Mitigating the ill-posedness of first-arrival traveltime tomography using slopes: application to crustal imaging from OBS data (Abstract S53C-0410)

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I - Context

• First-arrival traveltime tomography (FATT) models are often used in more resolving imaging methods such as full-waveform inversion (FWI). However FATT suffers from **ill-posedness** in terms of **non-uniqueness** of the solution due to the limited information carried out by the traveltimes.

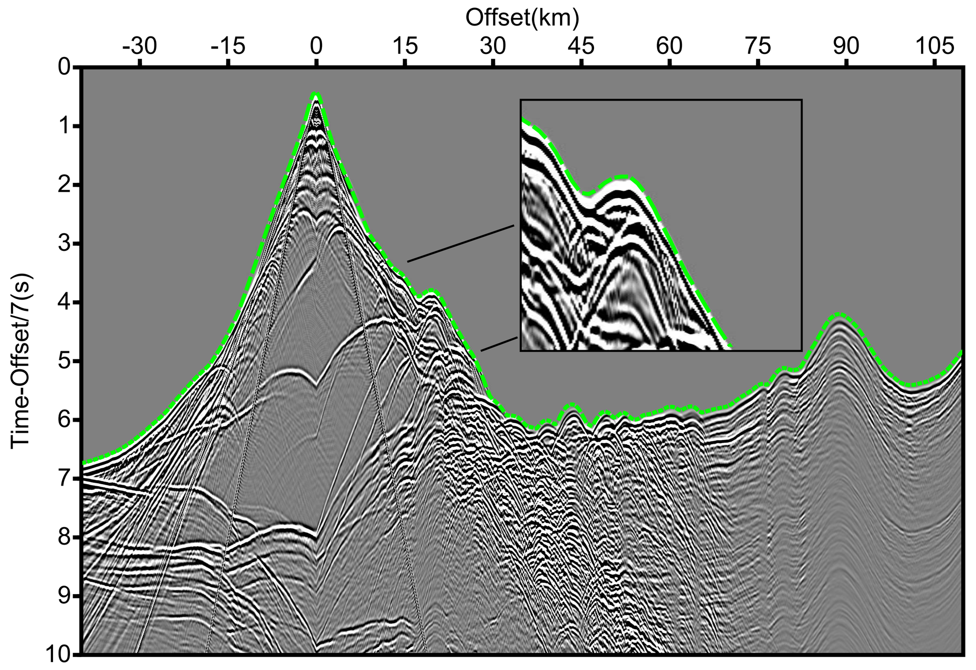

Figure 1: Traveltimes + slopes picked on a OBS gather.

• We promote the use of the traveltime perturbation with respect to the source/receiver positions (slope tomography - ST) as a supplement to the first-arrival traveltime (Tavakoli F. et al., 2018).

II - Role of slopes

• Slowness vector **sensitive** to velocity **gradient perturbations**: $\delta p = -\int \delta(\nabla v / v^2) dl$ (Hu et al., 1994).

• **Slope** straightforwardly accessible in dense acquisition or multi-component data. **Why not use it ?**

