Relaxing the initial model constraint for crustal-scale full waveform inversion with graph space optimal transport misfit function

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Outline

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Crustal-scale FWI of the OBS data

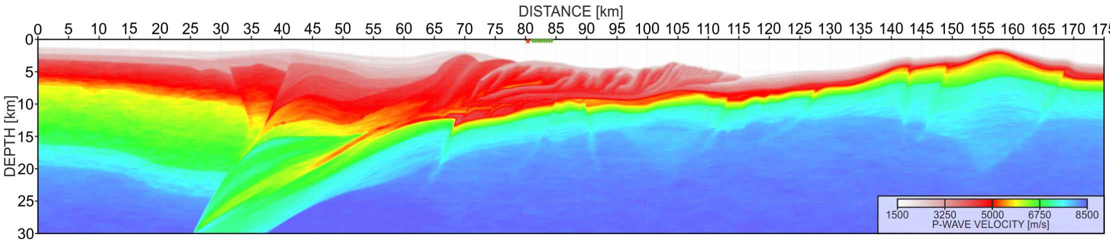
OT-based misfit function

Synthetic test

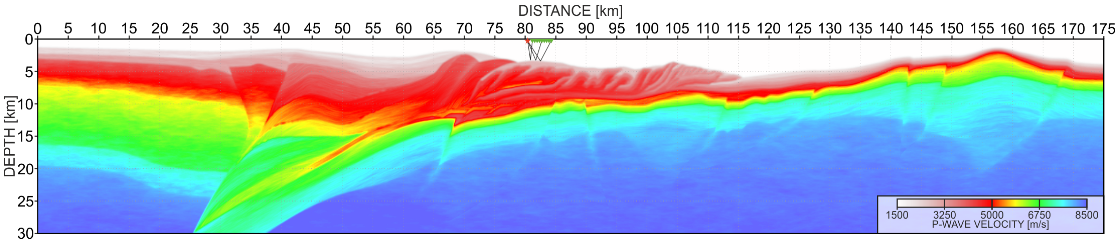
Results

Conclusion

Crustal-scale velocity reconstruction



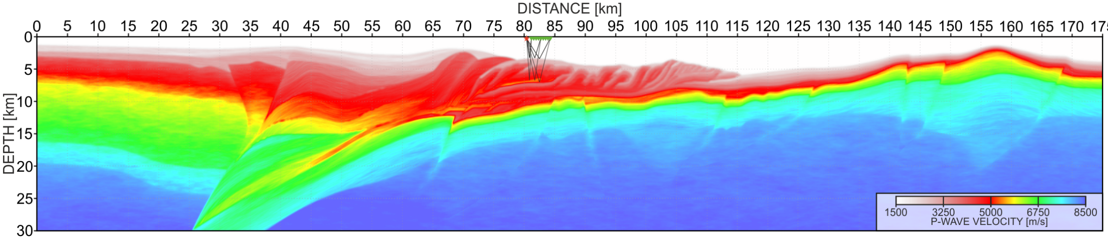
GO_3D_OBS model



MCS data:

- Short streamer - limited depth-penetration

GO_3D_OBS model



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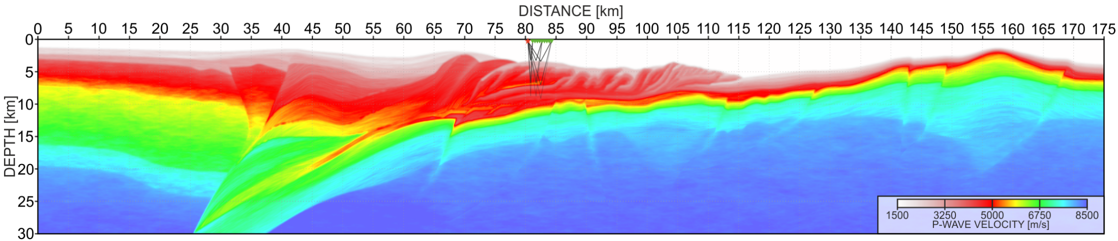
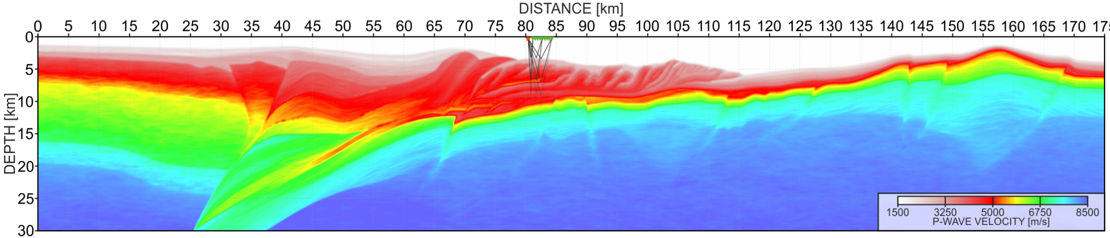
Crustal-scale velocity reconstruction



MCS data:

- Short streamer - limited depth-penetration
- 3D wavefield scattering from complex structures

GO_3D_OBS model



MCS data:

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- Need for illumination from the deep part of the model

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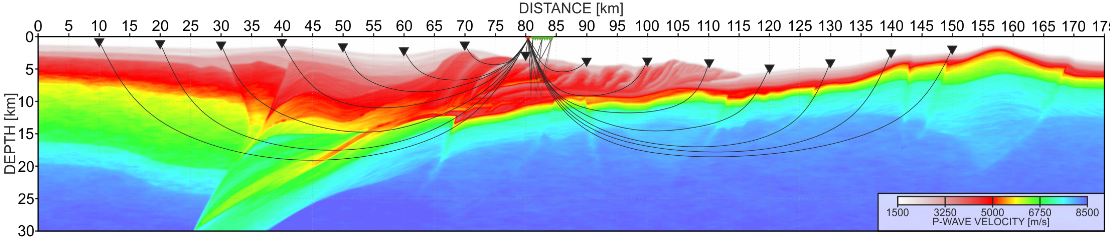

