Local Helioseismology of Supergranulation

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Abstract

We show time-distance travel times averaged over roughly ten thousand supergranules. The statistical (realization) noise in these measurements is substantially smaller than the noise associated with a single supergranule. We show that travel-time differences associated supergranulation are strongly frequency dependent. We show that depth-dependent flows can cause frequency-dependent travel time differences. We show preliminary results from numerical simulations of wave propagation through simple supergranulation-like flows.

The data & feature selection

- 68 hours of MDI/*SOHO* full-disk Dopplergrams (Scherrer *et al.*, 1995)
- Use time-distance helioseismology to measure the f-mode divergence signal (e.g. Duvall and Gizon, 2000)
- Identify supergranules in divergence signal
- Average travel times (Duvall *et al.*, 1993) around centers of supergranules (see Fig. 2)

Feature Selection

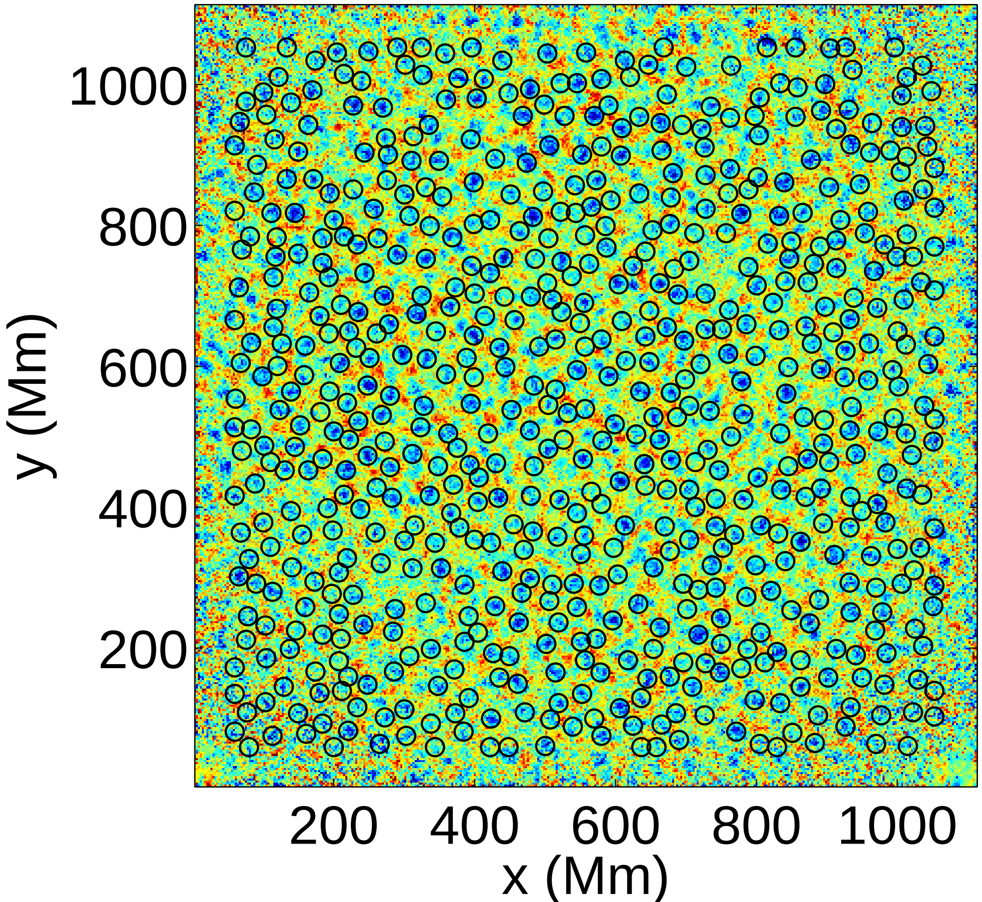

Figure 1: Example result from the feature selection algorithm. The background image is the horizontal divergence (blue shows regions of divergence) estimated from f-mode travel times. The algorithm picks localized regions of flow divergence.

