Vorticity of Solar Subsurface Flows and Torsional Oscillations

R. Komm[1], R. Howe[1] , I. Gonzalez Hernandez[1], F. Hill[1], D. Haber[2], B. Hindman[2], and T. Corbard[3]
[1] NSO, Tucson, AZ; [2] JILA, Boulder, CO; [3] Obs. de la Côte d Azur, Nice, France

Introduction

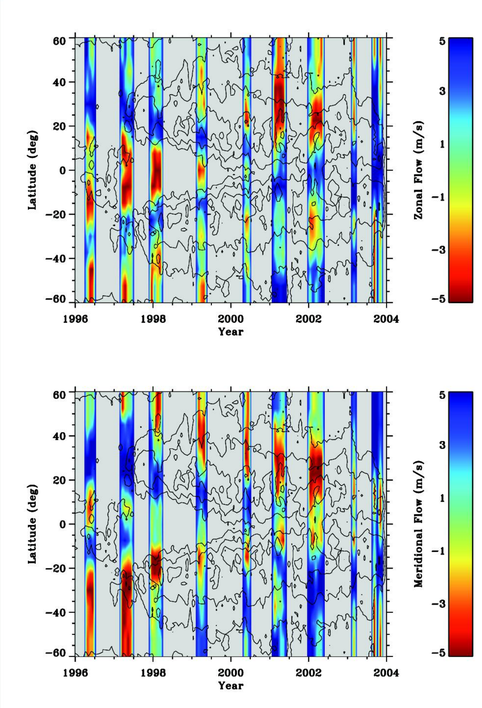
We measure the horizontal components of subsurface flows with the ring-diagram technique analyzing MDI Dynamics Program data covering 28 Carrington Rotations (Haber et al. 2002). We study the relation between horizontal flows and surface magnetic activity by calculating their divergence and vorticity. Using mass conservation, we derive the vertical velocity component from the measured divergence of the horizontal flows (Komm et al. 2004).

The vertical vorticity is dominated by differential rotation which leads to a nearly linear latitude dependence with positive/negative values in the northern/southern hemisphere (Zhao & Kosovichev, 2004). Positive vorticity implies a counterclockwise motion. To emphasize the variations, we subtract the contributions of the mean differential rotation and the mean meridional flow.

Here, we focus on:

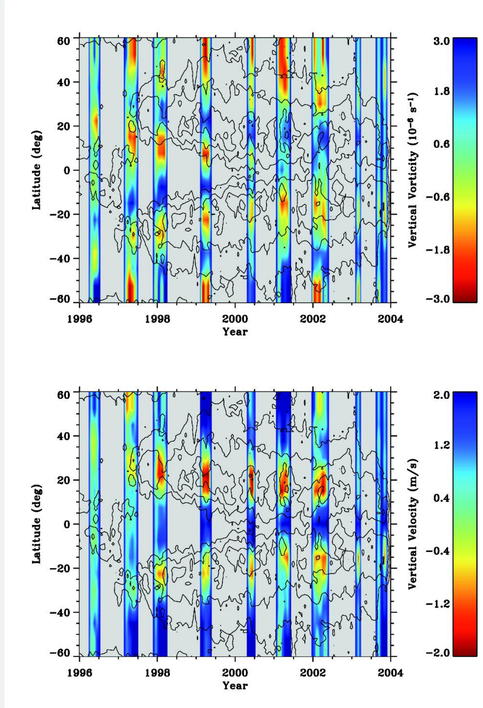
- Solar-cycle variation of the horizontal flows (torsional oscillations and meridional flow), the vertical flows and the vertical vorticity;
- Vertical velocity and vorticity during epochs of high and low magnetic activity (CR1988 analyzed by AZ, CR1910 by CO);
- Variance of 3-D vorticity and its relation to magnetic activity.

