Transport of supergranules and their vertical coherence

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Abstract

In the recent papers, we introduced a method for measuring the photospheric flow field, which is based on the tracking of supergranular structures. Here, in combination with helioseismic data we are able to estimate the depth in the solar convection envelope, where the detected large-scale flow field is coherent. We show that upper 10 Mm in the convection zone depict similar features in the horizontal velocities. We may interpret this observation that the supergranulation is a coherent structure 10 Mm deep and is subjected to the large-scale transport by the underlying velocity field.

Introduction

The supergranulation is a cellular pattern (size of ~30 Mm, lifetime ~24 hours) that covers the whole solar disc and is well visible especially in full-disc Dopplergrams. The visibility in Dopplergrams acquired with MDI@SOHO gives an opportunity to use the supergranulation as a tracer to calculate the large-scale velocity field. In recents papers (Švanda et al. 2006 and references to that paper) we introduced a method based on this idea and demonstrated that it is capable of measuring the large-scale velocity field, and that it reproduces well known properties (differential rotation, meridional circulation) in a good agreement with local helioseismology results.

Here we establish the range of depths in the solar convection zone, where the detected velocity field is coherent.

Data and Method

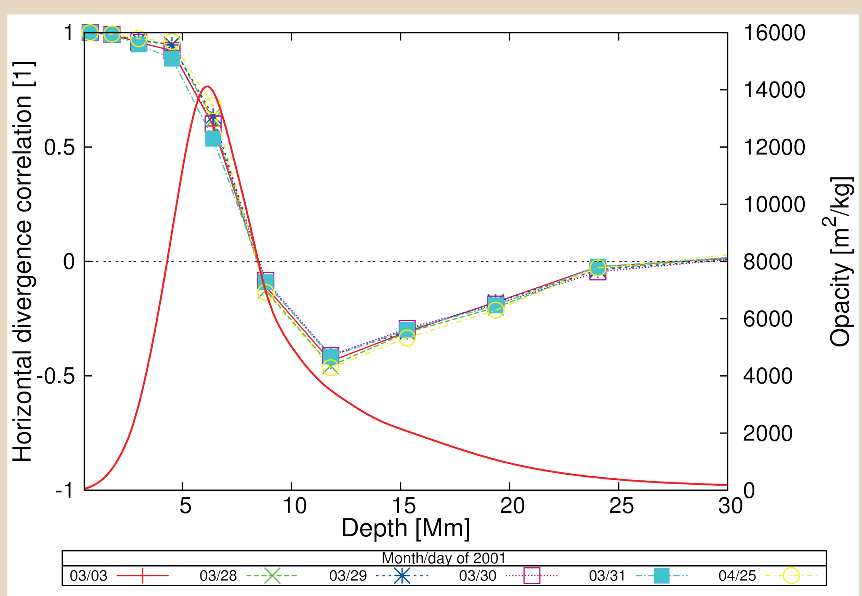
The method is based on the local correlation tracking (LCT) algorithm, which is applied to the processed 24-hours series of high-cadence full-disc full-resolution MDI Dopplergrams. The data processing consists of systematic effects and noise removal and coordinate transformation (fixed position Postel projection).

Here we compared the results of the tracking method with the flow maps coming from the time-distance helioseismology in six days in March/April 2001 in region of NOAA 9393/9433. Time-distance maps were smeared to remove the signal of internal velocity field in supergranules. As the measure of the comparison, the magnitude weighted cosine is used. We calculated the similarity of LCT results for each depth of the time-distance datacube.

To distinguish different regimes, we divided the maps into regions occupied by magnetic field and quiet Sun regions.

Vertical structure of supergranules

To determine the vertical structure of supergranulation, we removed the large-scale flows from the maps of the studied region and calculated the horizontal divergence as a characteristic of the inflows/outflows structure. Then we correlated the flow maps at different depths with the map just below the surface (similar analysis was done by Zhao & Kosovichev 2003).



