Inferring 3-D S- and P-velocity structure of D″ beneath Central America using waveform inversion

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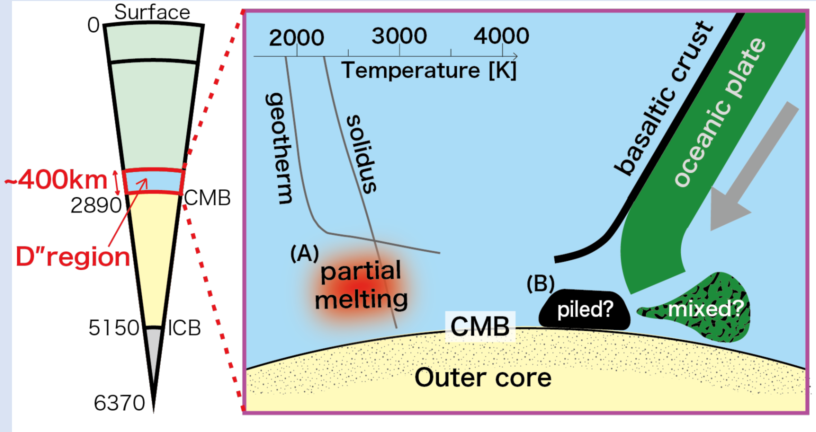
Points

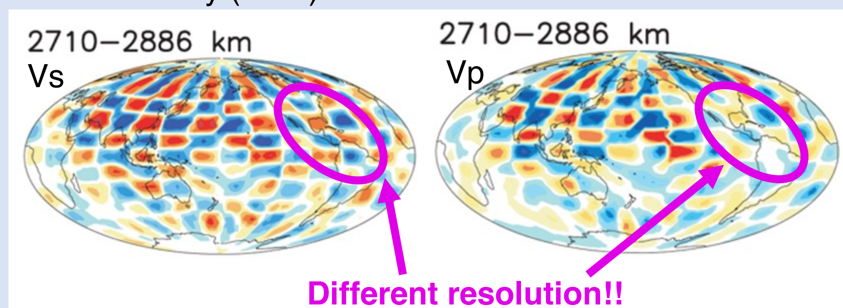
- We extend the waveform inversion method to infer Vs & Vp structure simultaneously.
- Our models are consistent with previous studies but have higher resolution than them.
- We image the paleo-Farallon slabs reaching the D″ region.



Conceptual figure in D″ based on Garnero+ (2008) & Tackley (2011)

Introduction

- The D″ region, the lowermost several hundred km of the Earth's mantle just above the core-mantle boundary (CMB), is thought to have 3-D chemical heterogeneities (Garnero+ 2008; Tackley 2011) and important to understanding the Earth's chemical evolution.
- It is required to infer both S- & P-wave velocity (Vs and Vp) anomalous structures in order to distinguish thermal and chemical effects on the seismic velocities (Masters+ 2000).
- Previous studies inferring Vs & Vp structure uses different kinds of data or has a different resolution between Vs & Vp (e.g., Houser+ 2008).

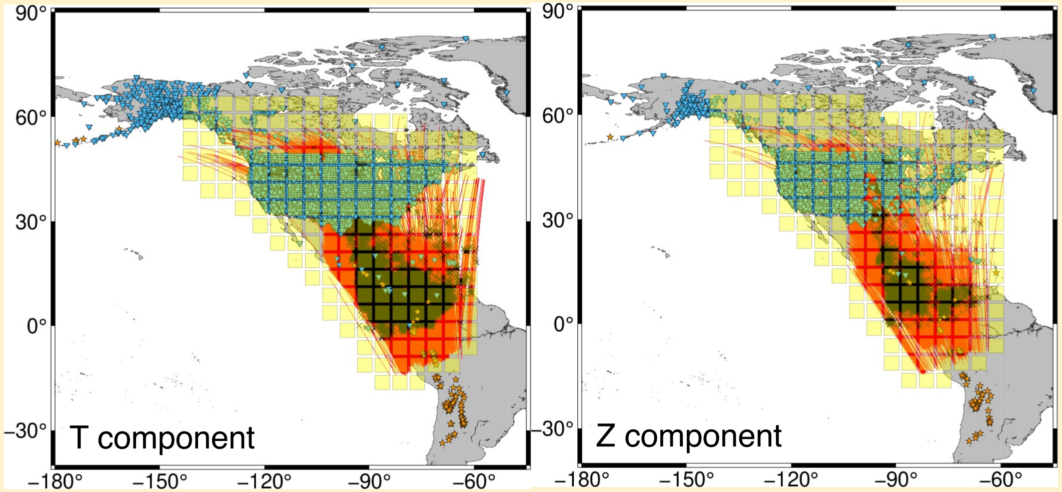


The results of synthetic resolution test of Houser+ (2008). The regions where checkerboard patterns are recovered well have good resolution

