Velocity fields in the solar photosphere

Michal Švanda [1,2]

supervisor: Michal Sobotka [2], advisers: Miroslav Klvaňa [2], Pavel Ambrož [2]

[1] Astronomical Institute of Charles University in Prague, Czech Republic
[2] Astronomical Institute of Academy of Sciences of the Czech Republic, Ondřejov Observatory, Czech Republic

Introduction

Motions of mass and structures on the Sun remain an open question, in spite of tens years of intensive studies. Their manifestations are known in various types of observations, but we have only a scarce knowledge about their physics, about connection of photospheric velocity field to the subphotospheric convection and magnetic fields. We think that velocity fields in the solar photosphere are important for redistribution of the magnetic flux, so that photospheric velocity fields can influence the solar activity in an important way.

Methodics

A really interesting structure in the solar photosphere is a supergranulation. It is formed by convective cells with a size approx. 30 Mm and a mean lifetime at least 20 hours (e.g. Wang and Zirin, 1989). Internal velocity field in supergranules is predominantly horizontal with an amplitude 300-500 m/s, while the vertical component is by one order less (Hathaway et al., 2002). Supergranulation can be observed in fulldisk dopplergrams in the whole solar disk, excepting its centre. We assume that supergranules are carried by a velocity field of larger scale, so we used supergranules as tracers to map its motions.

Velocity field can be determined on the basis of the tracking of structures (tracers) that are carried by this velocity field in the time series of frames. A method local correlation tracking (LCT) can be used (November and Simon, 1988). This method works on the principle of best match – local displacements in each positions are determined using correlation between a pair of subframes (limited by a spatial window – correlation window) and velocities of these displacements are calculated. To determine the subpixel amplitudes of vectors the nine-point method is used (Darvann, 1991).

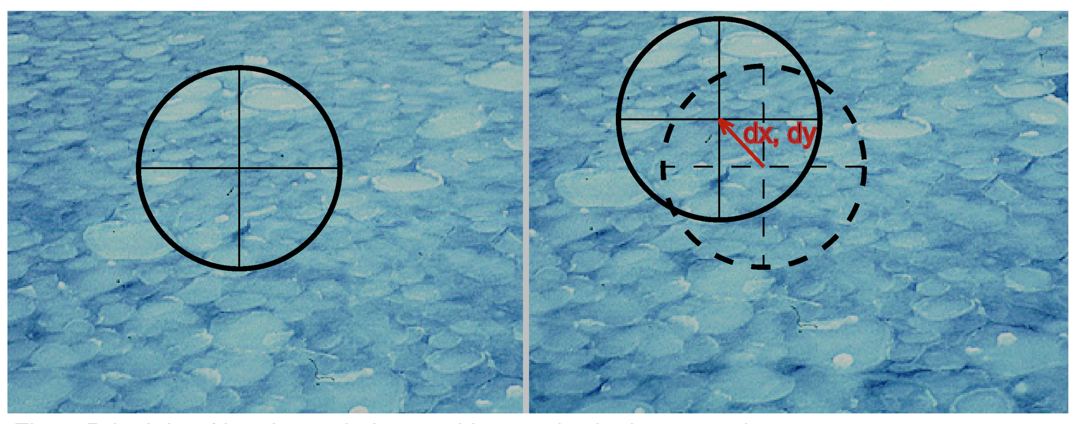

Fig.1: Principle of local correlation tracking method – best match.

Data processing

For this study we use high cadence (one observation per minute) full-disk dopplergrams acquired by the MDI instrument on board the SoHO observatory. These data cannot be directly used for ongoing processing, because they contain too much noise and other disturbing phenomena. So that it is necessary to do some data processing.

a) Data series homogenization

Missing measurement or missing parts of measurement are corrected using linear interpolation between two neighbouring error-free frames to get uninterrupted data series. From these frames, the line-of-sight component of the Carrington's rotation is substracted and the calibration error of MDI (Hathaway et al., 2002) is corrected.