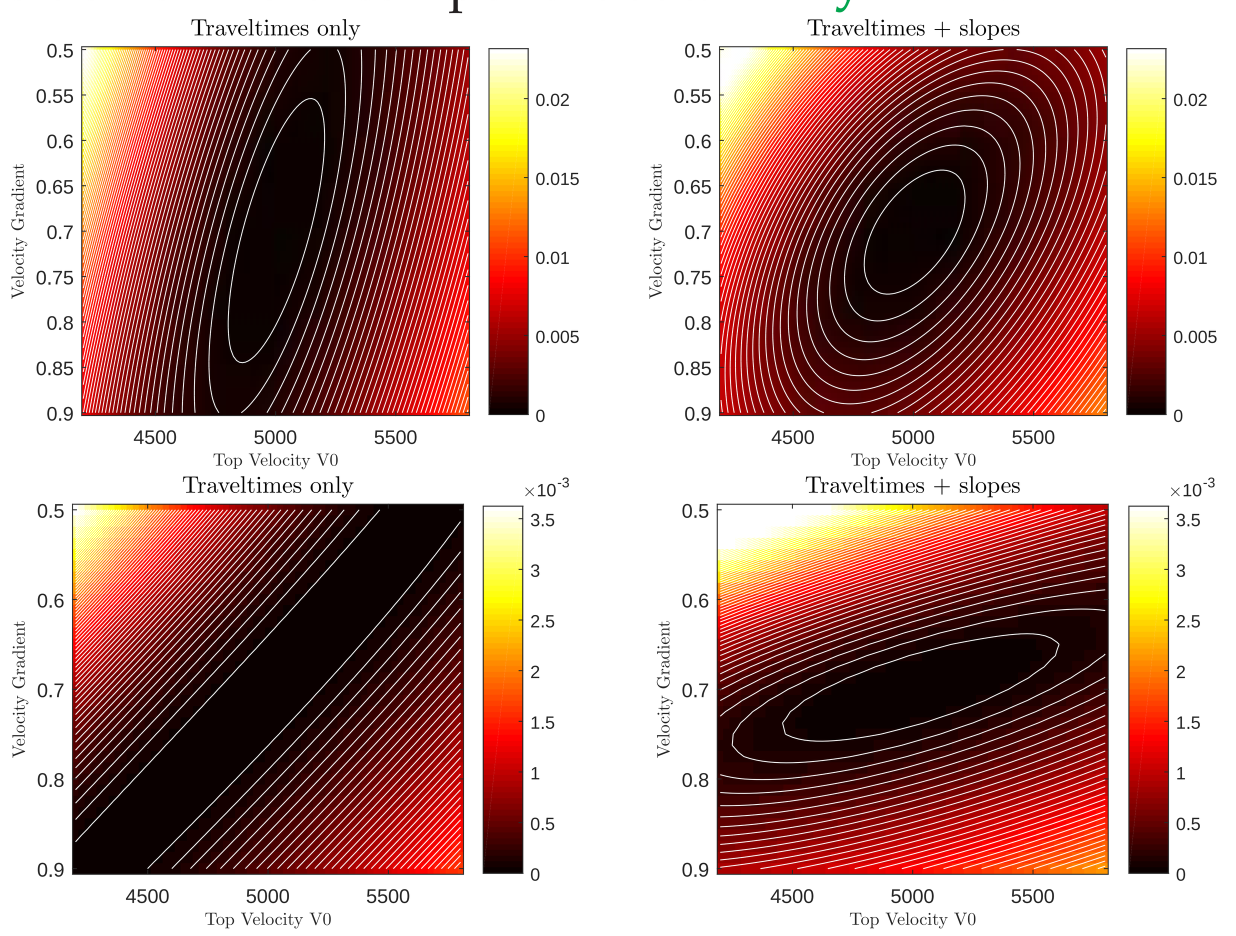

Figure 2: Sensitivity test. Two parameters (v,∇v) problem estimation. Contours define the cost function isovalues. Full coverage (top) and partial coverage (bottom).

✓ **Traveltimes with slopes ⇒ Improved sensitivity.**

• ST implemented with **eikonal solvers** and the **adjoint-state method** (Taillandier et al., 2009).

III - Exploration scale benchmark: Overthrust model

• EAGE/SEG Overthrust model: $20km \times 4.5km$ target extended by $25km$ laterally on each side for tomography. Soft regularization for resolution maximization. Frequency-domain FWI on the target ($3 - 20$Hz) using tomography results as initial models.

