Time-lapse FWI using simultaneous sources

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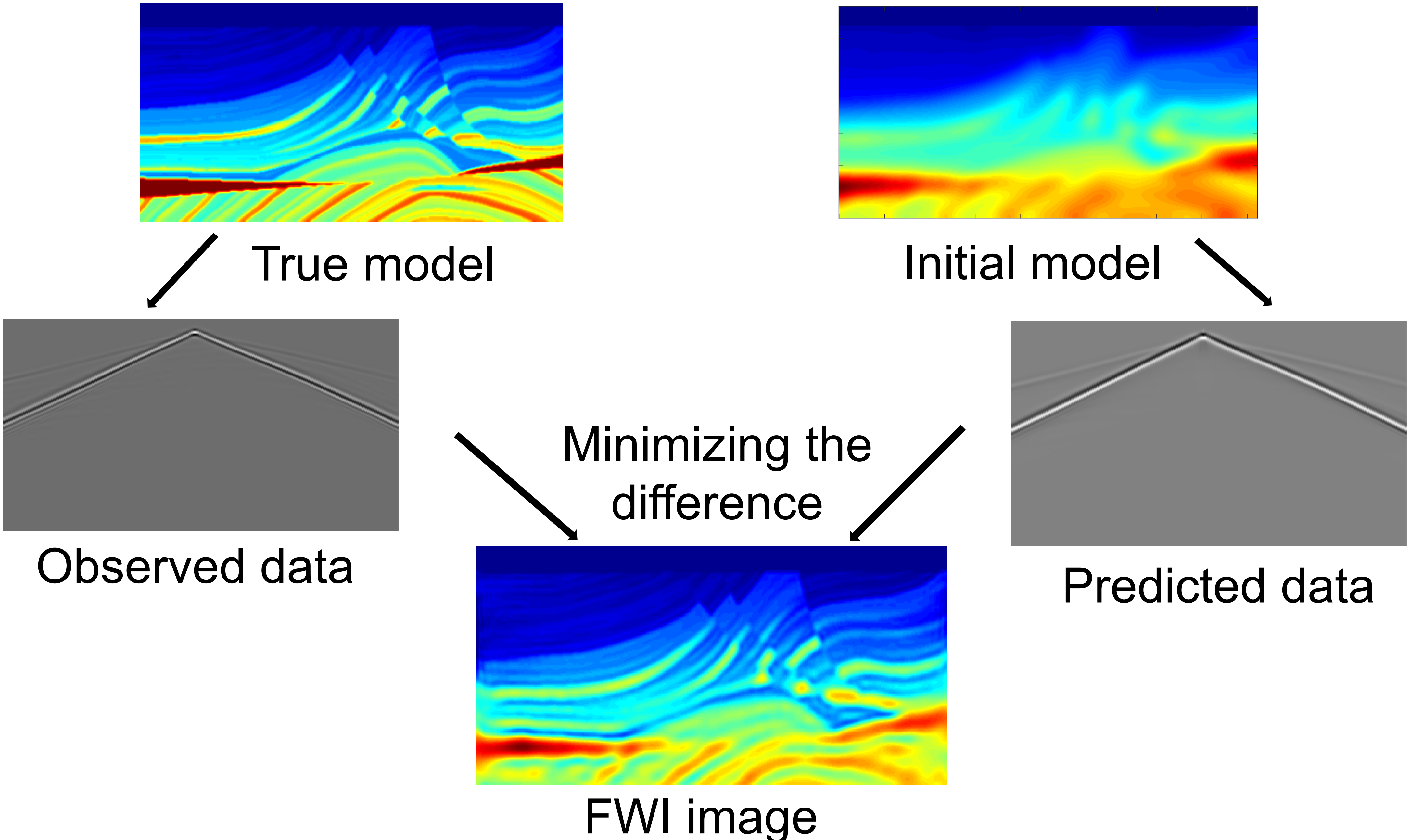
Outline

- Motivation
- Subsampling the shots
- Amplitude-encoding FWI
- Results for acoustic time-lapse FWI
- Results for elastic time-lapse FWI
- Conclusions

Motivation


True model
Initial model
Observed data
Minimizing the difference
Predicted data
FWI image

Motivation

The objective function is given by (Yang et al. 2014)

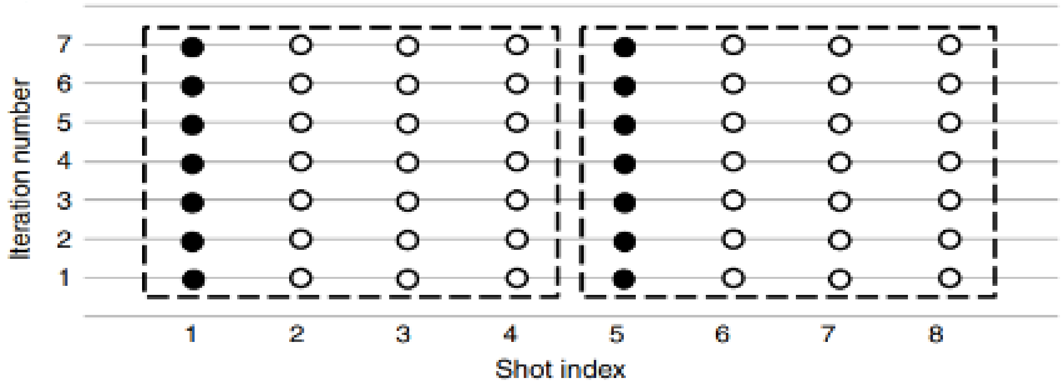
$$E(\mathbf{m}) = \frac{1}{2}\|\mathbf{p}_{\mathrm{cal}} - \mathbf{p}_{\mathrm{obs}}\|^2 = \frac{1}{2}\sum_{r=1}^{ng}\sum_{s=1}^{ns}\int_0^{t_{max}} \mathrm{d}t\,|p_{\mathrm{cal}}(\mathbf{x}_r, t; \mathbf{x}_s) - p_{\mathrm{obs}}(\mathbf{x}_r, t; \mathbf{x}_s)|^2 \tag{1}$$

- **Shot subsampling**: choose a small number of shots (Díaz and Guitton , 2011; Ha and Shin, 2013) .
- **Source-encoding**: encode all individual shots into super-shots (Krebs et al., 2009, Liu et al., 2021).

