PS-wave traveltime difference inversion for near-surface characterization in the tau-p domain

Prepared by

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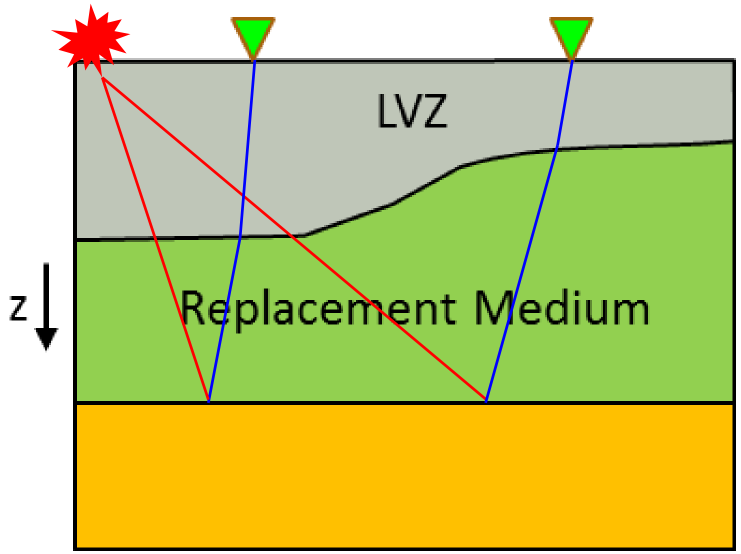
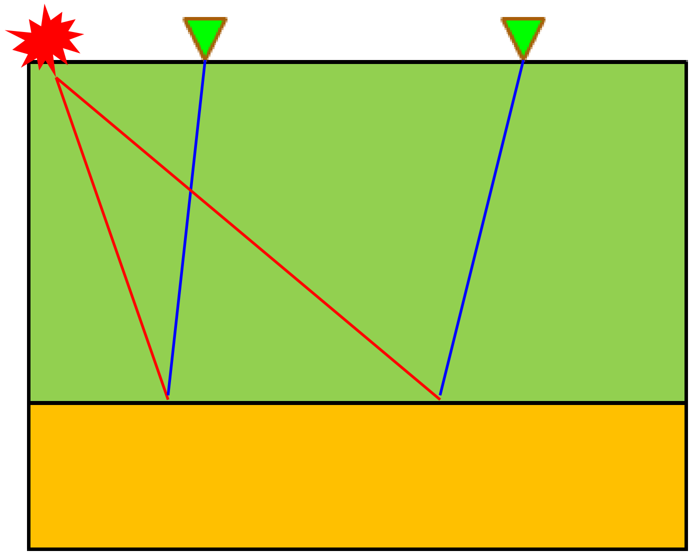
Near-surface Effects



LVZ: Low Velocity Zone



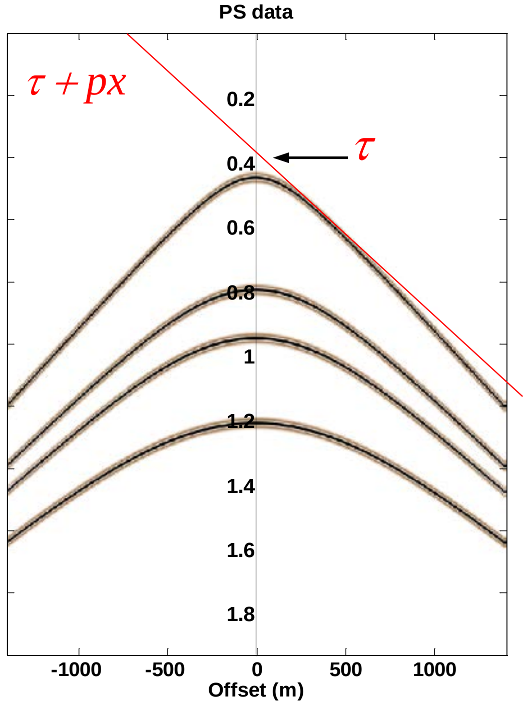
How to compute a near-surface velocity model for S-wave “static” corrections using PS data?

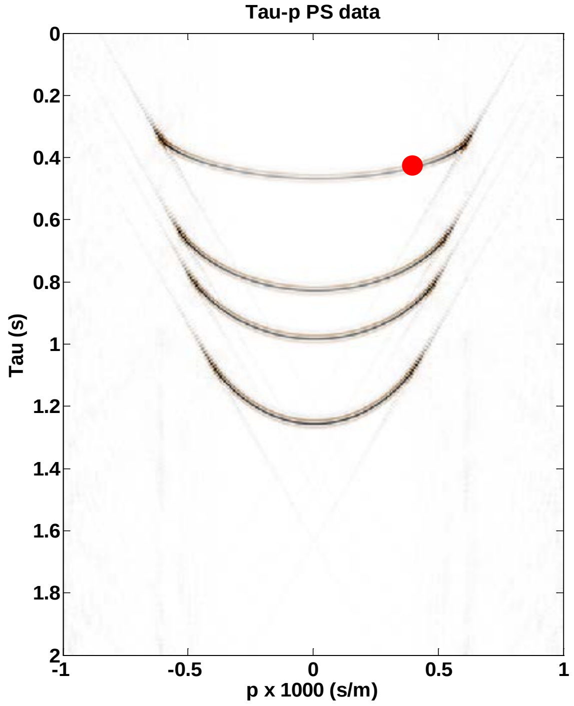
Tau-p coordinates

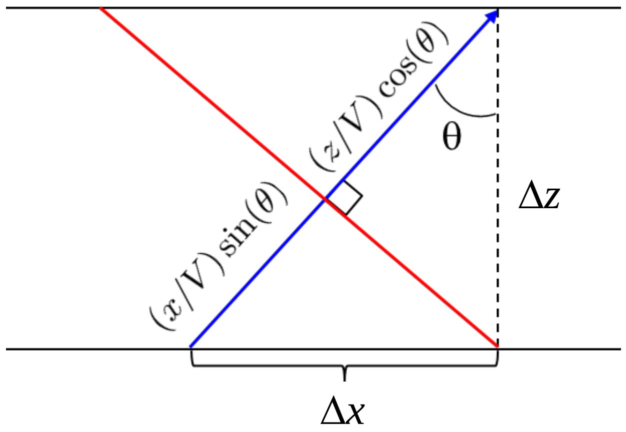
Tau-P Transform

$$U(\tau, p) = \int_{-\infty}^{\infty} u(\tau + px, x)\,dx$$

Sensitive to the emerging angle of the wavefield at the surface



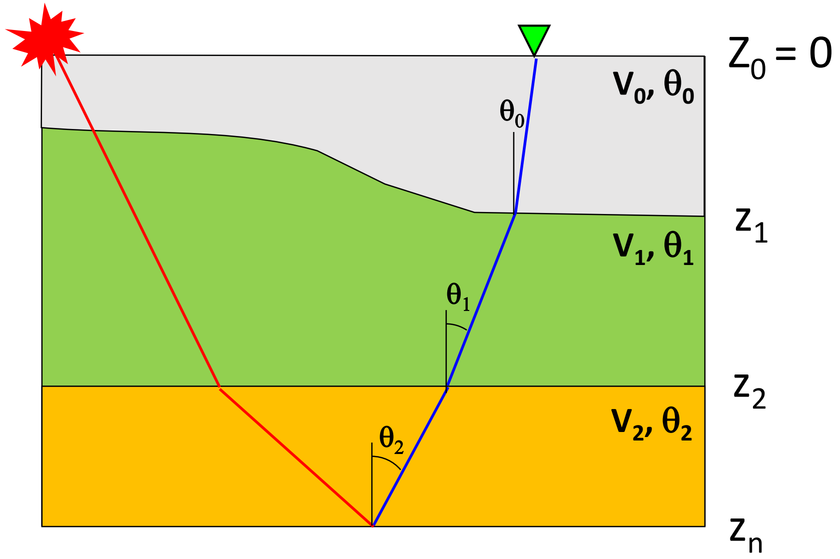




$$\Delta t = \frac{\sin(\theta)}{V}\Delta x + \frac{\cos(\theta)}{V}\Delta z \qquad p^2 + q^2 = \frac{1}{V^2}$$
$$= p\Delta x + q\Delta z$$
$$= p\Delta x + \Delta\tau$$

