Computing velocity models for S-wave static corrections using τ-differences in the rayparameter domain

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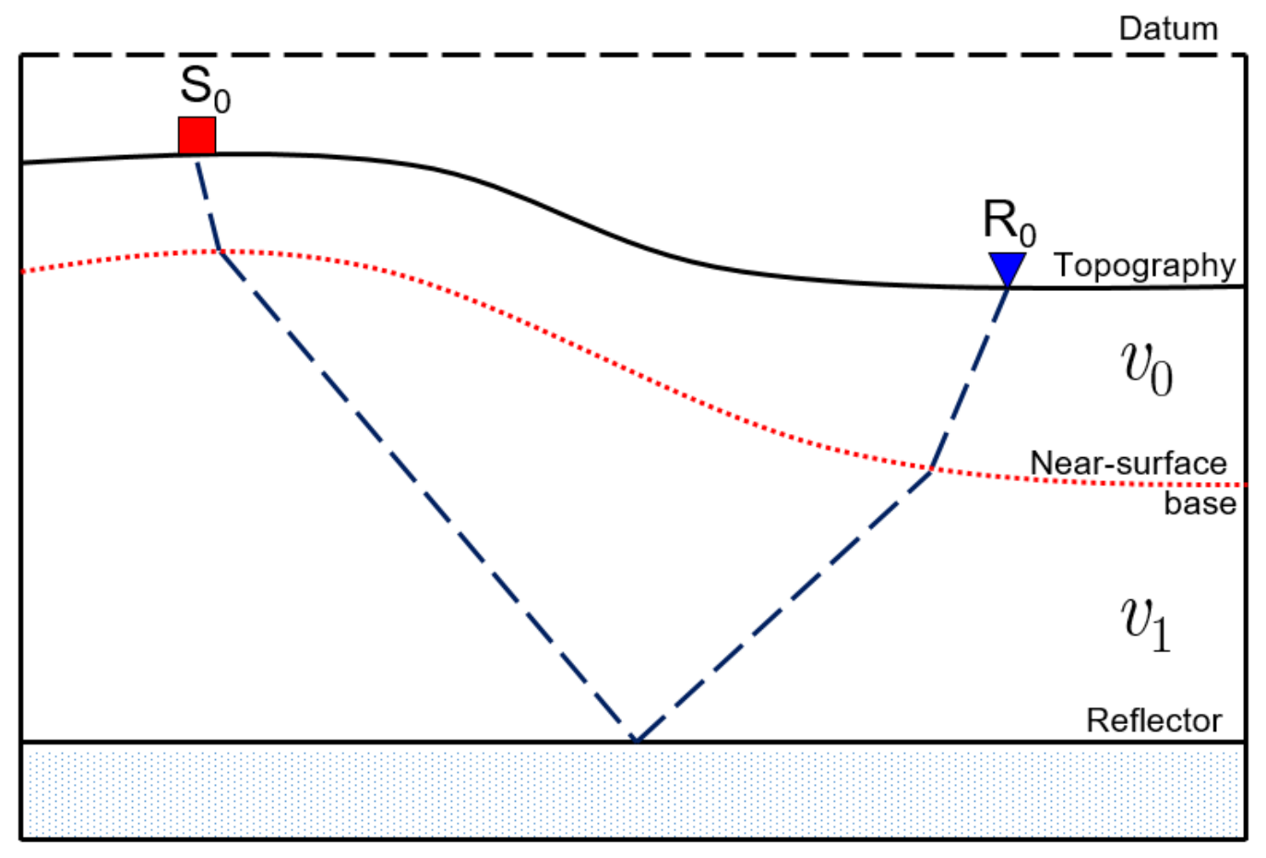
Abstract

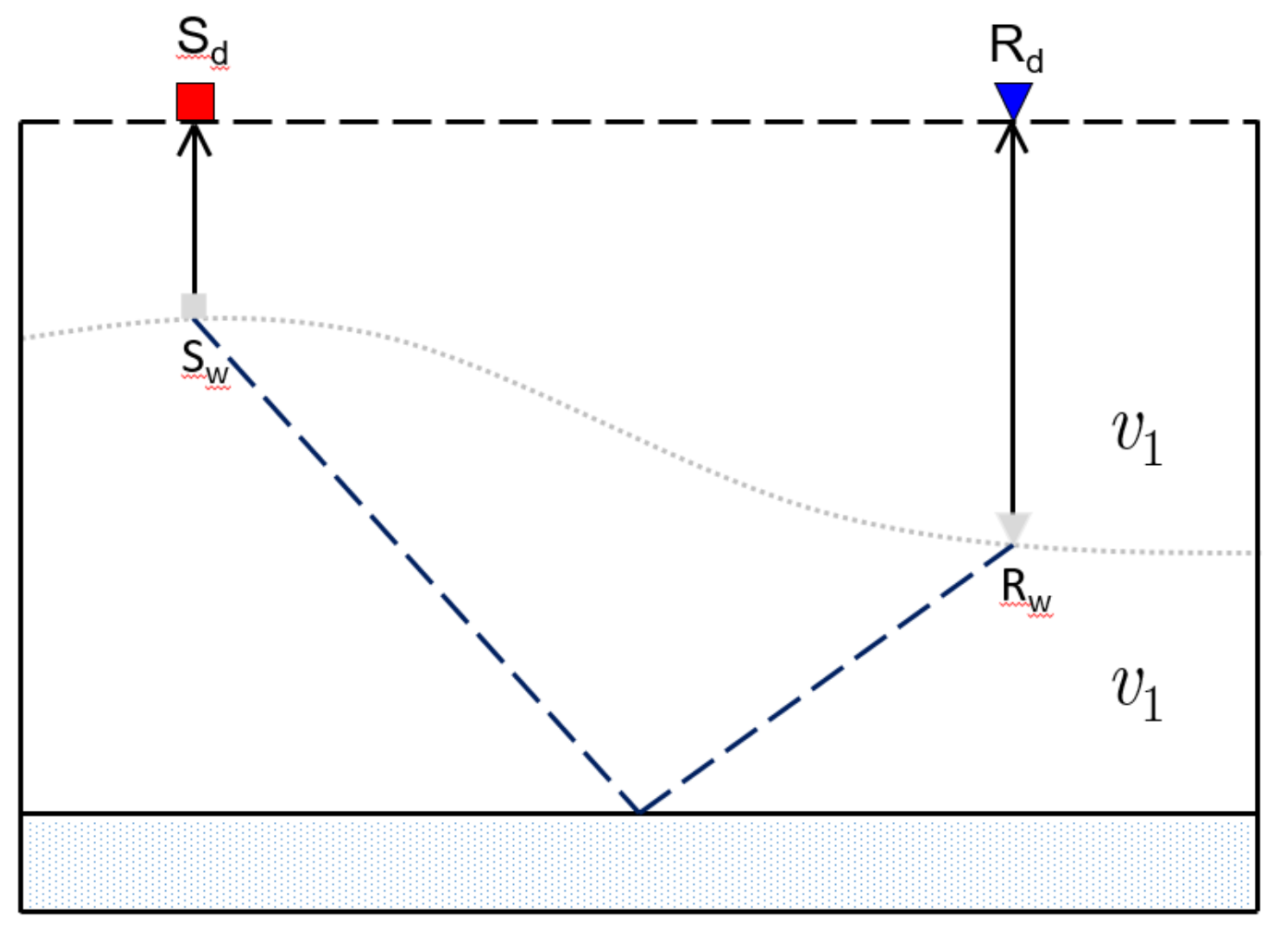
A near-surface velocity model is one of the typical products generated when computing static corrections, particularly in the processing of PP data. Critically-refracted waves are the input usually needed for this process. In addition, for the converted PS mode, S-wave near-surface corrections must be applied at the receiver locations. In this case, however, critically-refracted S-waves are difficult to identify when using P-wave energy sources. Here we use the τ-p representation of the converted-wave data to capture intercept-time differences between receiver locations. These τ-differences are then used in the inversion of a near-surface S-wave velocity model. Our processing work-flow provides not only a set of raypath-dependent S-wave static corrections but also a velocity model that is based on those corrections. Our computed near-surface S-wave velocity model can be used for building migration velocity models or to initialize elastic full waveform inversions. Our tests on synthetic and field data provided superior results to those obtained by using a surface-consistent solution.

