Can Teleseismic Travel-Times Constrain 3D Anisotropic Structure in Subduction Zones? Insights from Realistic Synthetic Experiments

Brandon P. VanderBeek & Manuele Faccenda
Università di Padova

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Summary

- Unmodeled anisotropic structure can generate significant artefacts in teleseismic body wave images (e.g. Bezada et al., 2016)
- We evaluate the ability of teleseismic P-wave travel-time tomography to recover realistic isotropic and anisotropic subduction zone structure

Summary of main results:
- Teleseismic P-waves can constrain lateral and depth variations in the azimuth and dip of mantle anisotropy
- While anisotropic structure can be recovered, isotropic artefacts remain particularly if only azimuthal anisotropy is considered
- SKS splitting intensity can be incorporated into P-wave inversions to better constrain azimuthal anisotropy patterns
Methods: Synthetic Data

- Create anisotropic elastic model from geodynamic simulation of subduction (Faccenda, 2014)
- Model teleseismic wavefield through model using SPECFEM + AxiSEM
  - 15 s double couple source
- 770 receivers spaced 75 km apart record the wavefield generated from 16 sources evenly distributed in back-azimuth and range
  - P arrivals picked via cross-correlation (VandeCar and Crosson, 1990)
- Synthetic data is independent of inversion algorithm
Methods: Tomography

- Use common sinusoidal approximation for hexagonal anisotropy:
  \[ v = v_i [1 + f(2[\cos(\theta) \cos(\gamma) \cos(\phi - \psi) + \sin(\theta) \sin(\gamma)])^2 - 1)] \]

- Simplified parameterization for SKS splitting intensity assuming azimuthal anisotropy and near vertical ray paths:
  \[ si = 2rLu_i [A \sin(2\lambda) + B \cos(2\lambda)] \]

- The A and B terms control anisotropy orientation and P-wave anisotropic magnitude; fixed ratio of P-to-S anisotropic fraction (r) is assumed
- Inversion includes approximate anisotropic finite-frequency kernels
- This presentation focuses on inversion results; method details will be presented in manuscript currently in preparation for Geophys. J. Int.
True Model

Isotropic Anomalies

Anisotropic Magnitude and Orientation
Isotropic Inversion of Isotropic Data

- In this case, inverting teleseismic data created with isotropic model
- Illustrates recovery of isotropic heterogeneity in absence of complications due to anisotropy
- Relative nature of teleseismic data requires that the fast slab be balanced by low velocity perturbations
- Low-velocity artefacts are small in amplitude and evenly distributed
Isotropic Inversion of Anisotropic Data

- Significant distortion of slab geometry
- Significant increase in magnitude of low velocity artefacts
- Low velocity zones have stronger amplitude beneath the slab
Azimuthal Anisotropy Inversion

Isotropic Anomalies

Anisotropic Magnitude and Orientation

More continuous slab anomaly

Reduced low velocity artefacts in wedge

Sub-slab low velocity artefacts still present

Toroidal flow pattern and transition from trench-normal to trench-parallel anisotropy imaged beneath down-going plate
Further reduced low velocity artefact amplitude in wedge

Sub-slab low velocity artefacts still present but smaller amplitudes

Trench-parallel anisotropy zone

Anisotropy in down-going plate + entrained flow
Data Fit

- Including anisotropy in inversion improves data fit
  - Expected since more model complexity is introduced
- For a given perturbational vector length, anisotropic solutions consistently yield better fit
Inclusion of SKS splitting intensity measurements significantly improves recovery of azimuthal anisotropic structure.

Inversion uses additional 8 SKS events evenly distributed in back-azimuth at 120° distance.

P Isotropic anomalies remain effectively identical to those previously shown (slide 8).
Conclusions

- Teleseismic P-waves can constrain 3D anisotropic structure but untangling anisotropic from isotropic structure remains a challenge
  - Low-velocity artefacts are persistent features
  - Reflect trade-off between symmetry axis dip and mean velocity
- SKS splitting intensity can be incorporated into P-wave azimuthal anisotropic inversions in a simple but effective manner
- Removing isotropic artefacts will require better starting models derived from prior geophysical or geodynamic constraints
- Caution should be exercised when inferring physical properties (e.g. temperature, melt) from subduction zone velocity anomalies derived from teleseismic delay times