Meridional Circulation Variability from Large-Aperture Ring Diagrams

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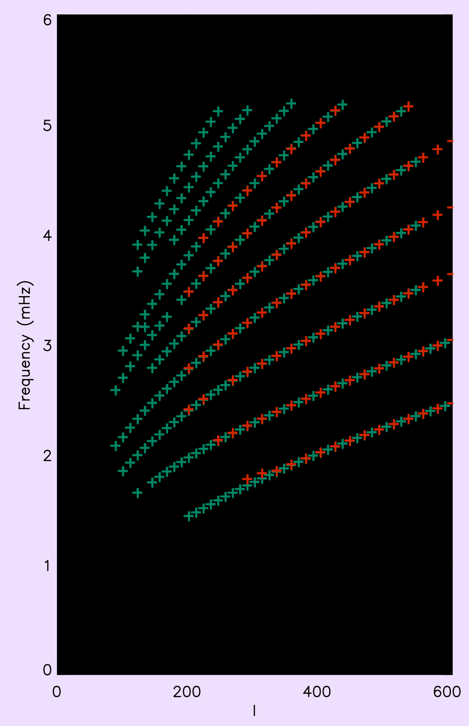
Large-Aperture Ring Diagrams

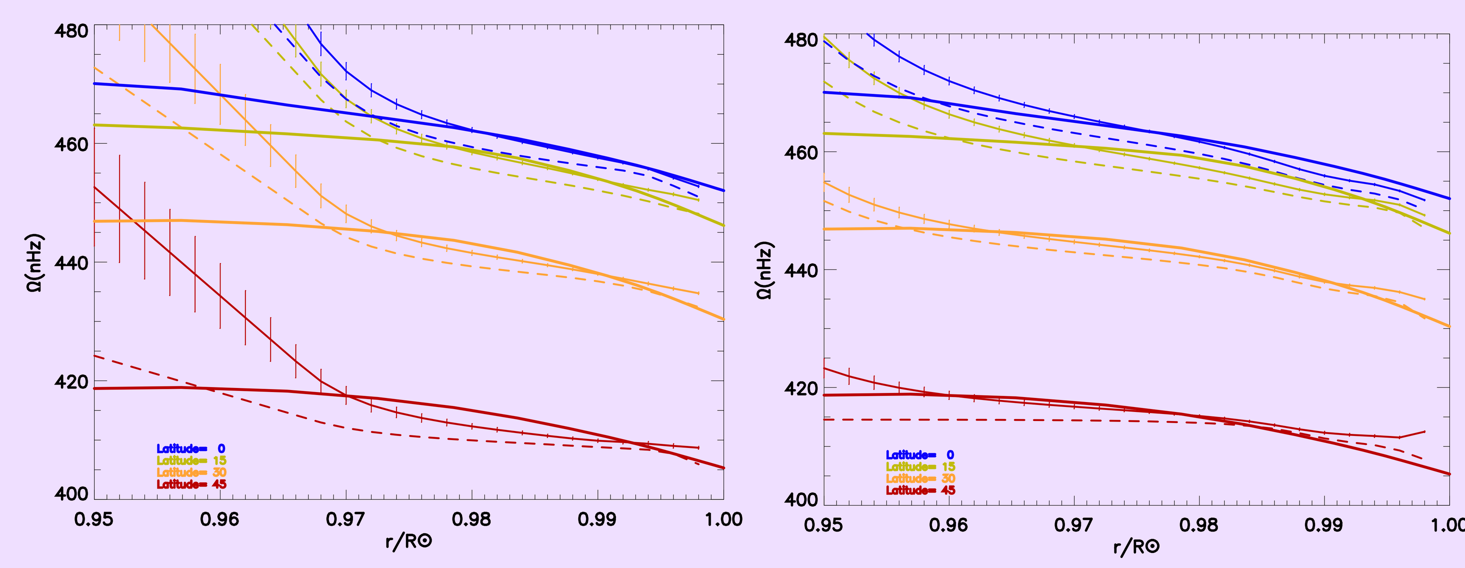
Ring Diagram analysis, a local helioseismology technique, has proven very useful in order to study the solar subsurface velocity flows down to a depth of about 0.97$R_\odot$. The depth range is determined by the modes used in this type of analysis and thus depends on the size of the area analyzed. Extending 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, 1989, 1990, 1991 and 1992.