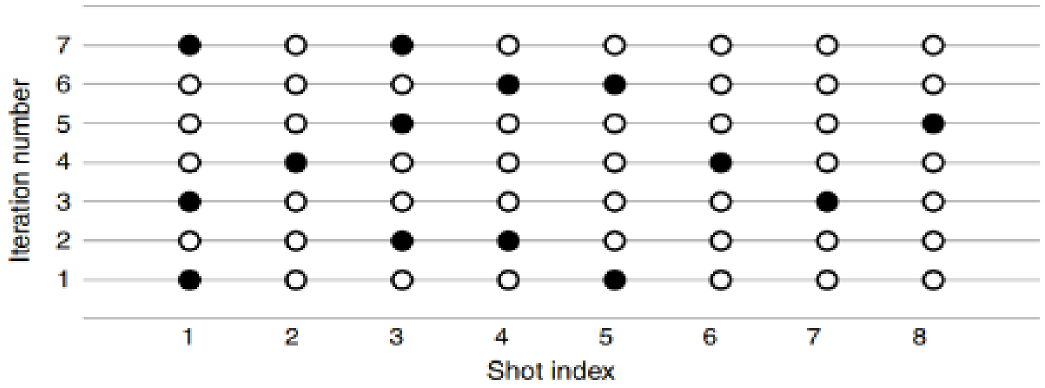
Subsampling the shots

Subsampling schemes

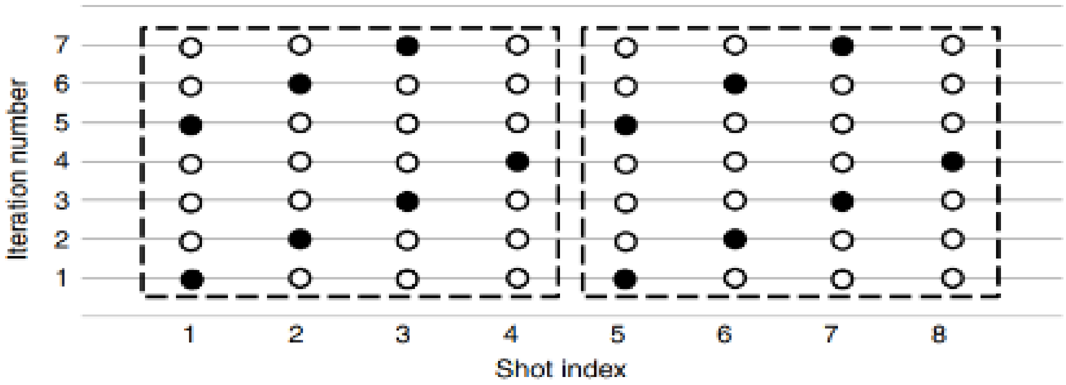
- No introduced crosstalk noise.
- Limited data reduction.



regular



random



cyclic

Fig 1. The black dots indicate the shots (adopted from Ha and Shin, 2013).

Amplitude-encoding FWI

In amplitude-encoding FWI, all individual shot gathers are blended into super-shots by

$$p^{\mathrm{sup}} = \mathbf{B}p \qquad (2)$$

The encoding matrix is defined as:

$$\mathbf{B} = \begin{bmatrix} b^{1,1} & b^{2,1} & . & b^{N_{ig},1} \\ b^{1,2} & b^{2,2} & . & b^{N_{sig},2} \\ . & . & . & . \\ b^{1,N_{sup}} & b^{2,N_{sup}} & . & b^{N_{sig}\cdot N_{sup}} \end{bmatrix}_{Nsup\times Nsig} \qquad (3)$$

where *Nsup* is the number of the super-shots and *Nsig* is the number of the individual shots (*Nsup* < *Nsig*).

Amplitude-encoding FWI

Redefined *l*-2 norm objective function in encoding FWI :

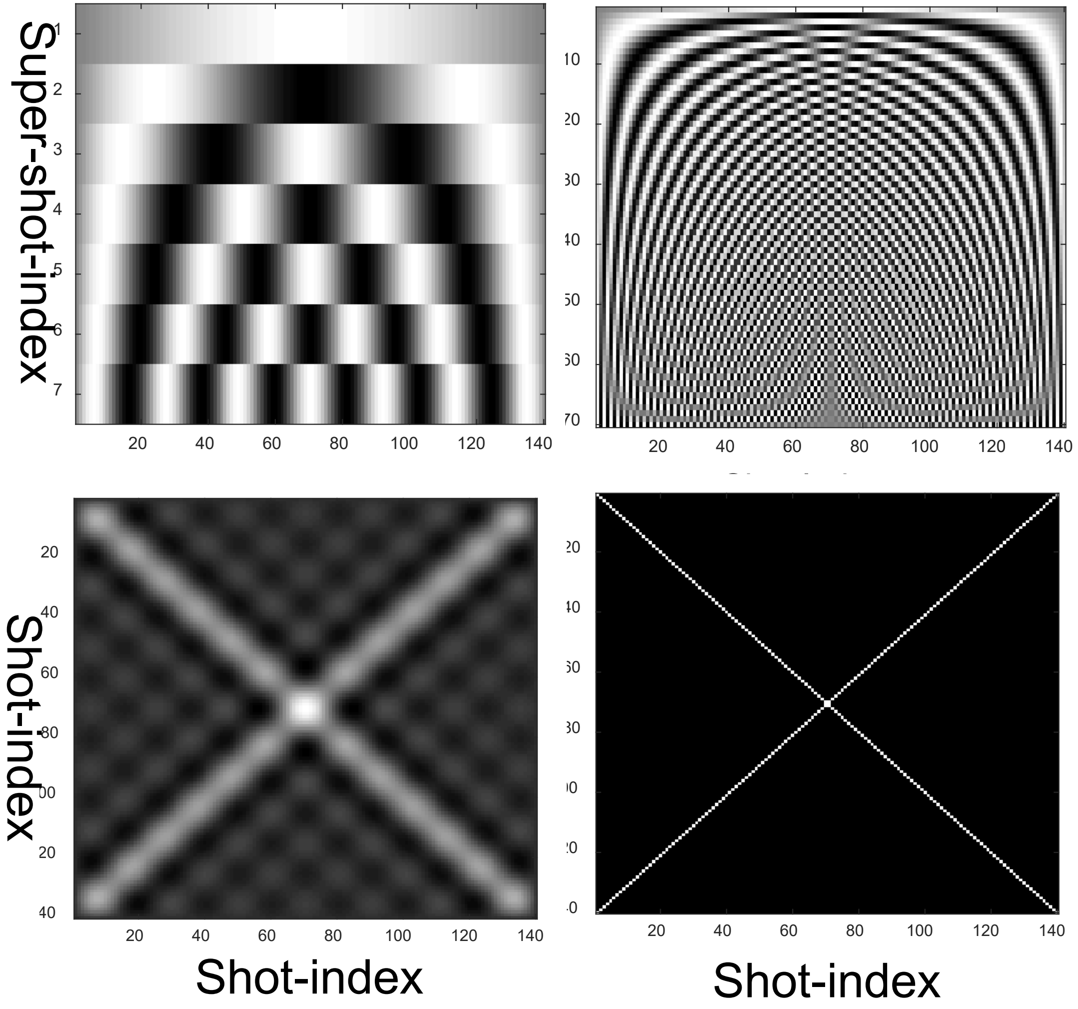
$$E(\mathbf{m}) = \frac{1}{2}\|\mathbf{B}p_{\text{cal}} - \mathbf{B}p_{obs}\|^2 = \frac{1}{2}(p_{cal} - p_{\text{obs}})\underbrace{\boxed{\mathbf{B}^T\mathbf{B}}}_{\text{crosstalk matrix}}(p_{\text{cal}} - p_{\text{obs}}) \quad (4)$$

The sine basis is defined as (Tsitsas et al., 2010) :

$$\mathrm{b}_{m,n} = \sqrt{\frac{2}{n_{\text{sig}}}}\sin\left(\frac{\left(m+\frac{1}{2}\right)\left(n+\frac{1}{2}\right)\pi}{n_{\text{sig}}}\right) \quad (5)$$