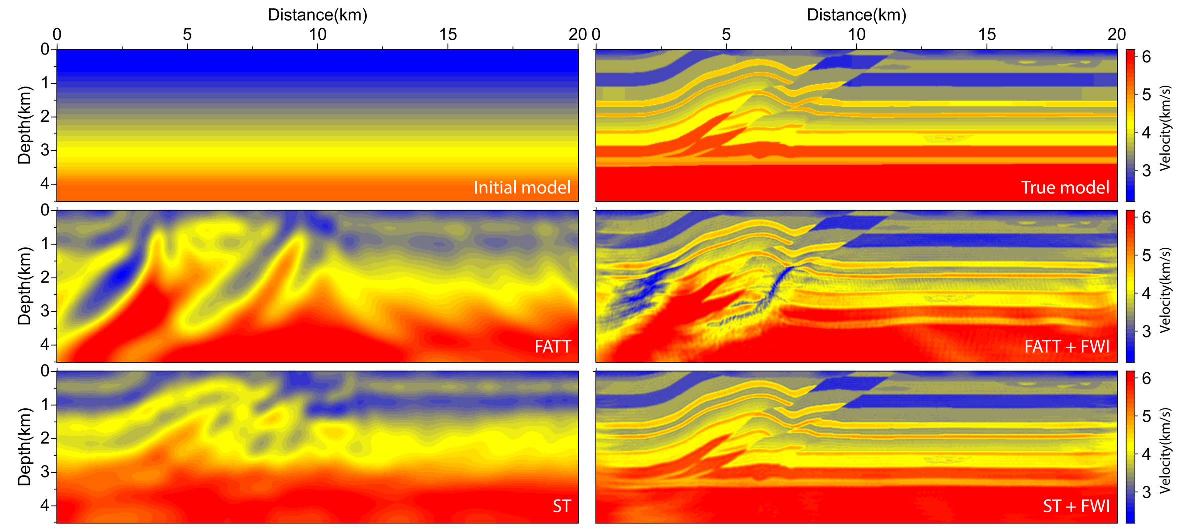

Figure 3: Dense acquisition case ($100m$ receiver spacing). FATT and ST results and their respective FWI.

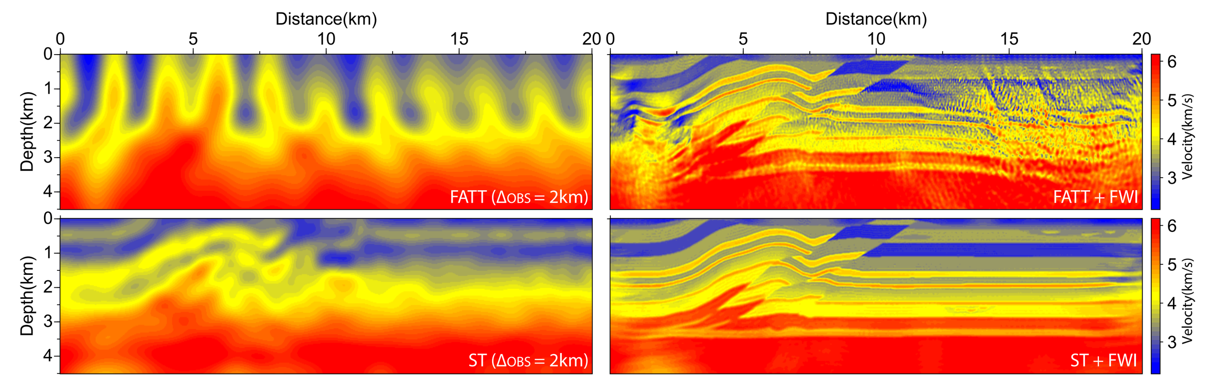

Figure 4: Coarse acquisition case ($2km$ receiver spacing). FATT and ST results and their respective FWI.

✓ First-arrival traveltime + slope tomography.
⇐ High resolution model, hence better FWI.
⇑ More resilient to illumination/coverage issues.

✗ First-arrival traveltime tomography.
⇐ Artifacts due to channeling in structures .
⇑ Extremely hampered by lack of regularization.

IV - Crustal scale application: eastern Nankai Trough (Tokai area)

• Nankai Trough case - SFJ Experiment: Profile of 100 OBSs spaced $1km$ apart cross-cutting the margin. Aligned $140km$ shot profile with $100m$ shot interval.

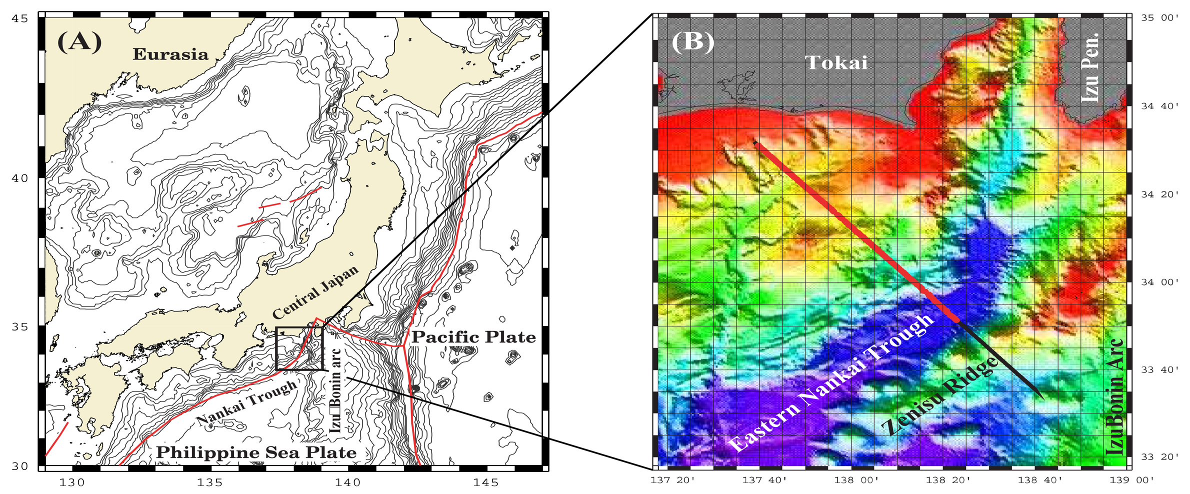

Figure 5: (A) Geodynamical setting of the Nankai trough area and (B) a zoom on the shot profile (OBS array in red).

