TITLE / AUTHOR LIST

# Time-lapse seismic full waveform inversion with targeted null-space shuttles

Scott D. Keating and Kristopher A. Innanen

OBJECTIVE / SCOPE (100 WDS)

Time-lapse seismic inversion is expected to be a critical technology in $CO_2$ storage and other monitoring intensive applications relevant to the ongoing energy transition. Targeted null-space shuttles are part of a theoretical and practical construct through which (1) time-lapse waveform inversion strategies can be characterized and compared, and (2) optimal algorithms can be selected. Here we set out the use of targeted shuttles in the time-lapse problem, compare it with other approaches, and examine its numerical behaviour in simulated settings.

METHODS (250 WDS)

We apply targeted null-space shuttles to time-lapse seismic full waveform inversion (FWI). In FWI, a model is determined through a set of updates which reduce an objective function to some acceptable value. A null-space shuttle is a further, subsequent update, which is defined such that the objective function value is held fixed (Figure 1). Exploration of the inversion null-space through these shuttles is a type of uncertainty analysis, in as much as shuttles produce models which satisfy the data equally. A targeted null-space shuttle is one which satisfies some additional external condition provided by the user, shrinking the region of the full null-space to be explored. In time-lapse FWI, where there are at least two datasets (baseline and monitoring), and therefore two null-spaces (Figure 1a-b), pairs of targeted shuttles can be designed based on their properties relative to one another. We make the case that the shuttles which minimize the time-lapse difference (Figure 1c) are optimal, in the sense that they represent the smallest change consistent with the data. In addition to generating difference estimates which suppress noise and non-repeatability, such shuttles also respond in an informative way in the "negative case", i.e., overlapping null-spaces (Figure 1c), clarifying that a single, unchanged model can adequately account for both baseline and monitoring data.

RESULTS / CONCLUSIONS (250 WDS)

We present a set of simple numerical examples of time-lapse FWI through targeted null-space shuttles, illustrating its basic behaviour (Figure 2). In particular, we systematically test the difference models generated on a backdrop of noise and imperfectly-repeated acquisition, as the size of the model change is reduced. This brackets the applicability of the approach both to producing maximally interpretable models when they are warranted, and to producing useful null results when the data (with its specific acquisition geometry and inaccuracies) do not support the interpretation that a change has occurred.

SIGNIFICANCE / NOVELTY (100 WDS)

We introduce new time-lapse FWI theory and algorithms, and at the same time provide a framework for understanding differences between other existing time lapse methods (e.g., parallel difference, sequential). Applicability is to all seismic monitoring problems, e.g., in “energy transition” spaces such as CO2 storage and verification, geothermal exploration and production, and hydrogen storage, etc. They have not been published or presented in any conference outside of internal research group meetings; this IMAGE conference is intended to be its first public presentation.