Measurement geometry

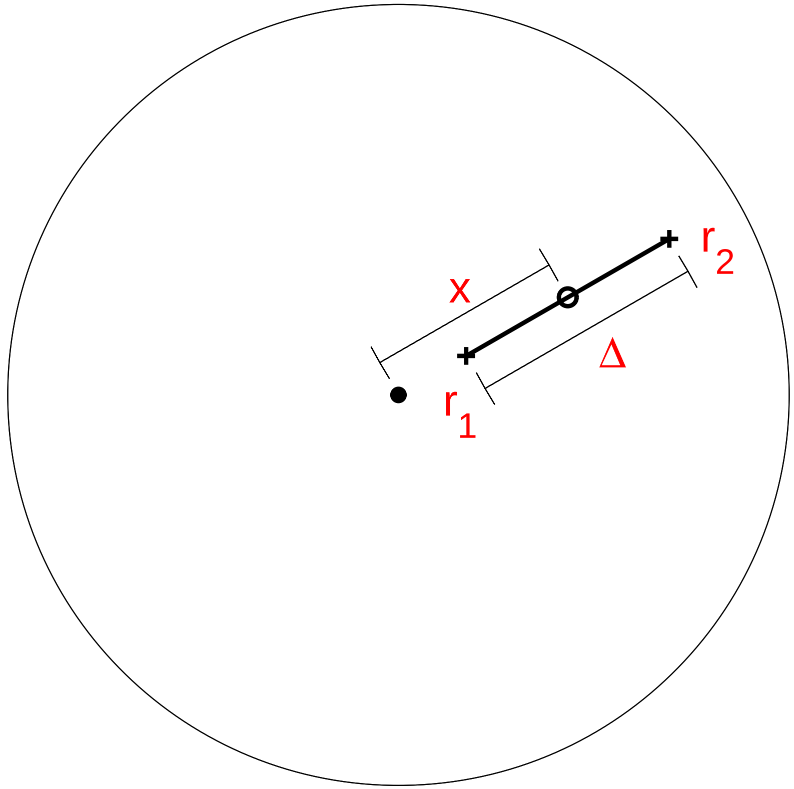

Figure 2: Geometry for measuring travel times. The offset from the center of the supergranule is x and $\Delta = \|r_2 - r_1\|$. The travel times from $r_2 \rightarrow r_1$ and $r_1 \rightarrow r_2$ are measured. These times are averaged over all azimuths from the center of the supergranule and over 10^4 supergranules.