b) Oscilation removal

Next step we remove high frequency oscilation using a weighted average (Hathaway, 1988). The weights have a Gaussian form with the length 30 minutes. We sample averaged images in the interval of 15 minutes. The filter suppresses more than five hundred times the solar oscillations in the 2–4 mHz frequency band.

c) Coordinate system transformations

The sequence of averaged frames of chosen lenght is transformed from the spherical coordinate system to the Cartesian one to compensate geometric distorsions of the shape of supergranules far from the centre of the solar disc. Longitude of central meridian remains the same in all frames. The existence of the differential rotation complicates the tracking of the large-scale velocity field, because the amplitudes and directions of processed velocity field have a significant dispersion in various parts of the solar disc. So that the data are transformed to the coordinate system that rotates with the angular velocity with respect to the observer, which is given by:

$$\omega = 13.064 - 1.69 \sin^2 b - 2.35 \sin^4 b$$

where ω is the angular velocity (in degrees per day), b is the heliographic latitude and coefficients were determined from the plasma rotation by Snodgrass (1984). After aplication of LCT on data sequence this rotation profile is added again to the resulting velocity field.

d) Fourier filtration

Noise in horizontal displacements coming from the individual evolutionary changes in the shape of supergranules is suppressed by a k-ω filter (Hirzberger et al., 1997) in the Fourier domain with the cut-off velocity 700 m/s.

After data processing done this way, the velocity pattern of supergranular cells in full-disk dopplergram is enhanced (Fig. 2). These data can be used to track supergranules and to compute large-scale velocity field.

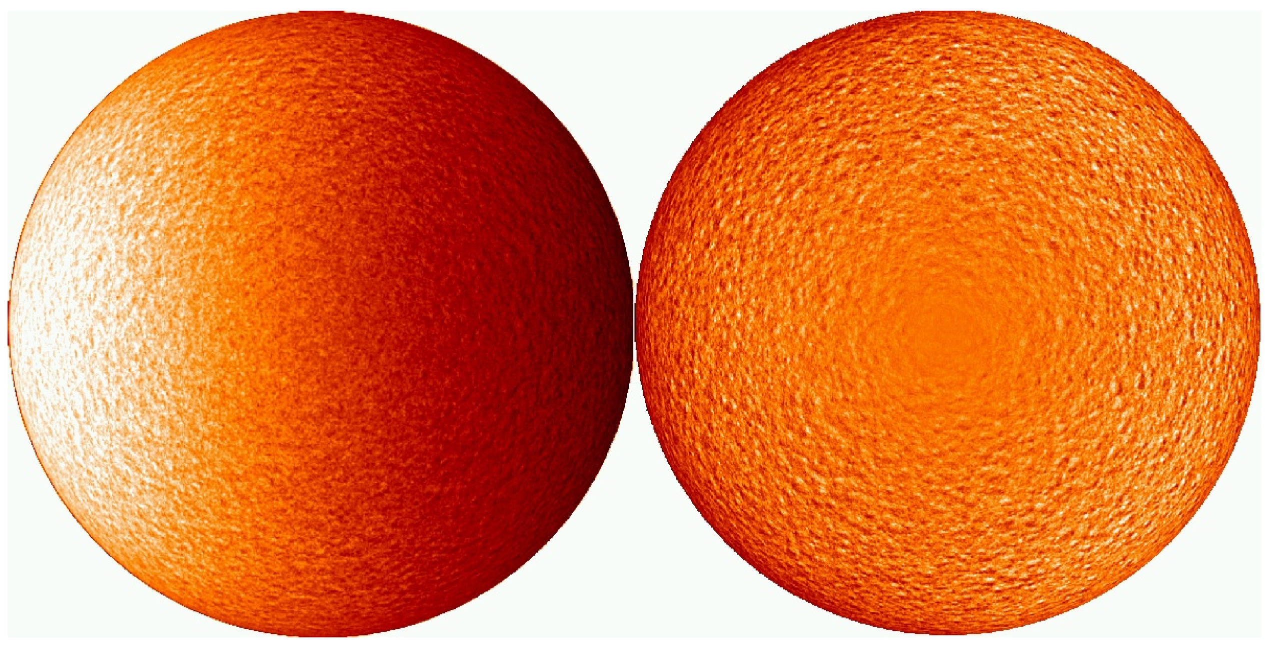

Fig.2: Comparison of the primary dopplergram (left) and the reduced one (right).

