Mapping low corona flow trends via time dependent AIA image processing

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ABSTRACT

Applying the Time-Normalized-Optical-Flow (TNOF) image processing technique to AIA extreme ultraviolet (177-305 nm) data reveals fine-scale and faint plasma motion that are tracked through optical flow methods, giving 2-D flow maps. The flows detected thus far appears to be oriented in the low corona [1,2], but the Lucas-Kanade (LK) method has known weaknesses near the solar limb, due to small separation in observational position, and varies in quality across AIA cameras. To reliably refine the method, synthetic image data is developed with a well defined velocity field and will serve as the testing platform to separate systematic biases from true flows. Once fully vetted, the strength of the project lies in understanding the faint moving disturbances that propagate and persist during the "quiet sun" period that is the standard solar condition. The method may be adapted to include elevation flow trends in/out of the low corona should tandem spacecraft be flown at L1 & L5, allowing 3-D maps of flows.

TIME NORMALIZED OPTICAL FLOW

Continuous AIA data is well suited for dynamics by normalizing a sliding time window on consecutive observations [2]:

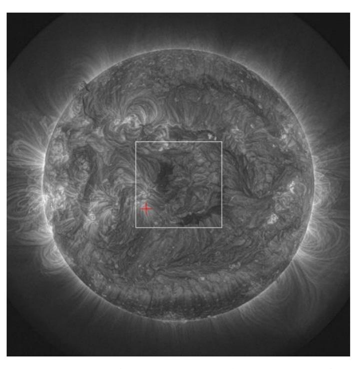


Figure 1: Example image from AIA's 193 Å channel. Processed via multiscale Gaussian normalization (MGN) to enhance faint structures. The red cross pixel position is used as an example of the method.

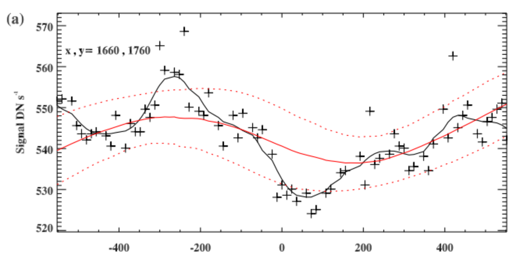


Figure 2: Crosses are 15-min time series of pixel in Fig 1. Black line is time-smoothed signal. Solid red line is the slow variation in the signal (user selected). Dotted red line is ±1 standard deviation from the mean.

$$TNOF\ processed\ signal = \frac{central\ observation - weighted\ mean}{standard\ deviation + constant}$$

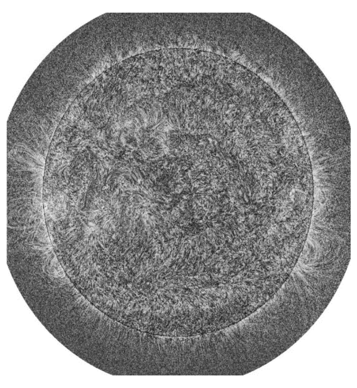


Figure 3: Example still image of Fig 1 after TNOF normalization to enhance faint structures. The red cross pixel position is used as an example of the method.

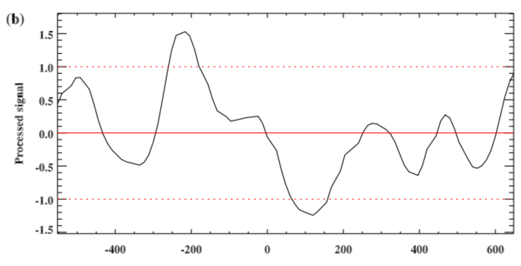


Figure 4: The TNOF processed signal, after applying the equation to ~75 images.

While time normalization limits still image structural context, it is crucial to reveal temporal faint motions across the solar disk that are usually dominated by spatial variations in intensity. In prior studies, application of TNOF has been most effective for AIA 171/193 images, with less coherent detail in other channels.