Amplitude-encoding FWI

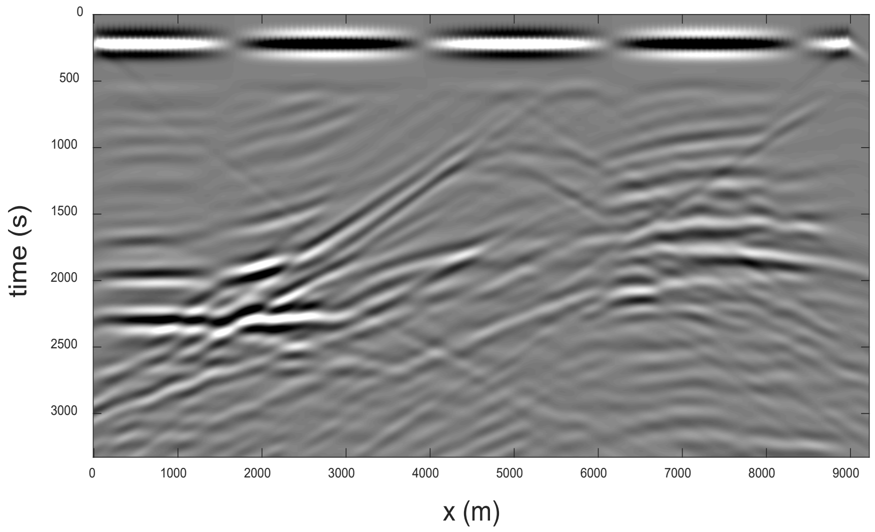
Encoding and crosstalk matrices



$\mathbf{B}$

$\mathbf{B}^T\mathbf{B}$

7 super-shots 70 super-shots



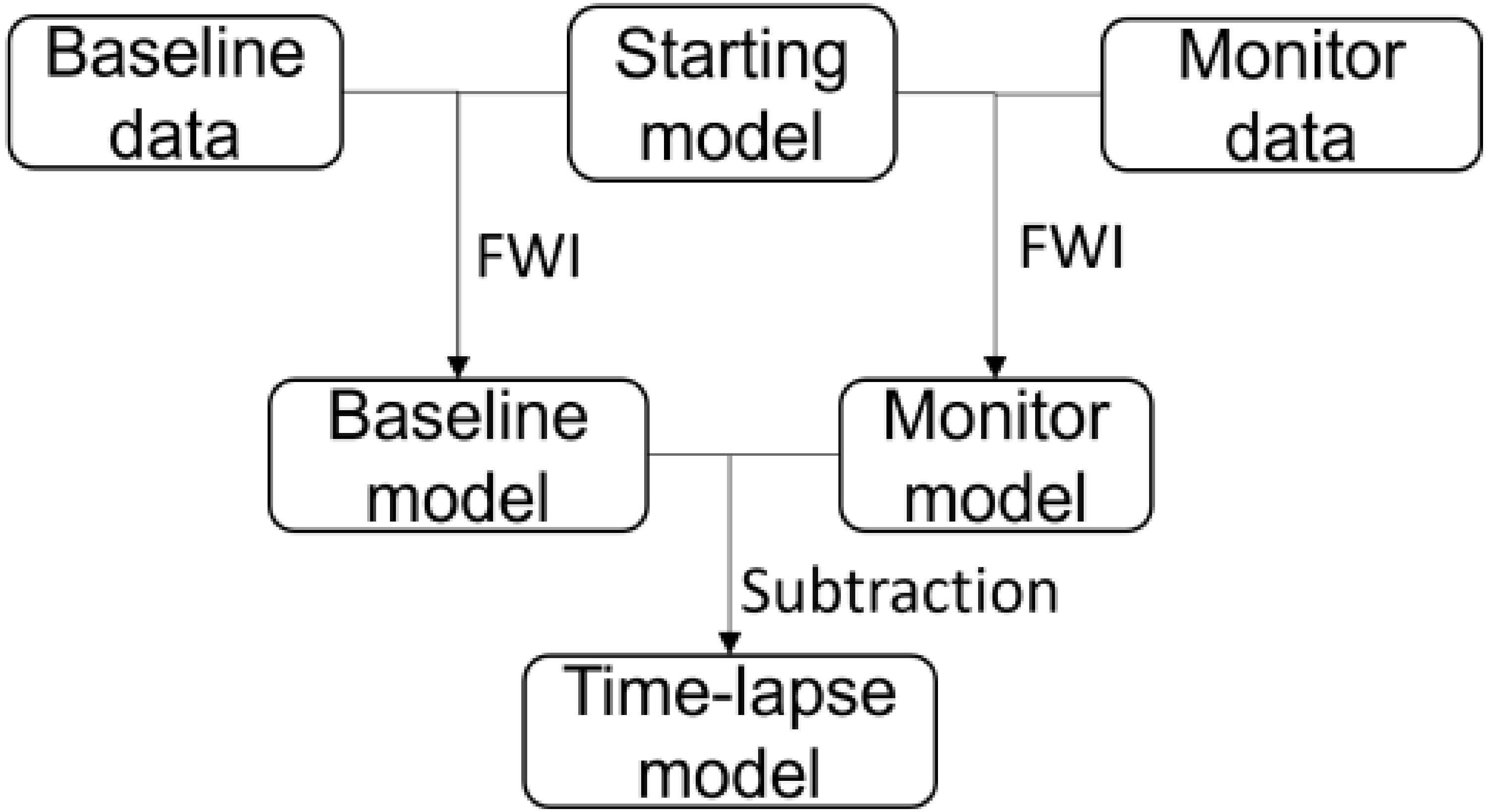
- Use all data information
- Introduce crosstalk noise

Encode subsampled shots

- Reduce data dimension
- Reduce crosstalk terms

Time-lapse inversion

Time-lapse strategy

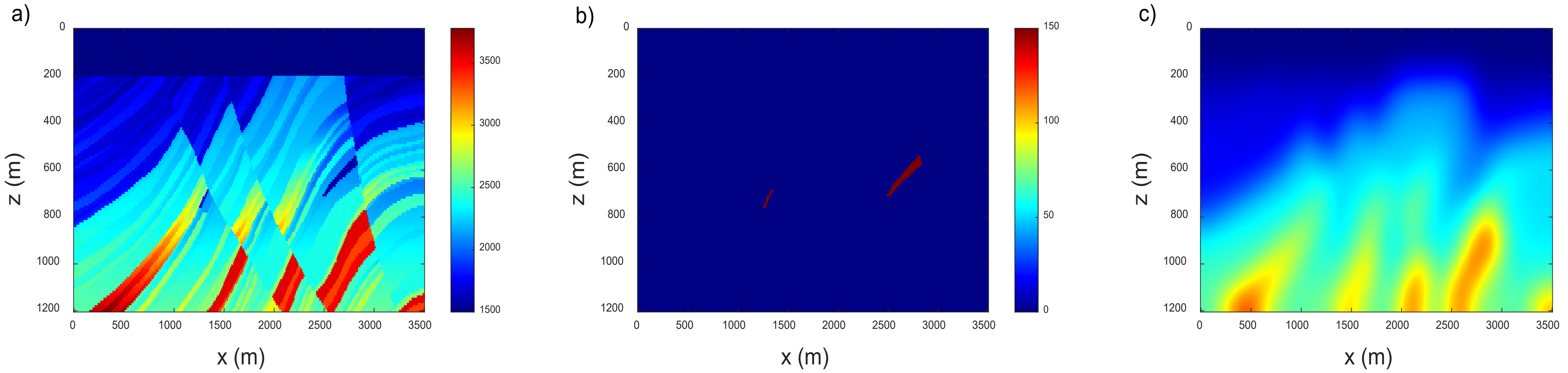


Flowchart of parallel strategy (PRS)

Acoustic time-lapse FWI

Acoustic Marmousi model

Model: 3500 m * 1200 m
Ns: 174 sources
F: 10 Hz.
Dt: 1.5 ms
Tmax: 2 s.

