Relating Shear Velocity in Solar Sigmoid Formation with Coronal Mass Ejection Events

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Introduction

This project's purpose was to study how the speed at which the plasma in the photosphere of the Sun affects the lifetime of a solar sigmoid. Solar sigmoids are S-shaped, twisted magnetic structures that form due to the shifting magnetic field lines emerging from the surface of the sun. The photosphere is the visible layer of the Sun's surface and is made up of cells of plasma that are highly conductive and influenced by the magnetic field of the Sun. Sigmoids form when shearing (a lateral shift between two objects in directions opposite each other) occurs in the photosphere plasma, causing ropes of magnetic flux to break and reconnect in S shapes. I predicted that when higher velocity shearing occurs in this plasma, solar sigmoid structures will be stretched out and as a result be less stable, extending just above the surface of the Sun, and at a lower shearing velocity a sigmoid will stay stable longer and be able to extend much further above the surface of the sun. By studying the shearing velocities I hope to relate large coronal mass ejection (CME) events to sigmoid formation and eruption.

Methods

The shear velocity of the photosphere at the base of the sigmoid was measured using the physics based Tracker software, which takes user uploaded videos and helps measure changes in position of an object within the video. The Helioseismic and Magnetic Imager (HMI) and atmospheric Imaging Assembly onboard the Solar Dynamics Observatory (SDO) were used to retrieve HMI magnetogram time lapse data and both partial and full solar view time-lapse data in different light wavelengths. The HMI magnetogram images help to identify different regions of polarity while the full disk wavelength images help identify the sigmoids. Matlab was used to analyze the data and produce graphs for the velocities of the polarity regions.

