Does the Selection of a Quiet Region Influence the Local Helioseismic Inferences?

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Abstract. We apply the ring-diagram technique to high resolution Dopplergrams in order to estimate the variation in oscillation mode parameters between active and quiet regions. We demonstrate that the difference in mode parameters between two quiet regions can be as large as those between a pair of active and quiet region. This leads us to conclude that the results derived on the basis of a single quiet region could be biased.

1. Introduction

In local helioseismic studies the oscillation mode parameters of an active region are often compared with those of a quiet region to estimate the influence of the magnetic field or differences in structure. There are various ways in which a quiet region can be selected: (i) a common quiet region for all the events analyzed (ii) a quiet region at the same heliographic longitude and latitude and within the same Carrington rotation, and (iii) an ensemble average of quiet regions. The first choice minimizes the differences that may arise from selection of different quiet regions but neglects the effect of temporal and spatial variations. The second choice has been used in several studies (e.g. Rajaguru, Basu, & Antia 2001) assuming that the differences in mode parameters between two quiet regions are small compared to a pair of active and quiet region. Here we investigate how the selection procedure affects the variations in inferred mode parameters.

2. Data and Methodology

To analyze the properties of the modes in quiet and active regions, we use the technique of ring diagrams (Hill 1988) where we analyze a time series of Dopplergrams. Each region of about $15^\circ \times 15^\circ$ in heliographic longitude and latitude is tracked with the mean surface rotation velocity for 1664 minutes giving a frequency resolution of about 10 $\mu$Hz. The three-dimensional power spectrum of the time series is fitted to obtain the mode parameters and flow velocities. More details of the procedure can be found in Corbard et al. (2003).

For this investigation, we have identified a total of 42 active regions during the period of September 2001 to December 2003 and use the high-resolution Global Oscillation Network Group (GONG+) Dopplergrams to obtain the mode parameters.
parameters. We also use Michelson Doppler Imager (MDI) magnetograms to calculate the Magnetic Activity Index (MAI) which is a measure of the strength of the strong field component of the associated magnetic field (see Rajaguru, Basu, & Antia 2001, for a detailed description). The MAI is calculated from the 96-minute magnetograms by integrating the unsigned, strong-field values within the selected regions and over the same time intervals used to track and calculate the power spectra.

3. Results and Discussions

To illustrate the variations in mode parameters between quiet regions, we select two quiet regions at the same latitude and within Carrington rotation 1998 corresponding to active region (AR) NOAA 10224 located at S22E25 on 2003 January 7 (MAI = 16.22 G). These regions (hereafter Q1 and Q2) are located at Carrington longitude 62.5° and 7.5° and have MAI values of 2.06 G and 2.08 G, respectively. Figure 1 shows the variations of different mode parameters. It is evident that the relative frequency differences (Figure 1a) are small and consistent with differences expected for low MAI regions. Figure 1b and 1c shows the amplitudes and line widths as a ratio between Q1 and Q2, respectively. A variation of about 20–30% is observed in both of the parameters which is not expected to be seen between two quiet regions having similar MAIs. This illustrates the intrinsic uncertainties associated with quiet regions and reveals the importance of selecting appropriate quiet regions for comparison studies.

To understand how the inferred mode properties of the AR can be affected by the choice of the quiet regions, we plot the same three parameters between AR with respect to Q1 and Q2 in Figure 2. Figure 2a depicts the relative frequency differences and we do not see significant changes between the two panels. Figure 2b shows the amplitude as a ratio between the AR and quiet regions and in general it is found that the power in the AR is suppressed compared to the quiet Sun. However, on a closer examination some differences are noticed. When the comparison is carried out with respect to Q1 (left panel) the maximum power
suppression occurs in the frequency range of about 3–3.5 mHz while the comparison with $Q_2$ (right panel) shows that the suppression decreases monotonically with frequency.

Figure 2: shows the ratio of line widths between the AR and quiet regions and indicates significant changes in widths both as a function of radial order and frequency. In general, we find that the line widths of AR are higher compared to the quiet regions. We also notice a few other subtle differences between the two panels, for example the right panel shows a 5–10% larger width compared to the left panel. This provides evidence that the changes in mode parameters of an active region can also be affected by the choice of the quiet regions.

In order to calculate an ensemble average of quiet regions which can then be used to compare the mode properties of all 42 active regions, we selected one quiet region at the disk center per Carrington rotation covered by the active regions. The MAI of these quiet regions varied between 0.387 G to 7.738 G. However, to minimize the effect due to intrinsic variations between different quiet regions, we averaged together the mode properties of those quiet regions that have a MAI less than 3 G. Only 22 quiet regions satisfied this criterion and the average mode parameters of these quiet regions are defined as the parameters of the control quiet region, $(Q)$ with an average MAI of 0.93 G. As a second choice, we select a quiet region at the disk center (QDC) on 2002 May 19 since this period roughly corresponds to the middle of the data sets; the region has a MAI of 2.78 G. In Figure 3, we compare the frequency-averaged line widths as a function of the MAI of ARs for these two different selection of quiet regions. The $f$ modes have been averaged over the frequency range of 2500–2750 µHz, $p_1$ and $p_2$ over the range of 3000–3500 µHz and $p_3$ over the range of 3250–3750 µHz. The left panel denotes the ratio with respect to the quiet region, QDC while the right
Figure 3. Frequency-averaged line widths as a function of the MAI of active regions. The left panel denotes the ratio with respect to QDC while the right panel shows the ratio with respect to the ensemble average ($Q$). The symbols have the same meaning as in Figure 2.

The behavior in line widths between the two panels are distinctly different. While the left panel shows smaller widths, the right panel shows higher widths except for widths associated with low MAIs. Therefore it is clear that the inferred properties of oscillation modes, specifically, the line widths, depend on the choice of the quiet region and can strongly influence the conclusions.

In summary, we find that the mode amplitudes and line widths between two quiet regions located within one Carrington rotation can show a large variation. Thus, we conclude that the choice of a single quiet region can mislead the interpretation and we propose that future studies involving comparison of mode properties between a pair of active and quiet region use an ensemble average of quiet regions as an optimum choice.

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