2 Years of Meridional Circulation from GONG Ring Diagrams

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Introduction

Ring Diagram analysis, a local helioseismology technique, has proven very useful in studying solar subsurface velocity flows to a depth of about $0.97R_\odot$. The depth range is determined by the modes used in this type of analysis and thus depends on the size of the analyzed area. Extending the analyzed area allows us to detect lower ℓ-modes that penetrate deeper into the Sun. However, there is a compromise between the size of the analyzed area and the validity of the plane wave approximation used by the technique. In this work we present the results of using this technique to search for meridional circulation variability using a 2-year GONG data series.

Data Analysis

We have applied Ring Diagram analysis to patches of 30° diameter over the solar surface as they crossed the solar central meridian. These patches are four times the size of the typically studied patches of 15° degrees diameter. A set of 15 overlapping patches centered at latitudes 0, ±7.5°, ±15°, ±22.5°, ±30.0°, ±37.5°, ±45.0° and ±52.5° have been analyzed for 24 intervals of 1664 minutes for 25 Carrington rotations (1985-2009) spanning Jan 2003 – Nov 2004. The range of modes recovered with these larger regions goes down to ℓ~100 and reach a maximum depth of approximately $0.96\ R_\odot$

To verify the horizontal flows obtained with these larger patches, we compare the differential rotation obtained by averaging the zonal component of the horizontal velocity vectors for CR 1989 with the global helioseismic measurements obtained for a 3 month period including CR 1989.

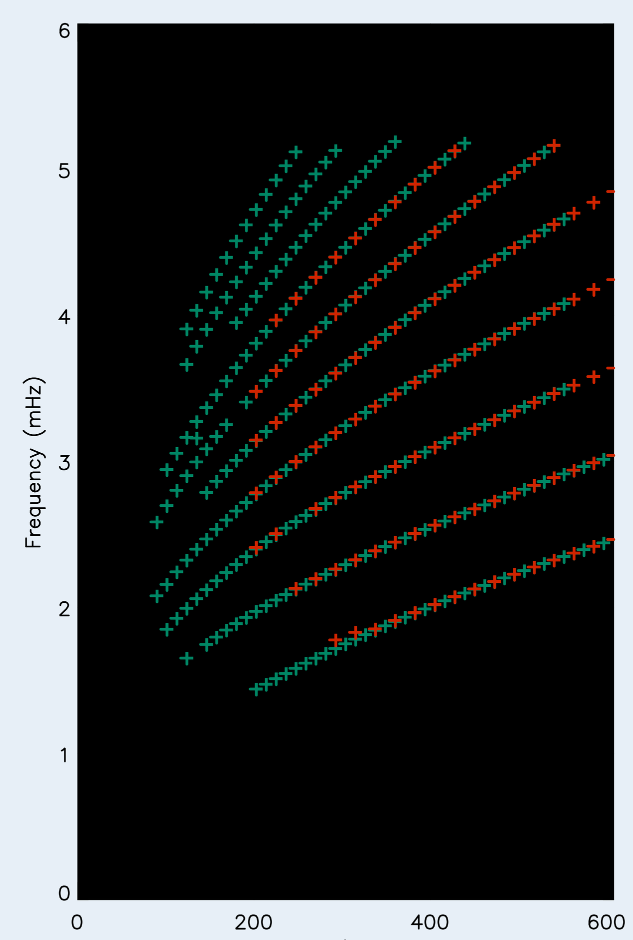

Fig 1: Comparison between fitted modes using a 15° diameter region (red) and a 30° one (blue)

