

## What?

**DAFFS:** Flare forecasting tool development for NOAA (US).

•Phase-I results met requirements to “improve on NOAA solar flare forecasts by 25%”.

•Phase II awarded for prototype development.

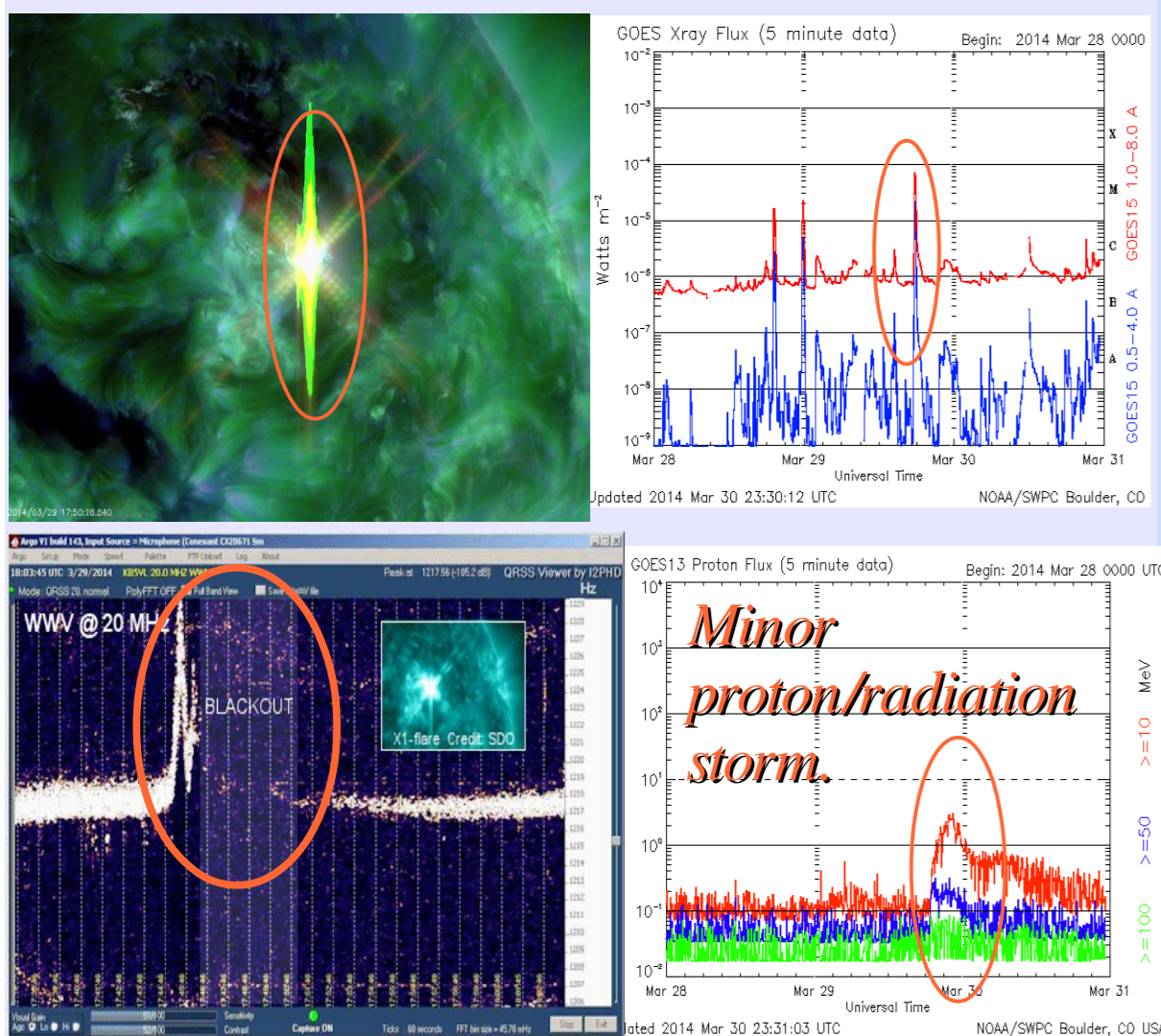
**Targets:** NOAA/Space Weather Prediction Center published forecasts:

- 1-day probability flare forecasts for visible active regions.
- C1.0+, M1.0+, X1.0+ thresholds.
- 1-, 2-, and 3- day full-disk probability forecasts (larger flares).