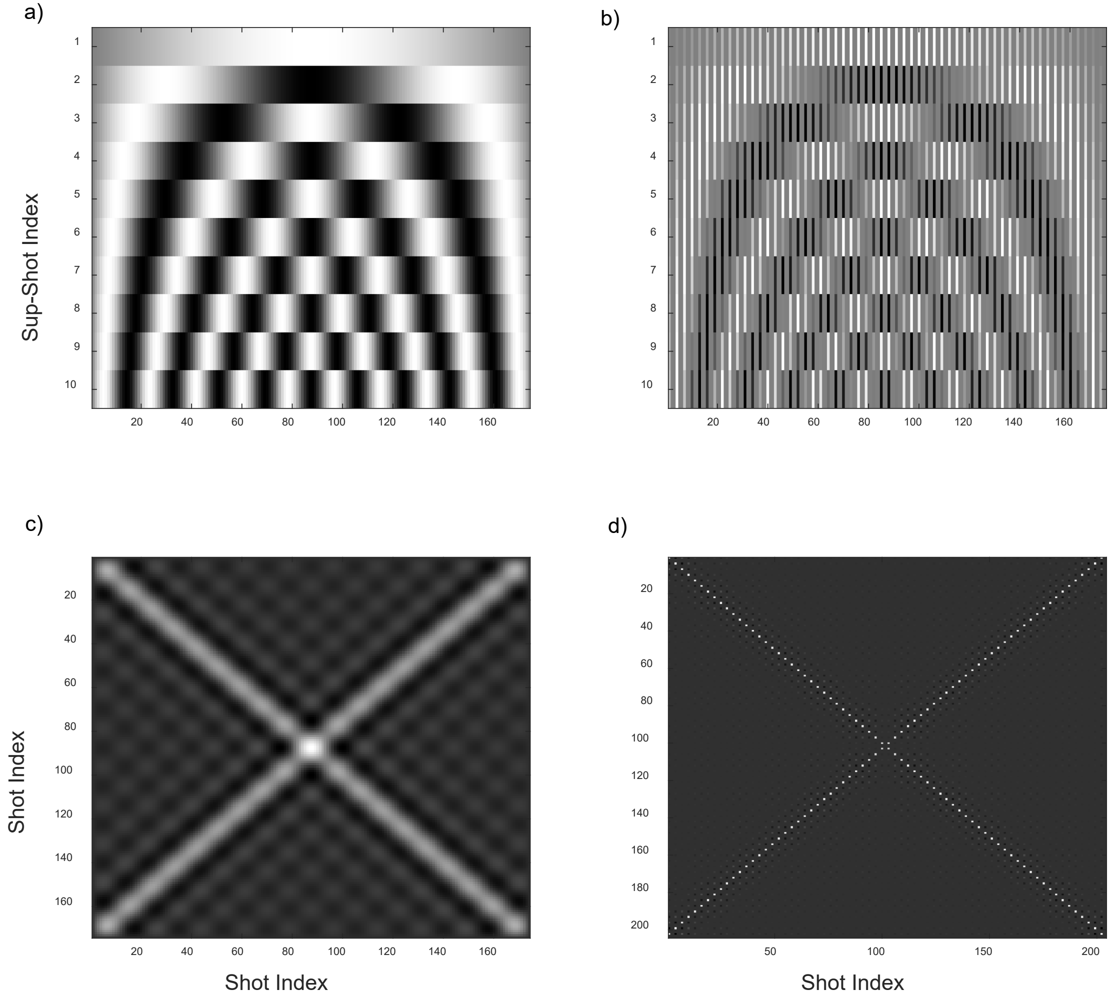


Baseline model Time-lapse model Initial model

Acoustic time-lapse FWI

- Subsample every 4 shots
- Use 58 shot gathers to compose 10 super-shots
- Re-subsample cyclically every a few iteration.