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 (far right panels).



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, Howe et al. 2000) and from Ring Diagrams (GONG solid line, MDI dashed line). The left panel shows the results obtained using the typical 15º patches, the right panel the same results using the larger 30º patches. The local results are an average over CR 1989; the global ones span 3 months including that CR.

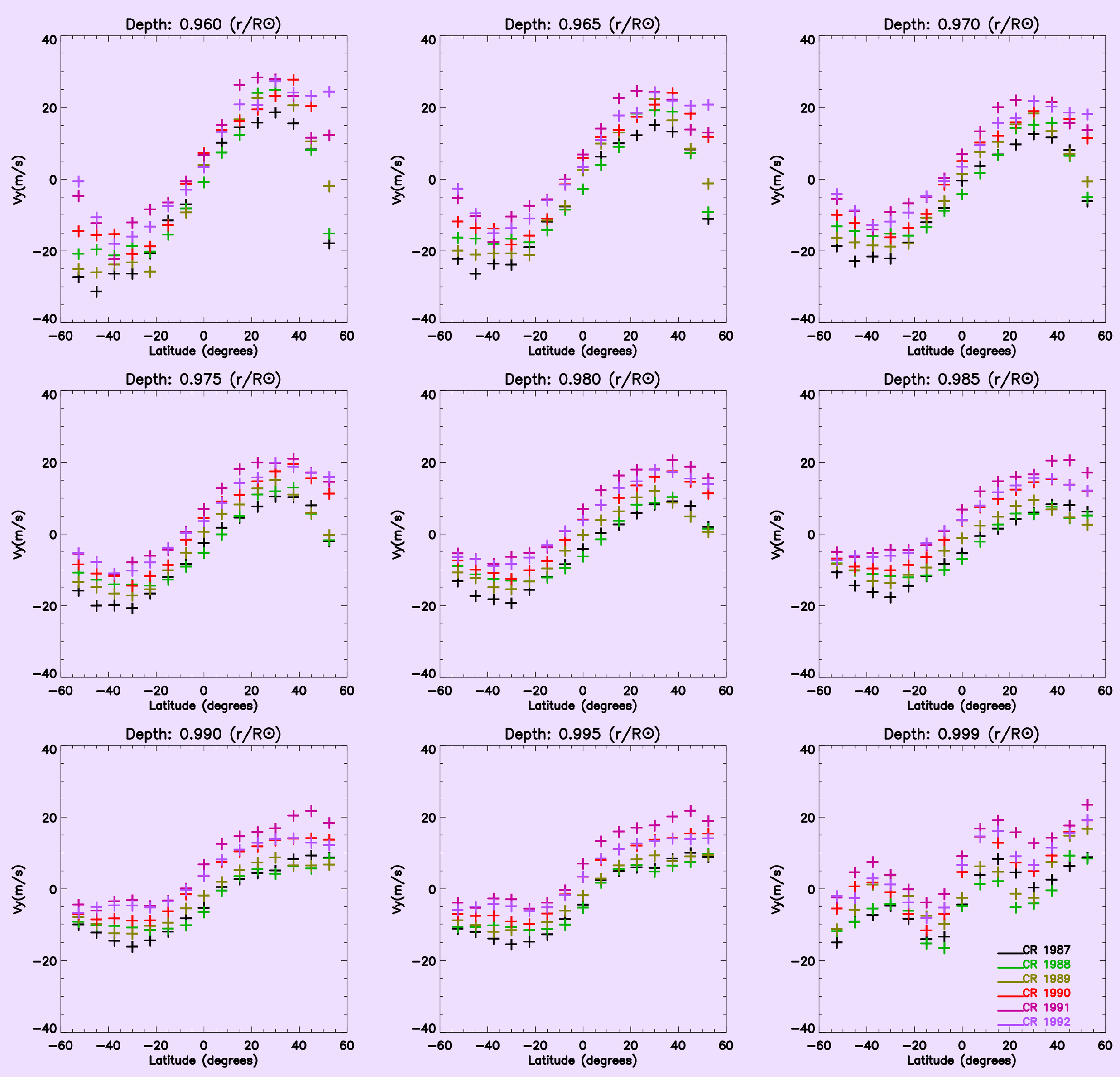
There is a clear improvement in the results when the larger areas are used. The systematic displacement between GONG and MDI results is still under investigation.

