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Temporal Variation of Large Scale Flows in the Solar Interior

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Abstract. We attempt to detect short-term temporal variations in the rotation rate and other large scale velocity fields in the outer part of the solar convection zone using the ring diagram technique applied to Michelson Doppler Imager (MDI) data. The measured velocity field shows variations by about 10 m/s on the scale of few days.

Key words. Sun: Oscillations, Rotation, Interior.

The ring diagram technique has been used to study large scale flows in the outer parts of the solar convection zone (Hill 1988; Patron *et al.* 1997; Basu, Antia & Tripathy 1999). The accumulation of MDI data over the last four years has made it possible to study temporal variations in both the zonal and meridional components of the velocity field (Basu & Antia 1999). While long term variations (time-scales of years) in the rotation rate (zonal flow) are reasonably well established from both Doppler and helioseismic studies, short term variations have not been clearly identified. There is some indication from Doppler measurements at the solar surface that these velocity field change on a shorter time-scale of a few days (Snodgrass 1992; Hathaway *et al.* 1996). Similarly, some variation in the interior has also been found in ring diagram study (Patron *et al.* 1998). In this work, we try to study changes in meridional and zonal flows over a time scale of several days.

We use a set of 3d spectra obtained from full-disk Dopplergrams taken during May – June 1996. Each region covers approximately 15° × 15° in latitude and longitude and is tracked for 4096 minutes. We have selected the regions centered at Carrington longitudes of 90°, 60°, 30° for rotation 1909 and at 360°, 330°, 300° for rotation 1910. For each longitude we select regions centered at latitudes of 0°, ±10°, ±20°, ±30°, ±40°, ±50° and ±60°. These spectra cover half of a solar rotation period. For each of these regions, we find the horizontal components of velocity as a function of depth, as explained by Basu *et al.* (1999).

In order to isolate the time-dependent part of the large scale flows, we subtract the mean velocity over the six longitudes covered in this study from the estimated velocity at each latitude, longitude and depth. Fig. 1 shows the resulting velocities at different depths. There is no obvious pattern on spatial scales covered by our study, though it is clear that there is significant variation with longitude (or time). There is also a pronounced north-south asymmetry in the flow pattern.

