Targeted nullspace shuttles for full waveform time-lapse seismic monitoring and CO_2 detection thresholds

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ABSTRACT

- Time-lapse seismic monitoring, a proven technique in hydrocarbon reservoir monitoring and optimization, can also be extended to full waveform inversion and applied to the measurement, monitoring, and validation (MMV) of CO_2
- Through targeted nullspace shuttling, we investigate an approach to find unique baseline and monitor models which minimize the time-lapse difference and preserve the data-fit, though explicitly navigating the nullspace, providing a minimum bound on CO_2 plume uncertainty.

TARGETED NULLSPACE SHUTTLES

- Traditional time-lapse FWI relies detects changes through differencing non-unique baseline and monitor models, $\boldsymbol{\Delta m_{TL}}$
- We would like the time-lapse change that minimizes the difference between baseline and monitor, $\boldsymbol{\Delta m_{SH}}$
- We use targeted nullspace shuttling (Keating and Innanen, 2021) on our FWI results to search for optimal models within the nullspace.

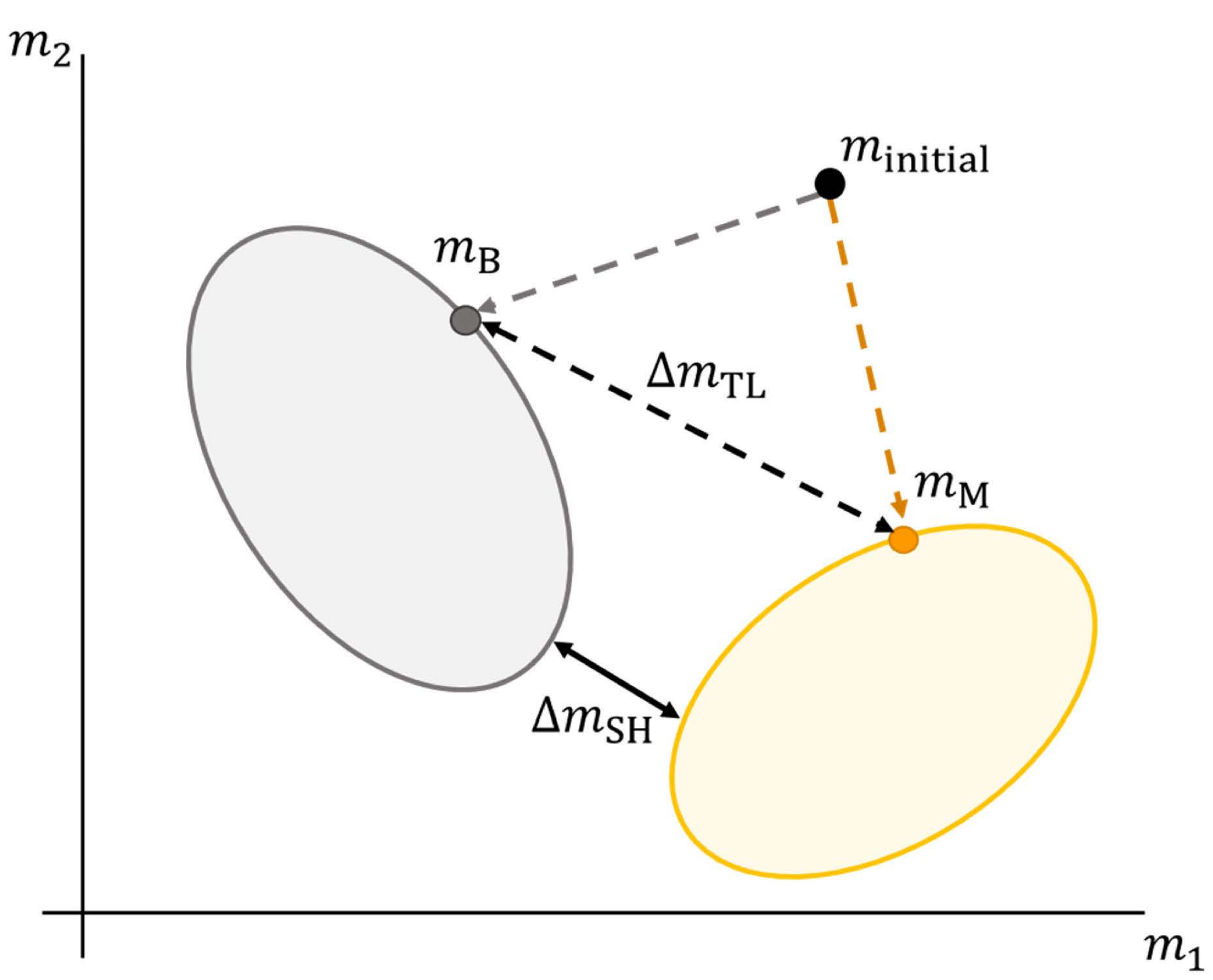

FIG. 1. Conceptual of the nullspace. The baseline FWI model m_B, and the monitor model, m_M, are a function of the initial model, $m_{initial}$, and are non-unique; their time-lapse difference, Δm_{TL}, is also non-unique. Through shuttling, we seek, Δm_{SH}, minimum difference between baseline and monitor FWI models.

SYNTHETIC DATA

- P-wave velocity log blocked at major velocity changes, guided by lithological boundaries.

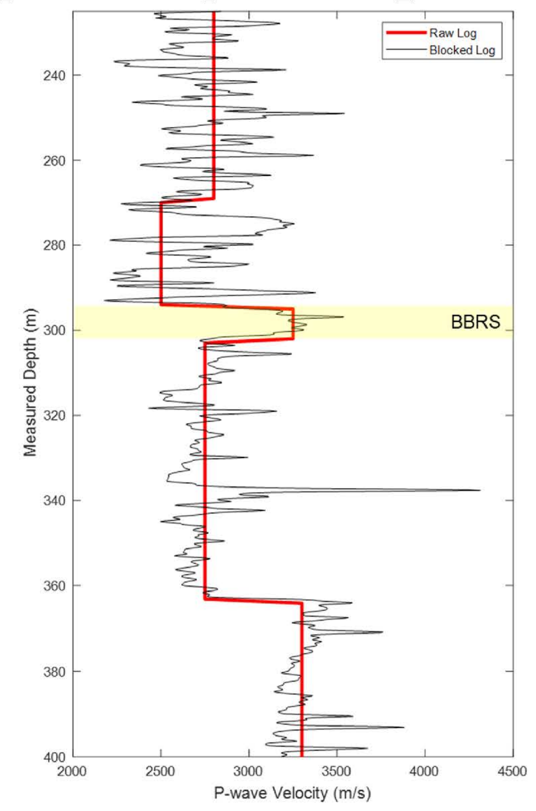

FIG. 2. P-wave velocity log (black) and blocked P-wave velocity log (red), zoomed to show the BBRS and surrounding geological layers.

2D DATA MODELS

- The blocked P-wave velocity log is used to populate a horizontally layered 2D true baseline velocity model comprised of 5 m x 5 m grid cells.
- V_P in CO_2 injection plume calculated using reservoir parameter-based rock physics modelling

