Mapping of large-scale photospheric velocity fields

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Motivation

Solar photosphere is a very dynamic layer of the solar atmosphere. Despite years of intensive studies, velocity fields in the photosphere remain not so well know. An attempt to describe the differential rotation by a parabolic dependence did not make for clear results. We assume that there exists a temporally variable large-scale surface streaming of plasma, for which the differential rotation is only the first approximation.

The long-term high-cadence Doppler measurements done by the MDI instrument on board the SoHO observatory made it possible to develop a method of the calculation of large-scale velocities in the solar photosphere. The proposed method is based on the local correlation tracking (LCT) algorithm (November, 1986) applied to supergranulation, an excellent tracer for its large temporal stability and for the cover of the full disc by its cells.

For proper setting of the parameters and for tuning of the method, synthetic (calculated by SISOID code) data with known properties are needed.

References

Gizon, L., Duvall., T. L., and Schou, J.: 2003, Nature, 421, 43

November, L. J.: 1986, Appl. Opt. 25, 392

Results & Conclusions

The proposed method was applied to the sixty-day series of the measured dopplergrams covering the interval May 25th – July 24th 1996; the one-day-averaged horizontal velocity fields in the Carrington coordinate system were sampled each 12 hours. The calculated velocity field (Fig. 1) has following properties:

- In the polar areas the plasma flows from the west to the east with the mean velocity of approx. 110 ms^{-1}. Along the equator the zonal flow from the east to the west slightly prevails with the magnitude 80–100 ms^{-1}. In the areas of middle latitudes no direction of flows is preferred, the magnitudes of the velocity vectors are typically under 50 ms^{-1}. Since the accuracy of the calculation is 10 ms^{-1}, the signal-to-noise ratio is the lowest here, so that the very small velocities (under 15 ms^{-1}) have to be treated as unreliable here.
- The integral characteristic can be simply inferred (cf. Fig. 2). The shapes of both curves correspond to types mentioned in the literature, both for the values of the fitted parameters B, C and for the velocity of meridional flow. The somewhat larger value of the coefficient A could be a manifestation of the surface low-frequency waves, recently detected in the supergranulation (Gizon, 2003).
- On one day from the processed series (July 7th 1996), the velocities were studied closer for the sake of possible influence by a photospheric magnetic field. Qualitatively there has not been found any interference with the underlying magnetic field (cf. Fig. 2 left); the velocity vectors seem to have the same character in both areas occupied by the magnetic field and areas without the magnetic field. While this contribution has a preliminary character, the coupling between the calculated velocities and the magnetic field in the photosphere will be studied later in more detail.

