Determining the Instrumental Rotation Rate of MWO’s 60’ Tower Image Plane and Its Impact on Results from Ring-Diagram Analysis

S. F. Pinkerton, 1 E. J. Rhodes, Jr.,1,2 R. S. Bogart,3 M. Orr,1 G. Martin,1 and A. Spinella1

1Department of Physics and Astronomy, University of Southern California, Los Angeles, CA 90089, USA
2Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA
3Center for Space Science and Astrophysics, Stanford University, Stanford, CA 94305, USA

Abstract. Time series of full-disk Dopplergrams were acquired at the 60-Foot Solar tower of the Mount Wilson Observatory every year between 1987 and 2009. The 60-Foot Tower was designed by George Ellery Hale to provide an image plane that did not rotate throughout each observing day. However, preliminary analyses of a portion of this archive, carried out in 2007, suggested that the focal plane of the Tower might actually be rotating slowly. If confirmed, such an instrumental rotation would suggest that the alignment of the optics has changed slightly over the years since 1907. This possible rotation of the image plane was uncovered through the computation of subsurface flow maps using the ring-diagram method of local helioseismology. Some of the initial MWO flow maps appeared to show evidence for a so-called “washing machine” effect similar to the pattern that was seen in the initial GONG flow maps. We have been working to confirm the early estimates of the focal plane rotation. The purpose of this paper is to report on the status of this endeavor as well as explore the ramifications of a rotating image plane on our anticipated meridional and zonal flow results.

1. Introduction

During Solar Cycle 23 (1996 – 2008), the most publicized local helioseismic data was gathered using the Michelson Doppler Image (MDI) on board Solar and Heliospheric Observatory (SoHO) and the Global Oscillation Network Group (GONG, later GONG+). There is also wealth of high-resolution, ground-based information taken from the 60’ Tower at the Mount Wilson Observatory (MWO) during Solar Cycles 22 and 23 that has yet to be fully analyzed by the helioseismology community. Observations were obtained on a total of 4624 days during the 23 annual observing campaigns, of which 3643 days were found to be usable. One of the main hurdles to overcome before these observations can be fully exploited is the study of a possible daily rotation of the focal plane of the Tower. It is the purpose of this project to resolve this image-plane rotation question in order to properly analyze the archived data from the MWO observing campaigns during Solar Cycles 22 and 23.
2. Methodology

The method we use to analyze the MWO data is ring-diagram analysis (Hill 1988). Pairs of images of the Sun were taken at a cadence of one pair per minute for up to 11 and 2/3 hours per day (resulting in up to 700 pairs per day) using either a 1024 × 1024 pixel CCD camera or a 512 × 512 Panasonic video-rate camera fed by either a Sodium or a Potassium Magneto-Optical Filter. The Dopplergrams that were produced in this manner are archived at Stanford where we have employed a modified MDI/HMI ring-diagram pipeline to generate and fit the power spectra, as outlined in Haber et al. (1998). The inversions are then done using the OLA technique to produce zonal and meridional flow profiles.

Previous USC graduate student Thad Szabo began work in 2007 to quantify the magnitude of the rotation of the image plane at the 60-Foot Solar Tower. With the help of Leonid Didkovsky, he developed an auto-correlation technique which revealed a rotation rate of approximately 0.018 deg/hr. A second method in which pairs of simultaneously-observed MWO and MDI Dopplergrams were cross-correlated to find the rotational offset for each Dopplergram pair revealed a 0.0117 deg/hr rotation rate of the MWO image plane relative to that of MDI. Rick Bogart then made a modification to the program that he had developed to track MDI images so that this tracking program could remove the effects of an assumed instrumental rotation rate. Because of this modification, we are now able to explore the effects of such an image plane rotation so that we may eventually correct our resulting flow vectors for it.

3. Effects on Zonal and Meridional Flows

Inspection of the preliminary inversion results obtained with the 0.0117 deg/hr rotation correction rate suggested that we needed to explore a wider range of rotation correction values as input to the new tracking program. In order to better estimate the size of this effect, we have been tracking Dopplergrams and then fitting and inverting flow maps using the following five assumed image plane rotation rates: 0.000, 0.004, 0.008, 0.012, and 0.016 deg/hr. Figure 1 shows the zonal (Upper Panel) and meridional (Lower Panel) components of the subsurface flows for all five of these assumed rotation rates at latitude 30° North averaged over Carrington Rotation (CR) 1949 (May 1 – 27, 1999).