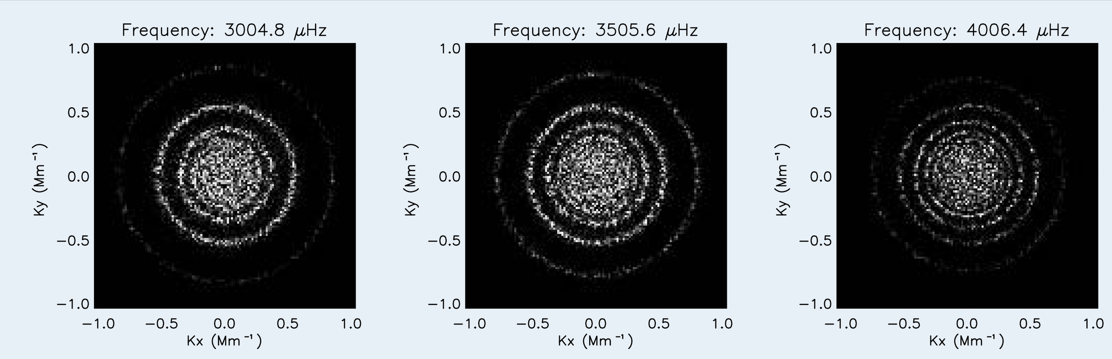

Fig 2: Cuts at different frequencies of the 3-dimensional power spectrum associated with one of the 30° diameter areas.

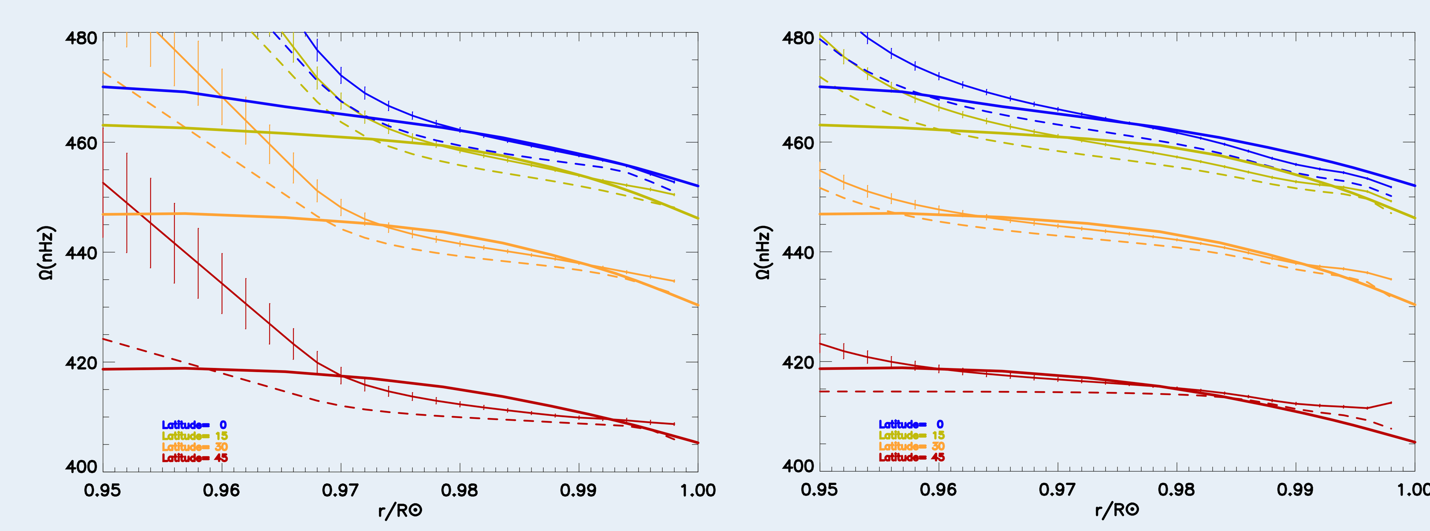

Fig 3: Rotation rate for several latitudes (0°, 15° 30° and 45°) from global analysis (thick solid line) and from ring diagrams (GONG solid line, MDI dashed line). The left panel shows the results obtained using the typical 15° patches, the right panel the same results using the larger 30° patches.