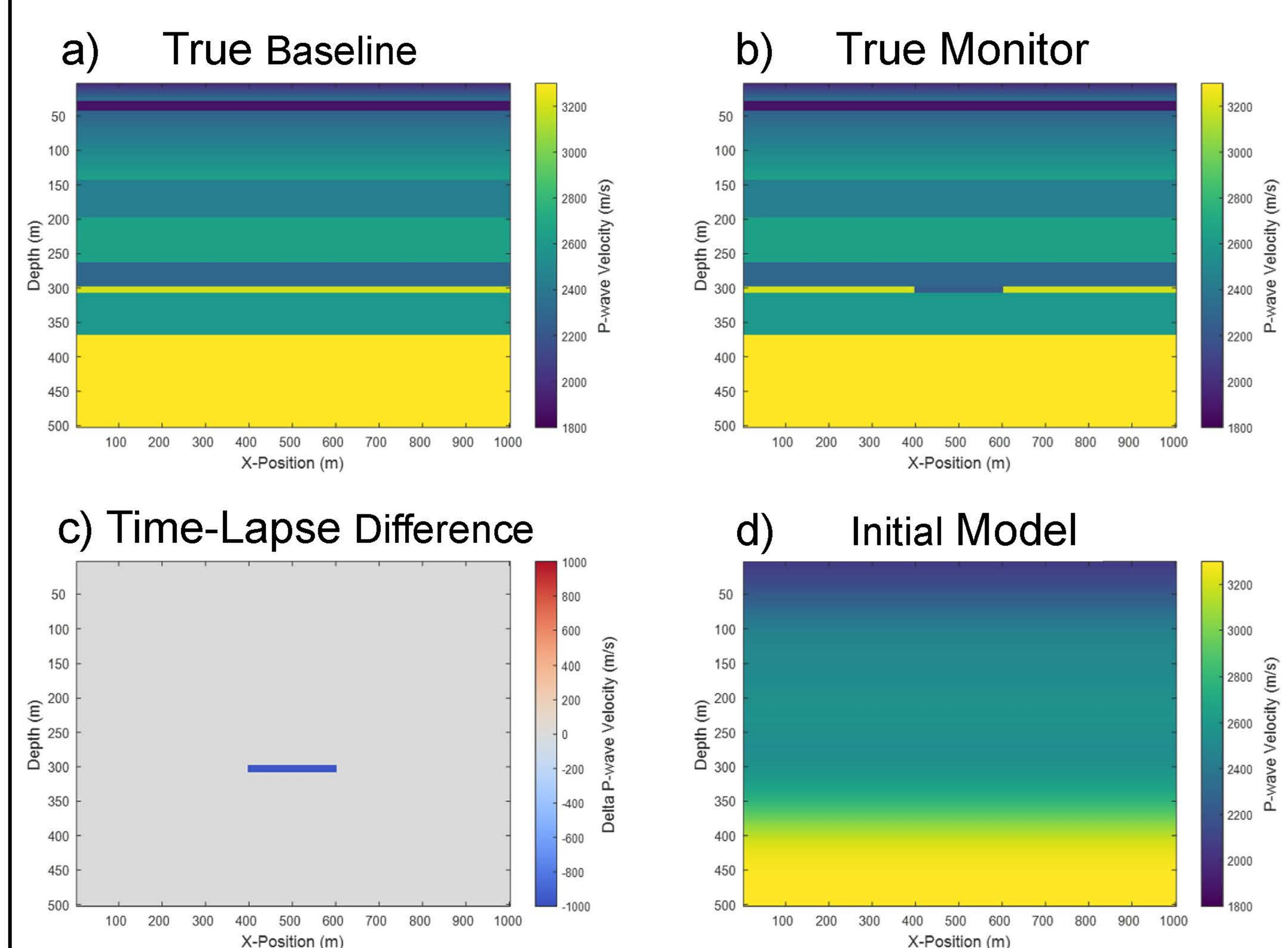

FIG. 3. a) True baseline, b) true monitor, c) time-lapse difference and d) the initial velocity model used for FWI.

- The BBRS is underlain by shales, and overlain by coals, resulting in a local velocity high
- A smooth initial model is used for all inversions