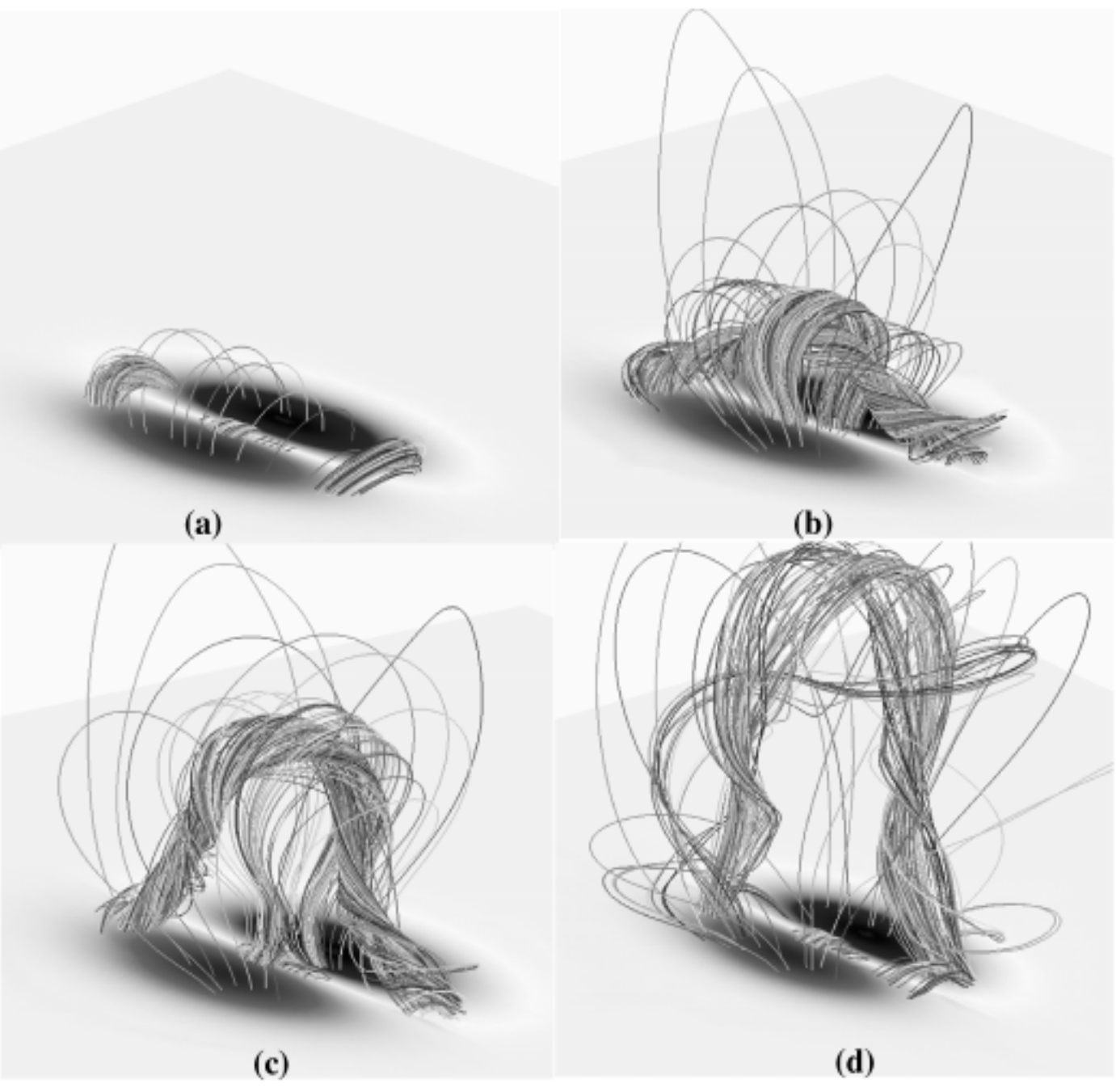


Figure 1 a) two magnetic regions of opposite polarity connected by magnetic flux tubes. b) magnetic connection of clustered tubes underneath the original connected tubes as a result of shearing along the polarity inversion line. c) Rising current density sheets generated by the connection underneath existing tubes causes the entire formation to rise. d) Eventually the sigmoid will undergo magnetic reconnection causing a portion of the plasma to be "pinched" off.

