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Sensitivity of ring analysis to near-surface magnetism

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ABSTRACT

While magnetic field has only second order effects on global sound waves, it can affect the mode frequencies and flow fields inferred using local helioseismology. A strong localized field can bias our results when one try to infer global scale flows such as the meridional circulation. On the other hand, one important object of research in this area is to determine whether one can detect changes in frequencies or sub-surface flow fields that could be a precursor of surface magnetic events. In this paper we review recent development in this area focusing on results obtained with the ring-diagram analysis technique.

Key words. solar interior - helioseismology - solar activity

1. Introduction

When using global helioseismology to infer internal flows, we can sense only the part of the rotation that is symmetric about the equator and sensitivity kernels are independent of longitude which prevent us from studying for instance the interaction between an active region and sub-surface flows. It is moreover impossible to separate the spherically asymmetric effects other than rotation (meridional circulation, magnetic fields, structural asphericity) and it is difficult to fit high degree modes in global analysis due to mode leakage. These difficulties can be partially overcome with local helioseismology: because the wavelength of high order modes is small compared with the typical scale over which equilibrium structure changes, the modes can be approximated locally by plane sound waves. High degree acoustic waves are damped and cannot travel around the full circumference of the sun and their frequencies are local measures of the sun's properties. In ring diagram analysis (Hill 1988), we typically analyze a mosaic of 16 degree patches tracked over about one day on Doppler images taken at 1 mn cadence. Peaks fitted in the 3D power spectra are typically in the frequency range from 1.7 mHz to 5.6 mHz and include the signature of modes with very short horizontal wavelengths corresponding to spherical harmonic degrees ranging from $\ell = 200$ to $\ell = 1100$ and short lifetimes. Local effects are thus expected to be more important for these modes. Some attempts have been made to detect magnetic effect directly by tracking the expected signature in the spectra when considering the contribution of the Alfvén velocity in the dispersion relation but this is a second order effect only and this research has not been conclusive to date (Hill et al. 1996). The ring shape of slices through the 3D power spectra are therefore mainly affected by the advection induced by sub-photospheric flows in both meridional and azimuthal directions but the presence of magnetic field in the tracked area also affect amplitude, power and frequencies of the peaks. This kind of analysis also allows us to make statistics about many fluid descriptors such as amplitude, direction, helicity or vorticity as a function of the

average magnetic field amplitude within the patch (Komm et al. 2004, 2005b) .

2. Effect of magnetic field on high degree modes sensed by rings

We know that for instance sunspots scatter and absorb p-modes. More generally, amplitude of solar oscillations decrease significantly in active regions either due to the absorption of acoustic modes or to a weaker excitation in active regions. There are well known temporal variations of global modes mean frequencies, amplitude and linewidths with the cycle which are likely linked to global magnetic field variations. With ring analysis, we can isolate active regions where the magnetic field amplitude is much higher than the mean global field and therefore we expect these effects to be magnified. In Rajaguru et al. (2001) pairs of active and quiet regions located at the same latitude have been analyzed showing a monotonic increase of mode frequencies with increasing magnetic activity. In the five minute band, a decrease in both mode power and lifetimes is clearly detected while, at higher frequencies, Howe et al. (2004) have shown that the trend is reversed revealing a regime around 5 mHz where the modes are absorbed like p-modes in presence of strong magnetic fields and enhanced like high-frequency waves at lower activity levels. When looking at the source location of coronal mass ejections (CMEs) with low value of the magnetic flux, Tripathy et al. (2008) realized that the oscillation modes have higher life times than other quiet regions thus indicating a slower damping process. They pointed out that this information may be use to forecast active region which may trigger CMEs.