p: Horizontal slowness
q: Vertical slowness

τ and the near surface



τ contribution from z_2 to the surface with velocity v_1 and raypath angle θ_1

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

τ contribution from the reflector to the base of the replacement medium Z_2

Near-surface effect

Subtract τ contribution from z_1 to the surface with velocity v_0 and raypath angle θ_0

Near-surface correction $$\Delta\tau_{NS}^u = z_1 \left(q_1^u - q_0^u\right)$$

Add τ contribution from z_1 to the surface with velocity v_1 and raypath angle θ_1

Dipping near-surface base

In this case p is not constant at all layers, therefore we introduce,

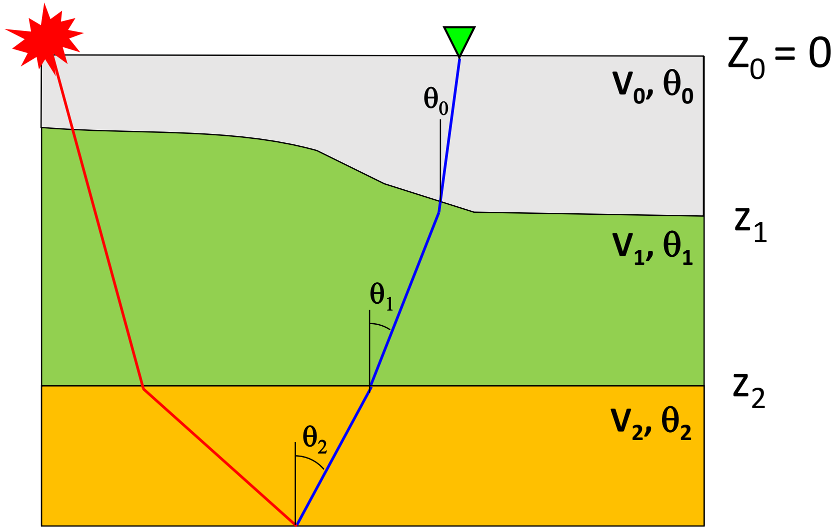
$$\Delta\tau^{u}_{NS} = z_1\left(q_1 - q_0(\phi)\right)$$

where,

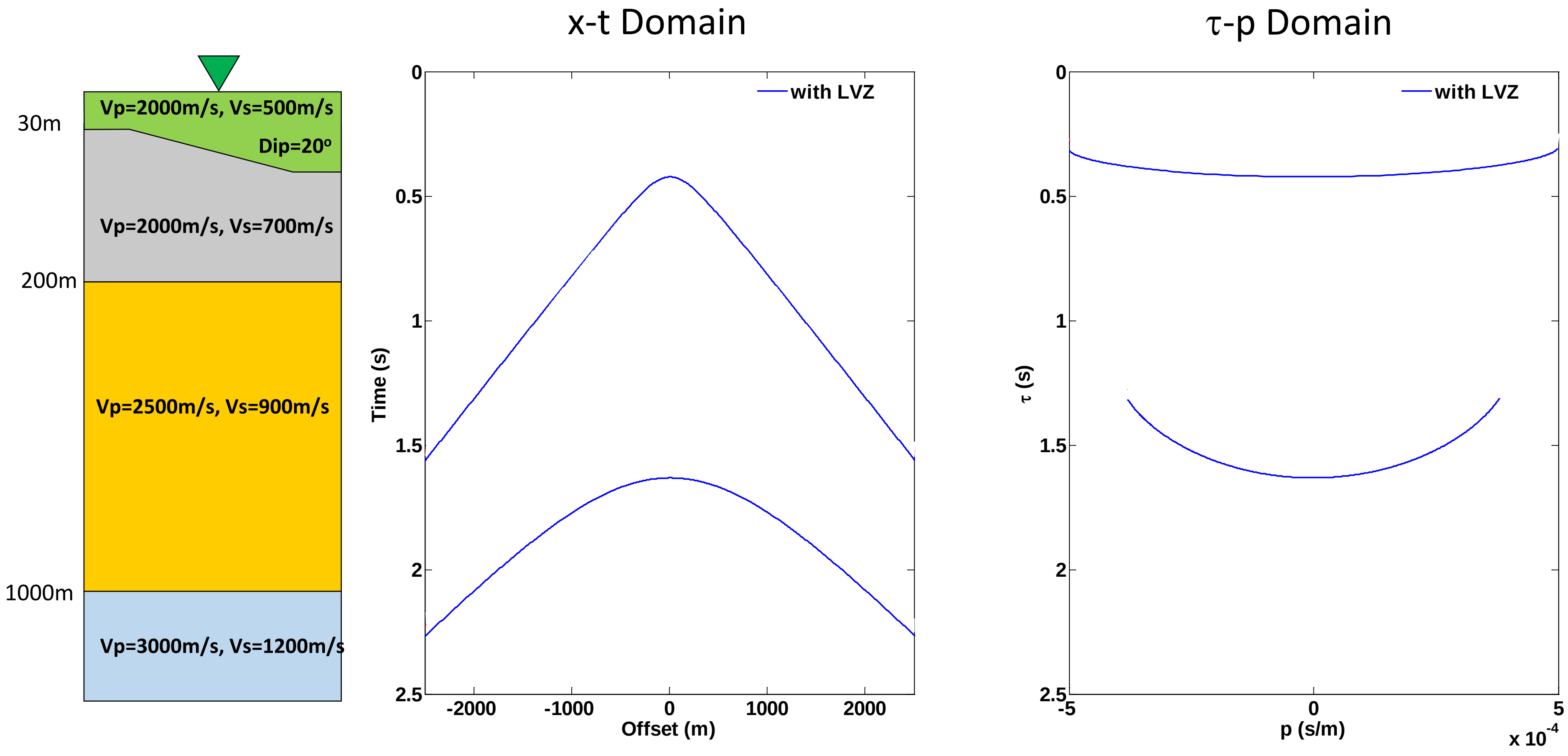
$$q_0(\phi) = q_a\cos(\phi) - p_a(\phi)\sin(\phi)$$

with,

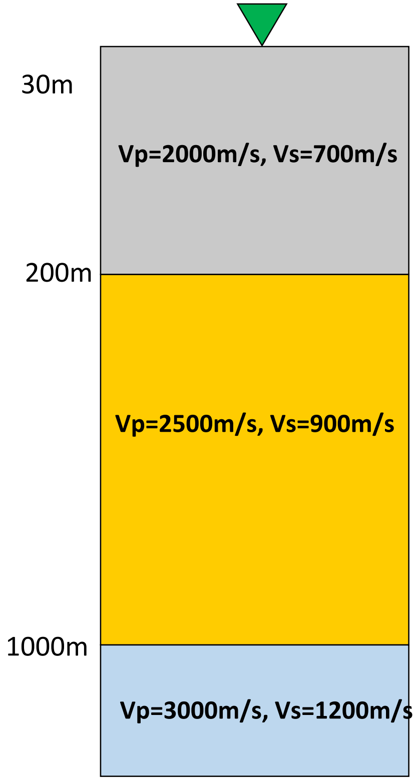
$$q_a = \sqrt{\frac{1}{v_0^2} - p_a^2}$$ and $$p_a(\phi) = p\cos(\phi) - q_1\sin(\phi)$$

