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Summary

the complexity and cycle skipping of FWI and provides improved velocity models by up-going wavefields. accounting for separate model updates from the up- and down-going wavefields at the We modify the conventional two-way FWI formulation (Tarantola, 2005; Virieux and receiver locations.

One-way Wavefields

In order to obtain separate model updates from the one-way wavefields, we need to decompose the two-way wavefields. Using wavefield decomposition (Wapenaar and Berkhout, 2014), we can decompose the measured two-way wavefields **q** at a certain depth level into one-way wavefields ${f d}^\pm$ in the (f-k) domain using a decomposition matrix N as follows:

$$\mathbf{d}^{\pm} = \mathbf{N}\mathbf{q}.$$

For the acoustic case, where we perform decomposition in an acoustic medium, the to: decomposition equation becomes:

$$\begin{pmatrix} p^+ \\ p^- \end{pmatrix} = \begin{pmatrix} \frac{1}{2} & \frac{\omega \rho}{2k_z} \\ \frac{1}{2} & \frac{-\omega \rho}{2k_z} \end{pmatrix} \begin{pmatrix} p \\ v_z \end{pmatrix},$$

p: acoustic pressure component

 v_z : vertical particle velocity component

 p^+ : down-going acoustic pressure

 p^- : up-going acoustic pressure

 ω : angular frequency

 ρ : density

 k_z : vertical wavenumber := $\sqrt{}$

 c_p : p-wave velocity

 k_x : horizontal wavenumber

The properties required for acoustic decomposition are assumed to be known and are kept fixed to avoid influencing the inversion gradient. Alfaraj et al. (2015) showed that the decomposition operators require only a rough estimate of these properties.

Waveform Inversion using One-way Wavefields

Seismic Full Waveform Inversion (FWI) estimates a high resolution velocity model by We present our proposed algorithm that utilizes the one-way wavefields in waveform minimizing the difference between the two-way observed data and predicted data inversion. The method is a two-step approach that first updates the overburden (Tarantola, 2005; Virieux and Operto, 2009). The non-linearity of the problem and the velocity model before updating the deeper subsurface model. Since we perform complexity of the Earth's subsurface, which results in complex wave propagation may decomposition just above the ocean bottom, considering OBC acquisition scenario, we lead to unsatisfactory inversion results. Moreover, having inaccurate overburden utilize the property that the down-going acoustic pressure contains pure down-going models, i.e water velocity model in the ocean bottom acquisition setting, may lead to wavefield while the up-going acoustic pressure contains both the up- and down-going erroneous velocity models due to cycle skipping. We present a method that mitigates wavefields. Therefore, we can perform two separate inversions using the down- and

Operto, 2009) from:

$$\min_{\mathbf{m}} \quad \sum_{i=1}^{n_s} \frac{1}{2} \|\mathbf{d}_i^{\text{pred}}(\mathbf{m}) - \mathbf{d}_i^{\text{obs}}\|_2^2$$

m: slowness squared

 $\mathbf{d}_{i}^{\mathrm{pred}}$: predicted data

 $\mathbf{d}_{i}^{\text{obs}}$: observed data

 n_s : number of sources

$$\min_{\mathbf{m}} \quad \sum_{i=1}^{n_s} \frac{1}{2} \|\mathbf{d}_i^{\pm \text{pred}}(\mathbf{m}) - \mathbf{d}_i^{\pm \text{obs}}\|_2^2.$$

We carry out the same optimization steps used to solve the conventional FWI problem, (Witte et al., 2018). Here is a summary of our proposed algorithm:

Algorithm 1 Waveform inversion using one-way decomposed wavefields.

1. Compute the two-way predicted data **d**^{pred} using the initial model,

2. Decompose **d**^{pred} and **d**^{obs} to up- and down-going wavefields,

3. Starting from the initial model, invert using the down-going wavefields: $\mathbf{m} =$

argmin $\sum_{i=1}^{ns} \frac{1}{2} \|\mathbf{d}_{i}^{+\text{pred}}(\mathbf{m}) - \mathbf{d}_{i}^{+\text{obs}}\|_{2}^{2}$

4. Use \mathbf{m} as initial model for the inversion using the up-going wavefields: $\mathbf{m}=$

 $\operatorname{argmin} \quad \sum_{i}^{ns} \frac{1}{2} \|\mathbf{d}_{i}^{-\text{pred}}(\mathbf{m}) - \mathbf{d}_{i}^{-\text{obs}}\|_{2}^{2}.$

We demonstrate the proposed algorithm on synthetic data produced from part of the Marmousi2 model. We perform non-inverse crime constraint FWI and compare it with constraint waveform inversion using our proposed method starting from different initial velocity models: (i) good initial model, (ii) poor initial model and (iii) poor initial overburden model with good subsurface model.

