What Do Time-Distance Observers Want from Simulators

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One Slide from My Talk at HMI 2005 Meeting

Numerical Simulations

- Validation of local helioseismological techniques is dependent on realistic numerical simulations that have sufficient spatial size and sufficient duration
- Numerical simulations are now being carried out by:
  - Mansour @ NASA Ames
  - Parchevsky & Kosovichev @ Stanford
  - Toomre @ Colorado, Boulder
  - Stein @ MSU
  - Werne @ CoRA
- We are waiting for your numerical simulation results!

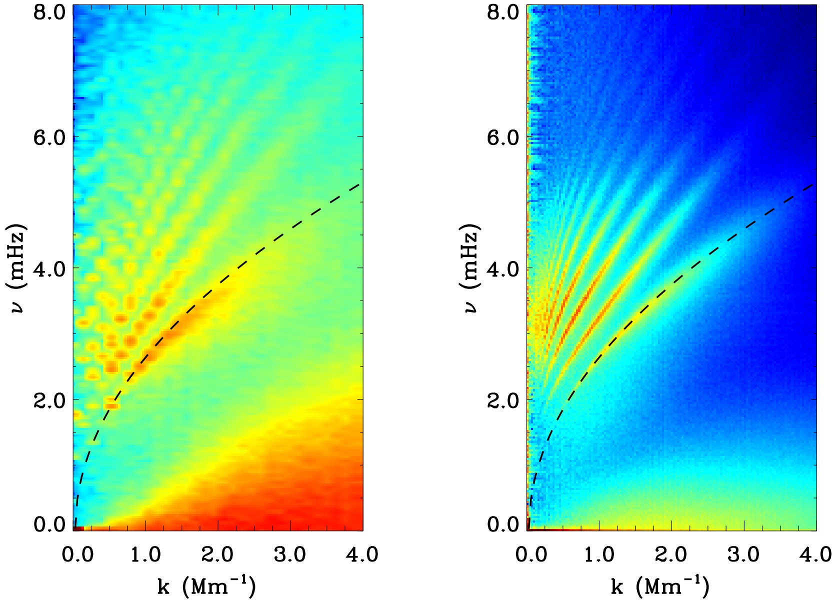
Great Achievements Have Been Made Since Then!

- Realistic 3D Simulation of Solar Convection (Benson, Stein, & Nordlund, 2005, SPD Meeting):
  - 48 Mm $\times$ 48 Mm $\times$ 20 Mm
  - High horizontal resolution and vertical resolution
  - Temporal resolution of 10 seconds
  - Great for time-distance helioseismology analysis
- Simulation of Acoustic Wave Propagation (Parchevsky & Kosovichev, 2005, AGU Fall Meeting):
  - Artificial oscillation is generated
  - Propagation of the acoustic wavefields is simulated
  - Sunspot-like structure is introduced to simulate the interaction between wavefields and local inhomogeneities
- There may be a few other works, sorry that I cannot include in this short talk

Recent Achievement: from MSU Simulations

Power Spectrum Comparison with MDI High-Resolution Observation

(Georgobiani, Zhao, Kosovichev, Stein, et al., 2006)

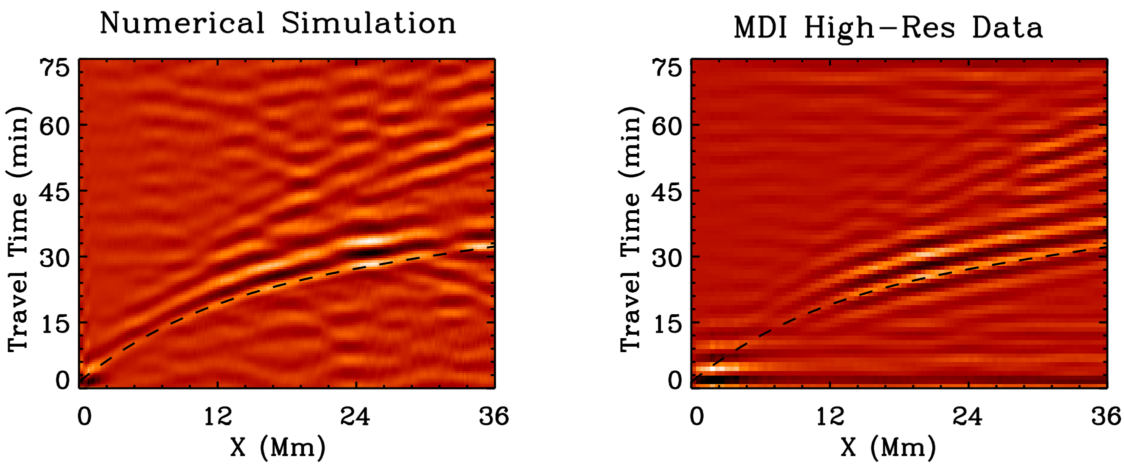


Left side image is $k-\omega$ diagram from simulations, and right side image is from MDI high-resolution observations with duration of 512 minutes. Dashed curve indicates the theoretical f-mode ridge.