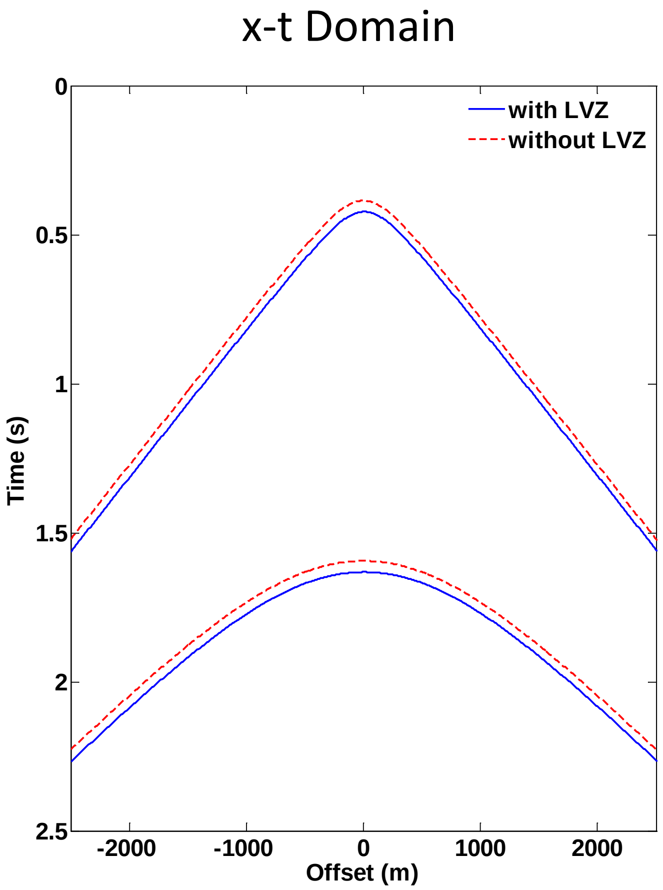


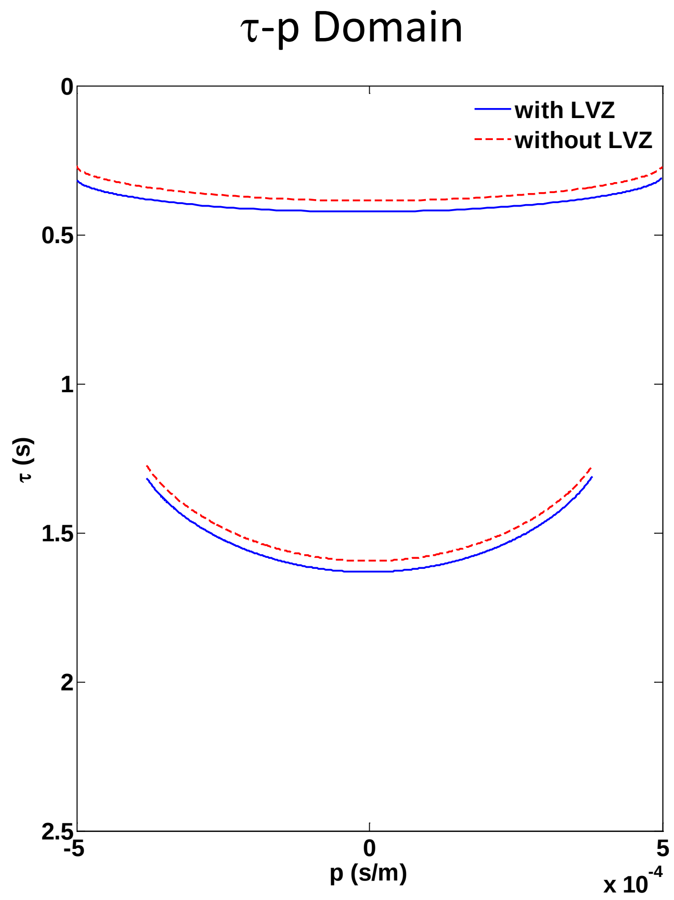
Travel times analysis



Travel times analysis

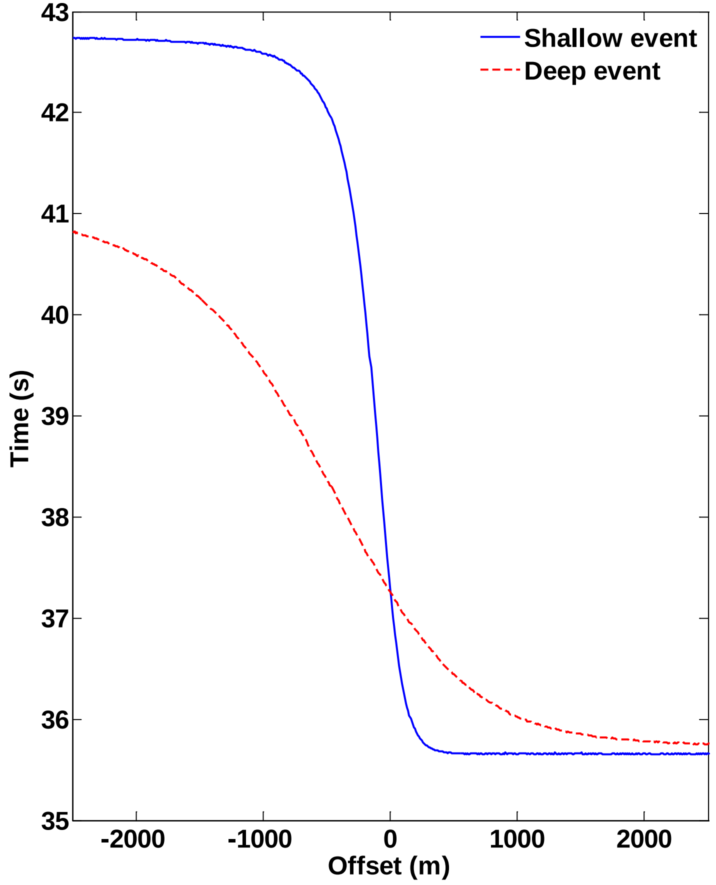






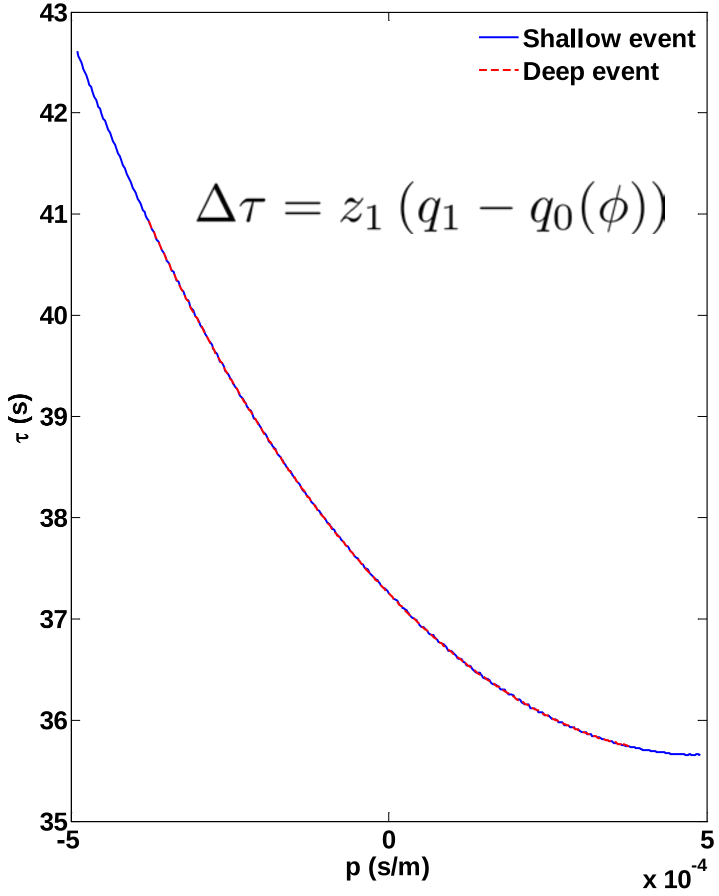
Dipping LVZ Model

x-t Domain



Non-stationary

τ-p Domain



Stationary

Quasi-Newton Inversion

Data Residuals — Forward modelled data — Observed data

Objective Function
$$\Phi(\mathrm{m}) = ||\delta \mathrm{d}||^2 = ||\mathrm{g}(\mathrm{m}) - \mathrm{d}_{\mathrm{obs}}||^2,$$

$$\mathrm{m_i} = \mathrm{m_{i-1}} + \delta \mathrm{m_i},$$
Model Update

