Do conditions of the chromosphere and corona foretell active region flaring?

KD Leka [1,2], Karin Dissauer [1], Graham Barnes [1], Eric L. Wagner [1]

1 NorthWest Research Associates, 3380 Mitchell Lane, Boulder, CO 80301, USA

2 Institute for Space-Earth Environmental Research, Nagoya University, Nagoya, Aichi 464-8601, Japan

HIGHLIGHTS:

• Case studies of the upper solar atmosphere reveal increased levels of magnetic reorganization, plasma dynamics, and temperature variation prior to solar flares.

• We analyze the coronal and chromospheric conditions for a statistically-significant sample of flare-imminent and flare-quiet active regions using data from the Solar Dynamics Observatory/ Atmospheric Imaging Assembly (AIA).

• AIA Active Region Patches ("AARPs"), region-targeted extractions of AIA time-series data in (extreme-) ultraviolet are matched to the HMI Active Region Patches (HARPs) for 2010-2018. AARPs are constructed daily, from 15:48-21:48 UT (13 min intervals each hour, time cadence 72s) matching a dataset produced for investigating the photospheric magnetic field (Leka+2018); AARPs will be freely available (with this study's publication; www.nwra.com/AARP).

• Coronal and chromospheric dynamics and heating are parametrized with high-order moment summaries of brightness and running-difference images, plus emission measure, temperature, and density images; temporal behavior is captured by sampling each parameter over a 7hr time-series.

• NorthWest Research Associates' Classification Infrastructure (NCI), based on Non-Parametric Discriminant Analysis is employed to statistically evaluate whether parameters describing the upper atmosphere differ significantly between flaring-imminent vs. flare-quiet populations. Preliminary results and their physical implications are presented.

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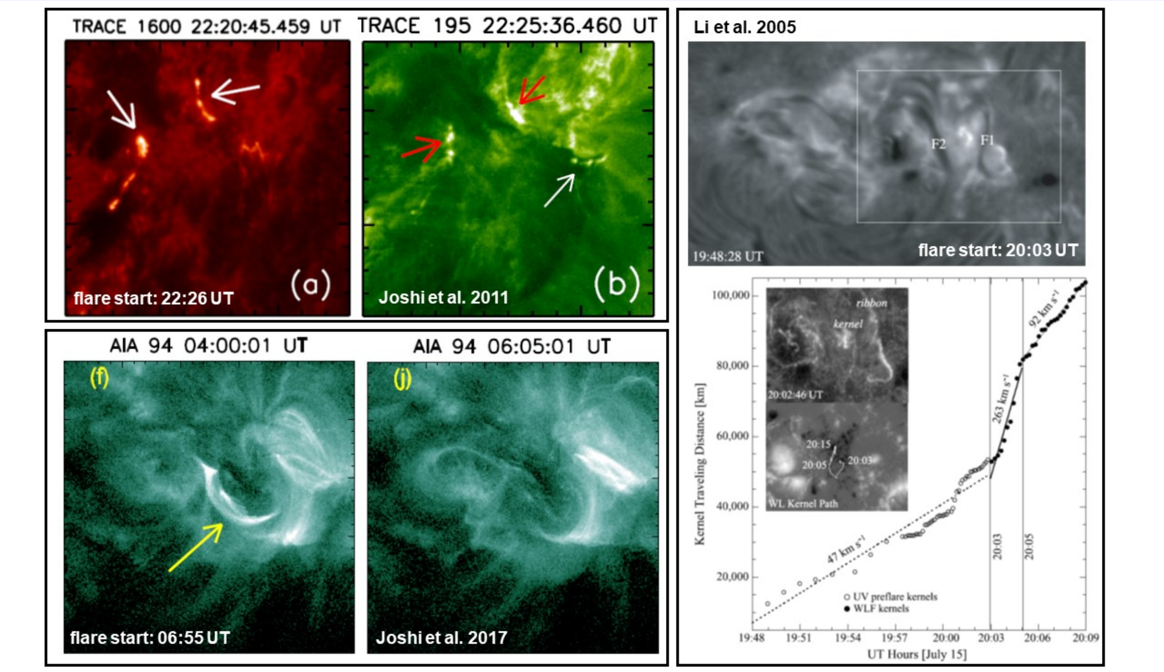
BACKGROUND

• Solar energetic events are powered by the evolution of the underlying magnetic field, *but* it is still impossible to deterministically predict when an active region will flare (or not) solely based on this information.

• Case studies of the solar chromosphere and corona reveal increased levels of magnetic reorganization, dynamics and temperature variation prior to solar energetic events such as solar flares and coronal mass ejections (CMEs).

• Enhanced chromospheric emission has long been known to signal increased flaring activity (Zirin & Liggett 1987, see BBSO "Bear Alerts")

• Whether these activities play a *physical* role in event initiation or just indicate an overall disturbed atmosphere is still unclear.



