Yes	**A**	**B**
No	**C**	**D**

Heidke Skill Score

HSS = (A+D-E)/(N-E)

N = A+B+C+D

E = ((A+B)(A+C)+(B+D)(C+D))/N

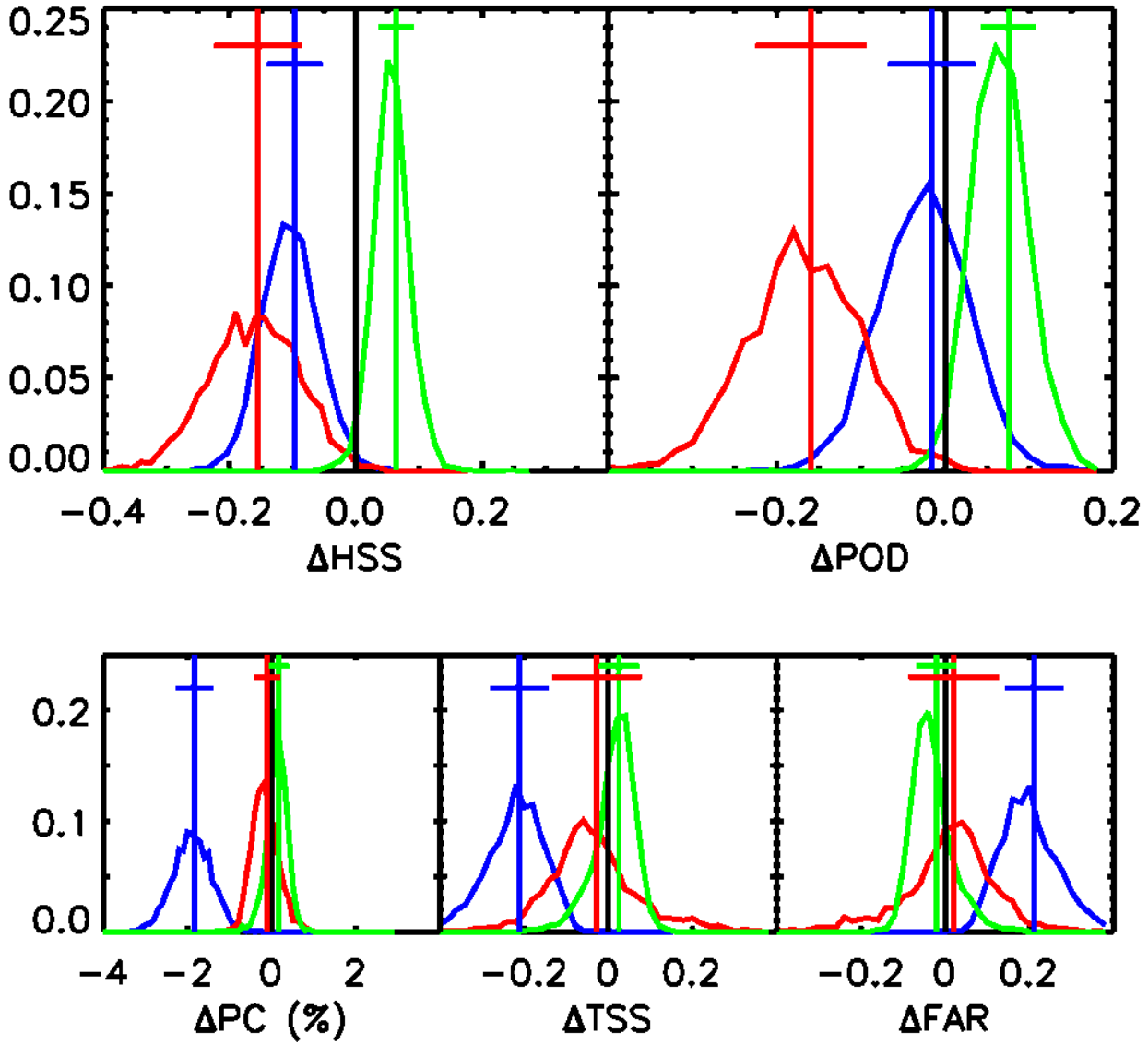
Conclusions

- We have developed a method to measure which forecasting technique is better and the statistical significance of the difference
- Ranking of Forecasting Methods from best to worse
  - **Upgraded MAG4** Free-energy proxy and previous flare activity
  - **Present MAG4** Free-energy proxy only
  - **McIntosh or Total Magnetic Flux**