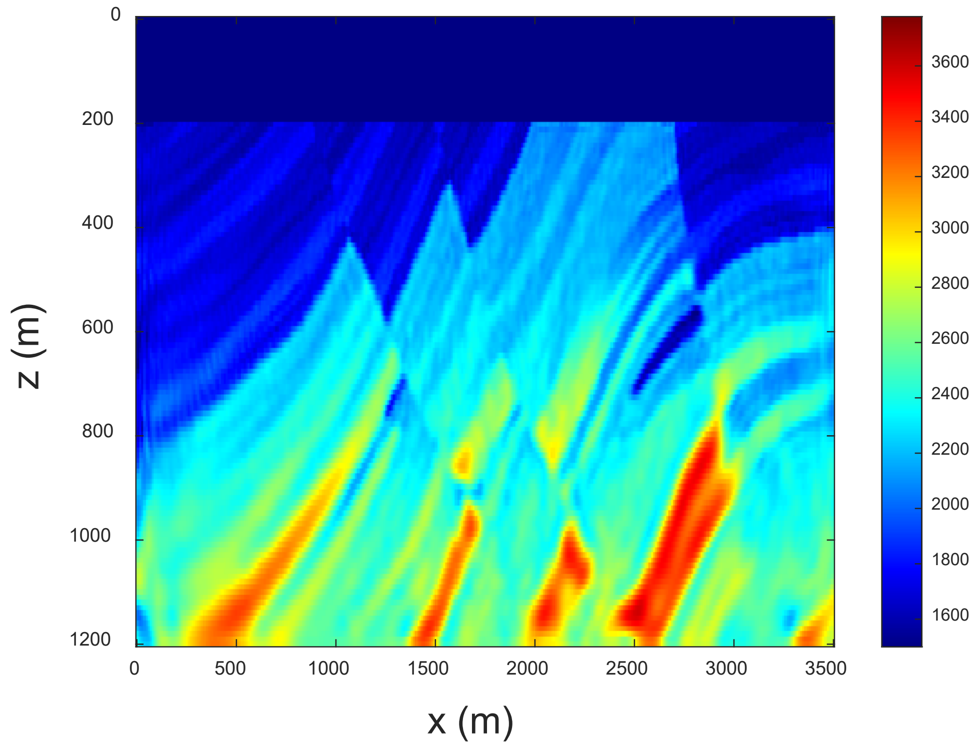
Encoding and crosstalk matrices



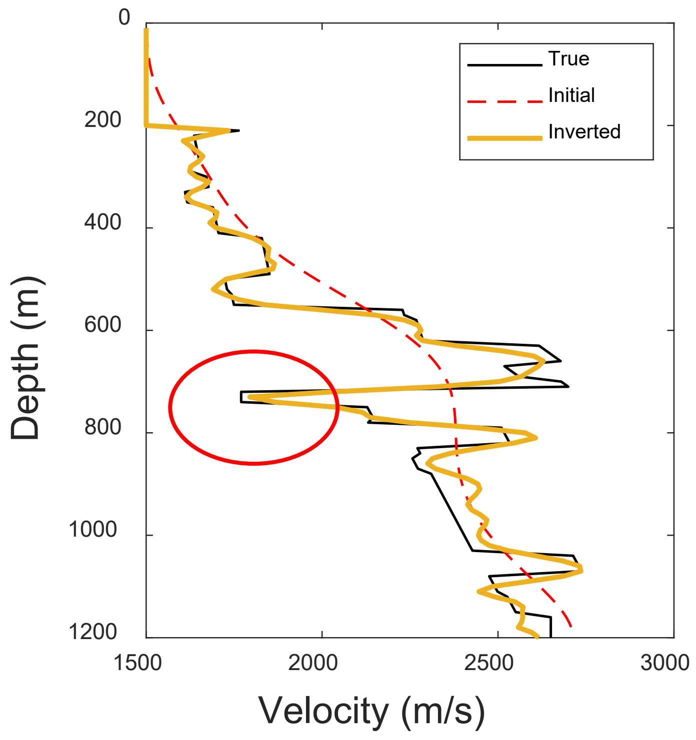
all shots   subsampled shots

Acoustic time-lapse FWI

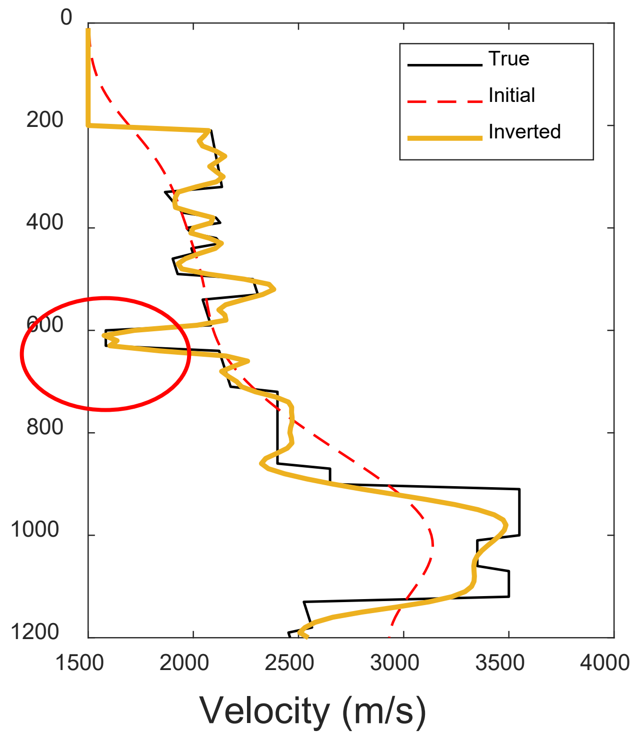
Inversion result for baseline model



Inverted baseline model



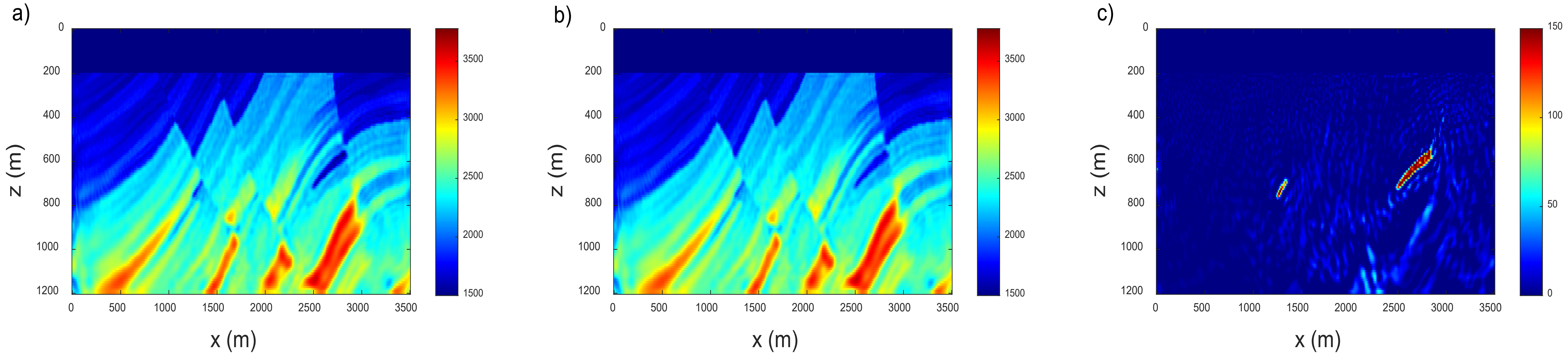
1300 m



2700 m

Acoustic time-lapse FWI