Near-surface traveltime corrections

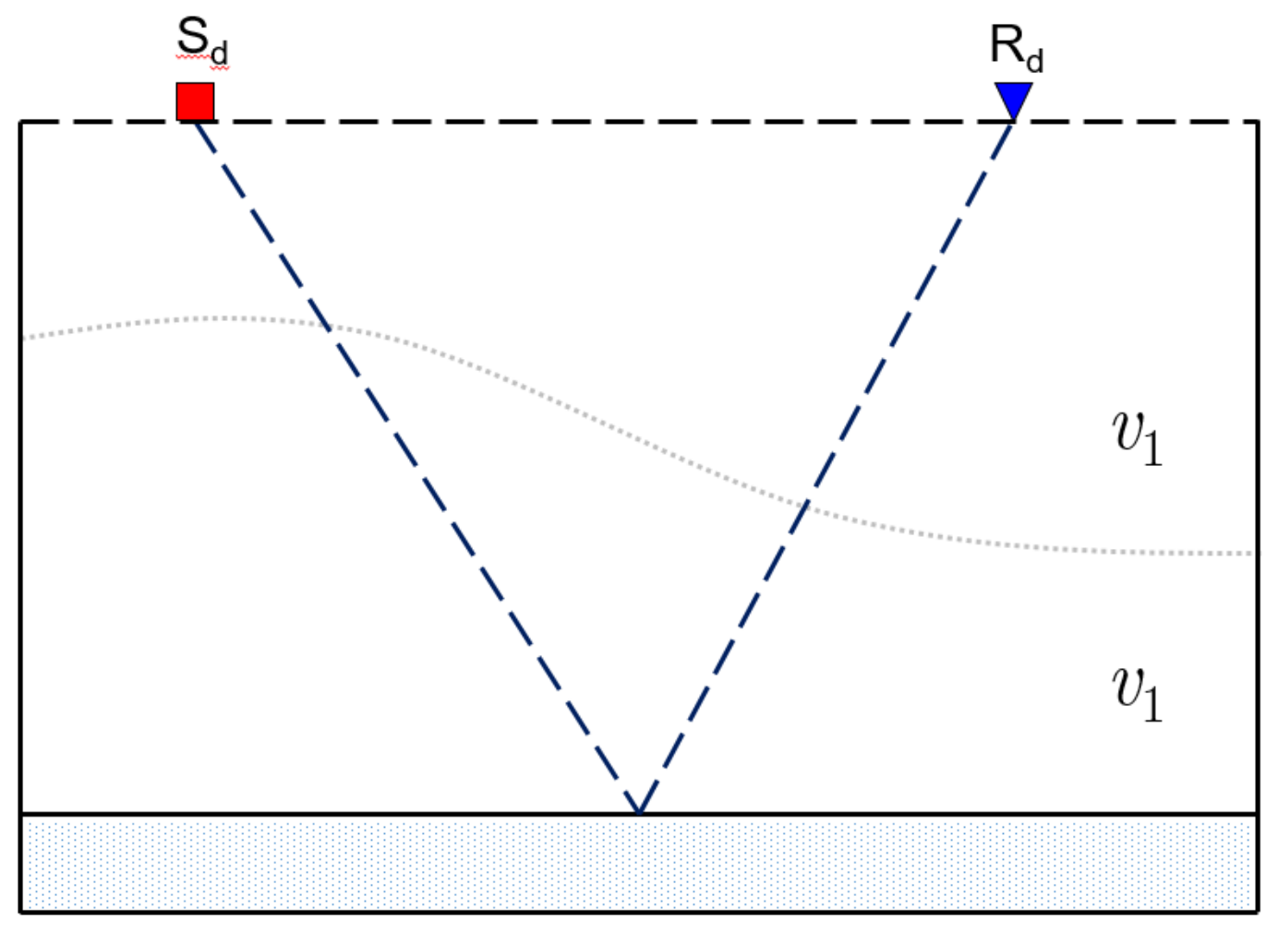
Elevation + Near Surface effects



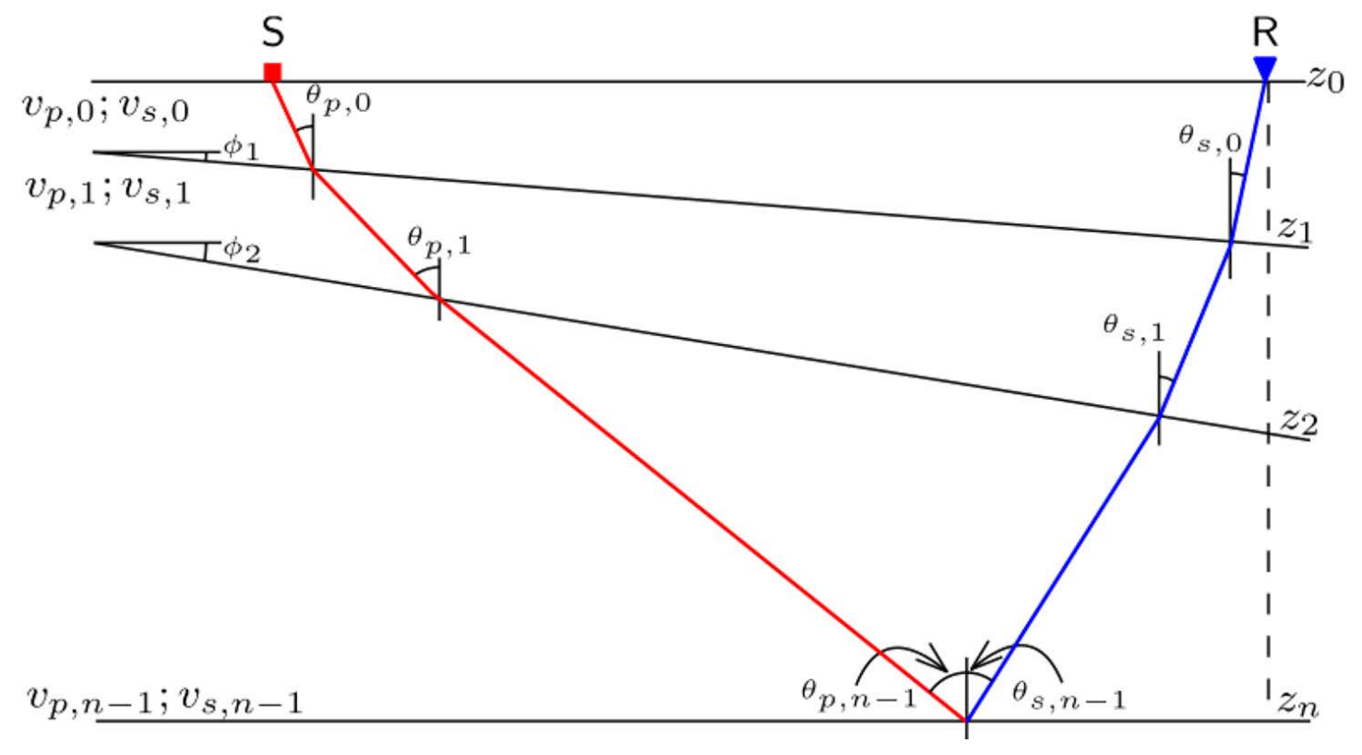
Surface-consistent Correction



Raypath-consistent Correction



Raypath-dependent corrections



Intercept time (τ) definition

$$\tau = \sum_{i=0}^{n-1} \Delta z_i \left(q_i^d + q_i^u\right) = \tau^d + \tau^u$$

Upgoing τ-contribution

$$\tau^u = \sum_{i=2}^{n-1} \Delta z_i q_i^u + z_2 q_1^u + \underbrace{z_1\left(q_0^u - q_1^u\right)}_{\text{Near-surface contribution}}$$

τ near-surface correction

