Automated Detection of Solar Eruptions

ABSTRACT

Any observation of the solar atmosphere reveals a wide range of real and apparent motions, from small scale jets and spicules to global-scale coronal mass ejections. Identifying and characterizing these motions are essential to advance our understanding the drivers of space weather. Both automated and visual identifications are used in identifying CMEs. To date, the precursors to these, eruptions near the solar surface (either from filaments or otherwise), have been identified primarily by visual inspection. Here we report on the Eruption Patrol, which is designed to automatically identify eruptions from data collected by SDO/AIA. We describe the method and compare it to previously identifications found in the Heliophysics Event Knowledgebase.

Identification Method

Our approach is to identifying solar eruptions is to extract velocity fields from sequences of solar images using the opflow3d method described in Hurlburt and Jaffey (2014). Ten frames (spanning two minutes) of full-resolution Level 1 data (scaled by the square root) are feed into opflow3d to extract a time-averaged velocity field with an effective spatial resolution of 60 arc seconds: these choices were settled upon as the optimum balance between reducing noise, minimizing motion blur, reasonable spatial discrimination and computing effort.

The computational time for a single velocity fit is approximately one minute on a 2013-vintage Apple iMac. The opflow3d method uses a least squares approach that has been shown to minimize the effects of detector noise, transient intensity variations and other sources of measurement error. Velocities are sampled every 20 minutes and the time, location and velocity at the point of maximum speed within each sample is recorded. The results are then and thresholded to identify time periods of significant motions. These periods, along with the largest velocity and its position, are then recorded to the HEK as preliminary reports of eruptions.

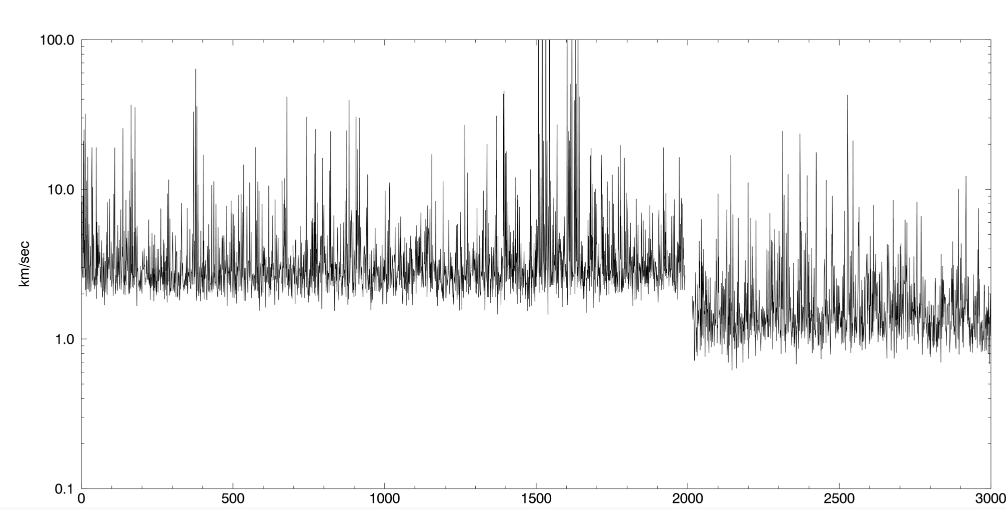


Figure 2. The peak speeds reported by EruptionPatroller in 3000 samples taken between 2014-04-04 to 2014-05-16. Results for April did not remove the effects of solar rotation, and hence have a flow of about 2km/sec. Data in May have that correction applied, and the remaining floor is a combination of differential rotation, meridonal flow, supergranulation and other ubiquitous sources. Spacecraft maneuvers and other calibrations are also present in the April results, most notably during April 23 (sample 1600).

Comparison	Hit	Miss
EP using Human FE list	25	1
Human using EP list	9	10

Table 1. A cross comparison between human and Eruption Patrol reports over a comparable time interval (Human from 3/26-4/22, EP as in Figure 2) clearly demonstrates a higher skill level for EP.