Inversion result for time-lapse model



Baseline

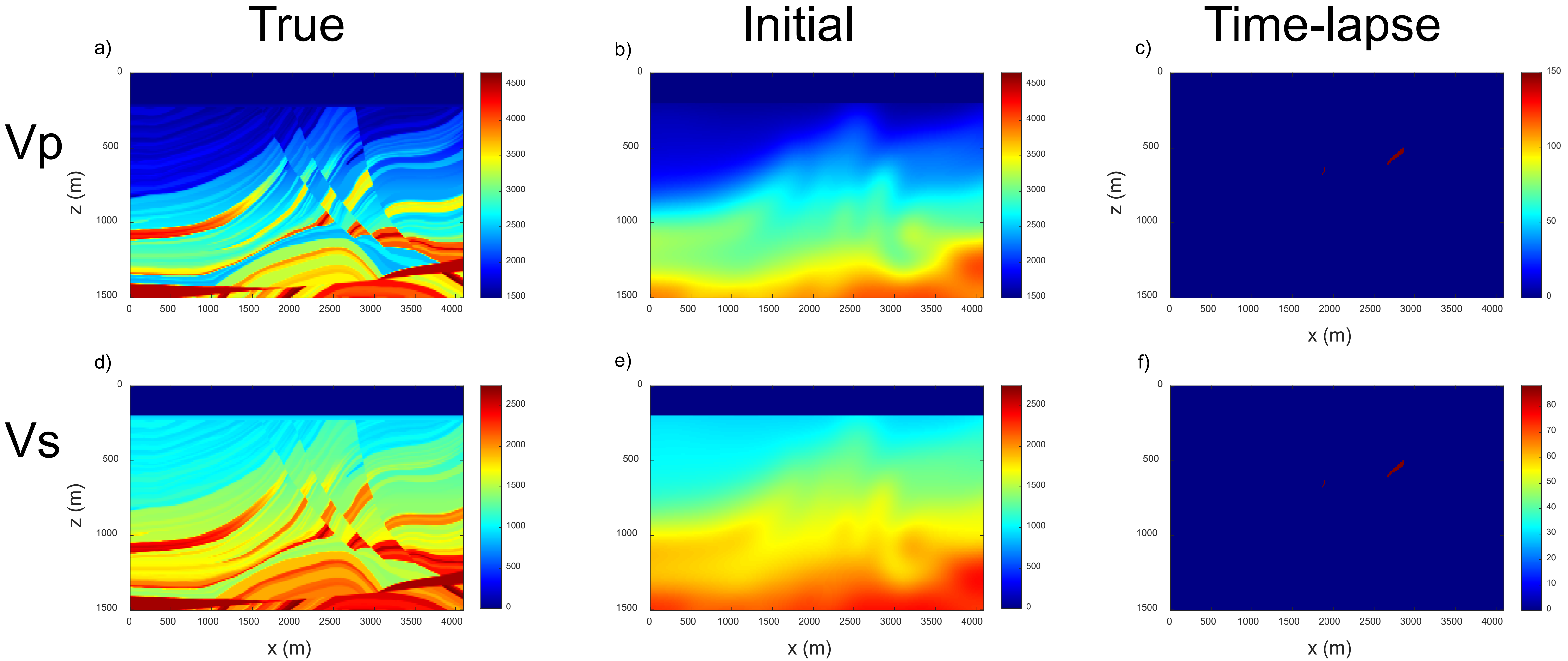
Monitor

Time-lapse

Elastic time-lapse FWI

Elastic Marmousi II model

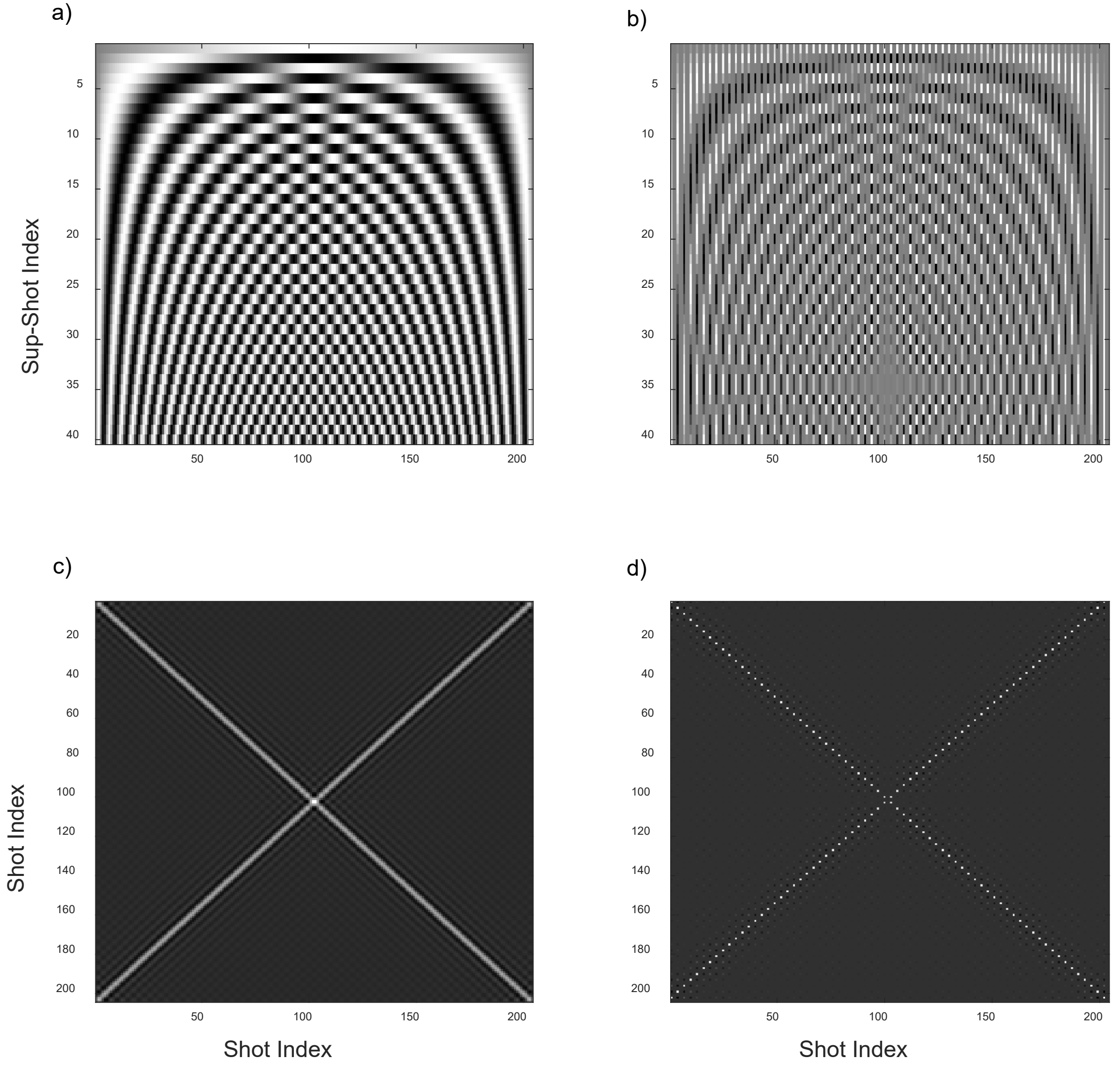
Ns: 204 sources
Multi-scale: 1 Hz to 20 Hz



Elastic time-lapse FWI

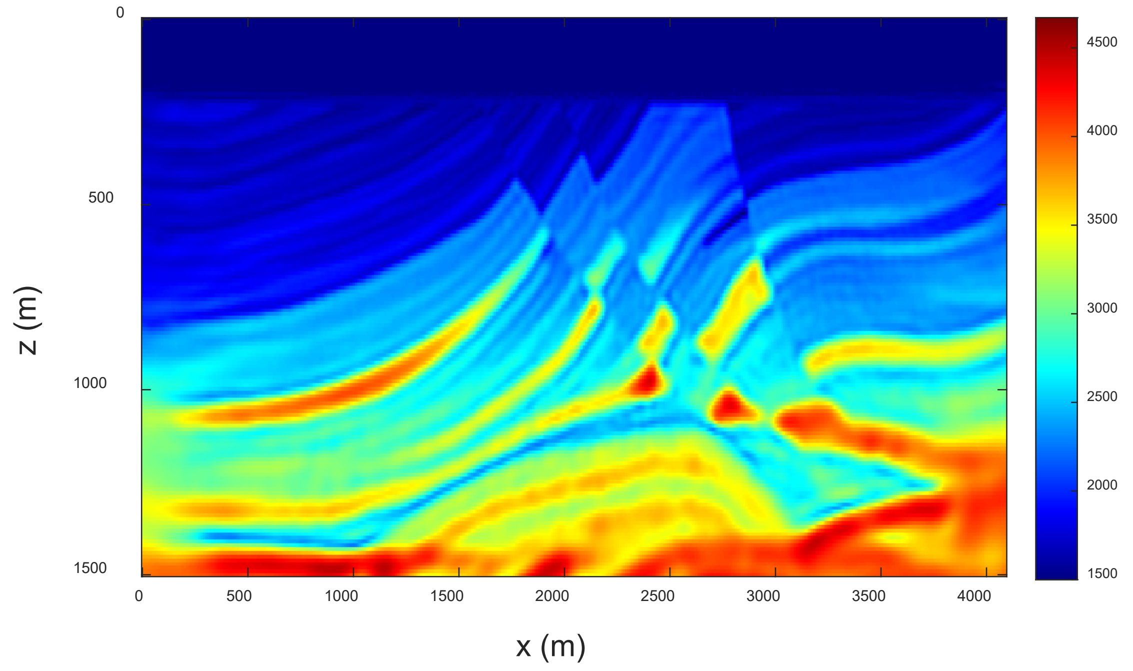
- 204 shot gathers
- subsample every 3 shots
- compose 40 super-shots