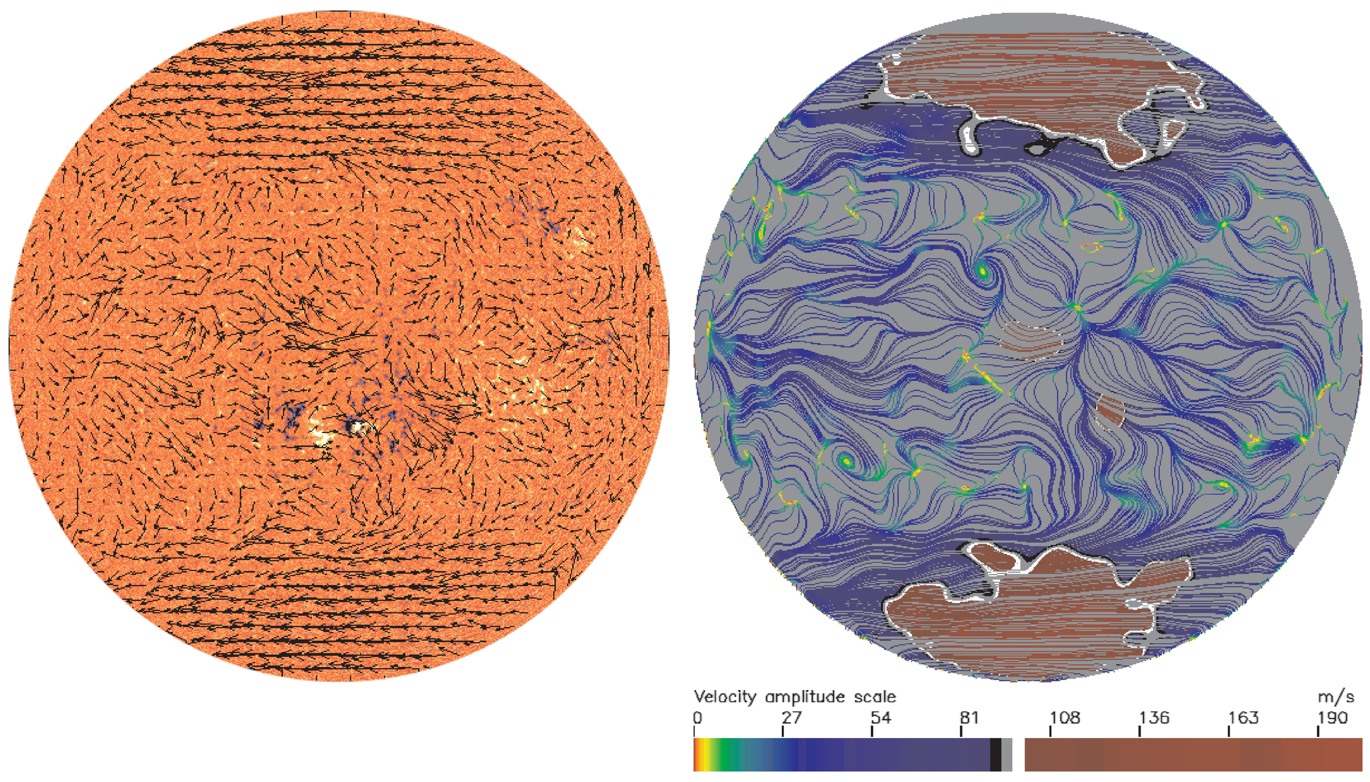

Fig. 1. Example of measured velocity fields in the Carrington coordinate system: Horizontal velocities on July 7th, 1996, one-day average. Left – visualisation with arrows (the MDI dopplergram in the background, blue (yellow) tones signify the negative (positive) polarity of the magnetic field). Right – visualisation by streamlines.

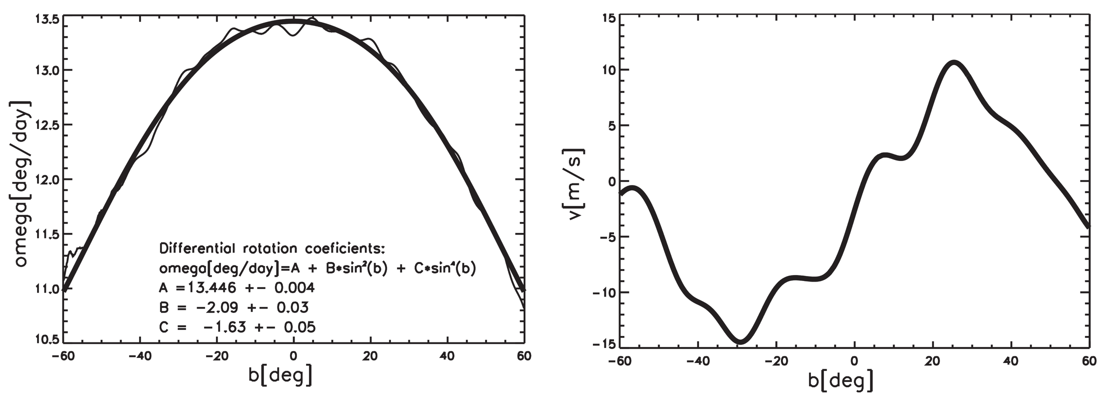

Fig. 2. Integral curves calculated from the horizontal velocity field obtained for July 7th 1996. Left – synodic differential rotation curve, right – meridional circulation curve.

Data processing

The steps of the data reduction to the form suitable for the computation of the large-scale velocites can be seen in Fig. 3. It follows from the tests on the synthetic data that the results have the spatial resolution 60" (43.5 Mm) and an accuracy of 10 ms^{-1}.

Calibration

From the test on the synthetic data (computed by the SISOID code) it came clear that small velocities are underestimated by the LCT algorithm while large velocities are overestimated. We found the calibration curve (1) that fix this issue. v_{calc} is the magnitude of velocities coming from the LCT, v_{cor} is the corrected magnitude; directions of the vectors before and after correction are the same; c is a constant related to the choice of units (c = 1 for "pix/lag" and c = 0.009 93 for ms^{-1}).