F-mode travel times

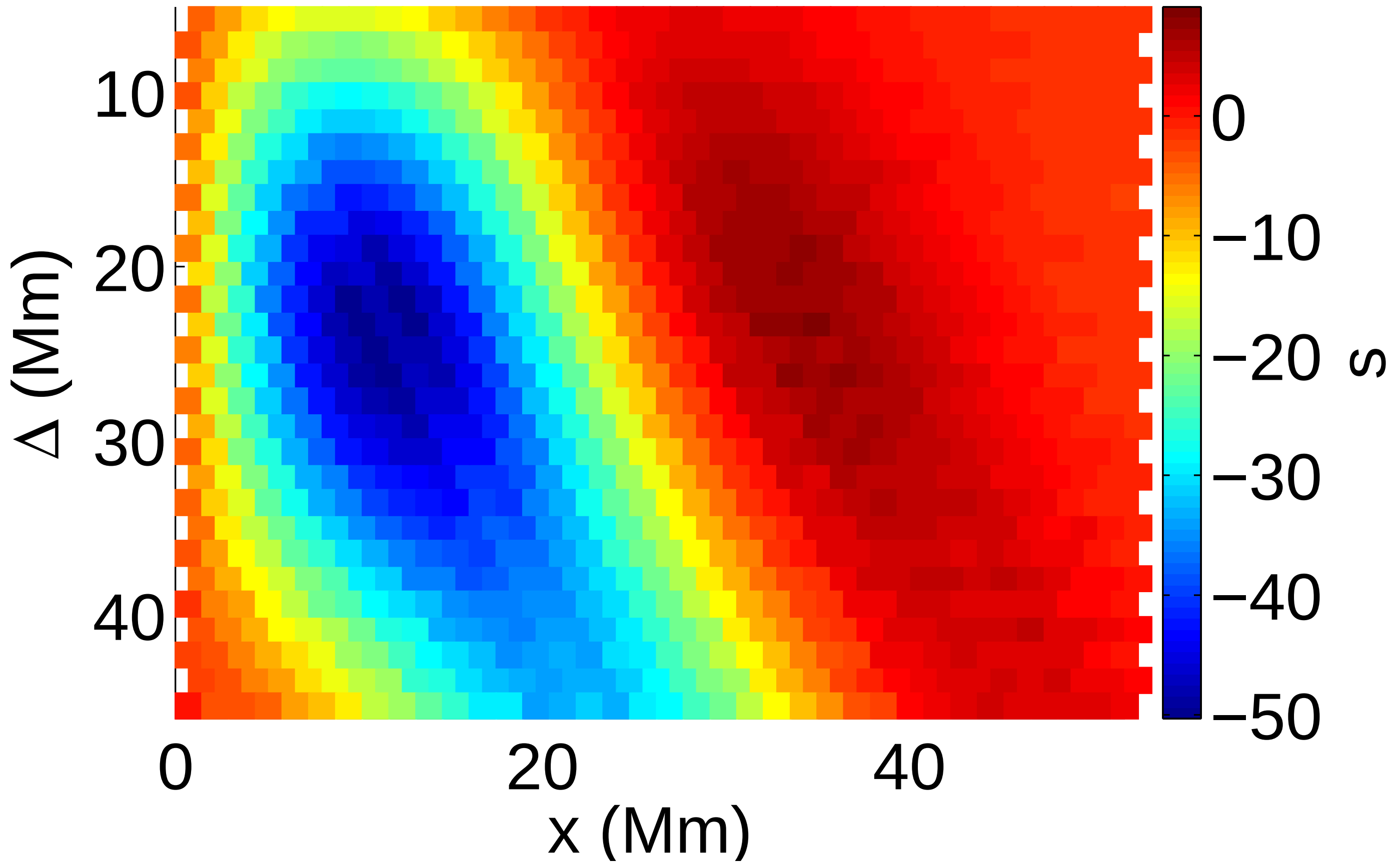

Figure 3: F-mode travel-time difference, $\delta\tau = \tau_{\rm out} - \tau_{\rm in}$ (in seconds) as a function of offset, x, and distance, Δ.

Frequency Filters

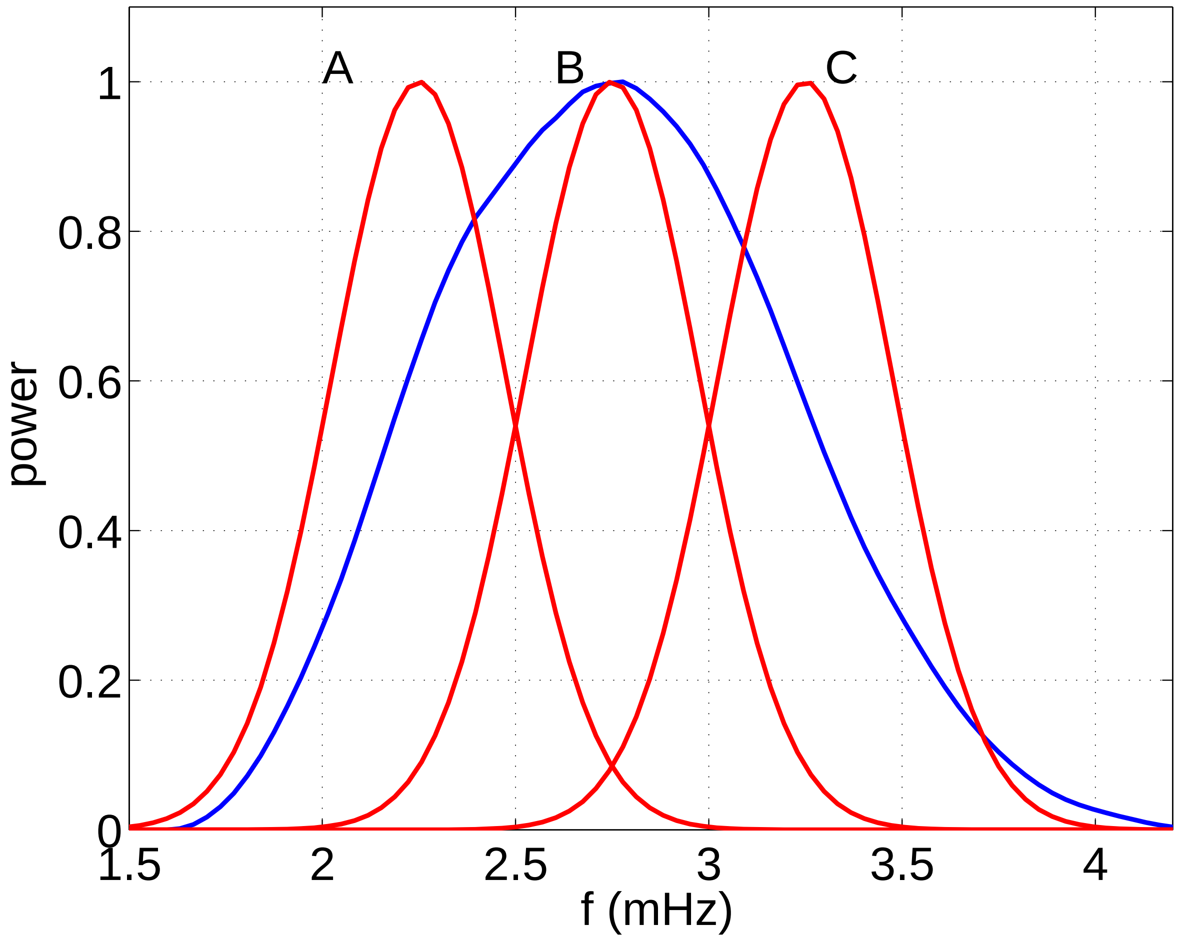

Figure 4: The three frequency filters (red) used in this poster (labeled A,B,C) and the mean power summed over wavenumber (blue).