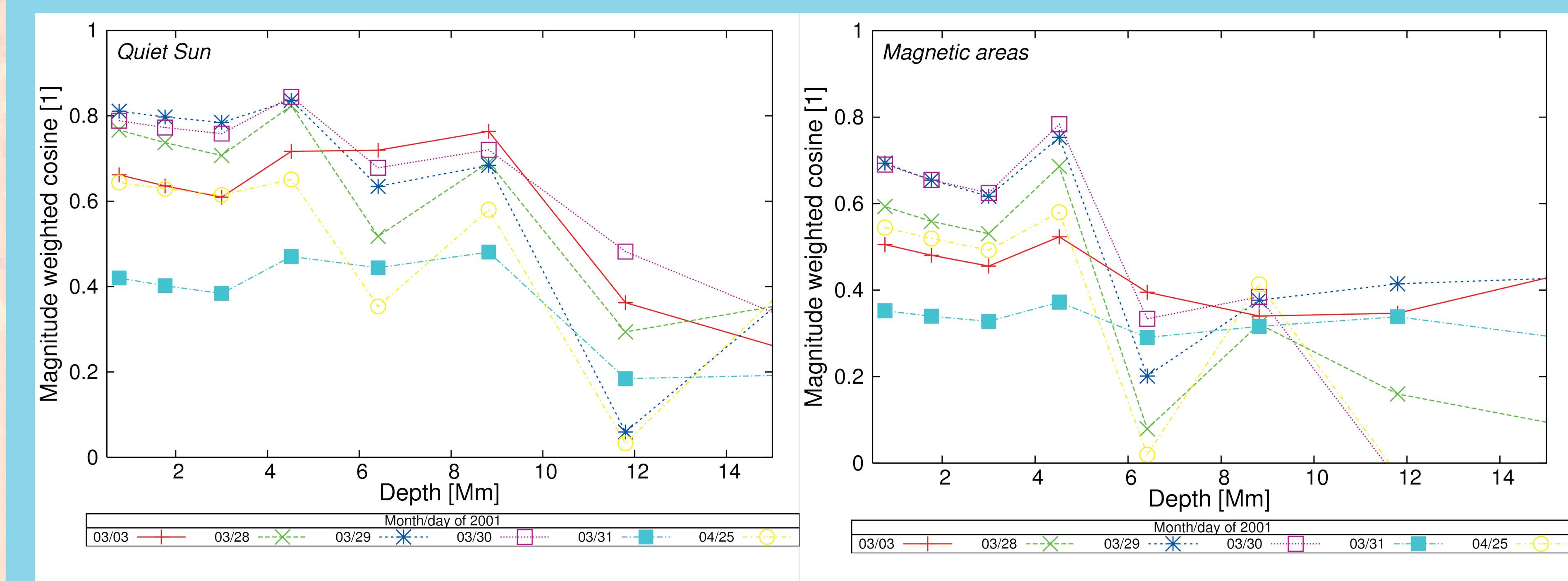
The results showed that the inflows/outflows structure is highly correlated in the top ~7 Mm of the convection zone. The correlation then turns negative, which suggest the existence of the return flow.

The supergranulation seems to exist as the well established structure within upper 10–12 Mm of the convection zone, however it is expected to start at ~25 Mm, where the opacity increases (the thick red line, after Christensen-Dalsgaard 1996). The surface-like supergranular pattern is well visible at depths, where the opacity reaches its maximum. In this point the convection process should reach its best efficiency (Schwarzschild 1975).