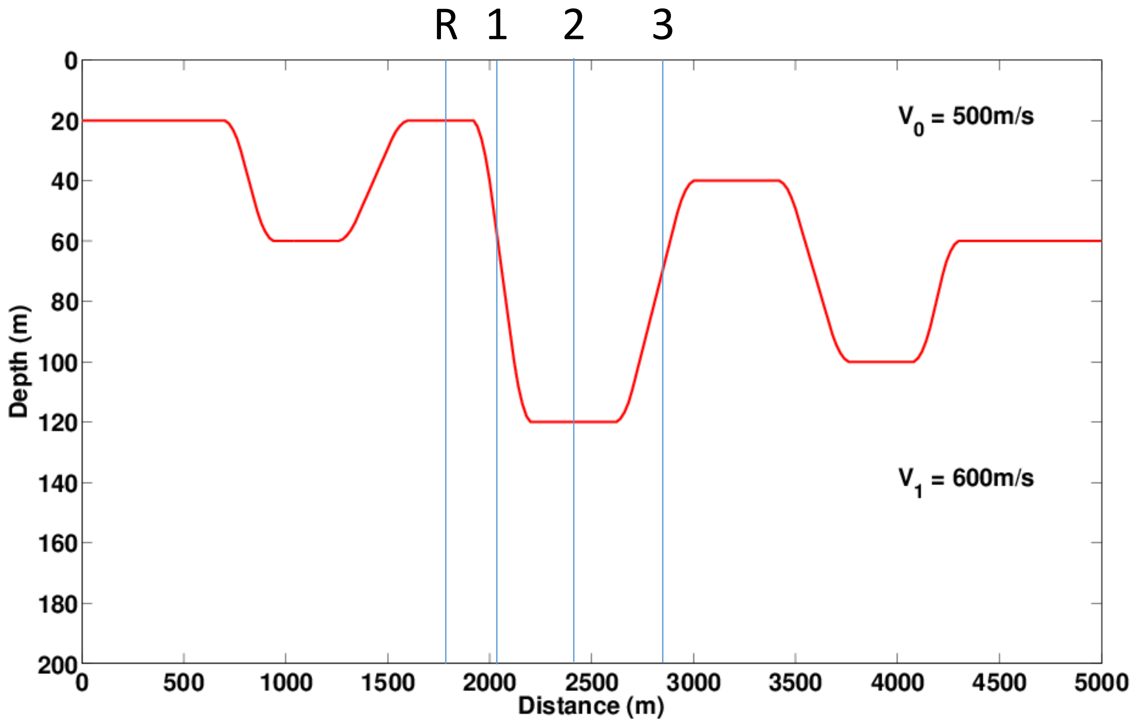
$$\delta \mathrm{m} = \left[\mathrm{J}(\mathrm{m})^{\dagger} \mathrm{J}(\mathrm{m}) + \mu \mathrm{I}\right]^{-1} \mathrm{J}(\mathrm{m})^{\dagger} \delta \mathrm{d}.$$

I : Identity matrix
μ : Regularization weight

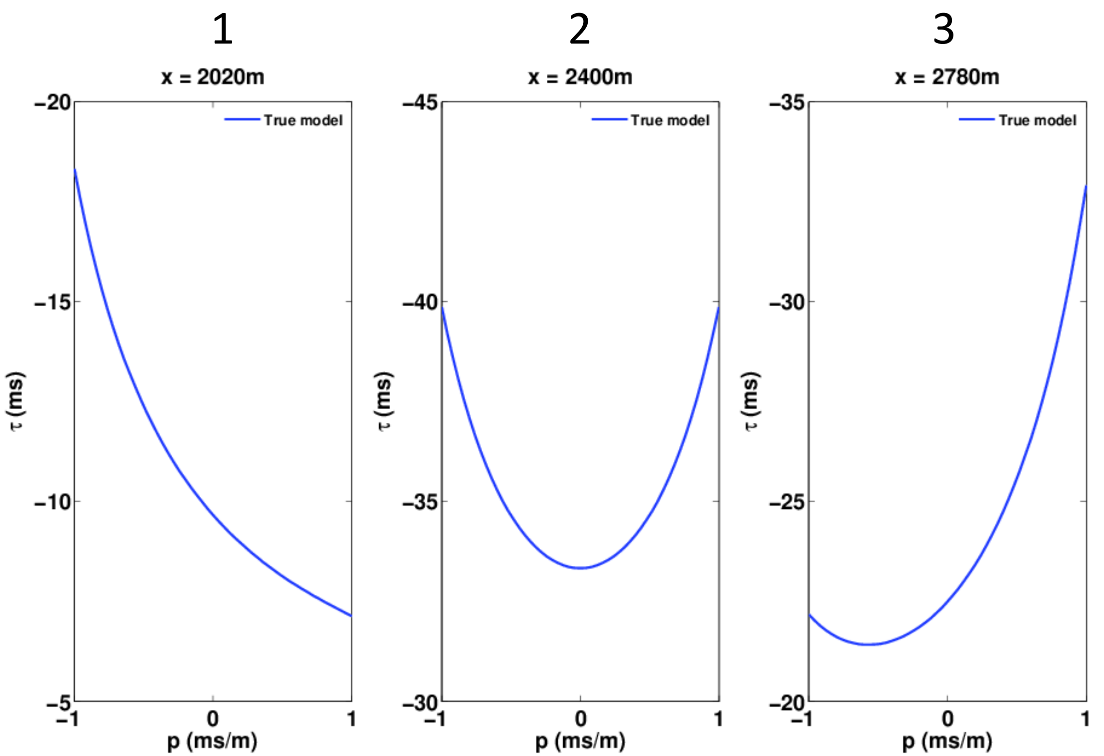
Jacobian
$$\mathrm{J}(\mathrm{m}) = \left[\frac{\partial \mathrm{g}(\mathrm{m})}{\partial \mathrm{m}}\right] = \left[\quad \frac{\partial g(m)}{\partial V_0}, \quad \frac{\partial g(m)}{\partial V_1}, \quad \frac{\partial g(m)}{\partial z}, \quad \frac{\partial g(m)}{\partial \phi}\right].$$