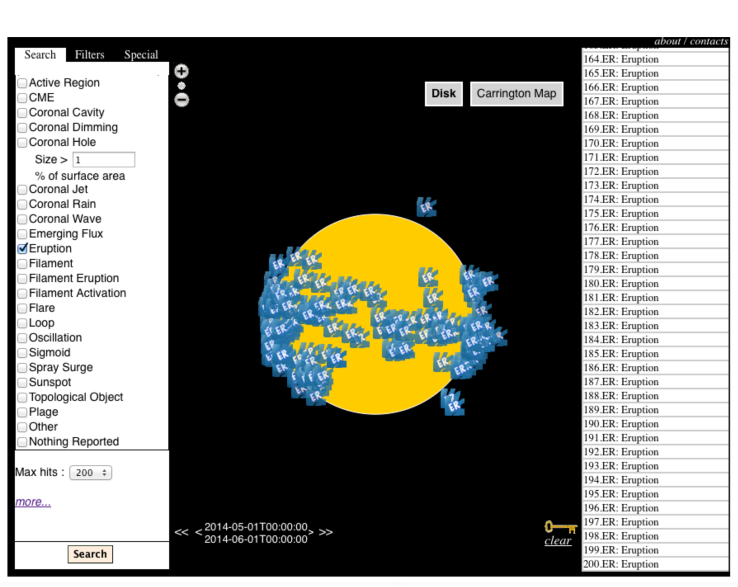


Figure 3. Eruption detections for the first two week of May 2014 as rendered by iSolSearch display a clustering near the east and west limbs.

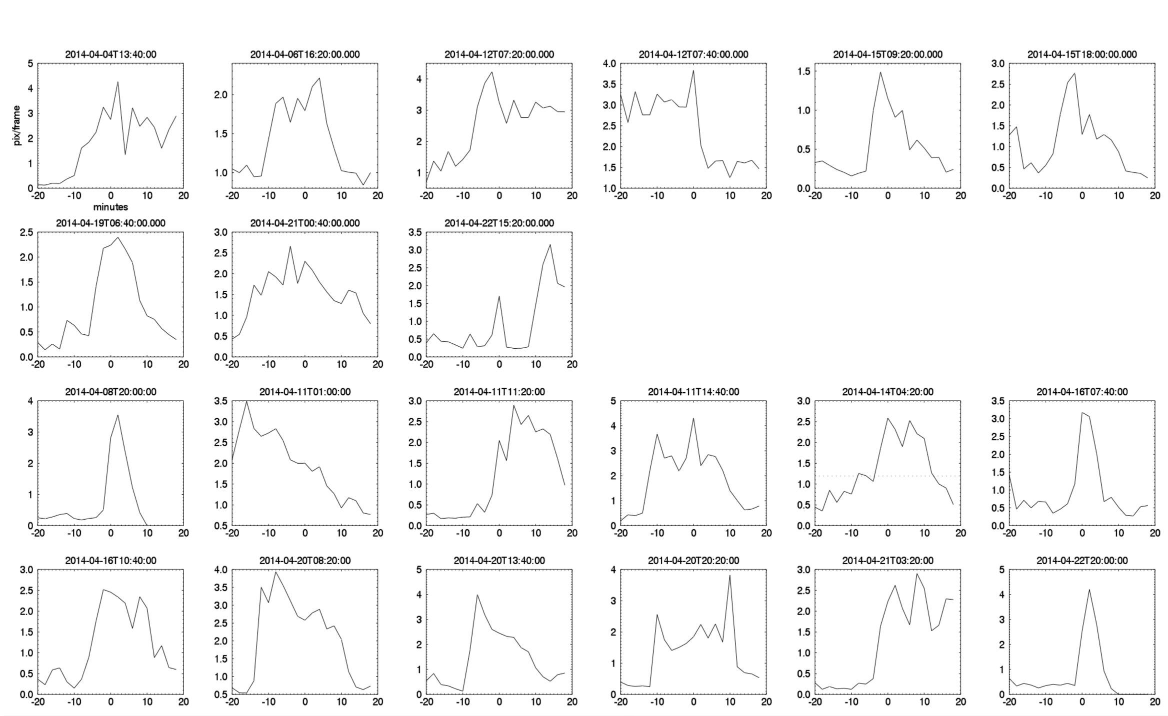


Figure 4. Detailed speed curves for the 19 fastest moving events between 4/4/2014 and 4/25/2014 as found by the Eruption Patroller (each spanning 40 minutes around the trigger location) display a variety of profiles. The first nine events were also found by human annotators (based on searching +/- 1 hour from the central point); The lower 10 were not.

