Solar Subsurface Flows and Vorticity

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Introduction

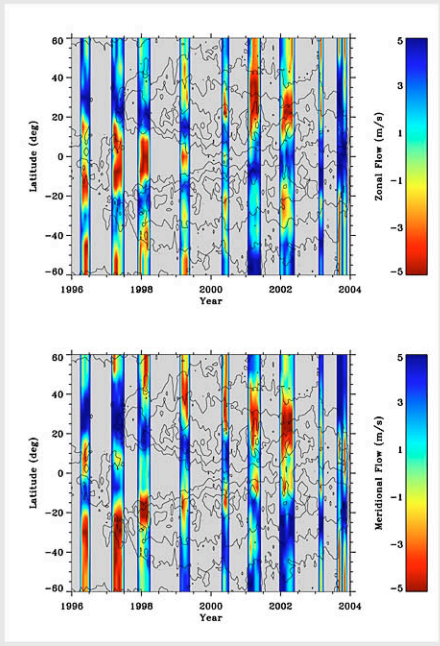
We measure the horizontal components of subsurface flows with the ring-diagram technique (Haber et al. 2002) and derive the vertical velocity component from the divergence of the horizontal flows (Komm et al. 2004). We study both subsurface flows on time scales of the solar cycle and single rotations and their relation to surface magnetic activity.

We also calculate the vertical vorticity (see Zhao & Kosovichev, 2004 and Komm et al. 2004) and the other two vorticity components. To emphasize the variations, we subtract the contributions of the mean differential rotation and the mean meridional flow.

We analyze MDI Dynamics Program and high-resolution GONG data covering 28 and 10 Carrington Rotations respectively. Here, we focus on:

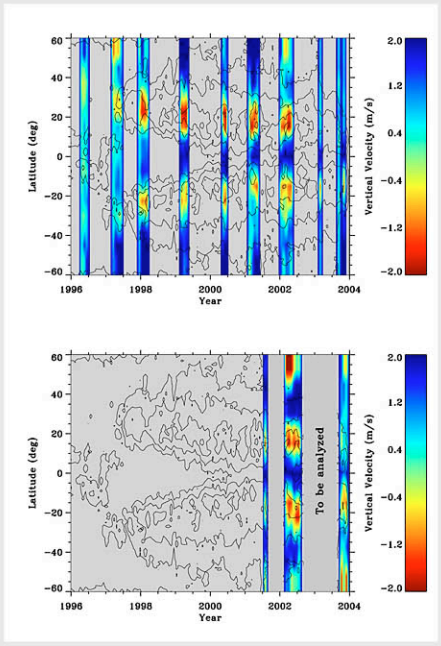
- Solar-cycle variation of the horizontal flows (torsional oscillations and meridional flow) and the vertical flows;
- Vertical velocity and vorticity during different epochs;
- Variance of 3-D vorticity and its relation to magnetic activity;
- MDI – GONG comparison of 2002 and 2003 Dynamics Program data (to establish consistency).

Solar-Cycle Variation of Horizontal Flows



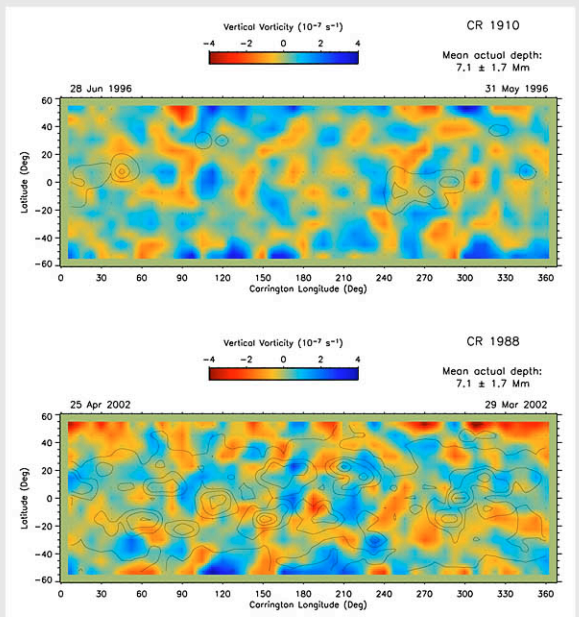
Zonal (top) and meridional flows (bottom) of near surface layers (0.9-4.4 Mm) derived from MDI data. The average was subtracted at each latitude. For meridional flows, positive/negative values indicate flows to the north/south.