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OBS data:

- Wide-angle data for deep illumination

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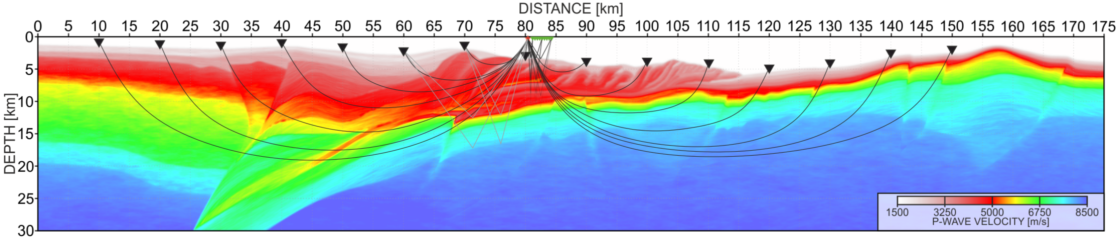

MCS data:

- Short streamer - limited depth-penetration
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OBS data:

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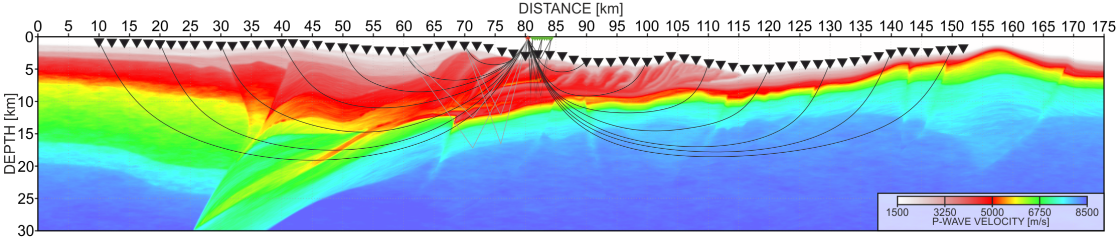
- Refracted waves and wide-angle reflections undershooting the structure

GO_3D_OBS model



MCS data:

- Short streamer - limited depth-penetration
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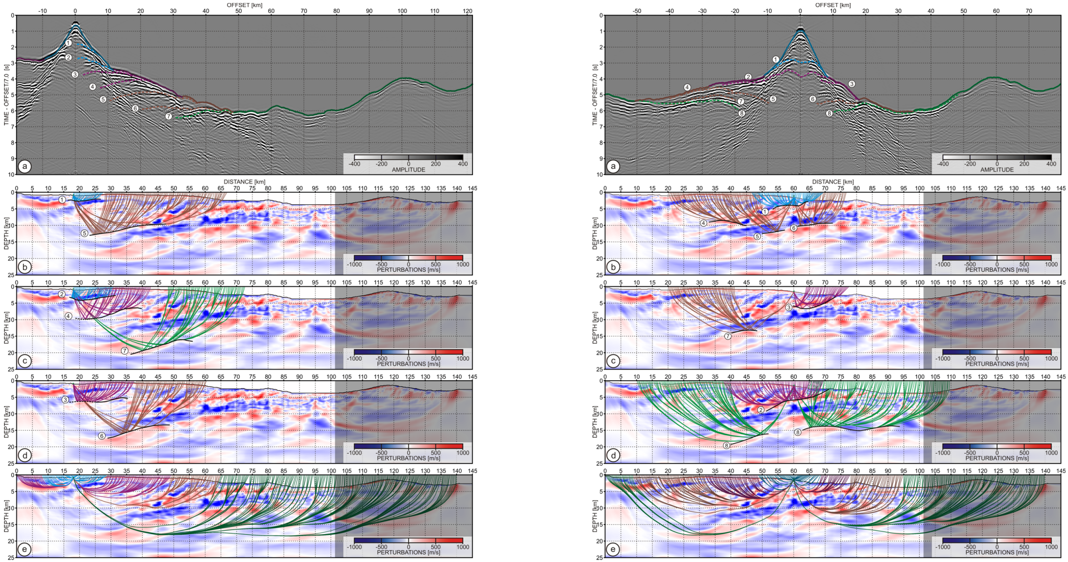
- Need for illumination from the deep part of the model

OBS data:

- Wide-angle data for deep illumination
- Refracted waves and wide-angle reflections undershooting the structure
- Dense nodes increasing the data redundancy

GO_3D_OBS model

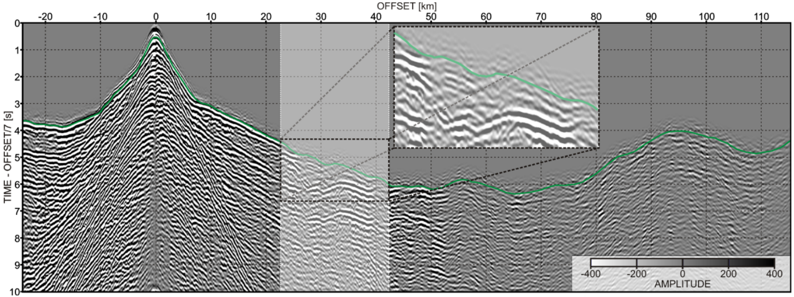
Challenge - large models constrained by sparse (but diverse) data



(Górszczyk et al., 2017)

Problem

- Precision of picking and prediction of first arrivals determines occurrence of cycle-skipping
- The criteria is difficult to fulfil
  ⇒ far offsets
  ⇒ long time of propagation
  ⇒ more wavelets to propagate
  ⇒ accumulation of error
  ⇒ higher probability of cycle-skipping (Pratt, 2008)
- Lack of information about the later arrivals



Solution

⇒ extract more information to constrain better tomographic model

⇒ use more convex misfit function able to mitigate cycle-skipping issue

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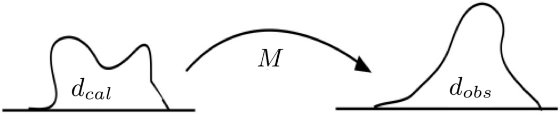
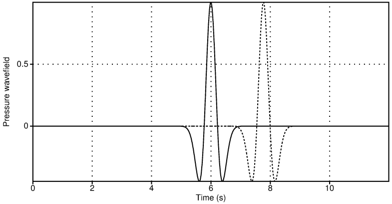
Recently Optimal Transport has been proposed to design more convex misfit functions.

