Solar Flare Forecasting:
From probabilities to targeted predictions

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Motivation & Questions

- Predict flare activity
  - Easy!
  - 80-85% days clear of flares ≥ C1.0
  - 90-95% days clear of flares ≥ M1.0
  - but to do it well...

- Specific questions
  - **Q1**: How well are we (the community) quantifying our forecasts?
  - **Q2**: How well do Poisson flare probabilities perform (from different sunspot group McIntosh classifications)?
  - **Q3**: How should we provide *relevant* forecasts to the space-weather community?

Forecast Performance Testing

- Forecasts studied using a contingency table
  - *TP* = true positives; *TN* = true negatives
  - *FN* = false negatives (missed flares)
  - *FP* = false positives (false alarms)

		Forecast	
		Flare	**Quiet**
Observe	**Flare**	*TP*	*FN*
	Quiet	*FP*	*TN*

- Quantify performance using skill scores
  - Success rate or accuracy, $ACC = \frac{TP + TN}{TP + FN + FP + TN}$
  - Most use Heidke skill score, $HSS = \frac{TP + TN - random\_ex}{TP + FN + FP + TN - random\_ex}$
  - Better to use true skill statistic, $TSS = POD - POFD = \frac{TP}{TP + FN} - \frac{FP}{FP + TN}$

Sunspot Group Classification

- McIntosh classification – '*Zpc*'
  - '*Z*' is the modified Zürich class
  - '*p*' describes main spot penumbra
  - '*c*' describes interior spot distribution
- Sunspots are visible "footprint" of magnetic field
  - complex visible structure → non-potential field → currents

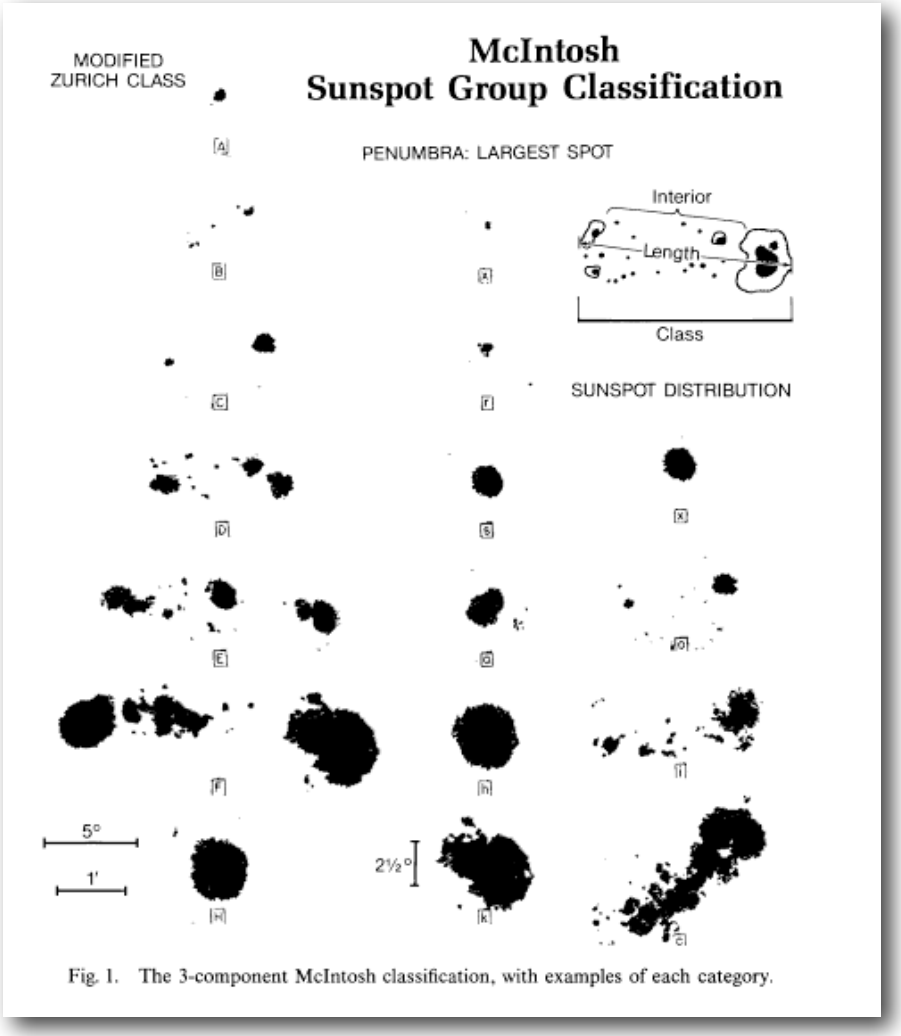


Fig. 1. The 3-component McIntosh classification, with examples of each category.