Recent Achievement: from MSU Simulations

Time-Distance Diagram Comparison with Real MDI Observation

(Georgobiani, Zhao, Kosovichev, Stein, et al., 2006)

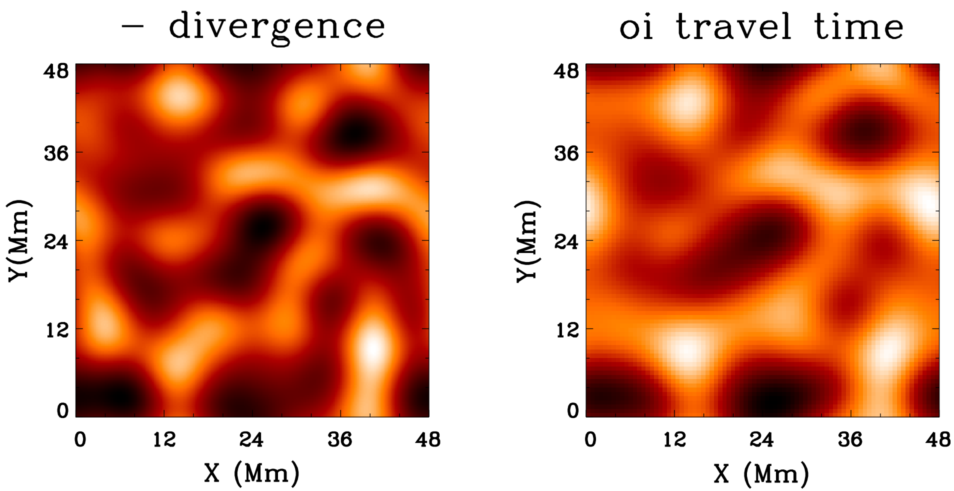


Left side image is the time-distance diagram computed from p-modes simulation data, and the right side image is computed from MDI high-resolution data. The dashed curve is the time distance relation computed from solar model. The second bounce can be seen in both plots.

Recent Achievement: from MSU Simulations

f-Mode Travel Times vs Simulated Flow Fields

(Georgobiani, Zhao, Kosovichev, Stein, et al., 2006)

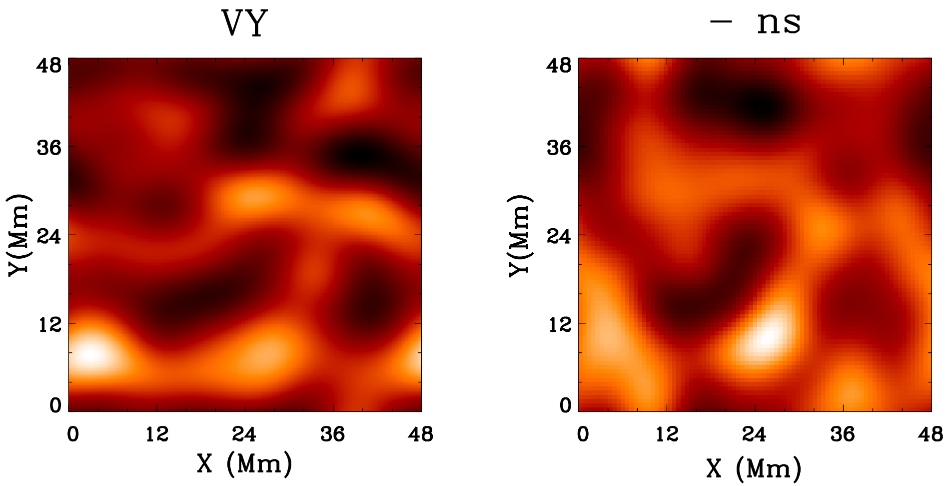


Right side image shows the f-mode outgoing and ingoing travel time differences, and the left side image shows the divergence computed from simulated flow fields. Large scale structures are believed to be corresponding to supergranular structures. Very nice similarities are found in both images.

Recent Achievement: from MSU Simulations

f-Mode Travel Times vs Simulated Flow Fields

(Georgobiani, Zhao, Kosovichev, Stein, et al., 2006)