Numerical Examples & Discussion

Figure 1: Example (i) Good initial model.

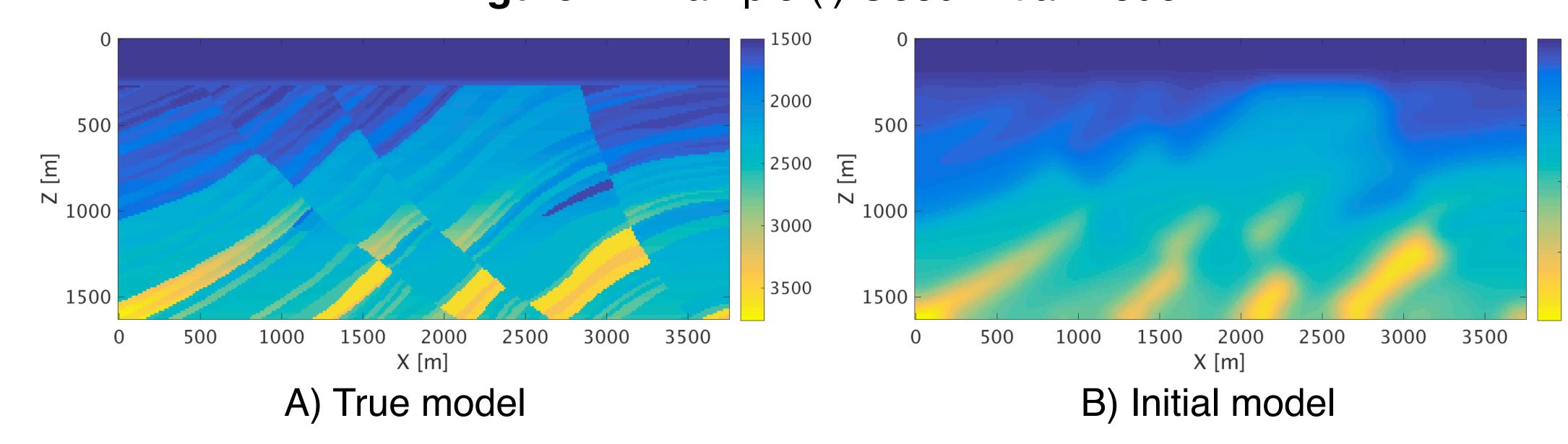


Figure 2: Data comparison.

