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Ring-diagram parameter comparisons for GONG, MDI and HMI

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Abstract. We examine the differences between ring-diagram mode frequency estimates from samples of Global Oscillation Network Group [GONG], Michelson Doppler Imager [MDI] and Helioseismic and Magnetic Imager [HMI] data, and find that different instruments and analysis pipelines do result in small systematic differences which may not be uniform across the solar disk.

1. Introduction
In the ring-diagram analysis technique of local helioseismology [1] peak parameters are obtained for small regions of the solar disk by fitting the three-dimensional power spectrum of a data cube, usually obtained by tracking a chosen region across the disk as the Sun rotates. This spectrum, when cut at constant temporal frequency, appears as a set of concentric rings, giving the technique its name. Flows cause the rings to shift in $k$-space, and changes in the acoustic cavity, such as those caused by magnetic activity, increase or decrease their size, changing the measured frequency of the peaks. The frequencies are also affected by geometric effects such as foreshortening as the patch moves away from disk center, and by instrumental distortions [2]. Here we consider the frequency parameters obtained from samples of GONG [3], MDI [4] and HMI data during the development of the HMI ring-diagram pipeline. Development is still ongoing, and the HMI results presented here are preliminary.

The data analyzed here are taken from square patches about $15^\circ$ on a side, tracked for approximately the time it takes for the Sun to rotate $15^\circ$. For GONG and MDI, where the detector pixels are about 2 arcsec, patches of $128 \times 128$ pixels, covering $16^\circ \times 16^\circ$ on the disk, are tracked for 1664 minutes at one-minute cadence. For HMI, the detector pixels are about 0.5 arcsec; the patches are remapped to $384 \times 384$ pixels covering $15.36^\circ$ on a side, and tracked for 1728 minutes at a cadence of 45s. The area covered by the HMI tiles extends farther from disk center, allowing up to 284 tiles to be tracked for each “day” instead of the 189 of the standard “dense pack” analysis [5] long used for GONG and MDI data. The HMI data are tracked at the Carrington rate for all latitudes in order to facilitate tracking over long periods, while for the MDI and GONG data the tracking rate varies with latitude following the Snodgrass rotation law.
2. Analysis techniques
The HMI ring-diagram pipeline includes two different fitting procedures: rdfitf [CO] and rdfitc [CT]. The rdfitf code that is used in this analysis is based on the standard ring-analysis fitting code originally developed [5] to quickly fit power spectra from many regions of the solar disk. The rdfitf procedure unwraps the given power spectrum onto a polar coordinate system $\theta,k$ and then filters out an average of the power in frequency at each $\theta$ and $k$ in order to eliminate any stationary instrumental effects. The data are then subsampled before being fit with the function

$$P(\theta,k,\nu) = A\Gamma/2/[(\nu - \nu_0 + U_x * k \cos \theta + U_y * k \sin \theta)^2 + (\Gamma/2)^2] + bg/k^3$$  \hspace{1cm} (1)$$

This is also the algorithm used in the routine analysis of GONG ring data. The rdfitc algorithm [6] uses a 13-parameter model with asymmetric peak profiles to fit at constant frequency:

$$P(k_x,k_y,\nu) = \exp[A_0 + (k - k_0)A_1 + A_2(k_x/k)^2 + A_3k_xk_y/k^2] \times [S^2 + (1 + S_x)^2](x^2 + 1) - 1 + e^{x1}/k^3 + e^{x2}/k^4$$  \hspace{1cm} (2)$$

The rdfitc method is more computationally expensive than rdfitf. Therefore, for the larger HMI tiles we have used this method only for patches on the central meridian.

3. Results
3.1. Preliminary checks
3.1.1. Carrington versus Snodgrass  Using MDI and GONG data, we checked for the effects of different tracking rates on the frequency parameter. To look for systematic effects across the disk, frequency differences in each dense-pack position were averaged over a range of peaks and over a full rotation of observations. Figure 1 shows the results for frequency differences between Carrington and Snodgrass-rate tracking for GONG CR 2069 and MDI CR 2068. In each case the differences are small and do not show a systematic pattern.

3.1.2. GONG versus MDI  We compared MDI data (tracked at the Snodgrass rate using the HMI pipeline and fitted with the CO algorithm) and GONG data analyzed with the standard GONG pipeline, for two rotations, 2068 and 2084 (Figure 2). In the second case the observations were made when SOHO was “upside down”; the distinctive pattern of the differences across the disk is rotated 180°, demonstrating that this is an effect of incompletely corrected instrumental distortion in MDI. (Earlier versions of the data with even less complete distortion correction showed more dramatic differences.)
3.1.3. CO versus CT

As might be expected because of the different peak models, the CO and CT fits give slightly different frequency estimates when applied to the same data. This is illustrated in Figure 3 for two rotations of MDI data. There appears to be a trace of the MDI-distortion signature in the differences, perhaps because the different peak models respond differently to the distortion effects.

3.2. HMI and MDI observations of CR 2096 – 2097

We analyzed results from several days of observations from HMI and from the MDI Dynamics Run during May 2010, with CO fits covering the whole disk for 15 days of HMI and 18 of MDI, and CT fits on the central meridian for 21 days of HMI and 20 of MDI. The variation of the frequency of a particular peak across the disk can be roughly described by the equation \( \nu = \nu_0 + a_1x + a_2x^2 + a_3y + a_4y^2 + a_5B + a_6B^2 \), where \( x \) and \( y \) are the distance from disk center in the \( x \) and \( y \) directions, as a fraction of the apparent radius, and \( B \) is magnetic activity index (in Gauss) for each patch, calculated by integrating the unsigned longitudinal magnetic field strength from MDI magnetograms over the area and duration of the patch. When only the central meridian patches are available, we omit the terms in \( x \). Figures 4 and 5 show the results of such an analysis with all four data sets plotted on the same axes.

4. Conclusions

Instrumental and geometric effects cause variations in the ring-diagram frequency estimates across the solar disk. The frequency estimates also, not unexpectedly, depend on the fitting
algorithm and model; differences tend to be more pronounced at high degree and nearer the limb. Tests with artificial data may eventually throw more light on these issues. Tracking at the Carrington rate rather than the Snodgrass rate has very little effect on the frequency estimates.

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