Published Paper

Falconer, D. A., Moore, R. L., Barghouty, A. F., and Khazanov, I., 2014, "MAG4 versus Alternative Techniques for Forecasting Active-Region Flare Productivity," Space Weather, published online, 5 MAY 2014

Backup


0.25
0.20
0.15
0.10
0.05
0.00
−0.4
−0.2
0.0
0.2
ΔHSS
−0.2
0.0
0.2
ΔPOD
0.2
0.1
0.0
−4
−2
0
2
ΔPC (%)
−0.2
0
0.2
ΔTSS
−0.2
0
0.2
ΔFAR

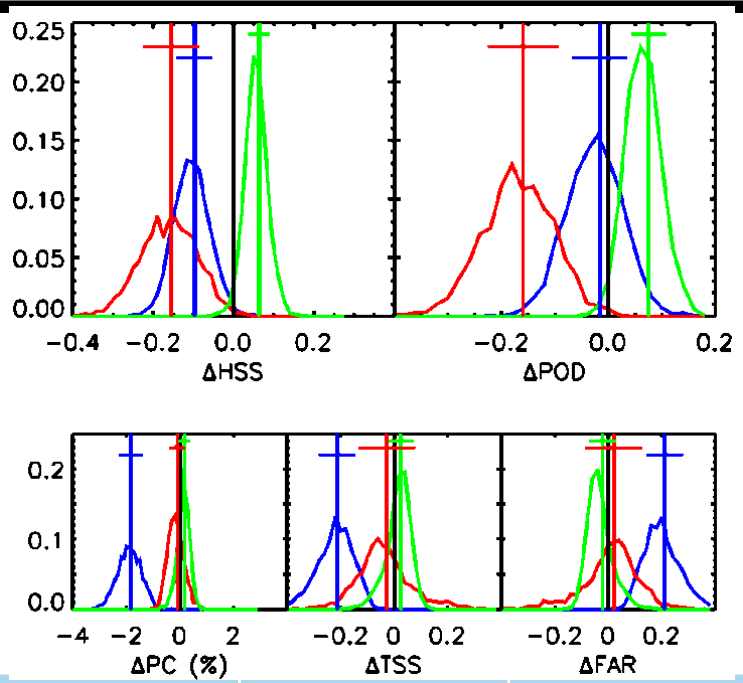
How Well Does MAG4 Forecast:

	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))