Characterization Method

An example of a derived flow field is displayed in Figure 1 . The resolution is about 30 arc seconds. The flow associated with the large filament eruption near the northern pole is clearly captured, as well as more persistent, steady motions associated with the active region on the left. We will eventually need to revisit the preliminary detections to extract both light curves similar to those in figure 4, as well as to distinguish and characterize mutliple eruptions within them.

But first we first survey the statistical properties of our preliminary detections.

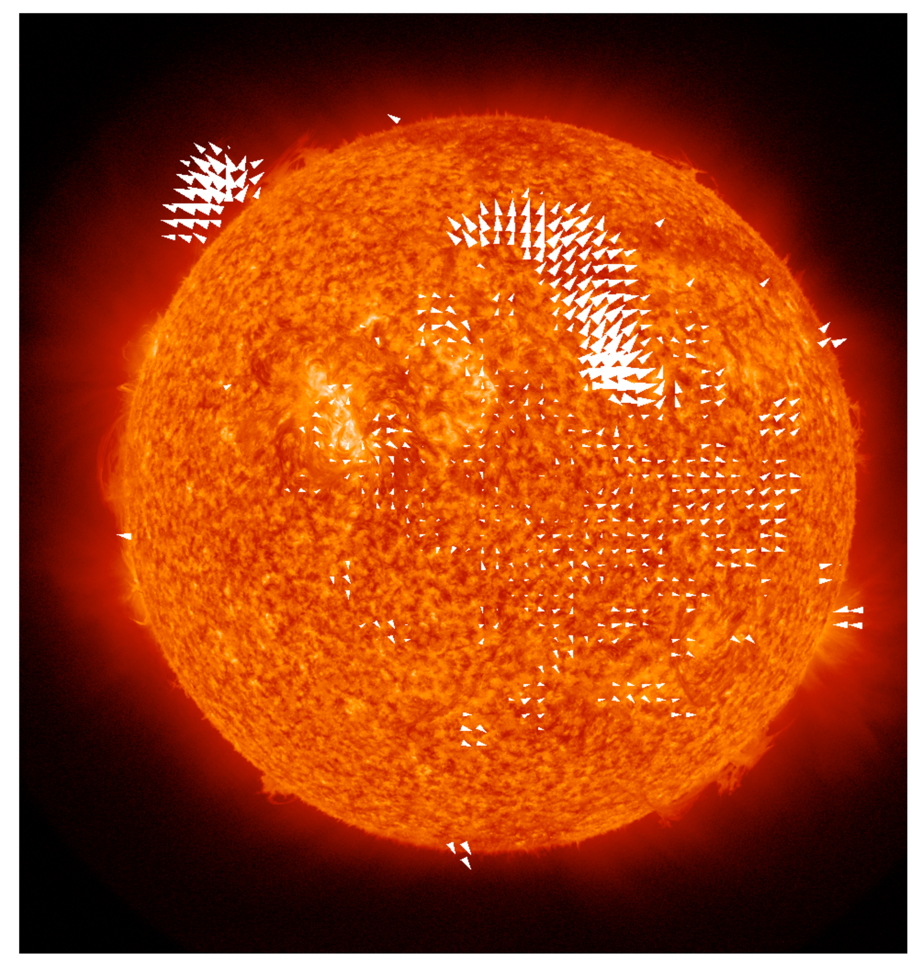
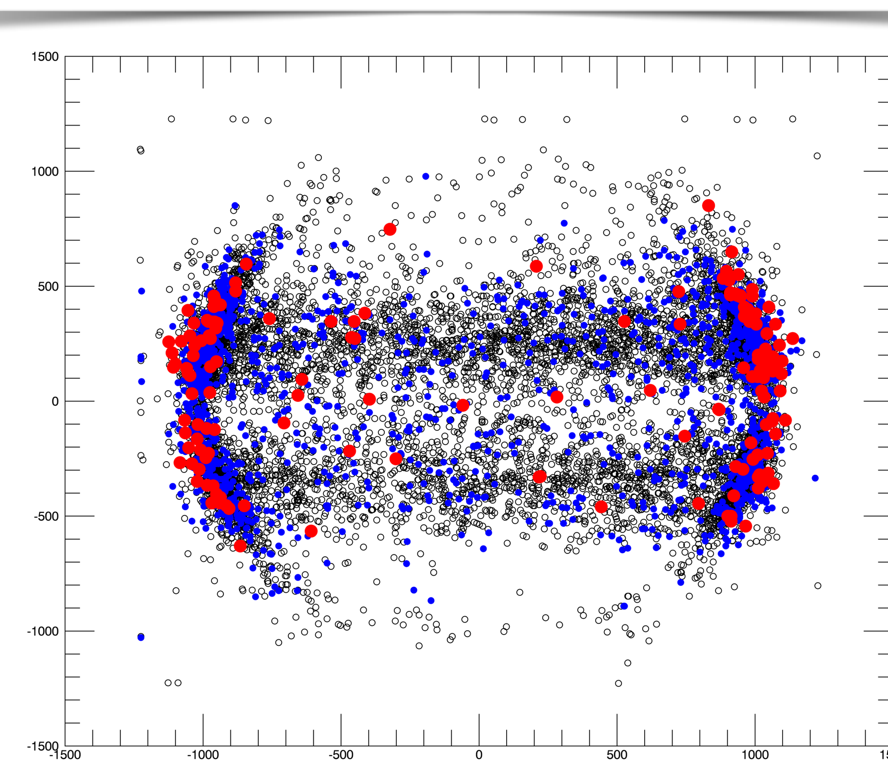
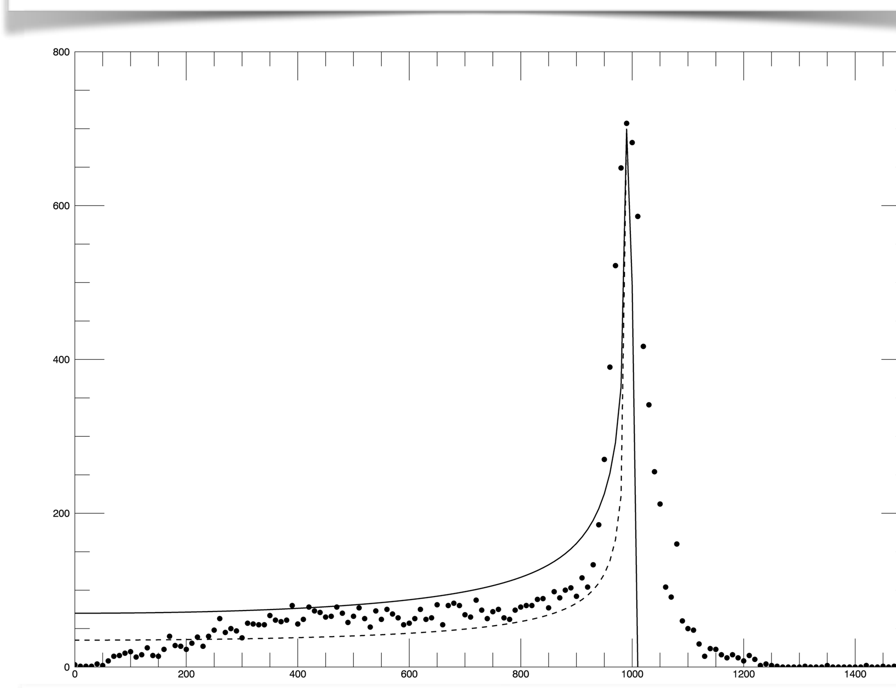