OPTICAL FLOW TRACKING

The LK method for optical flow analyses successive images of the same scene and draws an estimated path that features move along [3]. It does so by identifying changes in a pixel's intensity and comparing it against the known intensity gradients in the region of the pixel:

$$\frac{\Delta intensity}{\Delta x} v_x + \frac{\Delta intensity}{\Delta y} v_y = -\frac{\Delta intensity}{\Delta time}$$

Presently, optical velocity paths drawn via this method have aligned well with visible structures in MGN contrast enhanced images, there remains many paths with no clear contextual alignment across the "Quiet Sun".

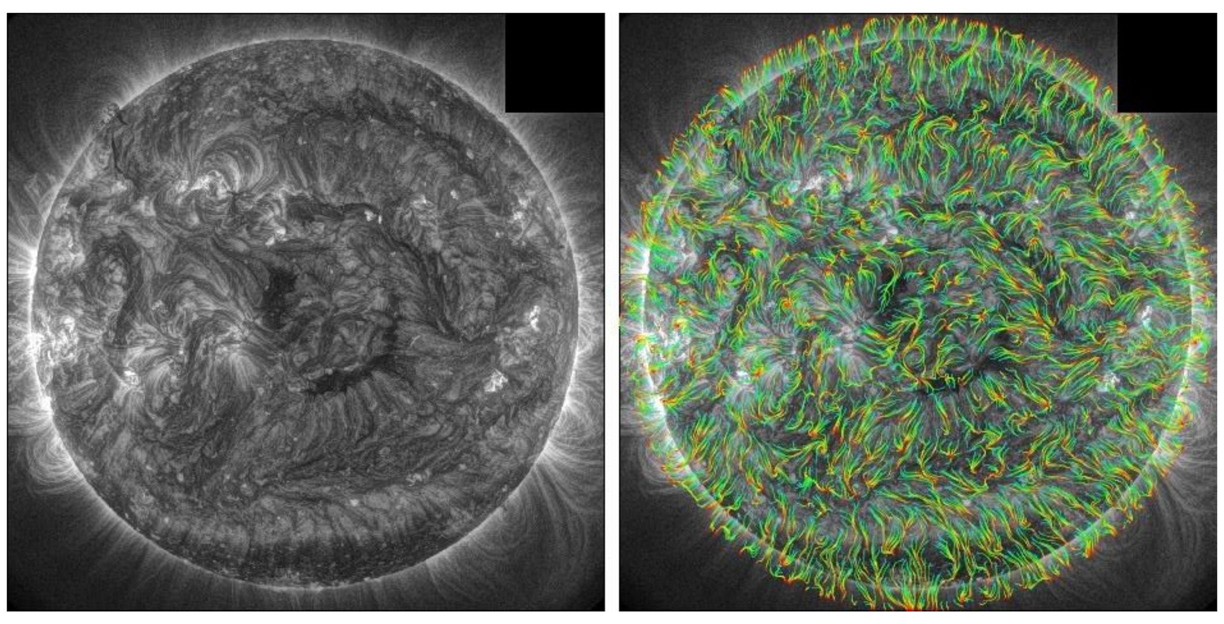


Figure 5: (Left) MGN processed image from the AIA 193 channel. (Right) Optical velocity paths plotted onto an MGN image from analysis of 300 images, apparent motion starts at the violet and ends red portions of each line.

REFERENCES

[1] Morgan, H., Druckmüller, M. 2014, Solar Physics, Vol. 289.
[2] Morgan, H., Hutton, J. 2018, Astrophysical Journal, Vol. 853.
[3] Lucas, B., Kanade, T. 1981. Proc. of Image Understanding Workshop.
[4] Cabral, B., Leedom, L. 1993. Proc. of 20th Conf. on Comp. Graphics.

SYNTHETIC DATA

Success with TNOF and LK methodology appears promising and has discovered ubiquitous and continuous propagating disturbances across the solar disk [2]. And yet, discrepancies in optical velocities among different AIA channels may be due to systemic scaling biases attributed to user-adjusted spatial and time-smoothing parameters. Without independent verification, synthetic data provides the best alternative for a controlled test environment.