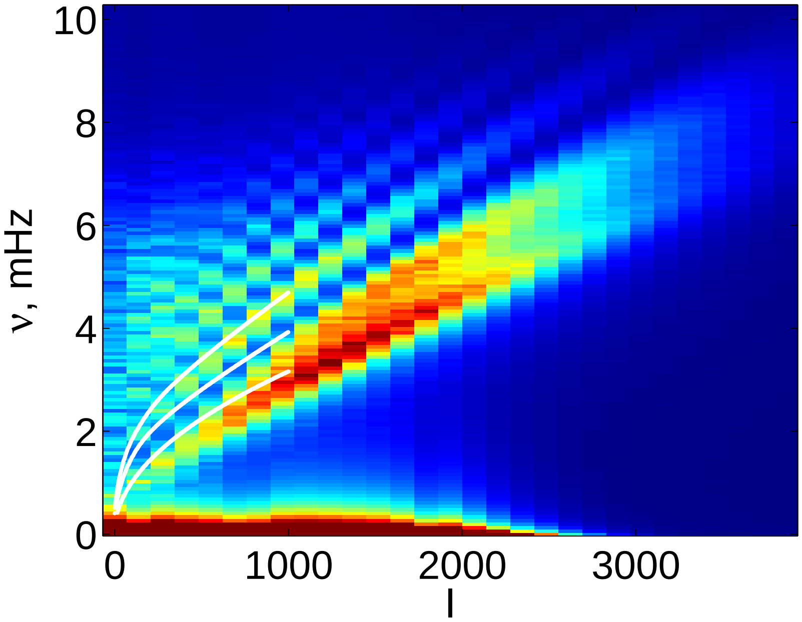
Right side image shows the f-mode north-going and south-going travel time differences, and the left side image shows the VY averaged from simulated flow fields. Again, very nice similarities are found in both images.

What Else Do We Want?

- From my point of view, MSU simulations are already very close to the reality. Such simulations give us a good opportunity to validate time-distance analysis, and on the other hand, helioseismic techniques are also able to check how realistic such simulations are.
- Current comparison finds that power distribution computed from simulated data is a little different with that computed from real observations, mainly in the low and high frequencies. Simulation needs improvement in this.
- We want the presence of magnetic field! Not just in small magnetic element scales, but in the scale of sunspots. It is of great interest to validate our analysis in sunspot areas, including both sound-speed variations and flow fields.
- Supergranular scale flows are already done in this simulation, we want to see larger scale flows, e.g., rotational or meridional flows.

Recent Achievement: from Stanford Simulations

$k - \omega$ Diagram from Simulations

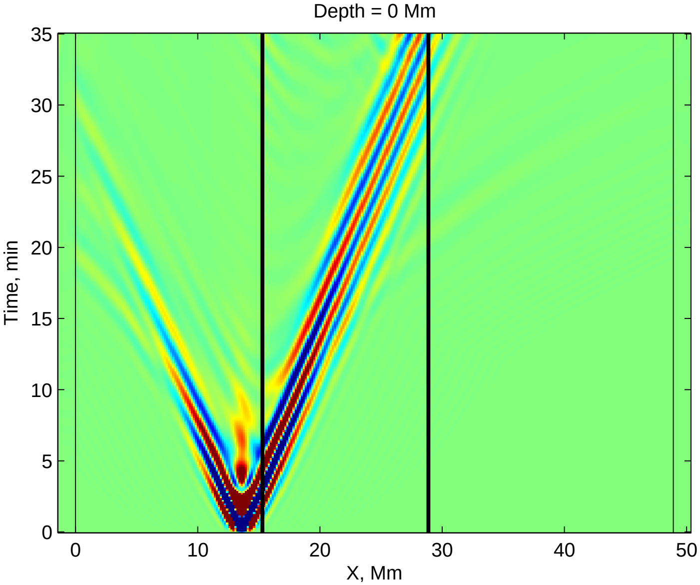


This simulation is to give an artificial oscillation below solar surface, and study the acoustic wavefield and wave propagation. Multiple oscillation sources can generate nice $k - \omega$ diagram like this one.

Recent Achievement: from Stanford Simulations

Time-Distance Relations after Encountering Local Inhomogeneities

(Parchevsky & Kosovichev)



This figure shows the time-distance relations after the acoustic waves encounter some local inhomogeneities, which are thought to be like sunspot cylindrical structure. For details, refer to Konstantin Parchevsky's presentation in session H9.

What Else Do We Expect?

- Sensitivity kernels. Such numerical simulation should be able to construct time-distance sensitivity kernels, which could be used to do inversions. Such kernels can also be used to test the existed ray-approximation and Born-approximation kernels.

- Magnetic! We want to know how the acoustic wavefield interact with the magnetic field inside a sunspot, as well as how acoustic propagation responds to the temperature variations inside a sunspot.

- Flows! We want to know how the acoustic waves respond to flow fields.

- Simple experiments of suppressing oscillation amplitudes, and monitoring the changes of acoustic wavefield caused by the suppression would help us better understand the 'masking' effects.

- Apparently, simulations with magnetic field can provide a tool to study the 'showerglass' effect.

Overall ...

- Simulations and observations are reciprocal. Simulations help helioseismologists to validate their observations, and applications of helioseismology techniques on simulated data can test how realistic the simulations are.
- The incorporation of sunspot scale magnetic field into simulations is very important for us to validate our studies of sunspot interiors.
- Various scale of flow fields are also important to be included in simulations to better test various scales of helioseismological inversion results.
- With recent great achievement in the past one year, we are confident that simulators will provide us very nice simulations in the years to come!