Time Lapse Full Waveform Inversion with Reflection Oriented Workflow

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INTRODUCTION

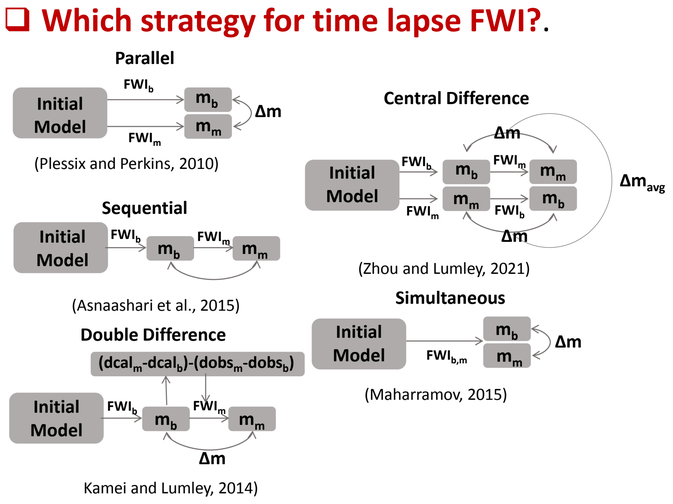
❑ Seismic time lapse

- Repeated survey at the same area over time -> assess changes of the subsurface.
- Consist of several surveys, called baseline (pre-production) and monitor (repeated survey).

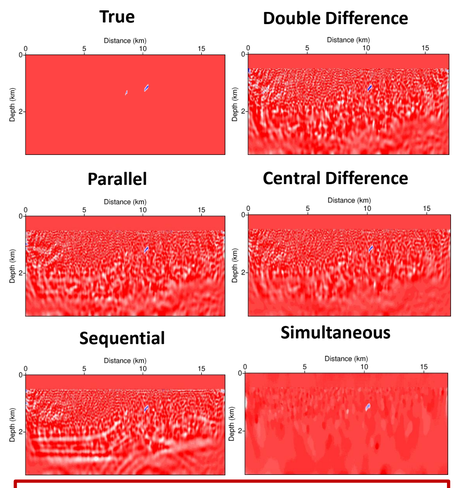
❑ Challenges on time lapse FWI

- **Non-repeatable geometry** -> practically difficult to obtain perfectly match acquisition
- **Noise repeatibilty** -> Different dataset has different level and type of noise
- **Inversion Convergence ->** FWI is ill posed and highly non-linear

❑ Which strategy for time lapse FWI?.



Time Lapse FWI Strategies



Comparison of Time Lapse Strategies

REFLECTION ORIENTED WORKFLOW – INGREDIENTS

❑ Motivations

- **Make the most of vintage datasets**
  -> Exploit reflections waves beyond diving wave penetration
  -> Develop Efficient workflow with minimal pre-processing
- **Handle time lapse in multiparameter way**
  -> Addres velocity-impedance coupling
  -> Addres sensitivity to other elastic parameters changes

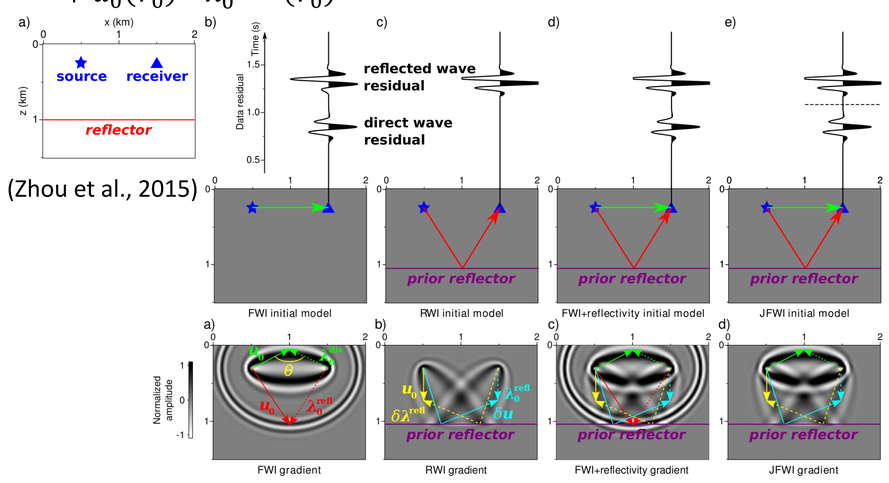
❑ Pseudo-time domain Joint FWI (Zhou et al., 2015; Provenzano et al., 2022)