NUMERICAL EXAMPLES

Example 1) Dense Baseline, Sparse Monitor

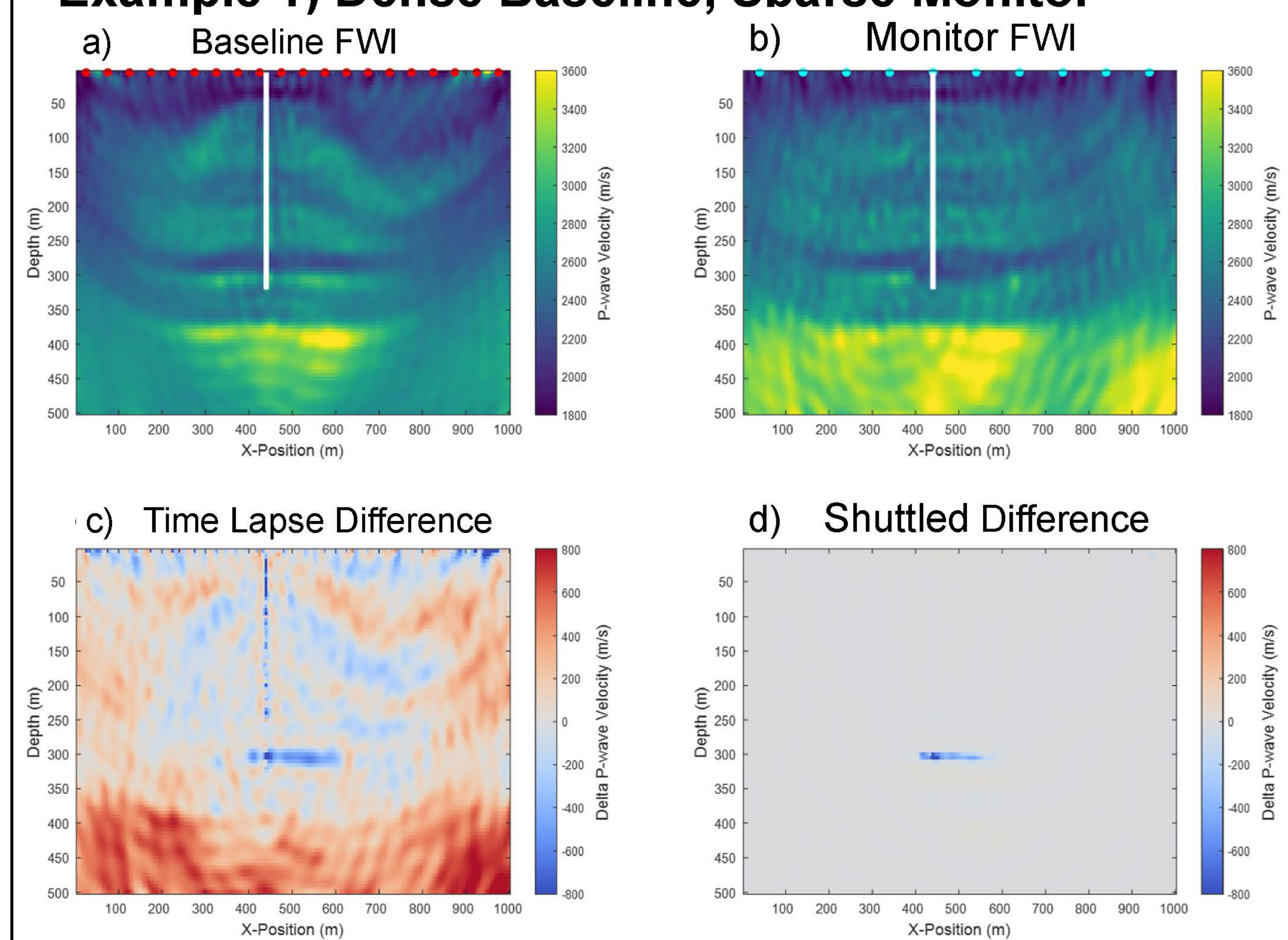

FIG. 4. a) Baseline inversion, b) monitor inversion, c) time-lapse difference and d) shuttled difference for the CO_2 injection case of offset unequally spaced source geometry, with added noise.