$$\Delta\tau = \sum_{i=0}^{m-1} z_{i+1}\left(q_{i+1} - q_i\right)$$

τ elevation correction

$$\Delta\tau_{elev} = \left(z_d - z_r\right) q_m$$

Apparent slowness measured along dipping interfaces

$$p_{a,m-1} = p\cos\phi_m - q_m \sin\phi_m \qquad q_{a,m-1} = \left(s_{m-1}^2 - p_{a,m-1}^2\right)^{1/2}$$

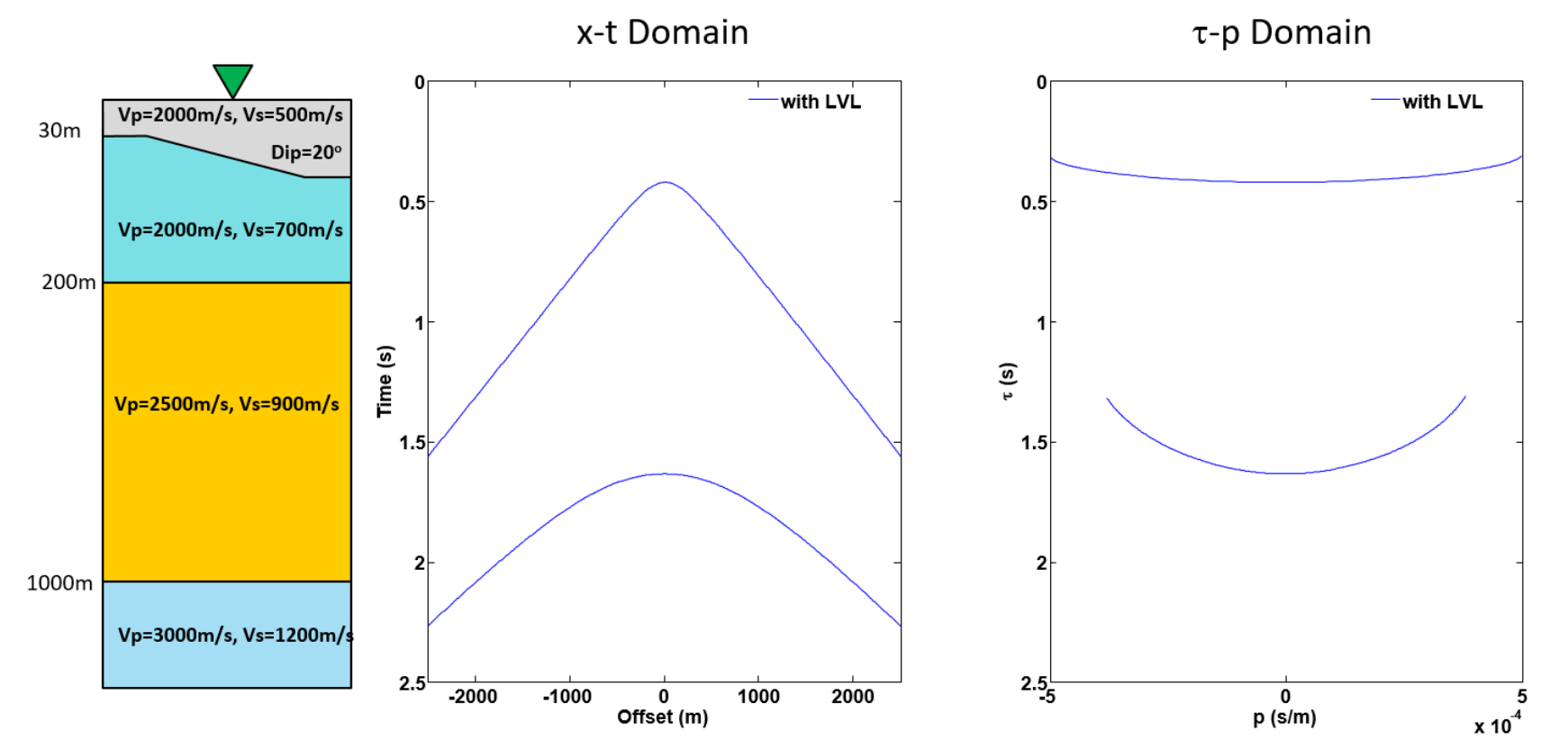
Slowness measured along the surface

$$\begin{pmatrix} p_{m-1} \\ q_{m-1} \end{pmatrix} = \begin{pmatrix} \cos\phi_m & \sin\phi_m \\ -\sin\phi_m & \cos\phi_m \end{pmatrix} \begin{pmatrix} p_{a,m-1} \\ q_{a,m-1} \end{pmatrix}$$