**Metrics:** Brier Skill Scores and Reliability plots

**Deliverable:** Real-time DAFFS Prototype in 2016.

**Why?** Example: From a complex, but *not* “monster” region, a very fast-onset X-class flare:



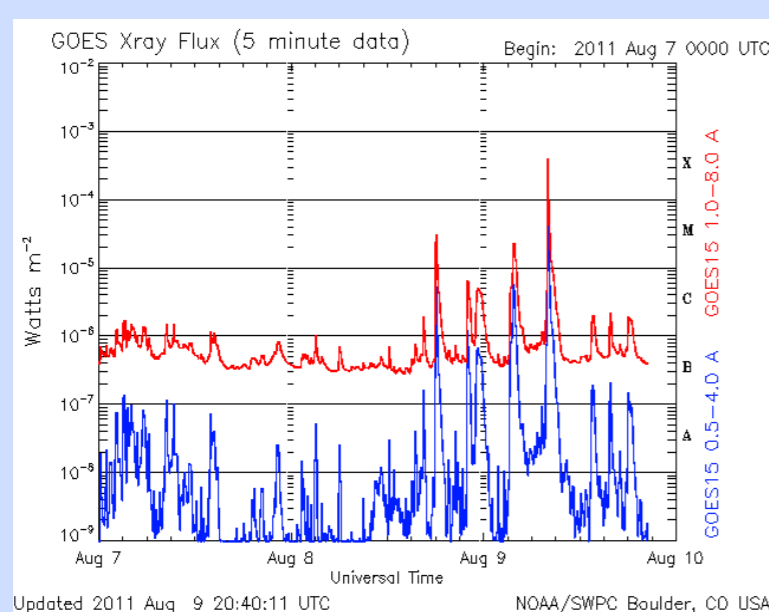
Images courtesy SDO, GOES, and spaceweather.com

Radio blackout for minutes at mid-latitudes, and a “magnetic crochet” disturbance indicating immediate D, E-region ionization.

## Data Set for Phase-I Training/Evaluation

- 2010.05.01 – 2015.02.28
- 12,311 samples of NOAA Active Regions
- 22,260 SDO/HMI “active region patches”
- 1,720 days
- 6,001 C flares, 571 M flares, 43 X flares

## Prior Flare History



➢ Previous flaring (persistence) is often a very good indicator of future flaring

- DAFFS parametrizes:
  - Indices based on flare peak X-Ray flux
  - Various relevant intervals included.
  - Flare history & flare-productivity evolution both included.

Funding for this work is acknowledged from NOAA/SBIR contracts WC-133R-13-CN-0079 and WC-133R-14-CN-0103, with additional support from NASA contracts NNH09CE72C, NNH12CG10C.

For additional information regarding DAFFS prototype development, access, and future product availability, please contact:

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# Discriminant Analysis Flare Forecasting System (“DAFFS”)

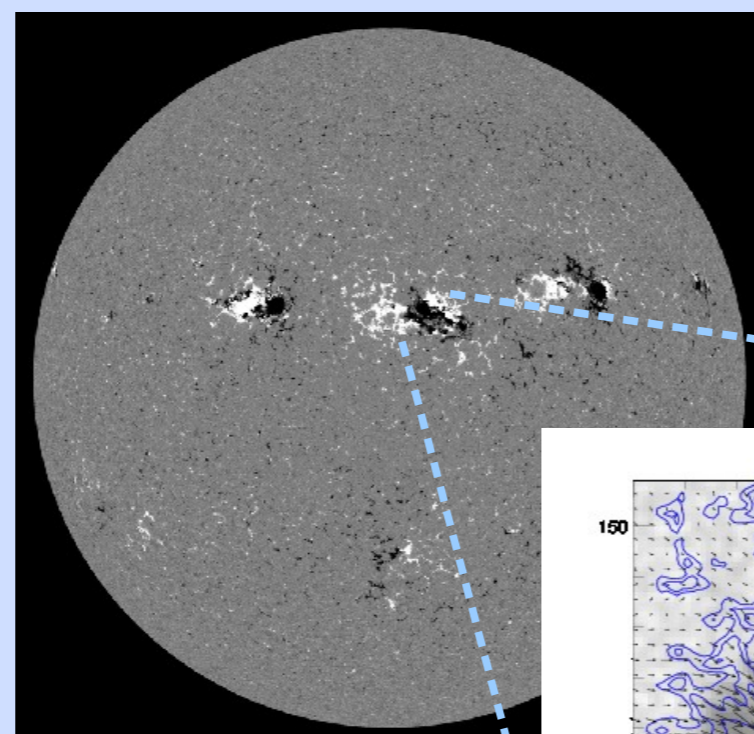
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## How?