$$v_{cor} = \frac{v_{calc}}{0.61 + 0.36\,c\,v_{calc}} \qquad (1)$$

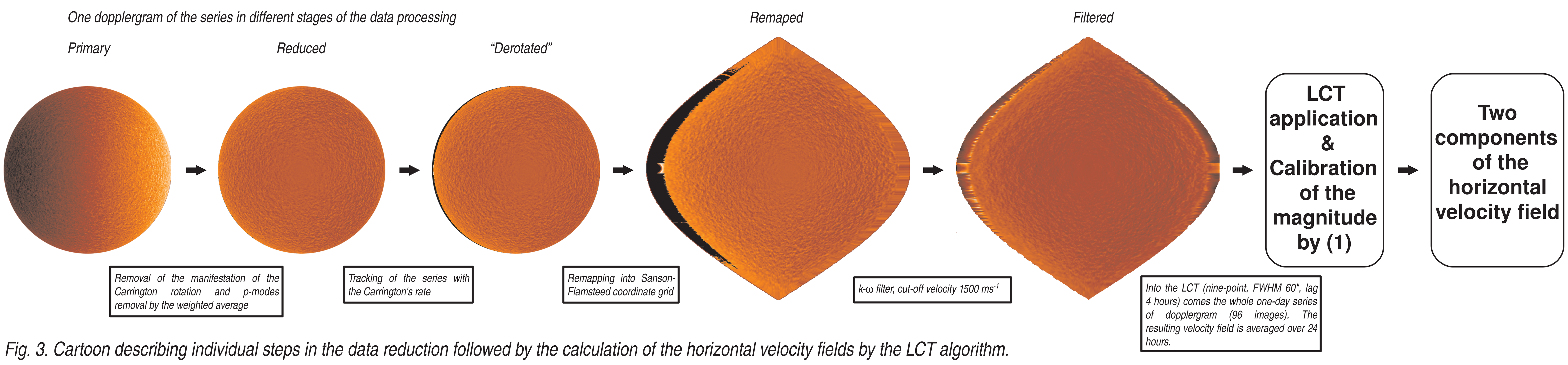

Fig. 3. Cartoon describing individual steps in the data reduction followed by the calculation of the horizontal velocity fields by the LCT algorithm.

Synthetic data – SISOID code

The SISOID (*SI*mulated *S*upergranules as *O*bserved *I*n *D*opplergrams) code is not based on physical principles taking place in the origin and evolution of supergranulation. It is based on the reproduction of known parametres that describe the supergranulation. Individual cells are characterised as centrically symmetric features described by position, lifetime, maximal diameter and characteristic values of their internal velocity components; all these quantities are chosen randomly according to the corresponding measured distribution function. The SISOID simulation is done in the pseudocylindrical Sanson-Flamsteed coordinate grid; in each step an appropriate part of the simulated supergranular field is transformed into heliographic coordinates.

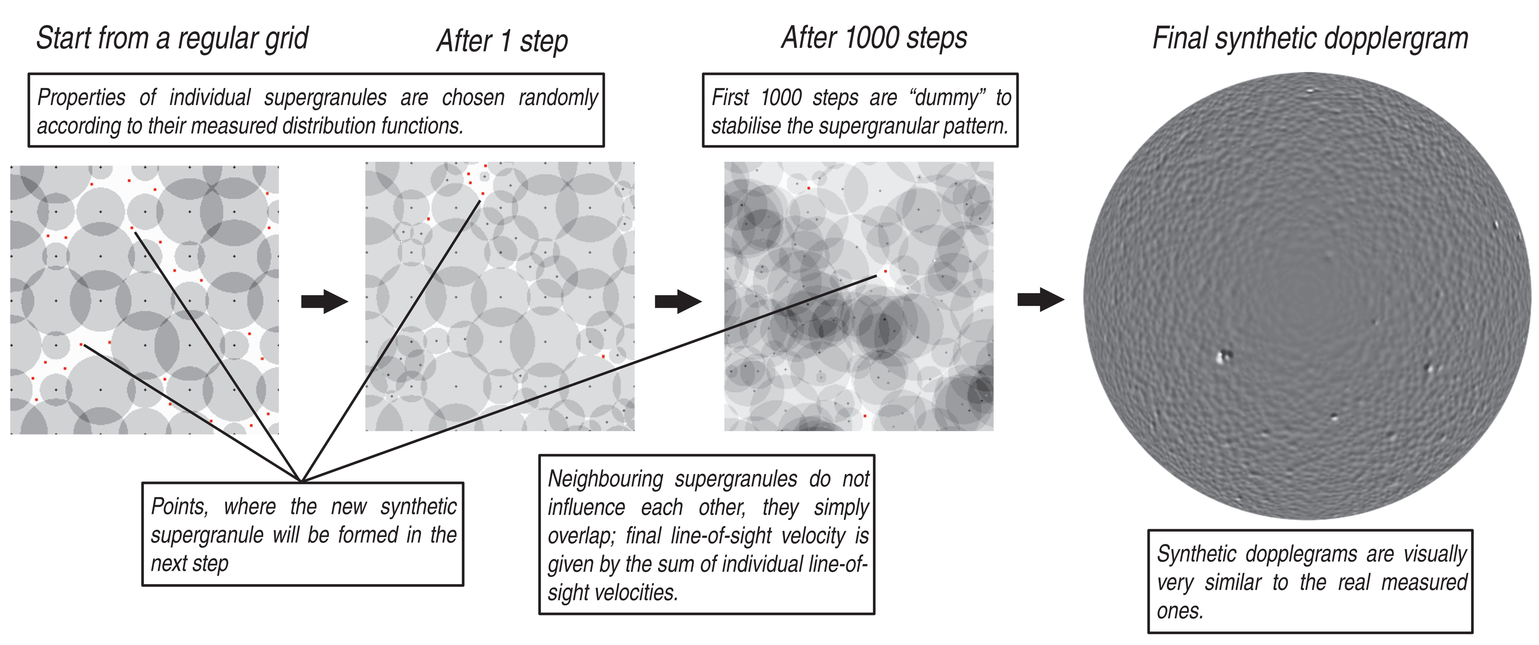

Fig. 4. Main principles of the SISOID code, which computes a synthetic supergranulation.

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