Wave-equation Imaging of Telesismic Body-wave Coda

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1. Introduction

- As multi-channel array deployments of broadband instruments become common, efforts to accurately image tectonic structure utilizing the teleseismic body-wave coda will replace property-perturbation models computed from relatively few, sparsely-deployed stations.
- Wave-equation-based migration is a multifaceted tool that allows accurate imaging in the presence of lateral velocity variation, strong velocity contrast, and significant velocity-model uncertainty.
- Wave-equation migration incorporated in a configuration fully representative of geometry of a teleseismic experiment, and affords a robust methodology that accommodates the imaging of all first-arrival, forward- and backfolded reflected and converted teleseismic arrivals.

2. Shot-profile migration methodology

1. Define source and receiver wavefields

2. Extrapolate source and receiver wavefields independently

   One-way wave propagation involves application of dip-dependent advection equation
   \[ \frac{\partial W(x, z, t)}{\partial t} = \frac{\partial}{\partial z} \left( V(x, z) \frac{\partial W(x, z, t)}{\partial z} \right) \]

   Forced convolution solution of advection provides operator for propagating a wavefield from a more shallow depth into the shot:
   \[ W(x, z, t) = W(x, z, 0) e^{i k z \frac{x}{\Delta x}} \]

   Was number, \( k = \frac{\omega}{V(x, z)} \), calculated through exponential relation
   \[ k^2 = \frac{4 \pi^2}{L^2} \]

   Velocity, \( V(x, z) \), either compositional or shear, introduces an earth model into the physics.

   Source wavefield extrapolated causally (positive exponential)

   Receiver wavefield extrapolated acausally (negative exponential)

3. Obtain image through imaging condition evaluation

   \[ I(x, z) = \sum S(\omega, x, z) R^*(\omega, x, z) \]

   Physically: co-located source and receiver wavefield energy at t=0s due to a scatterer at that model point

   Mathematically: zero lag of cross-correlation between source and receiver wavefields

4. Examine image focusing with offset imaging condition

   \[ I(x-h, z) = \sum S(\omega, x-h, z) R^*(\omega, x-h, z) \]

   If velocity model is correct, wavefields will correlate poorly at non-zero offsets.

5. Analogous imaging constructs may be devised for arbitrary earthquake arrival phase

   e.g. PP, SSS, PKP, PSS

3. Telesismic Novelties

1. Multi-mode scattering

   - Scattering arises when a wavefield interacts with discontinuities such as structure leading to changes in propagation angle, direction, or polarization.

2. Forward-scattering modes

   - Teleseismic source illuminates sub-thin-structure from below.

   - Direct P arrival interacts with discontinuous lithospheric structure giving rise to forward-scattered incident P-P or P-S converted arrivals.

3. Backscattering modes

   - Reflections and conversions of direct P arrival at the free-surface generates effective downgoing P and S waves sources.

   - Downgoing source wave interacts with structure giving rise to backscattering modes P-P, P-S, S-P, S-S, and S-Sv.

4. More scattering modes...more extrapolation parameters

   - For directly incident P-P wave source

<table>
<thead>
<tr>
<th>Scattering Mode</th>
<th>Source Velocity</th>
<th>Receiver Velocity</th>
<th>Source Exponential</th>
<th>Receiver Exponential</th>
<th>Receiver Components</th>
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<tbody>
<tr>
<td>FS P-P</td>
<td>P</td>
<td>P</td>
<td>-i</td>
<td>-i</td>
<td>P</td>
</tr>
<tr>
<td>FS P-S</td>
<td>P</td>
<td>S</td>
<td>-i</td>
<td>-i</td>
<td>SV</td>
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<tr>
<td>BS P-P</td>
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<td>P</td>
<td>+i</td>
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<td>P</td>
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<tr>
<td>BS P-S</td>
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<tr>
<td>BS S-Sv</td>
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<td>+i</td>
<td>+i</td>
<td>2S</td>
</tr>
</tbody>
</table>

   - FS and BS indicate forward- or backscattered modes.

   - Source and receiver velocity are the wavepaths used for independent wave propagation.

   - Sign of the source exponential indicates whether source wavefield is propagated causally or acausally.

   - Receiver component is the data rotated from field coordinates to wave vector polarization.

5. Analogous imaging may be devised for any arbitrary earthquake arrival phase e.g. PP, SSS, PKP, PSS

4. Synthetic Experiment

Zero-offset images

- Investigate reflectivity as a function of azimuth and angle between source and receiver wavefield.

- Aperture angle is equivalent to the line-of-sight angle for illuminating plane wave.

Angle-dependent images

- Flatness across angle axis indicative of velocity model accuracy

5. Application to Field Data – CANCADA 1993

6. The Truly Passive Telesismic Experiment

The case presented here details the use of a modified shot-profile migration algorithm to image the subduction with teleseismic coda energy. However, an observation by Andrew Dziewonski, the late seismologist, that the theory of passive seismics imaging extends directly to allow us to migrate raw data without imposing a priori assumptions during pre-processing steps such as deconvolution, wave vector component rotation, or linear source movement.

Using a wave-equation based migration algorithm, and performing the correlations after the imaging step, the physics of wave propagation is derived for all scattering modes from all earthquake scattering phases available within the data set. This extends the imaging process to higher frequency, lower seismicity as well as removing ambiguities associated with human interpretation of data prior to migration.

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