Reference

- Garnero, E. J., & McNamara, A. K. (2008). Structure and dynamics of earth's lower mantle. *Science, 320*(5876), 626-628. https://doi.org/10.1126/science.1148028
- Houser, C., Masters, G., Shearer, P., & Laske, G. (2008). Shear and compressional velocity models of the mantle from cluster analysis of long-period waveforms. *Geophysical Journal International, 174*(1), 195-212. https://doi.org/10.1111/j.1365-246X.2008.03763.x
- Masters, G., Laske, G., Bolton, H., & Dziewonski, A. (2000). The relative behavior of shear velocity, bulk sound speed, and compressional velocity in the mantle: implications for chemical and thermal structure. *Geophysical Monograph Series, 117*, 63-87. https://doi.org/10.1029/GM117p0063
- Tackley, P. J. (2011). Living dead slabs in 3-D: The dynamics of compositionallystratified slabs entering a "slab graveyard" above the core-mantle boundary. *Physics of the Earth and Planetary Interiors, 188*(3-4), 150-162. https://doi.org/10.1016/j.pepi.2011.04.013

Dataset



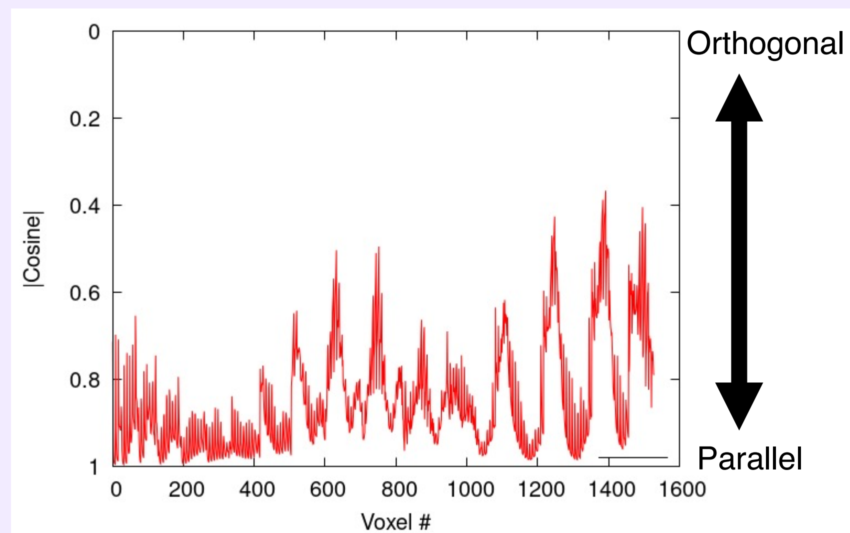
Event-station geometry. Red lines; The raypaths sampling the D″ region, black crosses; the turning points at the CMB, orange stars; seismic stations, and blue triangles; earthquakes

※ $\mathrm{Vs} = \sqrt{\mu/\rho}$, $\mathrm{Vp} = \sqrt{(\lambda + 2\mu)/\rho}$ (ρ: density)

- We use the waveforms from 105 deep- and intermediate-focus South American, Caribbean, and Alaskan earthquakes in the period 2001-2019 with moment magnitude 5.6 ≤ Mw ≤ 7.2 recorded at 2818 stations of the full USArray & other networks.
- For transverse (T) components, we use 14,116 waveforms cut from 20s before S to 60s after ScS with a period range 10s~200s.
- For vertical (Z) components, we use 3077 waveforms cut from 20s before P to 60s after PcP with a period range 5s~200s.
- We divide target regions into 1528 voxels of dimensions 5°×5°×50km
- Two isotropic elastic parameters (μ & λ) in each voxel are model parameters

The independence between $\partial u_Z/\partial\mu$ & $\partial u_Z/\partial\lambda$