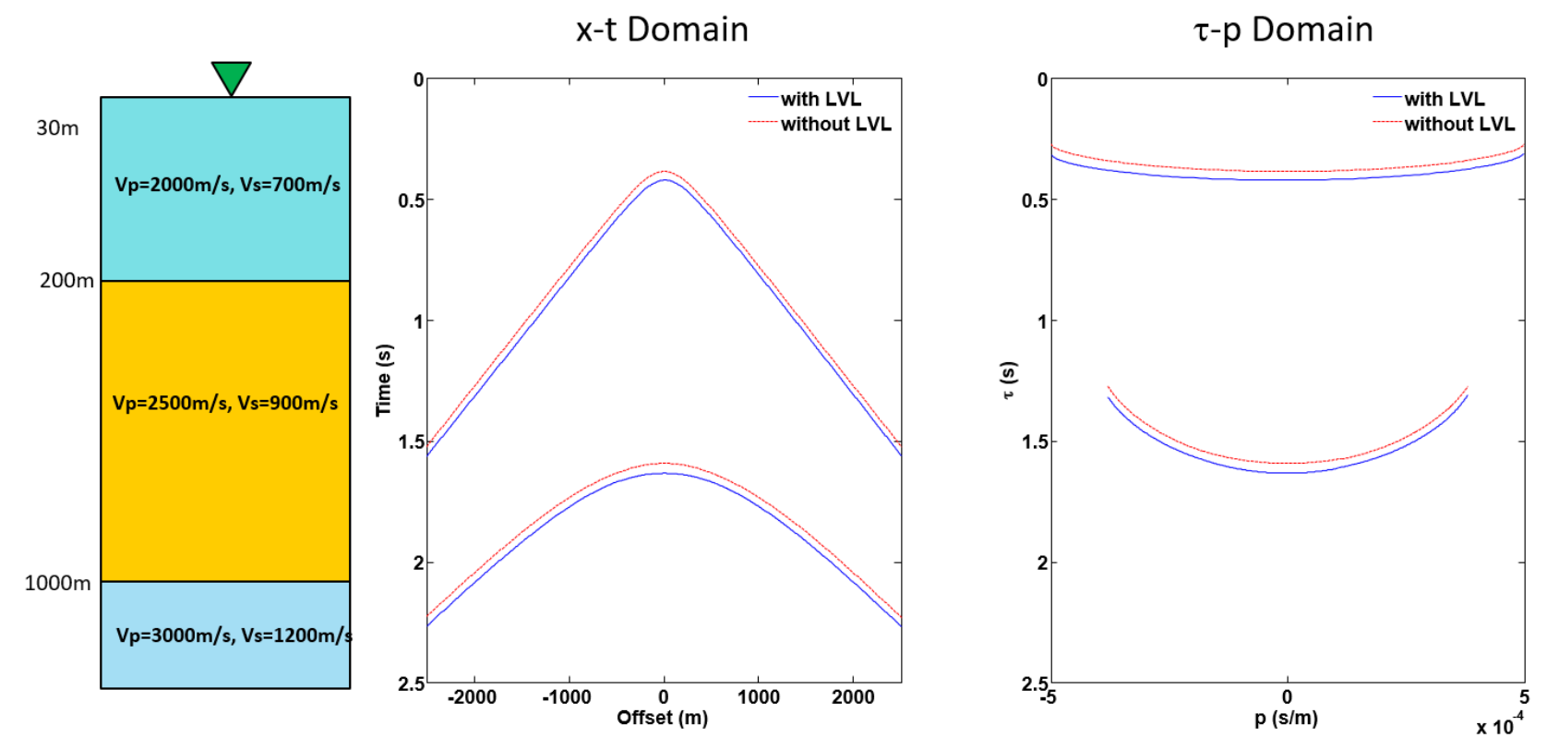
q_i : vertical slowness at i-th layer
p_i : horizontal slowness at i-th layer
ϕ_i : interface dip angle
z_i : vertical depth beneath receiver

