LOOKING FOR NON LOCAL FEATURES IN HORIZONTAL VELOCITY FLOWS

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ABSTRACT

The tridimensional maps of horizontal velocity flows obtained with ring diagrams analysis techniques show several common features at given depths for different horizontal positions. This could be interpreted as global, rather than local features. Tests have been performed in order to find large scale horizontal velocity flows under the solar surface. The procedure, based in a tridimensional analysis of solar oscillations (ring diagrams), has been applied to a section of the solar disk of about 45 degrees in latitude and longitude around solar disk center. The images used in this work correspond to a three days set of 1024x1024 pixel Doppler images obtained at Mt. Wilson in July 3, 4, 5, 1988 using the Magneto-Optical Filter. By using large scale sections of the solar disk, it is possible to expect an averaging or filtering effect of the local features of the results (horizontal velocity flows), raising the information about more global features.

Keywords: Sun, Oscillations, Velocity Flows.

1. INTRODUCTION

The analysis of 3-dimensional power spectra of the solar oscillations has proved to be an efficient tool to provide information about the spatial distribution of the horizontal velocity flows under the solar surface. For high-degree modes (l ≥ 190), a local plane wave approach for the decomposition of the modes is more appropriate than the usual spherical harmonics decomposition. By doing this, information about the two components of the horizontal wavenumber k can be obtained, and a 3-dimensional power spectrum in k_x, k_y and ω is constructed. Cuts at constant frequency of the distribution of power appear as individual rings for every radial order n; this is why the technique is known as a ring diagram analysis. A good description of this technique can be found in Hill (1988, 1994).

Ring diagrams have been obtained locally for 9 sections of the solar disk of about 15° square (Patróñ et al. 1994a, 1995, and Patróñ 1994b) around disk center giving a tridimensional view of the horizontal velocity flows. These results show that the velocity flows are oriented in the same direction for different positions in the solar disk at given depths (Figure 1). This suggests that we are perhaps looking at global features instead of local. In order to test this assumption we have applied the ring diagram analysis to a macro-image of 45° square corresponding to the same 9 previous sections all together, and we have tried to see if the behavior is similar for these given depths of common orientation of the velocity vectors.

2. DATA AND REDUCTION

The images used in this work are a set of three days, 3-5 July 1988, of 1024x1024 Dopplergrams in the Na D line, obtained every minute with the 60-Foot Tower and the Magneto-Optical Filter at Mt. Wilson Observatory. The spatial sampling at disk center is of 2.2°. The acquisition and calibration of the velocity images have been described in Rhodes, Cacciani, and Korzennik (1990).

Descriptions of the reduction process can be found in Patróñ et al. (1994a, 1995), and Patróñ (1994b). The construction of the power spectra starts with the remapping of the image onto an equally-spaced latitude-longitude grid, where the resolution is of Δl = 0.11°. Next, we select the section of study, being one of about 45° around disk center, with a total of 405x405 pixels. This section is tracked in time at solar rotation rate evaluated at the center of the section. After the subtraction of a 21-point running mean to temporally filtering the images, an FFT in three dimensions, latitude, longitude and time, is performed. The final power spectra has a k resolution of Δk = 0.0116 Mm⁻¹ and the ω resolution is Δω = 3.07 × 10⁻⁵ sec⁻¹, or Δν = 4.8225 μHz.

The estimation of the two components of the velocity, U_x and U_y is the result of the fitting of a Lorentzian profile to the variation of the power with frequency (see Anderson et al. 1990), where an effective Doppler shift of the unperturbed frequency is included: Δω = k_x U_x + k_y U_y.

In the practice U_x and U_y are fitted for every frequency and every radial order or ring. These data is then inverted using a least-squares with second derivative smoothing method, and finally the depth dependence of the velocity components is obtained for a depth range of about 60 Mm bellow the solar surface.

The results have been compared to the ones obtained for the nine subasters sampling the same region that the one sampled in this work. In order to make a
comparison we performed an average of the results for the 9 subrasters in $U_x$ and $U_y$. From now on we will refer as the macro-image results the ones obtained with the 405×405 pixels image, and as the averaged results the average of the nine subrasters.

3. RESULTS

Figure 1 shows the velocities of the nine subrasters of the previous work for 4 different depths: solar surface, 700 Km, 20 Mm, and 60 Mm of depth. In the three first plots we can see how there is a general common orientation of the flows, first to the West, then to the East, and back to the West. The gray vector in the center is the average of the nine subrasters, and the most clear one is the result from the macro-image. The following table shows a comparison between the amplitude of the vectors for the average and the macro-image results:

<table>
<thead>
<tr>
<th>Depth (Mm)</th>
<th>Velocity Amplitude (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.975</td>
<td>374</td>
</tr>
<tr>
<td>0.717</td>
<td>185</td>
</tr>
<tr>
<td>20.143</td>
<td>166</td>
</tr>
</tbody>
</table>

A comparison between the results for the two components of the vectors for the average and the macro-image is showed in Figure 2. The general behavior is similar in the upper layers, until about 20 Mm of depth. But the amplitude of the values is different, being higher, in general, for the average results.

Finally, in Figure 3, the depth variation of the flows, from both results (averaged and macro-image) is showed. The lines follow the arrow head of the vectors as they change with depth. The gray scale give the depth information. Again the general behavior is similar from the solar surface to about 20 Mm of depth.

4. CONCLUSIONS AND FURTHER WORK

In this test, we see that a local analysis technique (ring diagrams) seems to work very good for sections that are not local, but quite global (about 45°×45°). This tells us that the technique can be used for a wide range of sizes for the images in consideration.

The interpretation of the results showed in Figures 2 and 3 is not easy. We can see that the results from the average of the nine subrasters and from the macro-image are similar. From the average results, we cannot infer a global behavior for the whole
spatial extension; as an example, there can be some depths where we can find a large velocity flow from the average, just because there is a subraster with a large flow in that orientation. But it is not easy to say the same about the macro-image results. Probably, only the horizontal velocity flows that really affect the whole spatial extension of the macro-image, will be detected by the ring diagram technique. One possible evidence of this could be the fact that the amplitudes for the velocities obtained for the macro-image test are normally lower than the ones given by the averaging test at the same depth: not all the large flows that we see from the average results can be interpreted as global results.

What happen at the depths where most of the vectors point in the same direction? At these depths, showed at Figure 1 (solar surface, and 700 km and 20 Mm of depth), the 'global flows' in Figure 3 have relatively large amplitudes (look at the previous table), between 100 m/s and 200 m/s for the macro-image results.

If the correct interpretation of the results is that the flows present three shear layers of about 300 m/s to the West, 80 m/s to the East, and 150 m/s to the West, respectively, at depths of 0.975 Mm, 0.717 Mm and 20.143 Mm, then we have to assume that the material under the solar surface is moving in flows parallel to the equator, alternating the orientation a couple of times as we go deeper into the Sun. This results, coupled with the results obtained in a previous work (Patrón et al. 1994a, 1995) where the material is shown to be moving in convective rolls parallel to the equator in a toroidal way, give us an interpretation that we should study very carefully.
Since these results are just preliminary for these kind of tests, it is necessary to work a little further on it before assuming this interpretation. Many tests have to be performed and more data sets, taken in different epochs, should be analyzed in the same way to try to verify these results. Specifically, we should try to experiment with new sets of trade-off parameters in the inversion process, because we have used the same set in all the tests performed, and it is possible that one set of parameters that is adequate for the 9 subrasters results is not adequate for the macro-image due to the different size.

REFERENCES