All Metrics

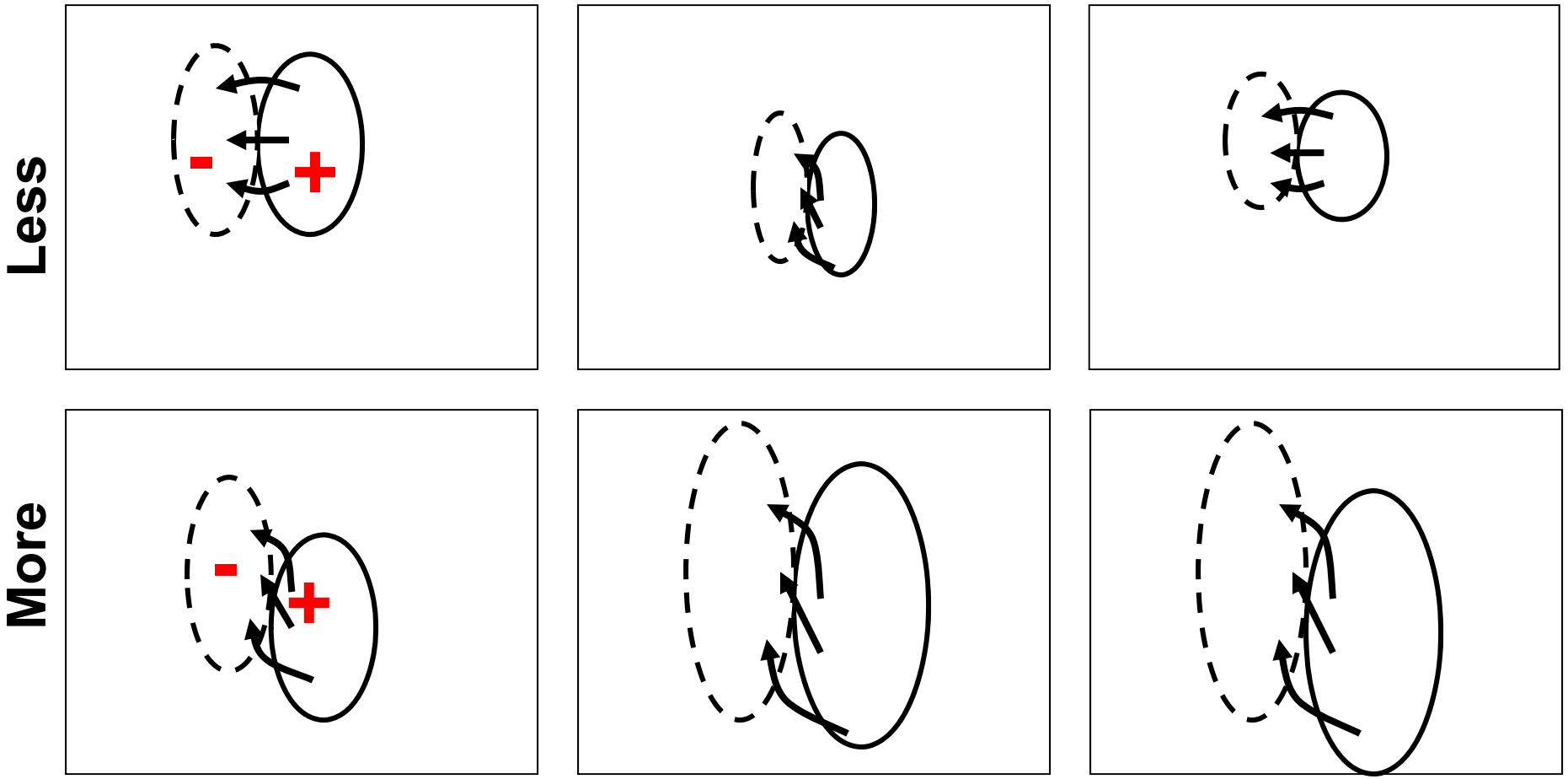


Improvement in Metric	PC(%)	POD	FAR	HSS	TSS
McIntosh/**NOAA** **Present MAG4**	1.8±0.5 **(4σ)**	0.02±0.05 **(0.3σ)**	0.21±0.07 **(3σ)**	0.10±0.04 **(2σ)**	0.21±0.07 **(3σ)**
Total Magnetic Flux **Present MAG4**	0.1±0.3 **(0.3σ)**	0.16±0.07 **(2σ)**	0.02±0.11 **(0.2σ)**	0.15±0.07 **(2σ)**	0.03±0.11 **(0.3σ)**
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)**

Free-Magnetic Energy

Contours Vertical Magnetic Field
Arrows Transverse Magnetic Field

Currents ~10^{12} Amps



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**
  Vector magnetogram actual cadence: **12 minutes**