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Stepsize sharing in time-lapse full-waveform inversion

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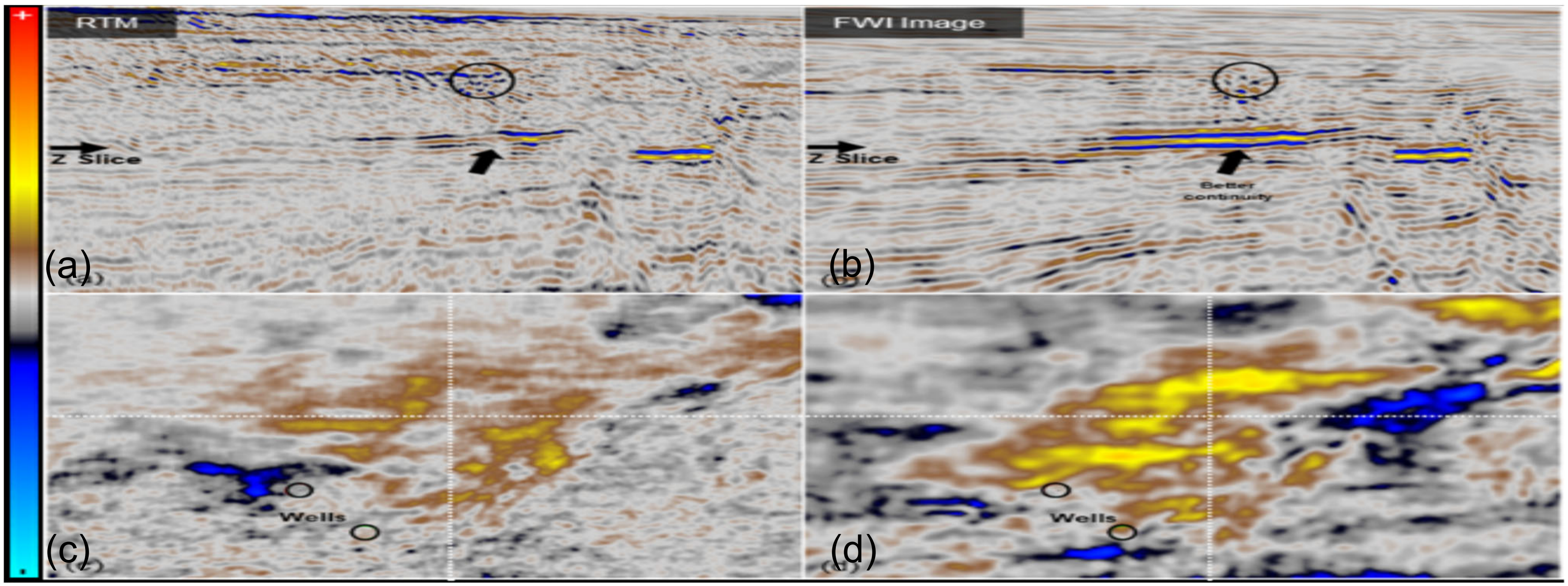
Outline

- Introduction
- Present time-lapse FWI strategies
- Stepsize sharing in time-lapse FWI
- Numerical example
- Conclusions
- Discussion

Introduction

- Enhanced oil recovery (EOR)
- CO_2 storage

Bortoni, et al., 2021



4D signal amplitudes (a) 4D 20 Hz RTM stack inline view; (b) 4D 20 Hz FWI Image inline view; (c) 4D 20 Hz RTM stack depth-slice view; (d) 4D 20 Hz FWI Image depth-slice view.

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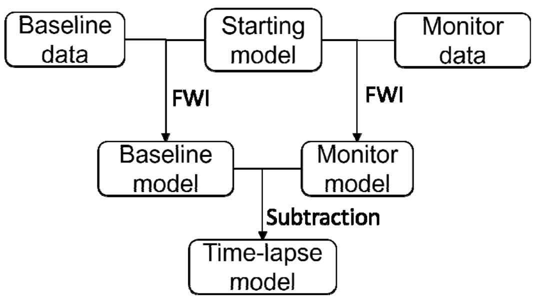
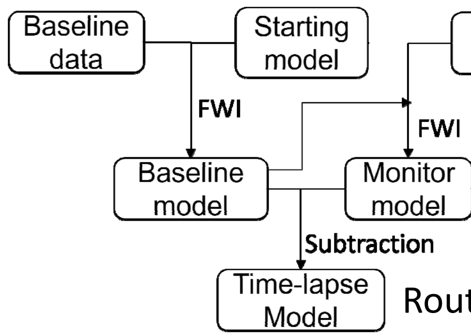
Present time-lapse FWI strategies

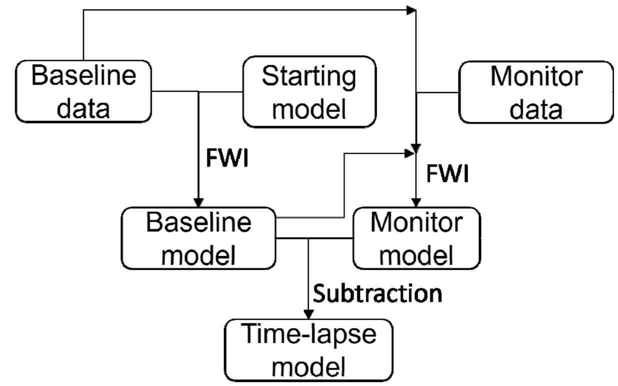


Parallel strategy (PRS)



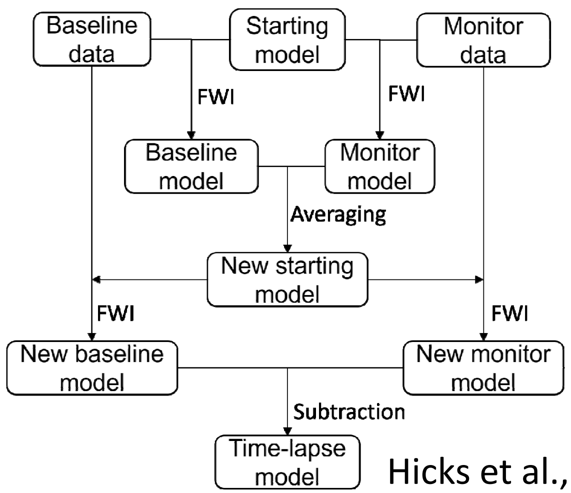
Routh et al., 2012

Sequential strategy (SQS)



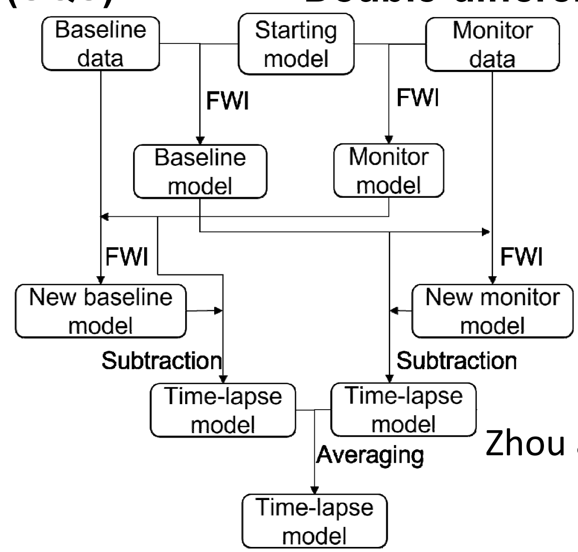
Double-difference strategy (DDS)

Zheng et al., 2011



Hicks et al., 2016

Common-model strategy (CMS)



Zhou and Lumley, 2021

Central-difference strategy (CDS)

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Stepsize sharing in time-lapse FWI

Monitor inversion: $\mathbf{m}_{mon}^{k-1}$ $\mathbf{d}_{mon,obs}$

$$\boxed{\mathbf{m}_{mon} = \mathbf{m}_{mon}^0 + \sum_{k=1}^{n} \mu_{mon}^k \mathbf{g}(\mathbf{m}_{mon,bas}^{k-1} + \mathbf{m}_{tl}^{k-1}, \mathbf{d}_{bas,obs} + \mathbf{d}_{dif})}$$

$$\mathbf{g}(\mathbf{m}_{mon,bas}^{k-1} + \mathbf{m}_{tl}^{k-1}, \mathbf{d}_{bas,obs}) \approx \mathbf{g}(\mathbf{m}_{mon,bas}^{k-1}, \mathbf{d}_{bas,obs}) + \mathbf{g}'(\mathbf{m}_{mon,bas}^{k-1}, \mathbf{d}_{bas,obs})\mathbf{m}_{tl}^{k-1}$$

$$\mathbf{m}_{mon} = \boxed{\mathbf{m}_{mon}^0 + \sum_{k=1}^{n} \mu_{mon}^k \mathbf{g}(\mathbf{m}_{mon,bas}^{k-1}, \mathbf{d}_{bas,obs})} + \sum_{k=1}^{n} \mu_{mon}^k \mathbf{g}'(\mathbf{m}_{mon,bas}^{k-1}, \mathbf{d}_{bas,obs})\mathbf{m}_{tl}^{k-1} + \sum_{k=1}^{n} \mu_{mon}^k \mathbf{g}(\mathbf{m}_{mon}^{k-1}, \mathbf{d}_{dif}).$$

