Meridional Flows from GONG Zonal Modes

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We present two different, but similar, time-distance techniques to measure meridional-flow induced travel-time differences. We use GONG zonal spherical harmonic coefficients (m = 0) and longitude-averaged time series for 1995 – 2007. Both data sets represent waves propagating only in the North – South direction. We demonstrate that it is possible to obtain travel-time differences with lower turning points about 200 Mm below the surface, which corresponds to the tachocline. We do not see any evidence of equatorward flow.

Data and analysis technique

Longitude-Averaged Data

Daily velocity images were remapped onto heliographic coordinates, surface differential rotation was removed, and the images summed along lines of constant longitude, resulting in an array with two dimensions (latitude and time). Two power spectra were computed corresponding to the north and south hemispheres covering the latitude range 20 – 50°. A phase-velocity filter was applied for different phase speeds to isolate waves with the same lower turning point. Travel times for opposite directions were measured from cross-correlation functions by fitting Gabor wavelets. More than 100 daily measurements were averaged for each year 2001 – 200. The differences between northward and southward travel times are presented in Figure 1.

Zonal Spherical Harmonic Coefficients

m = 0 spherical harmonic (SH) coefficient time series for degrees ℓ = 0 – 200 obtained from GONG during 1995 – 2007 were used to reconstruct images for the latitude range ±65°. Three-day-long time series were selected with duty cycles higher than 75% for each GONG month. Cross correlations between signals located at different latitudes for different angular separations were computed. Time shifts due to meridional flow are obtained from the difference between northward and southward travel times, for angular separations of 6 – 47°.

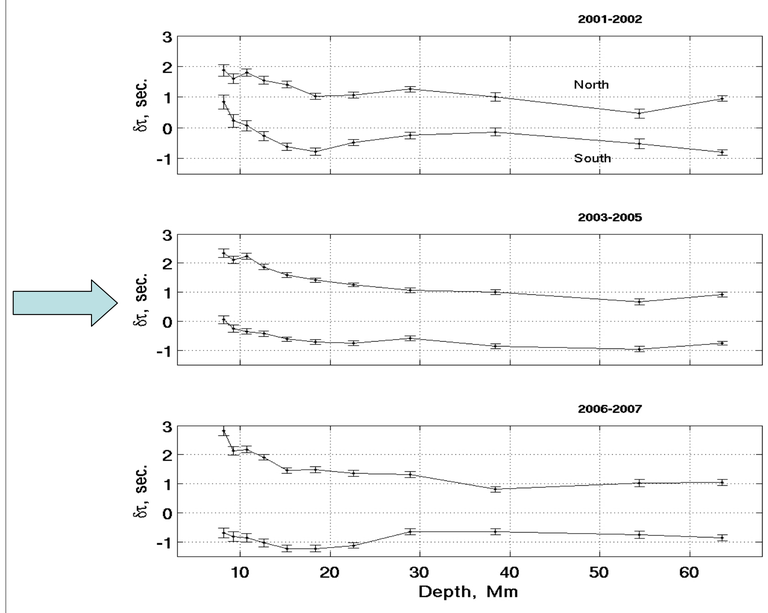

Figure 1 Travel-time differences for both hemispheres from longitude-averaged data series. Only in 2001 – 2002, for depth about 5 – 10 Mm, can sign changes be seen. There is no evidence of equatorward flow at 40 Mm depth.

Results

Recently Mitra-Kraev and Thompson (*Astron. Nachr.* **328**, 1009, 2007), using MDI longitude averaged data, found a change of meridional flow direction at depth about 40 Mm. We also produced similar measurements using a time-distance technique. Using 660 days of GONG data does not show any sign changes in either hemisphere. Only a few points near the surface (5 – 10 Mm) show non-significant change of sign in the southern hemisphere. We think that this can be the result of superposition of meridional flow and outflows from active regions. We divided our measurements into three temporal periods to look for equatorward flow if it happens only in some phases of solar activity. In all time periods, for depths 5 – 70 Mm, only poleward flow is clearly seen.