Results

We use the V_y component of the averaged horizontal velocity flows from the larger areas to study the meridional circulation. The flows are represented in Figure 4 as contour surfaces where dashed lines correspond to negative values. It can be seen that the amplitude of the flows increases towards the interior of the Sun in the depth range studied. The maximum amplitude very near the surface ($0.99R_\odot$) is close to 10 m/s and it increases gradually to 30 m/s at a depth of about 26 Mm ($0.96\ R_\odot$). The maximum amplitude of the meridional flows peaks at about 25° latitude in both hemispheres, but it varies with time. We find no clear variation of the location with time at our maximum explored depth, $0.96R_\odot$, however this location seems to be moving toward higher latitudes in the 2-year period in layers closer to the surface.

Haber *et al.* (2002) reported a second cell from the north pole toward the equator above 45° when analyzing MDI data from Carrington Rotation 1987 with the standard ring diagrams method ("*countercell*"). In our results, from about $0.965\ R_\odot$ down, a second cell appears for Carrington rotation intervals centered in 1987, 1992, 2001 and 2007 in the northern and southern hemisphere coinciding with maximum values of the B_0 angle respectively.

The temporal variation of the meridional flows at the equator shows no clear periodicity, at least for these 2-year series (see fig 5), which would be expected if the Carrington elements where incorrect as suggested by Beck & Giles (2005).