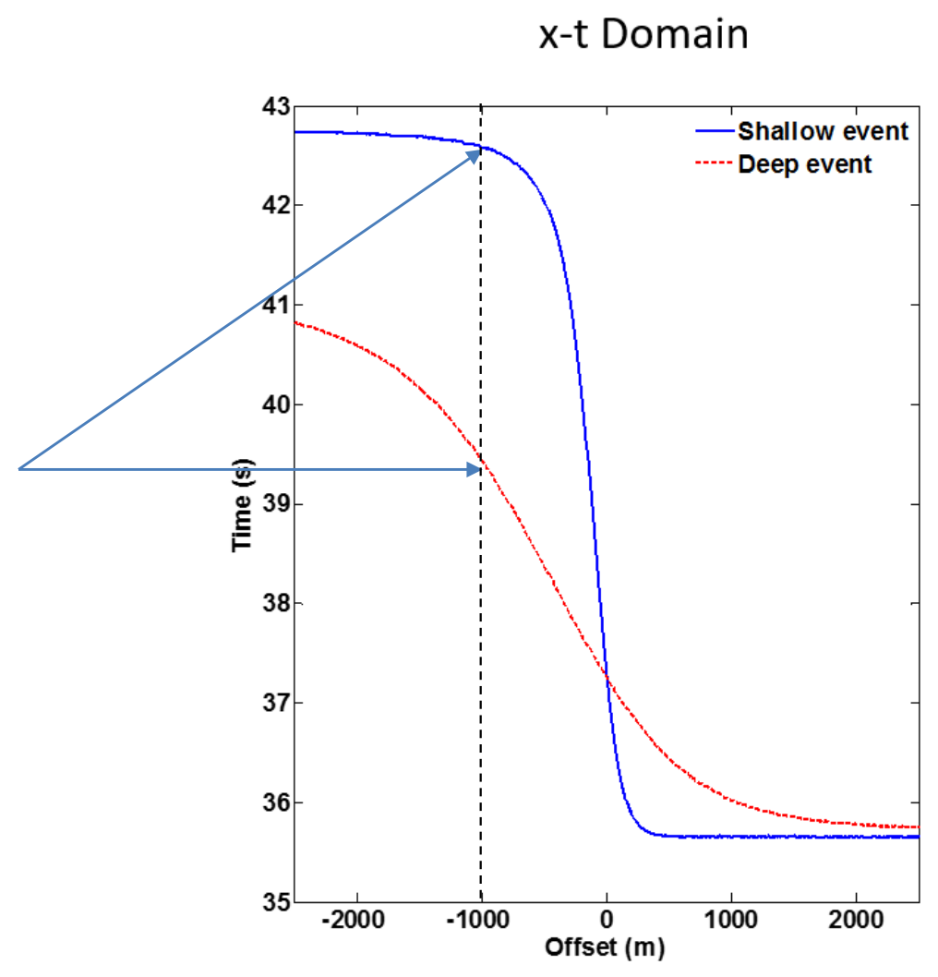
Analytic example

Model with dipping low velocity layer in the near-surface



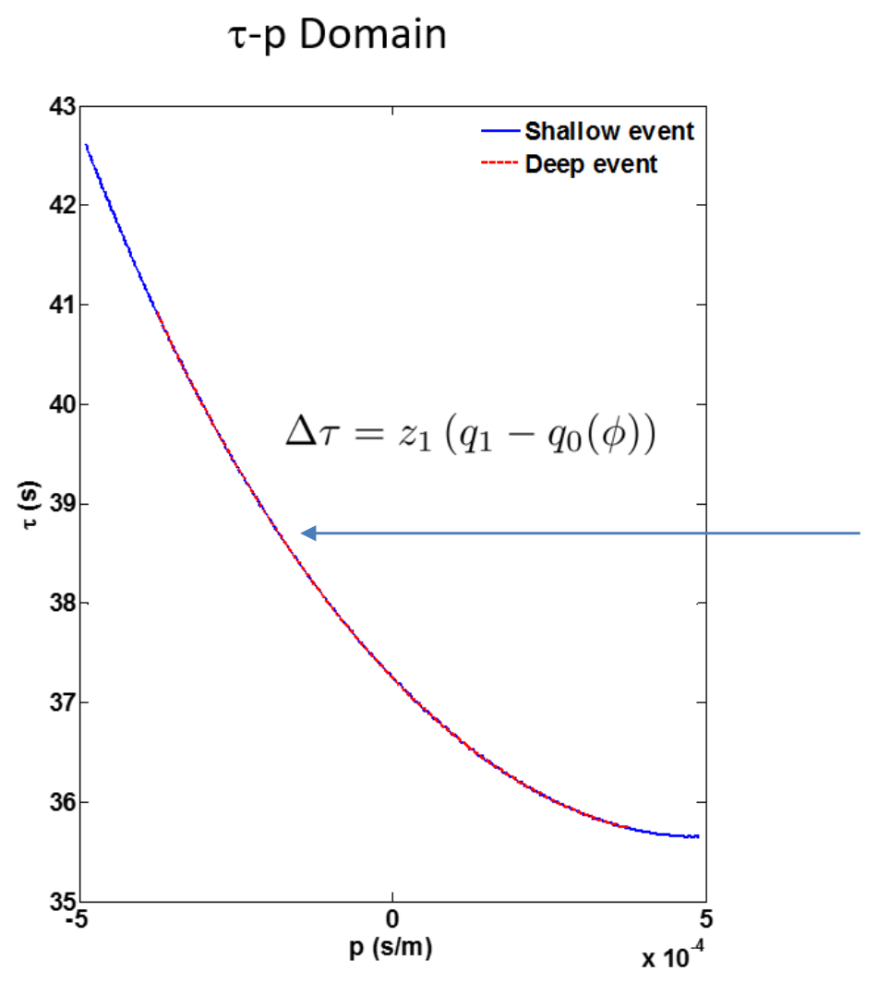
Model without low velocity layer in the near-surface





In x-t domain the effect of the near-surface is different for each event

A non-stationary (≠ static) correction is needed



In τ-p domain the effect of the near-surface is the same for both events

A stationary (static) correction will remove the near-surface effect

τ- difference between receivers

τ-difference at the j-th receiver:

$$\Delta\tau_{xcorr,j} = \overset{\tau\text{-contribution at current j-th location}}{\tau_j} - \tau_{j_0} \xleftarrow{} \tau\text{-contribution at reference location}$$

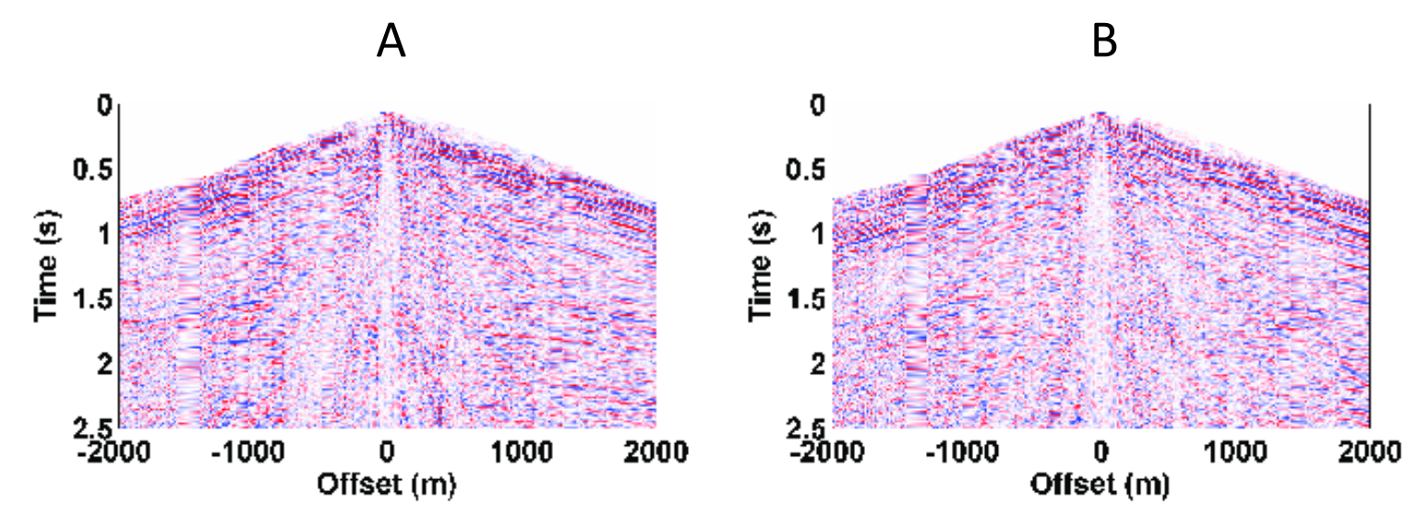
$$\begin{aligned}\Delta\tau_{xcorr,j} &= \sum_{i=0}^{m-1} z_{i+1,j}\left(q_{i,j}^u - q_{i+1,j}^u\right) + \left(z_d - z_{r,j}\right) q_m^u \quad \text{Total correction at current location} \\ &- \underbrace{\sum_{i=0}^{m-1} z_{i+1,j_0}\left(q_{i,j_0}^u - q_{i+1,j_0}^u\right)}_{\text{Near-surface correction}} - \underbrace{\left(z_d - z_{r,j_0}\right) q_m^u}_{\text{Elevation correction}} \quad \text{Total correction at reference location}\end{aligned}$$