See inserts on next page

The resulting 2-D velocity field is created and may be manipulated globally or with discrete discrepancies. For display purposes, the N=10 field is unadjusted:

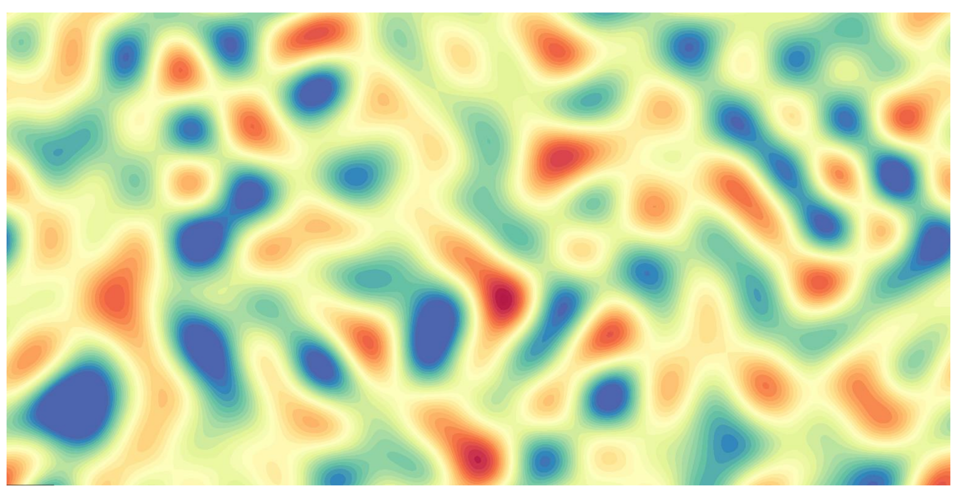


Figure 8: Velocity field generated in 360 x 181 grid points. Blue regions are local troughs where flow will migrate towards. Red regions are local peaks upon which flow will migrate away.

Flow within this field is mapped in two distinct methods, the first is via line-integral convolution (LIC) [4]. Linear and curvilinear filtering is performed locally along streamlines defined by the vector field to approximate flow speed magnitude. The algorithm is computationally expensive & reversible, but yields precise results for any particle motion within the field:

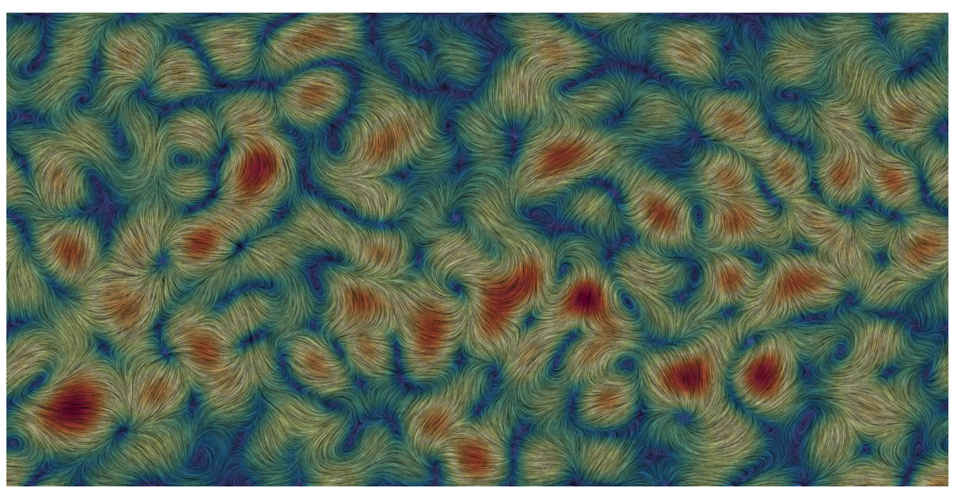


Figure 9: Example LIC of flow magnitude within the Fig 8 velocity field. Spatial resolution is set to 100 parts per grid point. Streamlines within blue regions indicate flow speed is fast and within red regions indicates flow speed is slow.