The zonal flow is significantly affected by the choice of rotation correction, as can be seen by the separation of the curves in the northern hemisphere as depth increases (Figure 1, Upper panel). This separation, where a higher rotation correction results in a more positive flow, is mirrored for zonal flows in the southern hemisphere. The meridional flow is relatively unaffected by the image plane rotation rate compared with the zonal flow; however, small residual differences are present between the different image plane rotation rates. The relative independence of the meridional flows on the image plane rotation gives us confidence that our estimates of the meridional flows will be robust.

3.1. Differences in Zonal and Meridional Flows between Hemispheres

Since an image plane rotation influences the zonal flows in opposite directions in the northern and southern hemispheres, such an instrumental rotation will introduce a difference in the magnitude of the zonal flows in the two hemispheres. We define the “spread” to be the difference in magnitudes between the northern and southern hemi-
Figure 1. Subsurface flow speeds from inversions of MWO data plotted as functions of solar radii at latitude 30° North during Carrington Rotation 1949. The tracking of the MWO data was corrected using five possible focal plane rotation rates: 0.000, 0.004, 0.008, 0.012, and 0.016 deg/hr. (Upper Panel) The zonal component of the flow shows a significant dependence on the chosen rotation correction. (Lower Panel) The meridional component does not show any such dependence.
Figure 2. Plots of the differences in the zonal flow component between the northern and southern hemispheres at latitude ±30° as a function of time. (Upper Panel) Scatter plot of MWO (pluses), MDI (crosses) and GONG+ (circles) data. Lower Panel) Plot of the spread for MDI (top curve, right axis) and GONG+ (bottom curve, left axis) during years 2001 – 2009. Note there is a 20 m/s vertical offset between the two curves.
Figure 3. Plots of the differences in the meridional flow component between the northern and southern hemispheres at ±30° as a function of time. (Upper Panel) Scatter plot of MWO (pluses), MDI (crosses) and GONG+ (circles) data. Unlike the zonal flows, the meridional flows do not depend systematically on the image plane rotation. (Lower Panel) Plot of the spread for MDI (top curve, right axis) and GONG+ (bottom curve, left axis) during years 2001 – 2009. A clear oscillation pattern is visible in the GONG+ data. Note the 20 m/s vertical offset between the two curves.
spheres for both flow components. As shown in Figure 2 (Upper panel), the MWO zonal spread strongly depends on the assumed instrumental rotation rate (pluses).

The MDI (crosses) and GONG+ (circles) zonal spreads reveal a relatively small difference in their northern and southern flows. Additionally, it is apparent that for small, non-negative values of the rotation correction, the MWO zonal spread is also nearly zero. On closer inspection of the MDI and GONG+ data shown in the right panel of Figure 2, we can see that both MDI and GONG+ have predominantly negative spread values meaning that the southern hemisphere had the marginally larger zonal flows for most of this time period.

As expected from the previous Section, and as seen in Figure 3 (Upper panel), the meridional flow component does not vary in a systematic manner with respect to the image plane rotation. Nevertheless, the figure suggests we are estimating a consistently stronger poleward flows in the northern hemisphere than the southern.

In the GONG+ plot of Figure 3 (Lower panel), there is a clear annual periodicity to the magnitude of the spread. This suggests that the GONG instrument observes the meridional flows to be stronger in the northern hemisphere in the summer and weaker in the winter. Additionally, there is a steady decline in the value of the spread from 2001 to 2009, which could be consistent with decreasing levels of solar activity. Despite being very prevalent in the GONG+ data, neither of these traits are seen in the MDI data from the corresponding time frame. This may be due to the ground-based nature of the GONG+ project, in which case we would expect to see similar patterns in the MWO data.

4. Conclusions and Future Work

Based on the results of this study thus far, it is becoming more apparent that the meridional flow does not depend heavily on the tiny image rotation rate that the 60’ Tower may be experiencing; however, the zonal flow is very dependent on the choice of rotation correction. Of the rotation corrections we have analyzed thus far, it appears that the 0.004 deg/hr rotation correction rate gives results closer to both GONG+ and MDI. Additionally, we can expect to see modulation in the MWO data due to the fact that it is a ground-based instrument, analogous to what is shown in the GONG+ data in the right panel of Figure 3. Future work along this vein will be done using additional MWO data sets from other years.

References