Solar-Cycle Variation of Horizontal Flows



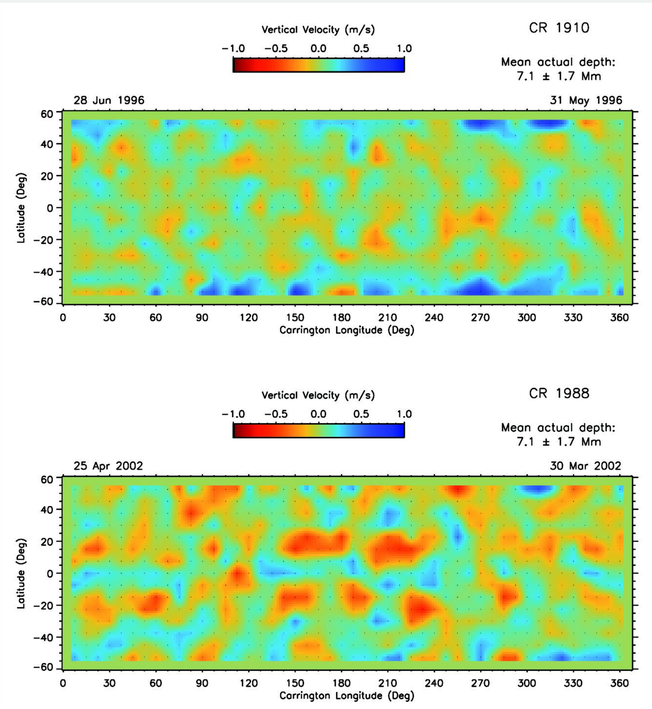
Zonal (top) and meridional flows (bottom) of near surface layers (0.9-4.4 Mm). The average was subtracted at each latitude. For meridional flows, positive/negative values indicate flows to the north/south.

Solar-Cycle Variation of Vertical Flows and Vorticity



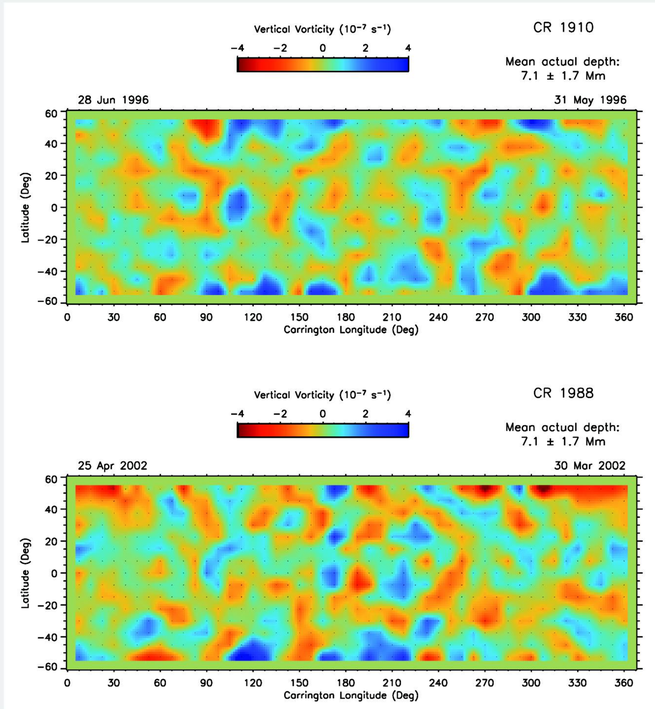
The vertical vorticity (top) and vertical velocity (bottom). The contour lines indicate magnetic flux. Downflows coincide with locations of magnetic activity. The vorticity pattern tracks the magnetic activity as well.