Solar-Cycle Variation of Vertical Flows



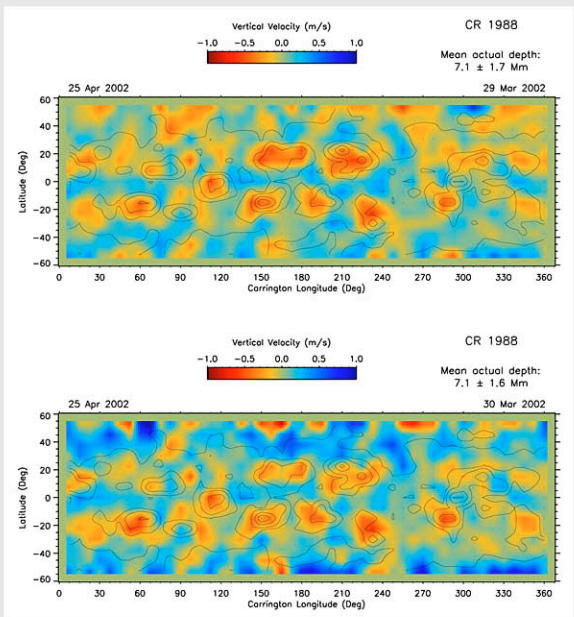
The vertical velocity of near surface layers (0.9 – 4.4 Mm) for each Carrington Rotation derived from MDI data (top) and from GONG data (bottom). The contour lines indicate magnetic flux. Downflows coincide with locations of magnetic activity.

Vertical Vorticity — CR 1910, CR 1988



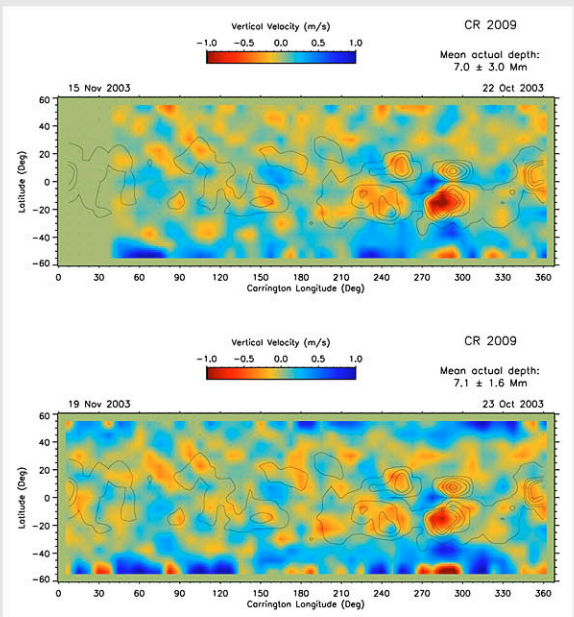
Vertical vorticity at a depth of 7.1 Mm during epochs of low and high magnetic activity derived from MDI data. Positive values imply a counterclockwise motion. The contour lines indicate magnetic flux (5, 20, 40, 80, and 120 Gauss).

Vertical Velocity — CR 1988



Vertical velocity at a depth of 7.1 Mm (Top: MDI; bottom: GONG). Positive/negative values indicate upflows/downflows. The contour lines indicate magnetic flux (5, 20, 40, 80, and 120 Gauss) from NSO Kitt Peak magnetograms.

Vertical Velocity — CR 2009

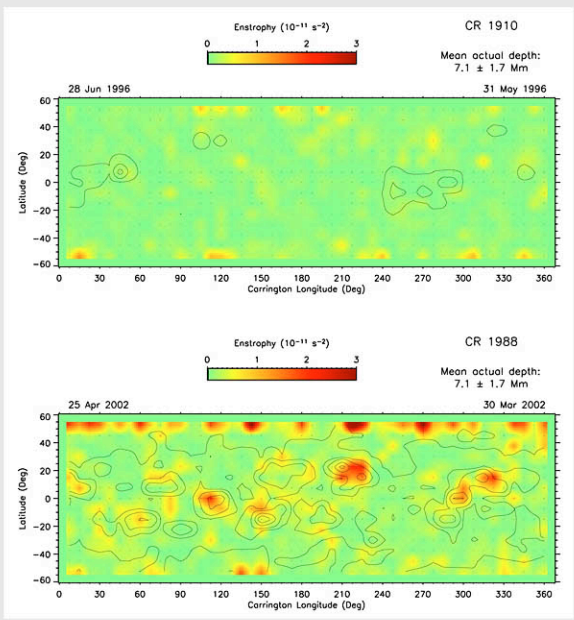


Vertical velocity at a depth of 7.1 Mm (Top: MDI; bottom: GONG). Positive/negative values indicate upflows/downflows. MDI and GONG data show very similar results; differences occur mainly at high latitudes.

Variance of 3-D Vorticity (Enstrophy)

To improve the visibility of the relation between vorticity and magnetic activity, we calculate an unsigned quantity from the complete 3-D vorticity vector, the so-called enstrophy, defined as the variance of vorticity (Lesieur, 1987).

Variance of 3-D vorticity at a depth of 7.1 Mm during epochs of low (top right) and high magnetic activity (bottom right). The difference in vorticity between high and low activity is now obvious.



Conclusions

- MDI and GONG data show similar results.
- We can derive the complete 3-D vector of velocity and vorticity in near surface layers.
- Strong downflows occur at locations of large magnetic flux. The variance of the 3-D vorticity is large at these locations.
- The smooth patterns on time scales of the solar cycle are averages of lumpy patterns on short time scales. No surprise.

References

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Komm, R., Corbard, T., Durney, B.R., González Hernández, I., Hill, F., Howe, R., & Toner, C. 2004, ApJ, 605, 554
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