Results

Because we study large-scale velocity field, we use the correlation window with FWHM 200" (100") and a time lag between pair of frames is 4 hours. We average the computed velocity over 24 hours and sample results every 12 hours. Until now we have processed one-month series covering time interval May 25th to June 25th 1996.

a) Integral characteristics

From the obtained velocity field, their integral characteristics can be easily inferred: The differential rotation and meridional circulation (Fig. 3). The shapes of both curves correspond to types mentioned in the literature (e.g. Gizon, 2003b). Values of fitted parametres B and C of the differential rotation and values of averaged meridional velocities are in good agreement with literature, too.

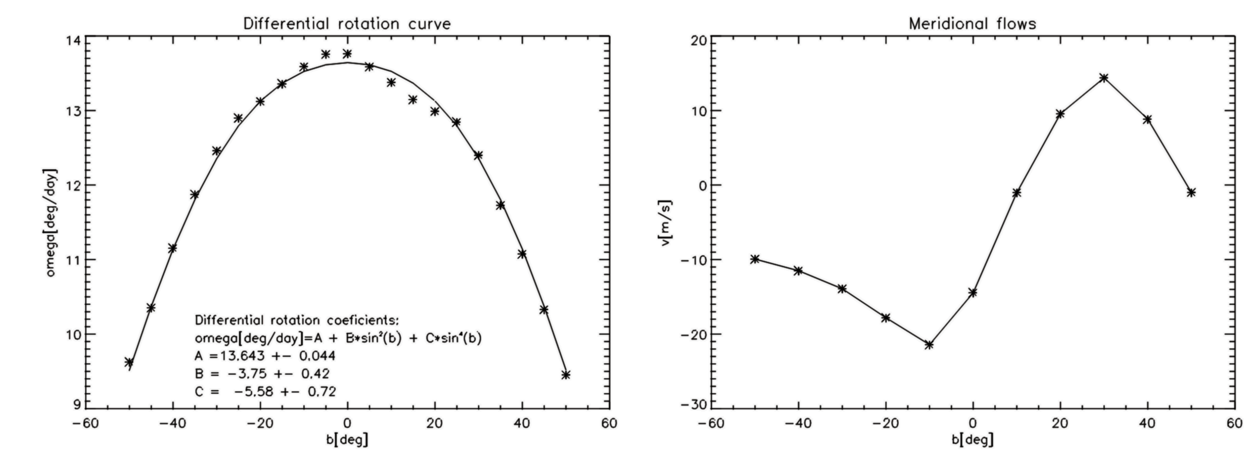

Fig. 3: Integral characteristics of calculated velocity field.

b) Topology of velocity field in the quiet photosphere

Topology of horizontal velocities can be analysed using the double-directional streamlines, where the amplitude of the velocity is represented by a colour. Streamlines representing motions of supergranular structures in the Carrington's coordinate system show laminar flows predominantly in the zonal direction in the equatorial and polar areas. In the images, where differential rotation was substracted, there is best visible a significant inclination of the zonal flow toward the meridional direction. This confirms the existence of meridional flow from the solar equator to the solar poles.

Amplitude of obtained velocities in the Carrington's coordinate system is about 100 m/s in zonal direction (from east to west) and max. 30 m/s in meridional direction in the equatorial area. In polar areas zonal velocities were up to 250 m/s (from the west to the east), meridional component is much fainter here.