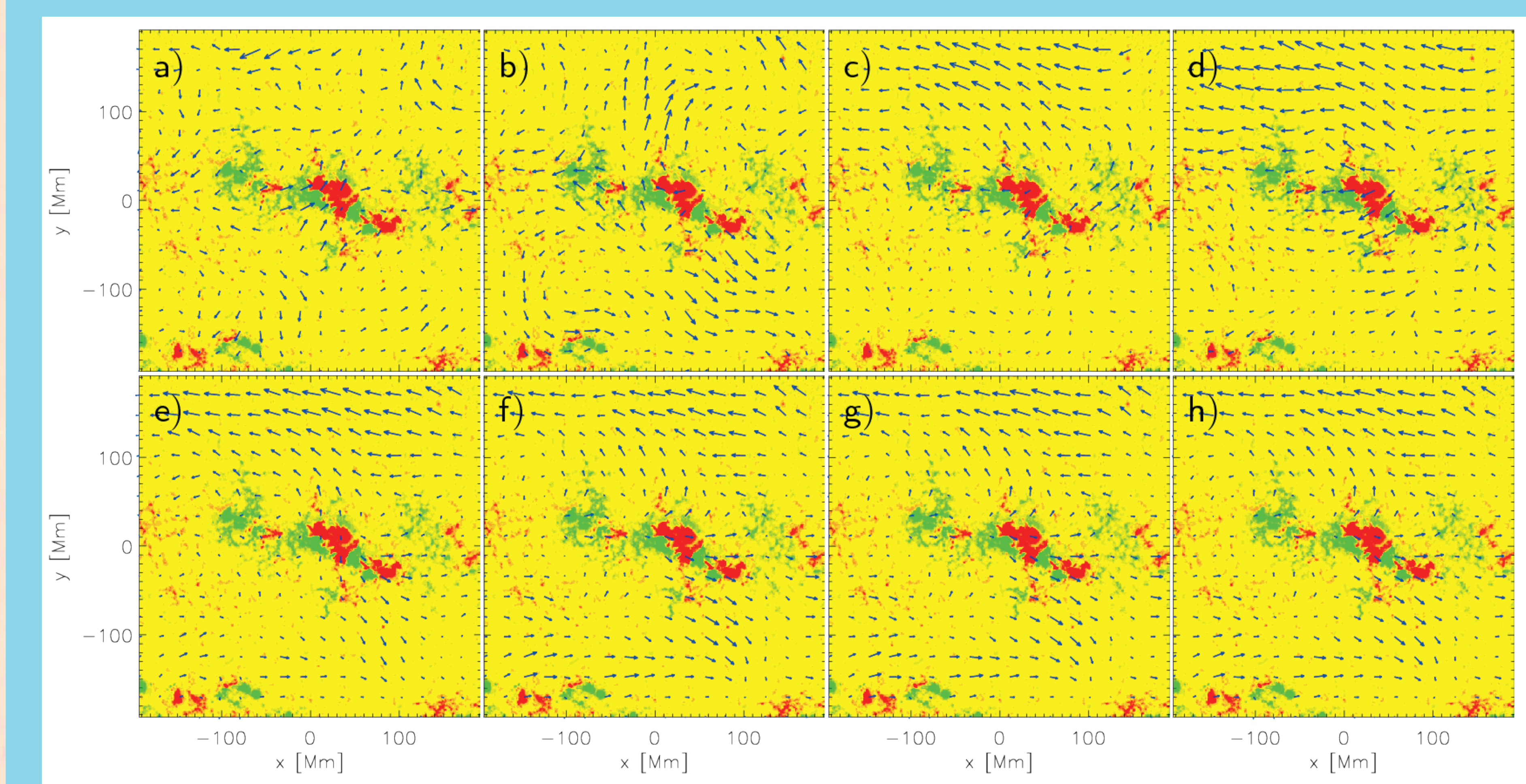
Results and Conclusions

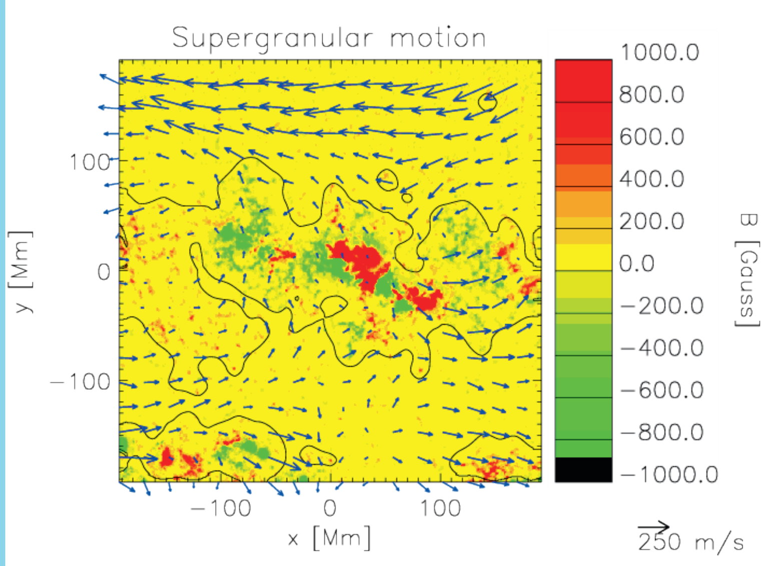
We got a clear answer what we actually track in the full-disc Dopplergram images using our method. It seems clear that in the quiet Sun regions, we indeed track the supergranulation. The large-scale flow does not vary much withing upper ~10 Mm in the convection zone.

In the magnetic regions, we track structures connected to magnetic field features rather than to supergranulation. Therefore the coherence drops down at 5 Mm depth, where other authors claim that sunspots stop suppressing the heat transport.



In the quiet Sun the topology of supergranular scale flows changes between depths of 8.8 and 11.8 Mm. Incorporating our other findings about the vertical structure of supergranulation we may interpret this behaviour as the fact that supergranules are advected by the larger-scale velocity field and that they move in layers down to ~10 Mm below the photosphere coherently. We conclude that supergranules are in nature close to convection cells driven by the opacity mechanism connected to the ionisation changes of helium and hydrogen.





A mosaic of the flows at various depths in the vicinity of NOAA 9393 on March 29th 2001. Compare the topology of the velocity field calculated by the time-distance helioseismology (upper two rows) and the local correlation tracking (on the left). The countours of mask for selection of magnetic and non-magnetic regions are overplotted in the LCT frame. Depths: a – 15.3 Mm, b – 11.8 Mm, c – 8.8 Mm, d – 6.1 Mm, e – 4.5 Mm, f – 3.0 Mm, g – 1.8 Mm, h – 0.8 Mm.

Unfortunately, our results are based only on datasets describing six days in evolution of the close vicinity of one particular very large and complex active region. Therefore, confirmation of our results deserves further investigation using larger set of data, which should be produced by ongoing HMI@SDO mission. More samples in various stages of solar cycle should be used.

We believe that presented results bring some challenges for solar convection envelope modellers.

References

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