Leka & Barnes 2003a, b  
Barnes & Leka 2006  
Leka & Barnes 2007  
Barnes et al 2007  
Barnes & Leka 2008  
Barnes et al 2015; the “All-Clear Workshop paper”, in preparation

- Analysis of solar magnetic field observations, coronal modeling, and prior flare history.
- Data sources: SDO/HMI, NOAA/SWPC event detection, and NSO/GONG.
- Parallel systems to accommodate data outtages.
- Discriminant Analysis to evaluate parameter-space and provide forecasts.
- Automatic Periodic Performance Evaluation

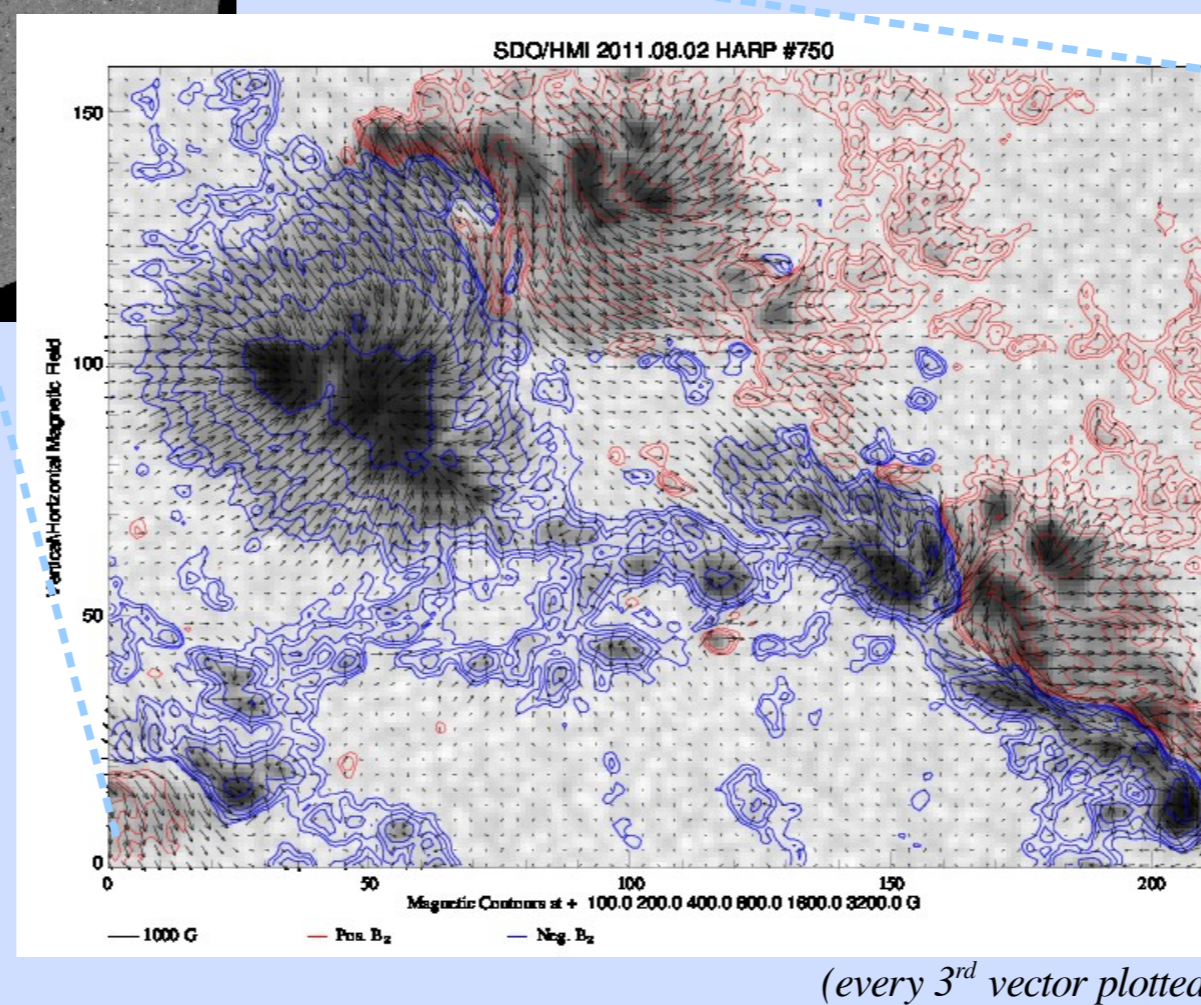
## Magnetic Field Analysis



Above: Line-of-sight full-disk magnetogram, Right: detail of the full vector field for one sunspot area (red/blue: radial magnetic field in/out of the surface, arrows are the horizontal magnetic components). DAFFS generally uses the full vector field, and line-of-sight data used in a backup parallel-running system.