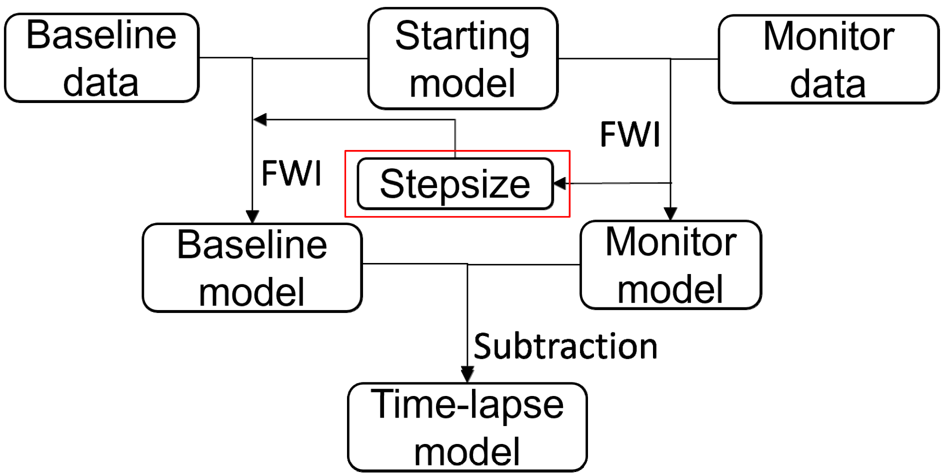
Implied baseline model:

$$\mathbf{m}_{mon,bas} = \mathbf{m}_{mon}^0 + \sum_{k=1}^{n} \mu_{mon}^k \mathbf{g}(\mathbf{m}_{mon,bas}^{k-1}, \mathbf{d}_{bas,obs})$$

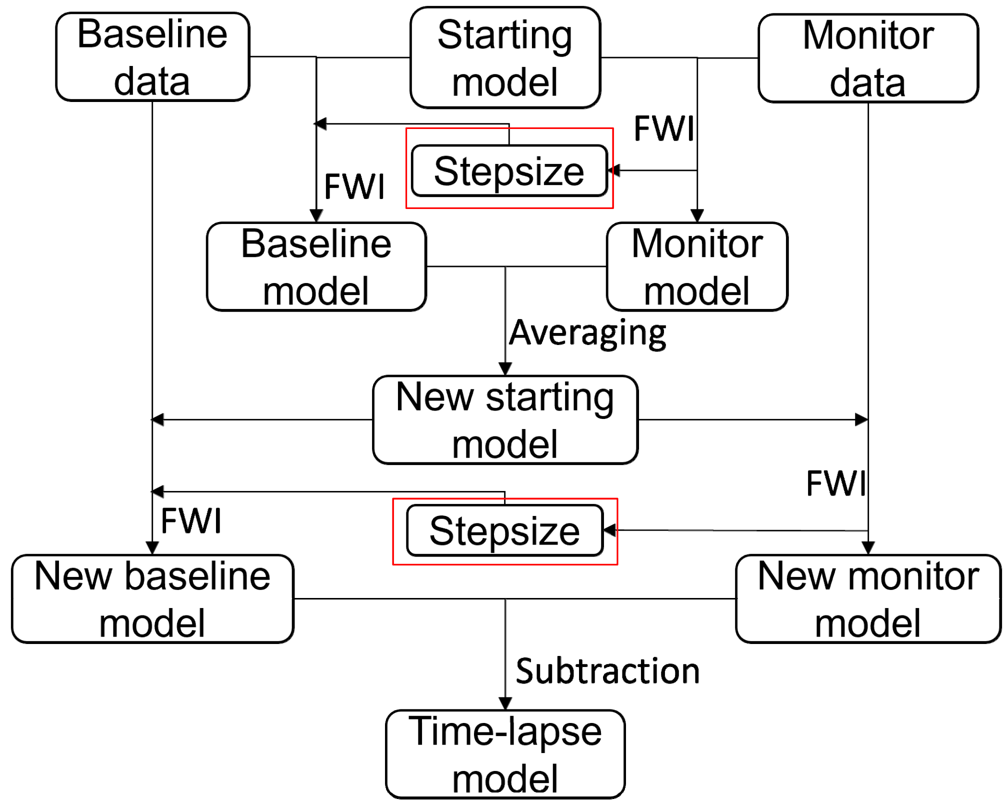
Baseline inversion:

$$\mathbf{m}_{bas} = \mathbf{m}_{bas}^0 + \sum_{k=1}^{m} \mu_{bas}^k \mathbf{g}(\mathbf{m}_{bas}^{k-1}, \mathbf{d}_{bas,obs}),$$

Stepsize sharing in time-lapse FWI



Stepsize-sharing parallel strategy (SSPRS)



Stepsize-sharing common-model strategy (SSCMS)

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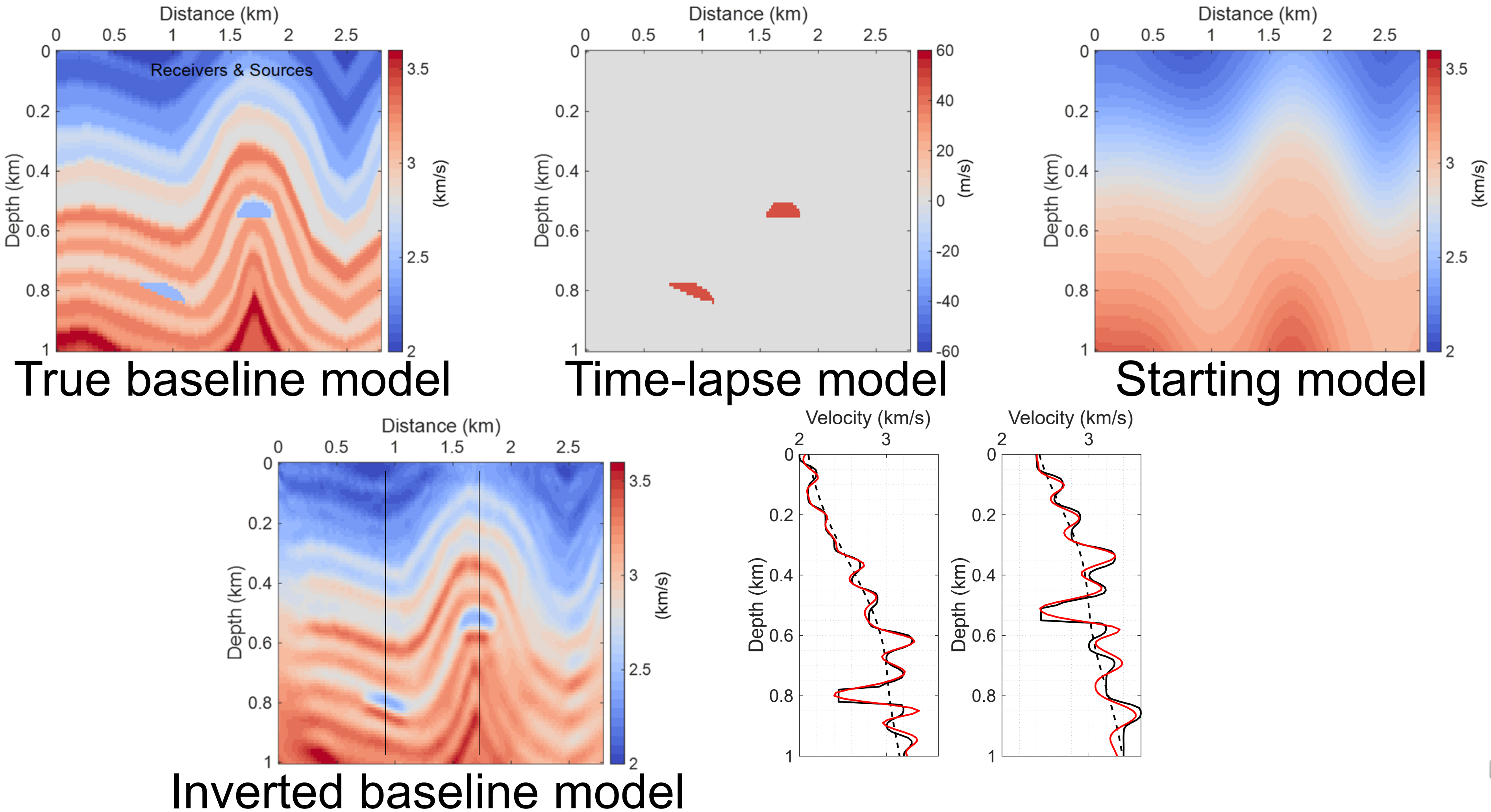
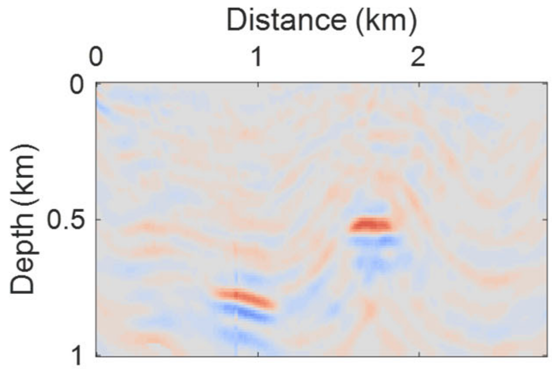
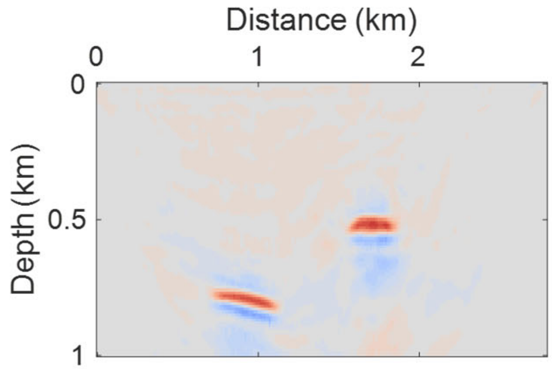
Numerical example



