

# HARPs: Tracked Active Region Patch Data Product from SDO/HMI

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## Summary

We have developed an HMI data product containing tracked magnetic features on the scale of solar active regions, abbreviated HARPs (HMI Active Region Patches). The HARP data series is intended for:

- Subsetting individual active regions
- Computation of space weather indices for individual active regions
- Defining closed magnetic structures for vector field disambiguation

The data series builds upon the 720s cadence active-region mask data product. These full-disk masks identify instantaneously-observed magnetic features at a pixel level. Large spatially-coherent regions are extracted from the masks and tracked from image to image, accounting for merges as regions grow.

After the region disappears, the numbered track ("HARP") is placed into the HARP data series by finding the smallest box of constant latitude/longitude extent that encompasses all appearances of the region.

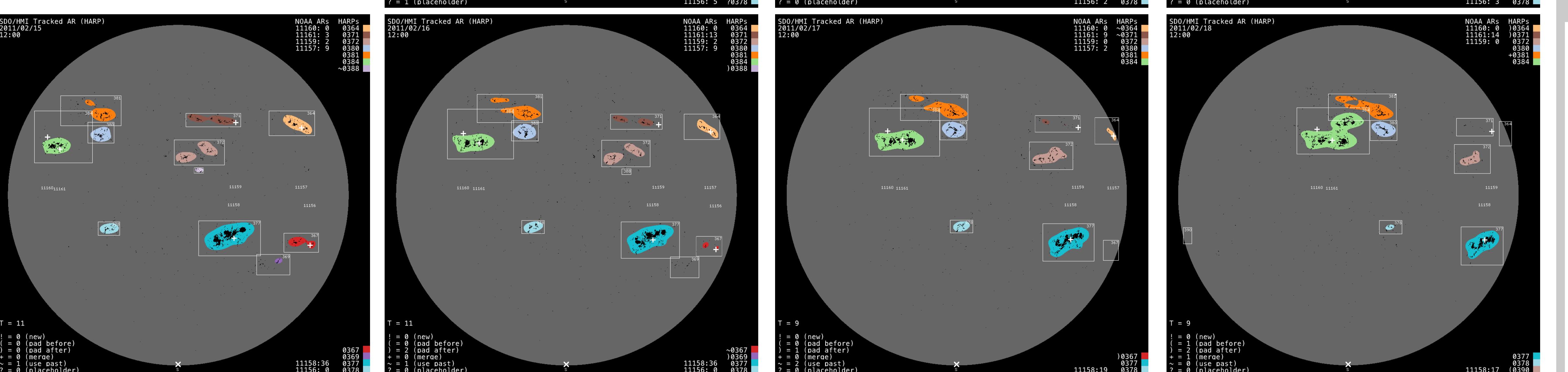
The HARP data series provides all geometric and heliographic information needed to track active patches in HMI and other solar data sets. For each numbered HARP, the data series defines at each time step a rectangular CCD cut-out, and it provides a mask within the cut-out indicating the active pixels within a regular, smoothly-evolving blob.

Summary keywords such as areas and integrated fluxes are included for each appearance of the region. Links to source magnetic field data are provided.

The HARP data product, `hmi_Mharp_720s`, is available in definitive and near-real-time (NRT) versions on JSOC for all times where magnetic data is present (since May 2010). Quick-look movies and synoptic maps are also available, and HARP location data is exported to the HEK. There is a matching SHARP product containing LOS and vector magnetic field data, as well as space weather indices computed within each HARP.

