Wave-equation Imaging of Teleseismic Body-wave Coda

S11E-0335

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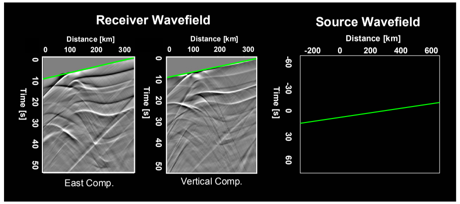
1. Introduction

- As multi-channel array deployments of broad-band instruments become common, efforts to accurately image lithospheric structure utilizing the teleseismic body-wave coda will replace property-perturbation models computed from relatively few, sparsely-deployed stations.
- Taking advantage of relative arrival-time measurements recorded across an array requires migration to correctly locate and focus energy scattered from geologic discontinuities.
- Wave-equation depth migration is a malleable tool that allows accurate imaging in the presence of lateral velocity variation, strong velocity contrast, and significant velocity model uncertainty.
- Wave-equation migration in shot-profile configuration easily represents the geometry of a teleseismic experiment, and affords a robust methodology that accommodates the imaging of all first-order, forward- and backscattered, 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

$$\frac{\partial W(x,z,t)}{\partial z} = -\frac{\cos\theta}{v}\frac{\partial W(x,z,t)}{\partial t}$$

- Fourier-domain solution to advection provides operator for propagating a wavefield from one depth level to the next:

$$W(x, z+\Delta z, \omega) = W(x, z, \omega)\, e^{-/+ i k_z \Delta z}$$

- Wavenumber, k_z, calculated from (acoustic) dispersion relation

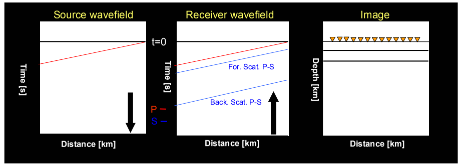
$$k_z^2 = \omega^2/v^2 - k_x^2$$

- Velocity, V, either compressional or shear, introduces an earth model to the physics.
- Source wavefield extrapolated causally (positive exponential)
- Receiver wavefield extrapolated acausally (negative exponential)

3. Obtain image through imaging condition evaluation

$$I(x,z) = \Sigma_\omega S(\omega, x, z)\, R^*(\omega, x, z)$$

- Physically: co-located source and receiver wavefield energy at t=0 is 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.

$$I(x,h,z) = \Sigma_\omega S(\omega, x+h, z)\, R^*(\omega, x-h, z)$$

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

3. Teleseismic Novelties

1. Multi-mode scattering

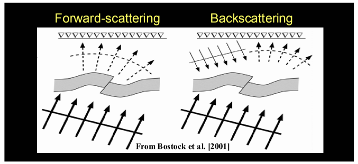
- Scattering arises when a wavefield interacts with discontinuous earth structure leading to changes in propagation angle, direction, or polarization.

2. Forward-scattering modes

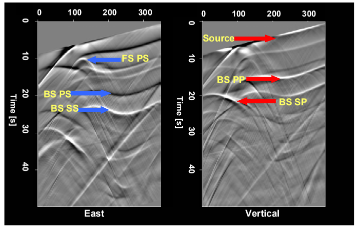
- Teleseismic sources illuminate subsurface structure from below.
- Direct P arrival interacts with discontinuous lithospheric structure giving rise to forward-scattering in either P-P or P-S converted modes.

3. Backscattering modes

- Reflection and conversion of direct P arrival at the free-surface generates effective downgoing P and S wave sources.
- Downgoing source waves interact with structure giving rise to 5 backscattering modes: P-P, P-S, S-P, Sv-Sv, and Sv-Sh.