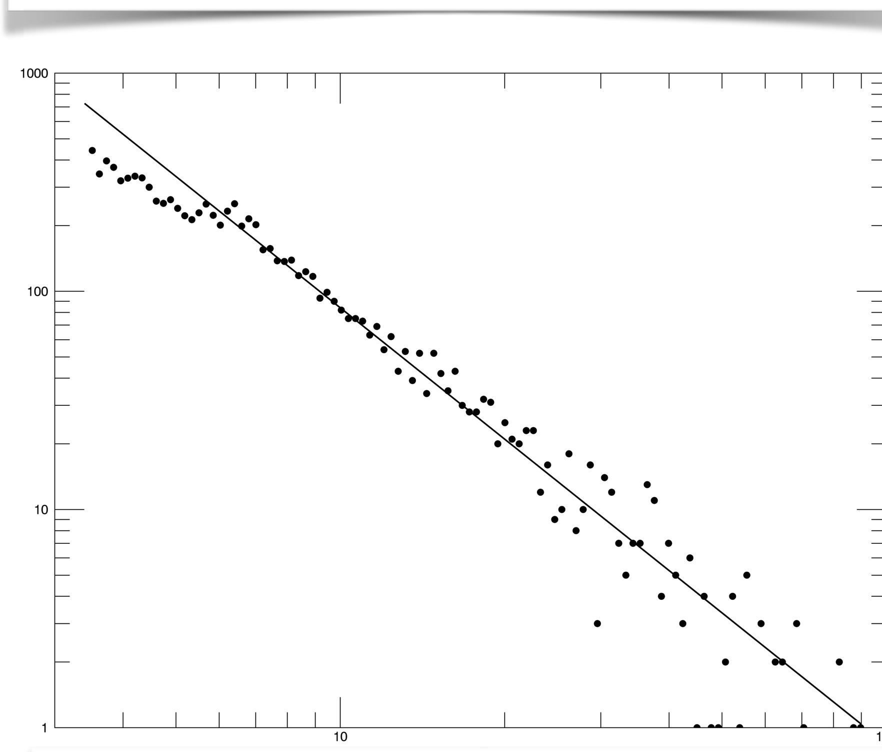
Figure 1. The velocity field obtained by applying our method to two minutes of SDO/AIA 304 data starting at 2010-Aug-1T21:20. The arrow are aligned with the local velocity with areas proportional to the speed. The corresponding image is shown in the color background. Two regions are seen to be erupting, a long filament on disk is ascending into the corona. The region in the center left is a steadier flow associated with an active region. Only velocities over 1km/sec are displayed and solar rotation is not removed.



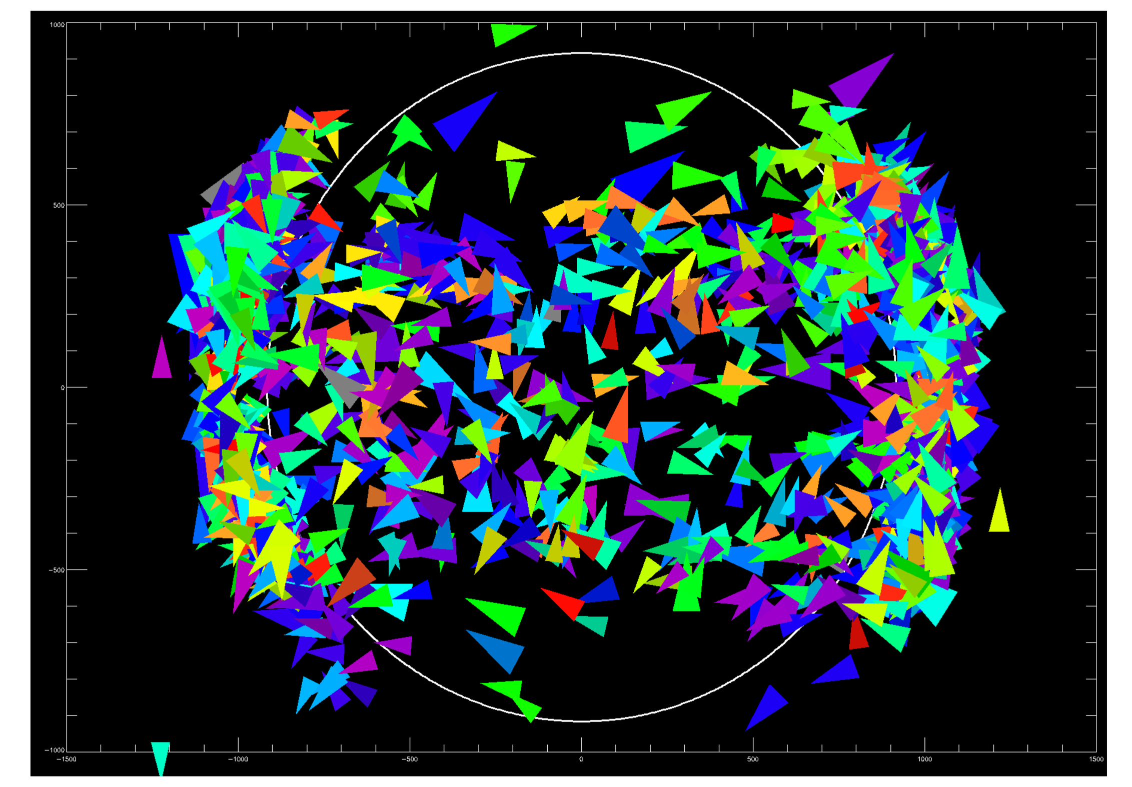
The distribution of all eruptions from 5/15/2010 to 7/12/2014 show clustering near activity belts and the limb. Black, blue and red circles display weak (<10km/sec), medium (<30km/ sec) and strong (>30km/sec) eruptions respectively.