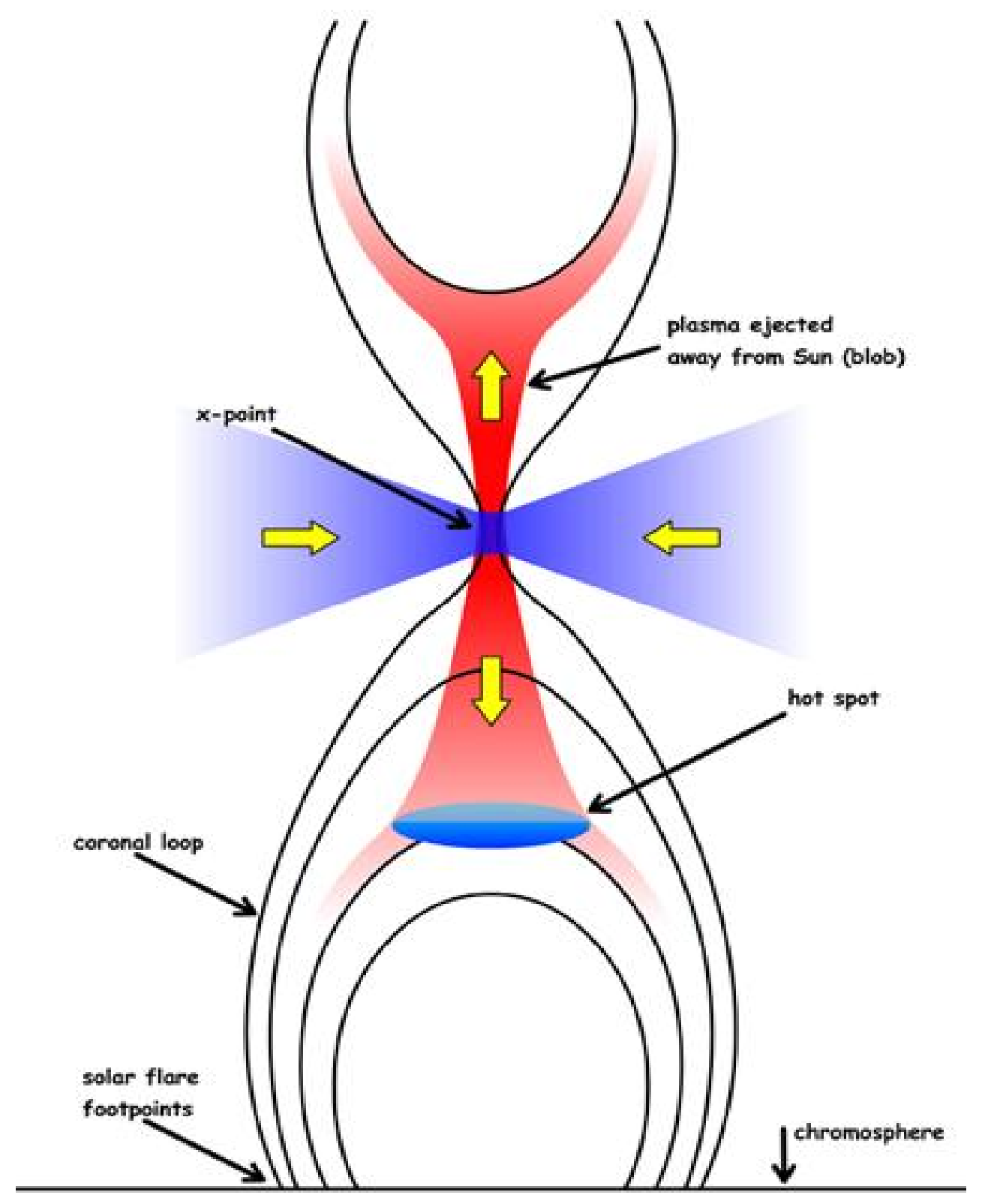


Figure 2 Magnetic Pinching effect. As the sigmoid grows, flux tubes (highly energized plasma tubes) will break at the x-point and reconnect together, rapidly falling back towards the chromosphere, ejecting plasma away from the sun. Sigmoids often have short lifetimes and their eruptions are almost always violent because the flux tube connections from the sigmoid's inception are unstable.