• Total of 124248 previously picked first-breaks (Gorszczyk et al., 2017). Slopes calculated by finite-difference from finely interpolated traveltimes.

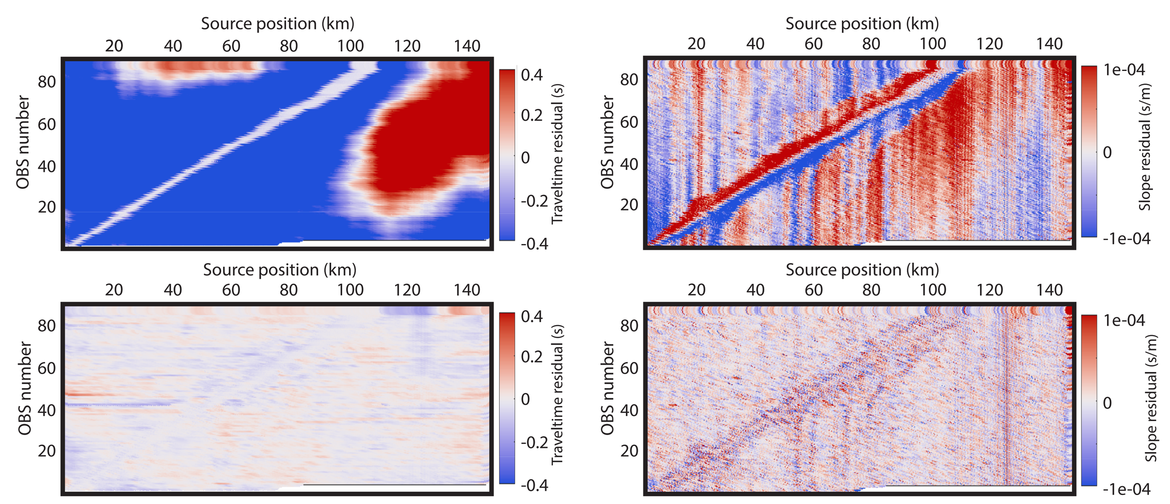

Figure 6: Data misfit at the initial (top) and final (bottom) stages of traveltime + slope tomography (ST).