3. Effect of magnetic field on subsurface flows sensed by rings

The depth dependence of the horizontal velocity field can be inverted from theoretical sensitivity kernels which are

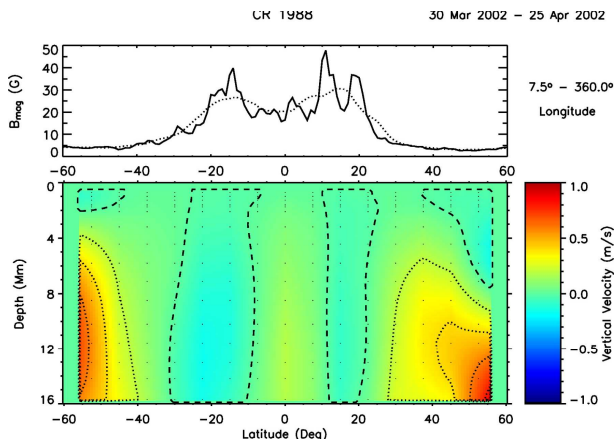


Fig. 1. Vertical velocity component averaged over Carrington rotation CR 1988 (2002 March 30 April 25) as a function of latitude and depth. Top: Surface magnetic flux as a function of latitude (solid line) and averaged over 15 (dotted curve). Bottom: Vertical velocity derived from GONG data after removing the large-scale flow components. (Komm et al. 2004)

essentially given by the mode kinetic energy density (Birch et al. 2007). These kernels however are symmetric and cancel out over the analysis patch for vertical flows. One way to get hints on the vertical flows is to assume mass conservation and to compute it from the divergence of the horizontal components (Komm et al. 2004). In general low surface magnetic activity corresponds to sub-surface upflows while medium magnetic activity is more likely associated with downflows. Figure 1 shows, for one Carrington rotation, the longitudinal average of the vertical velocities down to 16 Mm. Weak downflows of about 1 ms^{-1} are detected near active latitudes. But for strong magnetic field associated with surface magnetic features we can detect downflows down to about 10 Mm where there is a transition to upflows which are also typical for flux ropes in convectively unstable layers.

Concerning the meridional flows, most analysis agree on a poleward flow of about 10 to 20 meters per second increasing with depth and a secondary flow that converge toward the mean latitude of activity (Haber et al. 2002, Zhao & Kosovichev 2004, Komm et al. 2005b). There are strong debate on the existence of counter cells at high latitudes (Haber et al. 2002) where geometric calibration issues enter in consideration in a critical way (González Hernández et al. 2006). While studying how surface magnetic activity influence our inference on meridional flows, González Hernández et al. (2008) found that inflows associated to activity are confined to the upper layers but persist even after aggressively masking surface activity. It has also been shown by Zatri et al. (2006) using ring diagrams that the north-south asymmetry of the flow reflects the north-south asymmetry of the magnetic flux.

One interesting fluid descriptor that can be derived from horizontal flow maps is the kinetic helicity. Large helicity might be associated to highly twisted magnetic flux tubes that are likely to produce flare. Komm et al. (2005a) reported effectively a high correlation between the maximum kinetic helicity density and X-flare. From an analysis of 13 emerging regions, they investigate the question whether the increase of kinetic helicity coincides with the emergence of

flux and obtained a first result showing that the kinetic helicity in shallow layers lags behind the kinetic helicity in deeper layers which, if proved to be statistically significant, could be used in the future to predict the emergence of new flux and flare (Komm et al. 2008).

4. Conclusions

Ring analysis is sensitive to activity (to local and maybe also global field). Sensitivity to local field can be seen as a source of noise when one try to infer global flows (meridional, zonal) and how they vary with the cycle. An important question is then how to filter these effects and to what level. Pattern of global flows are mostly independent of activity level but their magnitude vary. When patches are sorted as a function of some magnetic activity index, it gives some hints on how the flow are organized below and around active regions. Lots of efforts are now made in trying to detect correlations between activity events (CMEs, flares, filaments) and some descriptors of the submerge flows (helicity) or underlying waves (linewidth) essentially in the hope of finding precursor indicators.

A lot of efforts have been made during the last few years that should be continued in making comparison between the different methods, understanding errors, methods resolution and correlations, understanding effects of image misalignment and geometric effects.

Finally we should mention that, together with the upcoming SDO mission which will provide higher resolution data, there are a lot of new developments in this field such as high resolution ring analysis using f-modes (Hindman et al. 2006), deeply penetrating ring techniques (González Hernández et al. 2006), full 3D inversion procedures or structural inversions for ring frequency shifts (Basu et al. 2004).

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