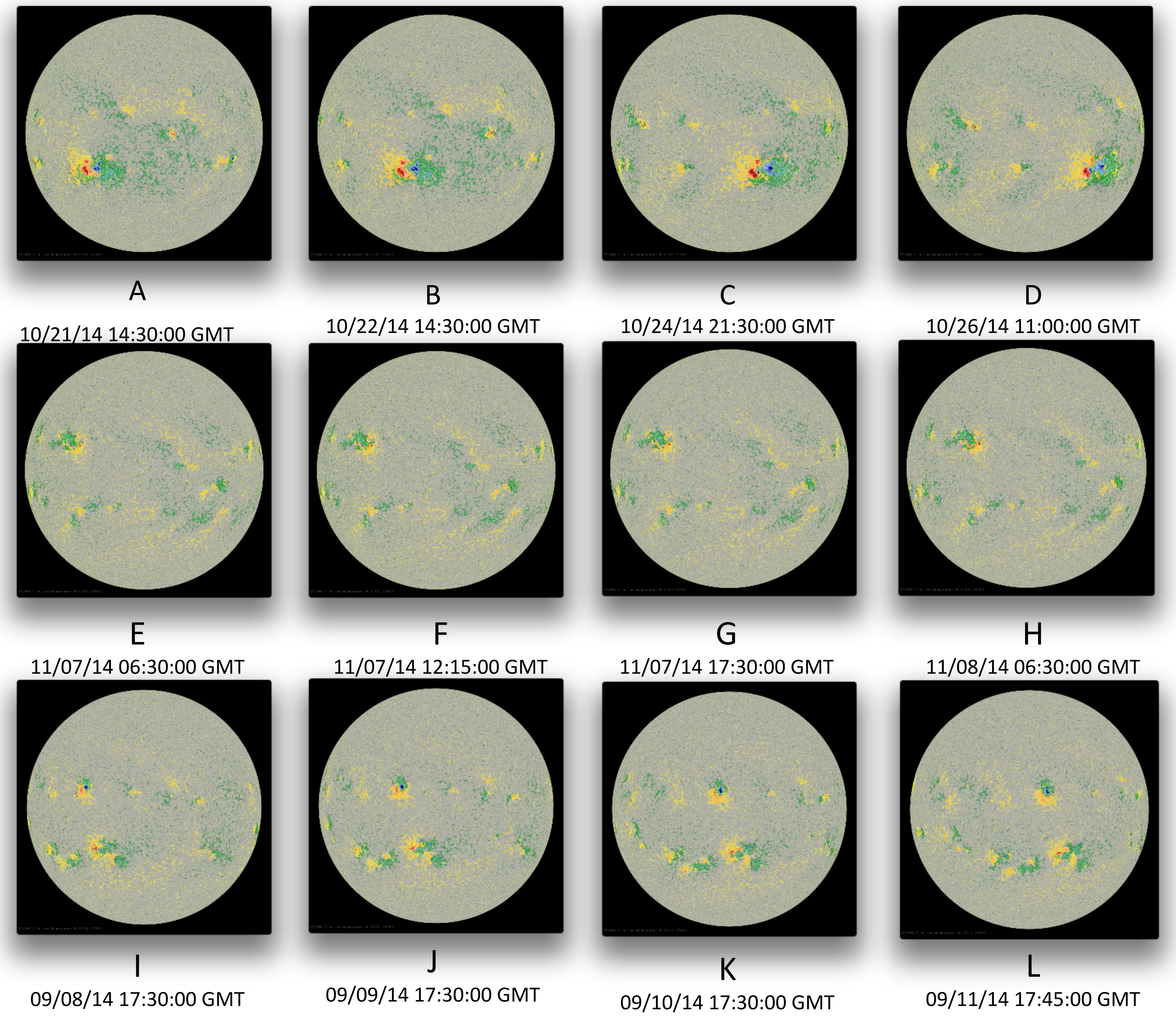
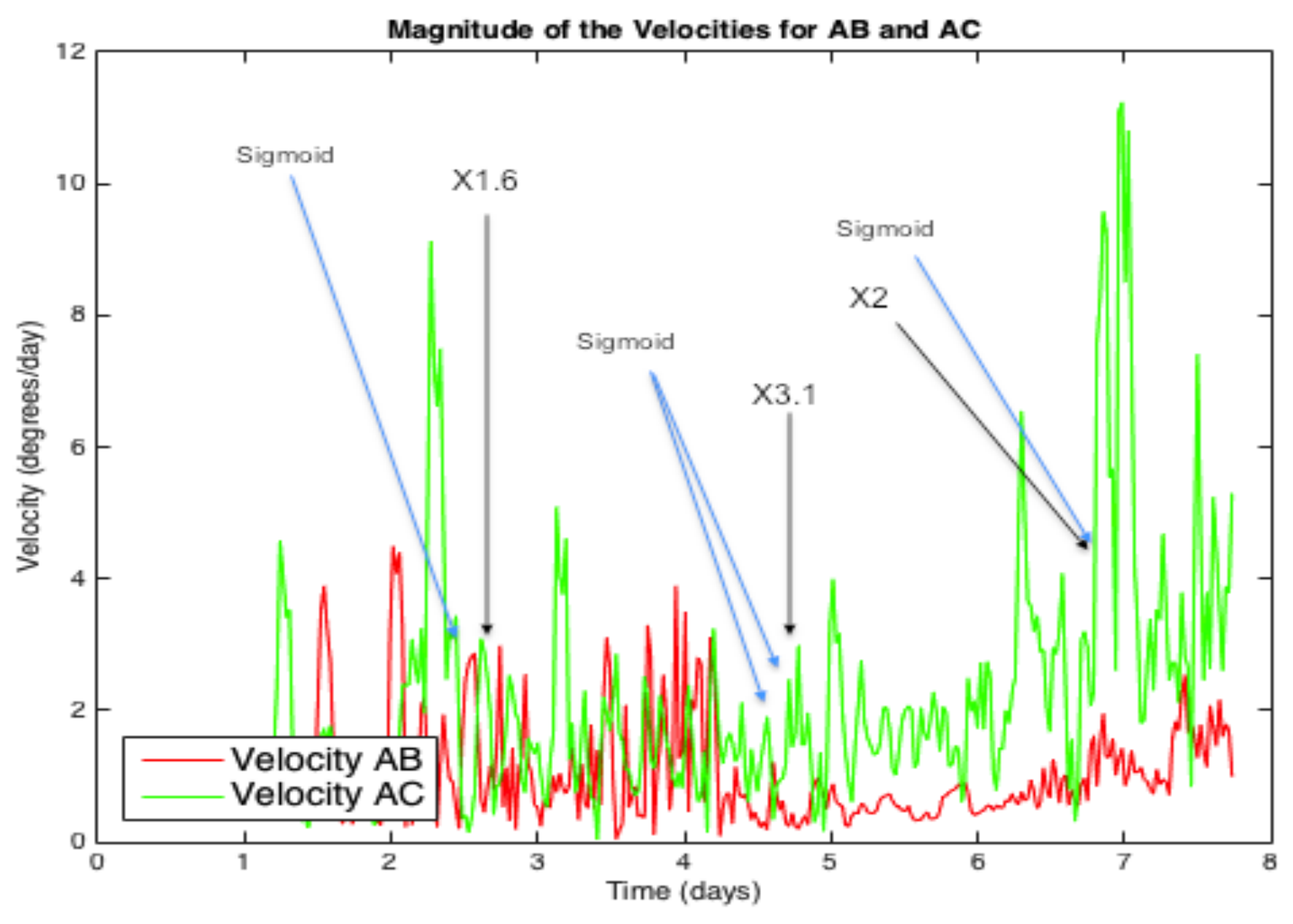
