Statistical methods for solar flare prediction

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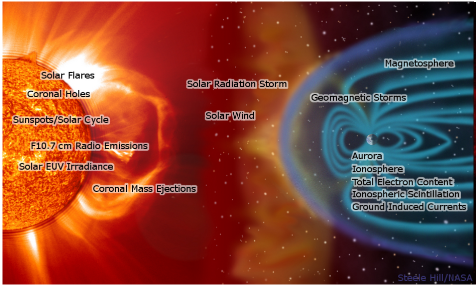
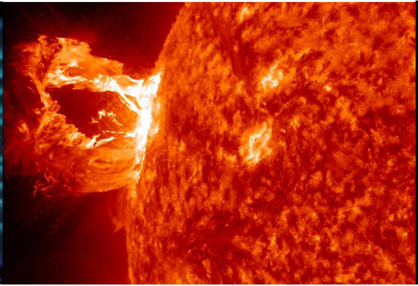
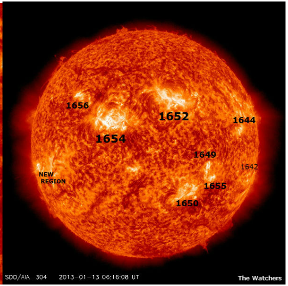
Joint work with Ward Manchester, Tamas Gombosi, Gabor Toth (CLaSP); Zeyu Sun, Alfred Hero (EECS); Hu Sun, Bach Viet Do, Noah Kochanski, Victor Verma, Long Nguyen, Stilian Stoev (Statistics)

Space Weather Phenomena

Rather than the more commonly known weather within our atmosphere (like rain, snow, heat, and wind), space weather can come in the form of radio blackouts, solar radiation storms, and geomagnetic storms caused by disturbances from the Sun.



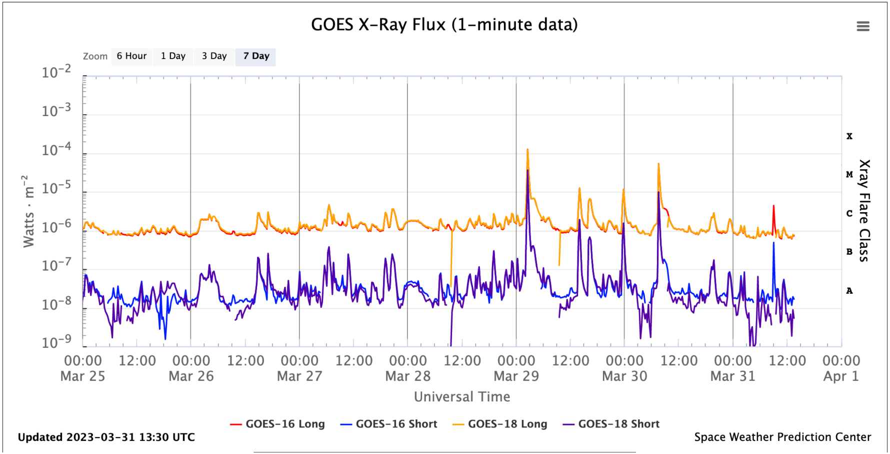




A solar flare is an intense localized eruption of electromagnetic radiation in the Sun's atmosphere. Flares occur in active regions and are often, but not always, accompanied by coronal mass ejections, solar particle events, and other solar phenomena.

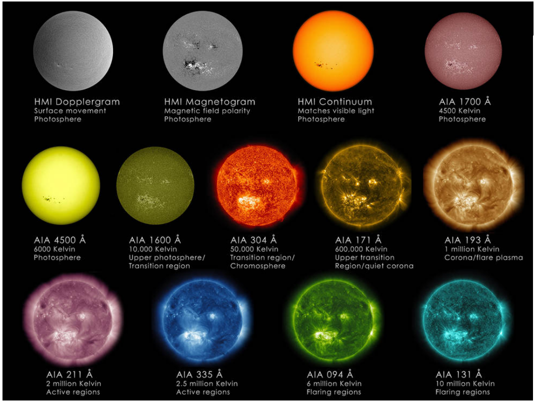
What Observation is Available? I

GOES: time series of flare events from the NOAA Geostationary Operational Environmental Satellites (GOES) flare list.



