Meridional Circulation Variability from Large Aperture Ring Diagrams

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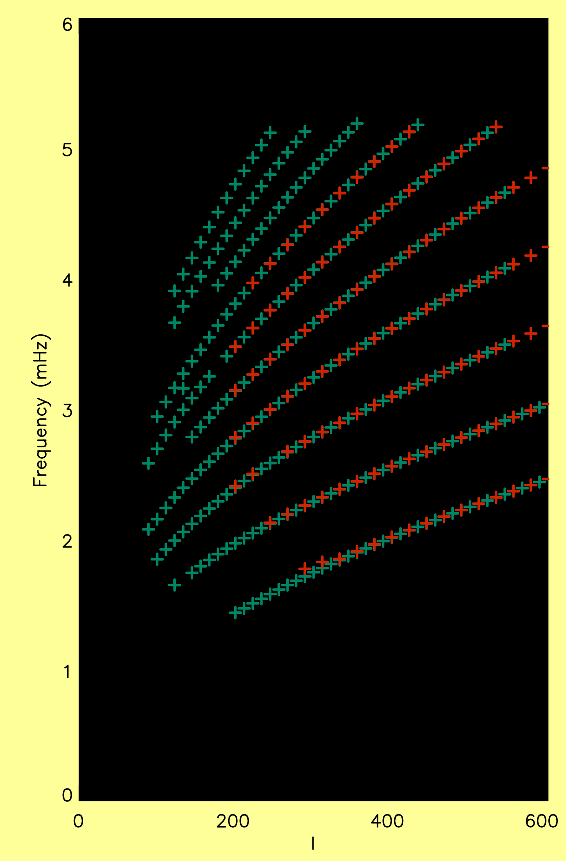
Large-Aperture Ring Diagrams

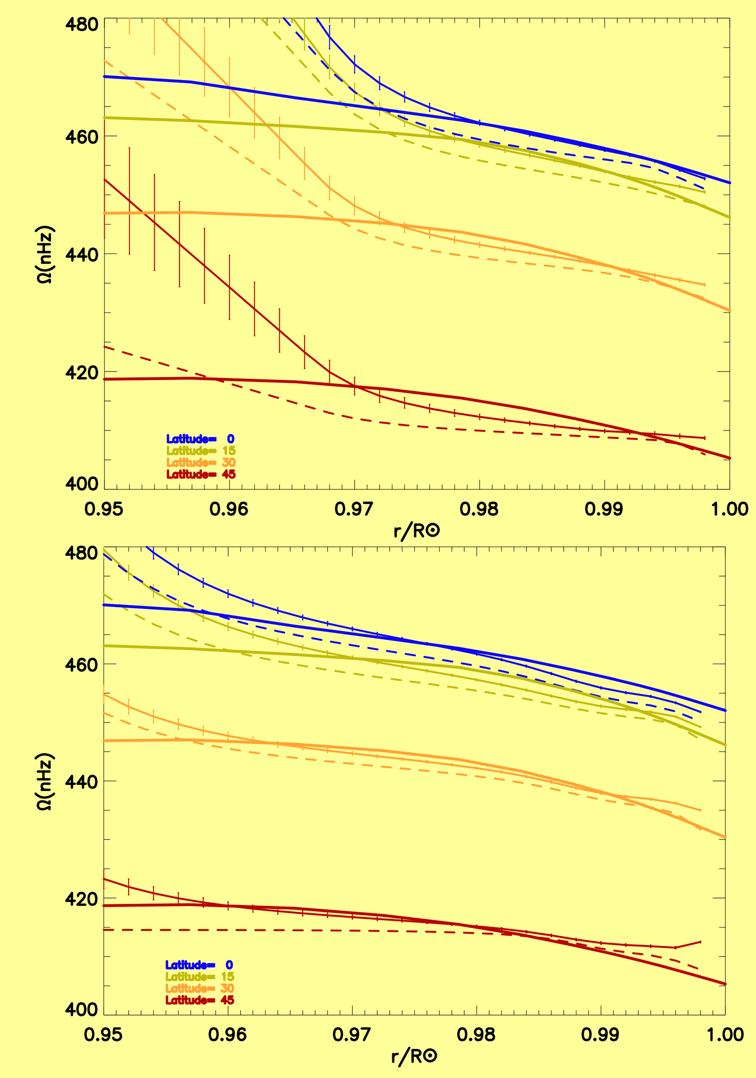
Ring Diagram analysis, a local helioseismology technique, has proven very useful in order to study the solar subsurface velocity flows down to a depth of about $0.97R_o$. The depth range is determined by the modes used in this type of analysis and thus depends on the size of the area analyzed. Extending the area allows us to detect lower *l* modes which penetrate deeper in the Sun. However, there is a compromise between the size of the patch and the validity of the plane wave approximation used by the technique.

