In this project I investigate the relationship between solar oscillation frequencies and surface magnetic fields over the course of the last solar cycle. Using MDI and GONG data, I study the variation in the even frequency-splitting coefficients $a_k$ (describing solar asphericity and effects of the magnetic field), and the variation in the coefficients $B_k$ of the latitudinal Legendre decomposition of the surface magnetic field, during the period 1996 - 2010. I find a strong linear correlation between the $a_k$ and $B_k$ coefficients, during both the rising and declining phases of the solar cycle, consistent with results published in 2001 (Antia et al. [1]). I also investigated different ways to handle the magnetic field decomposition at the poles, and find that the linear correlation persists, though with varying intercepts. The variation of slope with coefficient index that I find is non-monotonic, which disagrees with the previous study by Antia et al..

Comparison with Magnetic Field

In a 2001 paper, Antia et al. [1] found a linear correlation between the $a_k$ coefficients and the coefficients $B_k$ for the latitudinal Legendre decomposition of the surface magnetic flux (over the rising phase of the solar cycle). Other research (Fig. 4) suggested that the relation might not hold over the declining phase.

Figure 4: Frequency changes of oscillations (black points) and measure of sunspot number (red line) over the last two solar cycles [4]. There is a deviation during the declining phase of the last cycle. Since the frequency shifts are affected by conditions beneath the surface, while sunspot number is a measure of the surface magnetic field, this indicates that there are processes going on in the interior that are not visible on the surface.

Magnetic Field Decomposition

For a perfectly spherically symmetric Sun, modes of the same $n$ and $l$, but different $m$, are degenerate in frequency. In actuality, there is a frequency splitting which can be expressed as a sum of orthogonal Legendre-like functions:

$$w_{nm} = \sum_{l=1}^{\infty} a_l(m) Y_l^m$$

The odd $a_l$-coefficients ($k = 1, 3, 5$...) reflect frequency differences due to rotation, while the even coefficients are due to equatorial bulging and the solar magnetic field.

Data

- SOHO spacecraft - Michelson Doppler Interferometer (MDI)
- Global Oscillation Network Group - 6 ground-based observation stations

Oscillation frequency data was collected over chunks of 72 days (SOHO) or 36 days (GONG) and analysed using Fourier methods to find the average frequency of each mode during that chunk of time.

Coefficient Correlation

Figure 7: $a_k$ coefficients plotted against $B_k$ coefficients for various values of $k$ for SOHO (black) and SOHO (red) data, showing a strong linear correlation with alternating signs of slope.

Figure 8: The linear relationship holds during both the rising and declining phases, with no particular preference for either phase.

Figure 9: The absolute value of the slope of the linear correlation for GONG data, plotted against index number $k$ (black points). Also shown are the slopes found by Antia et al. [1] (red). My results behave non-monotonically, unlike Antia's.

Figure 10: Two different ways of fitting the Legendre functions at the poles. The left method imitates Antia et al., while the right is the method I used to obtain my results (reasoning that the rise in flux near the poles is probably an artificial effect due to projection effects). The difference in the resulting scaling of Legendre polynomials is apparent.

Figure 11: Black - results from imitation of Antia fitting; blue - results from my “flattening” method of fitting. The linear relation between $a_k$ and $B_k$ persists for all the various methods I tried for Legendre decomposition at the poles, with slopes relatively unaffected.

References