To get North – South travel time differences we reconstructed the velocity as a function of latitude using m = 0 SH coefficients for ℓ = 0 – 200. Then we computed cross correlations between pairs of points at the same latitude separated by different angular distances. In this study we used ±65° in latitude and 6 – 47° separations. The propagation depth for separations 43 – 47°. reaches the tachocline region. So, using this technique we can provide travel time differences for 20 to 200 Mm depth. Measurements using zonal SH coefficients show existence of some artifacts in the SH time series (Figure 2). The amplitude of the cross correlations at high latitudes exhibits a one-year periodicity. The magnitude of the periodicity decreases toward low latitudes and disappears around 20 – 25°. Fortunately travel times are not effected so much, although some quasi-periodic noise is visible. Moreover, travel time shifts are the difference between two opposite directions, therefore the periodicity largely disappears.

It is clear that the correlation amplitude increases after the GONG cameras were upgraded (month 61). The magnitude of the periodicity decreases after the upgrade, while the amplitude itself increases. The phase of periodicity in the two hemispheres is exactly opposite. Most likely this is *B*-angle effect.

In Figure 3 time variations of travel time differences are presented (a). To avoid contributions of the annual periodicity, measurements over exactly two years were averaged. Averaged time periods cover exactly two positive and two negative phases of the *B*-angle periods. Figure 3 panels (b) and (c) present two-year averaged measurements at two different depths. We do not see any systematic changes with solar activity cycle.