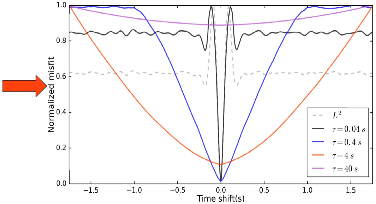
- OT distance looks for an optimal mapping M between synthetic and observed data



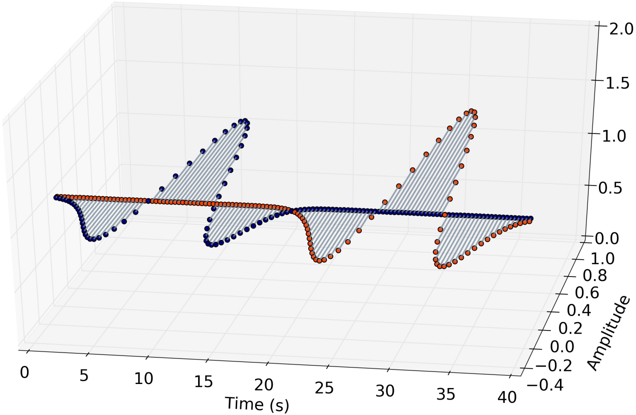
- OT is convex with respect to shifted patterns - proxy to convexity with respect to wave velocities

$$c_{ij} = |t_i - t_j|^2 + |\eta\,(d_{cal,i} - d_{obs,j})\,|^2;\ \eta = \frac{\tau}{A}$$



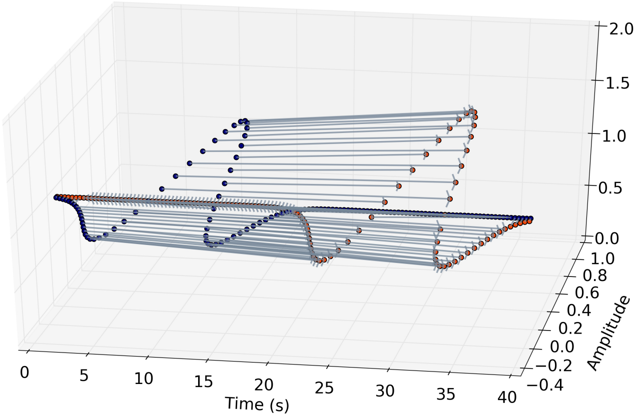


(Métivier et al., 2019)



- Comparison of two Ricker functions
- The gray arrows represent the assignment of the corresponding samples when small time-shift is used

(Métivier et al., 2019)



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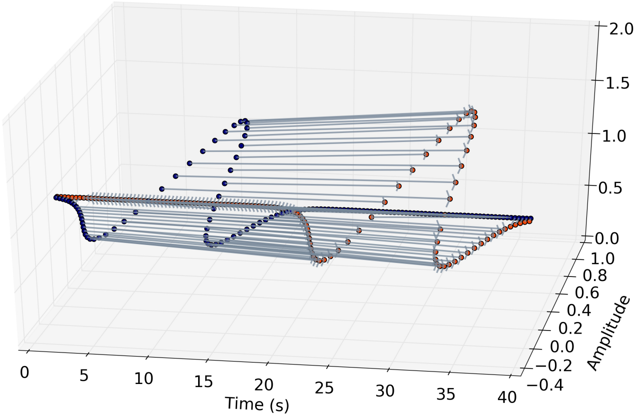
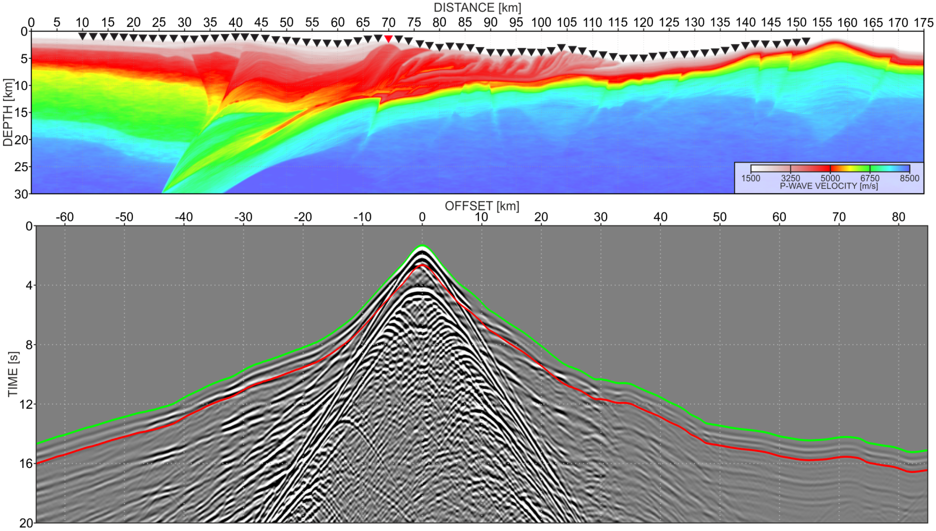


- QUESTION: Can we combine GSOT with proper data selection to relax the cycle-skipping constraint on the initial FWI model?