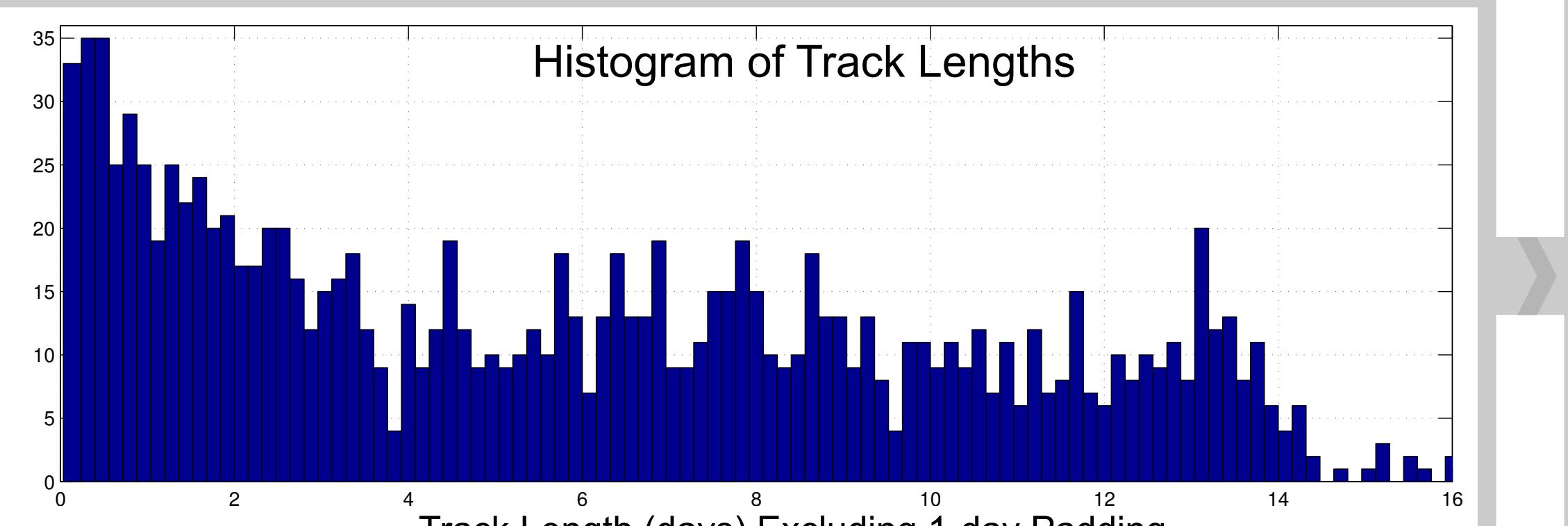
## Tracked Frames

- The quick-looks are 1024x1024; shown here sampled 1/day from the 720s (120/day) full set.
- February 2011 flaring AR is HARP 377 (blue) or NOAA 11158.
- The HARP/NOAA correspondence is found and coded in HARP keywords.
- HARPS merged: brown (371), tan (372), orange (381). Expired: 367, 369, 388.



## Track Data Characteristics

- Tracks to date include May 2010 – October 2012.
- 30 months, 107000 masks, 1219 HARPs.
- Median HARP length = 5.6 days = 675 frames
- 150 are  $\geq$  12 days (1440 frames)
- The ease of computing per-HARP quantities should enable new studies that would have been prohibitive.



## Methodology: Activity Masks

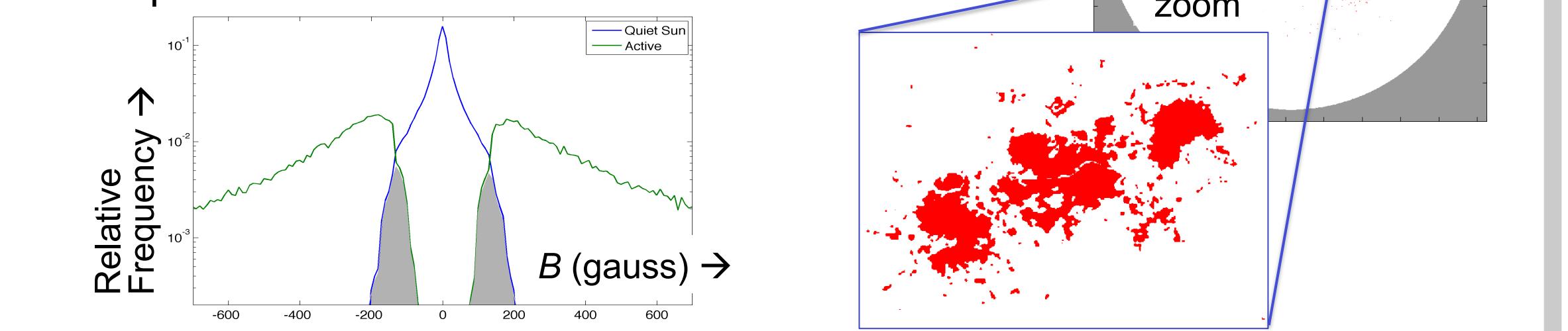
- Compute full-disk activity mask given input magnetogram and intensity images as in Turmon et al. 2002; Turmon et al. 2010.
- Mask data product is `Marmask_720s`, derived from `M_720s` and `Ic_noLimbDark_720s`. (Current region models do not use intensity information: `Ic_noLimbDark` has hour-of-day artifacts.)
- Pipeline module yields 4096x4096 BITPIX=8 masks, in image coordinate frame, with WCS and links to source data.