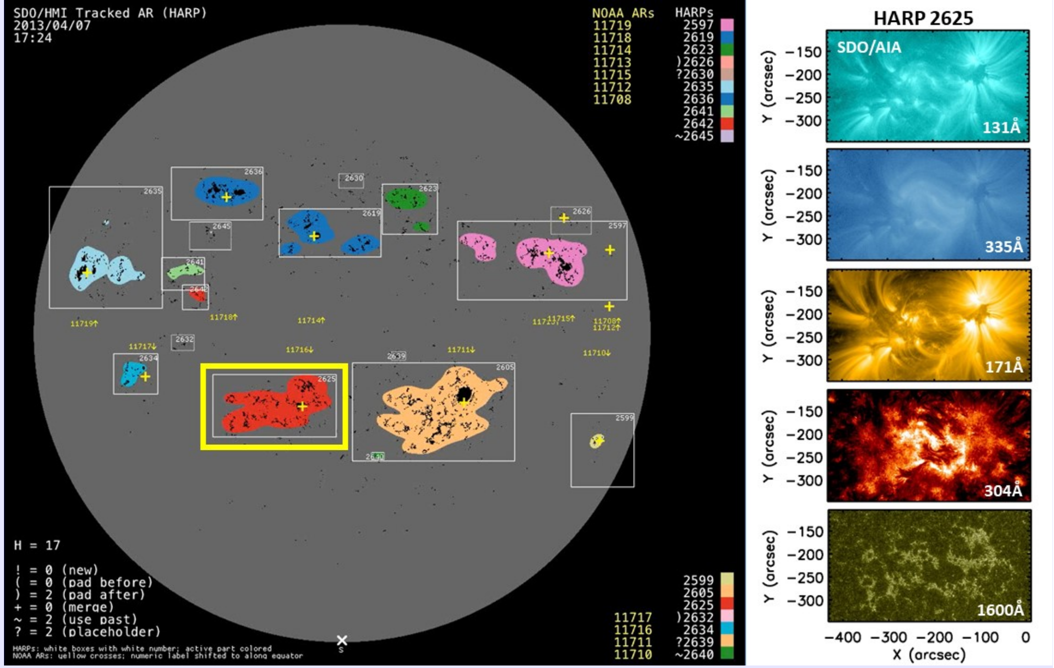
Examples of pre-flare and pre-CME coronal and chromospheric activity reported in the literature, see *e.g.* Joshi et al. 2011, 2017, Li et al. 2005, Hernandez-Perez et al. 2019. Also note BBSO Bear Alerts criteria.

• Following a series of papers examining the "Photospheric Magnetic Field Properties of Flaring vs. Flare-Quiet Active Regions", we ask the same question and take the same approach but with a focus on the dynamics and heating in the chromosphere and corona.

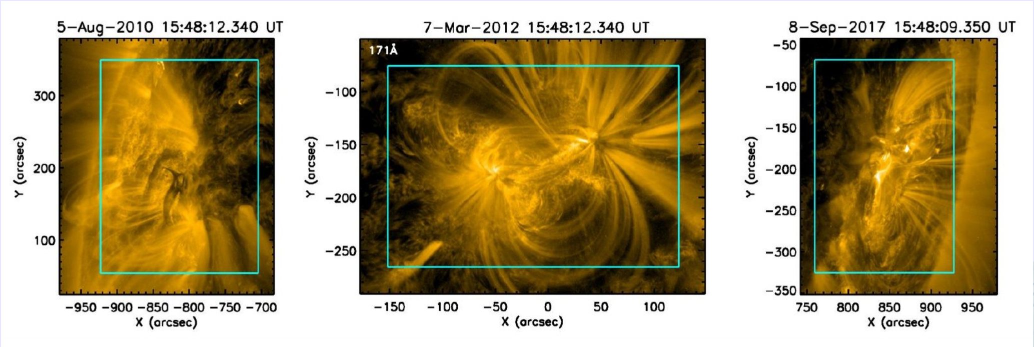
Leka & Barnes 2003 a, b
Barnes & Leka 2006
Leka & Barnes 2007
Leka, Barnes, Wagner 2018

AARP EXTRACTION

- Data requirements for this statistical analysis are huge.
- NWRA now produces AIA Active Region Patches (AARPs) for analysis:
    - Based on HMI Active Region Patches (HARPs; Bobra+2014). No further active-region size or activity level restrictions.
    - AARPs extend 20% from HARP boundaries to capture loop structures plus an additional increase as f(location) to account for height / projection when nearing the limb.
    - *Hourly* extractions of *13 minute duration* of *high-cadence (72s) images* @all EUV wavelengths [94, 131, 171, 193, 211, 304, 335]Å plus UV 1600Å provide:
        - Sensitivity to 0.1–10MK
        - Ability to quantify overall increasing / decreasing temporal and spatial variability
    - All latest calibrations and corrections are performed; fine-scale spatio-temporal alignment applied.
    - Produced as analog to NWRA HARP-based magnetic field dataset (Leka+2018).