Modelled differences at three locations

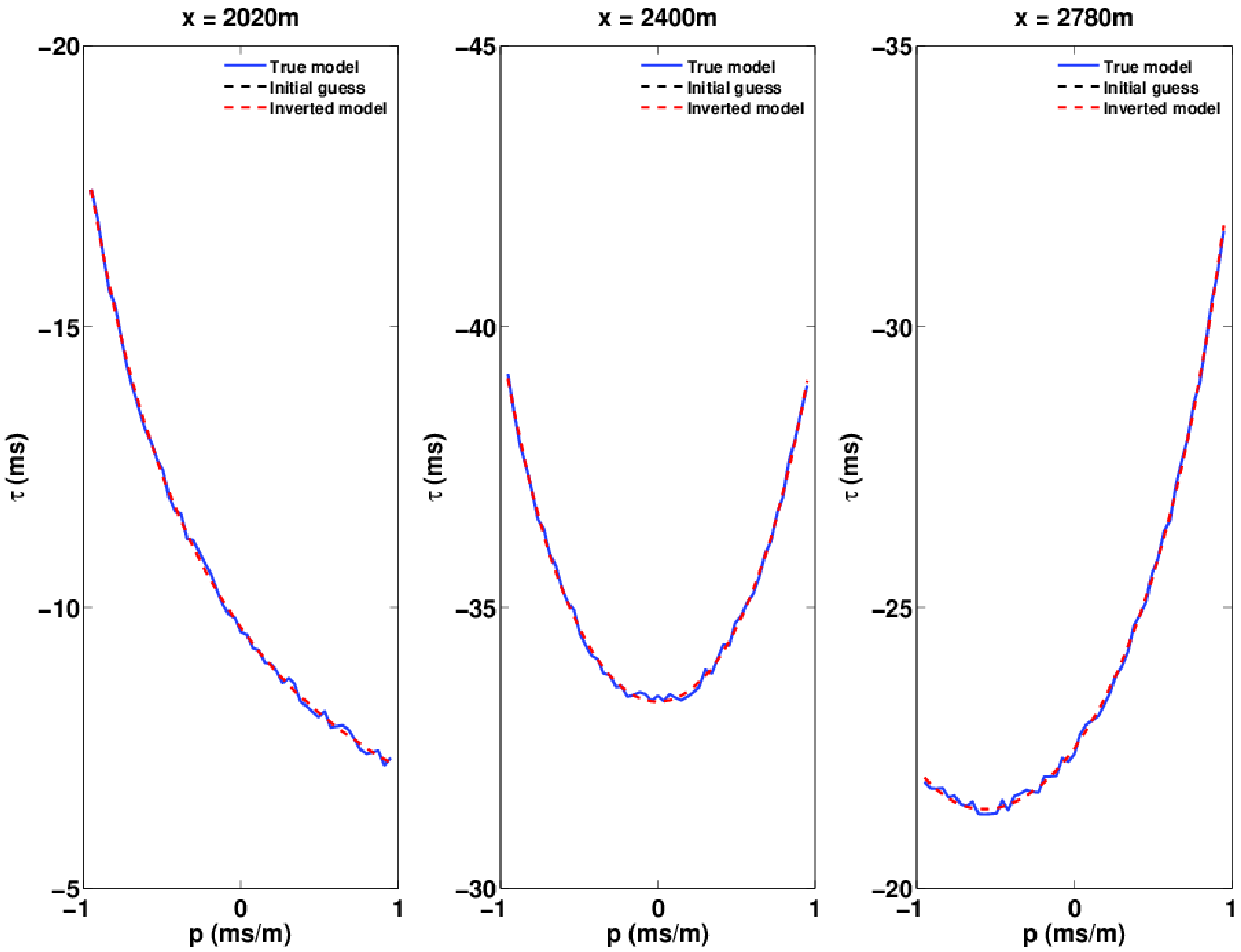
Velocity Model



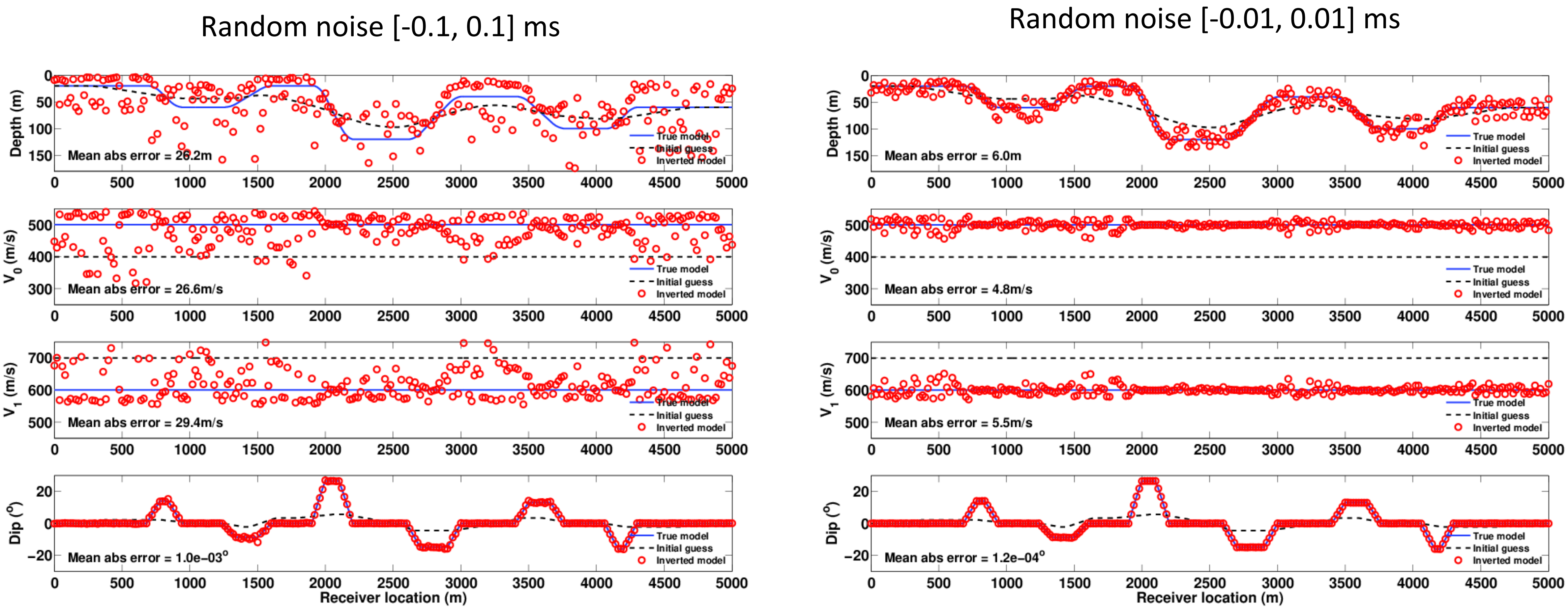
Data plots



Adding random noise [-0.1, 0.1]ms