Example 2: Dense Baseline, Single Source Monitor

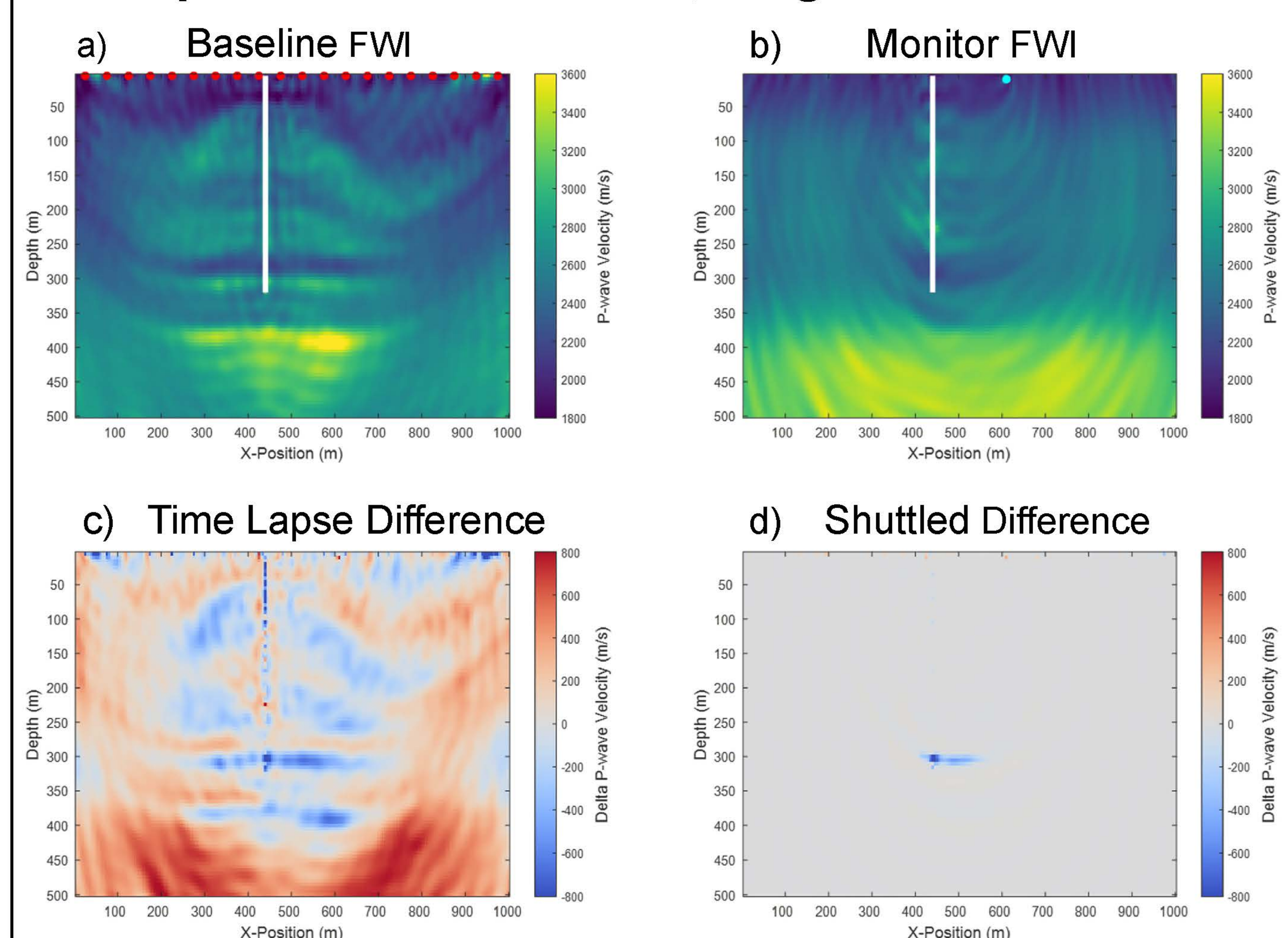

FIG. 5. a) Baseline inversion, b) monitor inversion, c) time-lapse difference and d) shuttled difference for the CO_2 injection case of a single source point located at 610 m, with added noise.

CONCLUSIONS

- Targeted nullspace shuttling, with knowledge of expected reservoir response, recovers of the minimum time-lapse anomaly.
- Nullspace shuttling effectively removes non-reservoir related noise.
- Nullspace shuttling may reduce the costly requirement of repeatability geometry in CO_2 MMV

References:
Keating., S.D., and Innanen, K.A., 2021, Null-space shuttles for targeted uncertainty analysis in full-waveform inversion: Geophysics, **86**, No. 1., R63-R76.

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