➢ DAFFS quantifies magnetic indicators of flare productivity.

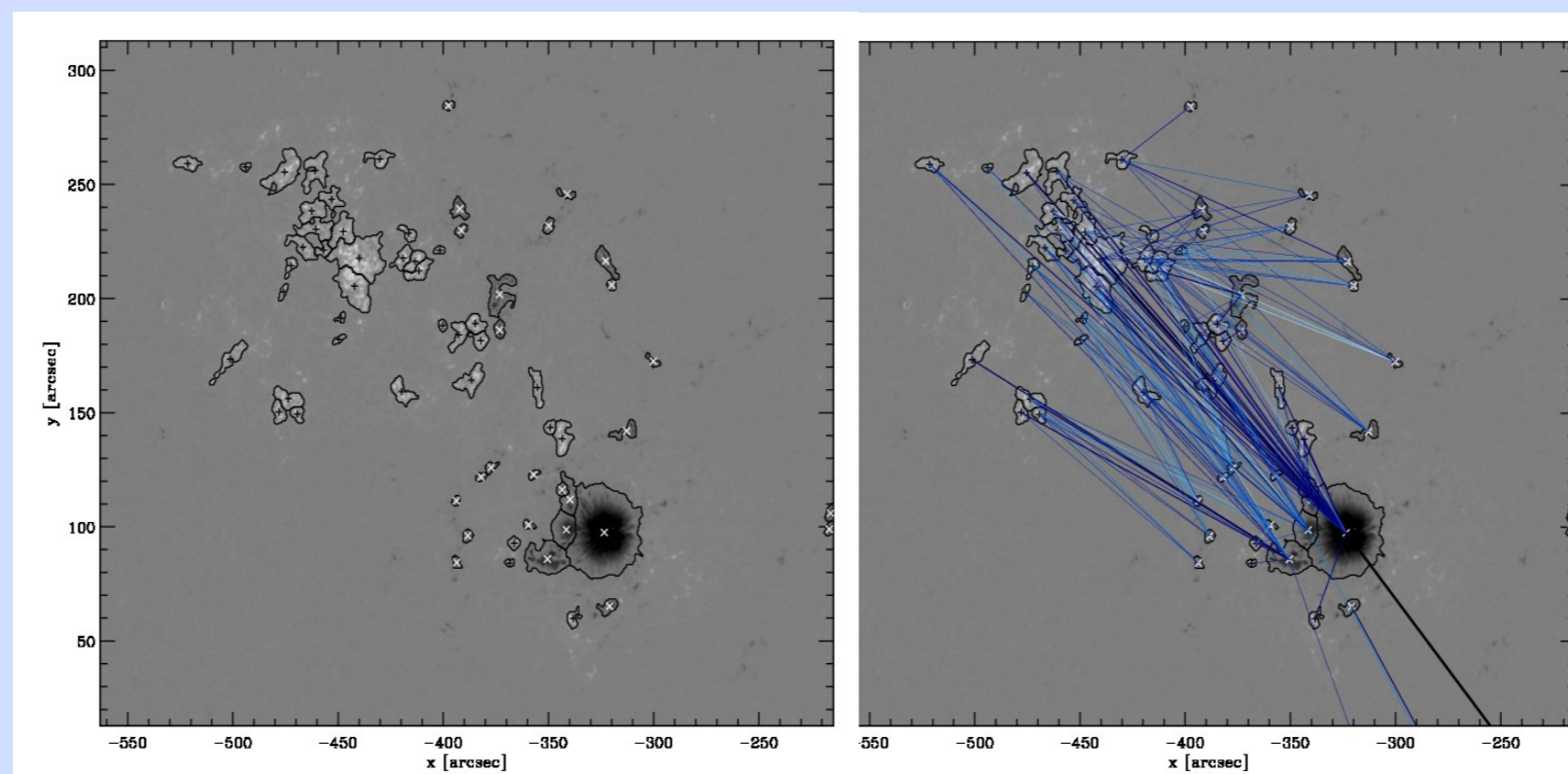
- Stored magnetic energy
- Magnetic stress & complexity
- Polarity-inversion line diagnostics