(Métivier et al., 2019)

Outline

- Subduction zone
- 30 km × 175 km
- 72 OBS - 2 km spc.
- 1500 SP - 100 m spc.
- 2Hz Ricker wavelet
- 20 s propagation



Experimental setting - GO_3D_OBS model

- Subduction zone
- 30 km × 175 km
- 72 OBS - 2 km spc.
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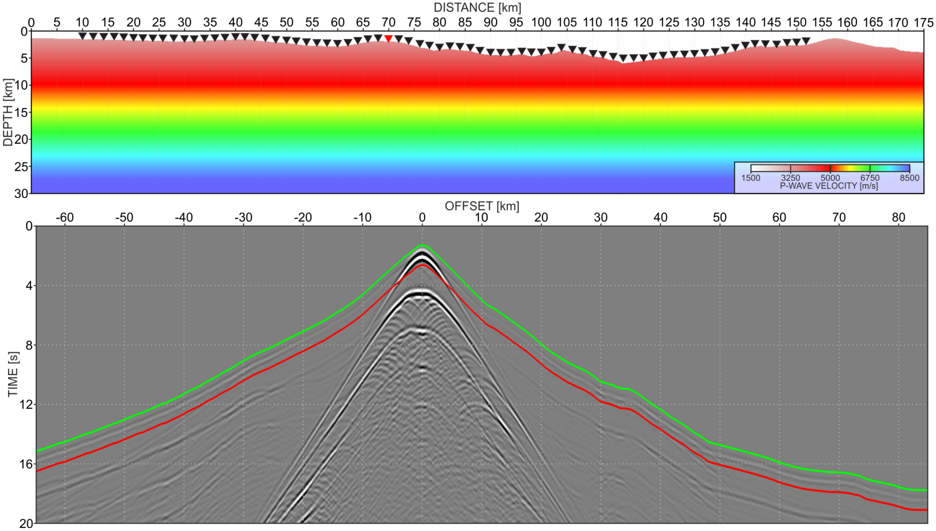
- 20 s propagation

- 1D initial model
- Clear cycle-skipping



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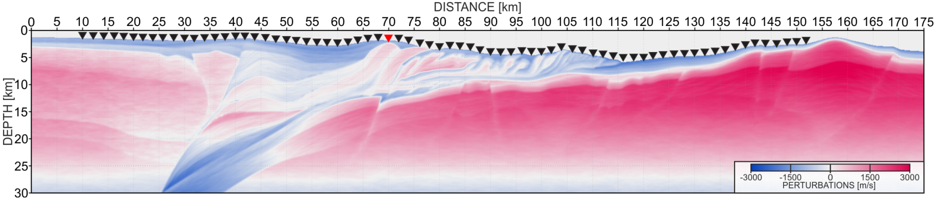
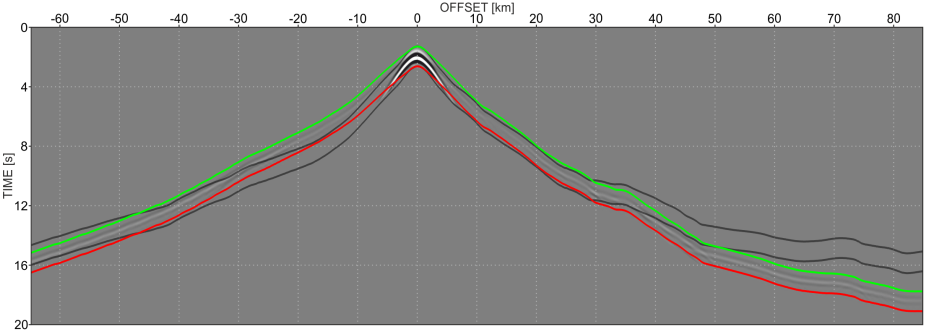
- TD acoustic FWI
- LBFGS optimization
- Density const. or true
- Single frequency band
- 3 time-windows
- MPI over OBS



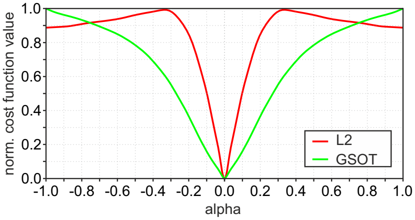


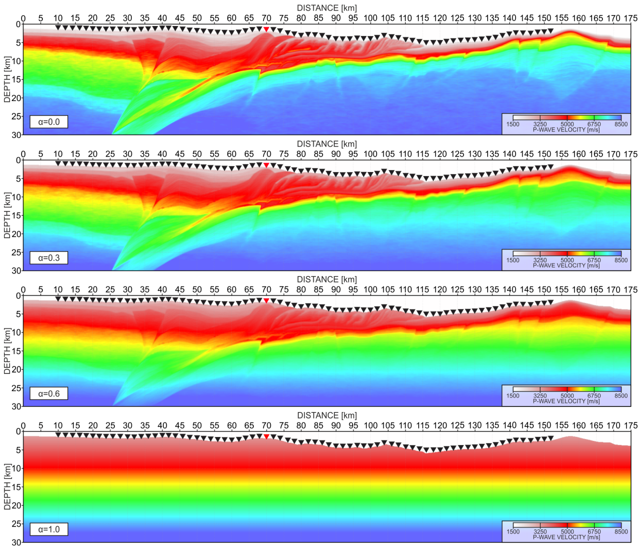
Convexity analysis

Population of the V_α models generated according to formula:

$$V_\alpha = V_{true} + \alpha^2 (V_{init} - V_{true})$$

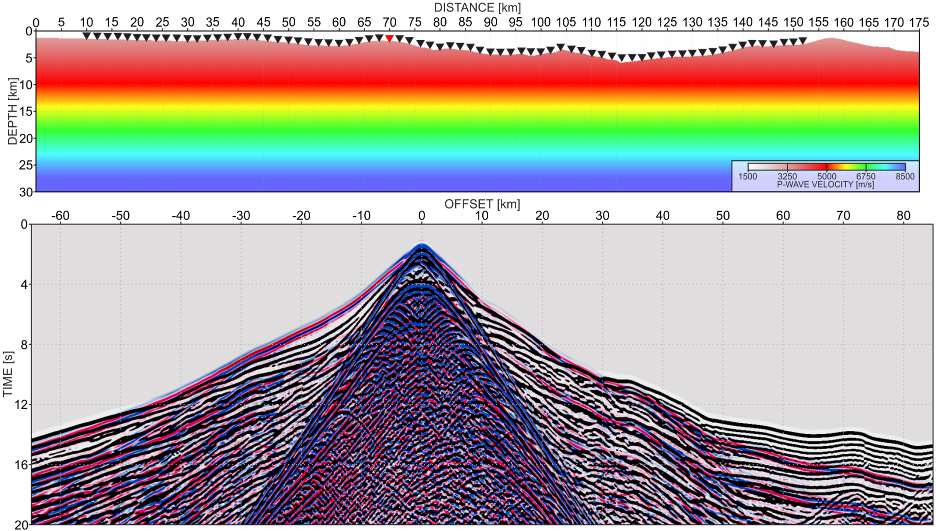
where $-1 \leq \alpha \leq 1$.





Outline

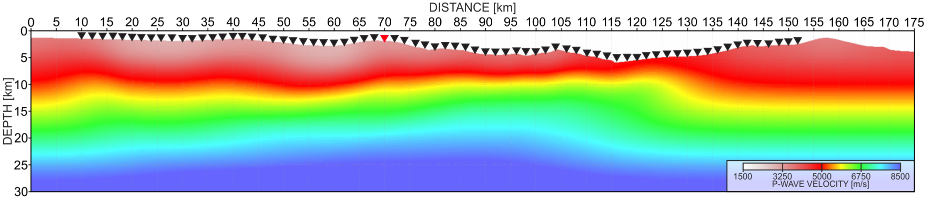
Model and data evolution

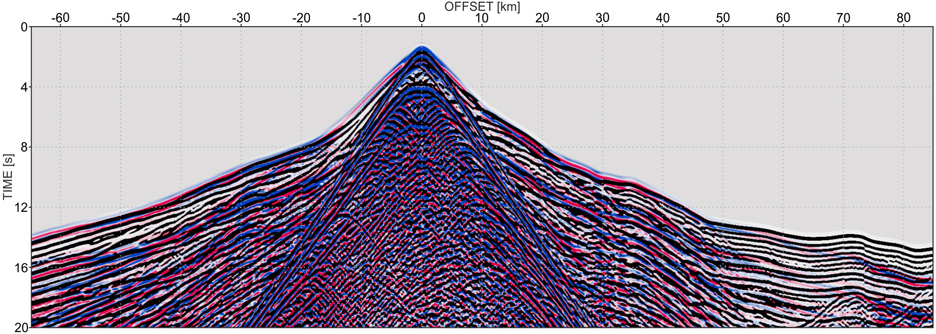


STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
- Normalized amplitude
- Strong smoothing

Iteration 10



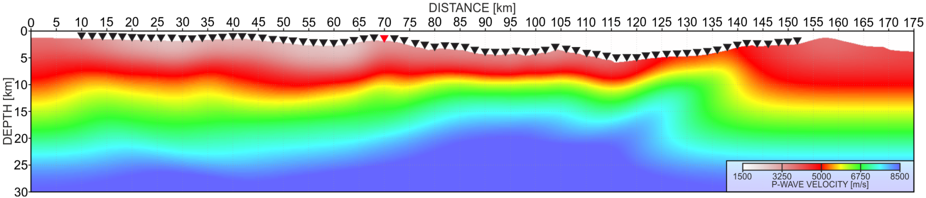


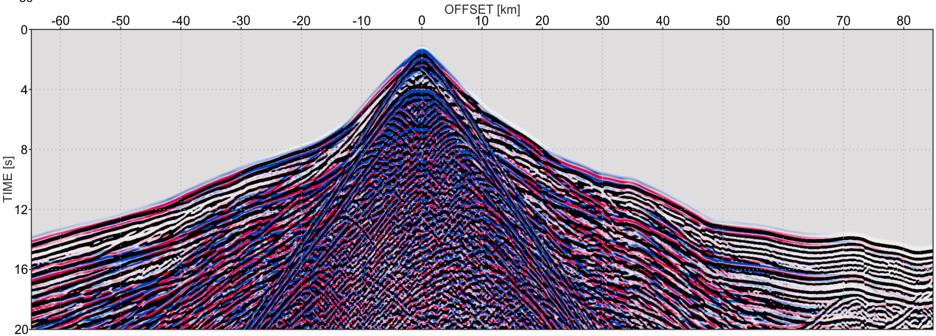
Model and data evolution

STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
- Normalized amplitude
- Strong smoothing