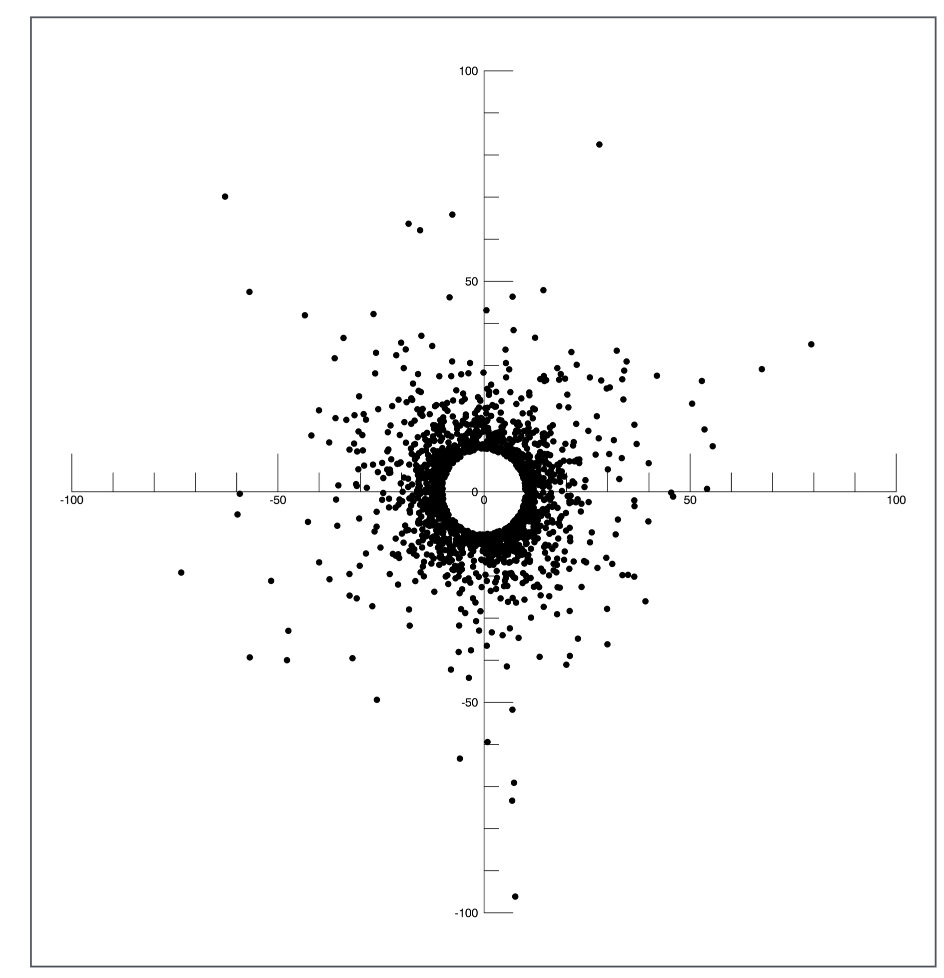
Histogram of radial positions of all eruptions from 5/15/2010 to 7/12/2014. Dots represent number of events in 10 arcsec bins. Solid line is theoretical PDF assuming the formation layer is a uniform 20 arcsecond thick (15Mm), dashed is same for 5 arcsecond-thick layer (3.5Mm) - with both scaled to match the maximum.



