Trans-dimensional multimode surface wave inversion of DAS data at the CaMI-FRS

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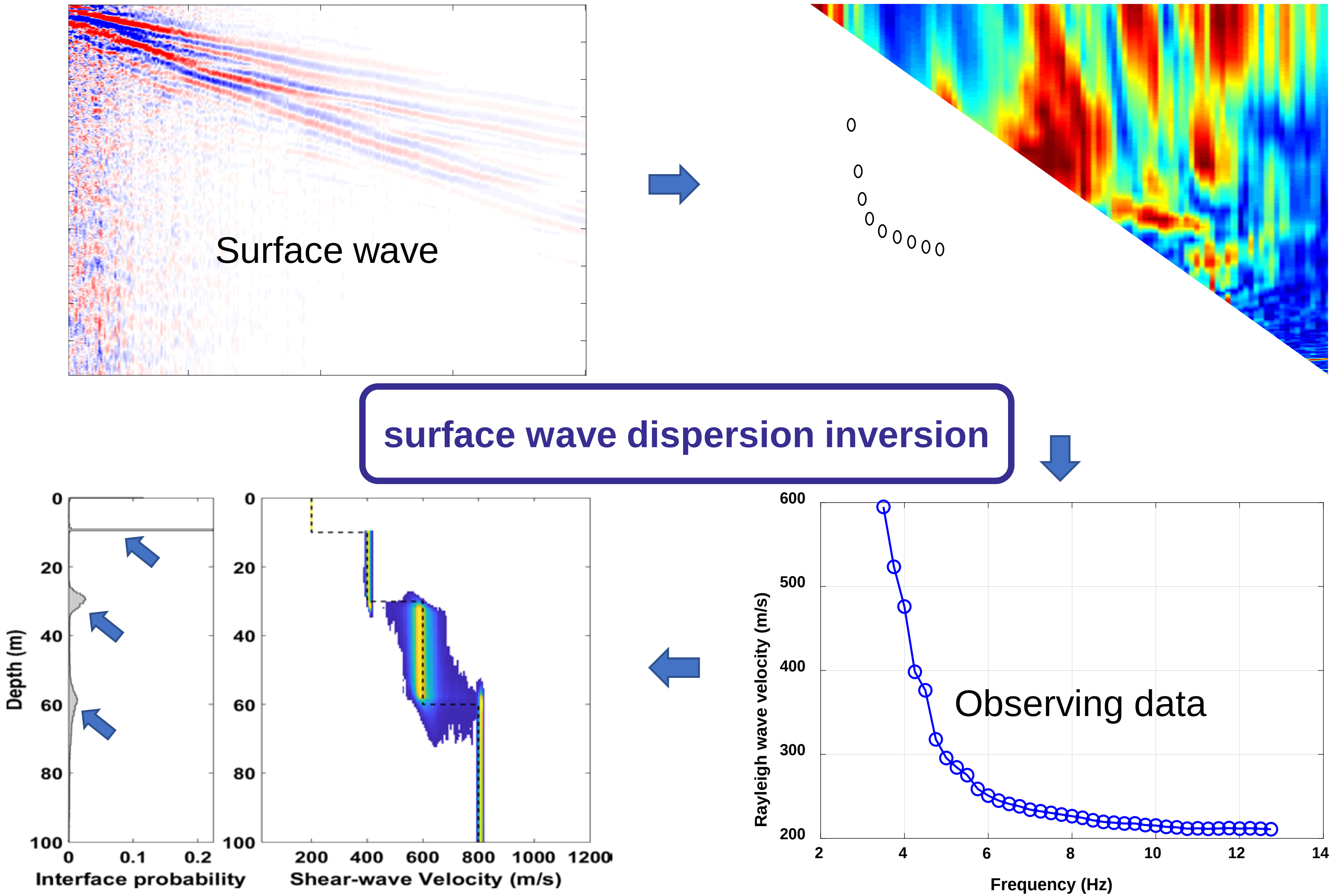
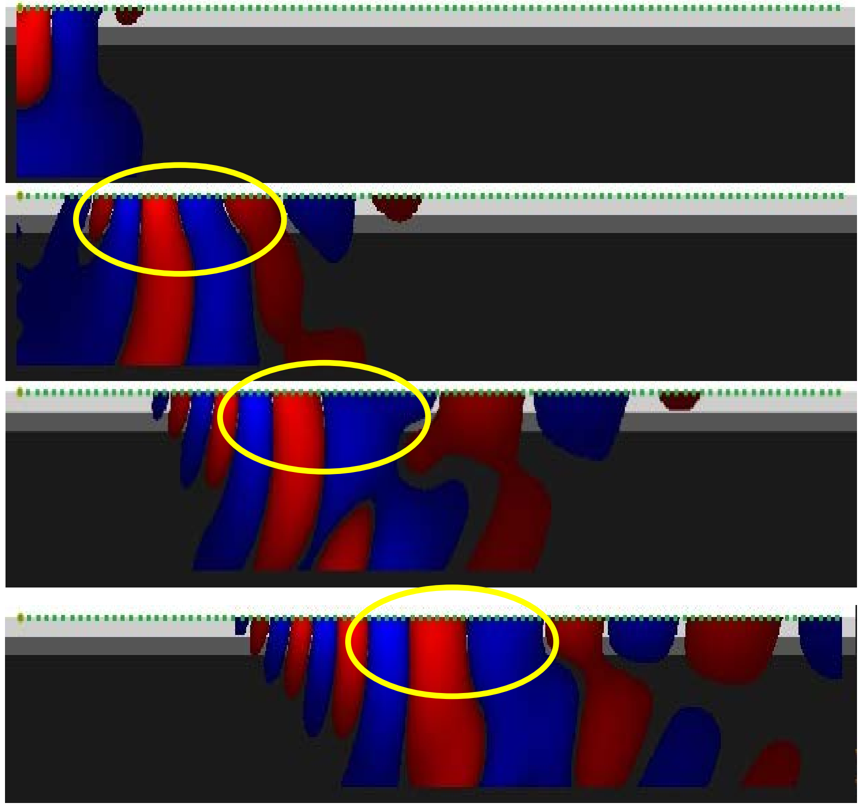
General workflow