τ-differences expressed in terms of near-surface corrections and elevation differences

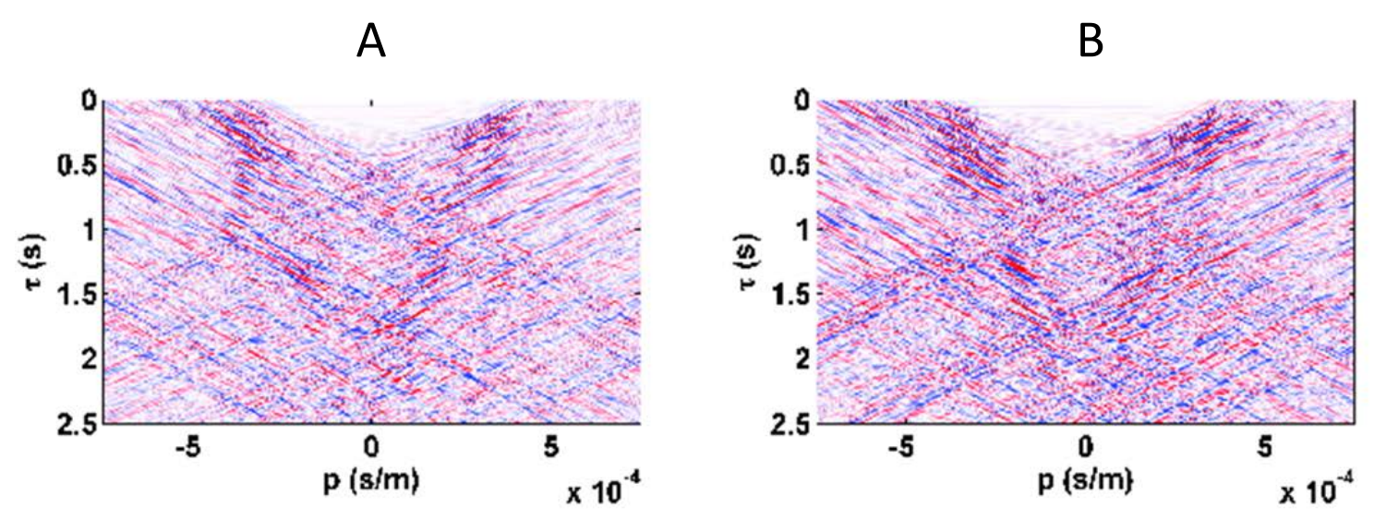
$$\Delta\tau_{xcorr,j} = \Delta\tau_{j_0} - \Delta\tau_j + \left(z_{r,j_0} - z_{r,j}\right) q_m^u$$

Field data workflow

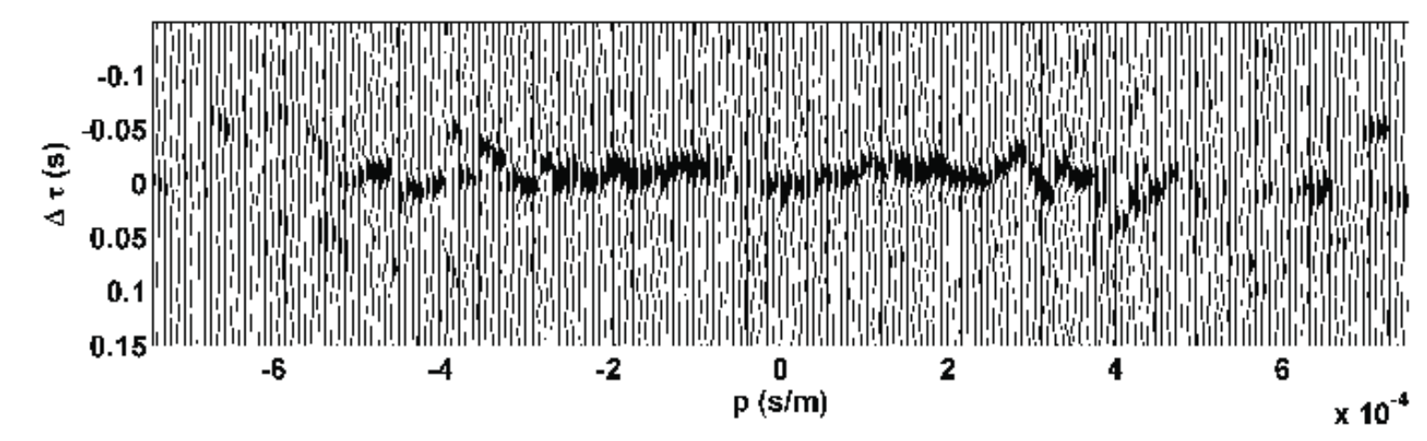
1. Input receiver gathers (reference and current receiver location)



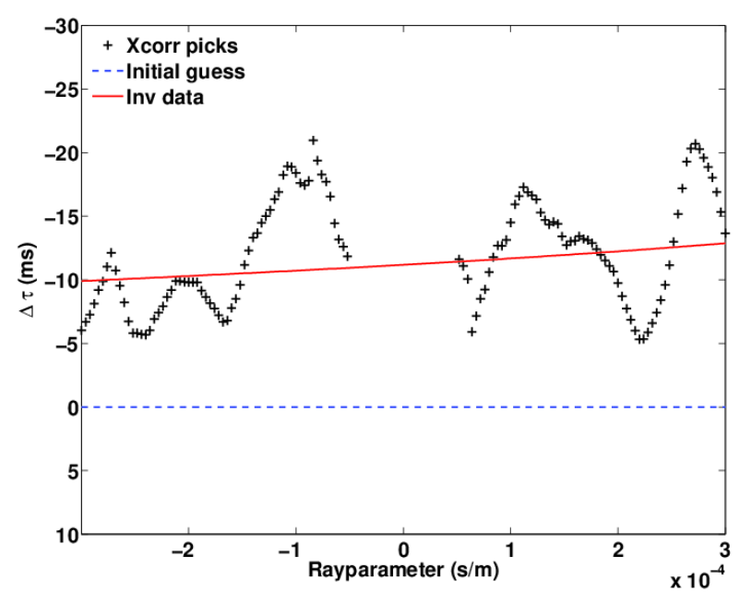
2. Transform receiver gathers to τ-p domain