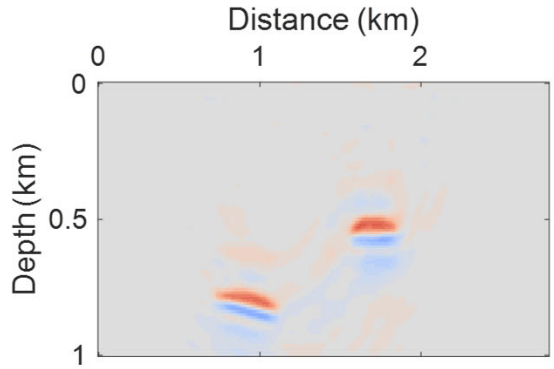
Numerical example-Noise-free and perfectly repeatable data sets



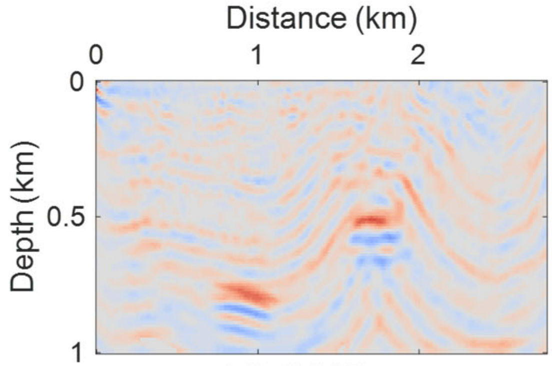
(a) PRS



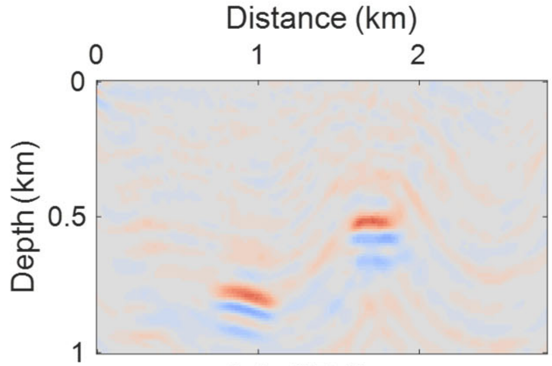
(b) SSPRS



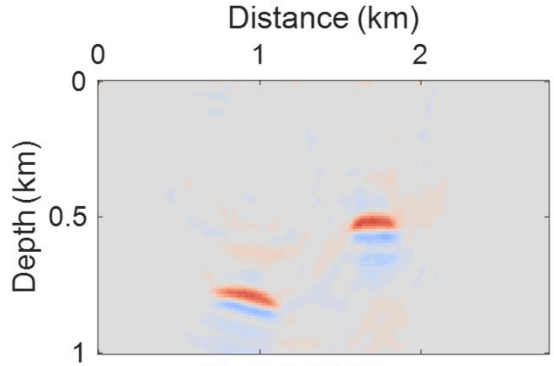
(c) DDS



(d) CMS

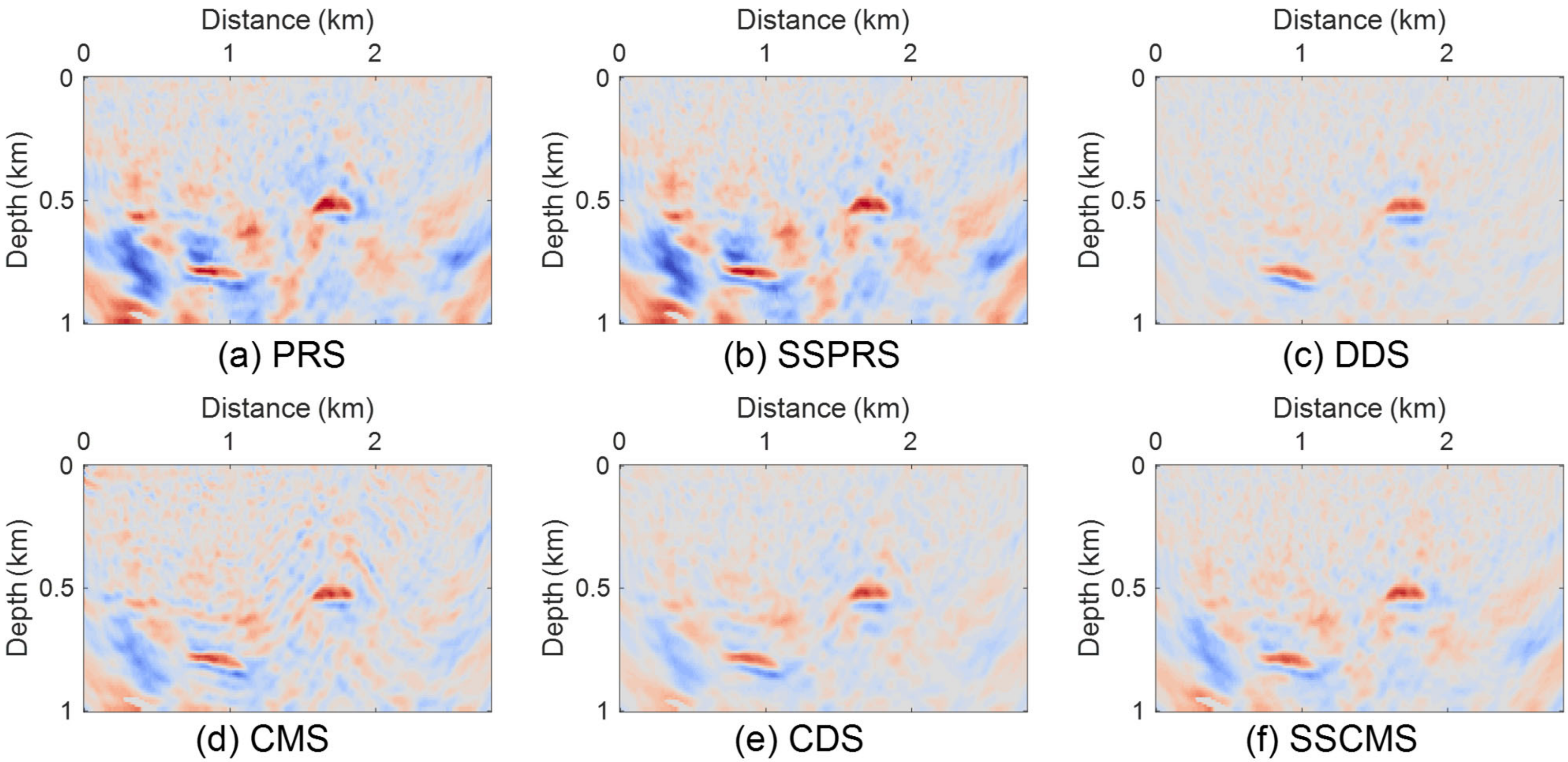