Overview of HARPs identified on the Sun on April 7, 2013. The yellow box marks HARP 2625 for which the corresponding AARPs are shown on the right.



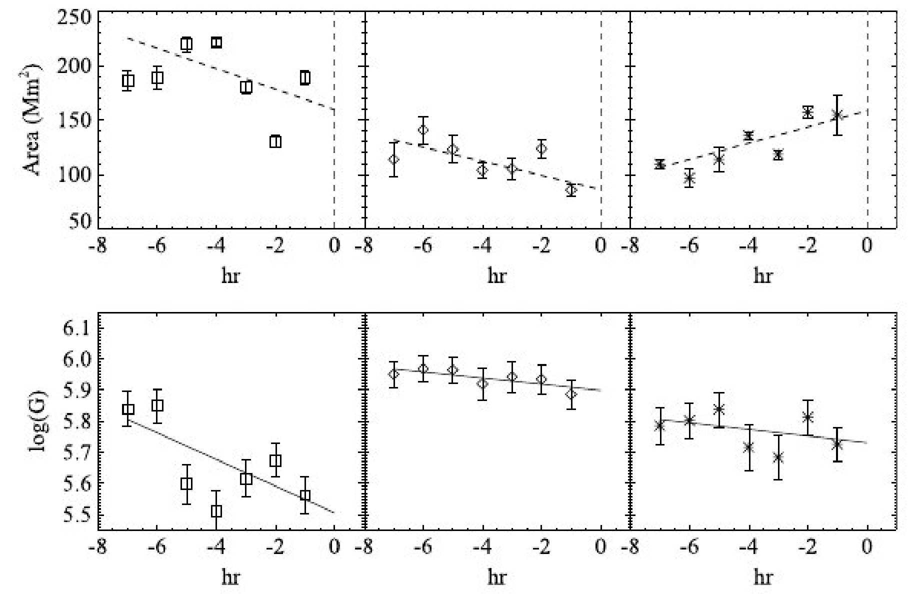
Examples of three AARPs in 171Å at different positions with respect to the central meridian illustrating the field-of-view expansions. Box marks HARP FOV.

AARPs and corresponding HARP-based magnetic field data product will be released upon the study's publication.

*coming soon

PARAMETRIZATION

- Following the earlier work on magnetic field analysis, we parametrize:
  - Images, running-difference images, maps of Differential Emission Measure* and Density*
  - Moment analysis (mean, variance, skew, kurtosis) plus totals when appropriate.
    - High-order moment analysis can help distinguish gradual heating over an extended region from smaller abrupt heating episodes
    - Mix of extensive (size-sensitive) and intensive (size-insensitive) parameters are included
  - Over the 7hr considered, linear slope and intercept provide parameters describing static / magnitude levels and indication of temporal variation.
  - 176 physically-interpretable parameters are analysed.



Example of parametrizing solar behavior (in this case magnetic field) for 3 different intervals, showing area of strongly-sheared field (top) and the “Schrijver $\mathscr{R}$ parameter (bottom) for 7-hr interval of NOAA AR 11283 ending just before an X1.8, and X2.1, and then a flare-quiet epoch.   From Leka+2018.

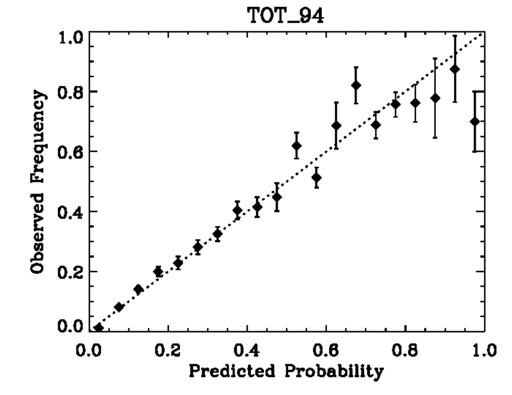
STATISTICAL ANALYSIS

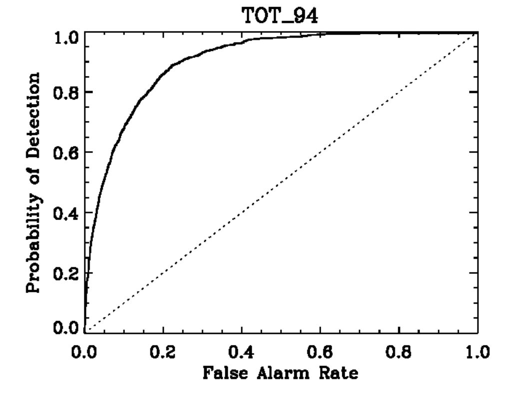
• The NWRA Classification Infrastructure (NCI) is based on Non-Parametric Discriminant Analysis and available for broad usage. Leka+2018.