(every 3<sup>rd</sup> vector plotted)

## Coronal Magnetic Field Modeling

- Highly complex coronal magnetic fields store more energy, and are more “ready” to flare.
  - Model coronal field using Magnetic Charge Topology.
  - Potential-field from point-source representation of active region. This method is fast, simple, and well-represents the important topological characteristics.
- Quantifying the topology of coronal magnetic field in active regions can indicate:
  - How much energy is available to release in a flare,
  - Whether the magnetic field is ready to reconnect (and flare).

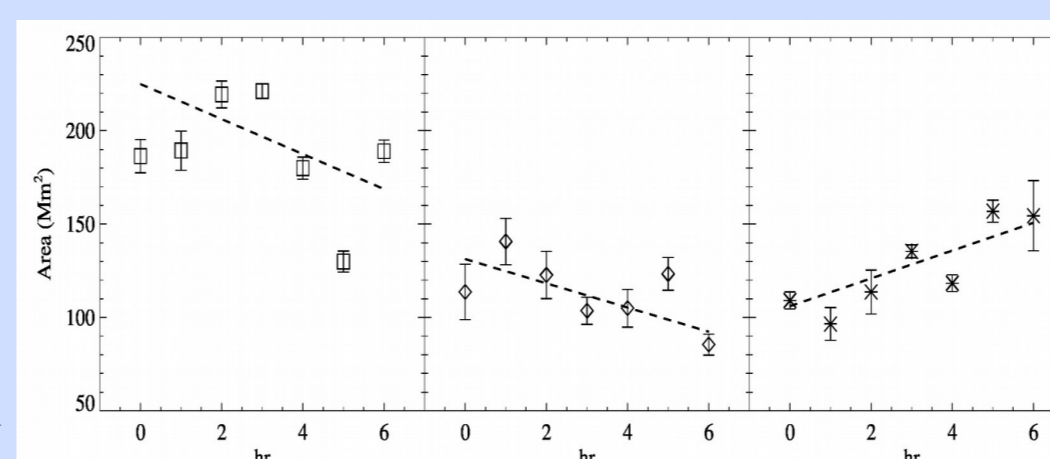


Magnetic-field map (left) showing the partitioning of the magnetic field data in an active region to a collection of sources which are used to construct a connectivity matrix (represented in the “spiderweb” plot, right) of connections between poles and the magnetic flux they contain (darker/lighter for more/less flux). The distribution of the connections and the magnetic flux they contain are parametrized as part of DAFFS.

## Recent Magnetic, Coronal Evolution

- Rapidly-evolving regions can be flare-productive.
- DAFFS includes recent evolution, parametrized through 1<sup>st</sup> order fits to temporally-sampled data.