FIGURES

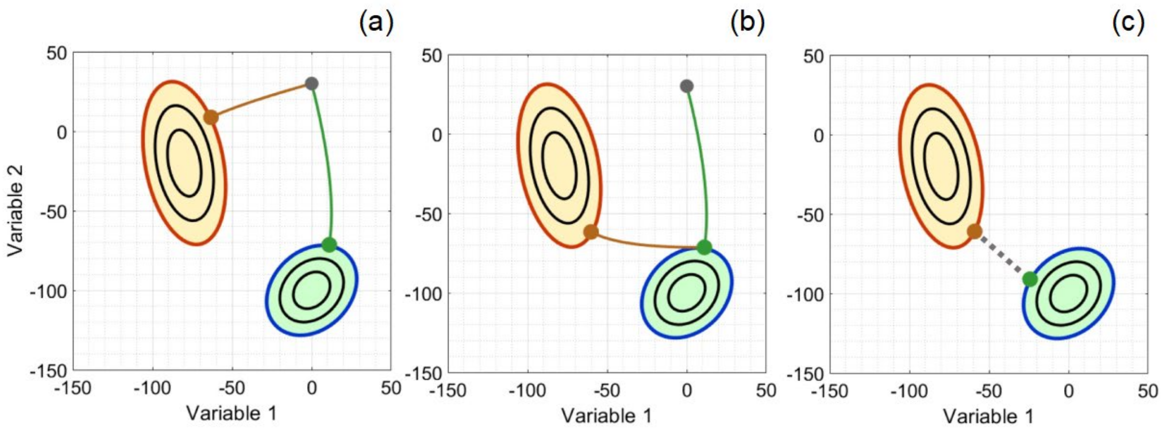


Figure 1. Schematic diagram of time-lapse seismic objective functions (green – baseline, yellow – monitoring). (a) Parallel strategy: 2 FWI procedures from the same initial model (top right). (b) Sequential strategy: Monitoring inversion uses baseline inversion as its initial model. Null space shuttles explore the “contour” of fixed misfit (dark yellow / blue). (c) In targeted null-space shuttles for time-lapse inversion, the nearest elements of the two inversion null-spaces are selected.

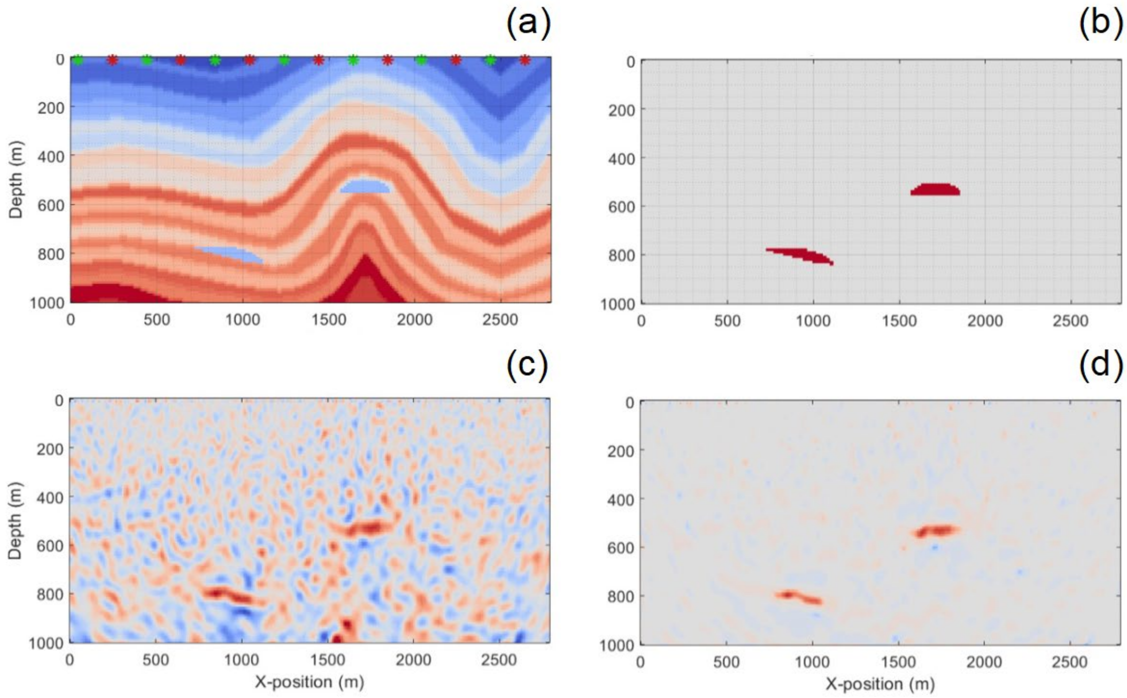


Figure 2. Numerical testing of time-lapse FWI through targeted null-space shuttles. (a) True model with two reservoir targets (inconsistent baseline/monitoring sources in red and green). (b) Simulated time-lapse change. (c) Parallel difference model. (d) After targeted shuttling of results in (c).