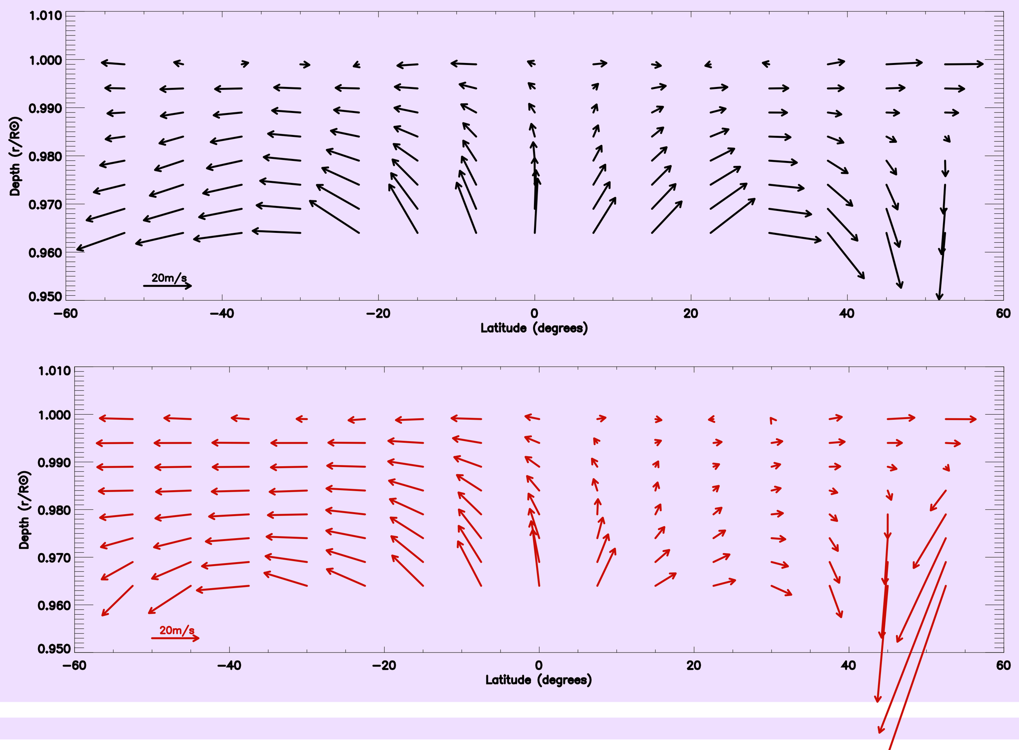
Meridional Circulation using Large-Aperture Ring Diagrams

We have studied six consecutive Carrington rotations 1987, 1988, 1989, 1990, 1991 and 1992 and averaged the results at each latitude for each of them. The data used for this work are GONG full-disk Dopplergrams. The figure to the right (top) shows the meridional component of the horizontal velocity flows at different depths for these six rotations.

We find an equatorward flow in the Northern Hemisphere below 0.975 R_o for CRs 1987, 1988 and 1989. This flow has been seen in MDI data for the same period and was named the *countercell* (Haber et al., 2002). A Southern hemisphere countercell appears for CR 1992.