Vertical Velocity



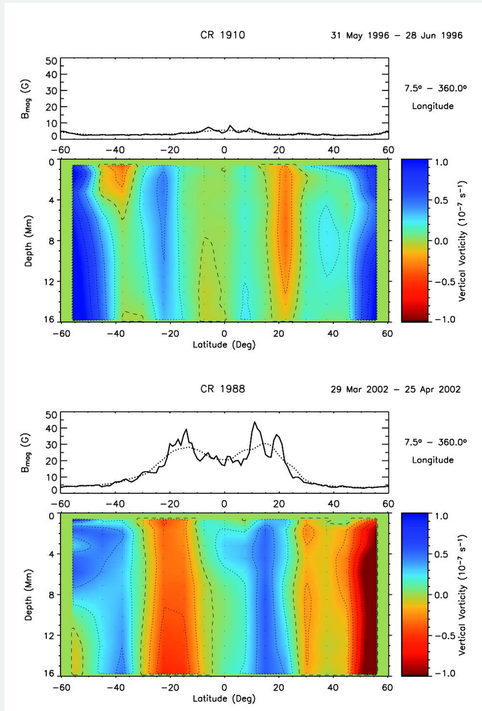
Vertical velocity at a depth of 7.1 Mm during epochs of low and high magnetic activity. Can you spot the active regions? Clue: Strong downflows occur at locations of large magnetic flux. Compare your answer to the transparency.

Vertical Vorticity



Vertical vorticity at a depth of 7.1 Mm during epochs of low and high magnetic activity. Can you distinguish between high- and low-activity epoch? Clue: Look for bands and check the panels to the right. Compare your answer to the transparency.

CR-Averaged Vertical Vorticity

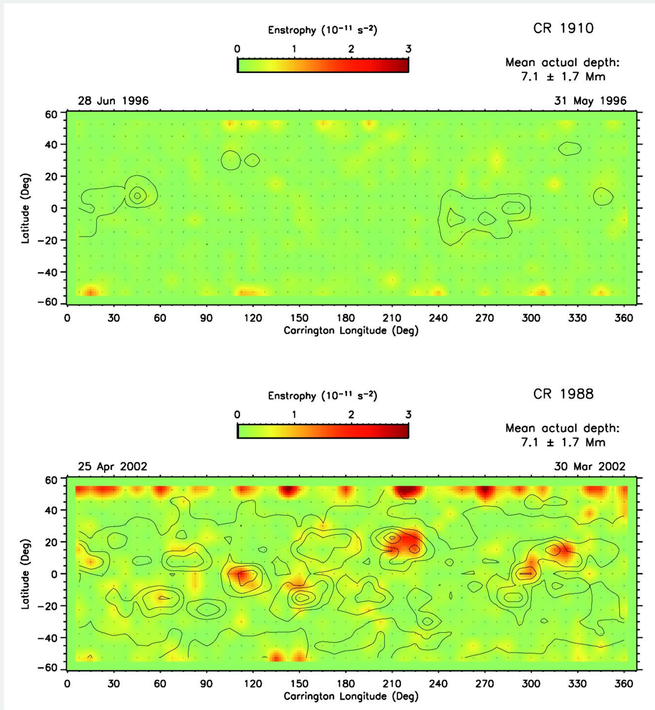


Vertical vorticity averaged over the two Carrington Rotations shown to the left. In the northern/southern hemisphere, the positive/negative residual vorticity is located near 10 and near 40 degree (top) and near 20 degree latitude (bottom).

Variance of 3-D Vorticity (Enstrophy)

The sign change at the equator makes it even harder to see a relation between vertical vorticity and magnetic activity (above center). To improve the visibility of this relation, 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 contour lines indicate magnetic flux (5, 20, 40, 80, and 120 Gauss) from NSO Kitt Peak magnetograms. Now. the difference in vorticity between high- and low activity is obvious.