Travel-Times after Filtering

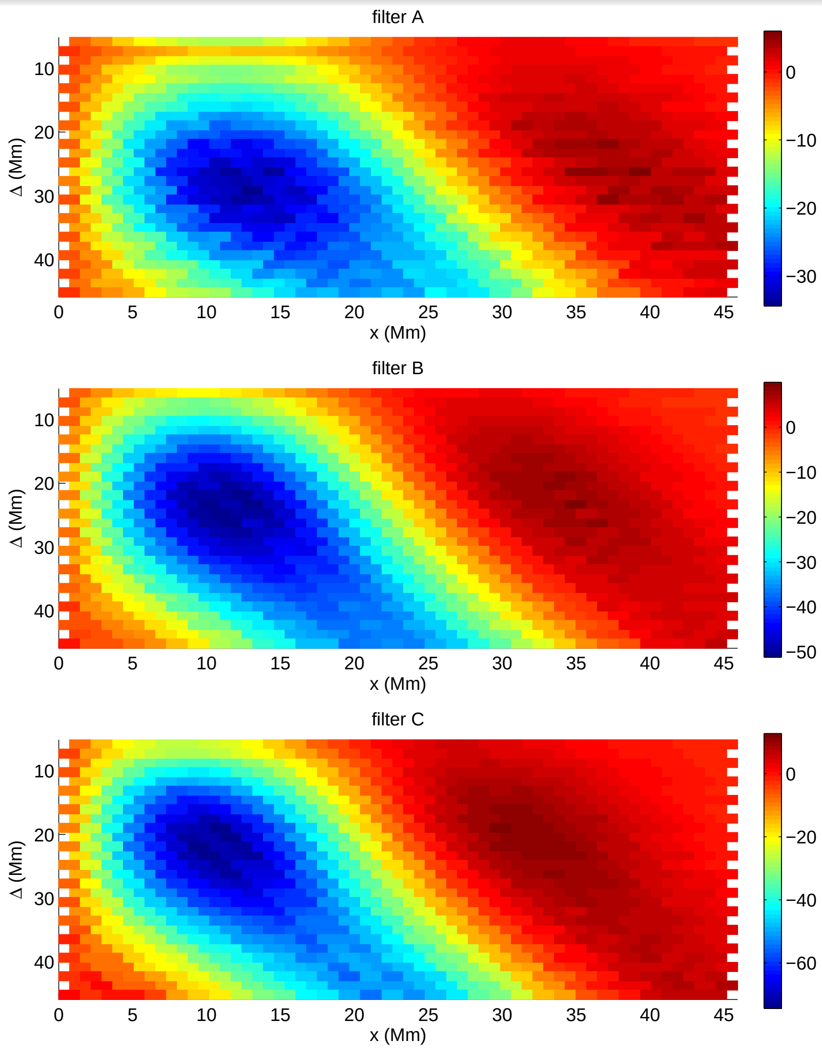

Figure 5: Travel-time differences after frequency filtering. The filters are shown in Figure 4.