(e) CDS



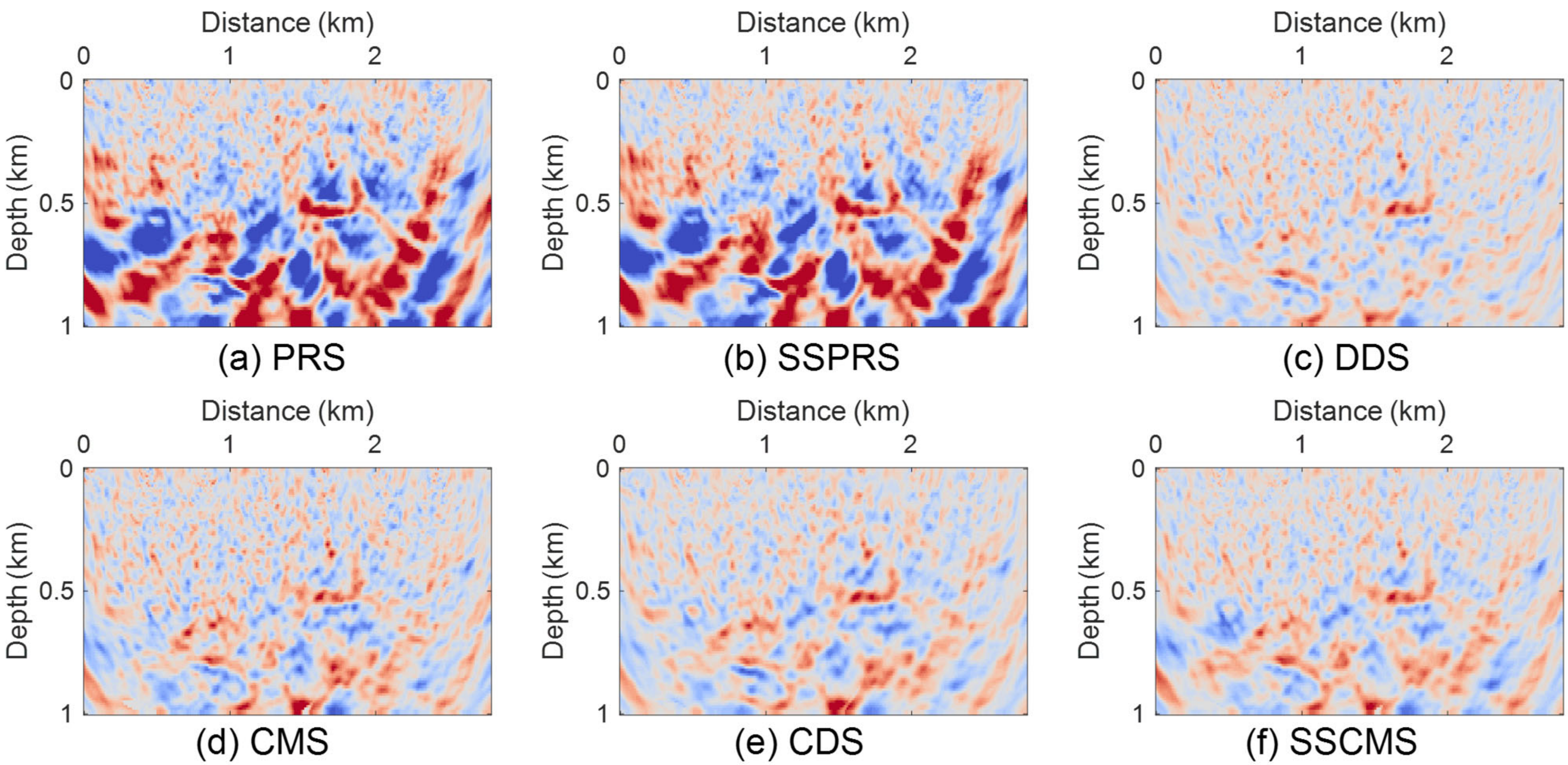
(f) SSCMS

Numerical example-Noisy data sets



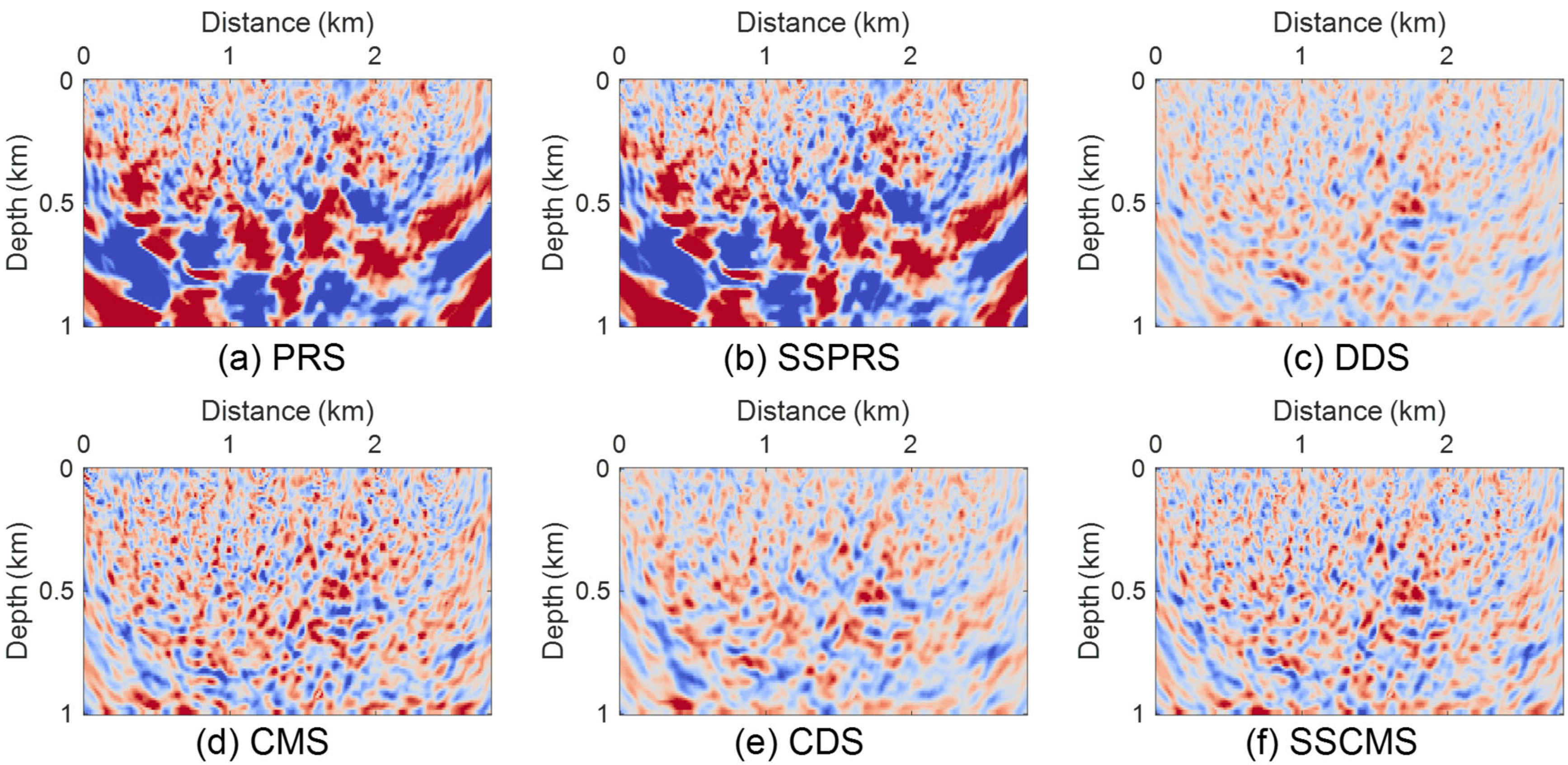
SNR=20

Numerical example-Noisy data sets



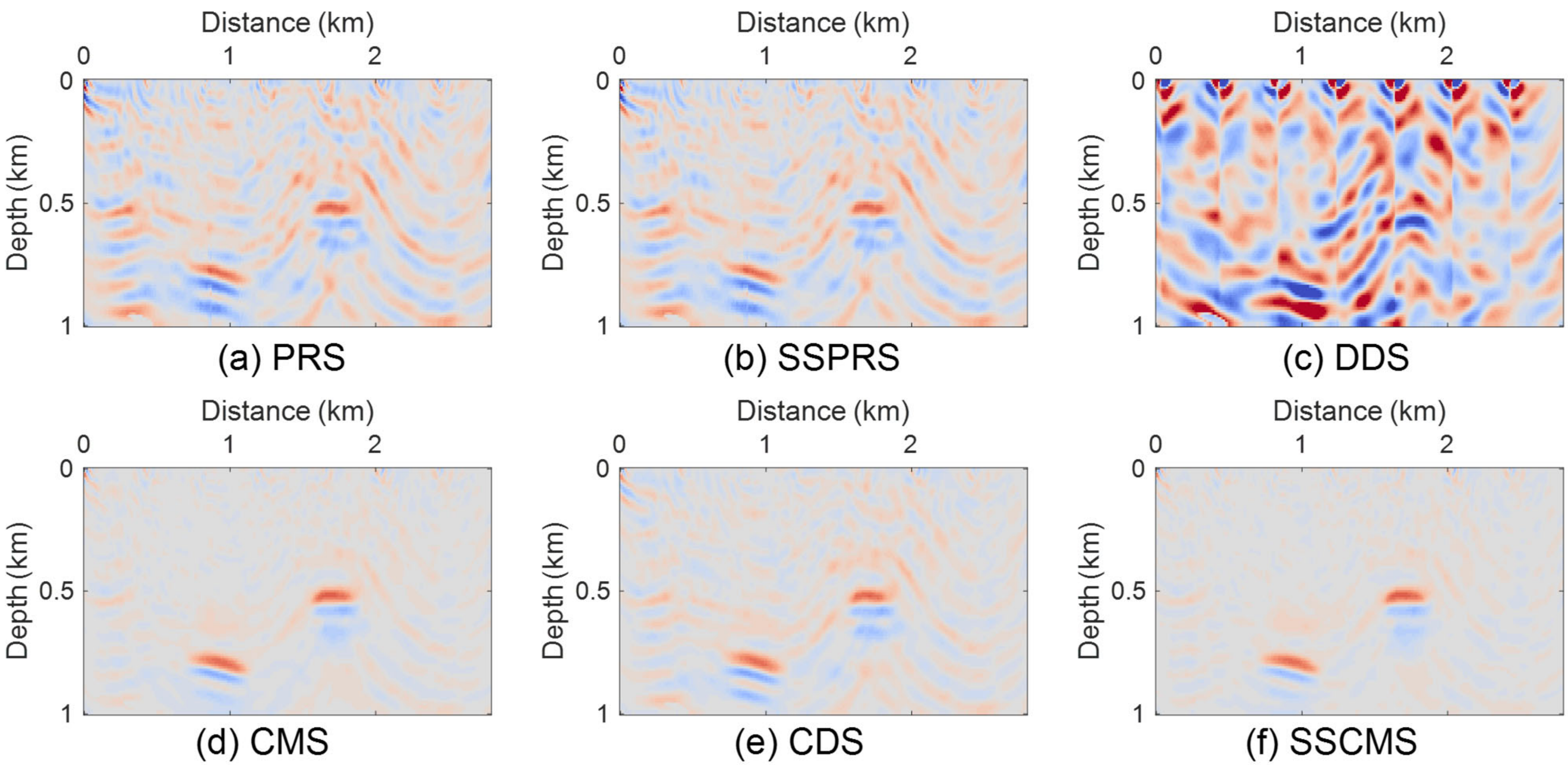
SNR=10

Numerical example-Noisy data sets



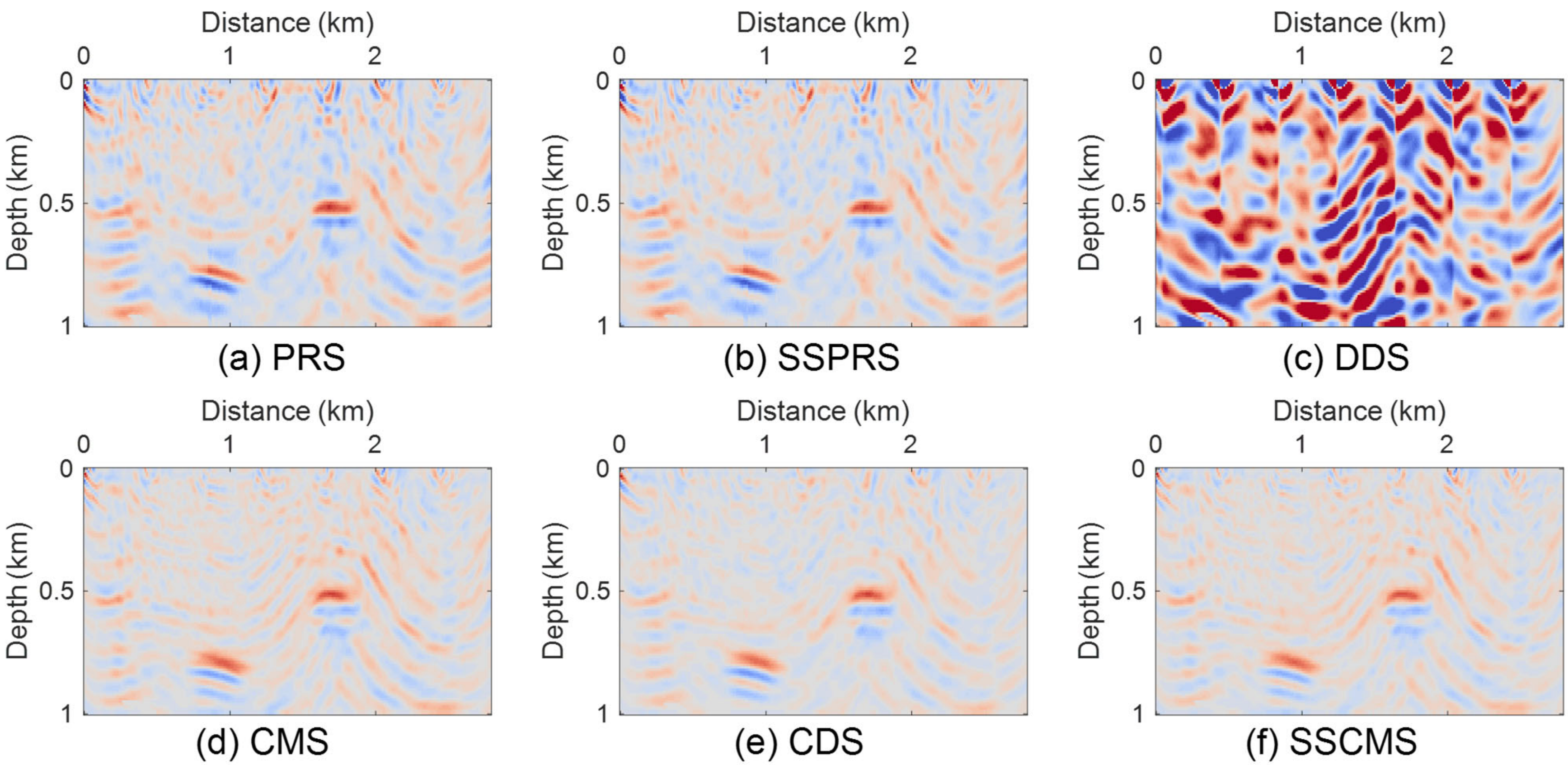
SNR=5

