Flare Forecasting and Sunspot Group Evolution

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Solar Cycle 22 Statistics

Active Regions:  
\[ \approx 2,700 \]

Flares:  
- C-Class  \[ \approx 6,000 \]
- M-Class  \[ \approx 1,400 \]
- X-Class  \[ \approx 100 \]
Using Sunspot Evolution to Forecast Solar Flares

- Most current forecasting techniques use point-in-time measurements of sunspot properties
  - Simplest forecasting method used is McIntosh-Poisson method (Gallagher et al., 2002)
- Few studies have investigated sunspot group evolution and its application in flare forecasting

- This work focuses on the evolution of McIntosh classifications and their associated flaring rates
Sunspot Classification Data

- NOAA SWPC daily sunspot properties (C. Balch, private communication)
- Data range 1988-1996 (Solar Cycle 22)
- Associated GOES 1-8 Å X-Ray flares
McIntosh Classification Scheme

- White-light structure
- Zurich
- Longitudinal extent
McIntosh Classification Scheme

- White-light structure
- Zurich
  - Longitudinal extent
- Penumbral
  - Size and symmetry of largest spot penumbra
McIntosh Classification Scheme

- White-light structure
- Zurich
  - Longitudinal extent
- Penumbral
  - Size and symmetry of largest spot penumbra
- Compactness
  - Interior distribution or “filling factor” of spots
Zurich Classifications

Modified Zurich Class of Active Regions (1988–1996)

(a) Full Disk

No. of Occurrences

A B H C D E F

(c) Within 75° Lon.

No. of Occurrences

A B H C D E F

Evolution of Active Regions (24hr)

(b) Full Disk

Frequency

-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6

(d) Within 75 Lon.

Frequency

-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
Zurich **Mis**classifications

> 75°

(e) East Limb

(f) East Limb

(g) West Limb

(h) West Limb

> 75°
Do sunspot groups produce more flares as they evolve upward or downward in class?
Evolution of Zurich Class

- Percentage occurrence of region evolutions from a given starting class

- No evolution dominates on 24-hr timescale

- Preferential evolution of ±1 step
McIntosh Evolution Flaring Rates

- Flaring rates produced using flares observed in following 24 hr after evolution step

- Highest flaring rates associated with smallest occurrences

- Majority of flaring rates are statistically significant
McIntosh Evolution Flaring Rates

Zur. Flaring Rates (≥ C1.0)

Zur. Flaring Rates (≥ M1.0)

Zur. Flaring Rates (≥ X1.0)

Starting Zurich Class: F

Starting Zurich Class: F

Starting Zurich Class: F

Starting Zurich Class: E

Starting Zurich Class: E

Starting Zurich Class: E

Starting Zurich Class: D

Starting Zurich Class: D

Starting Zurich Class: D

24hr Flaring Rate (Within 75° Lon.)

Complexity Decrease

No Evolution

Complexity Increase

A B H C D E F

A B H C D E F

A B H C D E F

A B H C D E F

A B H C D E F

A B H C D E F

A B H C D E F
Investigating full McIntosh classification evolution

These flaring rates (Cycle 22) can be applied to more recent data (Cycle 23) under the assumption of Poisson statistics to produce flare probabilities.

Equation \( P(n>0) = 1 - P(0) \)

Examples of rates to probs [High to Low - C, M and X ]
Forecast Verification

- Probabilistic verification methods
- Skill score in general
- Brier Skill Score
  - Brier Skill
  - MSE
  - Transform to score (climatology reference)
- Reliability Diagram
  - used to diagnose forecast performance
  - Forecast Probabilities vs. Observed Probabilities (frequencies)
Forecast Reliability

Above C-Class Reliability Plot

- Zurich
- Penumbra
- Compactness
Conclusions

- McIntosh evolution forecasting

- Penumbra and Compactness show qualitatively similar flaring rates
Additional Material
Penumbral Flaring Rates
Compactness Flaring Rates
McIntosh Evolution

NOAA AR: 12219
No. of Flares: 1 (>C1.0)
McIntosh Evolution

NOAA AR: 12219
No. of Flares: 0 (>C1.0)
McIntosh Evolution

NOAA AR: 12219
No. of Flares: 0 (>C1.0)
McIntosh Evolution

NOAA AR: **12219**
No. of Flares: **1 (C1.0)**

Dai

βγ
McIntosh Evolution

NOAA AR: 12219
No. of Flares: 5 (>C1.0)