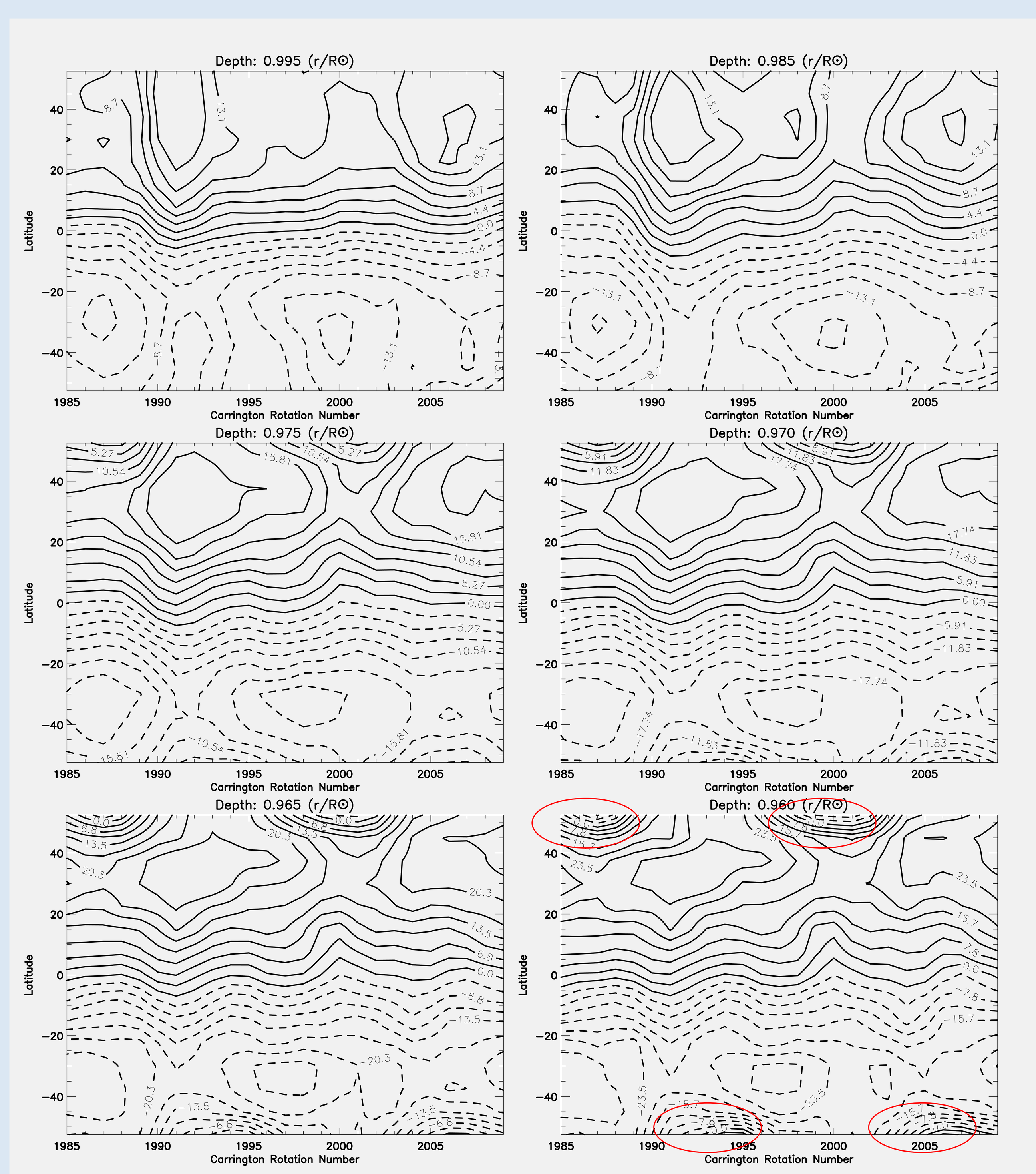

Fig 4: Evolution of meridional circulation at six depths during a two-year period, January 2002-December 2003. Continuous lines correspond to positive values (flows towards the North pole) and dashed lines to negative values

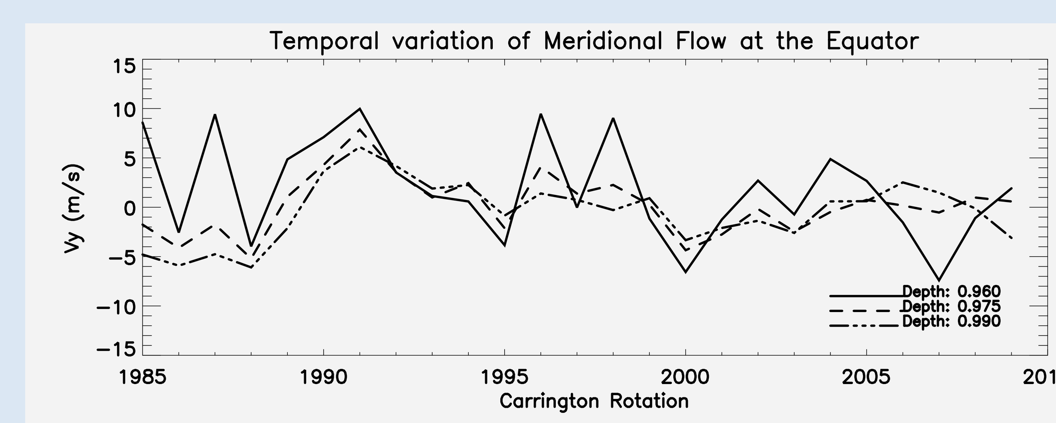

Fig 5: Temporal variation of the meridional flows at the equator for 3 depths. They fluctuate around zero suggesting there is no systematic P angle misalignment for the GONG instrument (Beck & Giles 2005)