From Bostock et al. [2001]



4. More scattering modes…more extrapolation parameters

- For directly incident P-wave source

Scattering Mode	Source Velocity	Receiver Velocity	Source Exponential	Receiver Components
FS P-P	P	P	-i	*P*
FS P-S	P	S	-i	*SV*
BS P-P	P	P	+i	*P*
BS P-S	P	S	+i	*SV*
BS S-P	S	P	+i	*P*
BS Sv-Sv	S	S	+i	*SV*
BS Sv-Sh	S	S	+i	*SH*

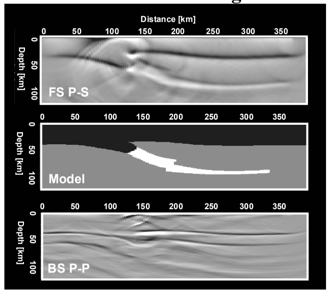
- FS and BS indicate forward- or backscattered modes.
- Source and receiver velocity are the wavespeeds used for independent wavefield propagation.
- Sign of the source exponential indicates whether source wavefield is propagated causally or acausally.
- Receiver component is the data rotated from field coordinates to wave vector polarization

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

- e.g. PP, SSS, PKIKP, PcS

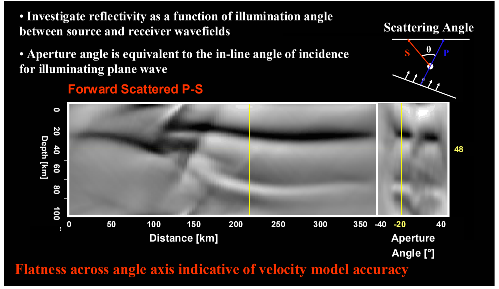
4. Synthetic Experiment

Zero-offset images



Angle-dependent images

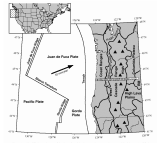
- Investigate reflectivity as a function of illumination angle between source and receiver wavefields
- Aperture angle is equivalent to the in-line angle of incidence for illuminating plane wave



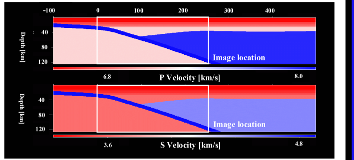
Flatness across angle axis indicative of velocity model accuracy

ACKNOWLEDGEMENTS: This work was funded by sponsors of the Stanford Exploration Project and grants NSF-EAR-Geophysics and ACS-PRF awarded to S. Klemperer and J. Claerbout. We would like to thank Biondo Biondi for many helpful discussions.

5. Application to Field Data – CASCADIA 1993



from Rondenay et al. [2001]



Imaging Highlights

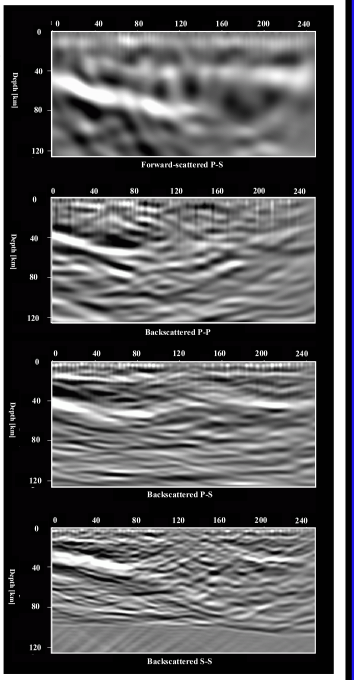
1. Data
- ~40 broadband 3-component receivers
- 5-10 km receiver spacing
- 31 usable events
- 'Usable' signal frequency content between .002 and .325 Hz

2. Preprocessing
- Source-signature deconvolution
- Rotation from field coordinates to wave vector components via FSTM

3. Velocity Models
- Based on 1-D receiver functions [Li, 1996]
- Iterative topological fit to structure
- Models scaled to the apparent inline velocity

4. Source Wavefield
- Line source developed from event ray-parameter estimates

5. Results
- Good resolution of Juan de Fuca plate, and continental Moho interface
- Continuation of Moho above mantle wedge
- Slab delamination?



6. The Truly Passive Teleseismic Experiment

The case presented here details the use of a modified shot-profile migration algorithm to image the subsurface with teleseismic coda energy. However, as demonstrated by adjacent poster *[S11E-0334]*, the theory of passive seismic 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 moveout.

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