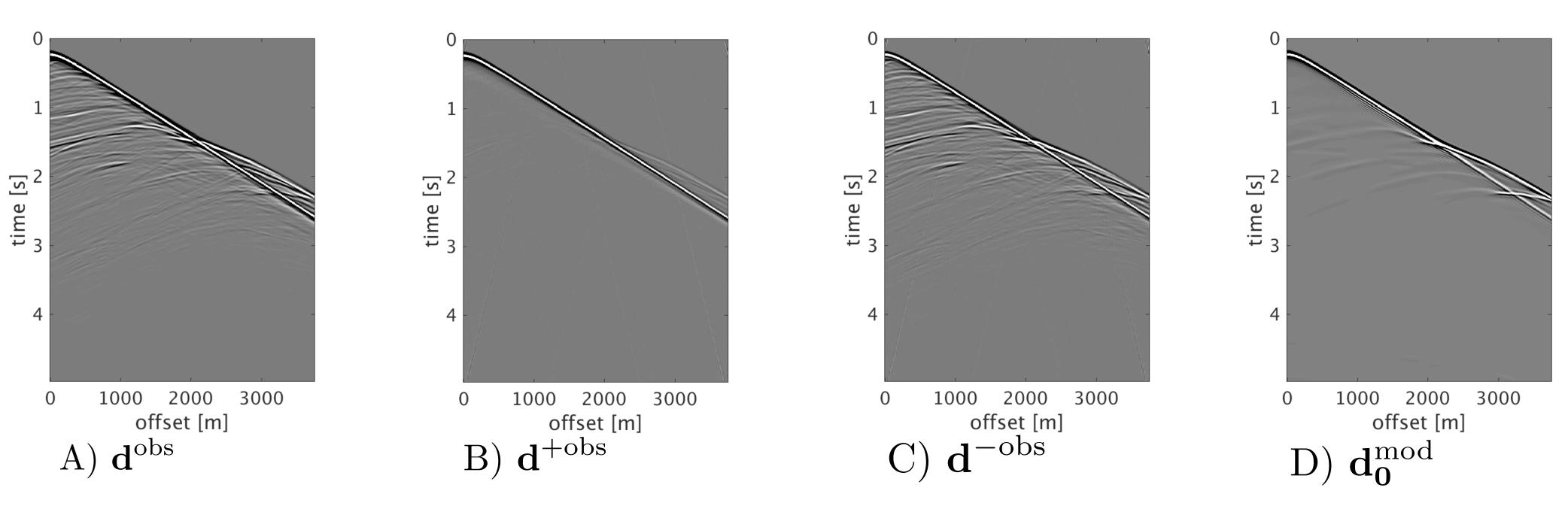


Figure 3: Inversion results starting from Figure 1.B.

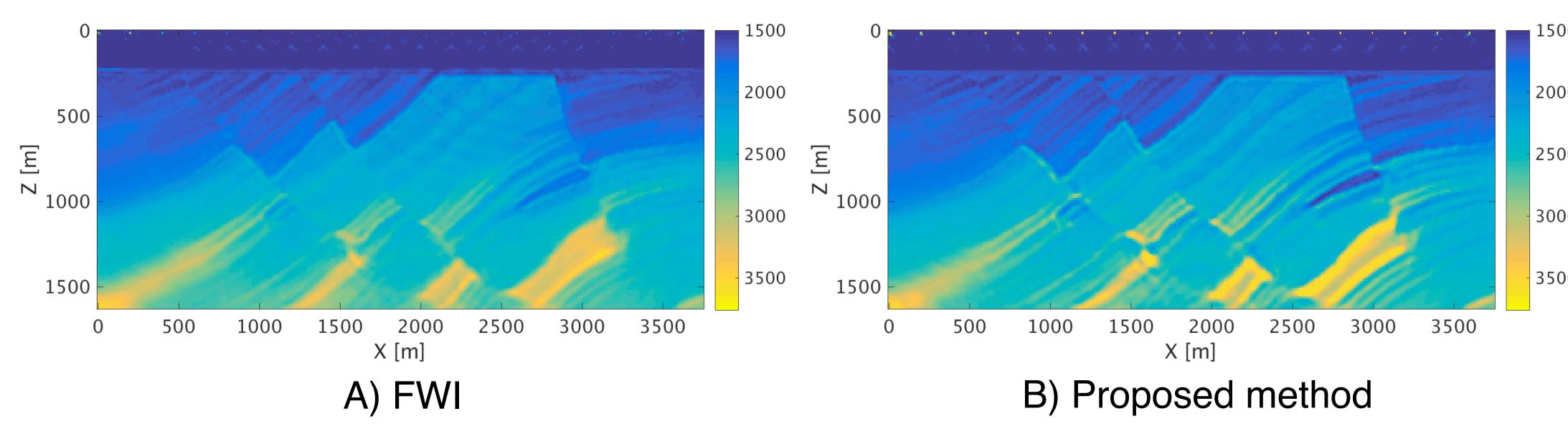


Figure 5: Example (ii) Multi-scale inversion from poor starting model.