## Mask Algorithm

- Bayesian approach trades off pixel-by-pixel agreement of the mask value to the data against spatial coherence of labels (a prior). Mask is found by discrete optimization of a posterior probability.
- The Bayesian method therefore uses spatial coherence to disambiguate pixels near the class boundary.
- Smoothness takes spherical geometry into account (Turmon et al. 2010).

## Mask Models and Examples

- Histogram (below) shows how pixels (shaded gray) near critical  $|B|$  do switch classes due to neighbors
- Sample mask (right) shows fine spatial structure is preserved.

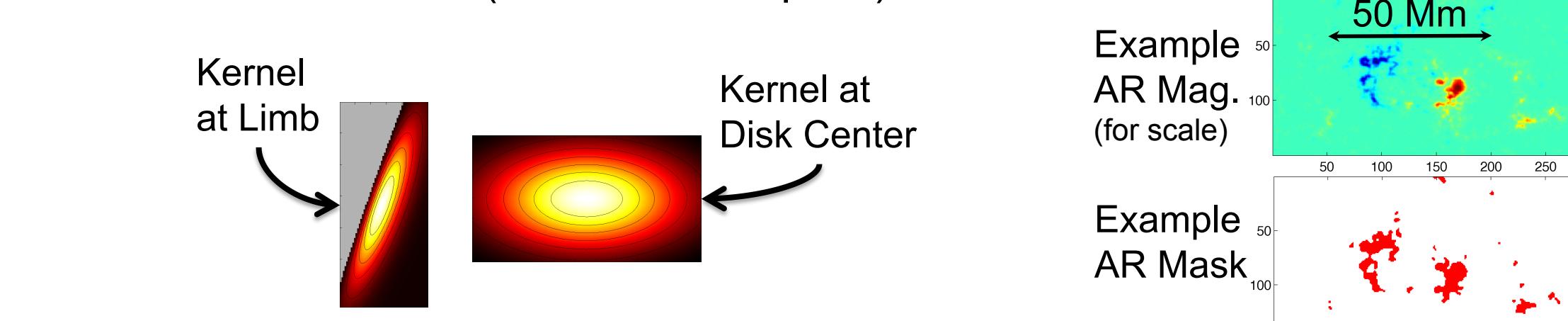


## Methodology: Active Region Grouping

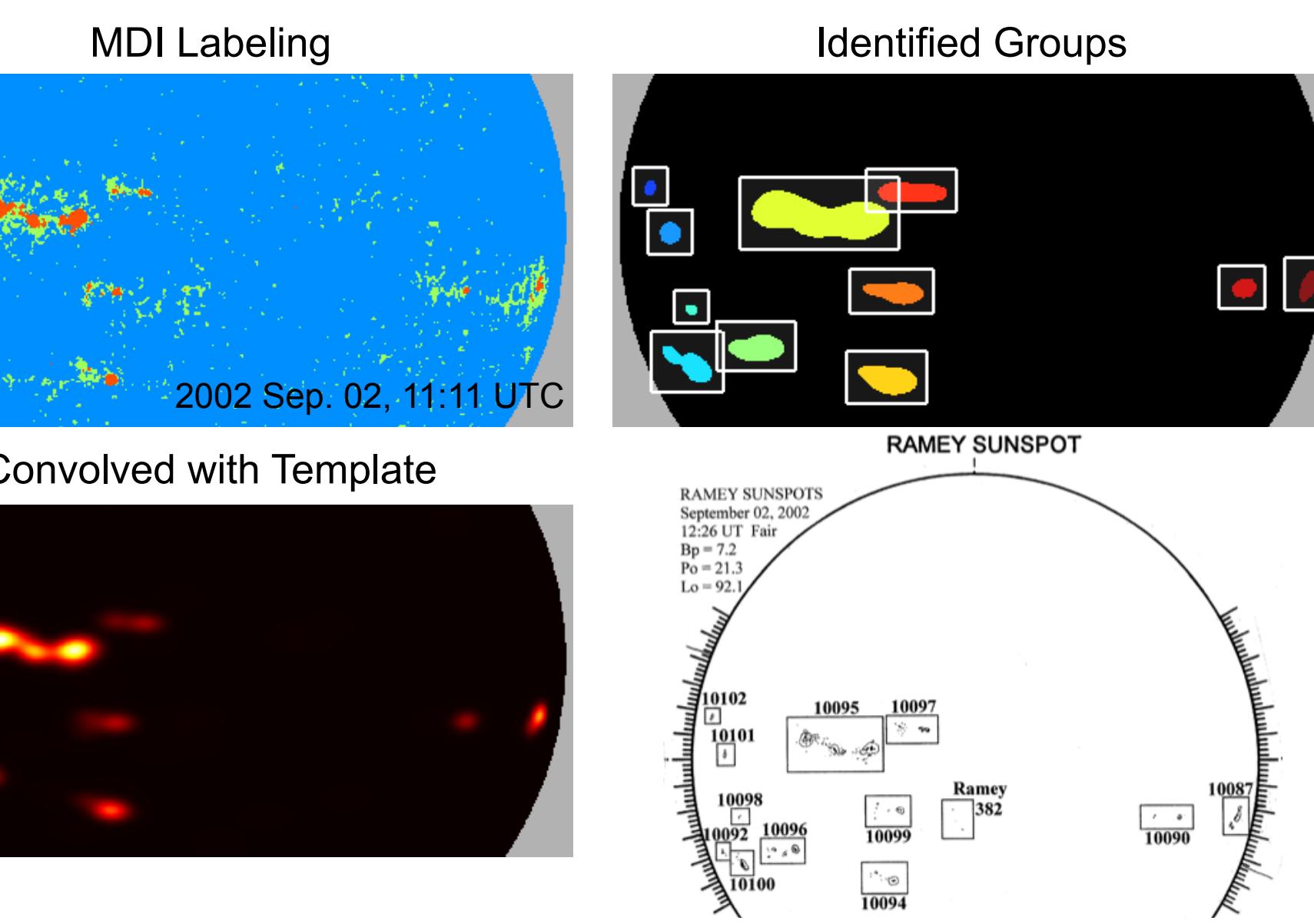
- Groups pixel-scale activity from masks into NOAA AR-scale regions
- We have used a matched filter approach with an elongated Gaussian kernel

It is a Gaussian as a function of 3D pixel-to-pixel distance

FWHM  $\sim 50 \times 25$  Mm ( $\sim 150 \times 75$  HMI pixel) at disk center

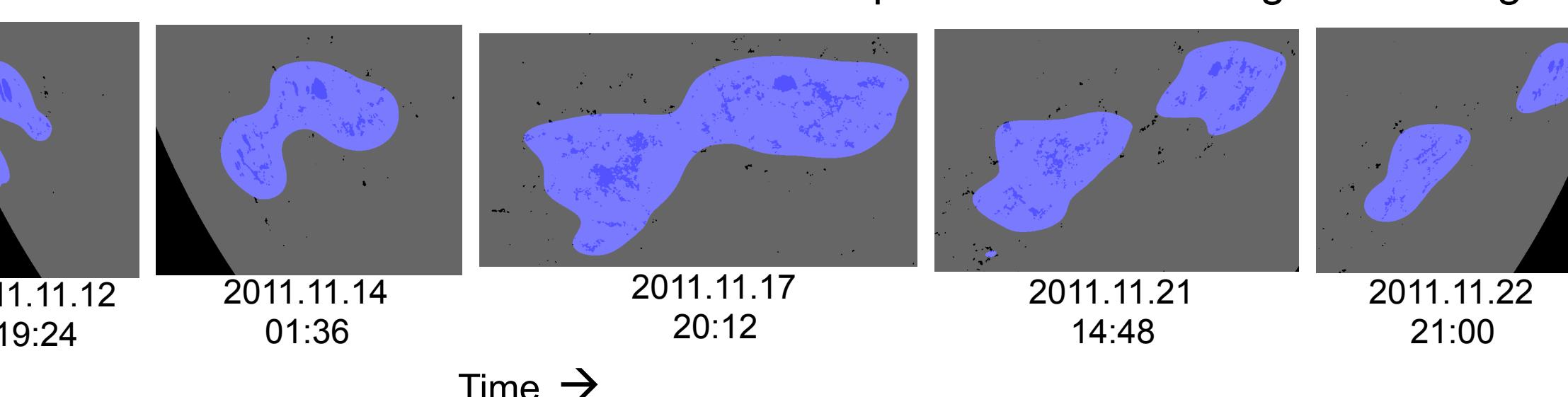


- Convolution is performed on the sphere to treat the limb fairly.
- AR masks are sparse: allows fast convolution (HMI: 12s).