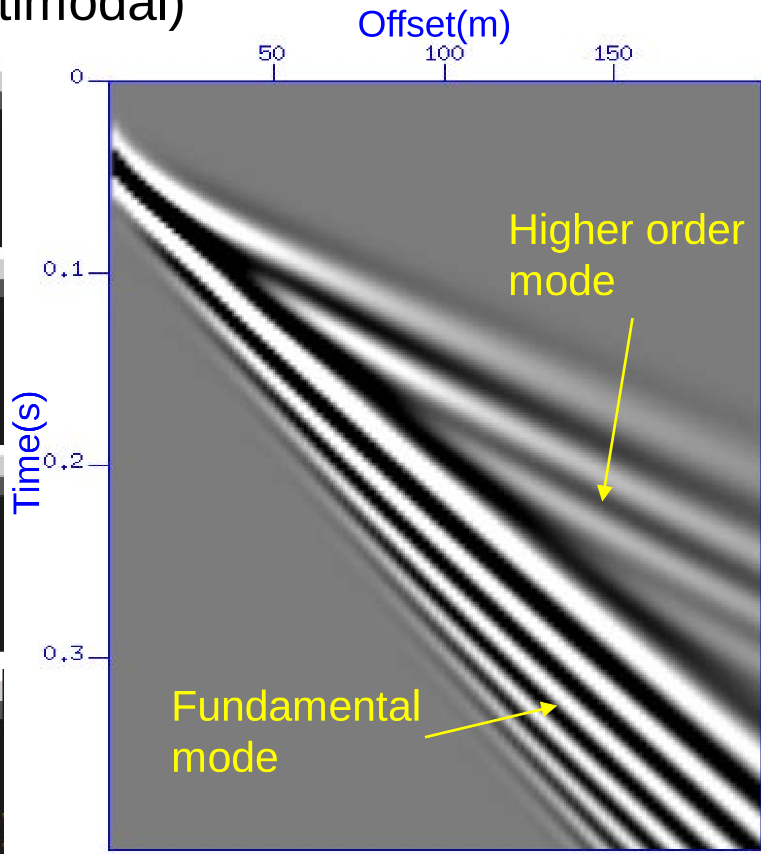


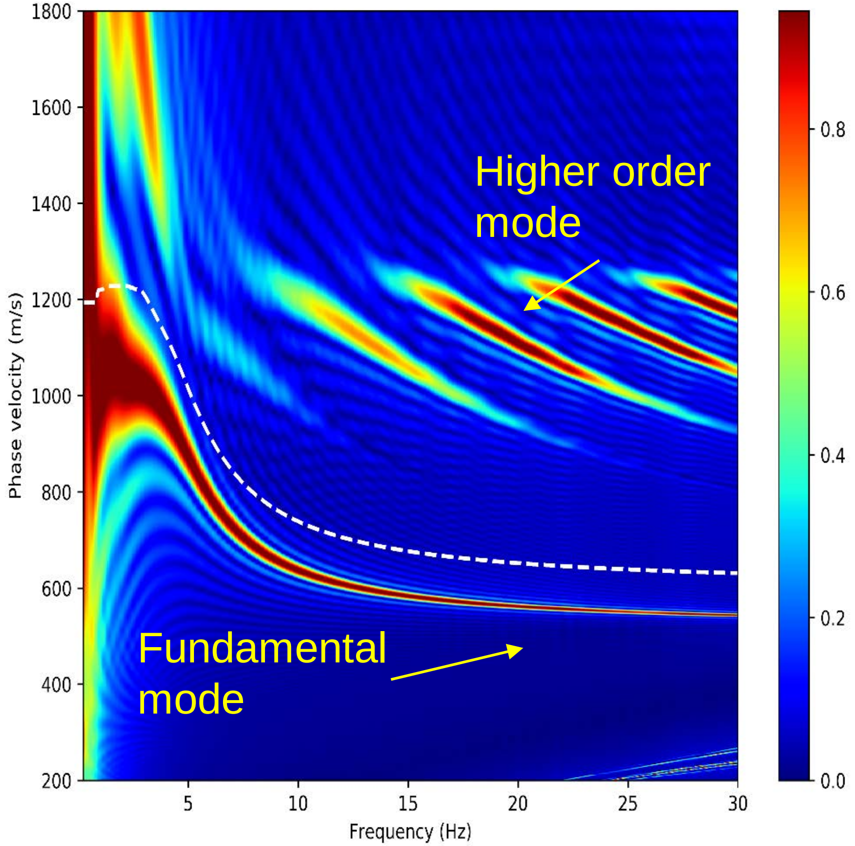
Introduction

Introduction