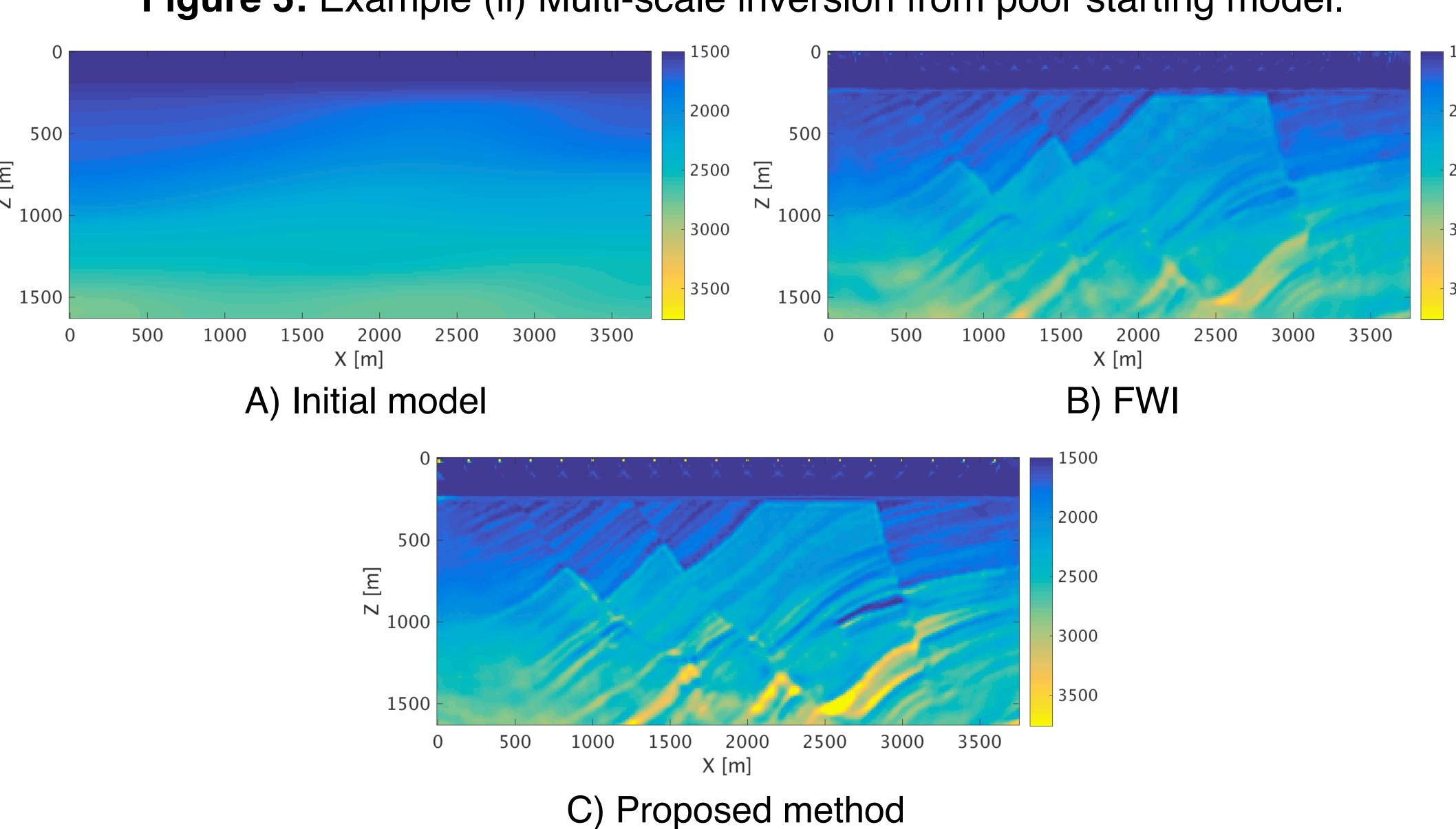


Figure 4: First gradients comparison for example (i).