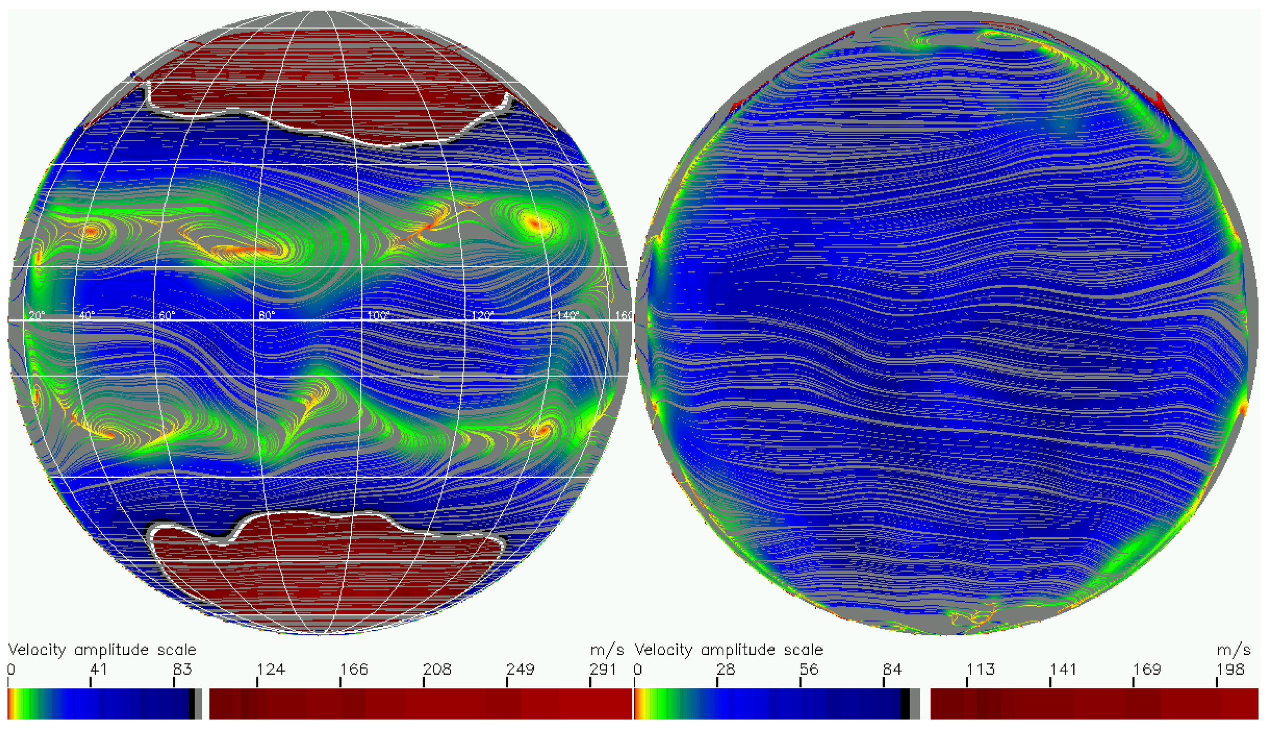

Fig. 4: Left: Streamlines representing the horizontal velocity field infered for May 26th 1996 with FWHM 200". Right: Rezidual velocities on the differential rotation coordinate system – this uniform pattern is easy to be found by the LCT method.

c) Persistent velocity structures

Result of the LCT method is a horizontal velocity field with two components – zonal velocity v_φ and meridional velocity v_θ. Simple formula to get line-of-sight component of this velocity can be used:

$$v_{los} = v_\varphi \sin \varphi + v_\theta \sin \theta$$

where φ and θ are heliographic longitude and latitude measured from the centre of the solar disc. In such "dopplergrams" (Fig. 5 left) we found areas, whose velocity is larger than the velocity of the surrounding photosphere. We can guess parametres of cells from the equatorial cut (Fig. 5 right) – a size about 300 Mm, internal velocity field with the horizontal component ~20 m/s and vertical component ~2 m/s. Slow changes and motions can be seen in temporal series of these "dopplergrams".