The second method is via direct interpolation of the vector field. This yields reversible time-series positions for an arbitrary number of particles. Each particle is set to a high intensity brightness and diffuses as it moves, complicating the original field in a verifiable manner:

Scan the QR code below to see a one minute video of Figures 1, 3, 5, 10

Or enter the URL:
http://users.aber.ac.uk/gam27/RAS2019animation.mp4

Figure 10: (Orange movie) Animation of direct interpolation of Fig 8 velocity field. 500 particles are tracked over 200 sequenced images. All particles have an arbitrary initial intensity set to 250 and the background initially is 0. Particles migrate towards local troughs and diffusion saturates the region. (Grayscale movie) Animation of TNOF method applied to the preceding set of images. Time normalization set to 20 images, which crops 10 frames from the start & end. Static particles are removed and only active motion is recorded

As shown in Fig 10, TNOF is a powerful tool for isolating faint, small-scale moving disturbances across the time series of 2-D images.

FUTURE WORK

The testing platform will evolve further to:

- Add solar-like features & resolution similar to AIA
- Implement & refine LK method on all channels
- Compare LK/LIC quality against other techniques
- Optimize efficiency well enough to map small-scale, faint motion across the entire AIA dataset.

Insert #1

Synthetic data is created by applying a sinusoidal basis function that randomly determines the underlying 2-D velocity field [2]:

$$S(x, y) = C + \sum_{k_x=1}^{N} \sum_{k_y=1}^{N} s_{k_x,k_y},$$

$$s_{k_x,k_y} = c_{k_x,k_y,0} C_{k_x} C_{k_y} + c_{k_x,k_y,1} S_{k_x} S_{k_y} + c_{k_x,k_y,2} S_{k_x} C_{k_y} + c_{k_x,k_y,3} C_{k_x} S_{k_y}$$

Figure 6 & 7: Lift this flap to see a detailed description of values within the function.

Insert #2

Integers k_x and k_y specify the function order as an N size box

C is a constant, $c_{k_x,k_y 0\ldots3}$ are random scalers $[-1,1]$

$$S_{k_x} = \sin(k_x x')$$
$$S_{k_y} = \sin(k_y y')$$
$$C_{k_y} = \cos(k_y y')$$
$$C_{k_x} = \cos(k_x x')$$

$$x' = \frac{\pi i}{n_x - 1}, \qquad i = 0, 1, 2 \ldots n_x - 1$$

$$y' = \frac{\pi j}{n_y - 1}, \qquad j = 0, 1, 2 \ldots n_y - 1$$

Figure 6: Description of values within the sinusoidal basis function S(x,y)

Insert #3

The complexity across a single axis of the velocity field is defined by the number of ordered pairs, N, summed within a grid point:

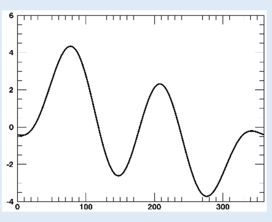
N = 2

$S(x_1,y_1)$	$S(x_2,y_1)$
$S(x_1,y_2)$	$S(x_2,y_2)$

N = 3

$S(x_1,y_1)$	$S(x_2,y_1)$	$S(x_3,y_1)$
$S(x_1,y_2)$	$S(x_2,y_2)$	$S(x_3,y_2)$
$S(x_1,y_3)$	$S(x_2,y_3)$	$S(x_3,y_3)$

N = 3



N = 10

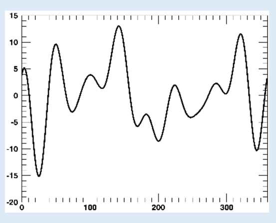


Figure 7: Examples of the effect of order, N, on the sinusoidal basis function. (N=2 red) Displays the four functions compiled within a single grid point, and (N=3 red) the increased complexity of nine functions compiled within the same point. (N=3 graph) Minor peak & trough sinusoidal complexity graphed across the x-axis, and (N=10 graph) is the complexity of the following velocity field.