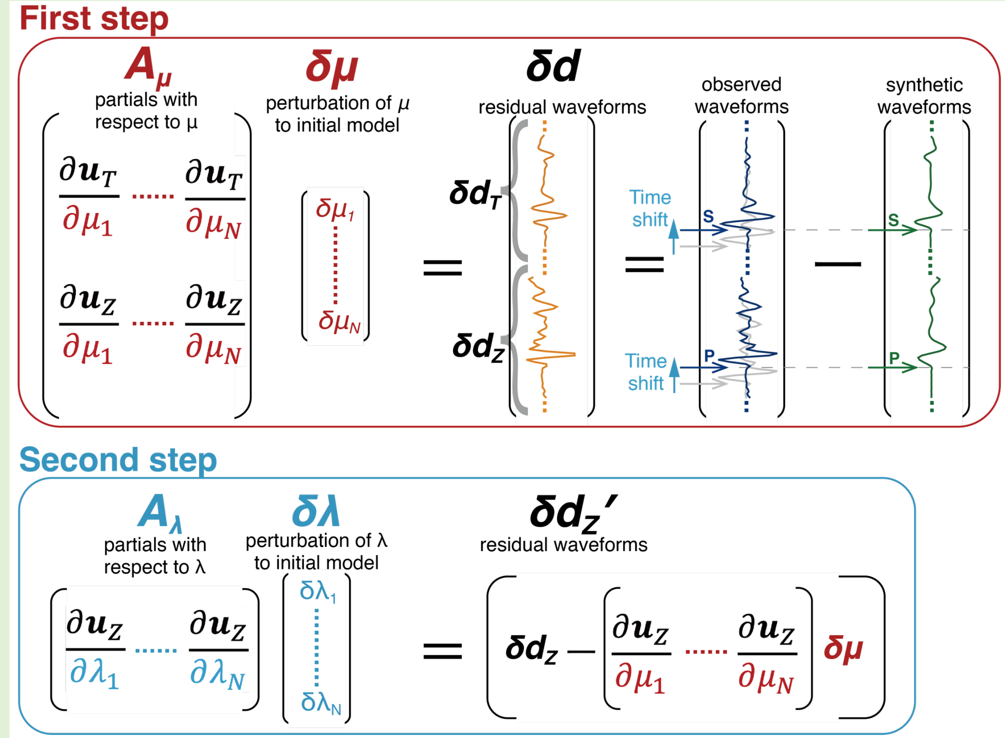
- The vectors of $\partial u_Z/\partial\mu$ & $\partial u_Z/\partial\lambda$ in each voxel are not orthogonal to each other, which means $\partial u_Z/\partial\mu$ & $\partial u_Z/\partial\lambda$ are NOT independent of each other
- It may be not easy to distinguish the effect of μ & λ from P wave



The absolute values of cosine of the angle between the vectors of $\partial u_Z/\partial\mu$ & $\partial u_Z/\partial\lambda$ in each voxel.

Waveform inversion

- Source parameter: GCMT (Global Centroid Moment Tensor) solution
- Initial model: PREM (Dziewonski+ 1981)
- Compute synthetic waveforms using DSM (Direct Solution Method; Kawai+ 2006)
- Compute partial derivatives using the algorithm of Geller+ (1993) & Borgeaud+ (2019)
- Solve the inverse problem using the CG (Conjugate Gradient) method
- Use AIC (Akaike's Information Criterion) to truncate the CG expansion