In this work, we have applied Ring Diagram analyses to patches of 30º diameter over the solar surface as they crossed the solar central meridian. These patches are twice the size of the typically studied sections of 15º in diameter. A set of 15 overlapping sections centered at latitudes 0º, ±7.5º, ±15º, ±22.5º, ±30.0º, ±37.5º, ±45.0º and ±52.5º have been analyzed for 25 intervals of 1664 minutes during Carrington rotations 1979, 1987, 1988 and 1989.

To verify the technique, we compare the rotation rate obtained with a traditional ring diagram analysis, the large-aperture approach and the global helioseismic results for CR 1989 using both GONG and MDI full-disk Dopplergrams.



Comparison between the set of modes in the *l* range of 0 to 600 fitted using a 15º patch (red) and the ones fitted when using a 30º patch (green). Modes in the *l* range of 100 to 200 are recovered with the larger areas.

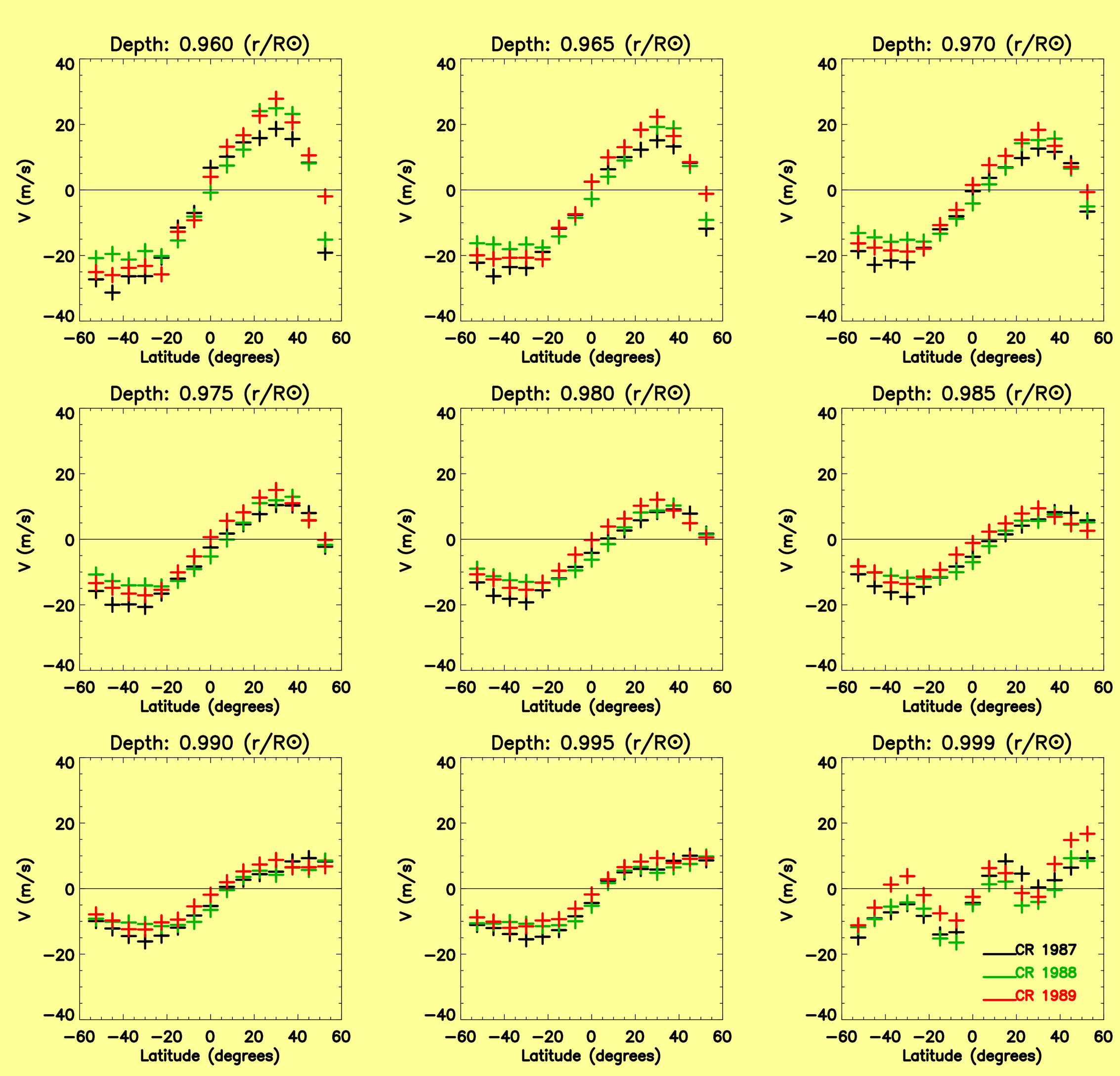


Rotation rate for several latitudes, 0º, 15º, 30º and 45º from Global Analysis (thick solid line) and from Ring Diagrams (GONG solid line, MDI dashed line). The top panel shows the results obtained using the typical 15º patches, the bottom panel the same results using the larger 30º patches.

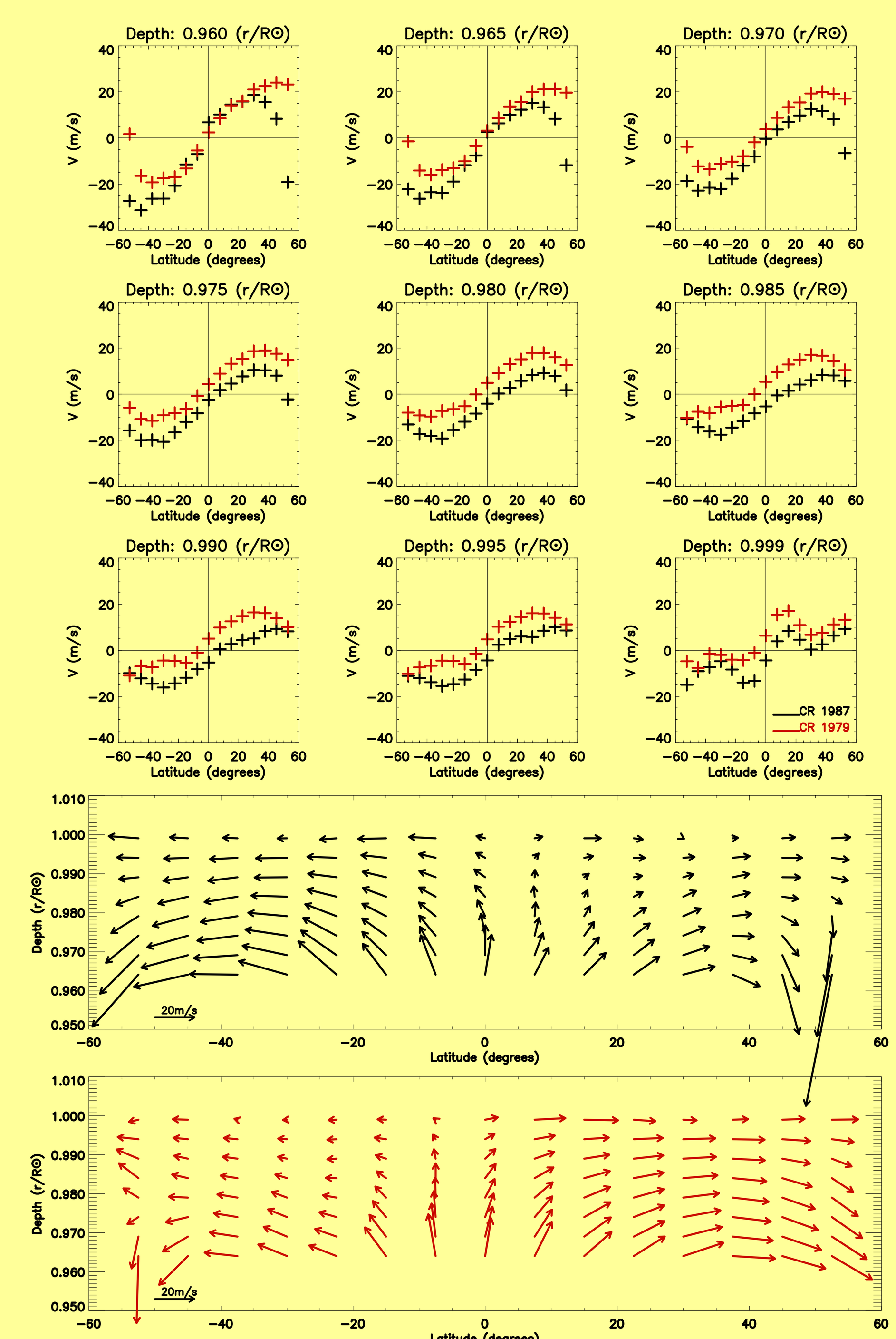
Meridional Circulation using Large-Aperture Ring Diagrams