Numerical example-Source locations are different



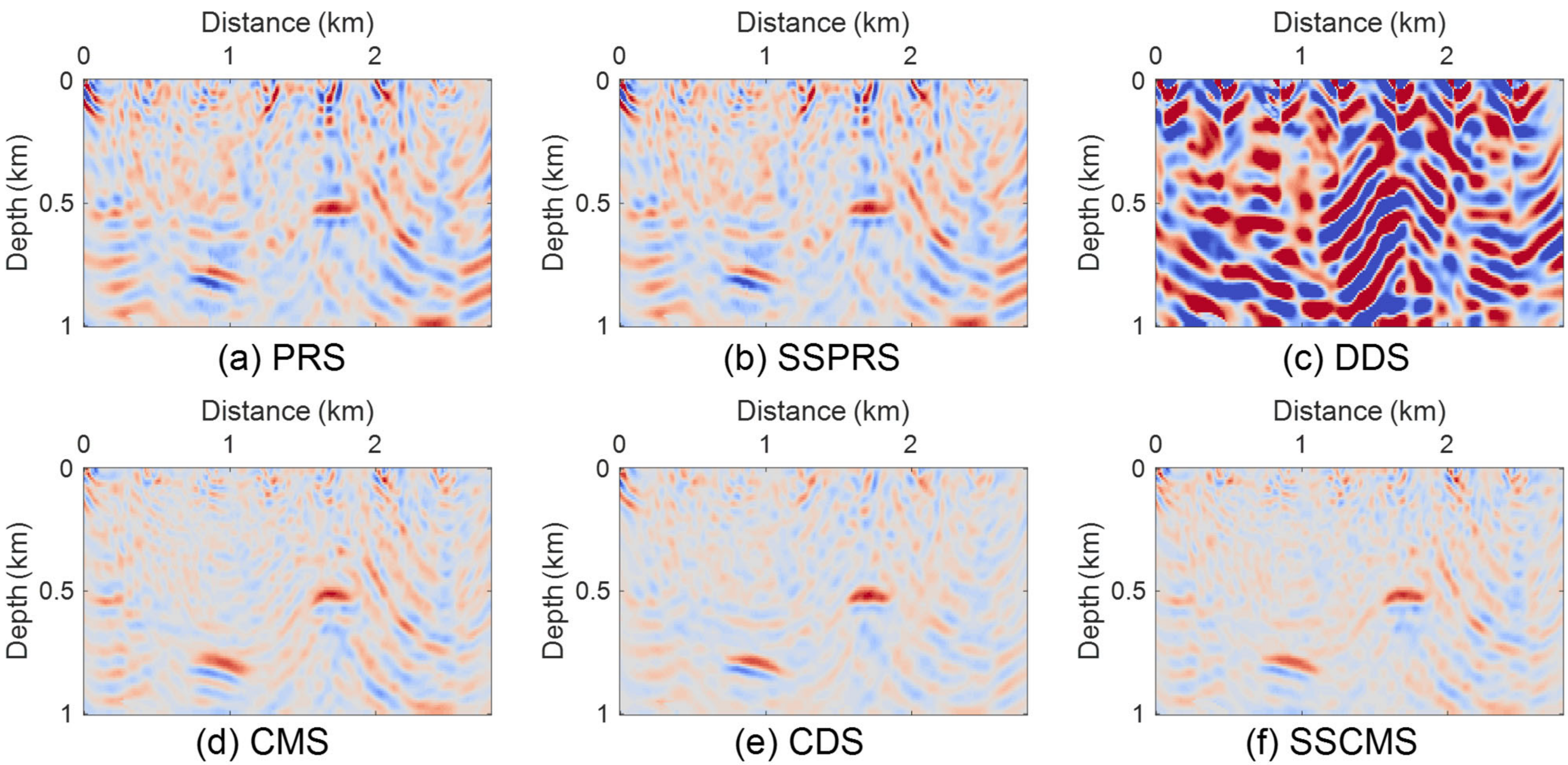
Monitor source locations are 10m larger than baseline source locations

Numerical example-Source location errors



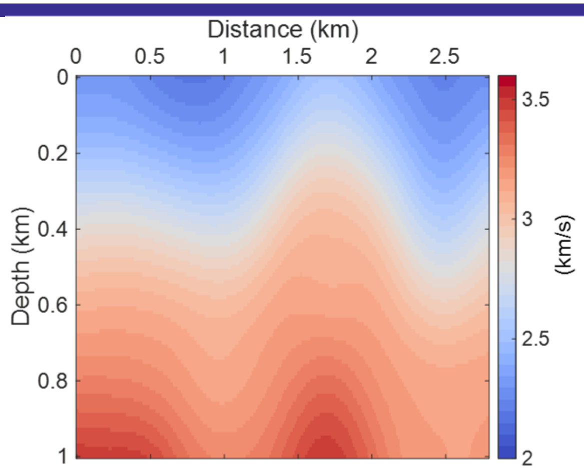
Monitor source locations are 20m larger than baseline source locations