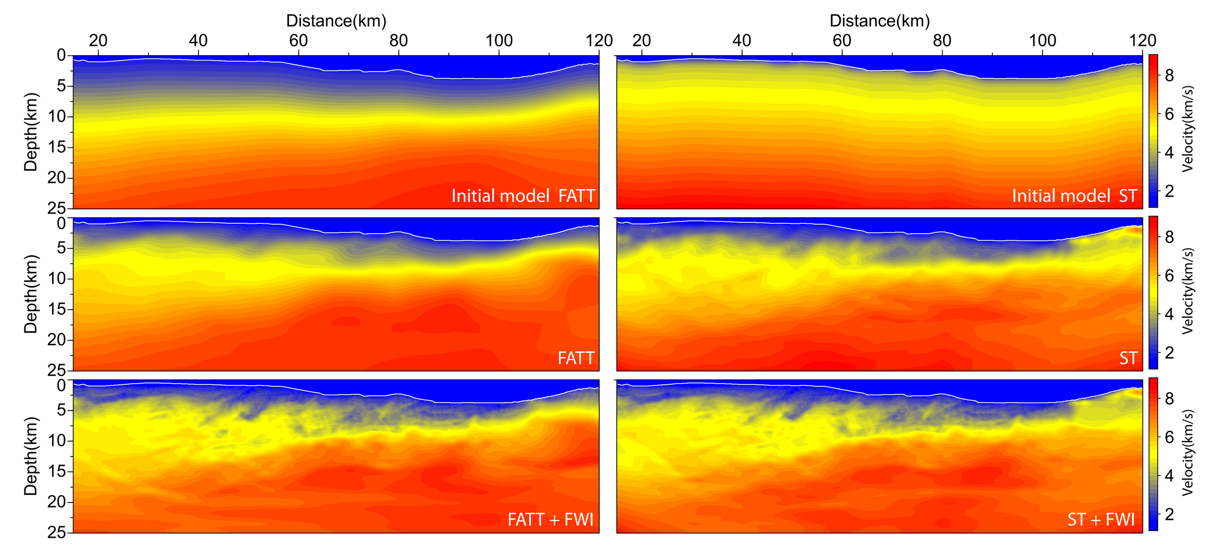

Figure 7: Tomography and FWI results for FATT (left) (Gorszczyk et al., 2017) and the proposed ST (right).

✓ Good data fit of ST starting from a crude model.
✓ ST provides an intermediary resolution between FATT and FWI especially in shallow structures.

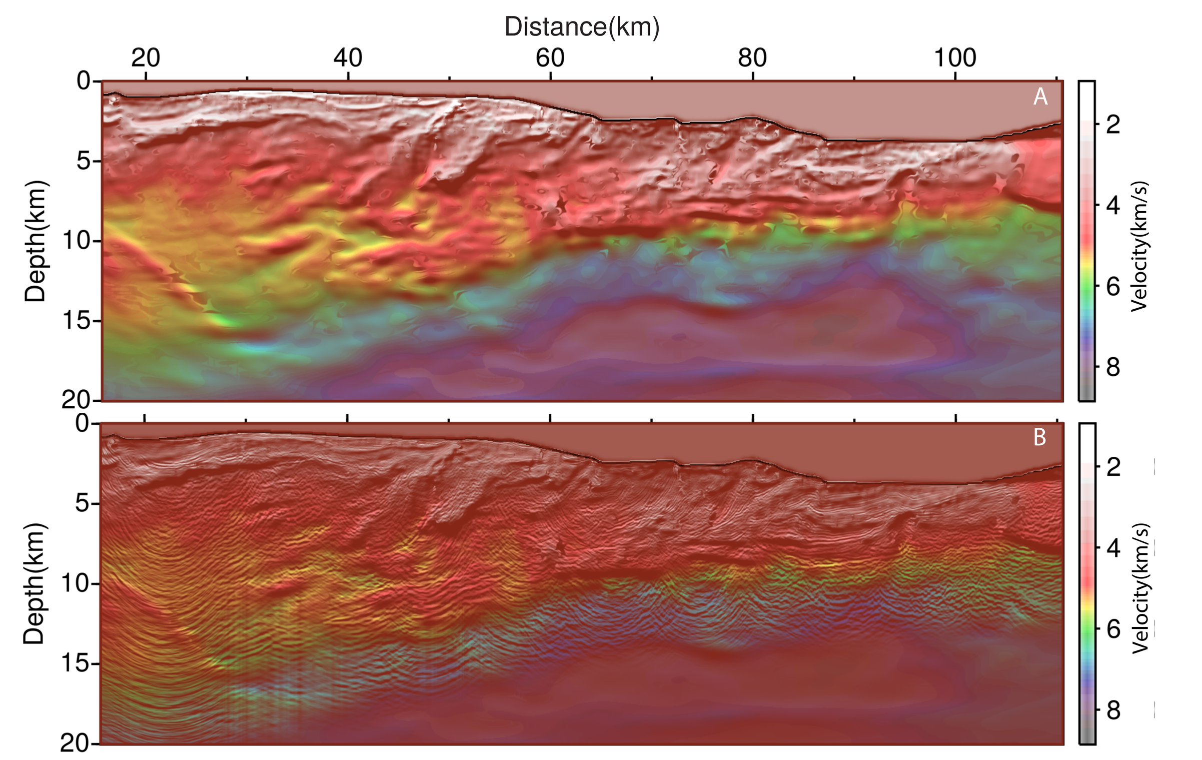

Figure 8: Images highlighting the geological features recovered through FWI. (A) ST+FWI model superimposed by its reflectivity. (B) Same as (A) but overlain by a Kirchhoff migration of an aligned MCS profile.