- **Simultaneously invert diving and reflection waves** under one misfit function

$$C_{JFW}\ (V_0, \delta I) = \frac{1}{2}\left\|W^{div}(d_{cal}(V_0) - d^{div})\right\|^2 + \frac{1}{2}\left\|W^{ref}\ (d_{cal}(V_0, \delta I) - d^{ref}\ )\right\|^2$$

- Update velocity through **two step gradient building**

$$\nabla_{V_0} C_{JFW} = u_0(V_0) * {\lambda_0}^{div}(V_0) + \delta u_0(V_0, \delta I) * {\lambda_0}^{ref}\ (V_0) + u_0(V_0) * \delta{\lambda_0}^{ref}\ (V_0, \delta I) + u_0(V_0) * {\lambda_0}^{ref}\ (V_0)$$



(Zhou et al., 2015)

- **Reformulation of JFWI gradient on pseudo-time domain** (Plessix, 2013)

$$\nabla_{\tau_{(i)}} C_{JFW} = \nabla_{z_{(i)}} C_{JFW} - \int_{z_i}^{z_{max}} \frac{dV_0{}^z}{dz} \frac{1}{V_0(z)} \nabla_z C_{JFW}\, dz$$

Fixing reflectors in pseudo-time help to mitigate velocity-reflector ambiguity

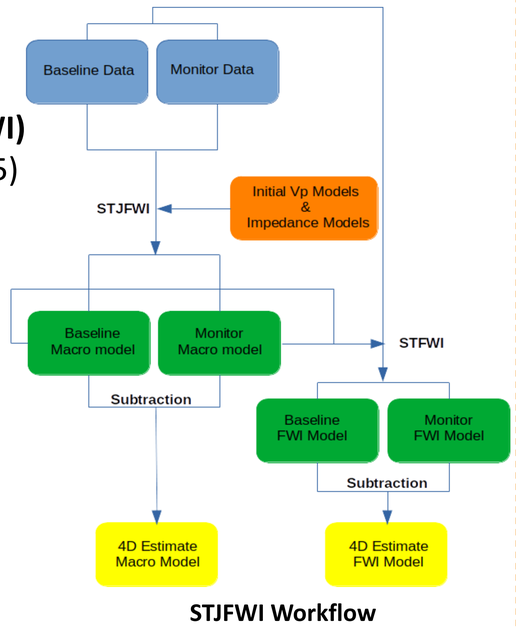
❑ Simultaneous time lapse JFWI (STJFWI)

(Fachtony et al., 2023)

- **Adopt simultaneous time lapse FWI (STFWI)** proposed by Maharramov and Biondi (2015) into **4D JFWI context**
- **STJFWI performs JFWI** on baseline and monitor data **simultaneously** and **enforce coupling of the dataset**

$$f(Vp_{base}, Ip_{base}, Vp_{mon}, Ip_{mon}) = C_{JFW}\ (Vp_{base}, Ip_{base}) + C_{JFW}\ (Vp_{mon}, Ip_{mon}) + \frac{\alpha}{2}\|\nabla(Vp_{mon} - Vp_{base})\|^1$$