Numerical example-Source location errors

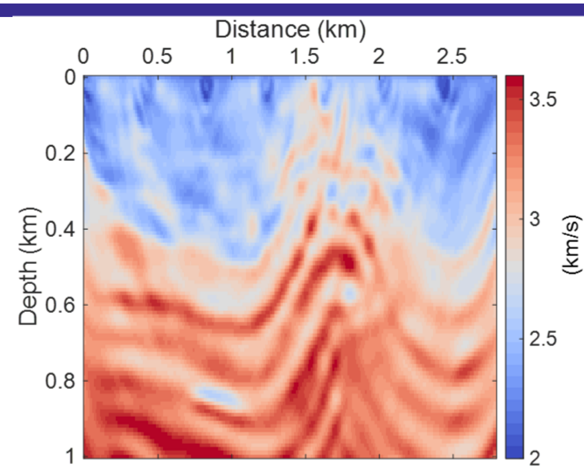


Monitor source locations are 40m larger than baseline source locations

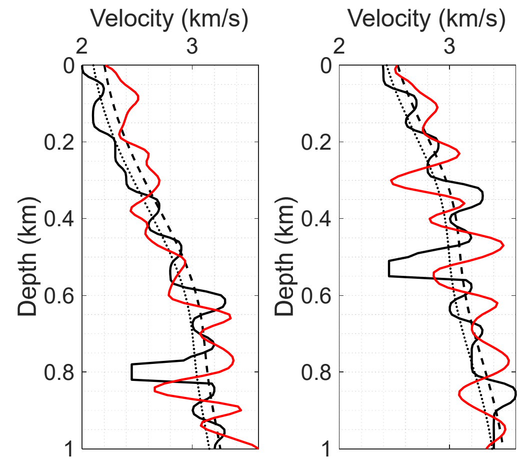
Numerical example-Biased starting models