Calibration of Travel-Times

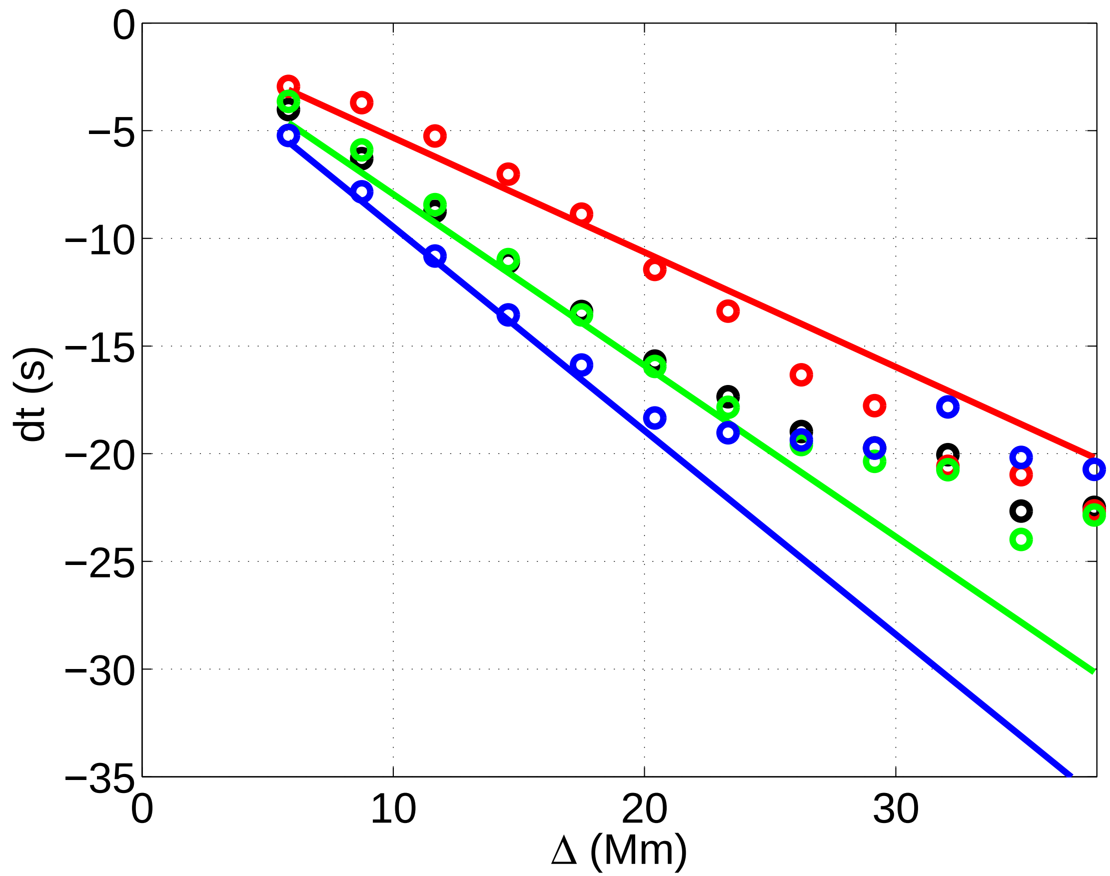

Figure 6: Travel-time differences (circles) after frequency filtering for a uniform flow of 50 m/s artificially introduced into the tracked data cubes. The lines show ray theory estimates. The red, green, and blue are for filters A,B, and C respectively.