## The HARP Data Product

- HARPs are indexed by HARP number, analogous to NOAA AR number, and time step ( $T_{REC}$ ).
- For a single HARP, the data series is a list of rectangular patches and metadata containing the observed lifespan of the HARP.
  - A 1-day pad is appended on both ends of the HARP.
  - About 12% of HARPs contain an entire disk passage (1440 appearances over 12 days).
- Each rectangular patch in the list is a cutout from the image plane. A patch can be overlaid on a full-disk image (e.g., from `M_720s`) by a simple coordinate shift. Patch WCS are included for other projections.
- The footprint covered by the patch is determined by the the smallest lat/lon bounding box that encompasses all appearances of that HARP. See below.
- The animating idea behind the sizing of the lat/lon bounding box is that the observer is hovering over the AR, staying at a constant latitude and moving at a constant angular rate in longitude.
- Shown below are five patches of the 1510 total making up HARP 1066. The colored masks below are stored as bitmaps in a suitable integer encoding.



## Status and Plans

- Masks, HARPs, quick-look HARP movies and synoptic charts, and space weather indices are computed in the pipeline for all incoming data in both near-real-time and definitive versions.
- Additional data: we hope to separate umbra/penumbra and identify faculae.
- Technical improvements: identify and compensate for spatially-varying noise or sensitivity.

## Methodology: Active Region Tracking

- Chain regions together to make a track: single-link most likely tracker using overlap area
- Compute the overlap area between extrapolated track (using standard latitude-dependent motion relationship) and new region.
- Overlap of patch  $a$  in  $A$  and patch  $b$  in  $B$  is  $D(a,b)$ .
- Solve linear assignment problem to match  $A$  up to  $B$ :

$$\max_P \sum_{a \in A} \sum_{b \in B} P(a,b) D(a,b)$$

where  $P$  is a permutation matrix giving the  $B$ -to- $A$  mapping.  
Fast, exact solution by linear programming.

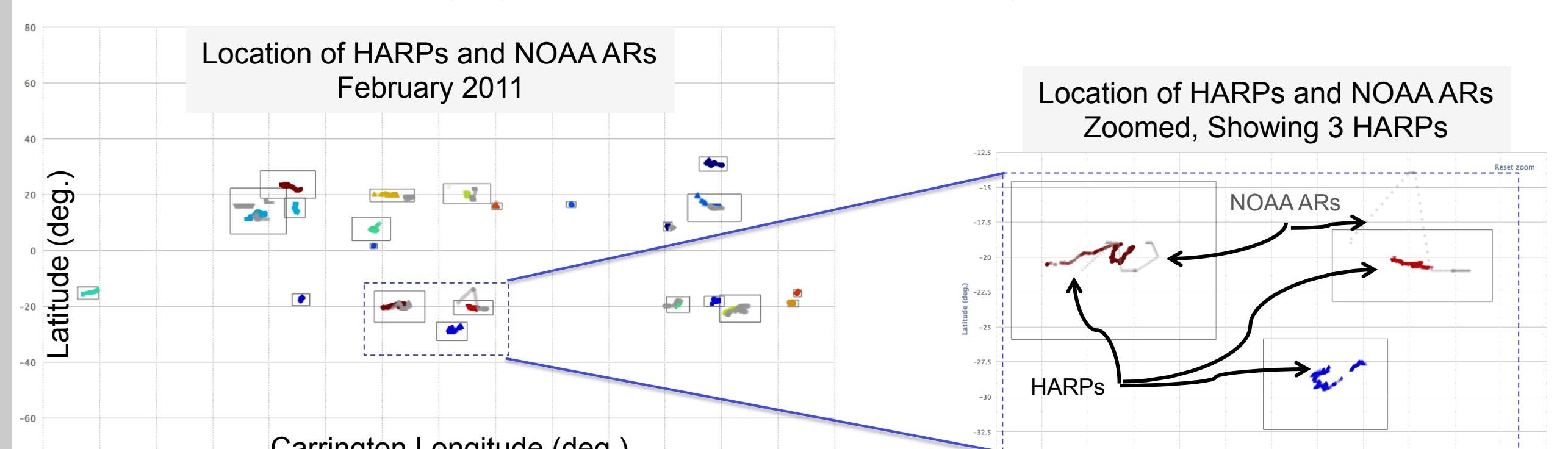
- Chaining this association across many frames yields complete tracks.
- Tracks can be finalized only after they are unseen for a long-enough time.