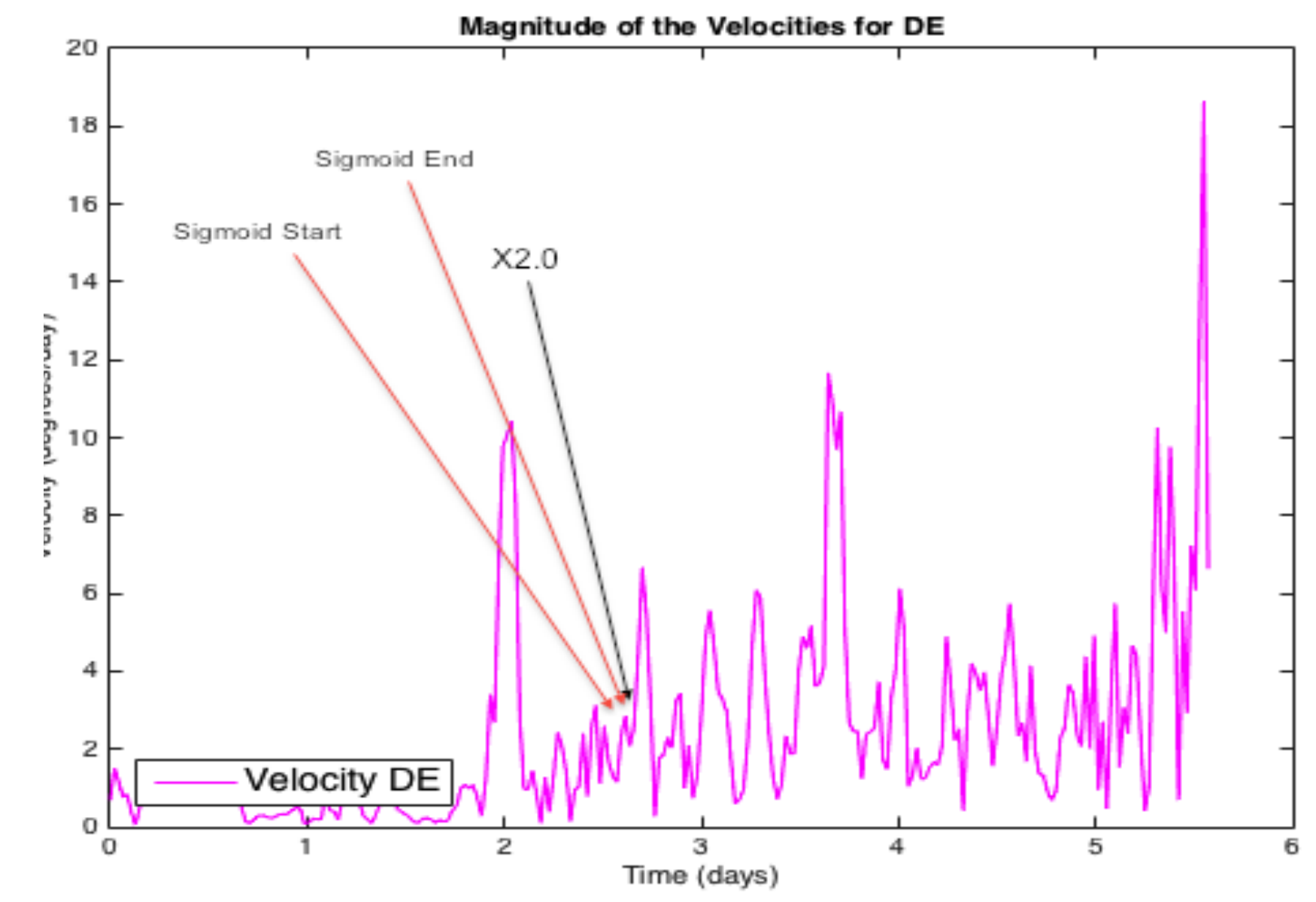