Calibrated Travel-Times

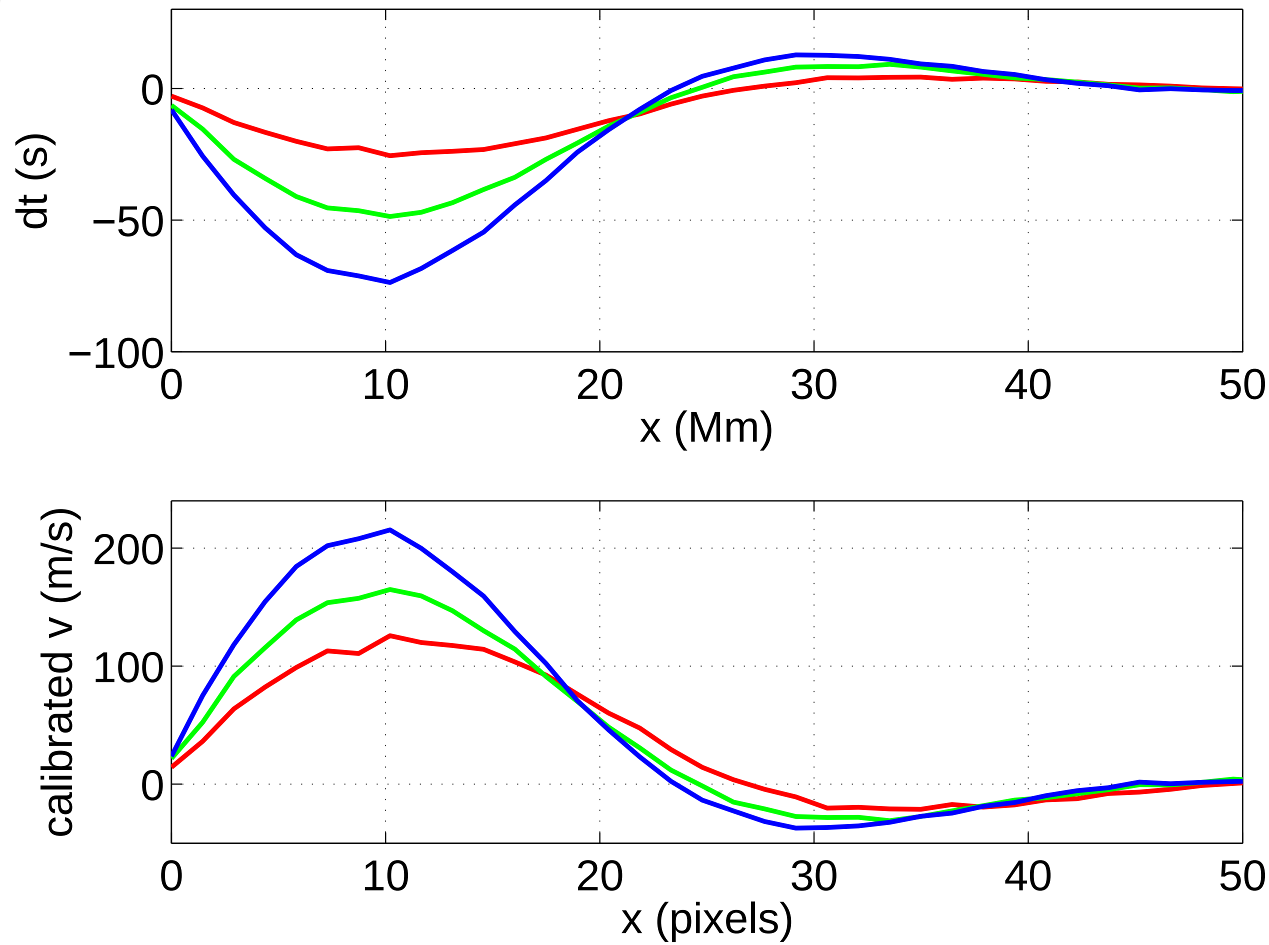

Figure 7: Travel-time differences (top) after frequency filtering, at fixed $\Delta = 18.9$ Mm. The red, green, and blue curves are for filters A, B, and C respectively. The bottom panel shows travel-time differences converted to units of m/s (see Fig. 6).

Depth Dependence ?

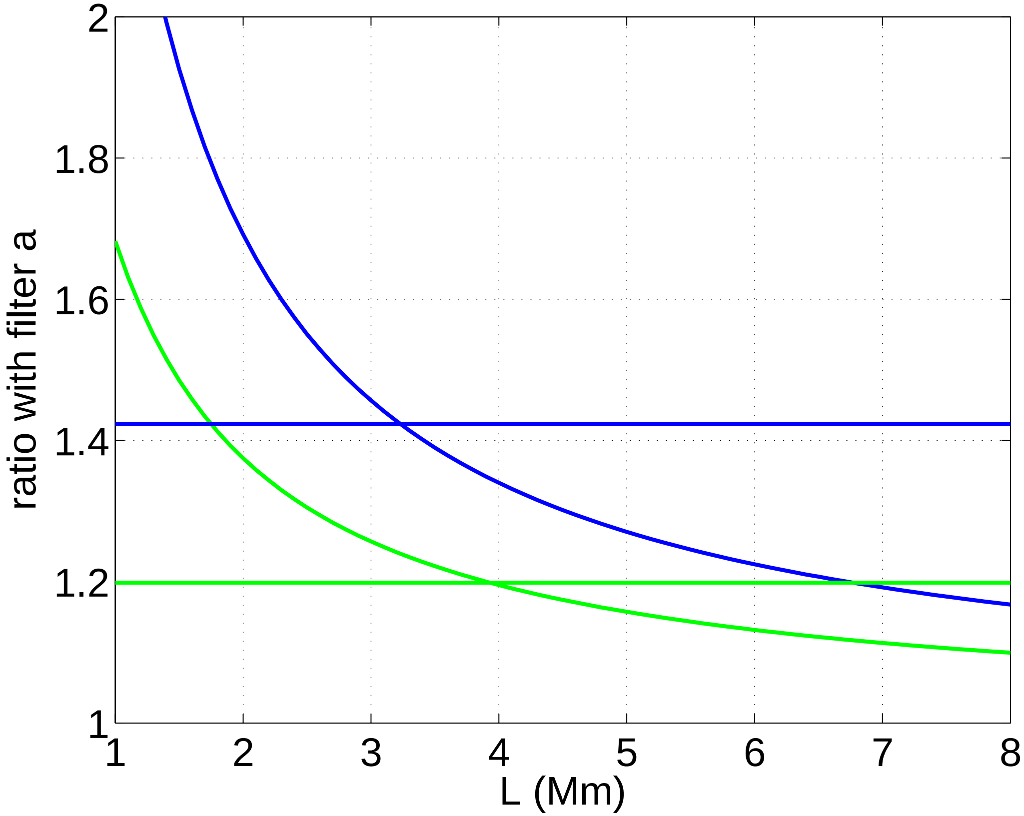

Figure 8: Model predictions of the ratio of filter B to filter A travel time differences (green) and the ratio of filter C to filter A travel-time differences (blue) as functions of the skin-depth L for a uniform horizontal flow of the form $v(z) = e^{-z/L}$. The horizontal lines show the ratios estimated from the data at $\Delta = 8.76$ Mm.

