Diagnosis of the Structure of the Active and Quiet Regions From Observations of High-Frequency Modes and From Time-Distance Seismology

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Abstract/Technical Summary

Study stratification and magnetic effects of the upper reflection layer by inferring the wave speed and the acoustic cut-off frequency from observations of high-degree high-frequency modes and from time-distance diagrams using the SOI Dynamics data.

Investigation Plan

The upper wave reflection layer is of particular interest in helioseimology because the oscillation frequencies are very sensitive to the structure of this layer and its variations with the solar cycle (e.g. Ronan *et al.*, 1994). The variations are particularly large near the acoustic cut-off frequency, ω_{ac}, thus providing potential for probing structural changes in the subphotospheric layer due to the magnetic field. However, the physics of the observed frequency shifts near ω_{ac} have not been understood.

In this project, we propose a complex study of the structure of the upper reflection layer using measurements of frequencies of modes of high angular degree (cf Milford *et al.* 1993) and the mean time-distance diagrams (Jefferies, *et al*, 1994) in both active and quiet regions, and developing theoretical models of propagation of acoustic waves excited by a localized source, in the subphotospheric zone and in the atmosphere.

For the observational part, we plan to use the Dynamics data. The main problem of the data analysis will be to obtain accurate measurements of high-degree, high-ν mode frequencies separately in quiet and active regions. Currently, such measurements have been made only for the full disk. The time-distance diagrams will be also obtained separately for the quiet and active regions, and for several different frequency bands.

The theoretical research will focus on studying the equation of propagation of acoustic waves in the presence of magnetic field with a right hand side stochastic source term

$$V'' + \frac{(\omega^2 - \omega_{ac}^2)}{(c_S^2 + V_a^2)} V = F_{\rm src}, \tag{1}$$

where V is the velocity perturbation, c_S is the sound speed, V_a is the Alfven speed, ω is the wave frequency, ω_{ac} is the acoustic cut-off frequency. Using this equation, we plan to study the theoretical spectrum of eigenmodes below and above ω_{ac}, the sensitivity of the spectrum to variations of ω_{ac}, c_S and V_a, and the amplitude spectrum of the modes excited by a localized source. The equation will be solved by numerical (Milford *et al*, 1992) and asymptotic methods. Various absorbing and non-reflecting boundary conditions will be formulated at the upper boundary which would avoid the spurious numerical reflections present in the Sommerfield radiation condition. From the asymptotic analysis it would be possible to create maps of the phase shifts due to the inhomogeneous medium in the presence of magnetic field. In short, the phase shift as a function of latitude, longitude and magnetic field will be calculated and an analogue to Duvall's law will be determined. The phase shift can be theoretically related to time-distance methods, from which it should be possible to determine the shift from observations. These results will be used to study variations of the frequency difference $\omega_{n,l} - \omega_{n-1,l}$ in the presence of magnetic field. The difference will be compared with the observational results. When the stochastic source term is included in the right hand side of equation (1), the spectrum becomes non-stationary lending itself to a time-frequency analysis in the form of a wavelet transform. A simplified physical model to mimic the observations will be developed. Including the source term entails in doing an eigenfunction expansion for the reduced wave equation (1) before applysing the outgoing radiation boundary conditions. The theoretical results will be also used to estimate the reflection coefficient above the acoustic cut-off frequency, and explain the physical phenomena of mode leakage and p-mode ridges above the acoustic cut-off frequency.

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