Conclusions

- 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.
- Are the patterns in vertical velocity and vorticity signatures of convective and magnetic patterns or are they just noise? To be continued.
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References

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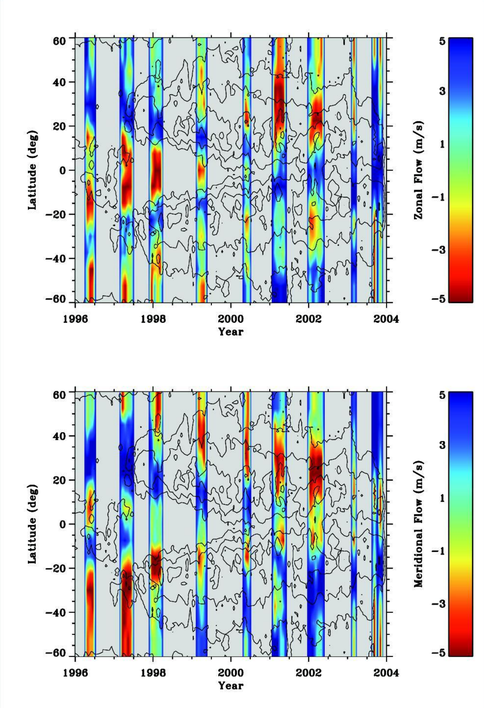

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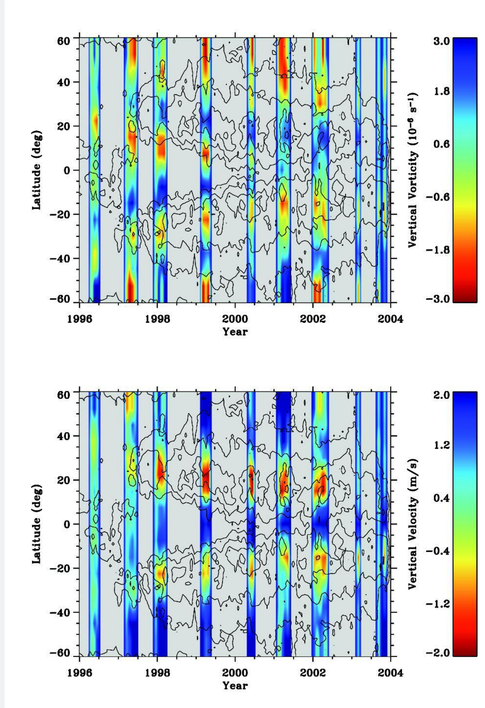

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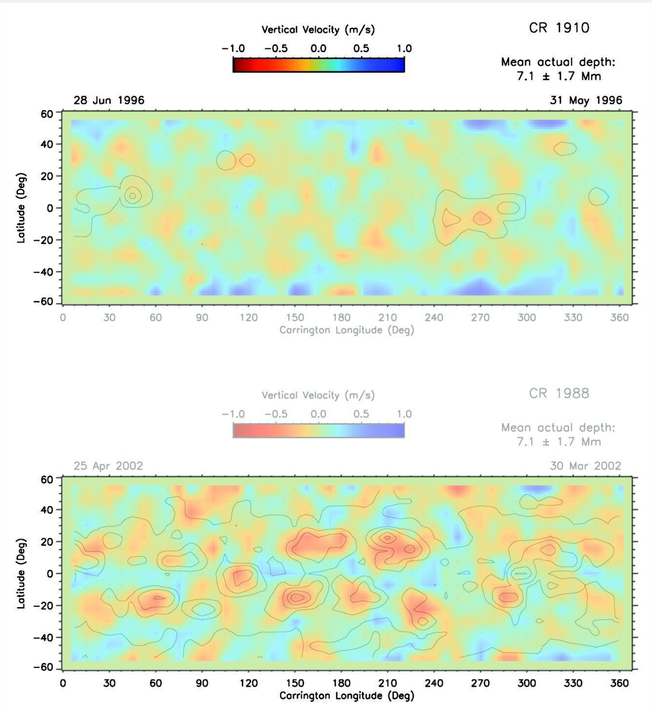