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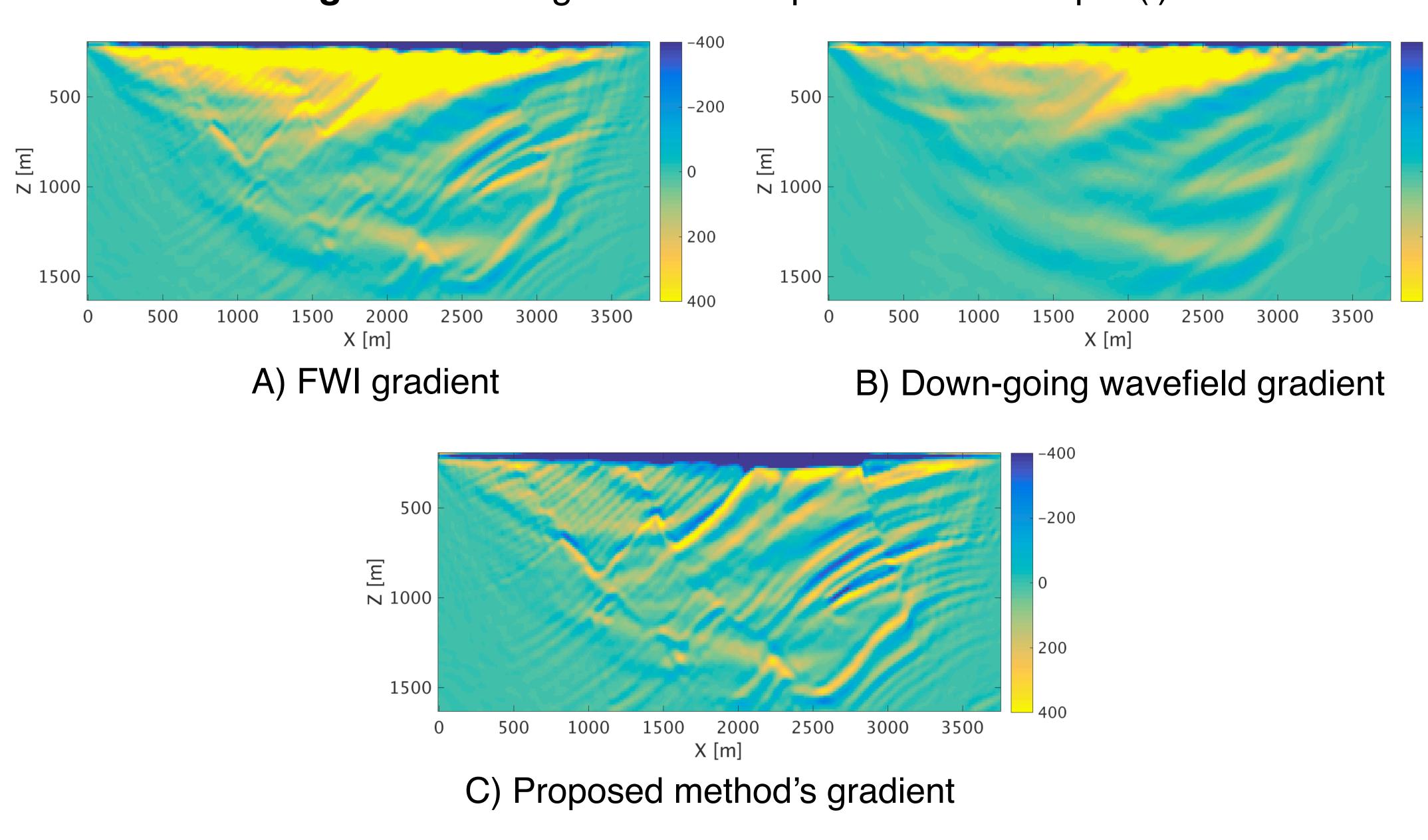
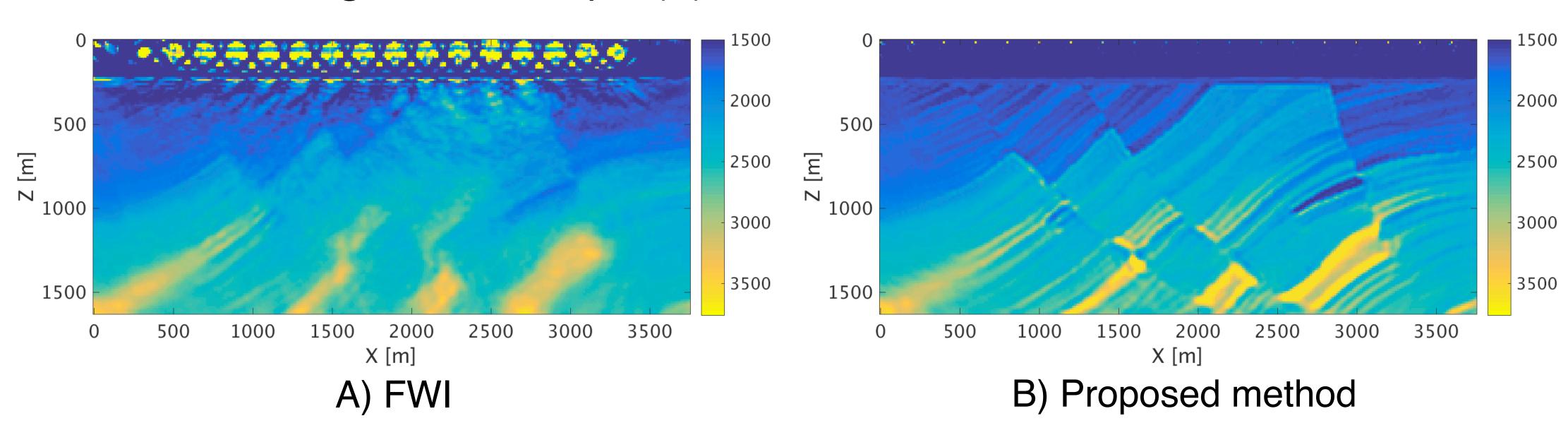


Figure 6: Example (iii) Poor initial overburden model.



Conclusions

We demonstrated through several examples that using the decomposed one-way wavefields in waveform inversion with our proposed algorithm provides improved and higher resolution velocity models compared with conventional FWI. In particular, when the initial overburden velocity was wrong, FWI failed to provide a satisfactory model due to cycle skipping while our proposed method did not because it was able to correct the overburden model from the down-going wavefield inversion.

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