Histogram of speeds of all eruptions from 5/15/2010 to 7/12/2014. Eruptions appear to possess a power law distribution near and inverse square (solid line).



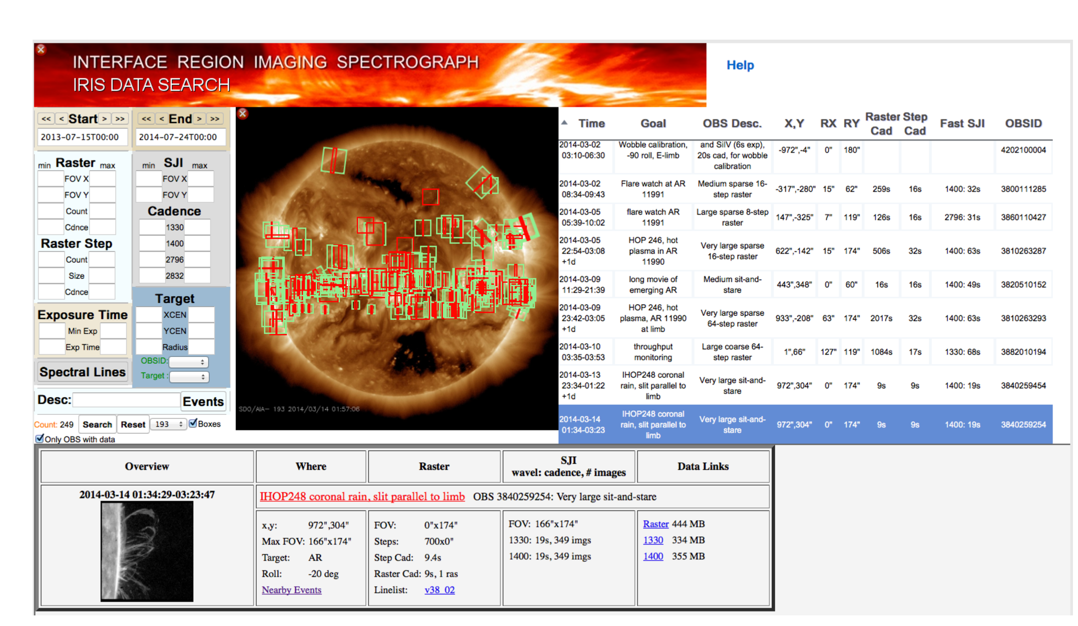
(above) The position and velocities for 1651 events with magnitudes greater than 10km/sec. Colors are assigned randomly to distinguish different events. (below) A polar plot of the velocity vectors show them to be reasonably isotropic with a maximum speed of 96.2km/sec.



Conclusions

We have developed an automated method for finding eruptions in the lower solar corona and are working to deploy it within the SDO/AIA Event Detection System (EDS). The method has been found to produce significantly more accurate and more consistent results than those obtained by human reviewers. It also provides a more complete characterization of eruptions by reporting both the location and plane-of-sky velocity.

The distribution of speeds is approximately and inverse square from the threshold of 3.6 km/sec to 96.2km/sec. Their spatial distribution clusters around the solar activity belts, but are otherwise uniformly distributed in what appears to relatively thin layer of formation of around 10Mm. The motions of the larger events are reasonably isotropic.



IRIS has observations of about 250 eruption over the past year. The IRIS Data Search tool is capable of guiding researchers to the best datasets for further study.

Future Work

Subsequent papers will explore how these eruptions compare with those found with other automated processes running within the EDS and will describe a characterization module that extracts more detailed information on the eruptions reported by the Eruption Patrol.

We will incorporate data from higher resolution observations including IRIS and Hinode. The IRIS Data Search tool correlates it observations times and fields of view with events recorded in the HEK. Over the first year of obervations about 250 eruptions have been captured. We will include flow measurements from these in our characterizations and feed the results back into the event descriptions.