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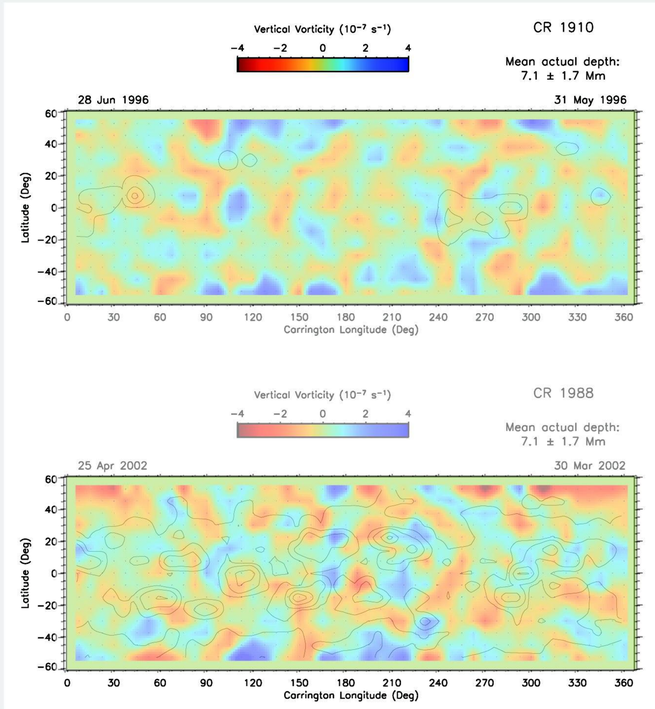

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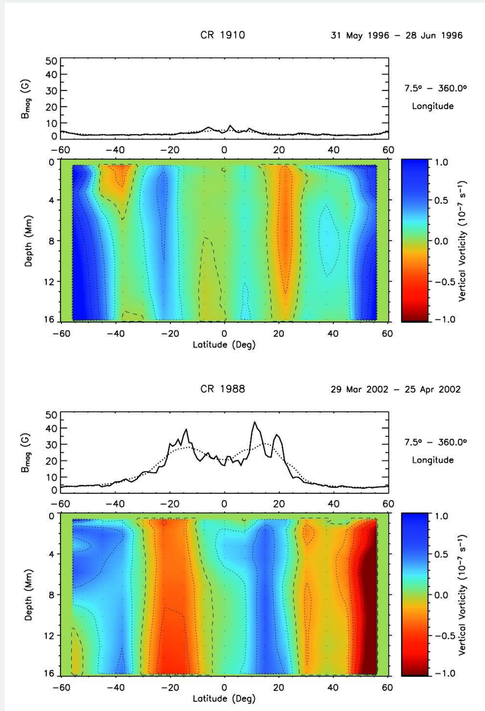

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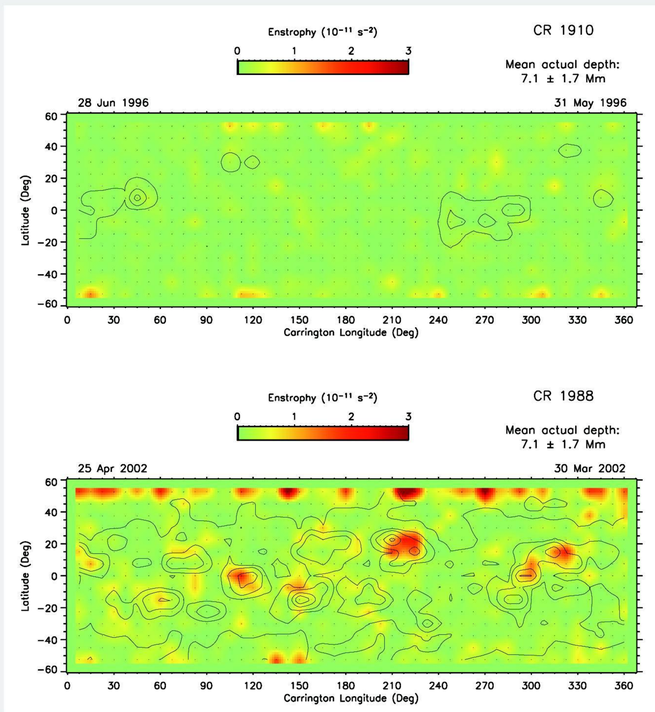

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