Iteration 20



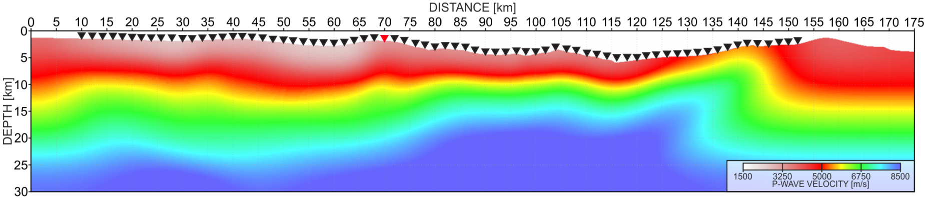


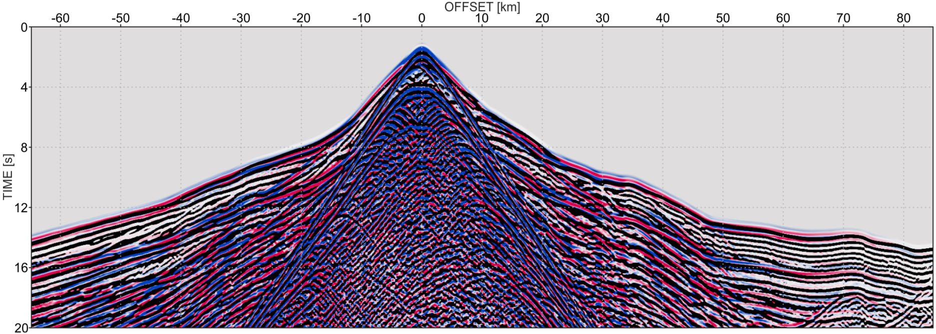
Model and data evolution

STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
- Normalized amplitude
- Strong smoothing

Iteration 30



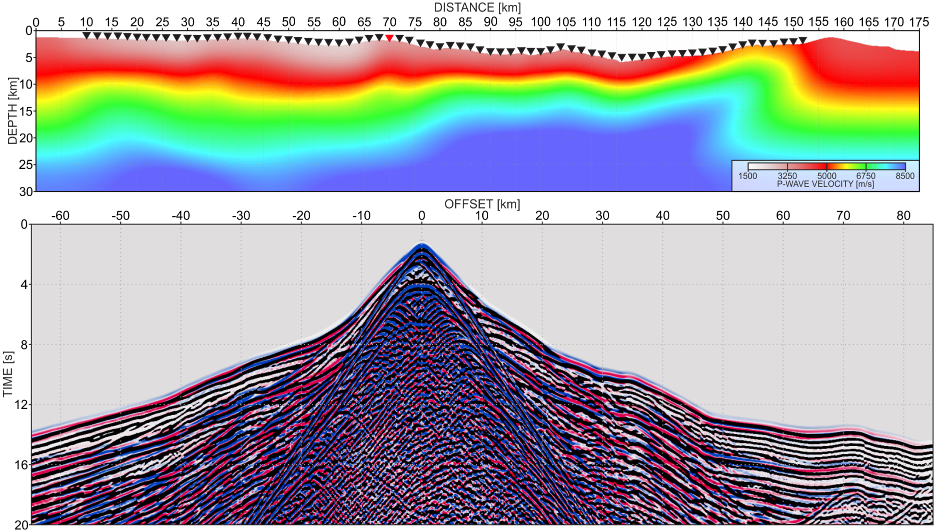


Model and data evolution

STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
- Normalized amplitude
- Strong smoothing

Iteration 40



STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
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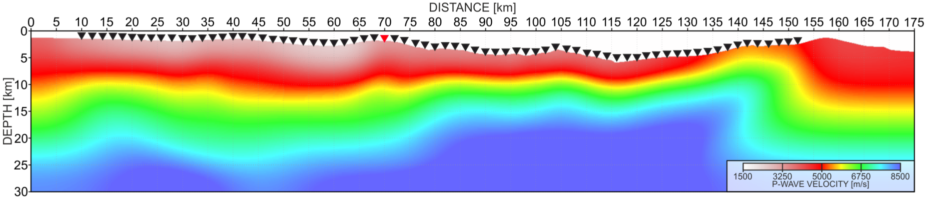
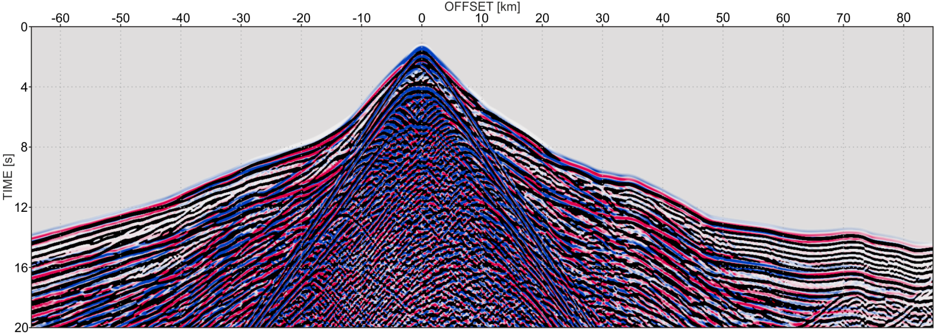
Iteration 50



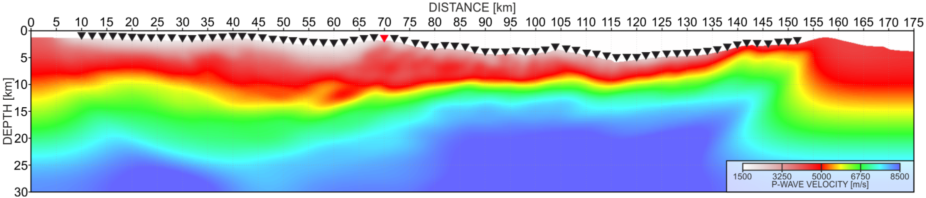


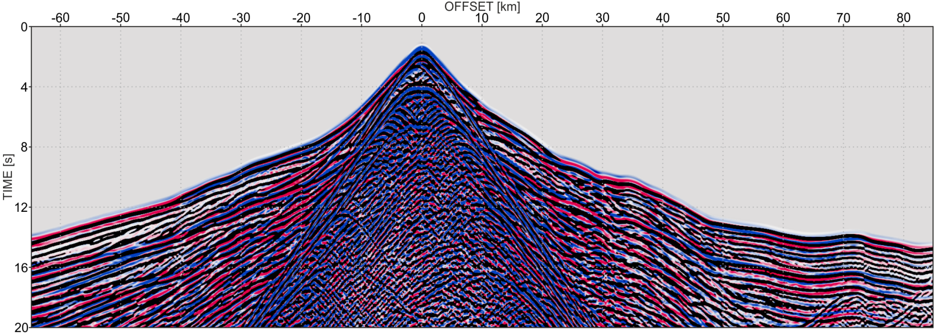
STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
- Normalized amplitude
- Strong smoothing

STAGE 2 - 20 it.