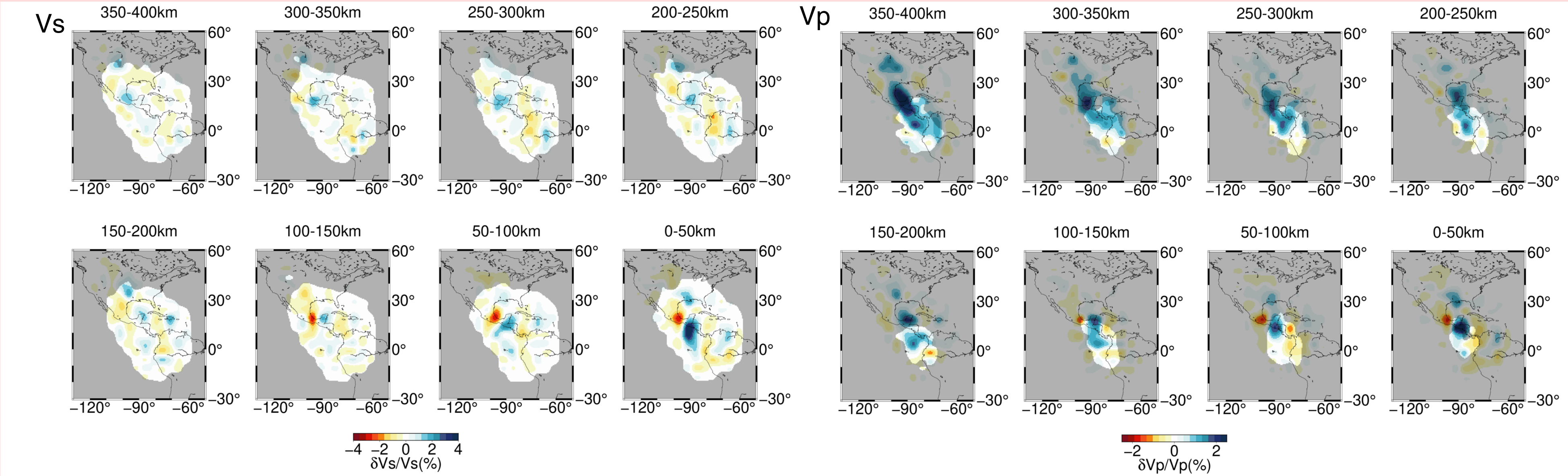


- Since the amount of data for estimating model parameters are different (about 17,000 waveforms for μ and about 3000 waveforms for λ) and since $\partial u_Z/\partial\mu$ & $\partial u_Z/\partial\lambda$ are not independent of each other, λ cannot be resolved when we infer μ & λ simultaneously using T & Z components of data.
- We conduct a two-step inversion. In the first step, we infer only μ using the T & Z components of data, and in the second step, we infer λ using inferred μ and only the Z components of data.
- This method is based on the assumptions that μ is well constrained by the first step and that the remaining residuals between observed waveforms and synthetics are due to the perturbation of λ.

Reference

- Borgeaud, A. F. E., Kawai, K., & Geller, R. J. (2019). Three-dimensional S velocity structure of the mantle transition zone beneath Central America and the Gulf of Mexico inferred using waveform inversion. *Journal of Geophysical Research: Solid Earth, 124*, 9664-9681. https://doi.org/10.1029/2018JB016924
- Dziewonski, A. M., & Anderson, D. L. (1981). Preliminary reference Earth model. *Physics of the Earth and Planetary Interiors, 25*(4), 297-356. https://doi.org/10.1016/0031-9201(81)90046-7
- Geller, R. J., & Hara, T. (1993). Two efficient algorithms for iterative linearized inversion of seismic waveform data. *Geophysical Journal International, 115*(3), 699- 710. https://doi.org/10.1111/j.1365-246X.1993.tb01488.x
- Kawai, K., Takeuchi, N., & Geller, R. J. (2006). Complete synthetic seismograms up to 2 Hz for transversely isotropic spherically symmetric media. *Geophysical Journal International, 164*(2), 411-424. https://doi.org/10.1111/j.1365-246X.2005.02829.x

Inversion results

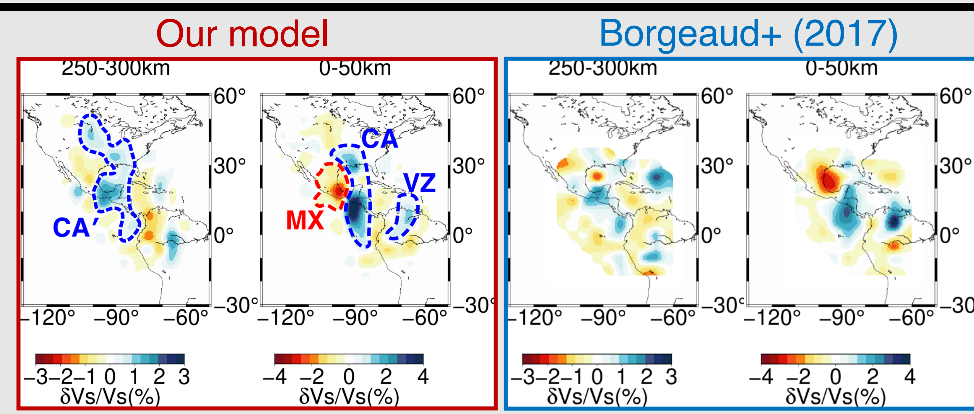


Inversion results. Each model is sliced 50 km radially from the CMB to 400 km above the CMB. The blue and red colors indicate faster and slower seismic velocity than PREM. The shadowed regions indicate where the model parameter is not resolved.

- Vs is resolved in a wide region, while Vp is resolved in the region densely sampled by P-wave

Discussion

- The two high-velocity anomalies (CA & VZ) and a low-velocity anomaly (MX) just above the CMB are consistent with our previous Vs model (Borgeaud+ 2017)
- Our inferred model images the sheet-like high-velocity structure (CA′) interpreted as paleo-Farallon slabs



Reference

- Borgeaud, A. F. E., Kawai, K., Konishi, K., & Geller, R. J. (2017). Imaging paleoslabs in the D″ layer beneath Central America and the Caribbean using seismic waveform inversion. *Science Advances, 3*(11). https://doi.org/10.1126/sciadv.1602700