We have studied three consecutive Carrington rotations 1987, 1988 and 1989 and averaged the results for each of them (center panel). The data used for this work are GONG full-disk Dopplergrams. We find an equatorward flow in the Northern Hemisphere below 0.975 R_o. This flow has been seen in MDI data for the same period and was named the *countercell* (Haber et al., 2002).

In order to search for systematic errors in the meridional flows caused by geometrical effects, we analyzed CR 1979. During this period the B0 solar angle is close to +6º while it is about -7º for CR 1987. The comparisons on the right panel show the meridional flows during these two CRs. The results look quite anti-symmetric, revealing a Southern Hemisphere countercell for CR 1979. We also show the velocities resulting from combining the meridional component of the averaged horizontal velocity flows with the calculated vertical component for these two CRs (right, bottom panel). The vertical component was derived using the continuity equation from the calculated divergence of the measured horizontal flows (Komm et al., 2004).



Meridional component of the horizontal velocity flows obtained from Large-Aperture Ring Diagram analysis using GONG full-disk Dopplergrams. The graphics show the velocities at different depths as an average of 25 consecutive series of 1664 min taken during each of three consecutive Carrington rotations: CR 1987 (black) CR 1988 (green) and CR 1989 (red).



Top: Comparison between the meridional component of the horizontal flows for CR 1987 (black) and CR 1979 (red).
Bottom: Meridional circulation obtained by combining the U_y component of the horizontal velocity flows from Ring Diagrams and the calculated vertical component for CR 1987 (black) and CR 1979 (red).

Conclusions

- Large aperture ring diagrams are very effective in searching for differential rotation and meridional circulation in deeper layers under the solar surface.
- Preliminary results suggest that the presence of the countercell could be related to the B0 angle. We suspect geometric calibration issues for the data or the analysis method may affect the meridional circulation results.
- We will use GONG continuous velocity data 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 and the rising phase of Cycle 22. They also find a general increase with depth in the meridional flows of up to 40m/s. Our work agrees with a slight increase in the magnitude of the meridional flows with depth; however, the major increase below 0.965 R_o is suspected to be an artifact of our inversion method and is under investigation.

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