McIntosh (1990) *Sol. Phys.*, **125**, 251

Poisson Flare Probabilities

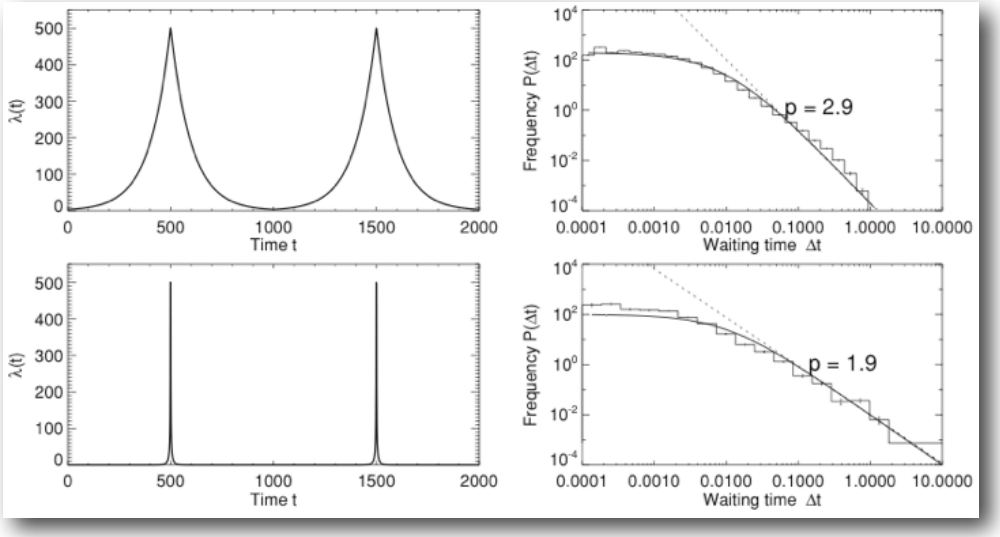
- If flare activity is a Poisson process...

- The probability of N flares from a rate λ over a time interval (e.g., 24 hr) is,

$$P_\lambda(N) = \frac{\lambda^N}{N!}\exp(-\lambda)$$

- Then probability of one or more flare is (Moon *et al.* 2001),

$$P_\lambda(N \geq 1) = 1. - P_\lambda(N = 0)$$
$$= 1. - \exp(-\lambda)$$



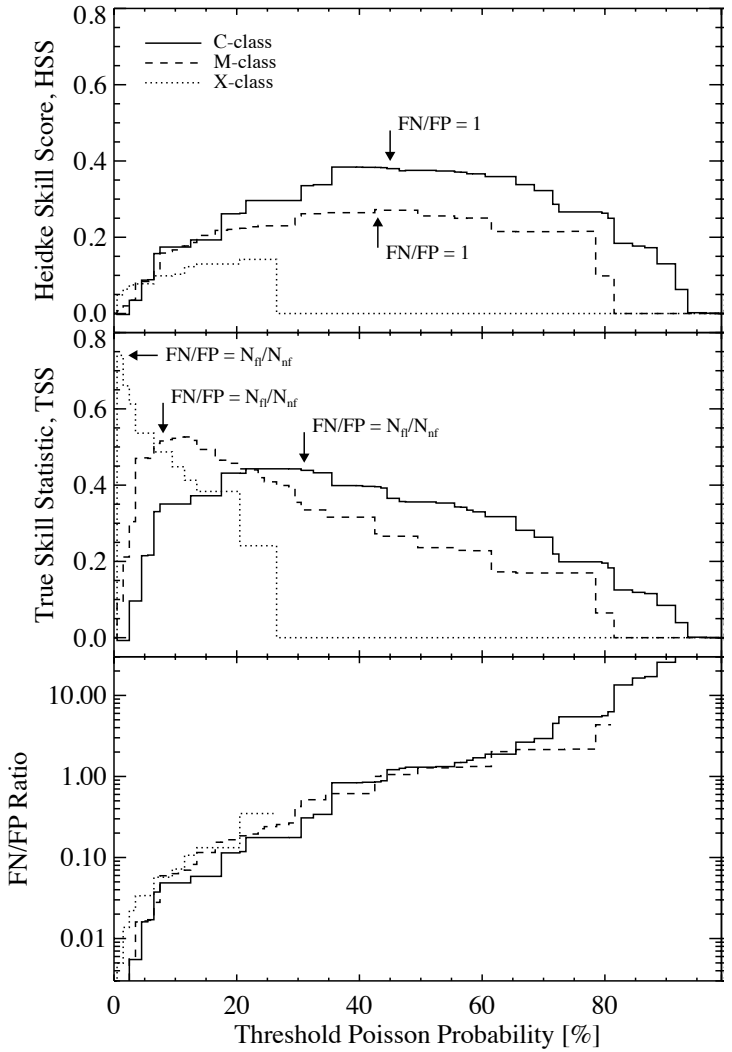
Aschwanden & McTiernan (2010) *ApJ*, **717**, 683