Figure 3 HMI Magnetograms. Images A-D show the changing magnetic field as the active region moves across the face of the sun between October 20, 2014 and October 26, 2014. Images E-H show the magnetic fields for November 7, 2014 through November 8, 2014. Images I-L show the magnetic fields for September 8, 2014 through September 11, 2014. Note: B) X1.6 flare peaks at 14:28:00 GMT C) X3.1 flare peaks at 21:41:00 GMT. D) X2 flare peaks at 10:56:00 GMT. G) X1.6 flare peaks at 17:25:58 GMT. K) X2.0 flare peaks at 17:45:00 GMT.



A



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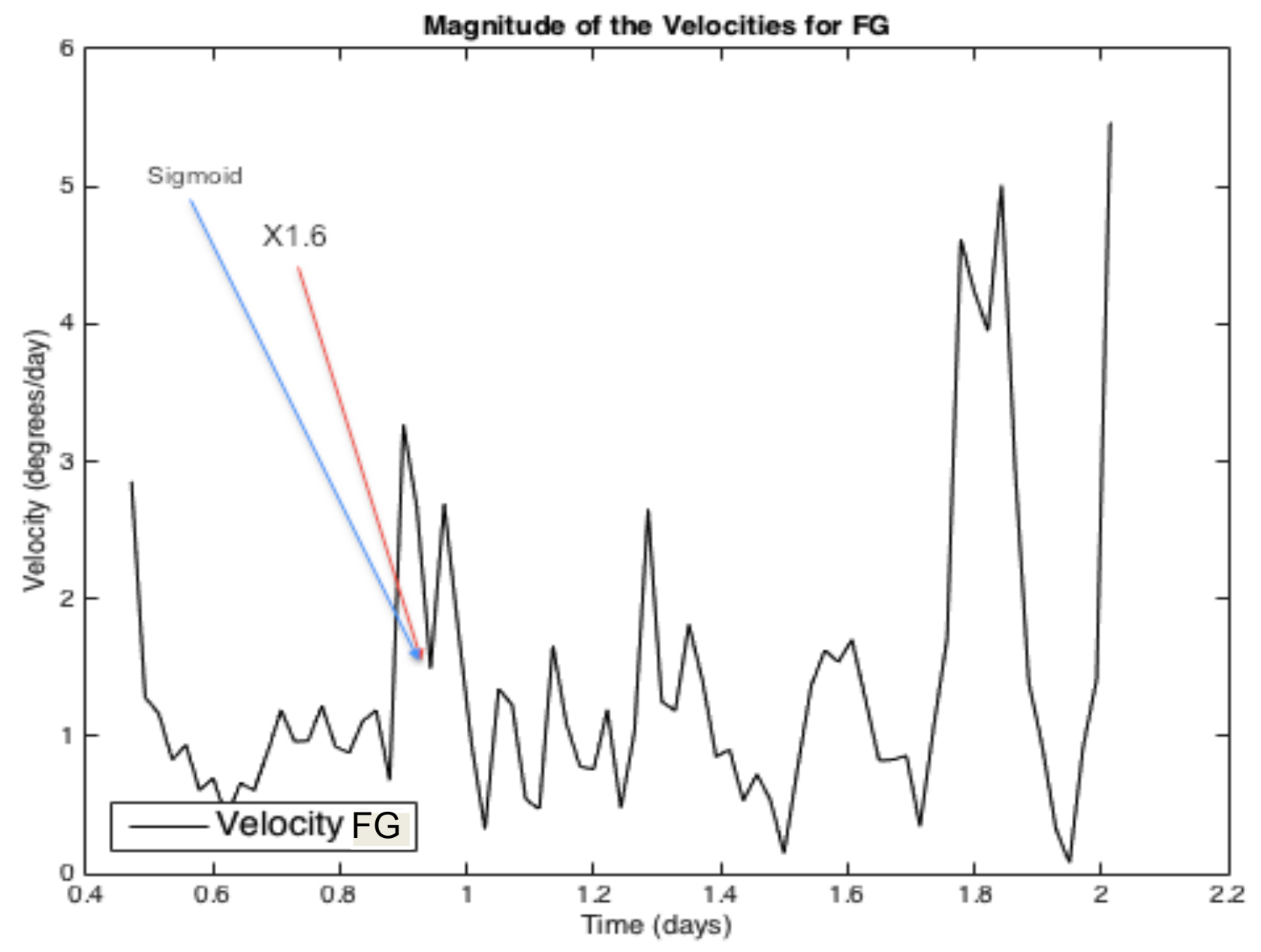

C

Figure 4 This graph represents the general direction in which each pair of polarity regions points. Each graph also highlights the approximate time each flare happened and whether or not a sigmoid eruption was related. A) Depicts two different polarity regions in the October active region. The negative polarity region is region A (a red color on the HMI data) while regions B and C are both negative in polarity. It can be seen in this same diagram that each flare event had a sigmoid preceding it by no more than 3 hours. The X2 flare had a sigmoid erupt during its peak at 11:00 GMT. B) This graph represents the time between September 8, 014 and September 11, 2014. Spot D was the negative polarity region while spot E was the positive polarity region. This flare was also preceded by a sigmoid that erupted at 17:38 GMT and the X2 flare experienced its peak at 17:45 GMT. C.) Region F was the negative polarity region and Region G was the positive polarity region. This region also experienced a sigmoid eruption at 17:12 GMT, just before the flare peaked at 17:25 GMT.

