A SEARCH FOR PHOTOSPHERIC SOURCES OF CORONAL LONGITUDINAL OSCILLATIONS

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ABSTRACT

It has recently been shown that longitudinal intensity fluctuations observed in TRACE 171Å loops come in what appear to be two separate populations. These populations are differentiated by their period, and are clustered distinctly around 3 and 5 minute periods. The 3 minute fluctuations appear to be rooted in sunspots, whereas the 5 minute sunspots are not.

This study presents two test cases in the search for a photospheric source to these oscillations. A wavelet analysis is presented in the search for a fluctuating magnetic component since previous studies show that a magnetic fluctuation may be intermittent. A Fourier analysis is used to look in the intensity and Doppler regions of the same area of interest. Some comments are made on the photosphere in relation to the search for the driver of the as yet unobserved driver of longitudinal coronal oscillations.

Key words: \texttt{\LaTeX}; ESA; macros.

1. INTRODUCTION

The ”zoo” of observed coronal phenomena has recently expanded to include several new species of oscillation, each of which holds the promise of allowing us to probe the corona in new ways. At time of writing much effort is being expended in matching theoretical descriptions to these oscillations which allows the community to derive previously difficult to obtain parameters, such as the coronal Reynolds number (Nakariakov et al. 1998), the coronal magnetic field (Nakariakov and Ofman, 2001). These papers use observed transverse coronal loop oscillations (as observed in the TRACE 171Å waveband) and the vast body of theoretical literature on oscillating flux tubes to derive the above mentioned parameters. This species of oscillation appears to be observed nearby flaring events generate an impulse which impacts on coronal loops, causing them to oscillate. In this case, both the cause and effect appear to be connected in an intuitively easy to understand way, even if the actual details of the impulse-loop interaction are not well understood at present (Schrijver and Brown, 2000). For further details of these oscillations the interested reader is referred to Schrijver, Aschwanden and Title (2002) and Aschwanden et al. (2002).

Longitudinal loop oscillations have also been observed in the corona in both the TRACE 171Å and 195Å wavebands (Robbrecht et al. 2001). The oscillations are detected more often in TRACE 171Å than in the 195Å waveband. The TRACE 171Å oscillations are spotted in long, apparently open loops in quiescent active regions (the other footprint of such loops has not been observed so the loop is long, at the very least). There appear to be two different populations of such loops (De Moortel et. al 2002) distinguished by the period of the oscillation that the loop supports. The periods are clustered around 3 and 5 minutes. This is interesting as 3 and 5 periods are commonly observed lower down in the solar atmosphere below the transition region. There is significant acoustic power in the 5 minute waveband at the photosphere; however, the acoustic cutoff frequency when these oscillations propagate upwards is 3 minutes (Beckers and Schultz, 1972; Scheuer and Thomas, 1981; Hollweg and Roberts, 1981) and so 5 minute acoustic power should not be seen higher up in the atmosphere.

Two other basic facts are known at present. Firstly, the 3 and 5 minute populations appear to be rooted in different parts of the photosphere. The 3 minute populations appear to be rooted in sunspot umbrae, whereas the 5 minute oscillations are not. Secondly, there appears to be no significant, observable coro-
Table 1. Dates, active region numbers and observation times of 3 and 5 minute oscillations as seen by De Moortel et al (2002). All the 3 minute oscillations are found on coronal loops that are thought to lie above sunspots. More complete details regarding the oscillations may be found in De Moortel et al (2002).

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>AR number</th>
<th>No. of 3(5) min oscillations</th>
</tr>
</thead>
<tbody>
<tr>
<td>07/06/01</td>
<td>0836-1314</td>
<td>9484</td>
<td>2(4)</td>
</tr>
<tr>
<td>13/06/01</td>
<td>0138-1300</td>
<td>9493</td>
<td>2(3)</td>
</tr>
</tbody>
</table>

3. ANALYSIS

In this paper we concentrate on looking for significant and consistent oscillatory phenomena at the photosphere. The tools we use are wavelet analysis for the longitudinal magnetic field and fast Fourier transform for the Doppler velocity and intensity data. The difference in tool is intended to reflect the nature of each dataset. Fluctuations in longitudinal magnetic field have long been observed (for example, Gurman and House, 1981; Riedi et al., 1998;) but their ultimate nature is still in question as there are many systematic and observational effects that can cause a fluctuation in the data without it having necessarily been caused by a magnetic oscillation. For instance, Settele et al (2002) show that the way MDI creates its line profiles leads to the generation of spurious magnetic oscillatory signals.