Prediction Method

- Determine historical λ for individual McIntosh sunspot group classifications
  - Cycle 21 M- and X-class flares (Kildahl 1980)
  - Cycle 22 C-, M-, and X-class flares (C. Balch SWPC, private communication)
- Make predictions for cycle 23
  - SWPC daily Solar Region Summary
  - SWPC (edited) *GOES* event lists
- Observe a McIntosh class
  - $\Rightarrow$ historical flare rate, λ
  - $\Rightarrow$ % Poisson probability
  - $\Rightarrow$ predict "flare" $\geq$ threshold
  - $\Rightarrow$ compare to "flare truth" within 24 hr

Forecast Threshold Variation

- Tune forecast performance
  - vary discriminating threshold
- No skill (*HSS* or *TSS*) for threshold probabilities of,
  - 0% → always predict "flare"
  - 100% → always predict "no-flare"
- Maximum skill at different magnitudes and threshold probabilities



Inter-forecast Comparison

Predicted Flare Level	Interval (hr)	*TSS*	*ACC*	Reference
C-class	24	0.65	0.82	Song et al. (2009) *Sol. Phys*., **254**, 101
...	24	0.44	0.71	This work: optimized *TSS*
M-class	24	0.62	0.87	Song et al. (2009) *Sol. Phys*., **254**, 101
...	24	0.53	0.83	This work: optimized *TSS*
X-class	24	0.69	0.95	Song et al. (2009) *Sol. Phys*., **254**, 101
...	24	0.74	0.88	This work: optimized *TSS*
≥M1.0	48	0.54 – 0.66	...	Huang et al. (2010) *Sol. Phys*., **263**, 175
...	24	0.54	0.83	This work: optimized *TSS*
≥C1.0	24	0.64	0.96	Ahmed et al. (2011) *Sol. Phys*., in review
...	24	0.46	0.83	This work: optimized *TSS*

Example Targeted Forecasts

- Different communities = different performance needs
  - commercial satellite operators: few false alarms (i.e., *FP*)
  - astronaut flight surgeon: few missed flares (i.e., *FN*)
  - science observation planners: few of both

Interest Group	*GOES* Class	*FN*/*FP* (Target)	*FN*/*FP* (Actual)	Threshold (%)	*TSS*	*ACC*
Satellite Operators	M	5	4.3	81	0.07	0.96
...	X	1	0.4	26	0.24	0.99
Science Planners	M	1	1.0	43	0.27	0.95
...	X	0.2	0.1	20	0.38	0.98
Flight Surgeon	M	0.2	0.2	23	0.44	0.90
...	X	0.1	0.1	12	0.41	0.98

Summary

- **Q1**: *How well are we quantifying our forecasts*?
  - Highly inconsistent
  - Easy to address with *TSS*
- **Q2**: *How well can sunspot group McIntosh classification Poisson flare probabilities perform*?
  - Surprisingly well, but room for improvement
  - Need flare rate distributions, not averages
- **Q3**: *How should we provide relevant forecasts to the space-weather community*?
  - Most likely through tailored *FN*/*FP* performance
  - Need specific requirements of end-user groups