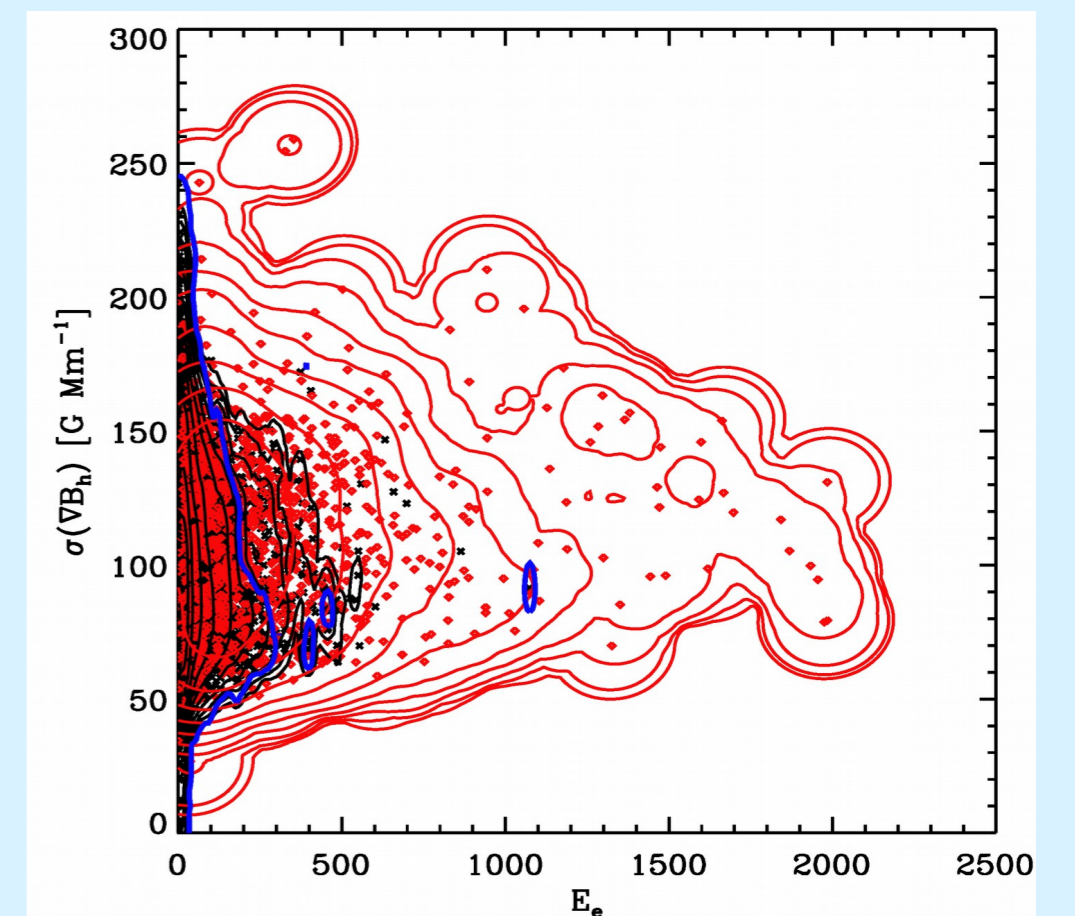
Right: Total Area of strongly-sheared magnetic neutral lines in NOAA AR 11283, plotted for 3 different 6hr intervals. Decay is visible in two intervals, growth in a third. Counter to intuition, the first two intervals ended in X-class flares, the third (increasing shear) did not. The evolution of this and many other magnetic-field and coronal topology parameters are thus quantified and incorporated into DAFFS.



## Discriminant Analysis

➢ Statistical Method for classifying a new measurement as belonging to one or another population by evaluating a **Discriminant Function**.

➢ The **Discriminant Function** is calculated using estimates of the *probability density functions* of parameters in one (or multiple) dimensions simultaneously, given samples from *Flare-quiet* and *Flaring* populations.



➢ Above: Non-Parametric DA, including an optimized smoothing algorithm for the density estimates, is applied to 2 variables from the magnetic field analysis (*x*-axis: a proxy of free energy; *y*-axis: standard deviation of the horizontal gradient of the horizontal field). *Flare-quiet/Flaring* data points are shown, with contours of the Non-Parametric density estimates; the **DF** is shown at the 50% probability level. It is *not* a simple threshold, but a function in 2-D parameter space.

➢ Discriminant Analysis extends from *categorical* to *probabilistic* forecasts using Bayes' theorem.

## Skill Results

➢ *Brier Skill Scores* and *Reliability Plots* are used to evaluate performance of probabilistic forecasts, matching NOAA products, e.g.:

- Full Disk Forecasts
- M1.0+, X1.0+
- 1-, 2-, and 3-day forecasts
- 2010.05.01 – 2015.02.28

➢ *Brier Skill Score*:

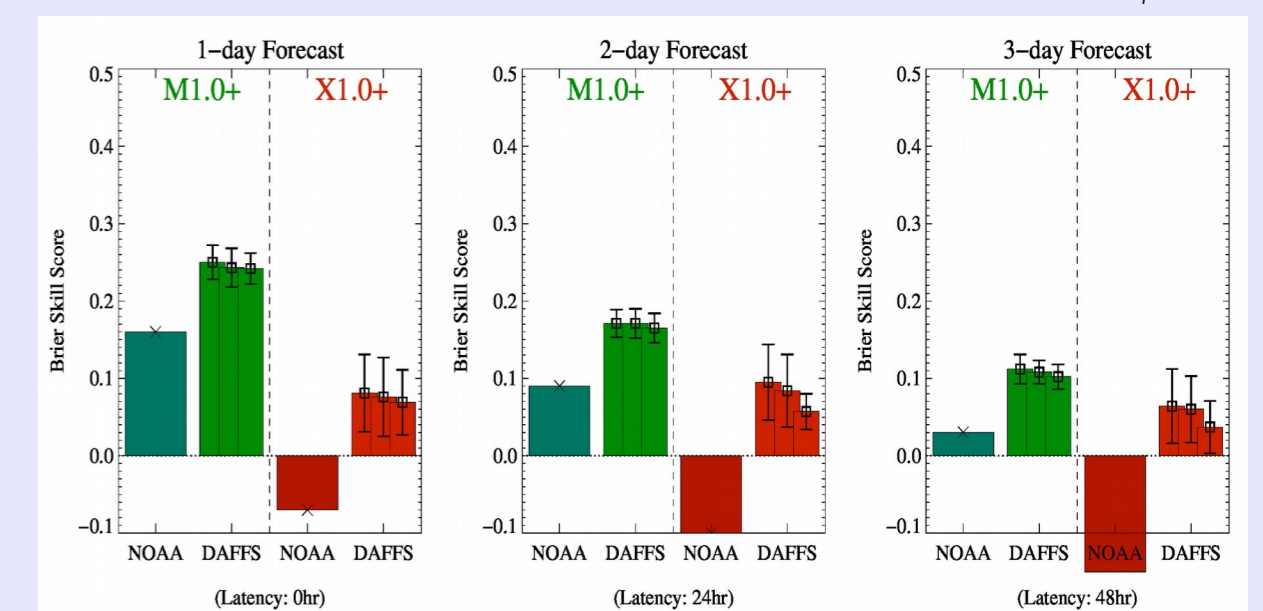
- 1.0: perfect forecast.
- 0.0: same as reference (climatology).
- < 0.0: not good.

$$o_i: \text{observed result}, o_i \in [0,1]$$

$$p_i: \text{predicted probability}, 0.0 \leq p_i \leq 1.0$$

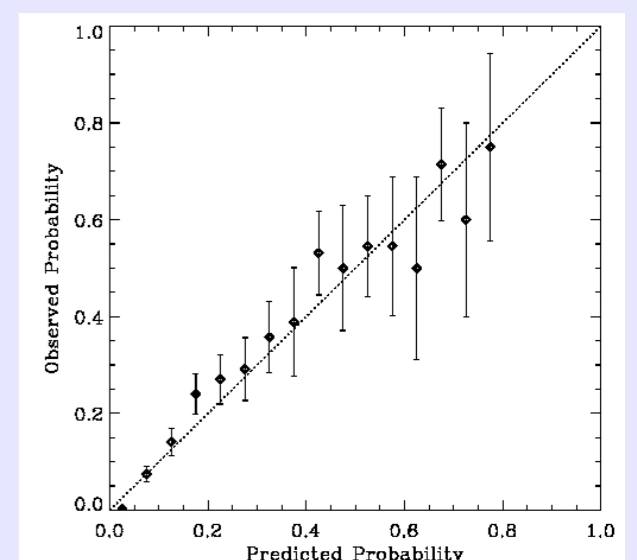
$$\text{Mean Square Error} = \frac{1}{N} \sum (p_i - o_i)^2$$

$$\text{Brier Skill Score} = 1.0 - \frac{\text{MSE}}{\text{MSE}_{\text{ref}}}$$



Above: Comparison of Brier Skill Scores for NOAA full-disk vs. DAFFS full-disk forecasts. Six different event definitions: 2 event thresholds (M1.0+, X1.0+) with three different latencies (the 1-, 2-, and 3-day forecasts, left to right). NOAA results are from the archive “RSGA” files, and uncertainties are not available. DAFFS results are shown for the 3 best-performing parameter pairs (comprising essentially an ensemble forecast), including cross-validation and error bars from a 100-draw bootstrap.

Right: example Reliability Plot, comparing event predicted probability with observed event frequency. Diagnostics are provided on sample sizes (error bars) and on any systematic over/under prediction.



## DAFFS Prototype:

- Initial tests running *now* (demonstration at ESWW12 and upon request); full prototype release scheduled for 2016.
- Runs in real-time on NWRA servers.
- Two forecasts/day.
- Operations-oriented data source(s) and backup forecast systems running continuously.
- Development emphasis on infrastructure.

### DAFFS customization options:

- Event definitions (threshold, event type).
- Forecast Windows, Latencies.
- Costs for False Alarms or Missed Events.