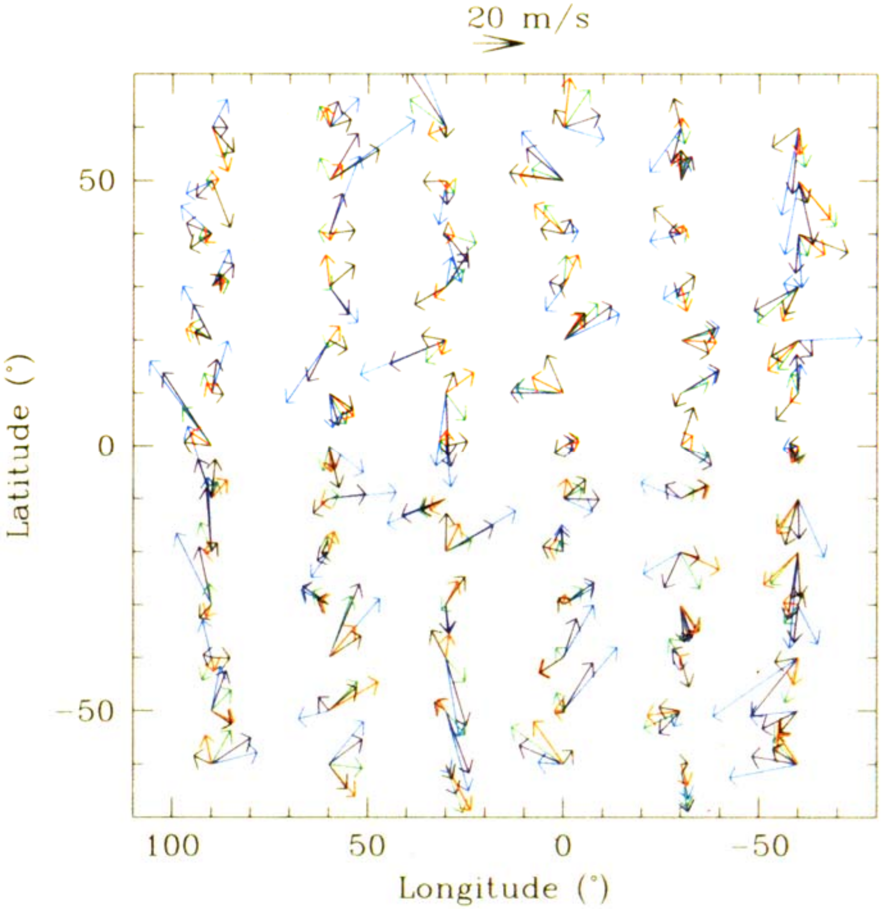

Figure 1. Horizontal flow velocities in horizontal planes at various depths obtained after subtracting the mean over six longitudes covered in this study. Each arrow represents the departure from the mean velocity at the corresponding latitude and longitude. The black, red, green, blue and cyan arrows correspond to depths of 0.995, 0.99, 0.985, 0.98, 0.975R⊙ respectively. The arrow at the top marks the scale and the direction of rotation. The errors in these measurements are not shown but they are typically 2 –5 m/s depending on latitude and depth. Note that the flow direction changes with depth at most points.

Fig. 2 shows the zonal (u_x) and meridional (u_y) component of the residual velocity as a function of longitude and latitude at a few selected depths. Fig. 3 shows these components as a function of depth and longitude at various latitudes. Once again it is clear that there is some variation, but there is no clear pattern. A part of this variation could be due to convective cells of differing sizes present in the solar convection zone. The averaging over a small fraction of solar surface may not remove the convective signal completely. Similar changes have been seen in Doppler measurement at the solar surface (Hathaway *et al.* 1996). If these changes indeed represent real changes in solar rotation rate, then we will also need to examine the long term variations carefully. These variations have been detected in data sets which are averaged over the entire longitude range and over a few months