- TW 0.2s + 0.5s taper
- True amplitude
- Moderate smoothing





Model and data evolution

STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
- Normalized amplitude
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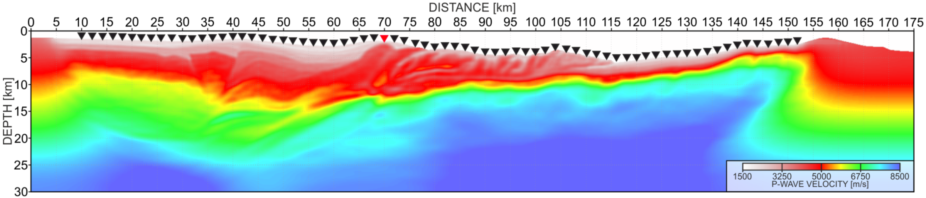
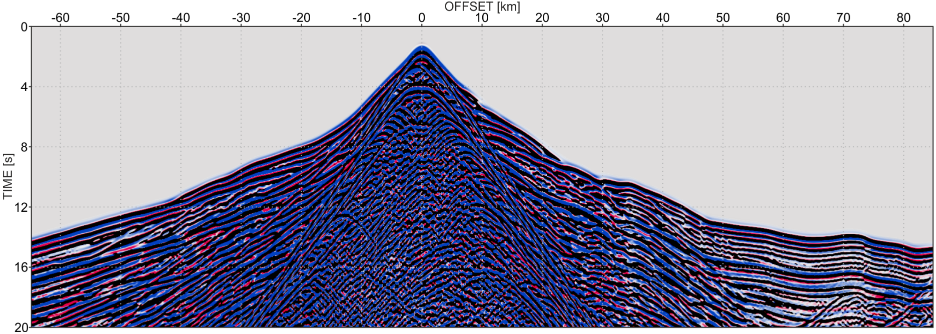
STAGE 2 - 20 it.

- TW 0.2s + 0.5s taper
- True amplitude
- Moderate smoothing

STAGE 3 - 150 it.

- TW 0.2s + 9s taper
- True amplitude
- Small smoothing





STAGE 1 - 50 it.

- TW 0.2s + 0.5s taper
- Normalized amplitude
- Strong smoothing

STAGE 2 - 20 it.

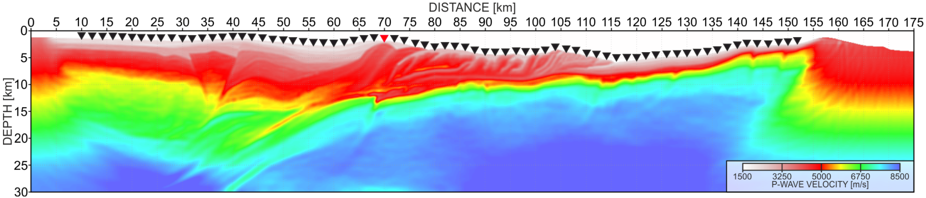
- TW 0.2s + 0.5s taper
- True amplitude
- Moderate smoothing

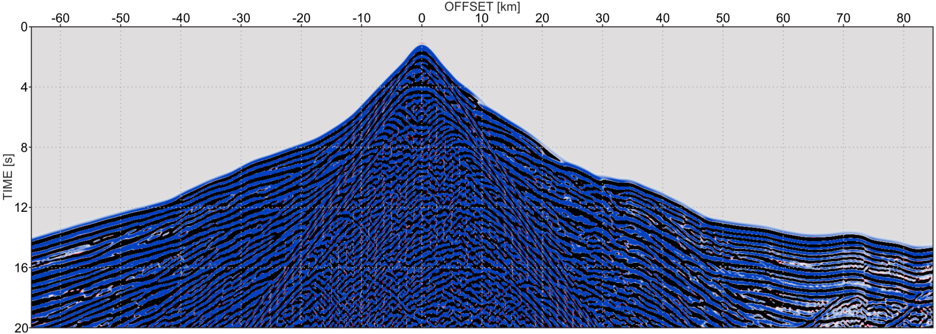
STAGE 3 - 150 it.

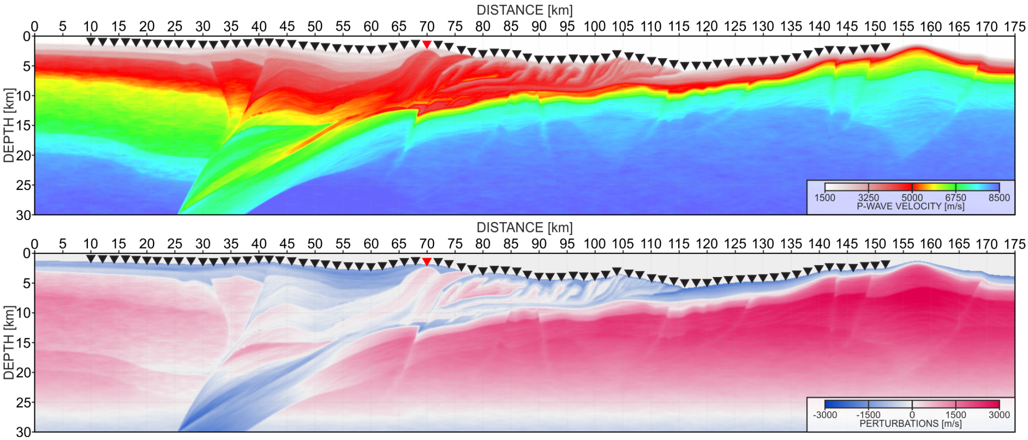
- TW 0.2s + 9s taper
- True amplitude
- Small smoothing

STAGE 4 - 150 it.