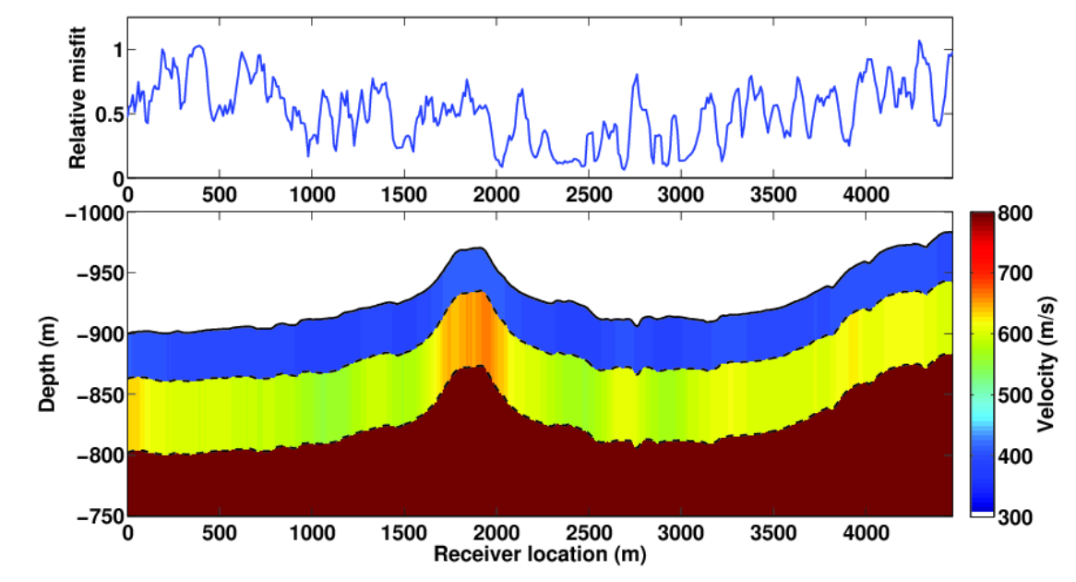
3. Crosscorrelate τ-p receiver gathers



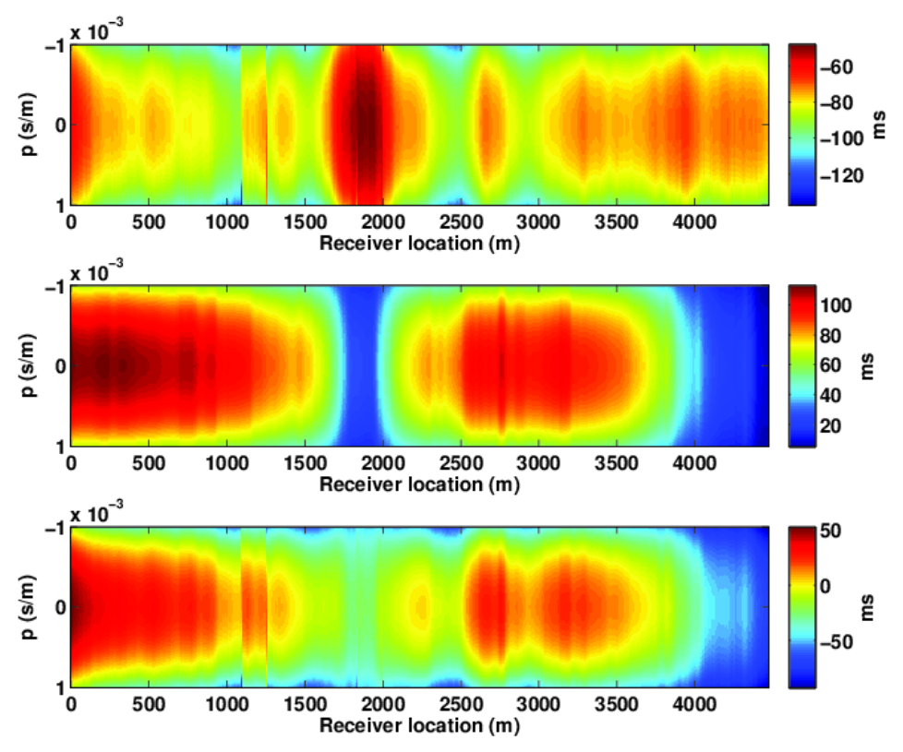
4. Input crosscorrelation lags into inversion algorithm