• Discriminant analysis in general classifies input as belonging to one of two (or more) populations

- *e.g.,* total intensity in 335Å in regions associated with imminent flares *vs.* in those associated with flare-quiet samples
- Classification is evaluated according to where the probability density function (PDF) of one population multiplied by the prior probability of belonging to that population exceeds that of the other.
- NCI uses Non-Parametric Discriminant Analysis
  - no assumption is made about the functional form of the distributions
  - *But,* large sample sizes are needed.

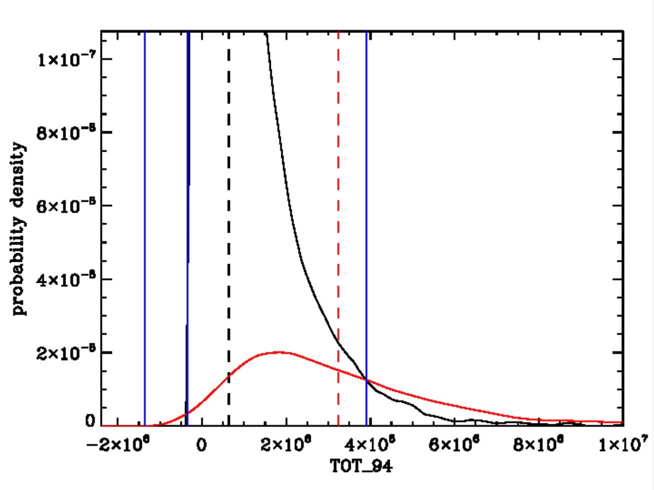
• Classifications are evaluated using numerous quantitative metrics and skill scores (Jolliffe & Stephenson 2012) plus graphical output.





Far Left: Reliability plot and **Near Left:** ROC plot for the same total image brightness in 94Å, C1.0+ flare within 24hr validity period plus 2hr latency.

"TOT_94" is one of the best-performing parameters for this event definition (4 years of data): BSS=0.30 ± 0.02



Non-Parametric Density functions of total image brightness in 94Å, **flaring** vs. **flare-quiet** populations, - - - / - - - indicate distribution means, —— mark the discriminant boundaries. Note significant separation between the means.

INITIAL RESULTS : *PRELIMINARY*

- 4 years of data processed:
  - For C1.0+/ 24hr validity / 2.2hr latency
    - 16095 samples, 1518 events (event rate=0.094)
- Sorting on Brier Skill Score:
  - Top-performing parameters indicate:
    - Increased Heating and distribution (*_94 parameters)
    - Increased likelihood of significantly enhanced or significantly diminished temporal variability ("kurt_diff_*")
  - Other notes:
    - Overall brightness in 1600 is mediocre
    - Mean brightness in [211,171,193,1600] perform poorly (do not differentiate).
- For larger flares only: TBD
- Overall scores only slightly lower than HARP-based magnetic-field based parametrizations (top BSS ~0.37)

- For further information, contact: leka@nwra.com or dissauer@nwra.com

Top 10	BSS	**Bottom 10**	BSS
TOT_94	0.301±0.200	DT_STDEV_131	-0.007± 0.016
KURT_DIFF_304	0.293±0.019	DT_MEAN_DIFF_131	-0.001 ± 0.015
KURT_DIFF_171	0.286±0.019	DT_MU	0.000 ± 0.000
TOT_335	0.282±0.016	DT_SKEW_211	0.000 ± 0.002
KURT_DIFF_193	0.277±0.019	DT_MEAN_DFF_171	0.001 ± 0.001
KURT_DIFF_131	0.272±0.018	DT_MEAN_DIFF_193	0.001 ± 0.000
TOT_131	0.269±0.020	DT_KURT_211	0.001 ± 0.005
TOT_DIFF_94	0.258±0.020	MEAN_DIFF_171	0.002 ± 0.001
KURT_DIFF_211	0.256±0.018	DT_STDEV_171	0.002 ± 0.001
DT_TOT_DIFF_94	0.254±0.018	DT_MEAN_193	0.002 ± 0.002
Other	**parameters**	**Of note**	
SKEW_94	0.232 ±0.017	MEAN_211	0.039 ± 0.004
KURT_94	0.218 ±0.017	MEAN_171	0.027 ± 0.004
STDEV_94	0.211 ±0.013	MEAN_193	0.025 ±0.003
STDEV_304	0.208 ±0.016	MEAN_1600	0.006 ±0.001
TOT_1600	0.187 ±0.013	MU	0.004 ± 0.001