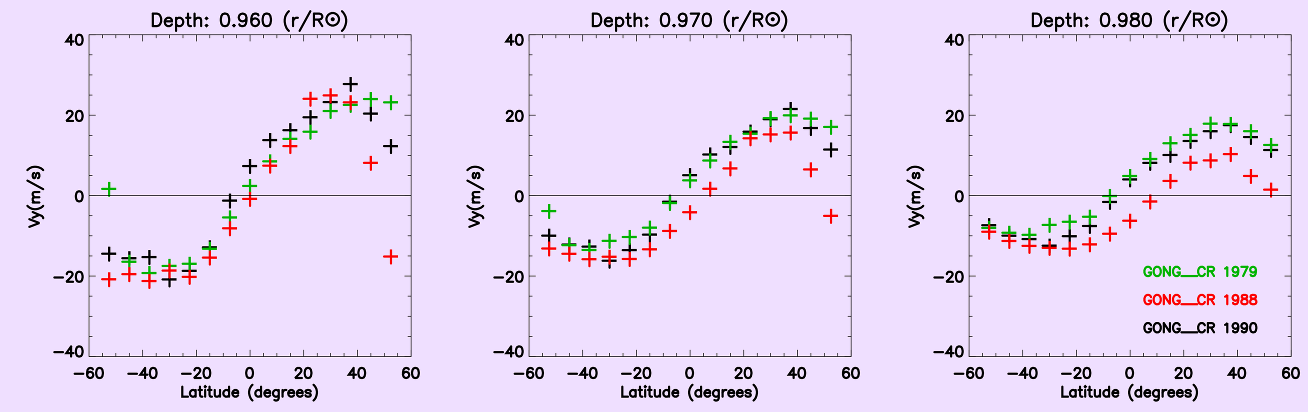
The bottom figures present the velocities resulting from combining the meridional component of the averaged horizontal velocity flows with the calculated vertical component. They have been calculated for CR 1988 using both GONG (black) and MDI (red) data. The vertical component was derived using the continuity equation from the calculated divergence of the measured horizontal flows (Komm et al., 2004).



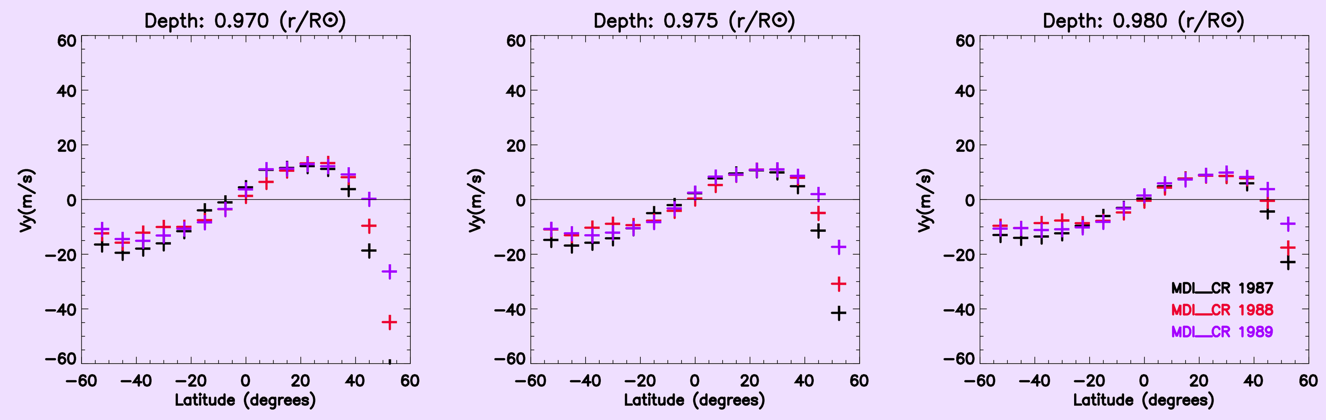


What causes the countercell?

In order to search for systematic errors in the meridional flows caused by geometrical effects, we analyzed CR 1979, CR 1988 and CR 1990 using GONG data. For these three CRs the B_0 solar angle is close to +6º, -6º and 0º respectively. The comparisons below show the meridional component of the horizontal flows. The results look quite anti-symmetric for CR 1979 and CR 1988, revealing a Northern hemisphere countercell for CR 1988, a Southern hemisphere countercell for CR 1979 and no counter cell for CR 1990.



Finally, we look at three consecutive CRs using MDI full disk Dopplergrams: 1987, 1988 and 1989. The bottom panel shows the meridional component of the horizontal velocity flows obtained for these three CRs. The B_0 angle during this period ranges from about -7.5º for CR 1987 to approximately -3º for CR 1989. It can be seen from the figure that there is a marked correlation between the value of the B_0 angle and the progression of the countercell.



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 B_0 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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