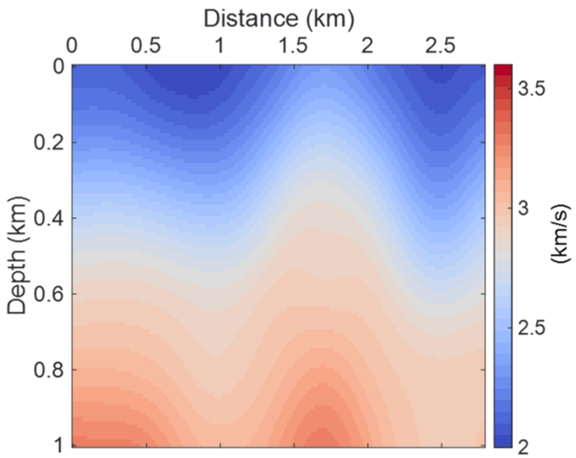


Starting model+100m/s

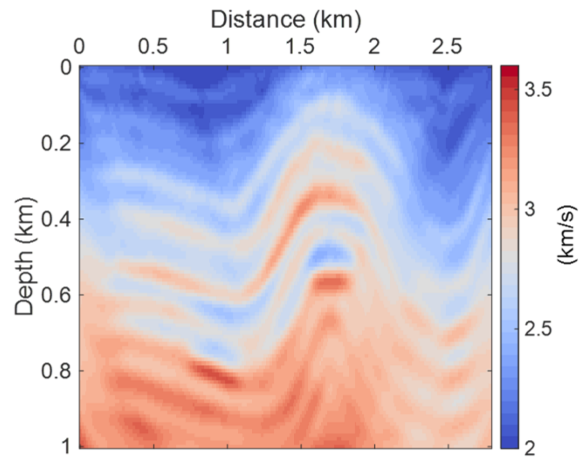


Inverted baseline model

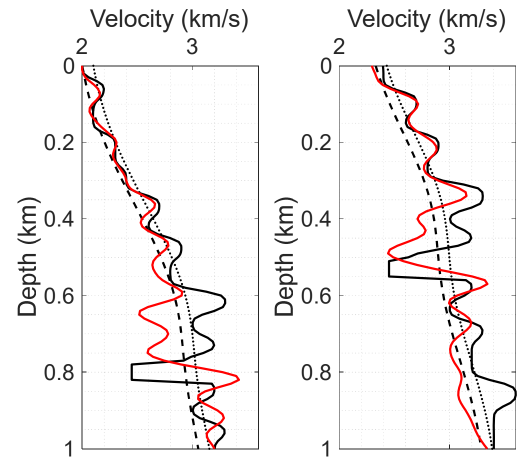




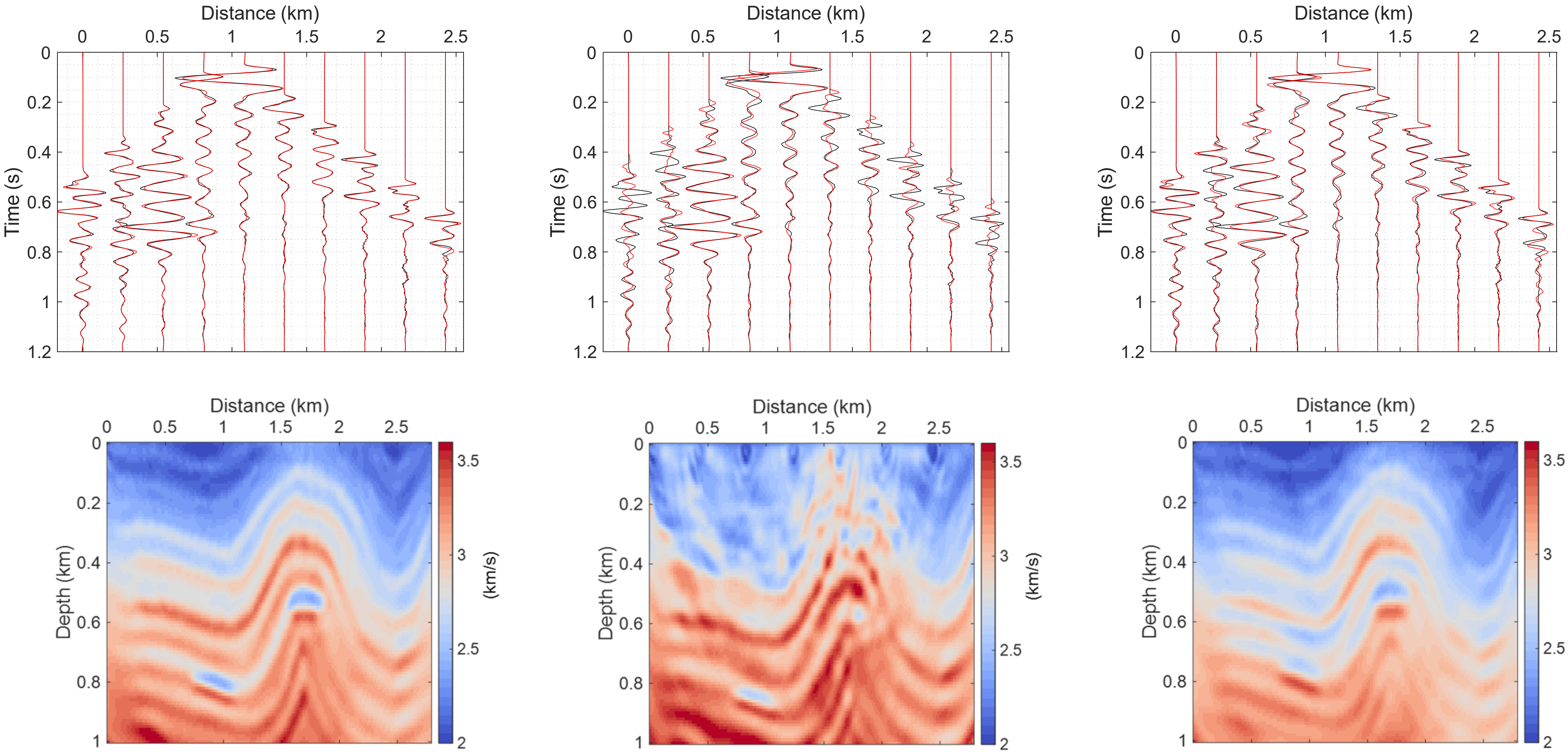
Starting model-100m/s



Inverted baseline model



Numerical example-Biased starting models data fitting

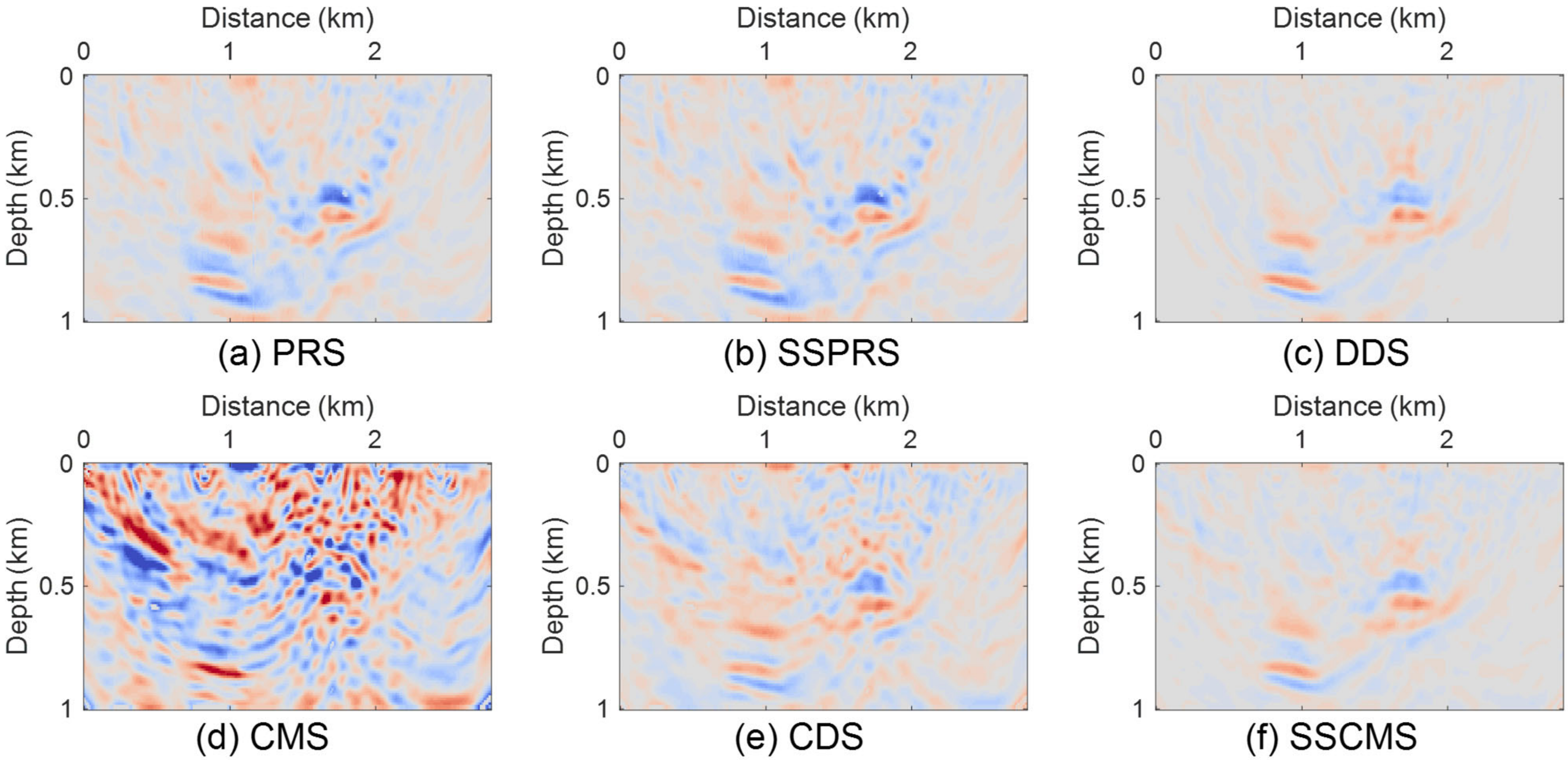


Starting model

Starting model+100m/s

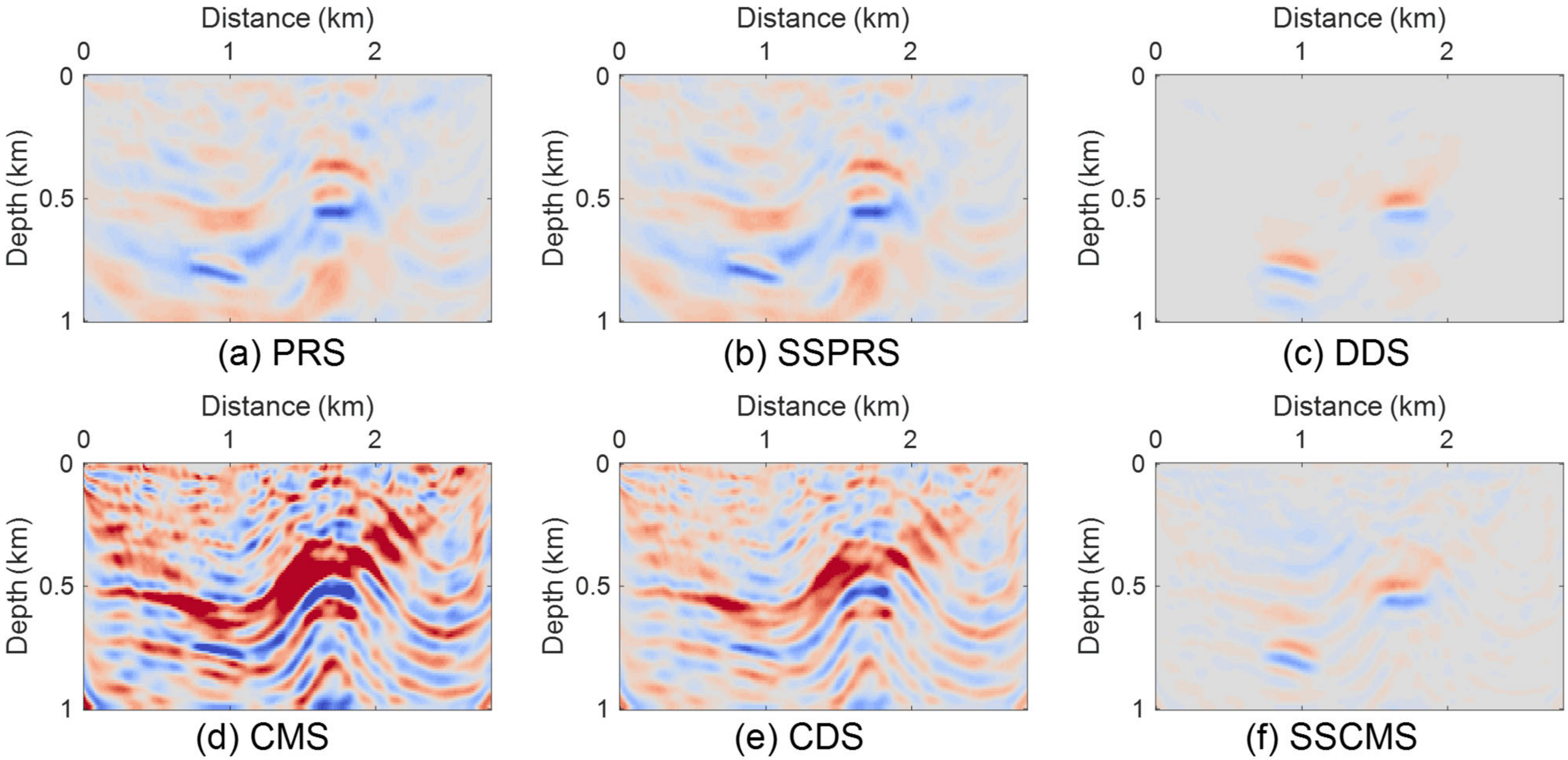
Starting model-100m/s

Numerical example-Biased starting models



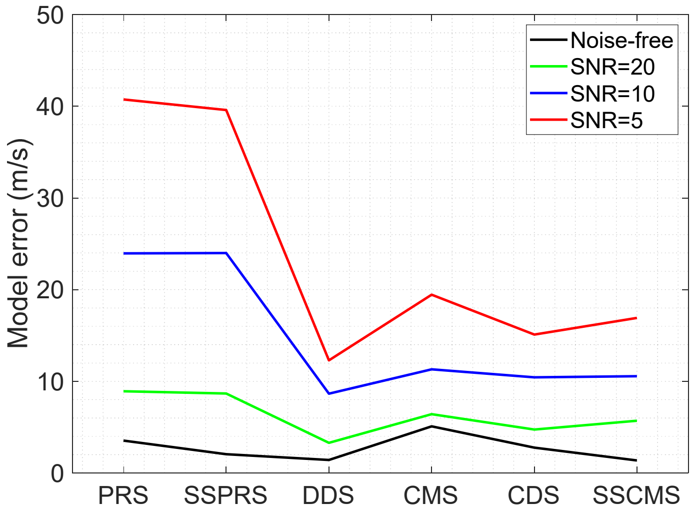
Starting model is 100m/s larger than the accurate starting model

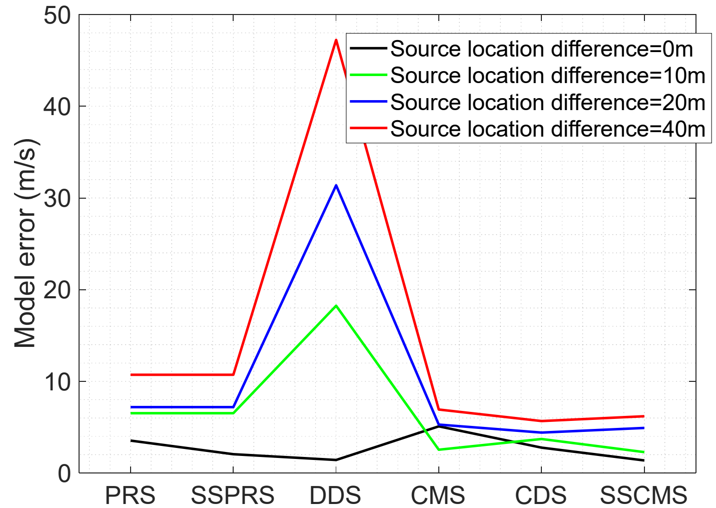
Numerical example-Biased starting models

