A Search for Large-Scale Photospheric Flows as Drivers of Mass Ejections

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Abstract. Previous observations of Keil et al. (1993) have suggested that photospheric longitudinal and surface flows play a major role in the dynamics of energy build-up locally in active regions (over several tens of arc seconds). In this paper, we present results from a test of our ability to track large-scale flows over a large enough area to include an entire active region. Observations were made at NSO/SP Vacuum Tower Telescope using a Tektronix (TiJ - 1024×1024) CCD camera with high spatial resolution and temporal sequencing. We plan to apply these techniques to many regions during the upcoming increase in solar activity, in an attempt to understand the relationship between surface flows and coronal mass ejections.

1. Motivation

Coronal mass ejections (CMEs) can cause geomagnetic disturbances and substorms. CMEs have been primarily identified from observations beyond the solar limb. We also know that some of the CMEs result from erupting prominences. Prominences are also observed as large filaments on the solar disc, as seen in Hα. Since prominences (or filaments) are believed to be structures supported by the magnetic field, it is natural to expect that these structures are magnetically tethered to the photosphere. As a result, conditions that lead to stable or eruptive CMEs must probably arise or at least be reflected in the photosphere. Energy drivers for CMEs probably originate at or below the photosphere.

We believe that the interaction between magnetic and velocity fields can provide the energy to produce CMEs. Since the plasma β (ratio of gas to magnetic pressure) is high in the photosphere, convective forces dominate over the magnetic field (Simon et al. 1988; Title et al. 1989; Title et al. 1992).

Photospheric surface flows are suspected to play a major role in energy

1Supported by Funding from the Air Force Office of Scientific Research

2Operated for the National Science Foundation by the Association of Universities for Research in Astronomy.
build-up leading to flares (see Keil et al. 1993; and references therein). The ultimate goal of this project is to test the hypothesis that photospheric surface velocities cause or reflect deeper lying conditions leading to mass ejections. We present preliminary results aimed towards that goal.

Since many prominence structures extend over large areas of the Sun, covering one or more active regions, it would be ideal to measure photospheric surface flows, Doppler velocities, the surface vector magnetic fields, and Hα intensities over a large FOV (7 – 10 arcminutes), and high enough spatial resolution to track the granular advected flows. However, making such a combination of observations is a challenge to future instrumental efforts. Here we present measurements of only the photospheric surface flows over a 7 arcminute square FOV, alongwith static data that includes Hα and Line-of-sight magnetograms obtained from other instruments.

2. Observations

The observations were made at the National Solar Observatory, Sacramento Peak Vacuum Tower Telescope, on 20 February 1995. A portion of the solar disc was directly imaged on to a Tektronix/TIJ 1024 × 1024 CCD camera. The spatial sampling was 0.41 arcsecond/pixel, and the field-of-view (FOV) was 7 × 7 arcminutes. Each image was exposed for 8 milliseconds, and the cadence (time between images) was 15.68 seconds, A total of 750 images were recorded in a time period of 3.2 hours.

3. Data Reduction

Each CCD image was corrected for dark current and flat-field distortions. The resulting white-light were then shifted to the nearest integral pixel in the two orthogonal directions corresponding to pixel rows and columns, to compensate for residual gross image motion beyond the capabilities of the telescope tracking. Fig. 1 shows a good high resolution white light image. A destretching algorithm was then applied to the tracked images, as described below.

November & Simon (1988) established that photospheric surface flows can be monitored by observing large-scale advection of convective flows using granules as tracers. Hence surface velocities can be deduced by following granular motions of successive images over long periods of time.

Measurement of the solar surface motion is distorted by the Earths atmospheric scintillation and turbulence (seeing). The image distortion due to atmospheric seeing is not spatially homogeneous, the seeing distortions are incoherently superposed on the solar surface motions. The image distortions due to seeing over the entire image can be broken down to image shifts over smaller portions of the image, each portion approximately representing about one-isoplanatic patch. For our observations, each sub-image was 4.9 × 4.9 arcseconds (12 × 12 box), separated by 3.3 × 3.3 arcseconds (8 × 8 box). The division of the images into sub-images for purposes of cross-correlation depends on the seeing quality of the data-set in question. Cross-correlation shifts measured between successive sub-images (for the same FOV) results in a curve that has two orthogonal components (one along a pixel row, and the other along a pixel col-
Figure 1. A high quality CCD image obtained at the NSO/SP Vacuum Tower Telescope on 20 February 1995. The field-of-view shown here is about $7 \times 7$ arcminutes. North is to the top, and East is to the Right. Notice the suppression of granular contrast around the sunspots, as well as the limb darkening as one moves from top right to bottom right, or bottom left to bottom right. This picture was exposed for 8 milliseconds.
Figure 2. Mean surface velocity vectors obtained during 3 hours. Small arrows represent the direction of the flows. The longest arrow length roughly corresponds to about 1 km s$^{-1}$. Grey scale image is same as in Fig 1.
Figure 3. Positions of test particles ("corks") representing the surface velocity obtained at the end of 3 hours. Grey scale image is same as in Fig 1.
Figure 4. Contours of convergence (black dotted) and divergence (black solid) derived from mean surface velocity. Grey scale image is longitudinal magnetic field from NSO/Kitt Peak. Thick white contours show trace positions of Hα filaments using a Big Bear Hα image.
umn). For each sub-image, the measured displacements have a high frequency temporal component that fluctuates over time scales of few seconds representing the seeing and a low-frequency temporal component that is due to slow solar surface flows. Seeing (high temporal frequency) is incoherently superposed on solar motions (low temporal frequency). We separate the two components of image motion by filtering the shifts, using high and low-pass filters. By removing the high frequency component of the displacements from the images (destretch) we can produce a time sequence that allows the advection of the granules to be observed. Using the low-frequency component of the displacements, we can trace the flow by allowing test particles ("corks") to follow the flow over time.

4. Preliminary Results

Fig. 2 shows the mean surface velocity vectors obtained by averaging all of the displacemenata over the 3.2 hour of observations. We find that a histogram of the velocity distribution peaks roughly at along 250 m s⁻¹. From Fig. 2 it is clear that surface flows is inhibited in very strong magnetic fields (sunspots). These results are in agreement with the Space-lab results of Title et al. (1989) Fig. 3 shows the positions of "corks" (test particles) at the end of the 3.2 hour run. Outside of sunspots the "corks" tend to converge near supergranular boundaries. From Fig. 3, we note that the corks clump at locations roughly separated by about 30000 km, although the clumping is not necessarily uniform over the FOV. We have also noticed that regions of convergence and divergence tend to occur near the end (but not center) of prominence structures, as seen in Fig. 4. During the increase in activity of this cycle, we plan to conduct these observations in a campaign mode for many active regions which have prominences and to determine the relation between the flow field and erupting prominences.

Acknowledgments. We thank all the staff at VTT for assistance with the data acquisition and observations. The use of NSO/KP magnetograms, as well as Big Bear Hα images (courtesy Dr. John Varsik) is gratefully acknowledged.

References