Solar turbulent convection at supergranulation scale

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Supergranulation: effect of rotation

- Known non-zero correlation $\langle \text{div}_h \text{curl}_z \rangle$ in supergranular flows
  $\Rightarrow$ net kinetic helicity

- Due to Coriolis force acting on convective flows

- How does the vorticity look in detail?
  $\Rightarrow$ Map it
  (BUT: net vorticity $\Rightarrow$ average supergranule)

Gizon & Duvall 2003
(Using time-distance helioseismology in MDI Dopplergrams)
Outline

• Map different quantities in the average supergranule

• Map vorticity using:
  ▫ Time-distance helioseismology
  ▫ Local correlation tracking (LCT) of granules

• Map magnetic field
  (advected by supergranular flows)
  ➔ network magnetic field

• Map line-of-sight velocity (Dopplergrams)
  ➔ vertical velocity component
Cross-correlate Doppler velocities at $r_1$ and $r_2$
Wave travel times are affected by flows
Waves travel faster along the flow than against the flow: $\tau_{\text{diff}} = \tau_+ - \tau_-$
How to measure $\text{div}_h$ and $\text{curl}_z$

Divergence-sensitive travel times

$\tau^{\text{oi}}$

“outward − inward”

Vorticity-sensitive travel times

$\tau^{\text{ac}}$

“anti-clockwise − clockwise”

Duvall et al. 1996

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Vorticity-sensitive travel times

$\tau^{oi}$

$\tau^{ac}$

“outward” – “anti-clockwise”

“inward” – “clockwise”

→ Use SDO/HMI Dopplergrams (patches ~180x180 Mm$^2$)

Duvall et al. 1996

Example travel-time maps

Divergence-sensitive travel times
\( \tau^{oi} \)

Vorticity-sensitive travel times
\( \tau^{ac} \)

\( 40^\circ \)

f modes
8h

\( \tau^{oi} \)

\( \tau^{ac} \)
Example travel-time maps

Divergence-sensitive travel times

Vorticity-sensitive travel times

\( \tau^{oi} \)

\( \tau^{ac} \)

Find positions of supergranules
The average supergranule

• Shift maps so supergranules are on top of each other
• Average over ~3,000 supergranules (many maps)

At 40° solar latitude
The average supergranule

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At 40° solar latitude
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At 40° solar latitude

Convert into velocities $v^{ac}$
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- Average over ~3,000 supergranules (many maps)

Convert into velocities $v^{ac}$
Local correlation tracking (LCT)

- Granules get advected by larger-scale flows
  - Use granules as tracers of supergranule motions

- Cross-correlate image parts at times $t$ and $t + \Delta t$
  - get shift $\Delta x$
  - get velocity $v_x = \frac{\Delta x}{\Delta t}$

→ velocity maps $v_x$, $v_y$
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- Cross-correlate image parts at times \( t \) and \( t + \Delta t \)
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→ velocity maps \( v_x, v_y \)
Local correlation tracking (LCT)

- Granules get advected by larger-scale flows
  - Use granules as tracers of supergranule motions
  
- Cross-correlate image parts at times $t$ and $t + \Delta t$
  
  $\Rightarrow$ get shift $\Delta x$
  
  $\Rightarrow$ get velocity $v_x = \frac{\Delta x}{\Delta t}$

$\Rightarrow$ velocity maps $v_x, v_y$
Comparison: Time-distance vs. LCT

Time-distance (f mode)

LCT

40° outflow
Comparison: Time-distance vs. LCT

Time-distance (f mode)

LCT

$-40^\circ$ outflow
Comparison: Time-distance vs. LCT

Time-distance (f mode)

\[ \theta^o \]
outflow

LCT

\[ v^{ac} \text{[ms}^{-1}] \]

\[ y \text{[Mm]} \]

\[ x \text{[Mm]} \]

\[ v^{ac} \text{[ms}^{-1}] \]

\[ y \text{[Mm]} \]

\[ x \text{[Mm]} \]
LCT: Spatially resolved $\text{curl}_z$

outflow

$40^\circ$

inflow

Langfellner et al., A&A, 2015a submitted
LCT: Spatially resolved $\text{curl}_z$

outflow

$-40^\circ$

inflow
LCT: Spatially resolved $\text{curl}_z$

outflow $\circ$ inflow
Line-of-sight magnetic field (SDO/HMI)

Langfellner et al., A&A, 2015b submitted
Magnetic field: anisotropy

outflow

$0^\circ$

\begin{align*}
B & \text{ [Gauss]} \\
\psi & \text{ [deg]} \\
x & \text{ [Mm]} \\
\langle B_{\text{LOS}} \rangle_{\text{ring}} & \text{ [G]} 
\end{align*}
Line-of-sight velocity (SDO/HMI)

outflow \hspace{2cm} 0^\circ \hspace{2cm} \text{inflow}
Line-of-sight velocity: anisotropy

outflow

\[ V_{\text{Los}} [\text{ms}^{-1}] \]

\[ x [\text{Mm}] \]

\[ \langle V_{\text{Los}} \rangle \text{ring} [\text{ms}^{-1}] \]

\[ \psi [\text{deg}] \]
Summary

- Circular velocity of the average supergranule mapped with time-distance and LCT → excellent agreement

- \( \text{curl}_z \) structure different for outflows and inflows (broad and weak vs. narrow and strong)

- Network magnetic field around average supergranule is anisotropic (stronger in the west)

- Anisotropy also seems to appear in line-of-sight velocity