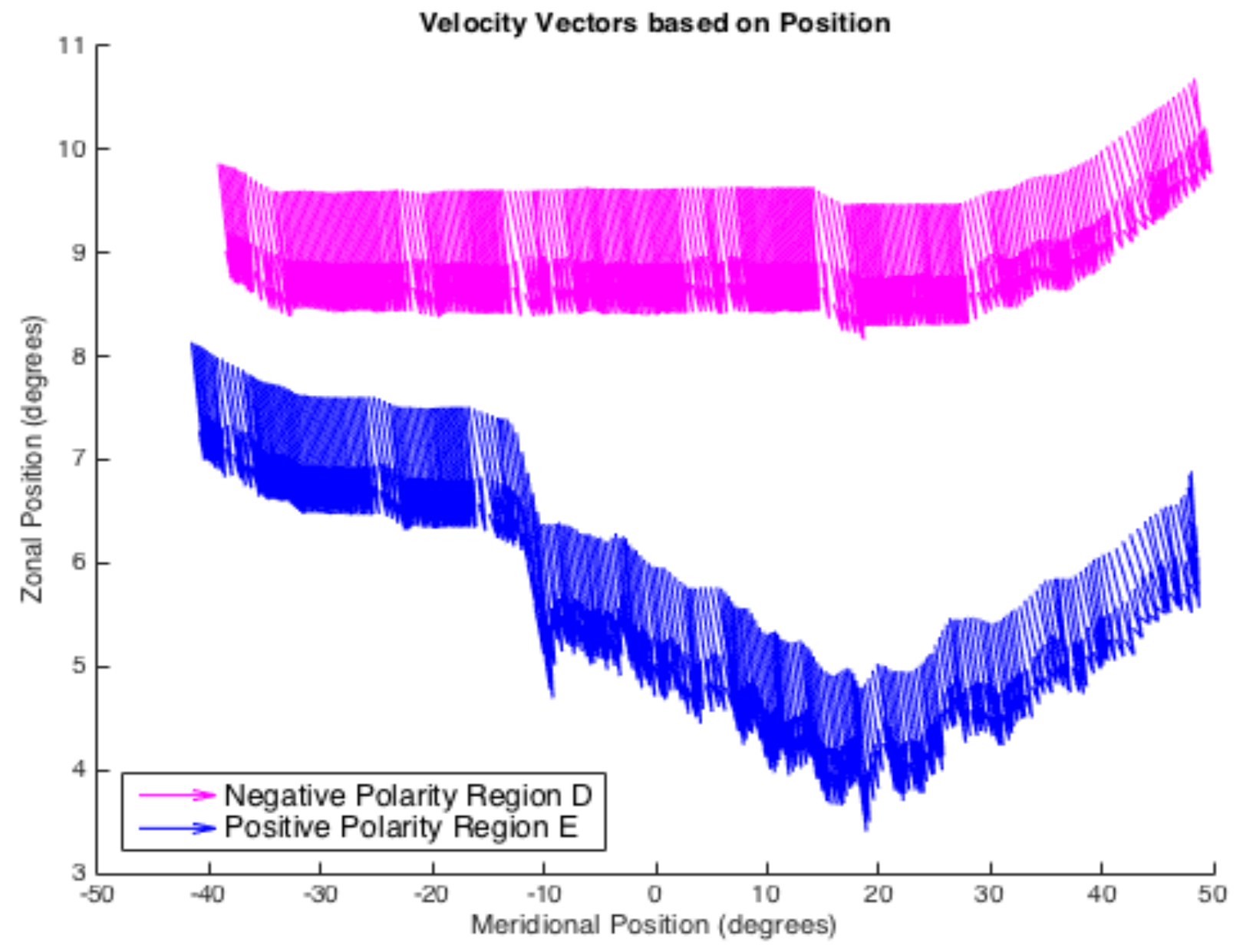

Figure 5

This figure shows the positions of the velocity vectors for regions D and E for each frame of the image time lapse. The positive polarity region is moving away from the negative region for ~2.5 days before moving at the same rate in the same direction as the negative region. Two days into the data is also when the eruption happens.