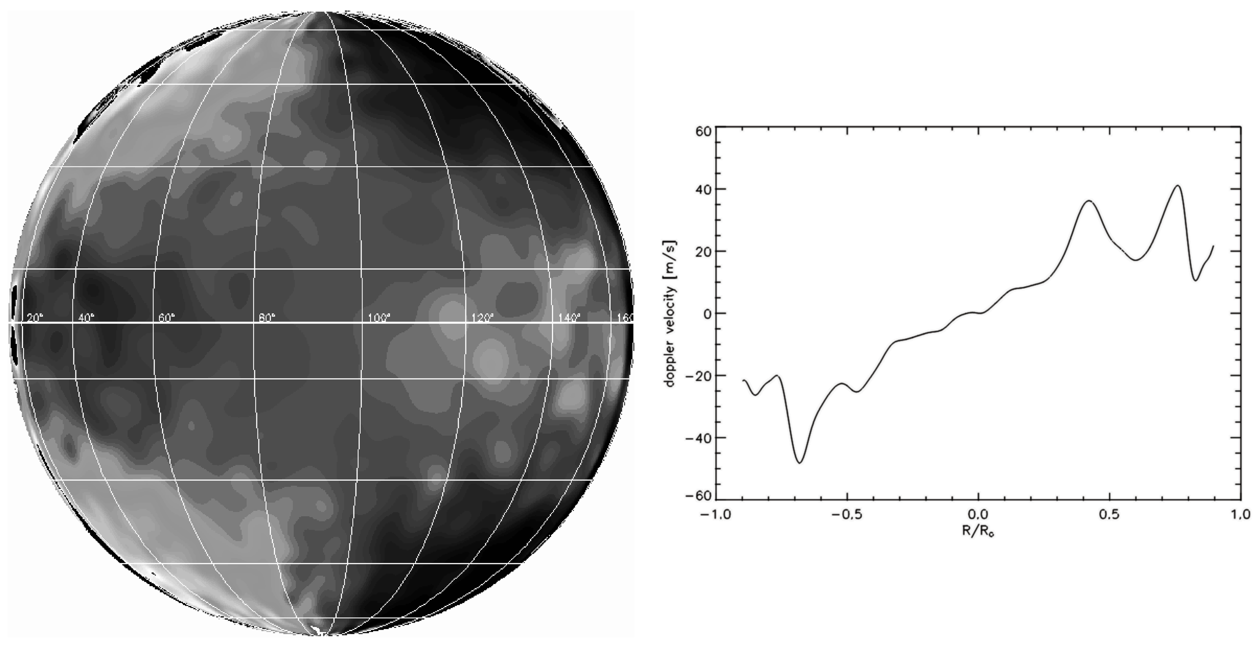

Fig. 5: Doppler component of the horizontal velocity field (left). Equatorial cut through the Doppler component.

Problems

- The vorticity structures in areas near +40 and –40 degrees of heliographic latitude depict areas with small values of velocities. In these areas, the signal-to-noise ratio decreases, so that the noise in the velocity field becomes more significant. Taking into account that streamlines are strongly sensitive to the local changes, suggestive vorticity structures probably do not describe any physical process and are consequences of short-lived morphological structures and of used mathematical techniques.
- In the temporal series of computed velocities we found two superimposed and topologically different components – the first one is moving across the solar disk and it is evidently related to the solar rotation, the second one stays on the solar disk without significant motion in the whole series. We have no idea about the origin of second one component.
- Reproducibility of the streamlines in time is difficult. We think that for large-scale velocity field it should be much better.
- We haven't found any significant evidence of persistent velocity structures in horizontal divergence maps. Only in "dopplergrams".

Reference

Darvann, T. A: 1991, "Solar horizontal flows and differential rotation determined by local correlation tracking of granulation", Ph.D. Thesis, University of Oslo
Gizon, L., Duvall, T. L., and Schou, J.: 2003a, Nature, 421, 43
Gizon, L.: 2003b, "Probing flows in the upper convection zone", Ph.D. Thesis, Stanford university
Hathaway, D. H: 1988, Sol. Phys., 117, 1
Hathaway, D. H, Beck, J. G., Han, S., and Raymond, J.: 2002, ApJ, 205, 25
Hirzberger, J., Vazquez, M., Bonet, J. A., Hanslmeier, A., and Sobotka, M.: 1997, ApJ., 480, 406
November, L. J., and Simon, G. W.: 1988, ApJ, 333, 427
Snodgrass, H. M.: 1984, Sol. Phys., 94, 13
Wang, H., and Zirin, H.: 1989, Sol. Phys., 120, 1

Address for correspondence: svanda@asu.cas.cz