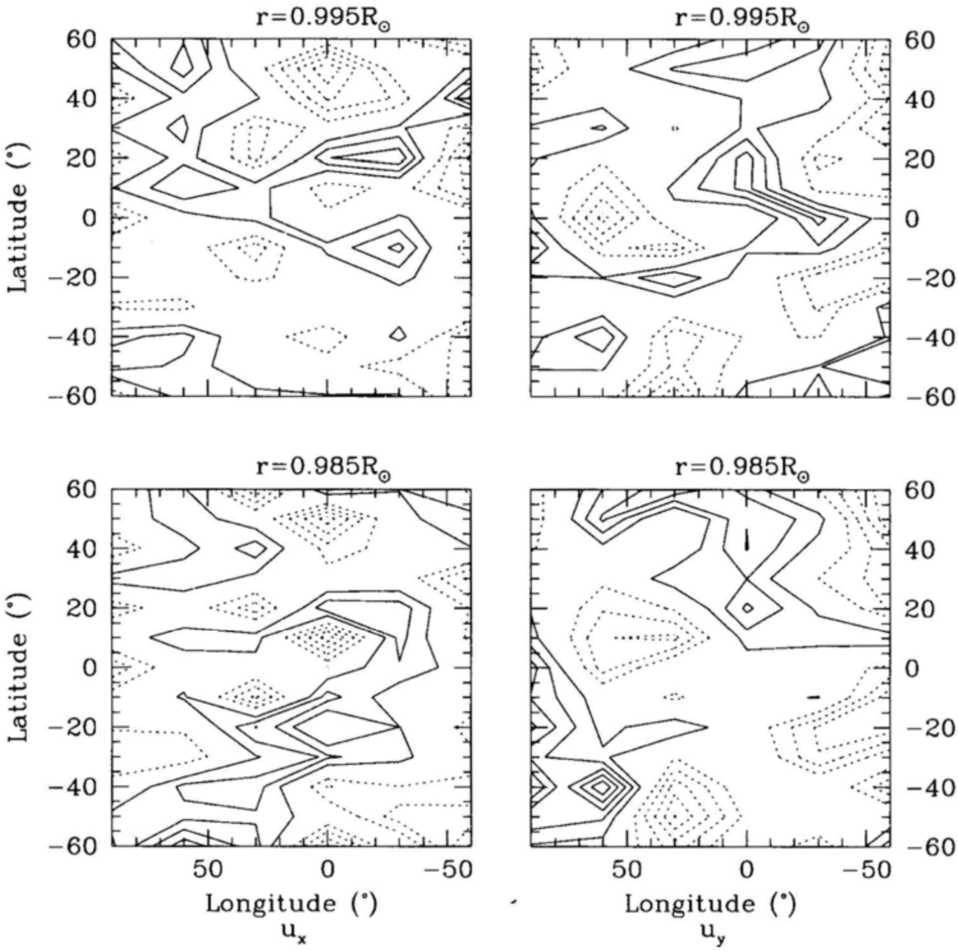

Figure 2. Zonal and meridional components of the time-dependent residual velocity at a few selected depths as marked above each panel, are plotted as contours of constant velocity in the longitude-latitude plane. The left panels show the zonal component, while the right panels show the meridional component. The continuous contours denote positive values while dotted contours display negative values. Contours are drawn at interval of 4 m/s.

in time (e.g., Howe *et al.* 2000). This averaging will tend to suppress the variations on a short time scale, but the entire contribution may not be removed. This residual contribution may produce some noise over the real signal of long-term temporal variations.

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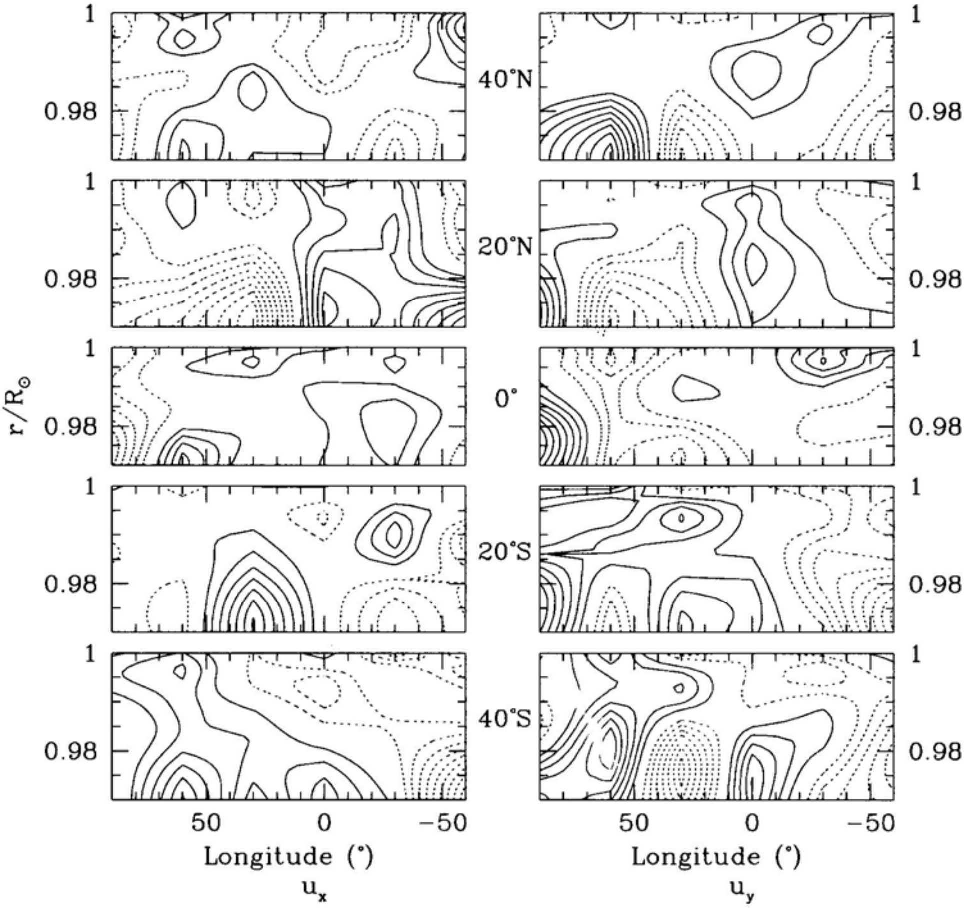

Figure 3. Zonal and meridional components of the time-dependent residual velocity at a few selected latitudes as marked in the center, are plotted as contours of constant velocity in the longitude-depth plane. The left panels show the zonal component, while the right panels show the meridional component. The continuous contours denote positive values while dotted contours display negative values. Contours are drawn at an interval of 4 m/s.

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