What Observation is Available? II

2-D photospheric maps of 3 orthogonal magnetic field components observed with 1.0 arcsecond spatial resolution (0.5 arcsecond pixel size), time cadence of 12 minutes.



USFLUX Total unsigned flux in Maxwells

MEANGAM Mean inclination angle, gamma, in degrees

MEANGBT Mean value of the total field gradient, in Gauss/Mm

MEANGBZ Mean value of the vertical field gradient, in Gauss/Mm

MEANGBH Mean value of the horizontal field gradient, in Gauss/Mm

MEANJZD Mean vertical current density, in mA/m^2

TOTUSJZ Total unsigned vertical current, in Amperes

MEANALP Total twist parameter, alpha, in 1/Mm

MEANJZH Mean current helicity in G^2/m

TOTUSJH Total unsigned current helicity in G^2/m

ABSNJZH Absolute value of the net current helicity in G^2/m

SAVNCPP Sum of the Absolute Value of the Net Currents Per Polarity in Amperes

MEANPOT Mean photospheric excess magnetic energy density in ergs per cubic centimeter

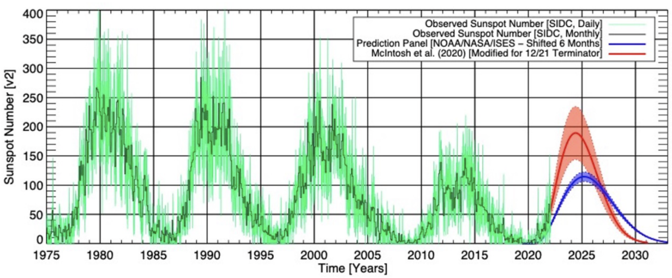
TOTPOT Total photospheric magnetic energy density in ergs per cubic centimeter

MEANSHR Mean shear angle (measured using B_{total}) in degrees

SHRGT45 Percentage of pixels with a mean shear angle greater than 45 degrees in percent

Data Analytic Challenges: Heterogeneity

The Solar Cycle 25 Prediction Panel, an international group of experts co-sponsored by NASA and NOAA, predicted that this would be a below-average solar cycle, like the one before it – Solar Cycle 24. However, the Sun has been much more active this cycle than anticipated. The cycle is aligning more with a study from a team lead by Scott McIntosh of National Center for Atmospheric Research, published in Solar Physics.



This chart shows the original predicted number of sunspots, represented as the blue line. The green lines show the observed sunspots, which are trending toward the red line – the McIntosh et al. study – which predicts a higher number of sunspots.

Forbes

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The Sun Is Now More Active Than NASA Predicted. It Could Be In Its Strongest Cycle Since Records Began