The literature (Bellet Rubio et al. 2000; Lites et al. 1998) shows that if magnetic oscillations are present then they are of a low amplitude and are spatially and temporally intermittent. Such time series data is well handled by a wavelet analysis. On the other hand, oscillations in Doppler velocity and line intensity are ubiquitous in the photosphere and so a Fourier analysis is sufficient to highlight any significant areas of interest. The details of each analysis are presented below.

2. THE DATA

The data analysed here forms part of JOP144, a Joint Observing Program involving SOHO-MDI (Scherrer et al., 1995), SOHO-CDS (Harrison et al., 1995), TRACE (Handy et al., 1999) and the Magneto-Optical Filter (MOF) at the Kanzelhöhe Solar Observatory in Austria. This JOP is designed to look for the source of longitudinal coronal oscillations. The MDI data forms an important part of this JOP as it is here we have the capability to look on fine lengthscales at longitudinal magnetic field and line of sight (Doppler) velocity of the photosphere. Note that the MDI cadence of one minute gives a high enough Nyquist frequency that the 3 and 5 minute oscillations are observable.

JOP 144 was run from 5-13 June 2001 involving all 4 of the instruments above. Not all the target active regions in JOP 144 supported longitudinal coronal oscillations in the TRACE 171Å waveband. De Moortel et al. (2002) provide a list of active regions in which oscillations are noted, and it is these oscillations we concentrate on in this paper. The days 7 and 13 June 2003 are taken from the De Moortel et al. (2002) list are chosen as they a) have sufficient SOHO-MDI data associated with them to make further study worthwhile b) contain examples of both 3 and 5 minute oscillations and c) demonstrate the qualities of both the MDI hi-resolution and full disk data in regard to this type of study.

3.1. Magnetic field

The data cube for each example is self-aligned using standard Solarsoft routines to sub-pixel accuracy. The wavelet transform for the timeseries arising from each pixel is calculated and then sieved for packets of significant wavelet power. Wavelet power in wavebands 2 mHz wide (full width) centred on the relevant frequencies (3.3 and 5.6 mHz) is summed in the frequency direction to form a slice in the data at the period of interest. A wavelet packet is called significant if i) the packets are above the 99% confidence level and inside the cone of influence and ii) the wavelet packet lasts at least 2 wavelet scales. A typical map of the results of such an analysis is shown in Figure 2. The map shows the number of wavelet scales at each pixel meeting the criteria above.

3.2. Doppler velocity and intensity data

The Doppler velocity data-cube is self-aligned using standard Solarsoft routines to sub-pixel accuracy. At each pixel, the time series is formed and a running mean subtracted, removing the rotation of the Sun. A fast Fourier power spectrum is calculated for each time series. Maps of spectral power in the same wavebands as noted in section 3.2 are calculated. A typical map of Doppler velocity is shown in figure 5. Intensity data is treated in a similar way. The time series which is to be transformed is formed...
from \((I - I)/I\), where \(I\) is a running mean. A typical map of intensity fast Fourier transform power from time series from this analysis is shown in Figure 8.

4. RESULTS

4.1. 7 June 2001

Figures 1 - 6 describe the results of the 7 June 2001 sunspot analysis. This data is MDI full disk data (1 pixel = 2 x 2 arcsecond\(^2\)) and is somewhat far across the disk. The effect of this is clearly seen in Figure 1; the westernmost portion of the sunspot shows a bright halo, indicating that the projection effect of having a sunspot so far west is influencing the detected longitudinal field. Hence magnetic results from so far round the disk must be treated with a degree of caution. From Figures 2 and 3, there appear to be very few wavelet packets detectable in this data. This is certainly consistent with the literature on magnetic fluctuations (for example, Horn et al 1997; Norton et al 1999). There appears to be a slight depression in the number of wavelet packets found where the longitudinal field strength is high; but the overall impression is that wavelet packets are of short duration and are randomly distributed in the lower field regions. In addition, there appears to be nothing very special about the loop footpoints with regard to magnetic wavelet packets detected.

Similar effects are seen in the Doppler FFT power maps; higher field areas have lower powers in both wavebands and there is nothing striking about the loop footpoints in comparison with other parts of the field of view.

4.2. 13 June 2001

The results of analysing this sunspot are shown in Figures 7 - 15. This is MDI hi-res data (1 pixel = 0.605 x 0.605 arcsecond\(^2\)) and so is necessarily much closer to disk centre than the previous example. Figure 7 shows the sunspot and the coronal oscillation footpoint locations. Note that the 5 minute oscillation in the top right hand part of the image is associated with a magnetic structure which can be taken as being unconnected with the sunspot inside the smaller rectangular box. It is interesting to note that De Moortel et al. (2002) claim that there is 3 minute oscillation not rooted in a sunspot. The white horizontal lines in Figures 7 and 8 are due to cosmic ray hits being dragged across the field of view by the derotation algorithm. It is interesting to note the presence of a ring of brighter power at the umbra/penumbra boundary in both 3 and 5 minutes, also seen by Muglach (2003) in TRACE UV lines. It is also interesting to note that the Doppler velocity equivalent results in Figures 11 and 12 also exhibit enhanced power either close to or at the sunspot umbral/penumbral boundary.

