Amplitudes of High-Degree p-Modes in the Quiet and Active Sun

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Abstract. We investigate mode amplitudes in the active and quiet Sun in both maximum and minimum phases of the solar activity cycle. We confirm previous studies showing that p-mode amplitudes at solar minimum are higher than at solar maximum. We mask active regions of a certain magnetic field strength and compare the masked and unmasked acoustic power. After applying the masks, the preliminary analysis indicates that the amplitude decreases over all degrees during solar minimum, compared to the unmasked case, while at solar maximum the amplitude first decreases up to $\ell \sim 300$ and then increases at higher degrees.

1. Motivation

Both global and local analyses of intermediate- and high-degree modes indicate that the mode amplitudes and the solar activity level are anti-correlated (e.g. Chaplin et al. 2000) and strongly depend on the local magnetic flux (Rajaguru, Basu & Antia 2001; Howe et al. 2004). This work addresses the following questions: How different are the mode amplitudes in active and quiet sun at minimum and maximum of the solar activity cycle? Does the quiet sun have more acoustic power at solar minimum in comparison with solar maximum or vice versa? These questions are addressed by masking active regions above a certain magnetic field strength and by comparing the masked and unmasked acoustic power at minimum and maximum phases of the solar activity cycle.

2. Data Analysis

We analyzed the following data sets:

- 10-hr time series of Michelson Doppler Imager (MDI) Dopplergrams, one at solar minimum (May 24, 1996) and at solar maximum (September 9, 2000).

- Eleven 10-hr long Global Oscillation Network Group (GONG) Dopplergram time series around solar minimum (June 02-13, 2007) and solar maximum (December 03-14, 2001).
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Figure 1. From left to right: (i) An MDI magnetogram from Sept. 9, 2000; (ii) Smoothed unsigned magnetogram averaged over time; (iii) Masked magnetogram obtained from the smoothed image with a cut-off value of 20 G showing only the quiet regions; (iv) Mask of strong field regions.

- MDI full-disk magnetograms to identify active regions and create masks. An example of the mask used in this work is shown in Figure 1. The mask consists of zeros (black) in active regions and ones (white) otherwise.

We combine two analysis methods (i) the standard ring-diagram technique from the GONG pipeline (Corbard et al. 2003) where patches within 30° of disk center are analyzed, and (ii) the asymmetric-peak-profile fitting of the power spectrum ($\ell$-$\nu$ diagram) (Nigam & Kosovichev 1998). In this procedure, Dopplergrams are remapped, tracked, filtered with a 15 min running mean, and decomposed into Spherical Harmonic coefficients to construct an $\ell$-$\nu$ diagram. In this study, we restrict the analysis to $p_1$-$p_4$ ridges as a function of the mode degree $\ell$.

Figure 2. Amplitudes of $p_1$-$p_4$ modes as a function of the mode degree obtained from power spectrum analysis of 10-hr time series of GONG Dopplergrams, averaged over 11 days each in 2001 (solar maximum) and 2007 (solar minimum). The line styles are defined in the right bottom panel.
3. Results and Discussion

From power-spectrum and ring analysis applied to 10-hr MDI data sets, we observe that the amplitude of $p_1$-$p_4$ modes at solar minimum is lower than that at solar maximum up to $\ell \sim 300 - 400$, and higher for $\ell > 400$. The same trend is noticed when we apply the mask but the amplitudes decrease for all modes in comparison with the unmasked case. The analysis showed significant day-to-day variations. In order to minimize these systematic variations, we averaged the data over a period of 11 days each in 2001 and 2007.

In Figure 2, the averaged amplitudes of $p_1$-$p_4$ modes as a function of $\ell$ obtained from GONG in 2001 and 2007 are presented. The results confirm that the amplitude at solar minimum is higher than at solar maximum for the entire analyzed $\ell$-range. After masking the active regions, we observe that the amplitude at solar minimum decreases over all degrees, while at solar maximum the amplitude decreases up to $\ell \sim 300$ and increases at higher degrees.

In an attempt to understand the cause of the decrease in amplitude when the mask is applied, we excluded active regions by masking pixels with unsigned magnetic field above a certain threshold levels and reprocessed the Dopplergrams through the ring-diagram technique. The results in Figure 3 show that the mode amplitudes decrease with removal of flux; the mode amplitudes became smaller as more activity was removed. These results are consistent with those obtained from the masking of the active region and discussed above.
Figure 4. Amplitudes of $p_1$-$p_4$ modes as a function of the mode degree obtained from the power spectrum analysis of MDI data (Nov. 12, 2006). Here we construct circular artificial masks of different radius. The line styles are defined in the right top panel.

In order to understand the changes in amplitude, we performed a numerical simulation where we applied a circular artificial mask of three different radii to one day of MDI data (November 12, 2006). The results obtained from fitting of the power spectrum are shown in Figure 4. It appears that the variation in the amplitude could be due to the effect of the mask alone. We plan to extend this study with artificial masks of different sizes and locations on the solar disk. We further plan to carry out center-to-limb corrections of the line-of-sight velocity to understand its effect on the mode amplitudes.

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