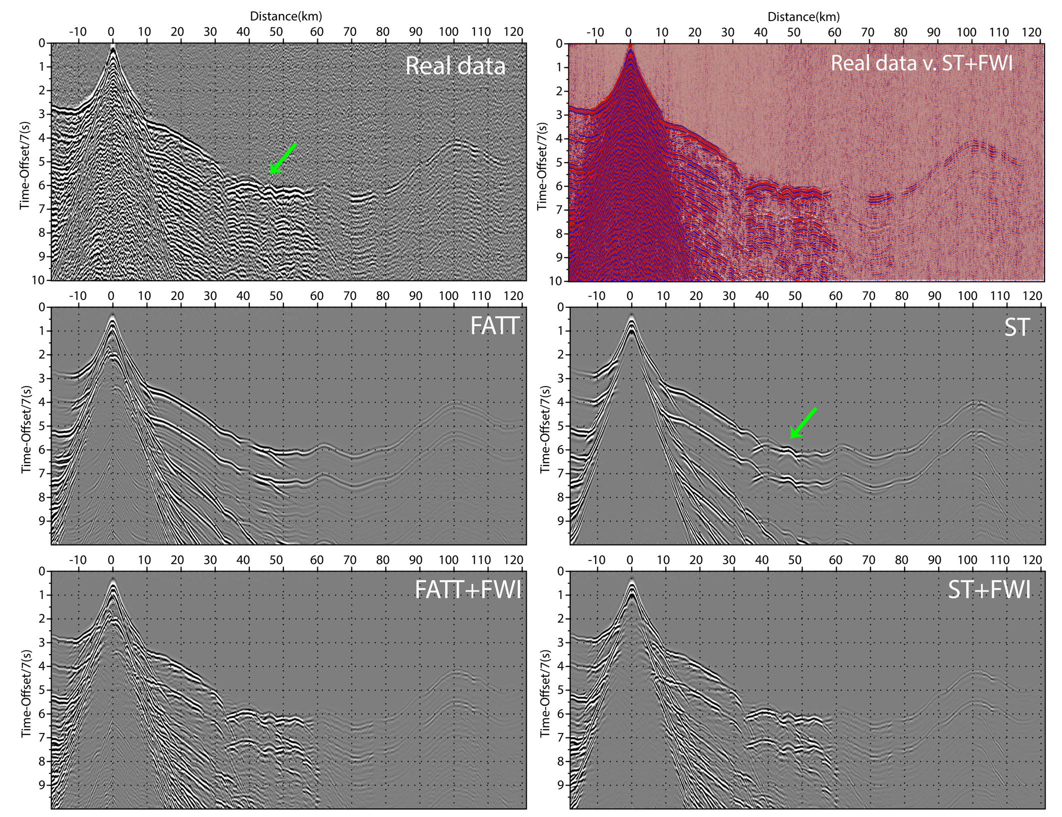

Figure 9: Comparison between observed and modeled seismograms of OBS 17 for the models of figure 7.

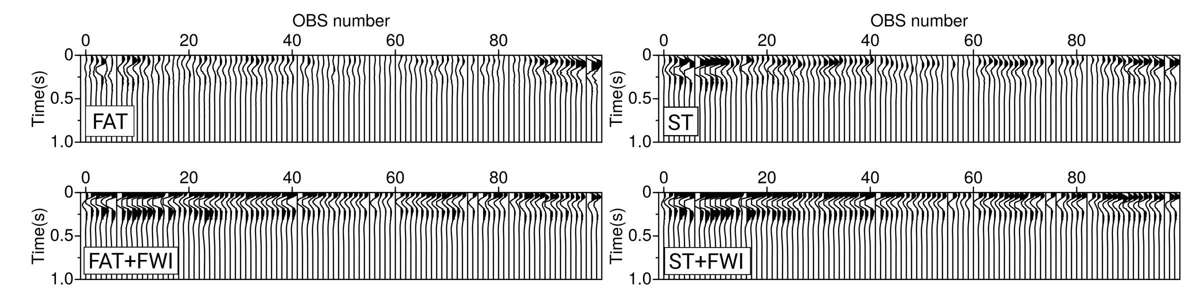

Figure 10: Wavelets estimated from the models of Figure 7 by waveform inversion.

✓ Similar FWI results in both cases. Complex FWI worklow with $1.8Hz$ starting frequency. Could ST models ease up the exhaustive tuning of FWI?
✓ Quality control by seismic modeling and wavelet estimation confirm the improved resolution of ST model with respect to FATT counterpart.

Conclusion & Perspectives

The differential information carried out by slopes lead to more resilient inversions to coverage and illumination. Slope tomography models are more resolved, hence provide more suitable initial guess for full-waveform inversion.
Recent developments around multi-component stations motivate the extension of our approach to late arrivals by source and receiver slope inversions.

References

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