Local-Helioseismology Study of Supergranulation in the Polar Region

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Abstract. Hinode/SOT data have been used to study supergranulation in the polar region. Although foreshortening generally makes it difficult to observe the polar region in detail, to partially overcome the difficulty we use the high-resolution Hinode/SOT observations of the polar regions during the period of the highest inclination of the solar axis to the ecliptic. By time-distance helioseismology we have found ‘alignment’ of the supergranular cells peculiar in the polar region. This might be an indication of the giant-cell structure in the polar region.

1. Introduction

It is important for us to understand the solar interior dynamics because the flows in the Sun are considered to play a key role in driving the solar activity via dynamo process. Our knowledge of the interior dynamics is insufficient, however, especially in the polar region; we have difficulty in observing the polar region from the ecliptic plane because of foreshortening. The global helioseismology has revealed rotation rate in the Sun, but the rotation rate in the polar region (and in the deep interior also) has not been determined well. The high-resolution observation by Hinode/SOT and local-helioseismology technique enables us to investigate the polar region with moderate resolution. We exploit this capability of Hinode/SOT to investigate the subsurface flow in the polar region, focusing on supergranulation.

Supergranules are usually considered to be manifestation of convective motions of a certain scale in the Sun. The spatial scale is about 30 Mm and the lifetime is about 1 day. Recent helioseisology studies (e.g., Duvall et al. 1997; Sekii et al. 2007) showed that the depth of the supergranular cells is smaller than the horizontal width and is up to only a few Mm. What determines the structure of supergranulation is unclear, however. Simon & Leighton (1964) suggested that helium ionization zone produces the supergranular cells, although the depth of the zone is about 20 Mm and does not correspond to the shallower helioseismic depth of a few Mm. Stein et al. (2007) suggested magnetic origin of the supergranular cells on the basis of their numerical simulation. We
need further investigation of the interior structure and dynamics of the supergranular cells to confirm their origin. In this work, to compare the supergranulation in the polar region with that in the lower latitude region, we applied the time-distance helioseismology technique to the Hinode/SOT dataset.

2. Observation

The Solar Optical Telescope (SOT; Tsuneta et al. 2008) on board Hinode (Kosugi et al. 2007) observed the polar region in the northern hemisphere on 25 September, 2009. We chose the observation period when the absolute value of the $B_0$ angle of the Sun, which is the heliographic latitude of the disk center, attains its maximum to observe the region at the highest latitude best. We used Ca II H line intensity dataset for our analyses. SOT took Fe I 557.6 nm intensity data as well, and since the Fe intensity images cover wider field of view than Ca intensity images, we used the solar limb in their field of view to track the limb and to determine the coordinates of the field of view for both datasets. After the limb tracking we tracked the differential rotation by the Snodgrass rate (Snodgrass 1984).

Since the observed region is close to the north pole of the Sun, the image obtained by SOT on the ecliptic plane suffered from significant foreshortening. We chose three points with different latitudes for projection centers and remapped the images by Postel’s azimuthal equidistant projection (e.g., Bogart et al. 1995; Zaatri et al. 2008) for analyses.

3. Travel–Time Analysis

Using the tracked and projected dataset, we calculated cross-correlation functions of the oscillation signal to measure the travel times. We used annulus geometry: we calculated the cross-correlation function between a signal at a target point and a signal averaged over an annulus around the target point with a certain radius. Such a cross-correlation function indicates the outward travel time (from the target point) $\tau_{\text{out}}$ and the inward travel time (to the target point) $\tau_{\text{in}}$, and the difference between these travel times indicates divergent/convergent flow around the target point. We used 7 different annulus sizes ranging from 5 Mm to 26 Mm. Cross-correlation functions were fitted by the Gabor-type wavelets (Kosovichev & Duvall 1997) to obtain the phase travel times.

Figure 1 shows the outward-inward travel-time difference map for 14-Mm size annulus. We combined three projected maps for different projection centers into this single map. The dark region indicates the region with the diverging flow ($\tau_{\text{out}} < \tau_{\text{in}}$) and the bright region indicates the region with converging flow ($\tau_{\text{out}} > \tau_{\text{in}}$). The ~ 30-Mm size cells in the map are the supergranular cells. We have found that in the higher latitude region the supergranular cells seem to align in roughly north-south direction. In addition to that, the adjacent cells with diverging flow (dark area) seem to be connected with each other in the alignment direction. This kind of features did not exist in the disk center (Sekii et al. 2007).

The supergranular pattern is also seen in the travel-time difference maps for different annulus sizes, although in the maps for larger annuli (21-26 Mm) it is rather faint. This gives us a clue as to the depth of the cells. The penetrating depth of the acoustic
waves whose skip distance is about 20 Mm is \( \sim 5 \) Mm; the depth of the cells is, therefore, a few Mm and this is consistent with the previous works (Duvall et al. 1997; Sekii et al. 2007) and with our travel-time inversion results (Nagashima 2010).

We also note that when we compared correlation length of the travel-time difference maps of the north polar region dataset with that of a disk center dataset, the correlation length in east-west direction is smaller in the polar region. This implies that the cell size tends to be smaller in the polar region.

4. Discussions and Conclusions

We have found ‘alignment’ of the supergranular cells peculiar in the polar region of the Sun, and also found that the cells are smaller in the polar region, compared to the disk center region. To check if these features are some unknown artefacts due to the observations close to the limb, we also examined a dataset acquired in the east-limb region. We found no obvious peculiarity in the east-limb supergranules.

In the lower latitude region, north–south alignment of the cells have been reported by Lisle et al. (2004). They interpreted that the alignment is of a giant-cell origin; the supergranular cells are aligned along the boundary of the ‘banana cells’. Their observation was 8 days long, while our observation was only 16 hours long. The alignment we have found is a kind of snapshot of the supergranulation and indicates a simple alignment of individual cells at a certain time, whereas the alignment they reported may imply a statistical concentration of the cells in a specific region.

Convective cells in supergranular scale has been unresolved in recent numerical simulation of global turbulent convections. The cells in giant-cell scale (\( \sim 100 \)Mm) in the simulations (e.g., Miesch et al. 2006) show latitudinally elongated cells (so-called
‘banana-cells’) around the equators. The patterns of the cells are more complicated in the higher latitude regions, however, and the ‘alignment’ in the polar region is not expected from the simulations. The alignment we found in the polar region may be an indication of the giant-cell structure in the polar region.

It may also be related to the active longitude where active regions frequently appear. They are manifestation of magnetic field concentration via non-axisymmetric dynamo process. Since during the observation period an active region was around the meridional line, the observed area is centered at the active longitude. Further observations are required to confirm such a relationship between the alignment and the active longitude.

More details are found in Nagashima (2010).

Acknowledgments. K. Nagashima is supported by the Research Fellowship from the Japan Society for the Promotion of Science for Young Scientists. Hinode is a Japanese mission developed and launched by ISAS/JAXA, with NAOJ as domestic partner and NASA and STFC (UK) as international partners. It is operated by these agencies in co-operation with ESA and NSC (Norway). This work was carried out at the NAOJ Hinode Science Center, which is supported by the Grant-in-Aid for Creative Scientific Research “The Basic Study of Space Weather Prediction” from MEXT, Japan (Head Investigator: K. Shibata), generous donations from Sun Microsystems, and NAOJ internal funding.

References

Nagashima, K. 2010, PhD thesis, Graduate University for Advanced Studies