Numerical Simulations

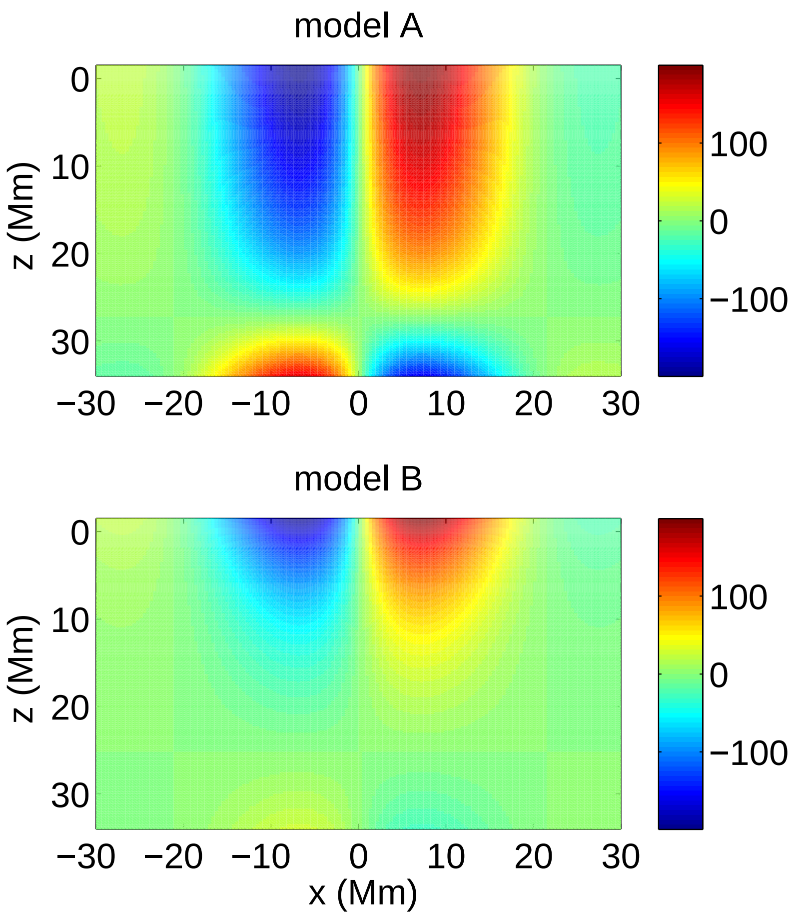

Figure 9: x component of flows for two simple supergranulation-like models. Both models are azimuthally symmetric and have mass-conserving flows.