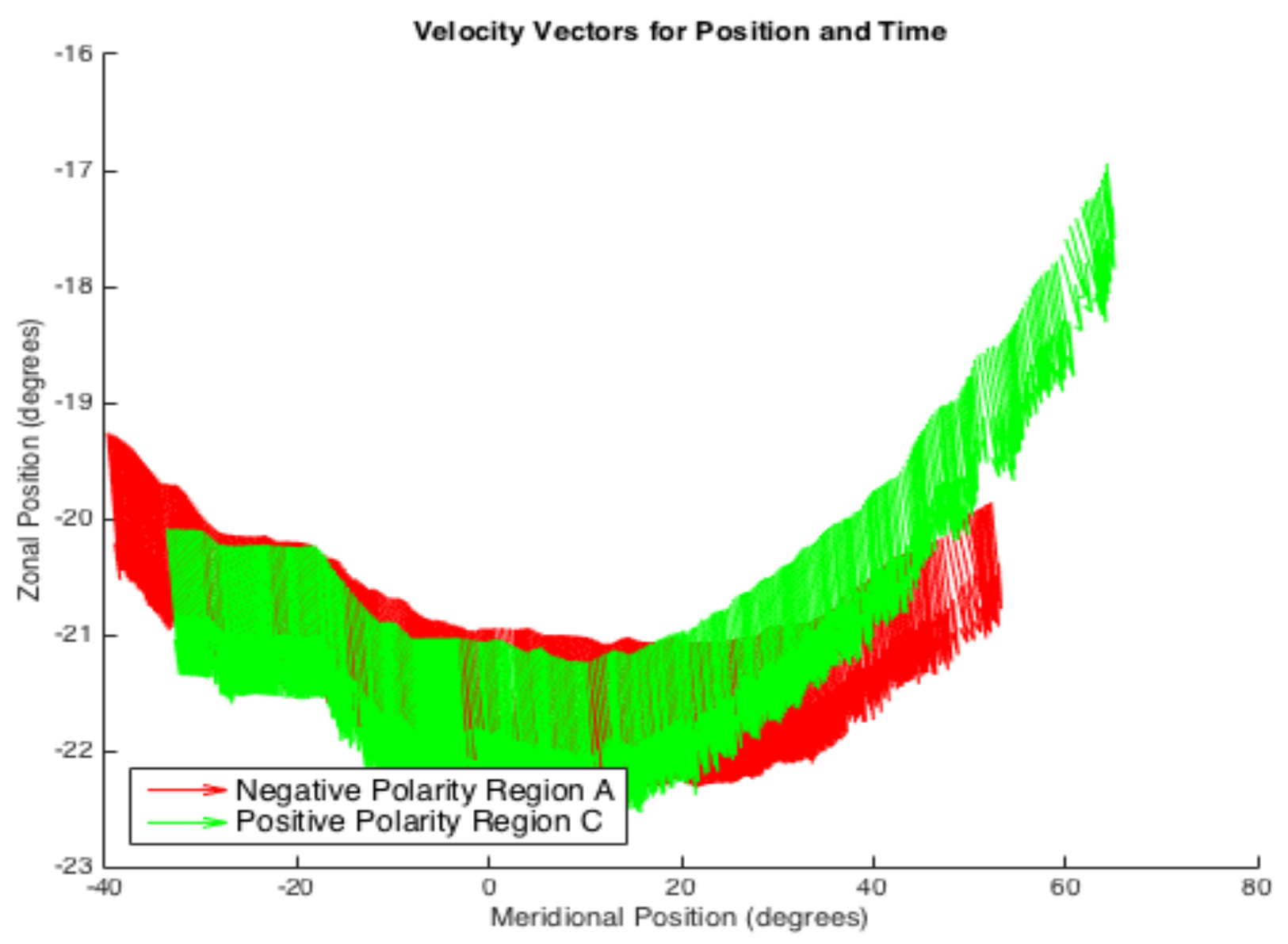

Figure 6

This figure depicts the same situation as Figure 5, but for the October active region. The C region (positive polarity) has a drastic change in position with respect to the A region, even though it's velocity vectors begin to decrease in magnitude towards the end of the time frame.

Conclusion

The movement of the plasma on the photosphere is linked tied heavily to the changing magnetic field lines of the sun and the convection currents within the sun. These forces make it hard to correlate the movement of many of the features on the sun to a specific cause. However, the belief that the separation distance between the polarities relates to the formation of solar sigmoids in active regions on the sun can be further supported with this evidence. Figures 5 and 6 support the separation claim while Figure 4 draws clear distinctions between sigmoids and eruptive events. The peak of each X class flare in these three regions was preceded by a sigmoid, and three of the five showed sigmoid eruption during said flare peak. It is evident that the polarity regions of these active regions do move relative to one another, which leads me to believe that sigmoidal eruptions are directly related to flare events. One inconclusive result of this data is whether or not shearing along the polarity inversion line is a direct cause of these large eruptions..

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