- **Enforce Total Variation Regularization** on macro **model difference**



STJFWI Workflow

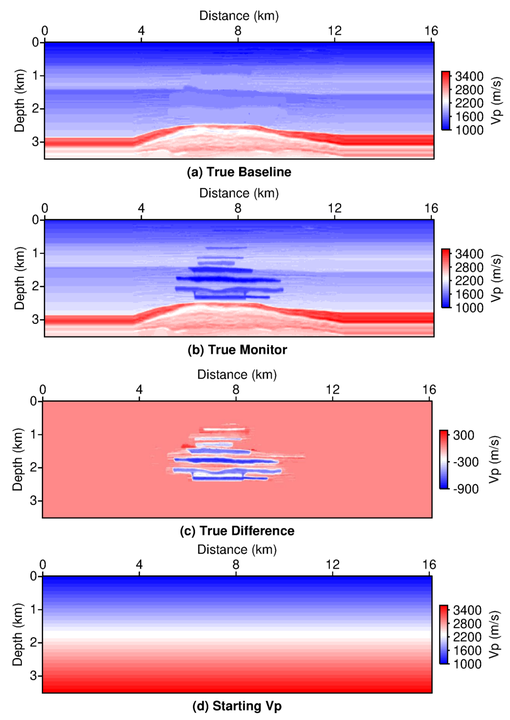
SYNTHETIC STUDY

❑ Model setup

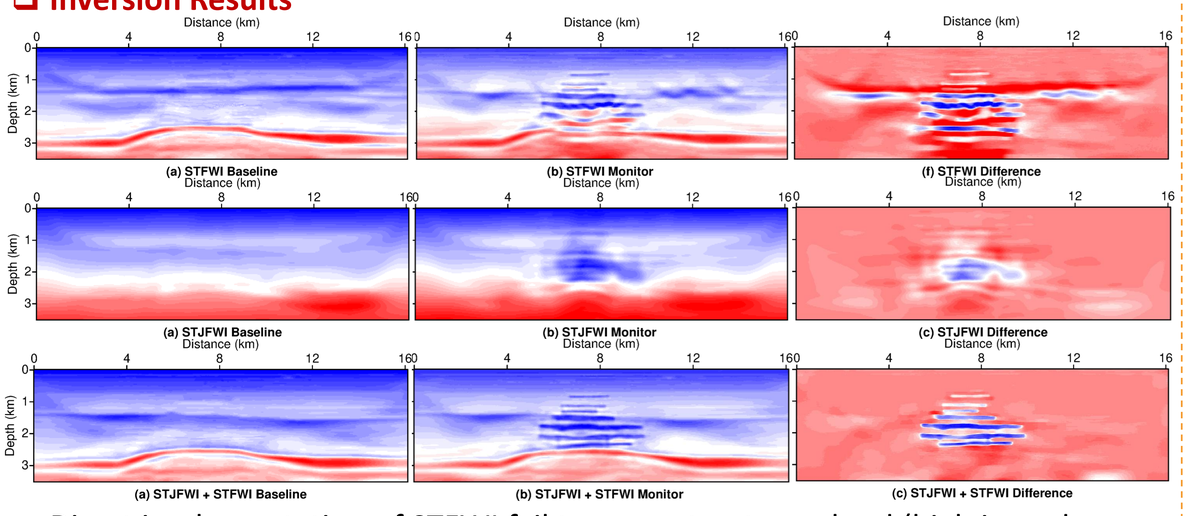
- 2D Valhall Model with gas cloud anomaly, 10m grid interval
- Streamer acquisition: 96 sources and 120 channel ($\Delta S_x = 50$m)
- $S(t) =$ Ricker centred at 6 Hz
- 2ms sampling rate

❑ Inversion setup

- Three test: 1. STFWI, 2.STJFWI, 3. STJFWI + FWI
- Mono parameter inversion:
  >> Vp only, for STFWI.
  >> Ip only (fix Vp), STJFWI Ip cycle
  >> Vp only (fix Ip), STJFWI Vp cycle
- Depth preconditioning for gradient



❑ Inversion Results



- Direct implementation of STFWI fail to reconstruct gas cloud (high impedance contrast
- STJFWI produce accurate macromodel with less artifacts
- Subsequent run of FWI from STJFWI reconstruct the structure accurately

CONCLUSION & FUTURE WORKS

❑ STJFWI

- Exploit short offset data, promote deeper penetration from reflection in 4D context
- Promote accurate 4D model with minimal time lapse artifacts
- Better constraint impedance contrast while mono-parameter failed

❑ Future investigation

Short term

- Application to Sleipner Norway dataset by SINTEF

Mid term

- Application Valhall OBC dataset by AKERBP
- Comparison of time lapse strategies on real data

Long term

- Multiparameter? More physics? Sensitivity to time lapse changes

REFERENCE

Asnaashari, A., Brossier, R., Garambois, S., Audebert, F., Thore, P., and Virieux, J. (2015). Time-lapse seismic imaging using regularized full waveform inversion with prior model: which strategy? Geophysical Prospecting, 63(1):78–98.

Kamei, R. and Lumley, D. (2014). Passive seismic imaging and velocity inversion using full wavefield methods. In SEG Technical Program Expanded Abstracts 2014, pages 2273–2277.

Maharramov, M. and Biondi, B. (2015). Robust simultaneous time-lapse full-waveform inversion with total-variation regularization of model difference. In 77th EAGE Conference & Exhibition, Expanded Abstracts, We P3 09.

Plessix, R. E. (2013). A pseudo-time formulation for acoustic full waveform inversion. Geophysical Journal International, 192:613–630.

Plessix, R. E. and Perkins, C. (2010). Full waveform inversion of a deep water ocean bottom seismometer dataset. First Break, 28:71 78.

Provenzano, G., Brossier, R., and Métivier, L. (2022). Robust and efficient waveform-based velocity-model-building by optimal-transport in the pseudotime domain: methodology. Geophysics, accepted.

Zhou, W., Brossier, R., Operto, S., and Virieux, J. (2015). Full waveform inversion of diving & reflected waves for velocity model building with impedance inversion based on scale separation. Geophysical Journal International, 202(3):1535–1554.

Zhou, W. and Lumley, D. (2021). Time-lapse joint full-waveform inversion of diving and reflected waves, pages 3495–3499.

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