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

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Crustal-scale FWI of the OBS data

OT-based misfit function

Synthetic test

Results

Conclusion
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Crustal-scale velocity reconstruction

- MCS data:
  - Short streamer - limited depth-penetration
  - 3D wavefield scattering from complex structures
  - 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
Crustal-scale velocity reconstruction

MCS data:
- Short streamer - limited depth-penetration

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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

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

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

(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
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GSOT for FWI

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

(Métivier et al., 2019)
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Experimental setting - GO_3D_OBS model

- Subduction zone
- 30 km × 175 km
- 72 OBS - 2 km spc.
- 1500 SP - 100 m spc.
- 2Hz Ricker wavelet
- 20 s propagation
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- TD acoustic FWI
- LBFGS optimization
- Density const. or true
- Single frequency band
- 3 time-windows
- MPI over OBS
Population of the $V_\alpha$ models generated according to formula:

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

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

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Model and data evolution

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
Model and data evolution

STAGE 1 - 50 it.
- TW 0.2s + 0.5s taper
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- 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
STAGE 1 - 50 it.
- TW 0.2s + 0.5s taper
- Normalized amplitude
- Strong smoothing

Iteration 40
Model and data evolution

STAGE 1 - 50 it.
- TW 0.2s + 0.5s taper
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Iteration 50

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

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STAGE 4 - 150 it.
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TRUE MODEL
FINAL MODEL: $\sim$400 iterations; $\sim$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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