Numerical Simulations: Travel times

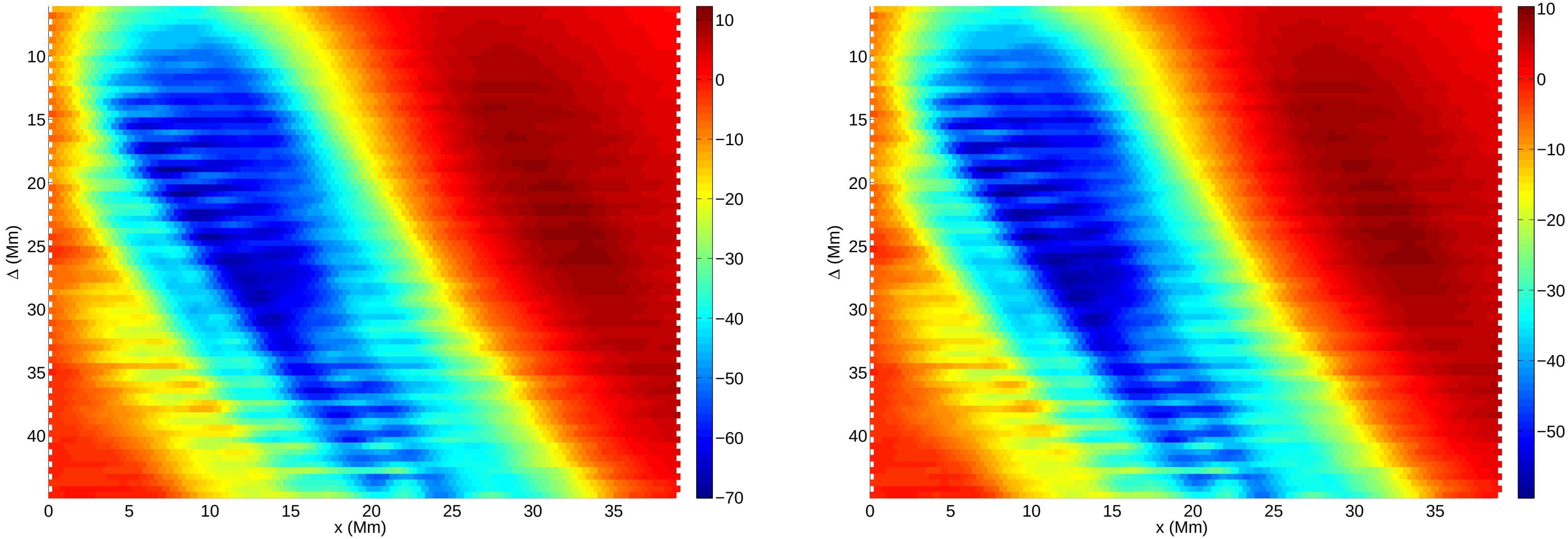

Figure 10: Travel-time differences (after smoothing in both x and Δ) for the two models (model A on the left and model B on the right). These are obtained by running the wave propagation code of Hanasoge to obtain artificial data cubes. Travel-times are then obtained using the same analysis procedure as was applied to the solar data.

Non-linear effects ?

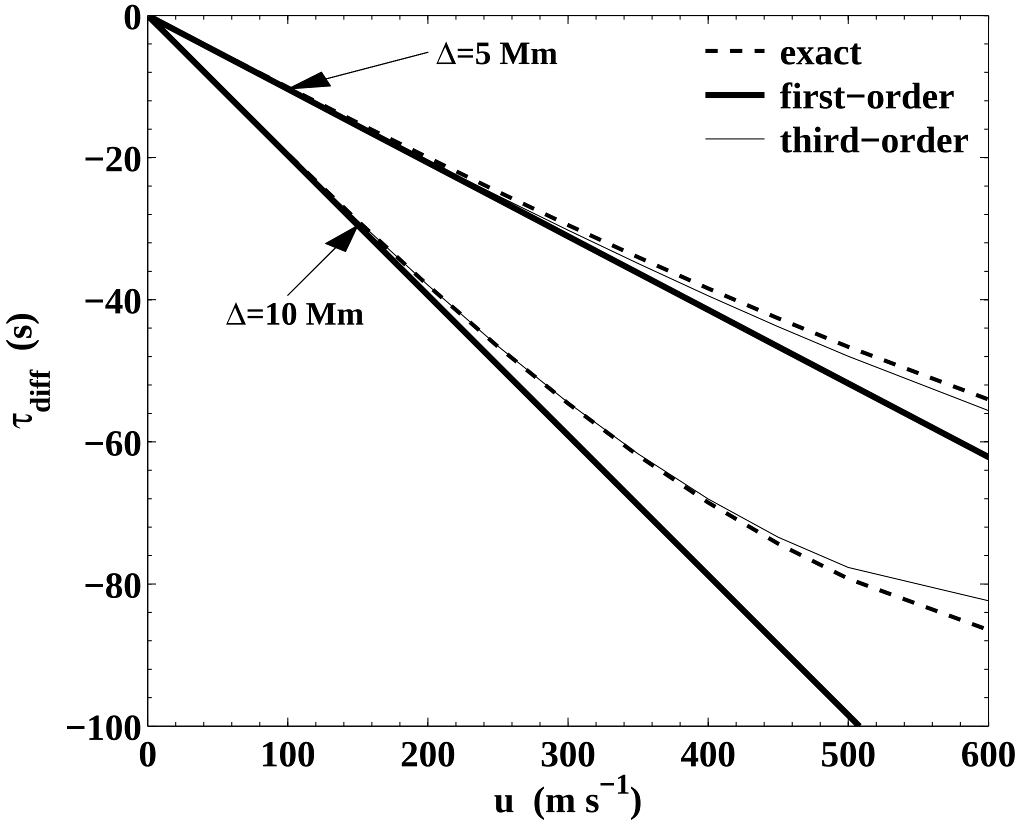

Figure 11: Travel-time difference for a uniform horizontal flow, from Jackiewicz *et al.* (2007). At roughly 200 m/s the first-order approximation begins to break down for $\Delta = 10$ Mm. This is roughly the amplitude of supergranulation-scale flows.

Conclusions

- Strong frequency dependence in travel times
- Depth dependence with scale depth of $L \approx 4$ Mm
- Numerical simulations: depth dependence hard to see directly, need p-modes
- Still to be done:
  - p modes
  - inversions
  - non-linearity (second Born approximation ?)

References

Duvall, T. L., J., Gizon, L., 2000, “Time-Distance Helioseismology with f Modes as a Method for Measurement of Near-Surface Flows”, Sol. Phys., **192**, 177–191

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