The magnetic wavelet packet analysis is done over the entire field of view of Figure 13 (also Figures 7 and 10). Short duration 5 minute scale wave packets are found all over the field of view (Figure 14), with no noticeable preference for any given location in the data when compared to the intensity, Doppler and magnetic images (Figures 7, 10 and 13). The 3 minute wavelet scale packet map of Figure 15 is somewhat different, however. Although wavelet packets of short duration are found everywhere in the field of view there are areas where almost no wavelet packets are found. These areas are coincident with the locations of higher longitudinal field strength. This suggests that the fluctuations in these areas at the 3 minute scale have lower power than at the 5 minute scale, that is, there is a depression in the number of 3 minute wave packets when compared to the 5 minute scale. Also, the 3 and 5 minute oscillation footpoint locations appear to be in these higher field regions.

5. DISCUSSION

We have examined only a small portion of the number of footpoint locations provided by De Moortel et al., (2002) and so any conclusions reached in the paper regarding the source of these oscillations must remain qualified until more data is studied (such work is underway). It is somewhat frustrating to report that little consistent behaviour is seen between the two datasets with regard to the presence (or absence) of significant photospheric fluctuations that may be tied to the existence of coronal longitudinal oscillations. Stronger magnetic field appears to suppress fluctuations in all three variables (intensity, Doppler and longitudinal magnetic field) and in all wavebands studied. The lack of any suggestive and consistent results means one of two things: either the source of these coronal oscillations is not detectable by MDI or that the coronal longitudinal oscillations do not have a source in the MDI; instead, they are generated further up in the solar atmosphere. Oscillations are certainly detected higher up in the solar atmosphere. Maltby et al (1999) and Brynildsen et al. (1999) describe 3 minute transition region oscillations and Brynildsen et al. (2002) describe oscillations that are seen from the chromosphere upwards through to the low corona in TRACE 171Å. So certainly they exist at the chromosphere, but their source further down in the solar atmosphere, if present, is not demonstrated. Clearly more data needs to be analysed to obtain consistent information.

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Figure 1. An MDI longitudinal magnetogram image from 7 June 2001. The oblong box denotes the subregion where the wavelet analysis of the time series at each pixel is calculated. The sunspot umbra (penumbra) is denoted by the inner (outer) white contour. The white diamonds (squares) denote the footprint locations of the coronal 3(5) minute oscillations, as found by De Moortel et al. (2002).

Figure 2. 7 June 2001: number of magnetic wavelet packets in the 5 minute waveband.

Figure 3. 7 June 2001: number of magnetic wavelet packets in the 3 minute waveband.

Figure 4. 7 June 2001: an MDI Doppler image from 7 June 2001. The oblong box denotes the subregion where the fast Fourier transform of the time series at each pixel is calculated. The sunspot umbra (penumbra) is denoted by the inner (outer) white contour.

Figure 5. 7 June 2001: image of Doppler FFT \( \log_{10}(\text{power}) \) in the 5 minute waveband for the subregion shown in Figure 4.

Figure 6. 7 June 2001: image of Doppler FFT \( \log_{10}(\text{power}) \) in the 5 minute waveband for the subregion shown in Figure 4.
Figure 7. An MDI intensity image from 13 June 2001. The oblong box denotes the subregion where the fast Fourier transform of the time series at each pixel is calculated. The sunspot umbra (penumbra) is denoted by the inner (outer) white contour.

Figure 10. An MDI Doppler image from 13 June 2001. The oblong box denotes the subregion where the fast Fourier transform of the time series at each pixel is calculated. The sunspot umbra (penumbra) is denoted by the inner (outer) white contour.

Figure 8. 13 June 2001: Image of intensity FFT $\log_{10}(\text{power})$ in the 5 minute waveband for the subregion shown in Figure 4.

Figure 11. 13 June 2001: image of Doppler FFT $\log_{10}(\text{power})$ in the 5 minute waveband for the subregion shown in Figure 4.

Figure 9. 13 June 2001: image of intensity FFT $\log_{10}(\text{power})$ in the 5 minute waveband for the subregion shown in Figure 4.

Figure 12. 13 June 2001: image of Doppler FFT $\log_{10}(\text{power})$ in the 5 minute waveband for the subregion shown in Figure 4.
REFERENCES