5. Repeat for all receivers and interpolate

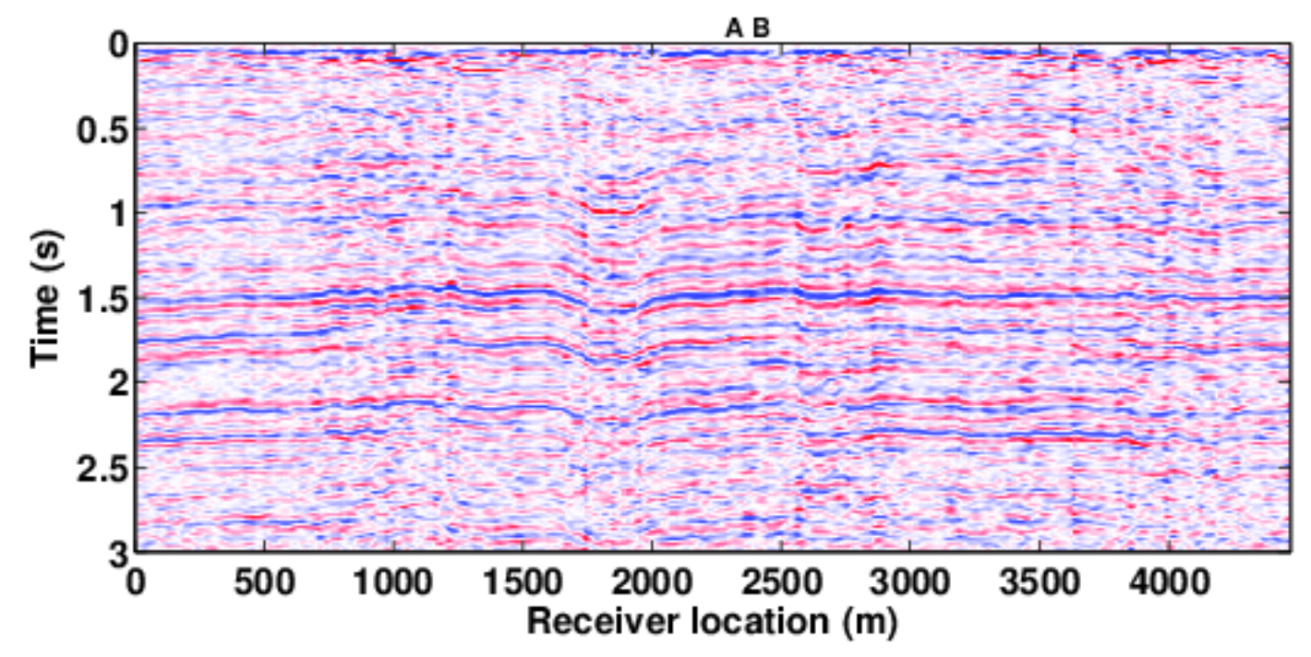


6. Compute rayparameter dependent τ-corrections

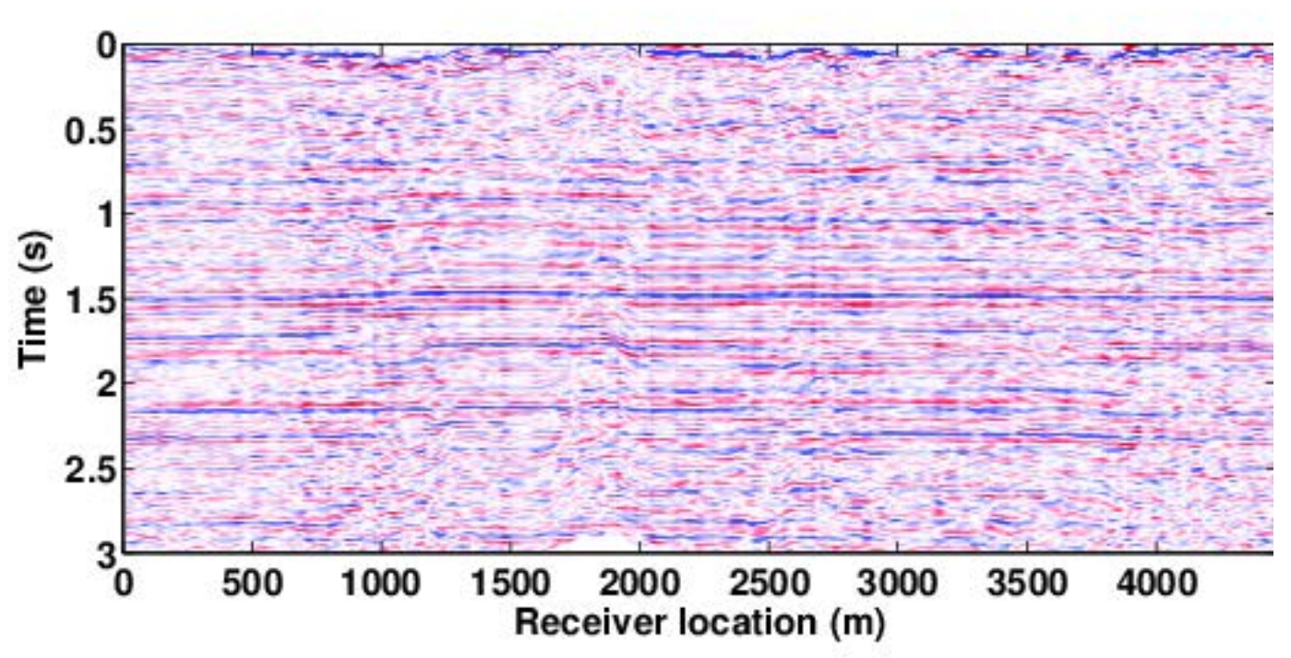


Common receiver stacks:

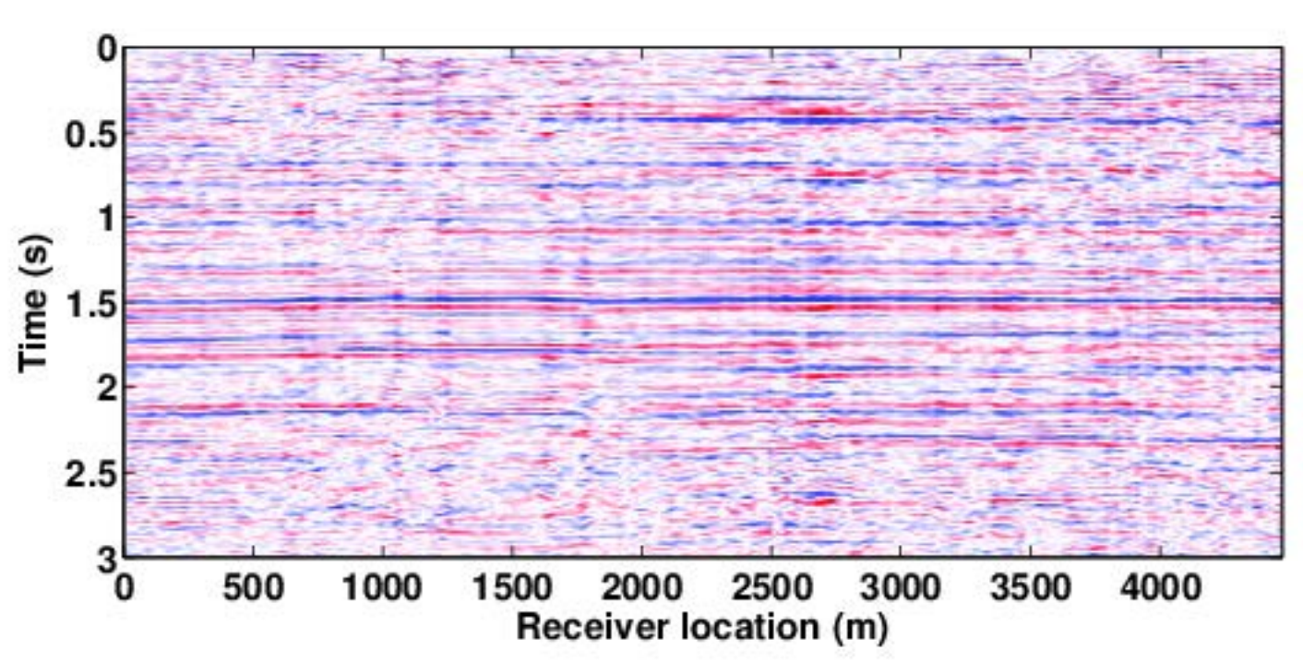
Before near-surface corrections



After surface-consistent corrections



After raypath-consistent corrections



Conclusions

Removing near-surface effects in a raypath-consistent framework provides stacked sections with enhanced coherence and resolution. Our approach removes raypath-dependent near-surface effects while simultaneously extracting information about the velocities in the near-surface. In this way, the corrections applied to the data can be removed at later stages of the processing if needed. Also, the velocity information about the near-surface layers can be useful for building velocity models for migration or elastic full waveform inversion.

Even though the field data processing shown here considered a two-layered velocity model, the physical framework presented earlier allows for models with several layers. The extension of this approach into a tomographic solution is also possible and this application remains to be explored.

Acknowledgements

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