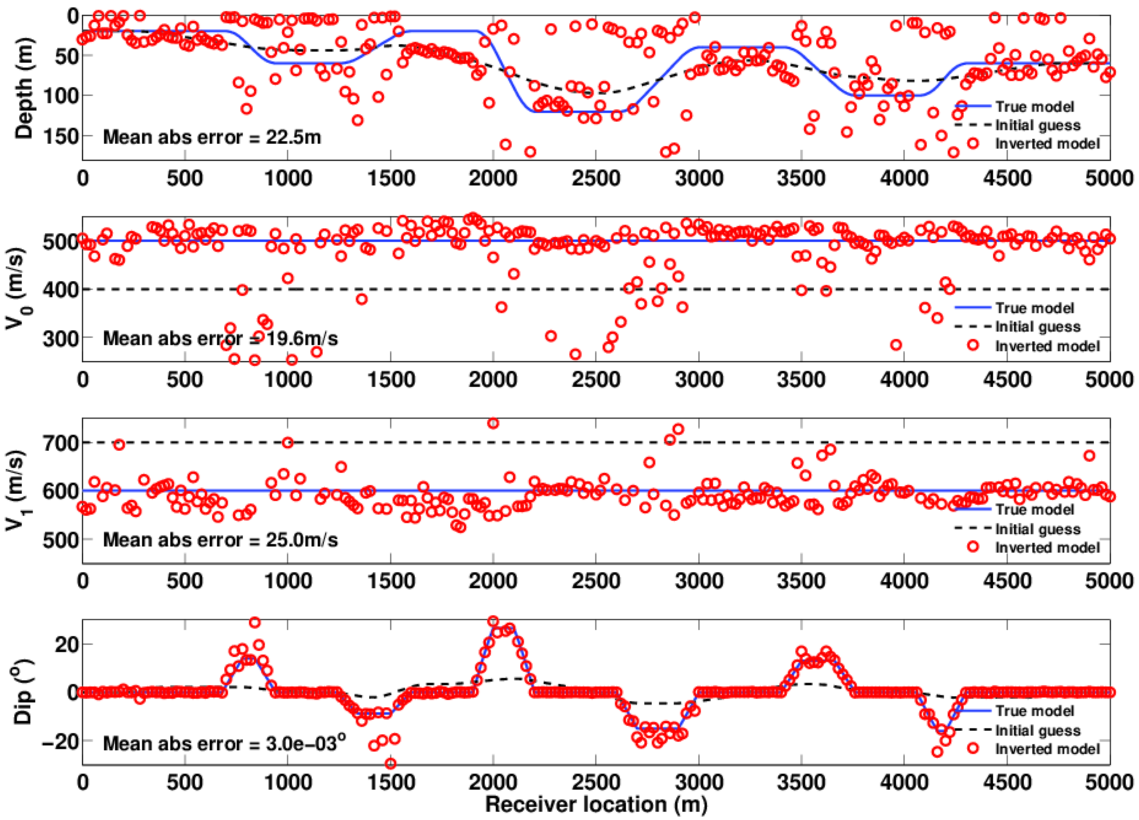
Random noise effect



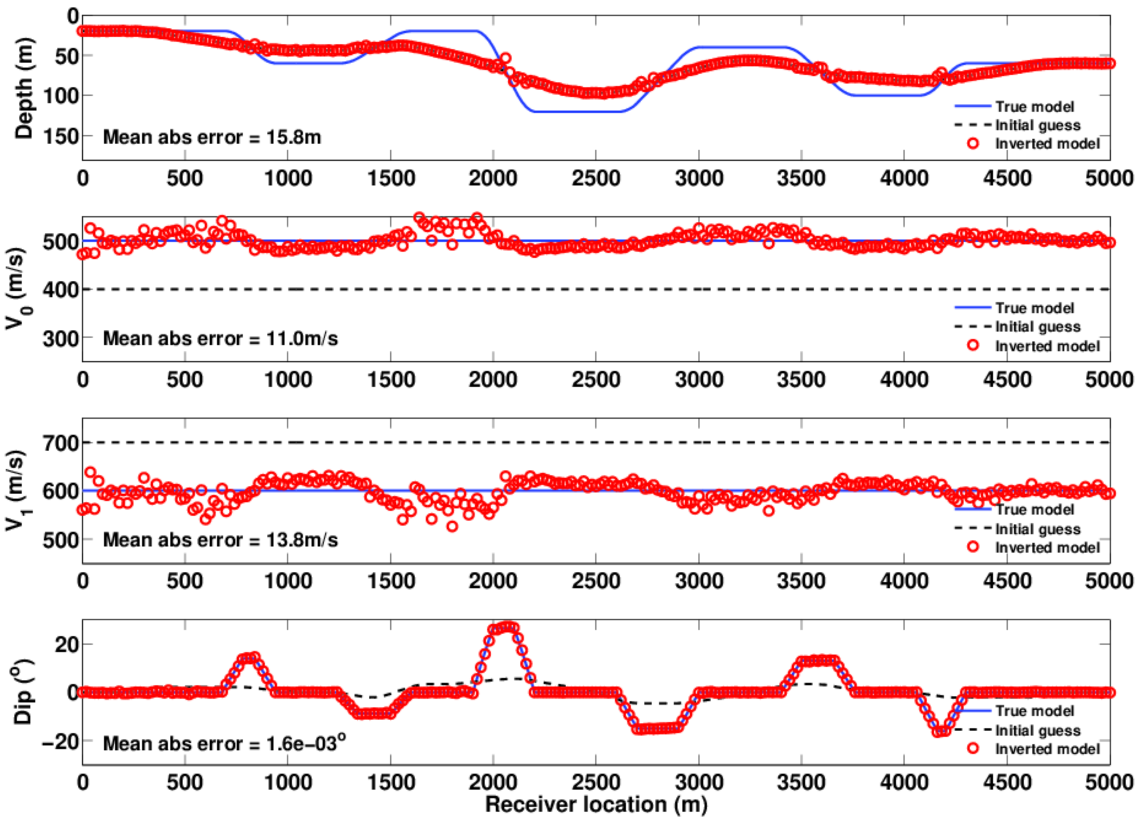
- Inversion seems to be very sensitive to noise in traveltime differences.
- Dip estimations display stable results