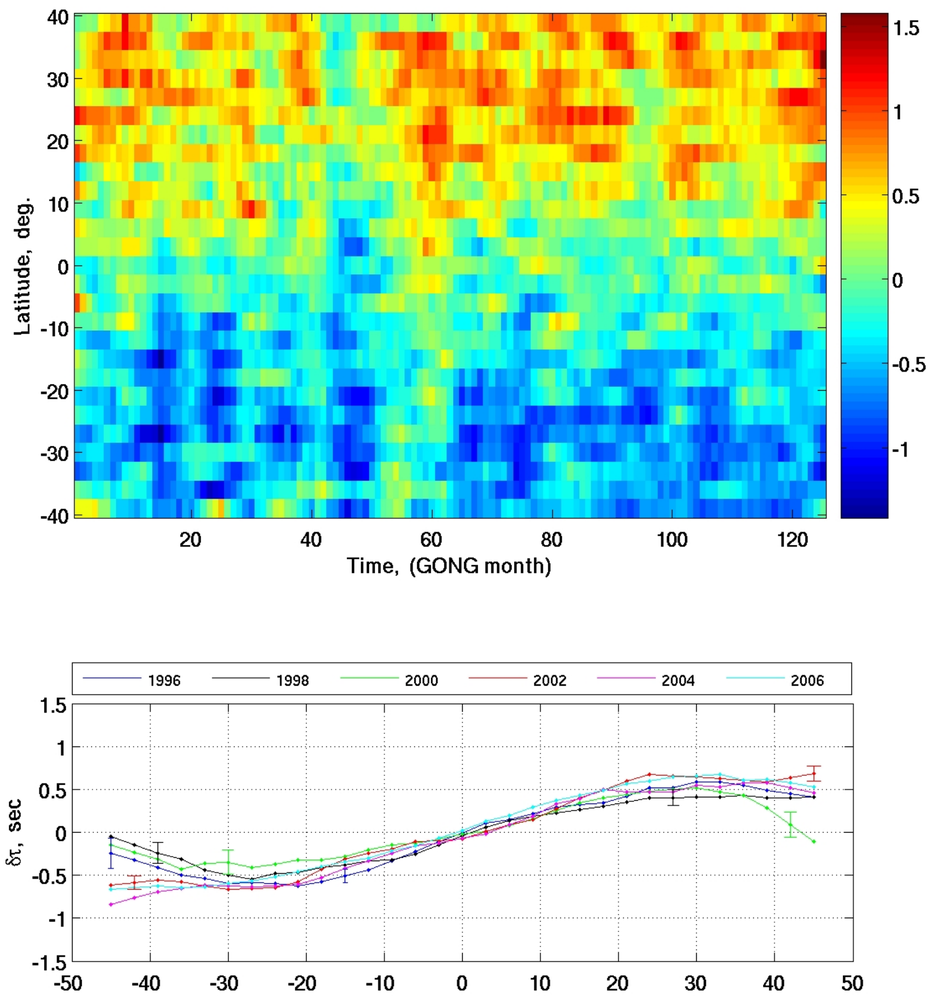

Figure 3 North – South travel time differences from zonal SH time series. Upper panel shows time variations of measurements for lower turning point about 40 Mm. Lower two plots are two-year-averaged measurements corresponding to 40 (top) and 200 (bottom) Mm. Different colors represent different time periods. No systematic variations can be seen.

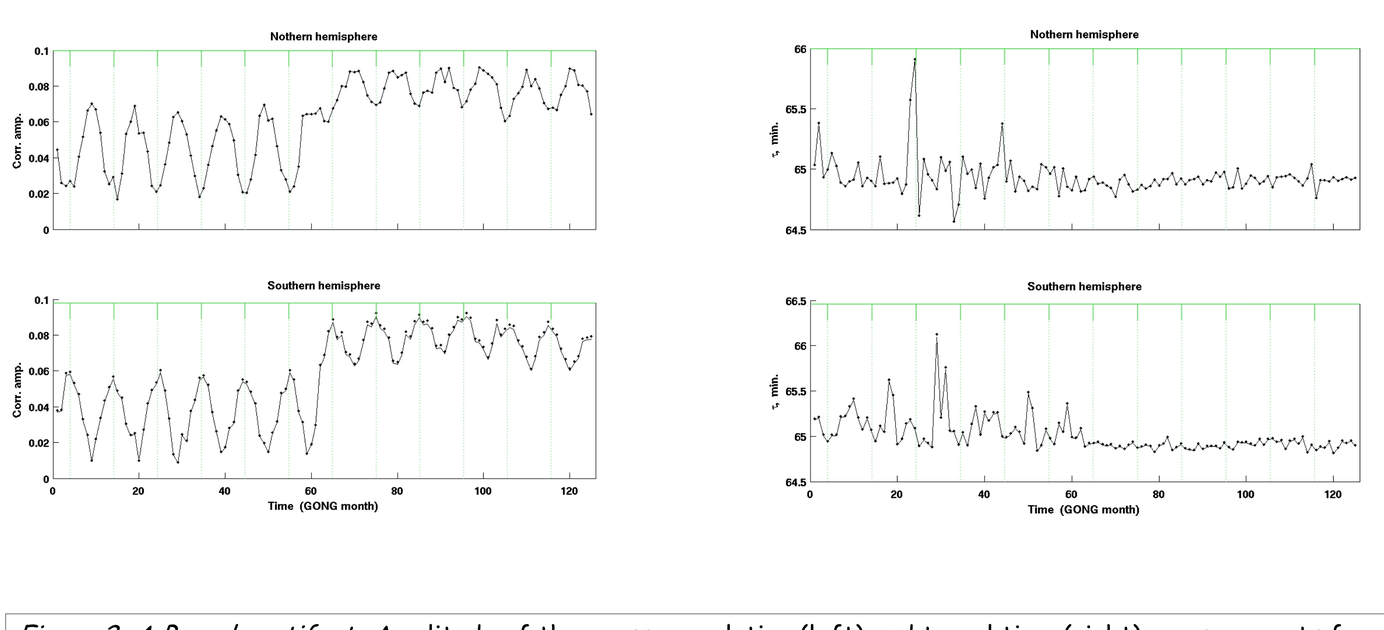

Figure 2 *A B-angle artifact*. Amplitude of the cross correlation (left) and travel time (right) measurements from zonal SH time series for 45° latitude as a function of time. Horizontal ticks on the top in green correspond to *B*-angle maxima. The first GONG month starts in May 1995. Clear anti-phase variation of correlation amplitudes is visible. The CCD upgrade to GONG++ occurred in August 2001 (month 61) where an increase of amplitudes can be seen. For the time being, we have suppressed this effect by averaging over multiples of one year.

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