## Merging Tracks and Complex HARPs

- Tracks are identified based on retrospective data (essential for near-real-time products). Thus, growing regions may merge in later appearances.
- Coping with the consequences of merges adds considerable complexity to the implementation. This complexity is hidden in the final data product.
- Care is taken so that regions near the detection threshold are not cut into separate temporal pieces as they exceed and then sink below the threshold.
- The HARP is often not a contiguous region. For shrinking regions, the HARP lat/lon bounding box can be much larger than the currently active area. It can even contain other HARPs. Use the HARP bitmap to determine what is part of the HARP.

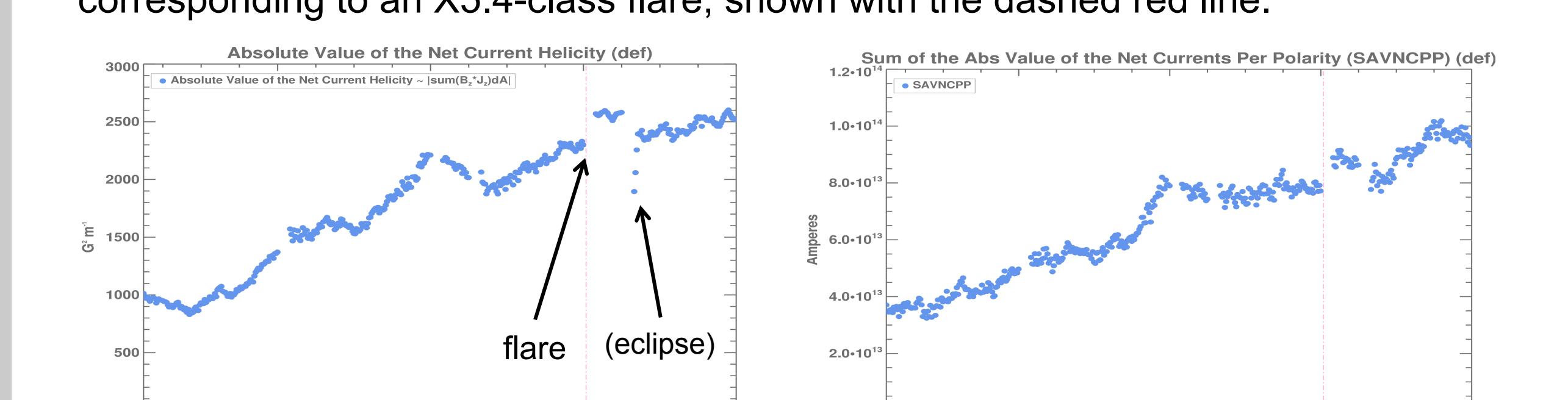
## Derived Products

We produce a monthly synoptic map of HARPs as a dynamic plot in a browser.



Each HARP has a space weather HARP (SHARP, Bobra et al. 2011) with relevant space weather quantities computed using the disambiguated vector magnetic field.

Below are two such quantities for the HARP encapsulating NOAA AR 11429, over 2012 March 4–8. The GOES X-Ray flux peaked at 0:40 UT on 2012 March 7, corresponding to an X5.4-class flare, shown with the dashed red line.



## References

- M. Bobra, J. T. Hoeksema, X. Sun, M. Turmon, "SHARPs – A new space weather data product from SDO/HMI," 2011 AGU fall meeting, abstract #SH51B-2006.
- M. Turmon, H. Jones, J. Pap, O. Malanushenko, "Statistical feature recognition for multidimensional solar imagery", *Solar Physics*, 262(2), 2010.
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- M. Turmon, J. Pap, S. Mukhtar, "Statistical pattern recognition for labeling solar active regions: Application to SoHO/MDI", *Astrophys. Jour.*, 568(1), 2002, 396-407.
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