Encoding and crosstalk matrices

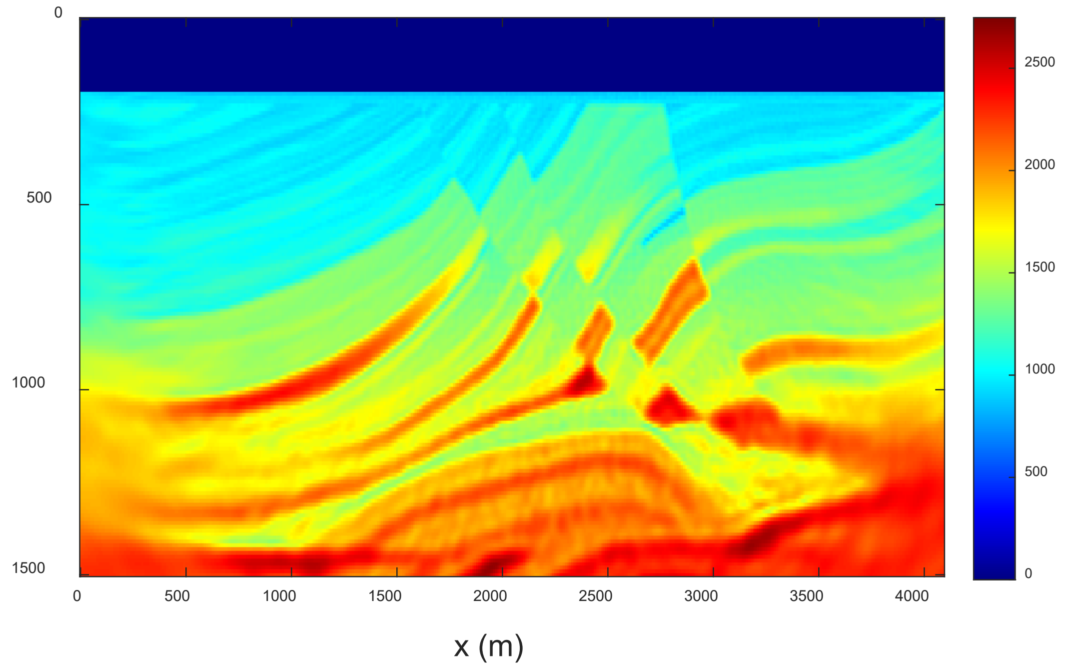


all shots subsampled shots

Inversion results for baseline model



Vp



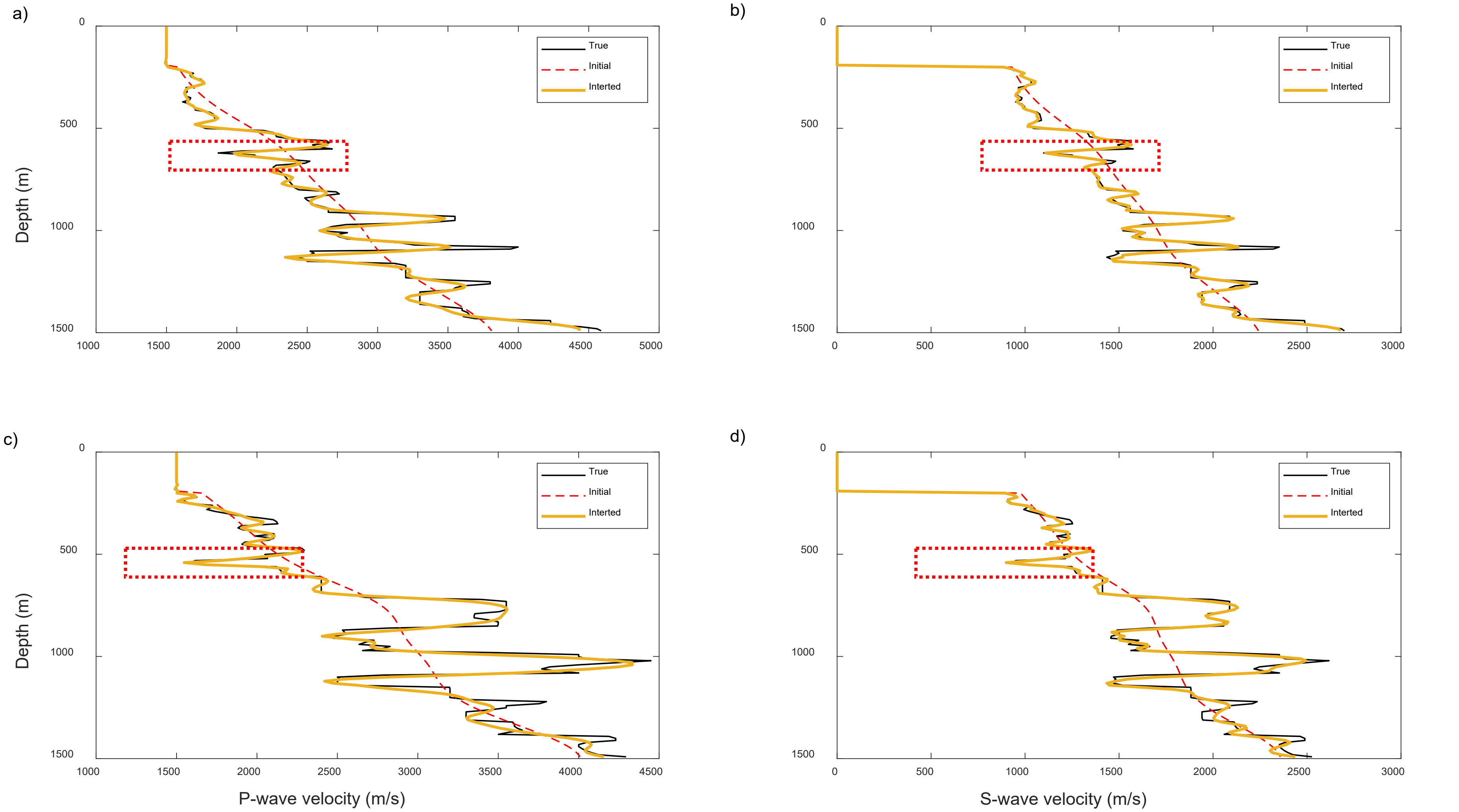
Vs

Elastic time-lapse FWI

Vertical profiles for baseline model

2.1 km

3 km

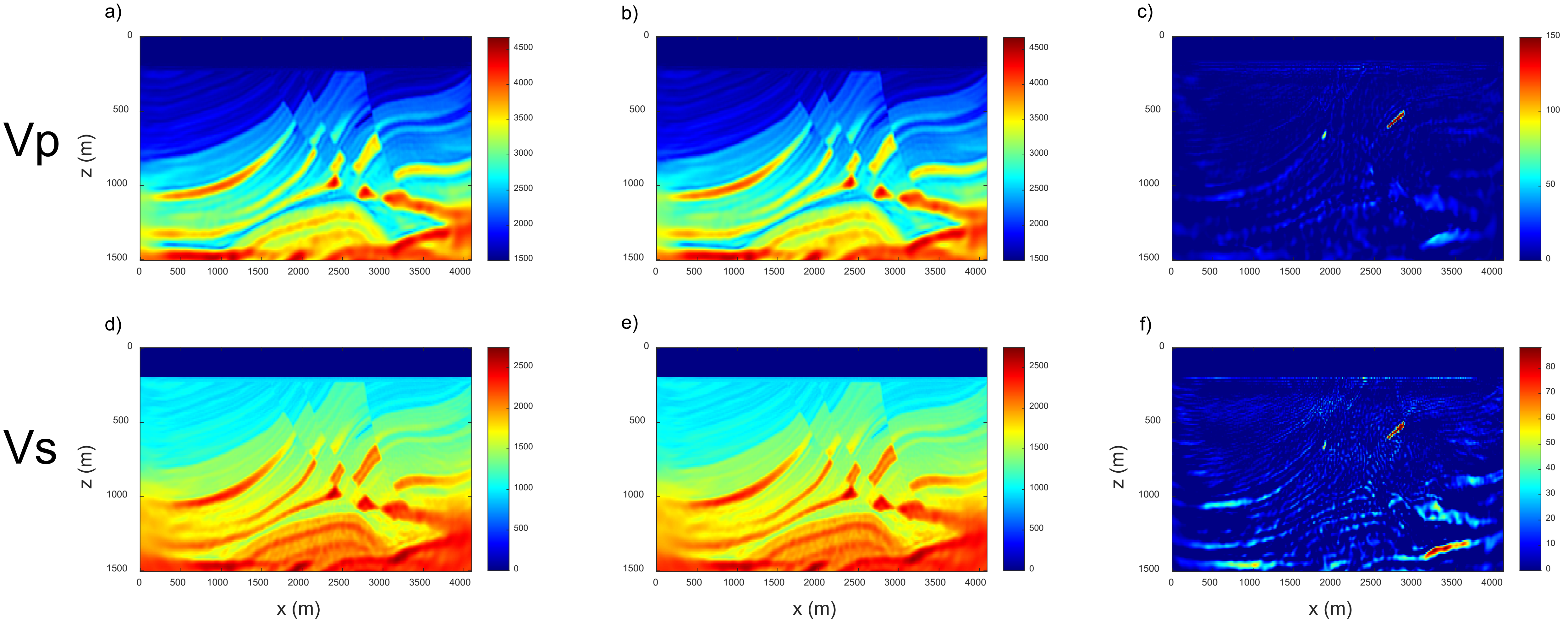


Vp

Vs

Elastic time-lapse FWI

Inversion results for time-lapse model

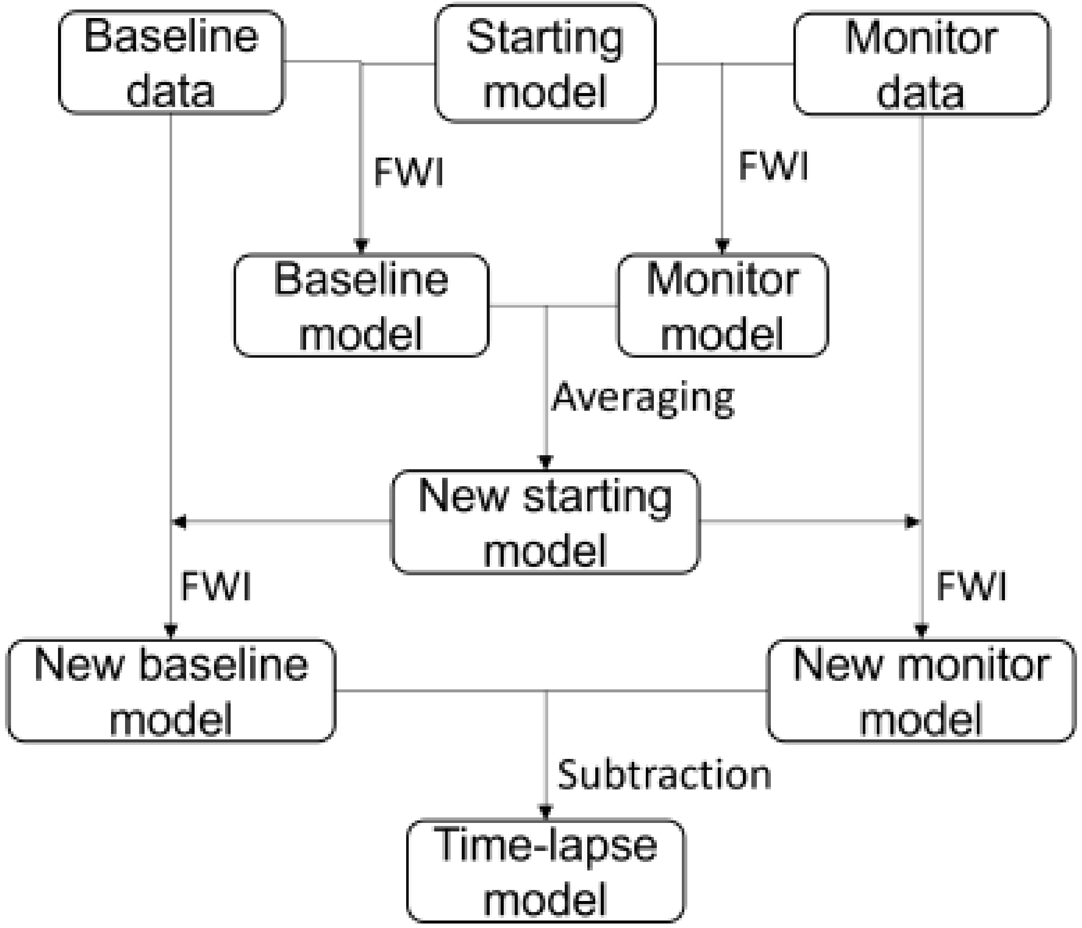


True

Initial

Time-lapse

Common-model strategy (CMS) (Hicks et al., 2016)

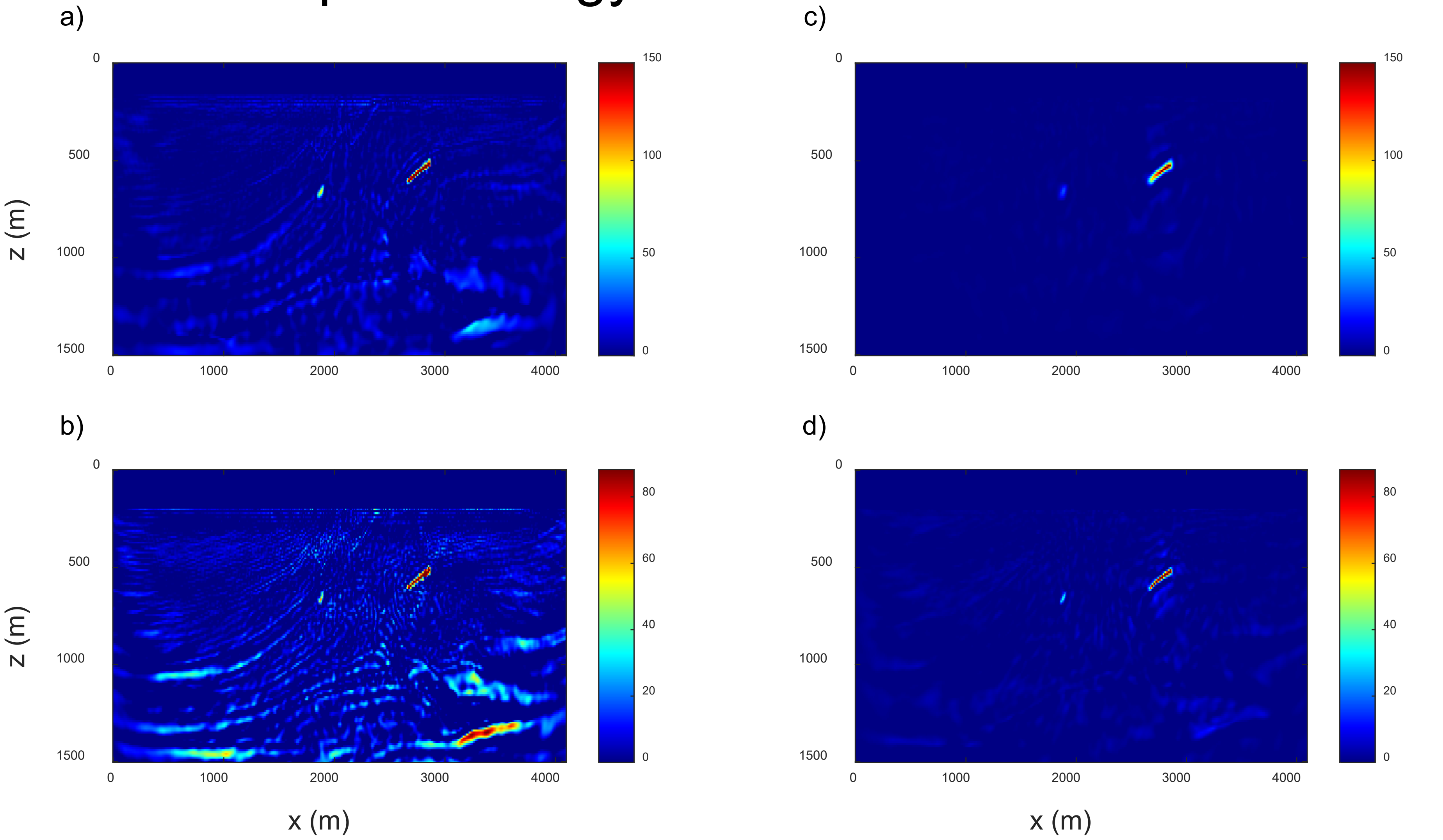


Flowchart of common-model strategy (CMS)

Comparison of time-lapse strategy

Vp

Vs



PRS

CMS

Conclusions

- We presented cyclic subsampled data-based amplitude-encoding time-lapse FWI in the time domain.
- We have applied this scheme to both acoustic and elastic time-lapse FWI, synthetic examples show that using this scheme can make the inversion process efficient with minimum sacrifices in the inversion results.
- We applied common-model strategy to elastic time-lapse FWI and obtain time-lapse models with better mitigated artifacts.

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