Jamie Carter Senior Contributor

I inspire people to go stargazing, watch the Moon, enjoy the night sky

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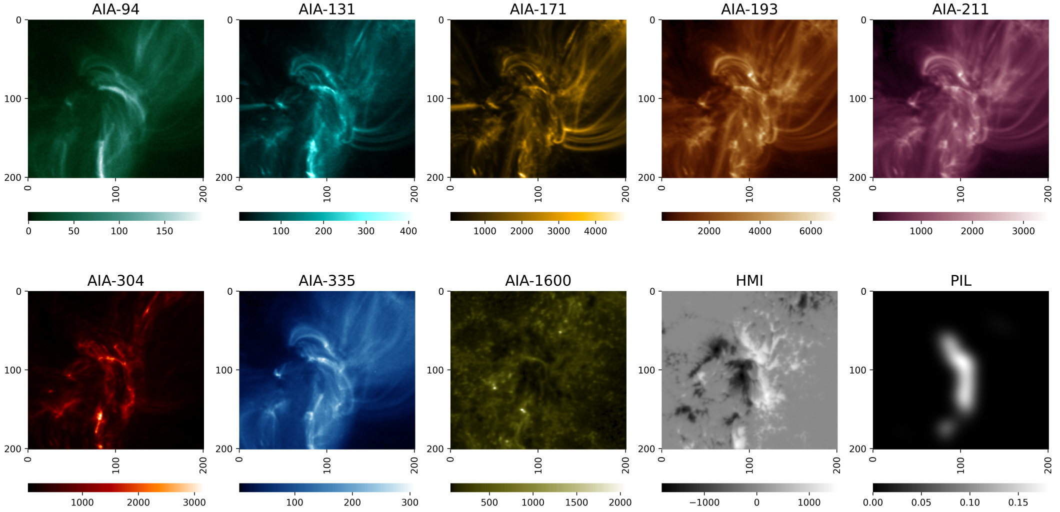
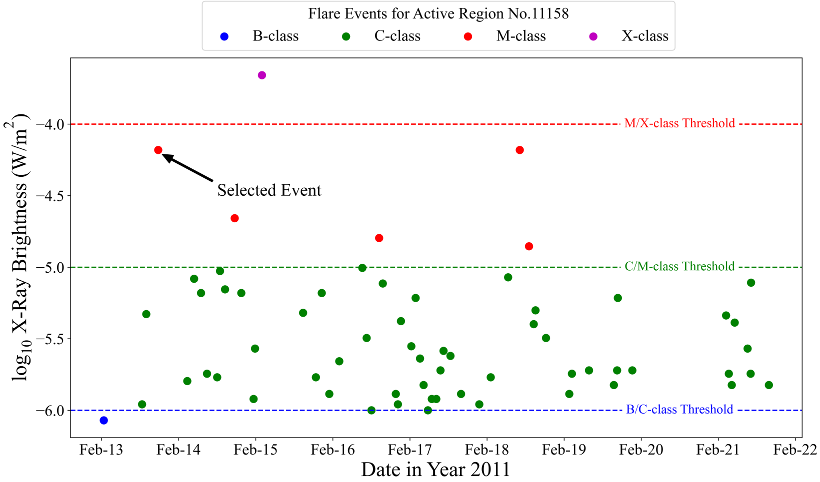
Data Analytic Challenges: Large Data Volume



Data Analytic Challenges: Extreme, Rare Events



Overview of our work on flare predictions

- Feature Engineering – physics, ML, statistics [Chen et al., 2019, Sun et al., 2021]
- Flare classification and prediction [Jiao et al., 2020, Wang et al., 2020, Sun et al., 2022]
- Models with high dimensional images [Sun et al., 2023]
- Accounting for heterogeneity (Viet Do et al., 2023+)
- Flare dependency characterization (Kochanski et al., 2023+)
- CME and SEP studies [Kasapis et al., 2022, Jivani et al., 2023]
- Operational forecasting – unique challenges (Verma et al., 2023+)

Ongoing and Future Work

- Extreme value theory and GEV regression
- Distribution shift prediction model with solar cycle dependence
- Flare dependency characterization
- Transformation invariance model
- Parallelizable computational algorithms

Operational forecasting: Unique challenges

- Sequential updates based on flare dependency structure
- Uncertainty quantification propagation and data assimilation

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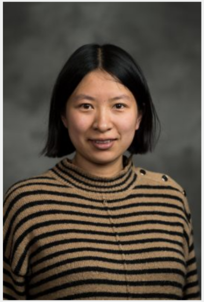

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Other Works in Geo-sciences

- Explainable Sym-H Prediction. Iong, Daniel, Yang Chen, Gabor Toth, Shasha Zou, Tuija Pulkkinen, Jiaen Ren, Enrico Camporeale, and Tamas Gombosi. "New findings from explainable SYM-H forecasting using gradient boosting machines." Space Weather 20, no. 8 (2022): e2021SW002928.

- Delta-B Prediction. (Iong, McAnear, Chen, Toth et al., forthcoming)

- Global TEC Map Reconstruction.

  - Methodology. Sun, Hu, Zhijun Hua, Jiaen Ren, Shasha Zou, Yuekai Sun, and Yang Chen. "Matrix completion methods for the total electron content video reconstruction." The Annals of Applied Statistics 16, no. 3 (2022): 1333-1358.

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