- Full time
- True amplitude
- Small smoothing



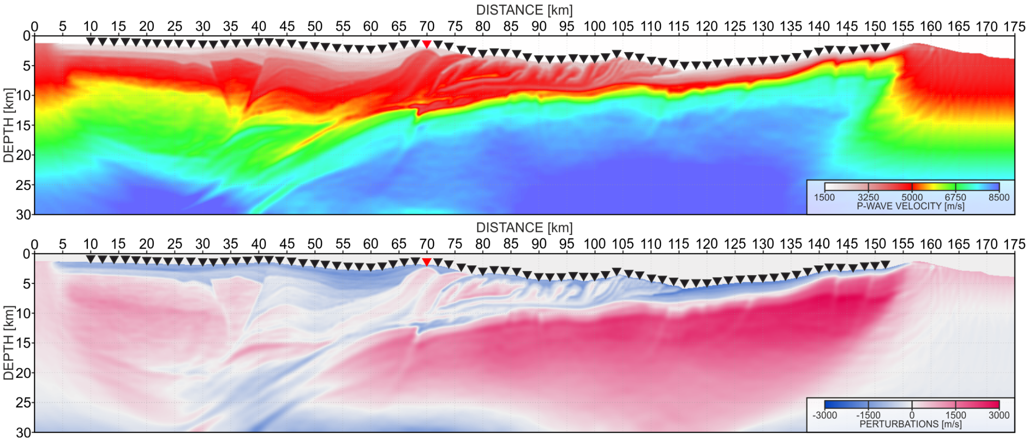




DISTANCE [km]
DEPTH [km]
1500 3250 5000 6750 8500
P-WAVE VELOCITY [m/s]
DISTANCE [km]
DEPTH [km]
-3000 -1500 0 1500 3000
PERTURBATIONS [m/s]

TRUE MODEL

Model and data evolution



FINAL MODEL: ∼400 iterations; ∼30 hours; 3 nodes; 72 cores

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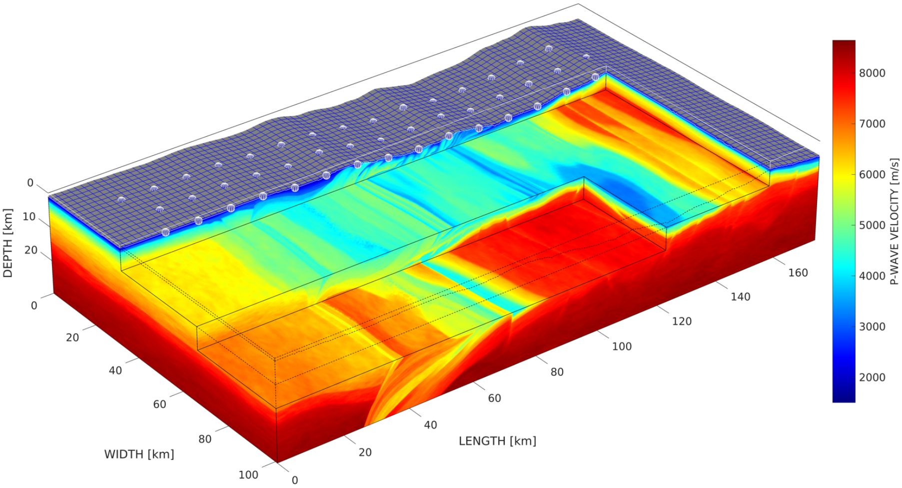
- GSOT-based FWI can significantly reduce the constrain on the accuracy of initial FWI model
- Traveltimes defining mute window can be approximate and not precise - less problematic picking
- Multiscale FWI strategy and proper data-selection seem still obligatory
- Challenges for real data application - accurate source estimation, elastic effects, noise
- Future development - extensions from trace-by-trace to 2D misfit

GO_3D_OBS model



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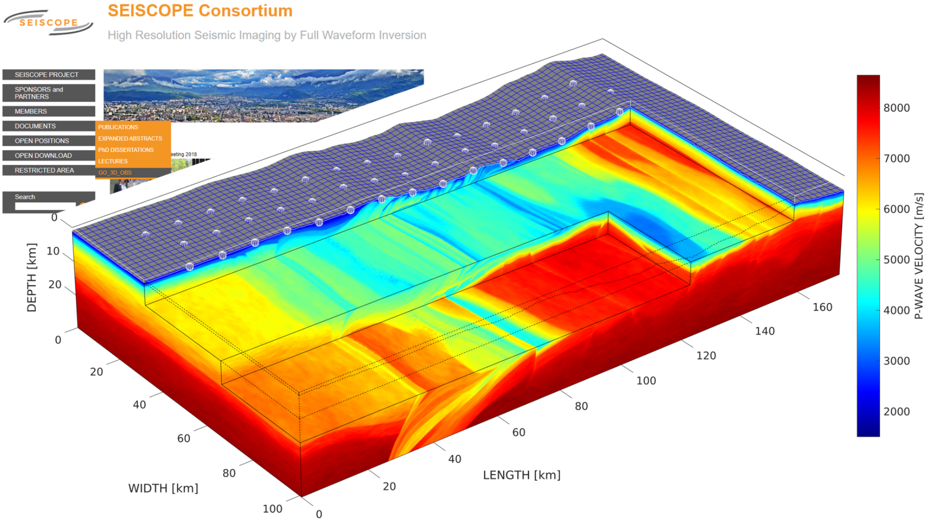

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- Université Grenoble Alpes, UGA *https://univ-grenoble-alpes.fr*
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