Random Noise [-0.1 0.1]ms, p=[-0.5, 0.5]ms/m

u=0.01

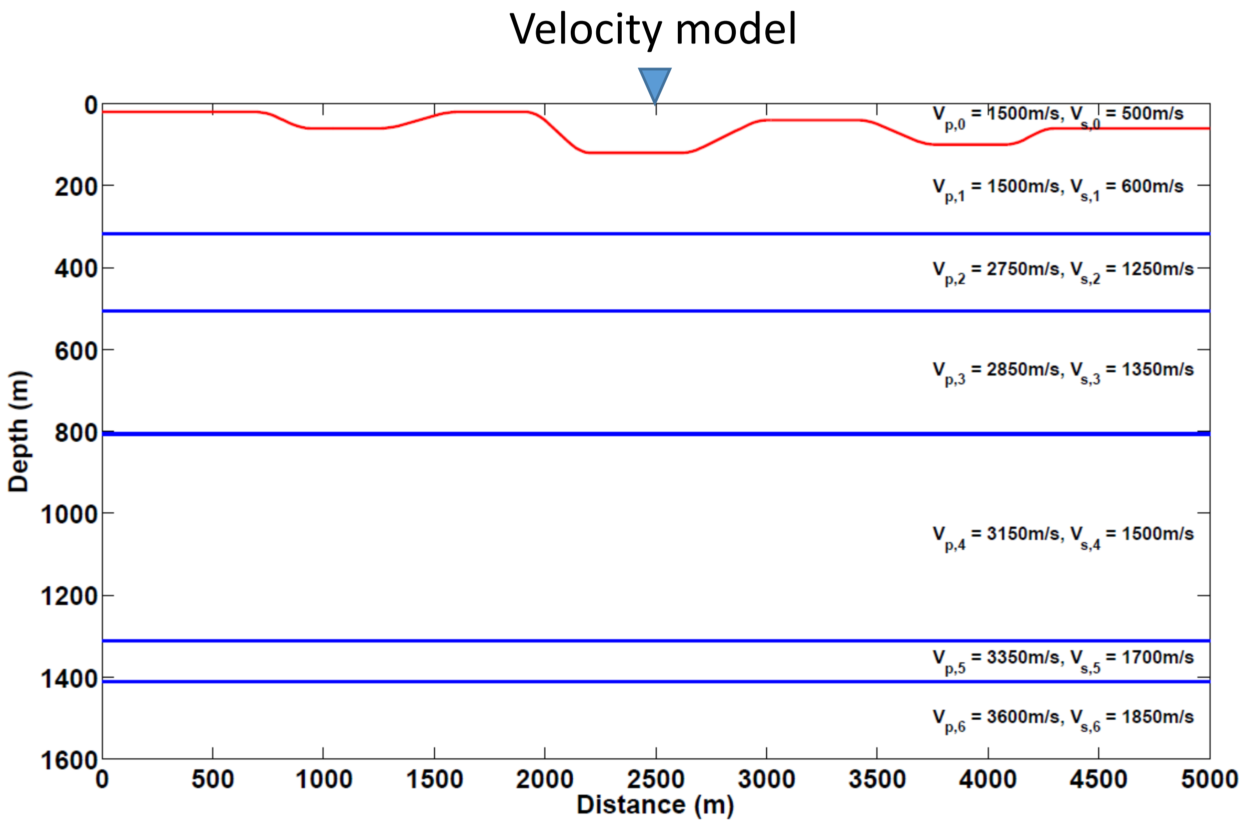


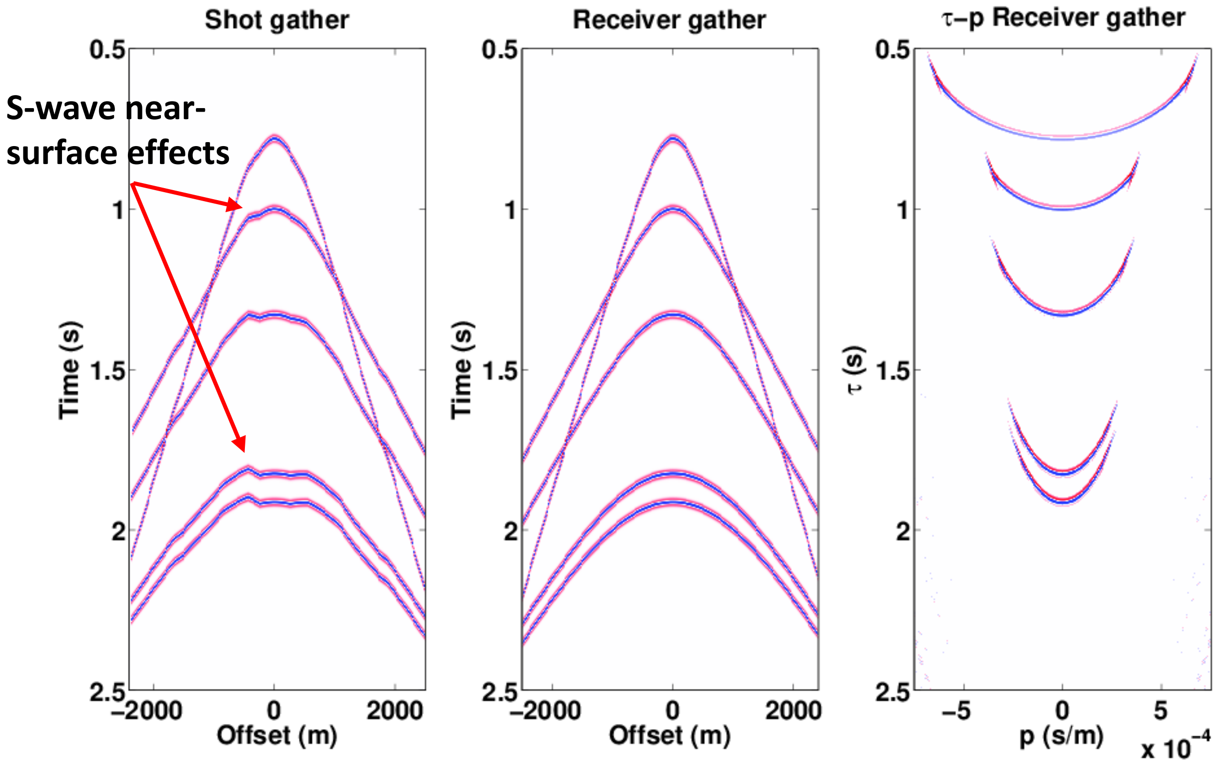
u=0.1



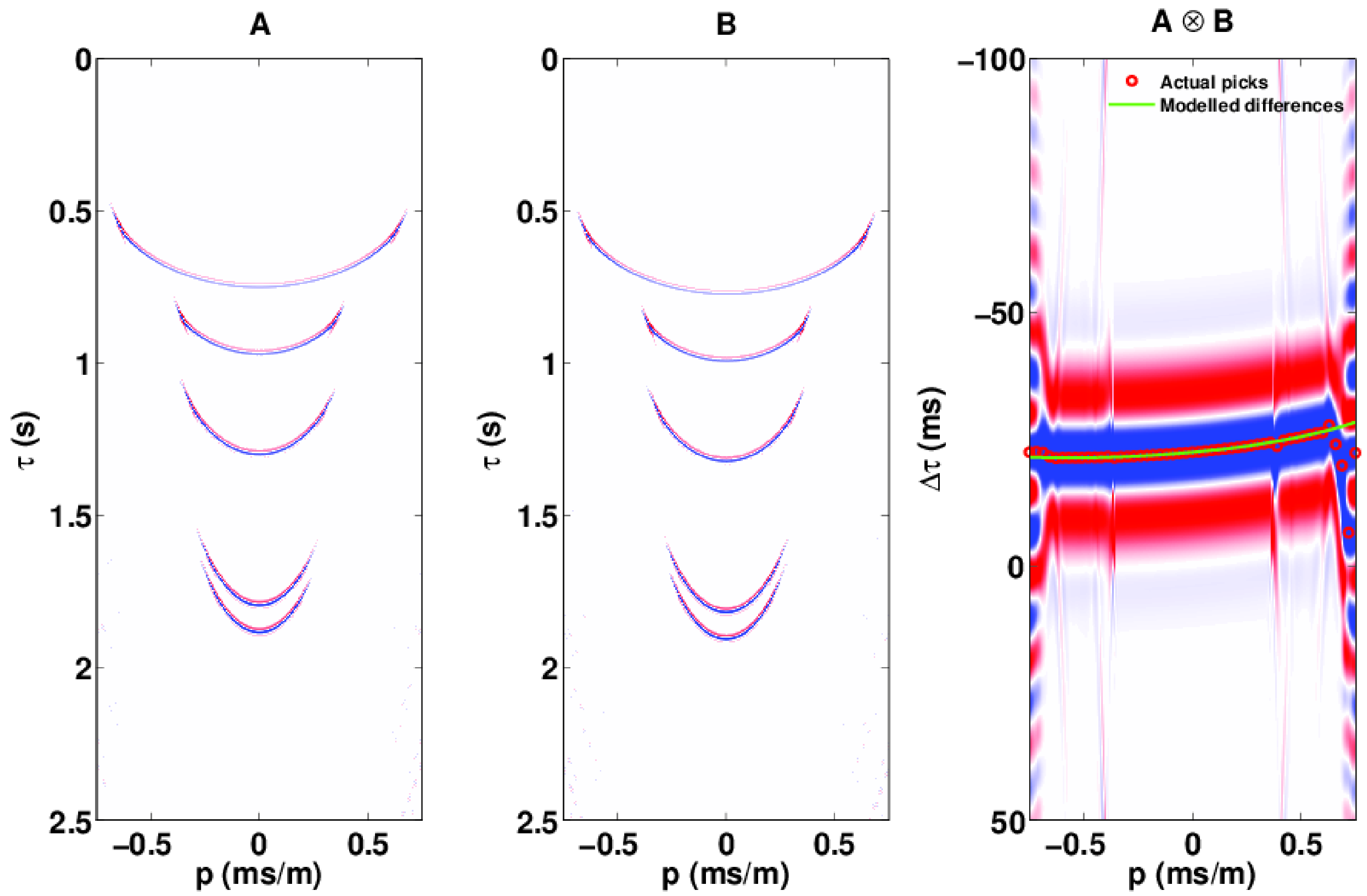
- Increasing regularization weight from 0.01 to 0.1, stabilizes the inversion.
- Depth estimation is now largely constrained by the initial depth model
- Dip inversion is very well behaved

Rayatrace Modelling

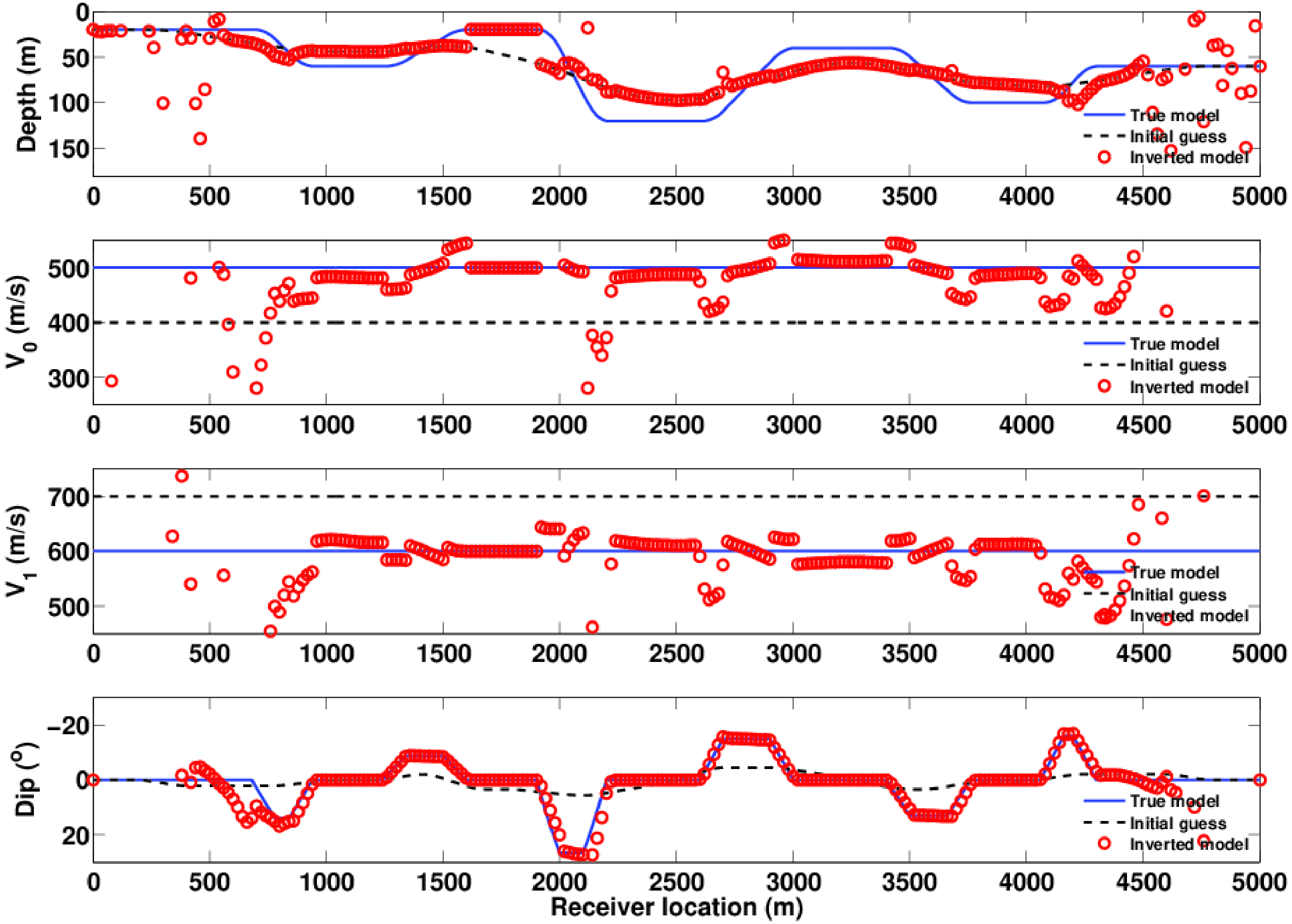




Data Crosscorrelation



Ray Trace inversion u=0. 1



Conclusions

- Since our approach requires the near-surface parameters to be known at one reference location, any result provided by the inversion will depend of the accuracy of this information.

- The presence of noise in the picks or the lack of a wide range of p-values had an important effect on the stability of the inversion of the depth values. The inverted velocities were also affected by these limitations although to a lesser degree.

- The inverted dips displayed by far the most stable results. Since this parameter controls the shape of the data, it is less sensitive to errors in the individual picks.

- Different parameterizations and inversion methods should be explored to improve the results for this study. Application of this method on real datasets remains to be explored.

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