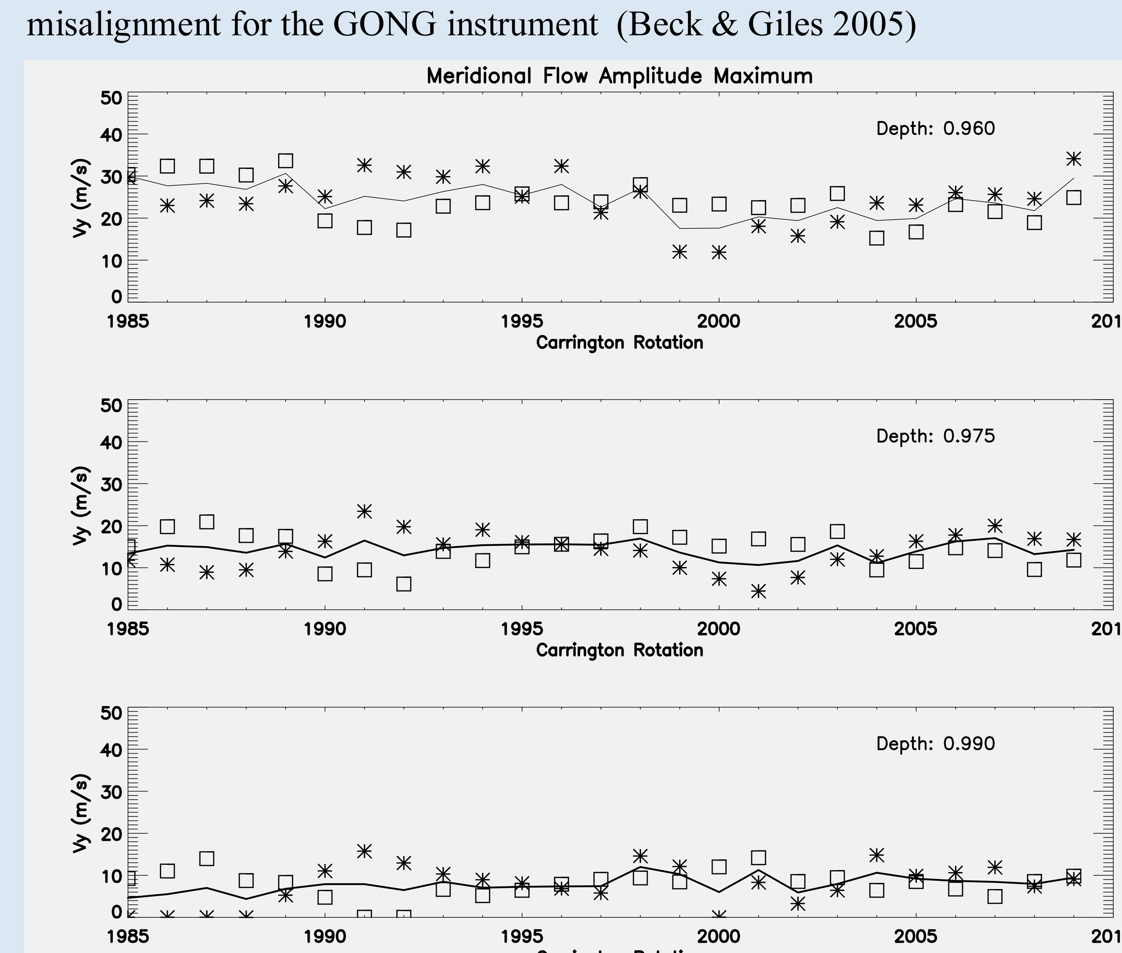

Fig 6: Temporal variation of the maximum amplitude of the meridional flows at three depths. The figures show the average of the north and south hemisphere (continuous line) and the independent hemisphere results (squares for north, stars for south).

Conclusions

- We have shown that large aperture ring diagrams are effective in extending the measurement of differential rotation and meridional circulation to deeper layers beneath the solar surface.
- The presence of the countercell/down flow and the systematic differences in the averaged horizontal flows between GONG and MDI are still under investigation.
- We find variation in the maximum amplitude of the flows through this 2-year period.
- GONG continuous velocity data will allow us to search for a meridional circulation variation with the solar cycle. A previous study by Chou *et al*. using TON data found variations that were different for the declining phase and the rising phase of Cycle 22. They also find a general increase with depth in the meridional flows of up to 40 m/s. Our work agrees with a slight increase in the magnitude of the meridional flows with depth, however we suspect the inversion technique may account for the major increase below $0.965\ R_\odot$

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Electronic versions of this and many other GONG posters are available on the GONG CD and also at http://gong.nso.edu/gallery/cd_data_2005/

NSO National Solar Observatory GONG NSF AURA Observatoire de la Côte d'Azur