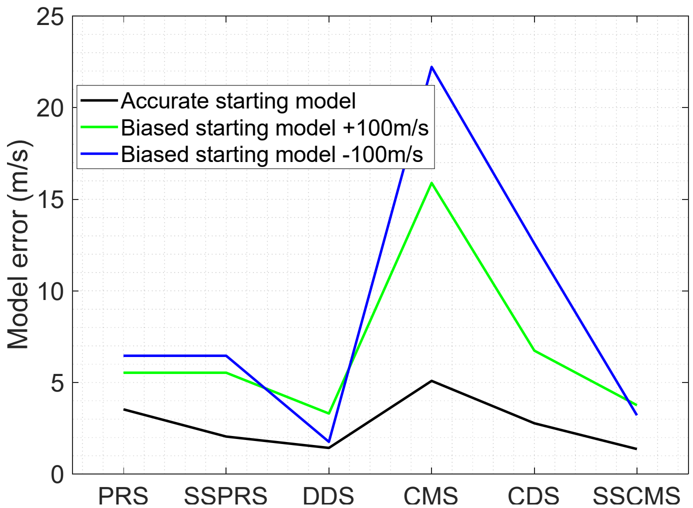


Starting model is 100m/s smaller than the accurate starting model

Numerical example-Model errors

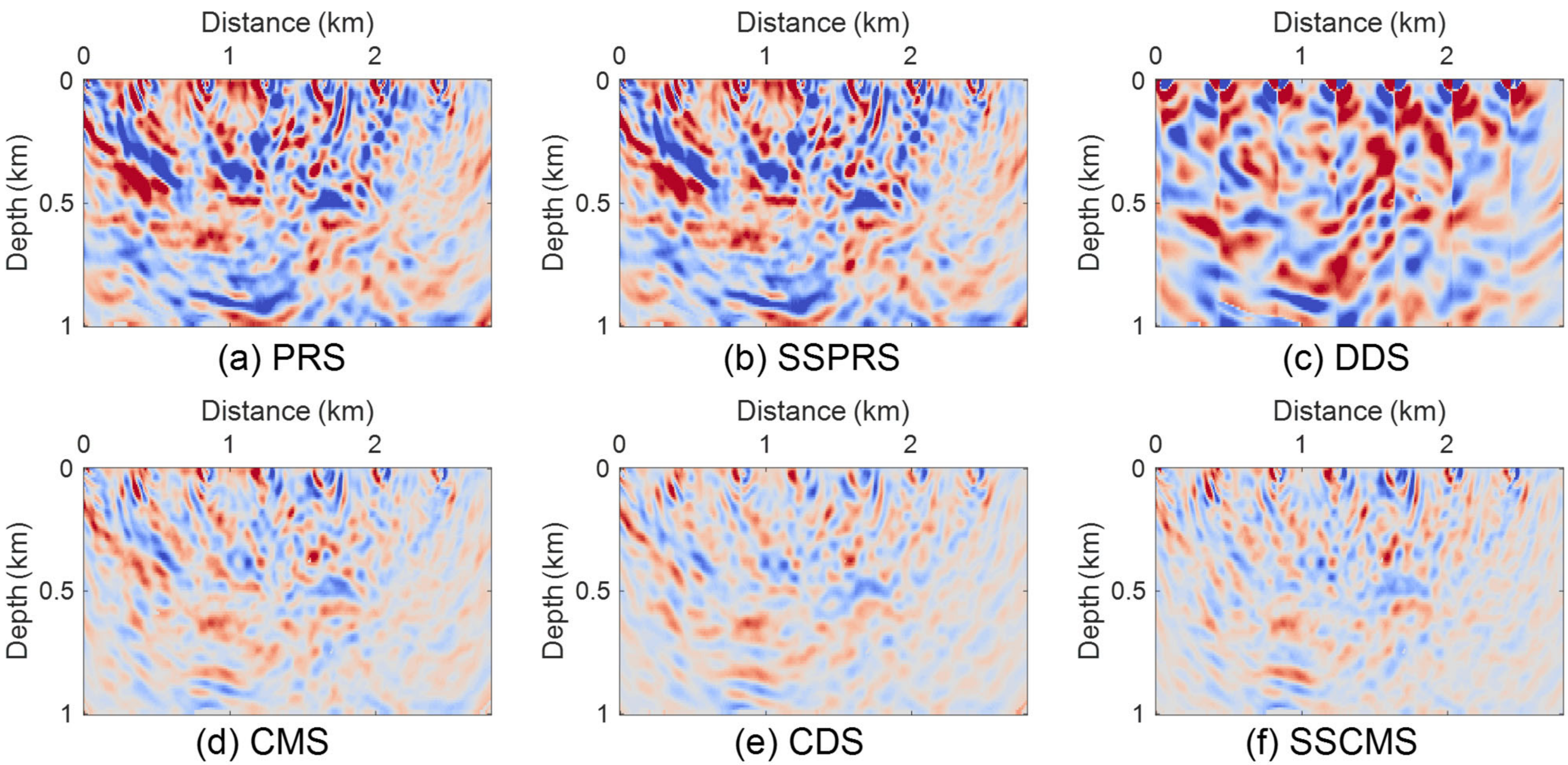






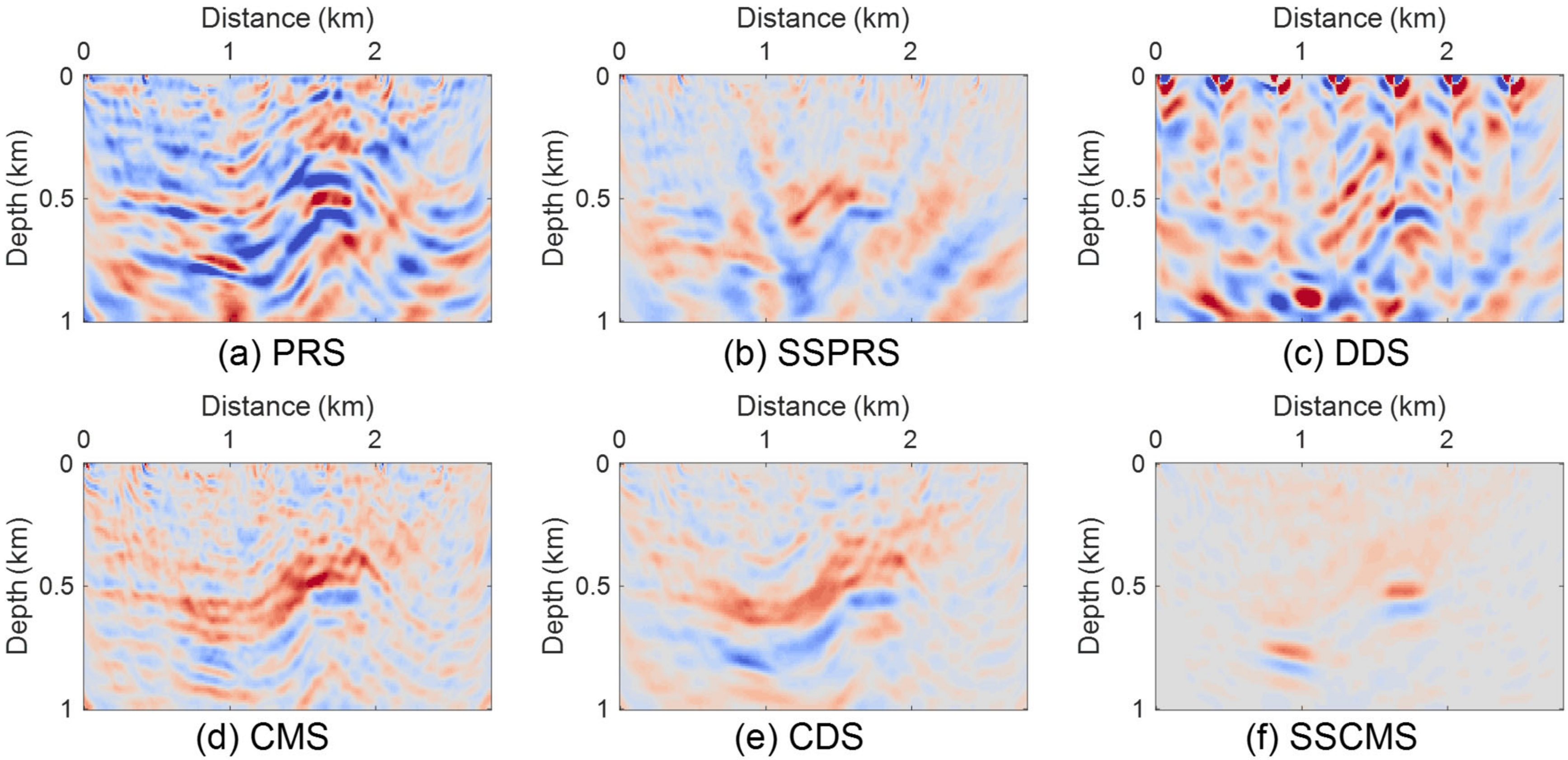
- Noise-free and perfectly repeatable:
  SSPRS DDS CDS SSCMS
- **Noisy** and identical source locations:
  DDS CMS CDS SSCMS
- Noise-free and **different in source locations**:
  CMS CDS SSCMS
- **Biased starting models**:
  DDS SSCMS

Numerical example-The case of combined conditions



- Monitor source locations are 20m larger than baseline source locations
- SNRs are 20
- Starting model is 100m/s larger than the unbiased one

Numerical example-The case of combined conditions



- Monitor source locations are 20m larger than baseline source locations
- SNRs are 20
- Starting model is 100m/s smaller than the unbiased one

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Conclusions

- The parallel strategy (PRS) has the artifacts caused by the difference of the convergences, is not noise resistant, and is sensitive to biased starting models.
- The double-difference strategy (DDS) is well applicable for the case of well-repeatable time-lapse surveys, but it is too sensitive to the difference in source locations
- The common-model strategy (CMS) cannot solve the artifacts resulting from the difference of the convergences, but can improve the anti-noise property, and is stable in unrepeatable source locations, but fails in the case of biased starting model.
- The central-difference strategy (CDS) has good performance in the cases of noisy data and non-repeatable source locations, also can decay the artifacts resulting from the difference of the convergences in some degree, but it fails in the case of biased starting model too.
- The stepsize-sharing common-model strategy (SSCMS) has good performance on reducing the artifacts caused by the convergences difference, noisy data, non-repeatable source locations, and biased starting models. It may as a potential strategy for real field data inversion.
- Biased starting models can mislead the interpretation of inversion results .

Discussion

- In this study, elastic effects are not considered.
- Only the land model is discussed, things could be different in the marine model, such as water level and/or velocity change.
- The surface change could happen in different seasons on the land.
- Source wavelets' non-repeatability will also be tested in the future study.

Acknowledges

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Thank you!