Rayleigh wave (Dispersive and Multimodal)





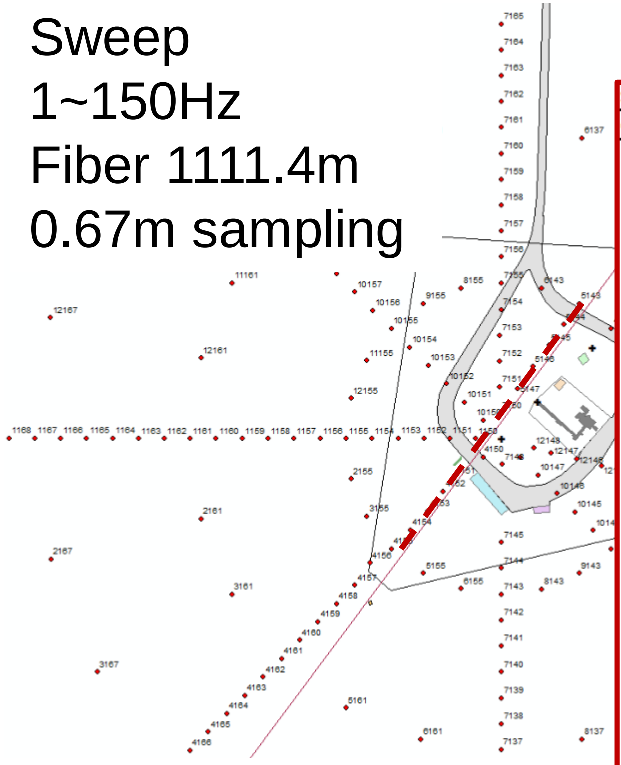


Goals of surface wave study:

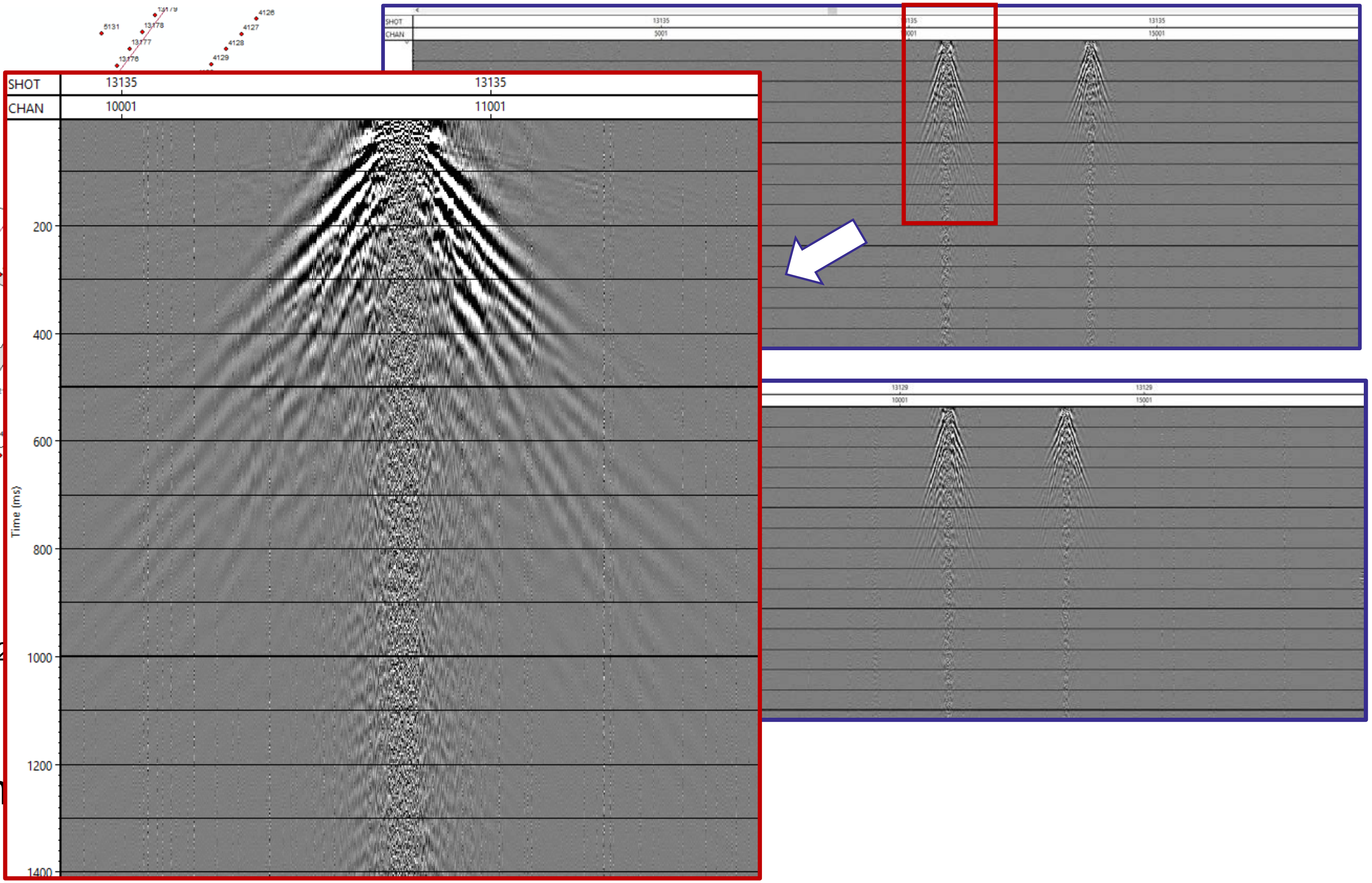
- Surface wave removal
- Invert for shear wave velocity in shallow site

DAS data

2018 DAS data
Sweep
1~150Hz
Fiber 1111.4m
0.67m sampling



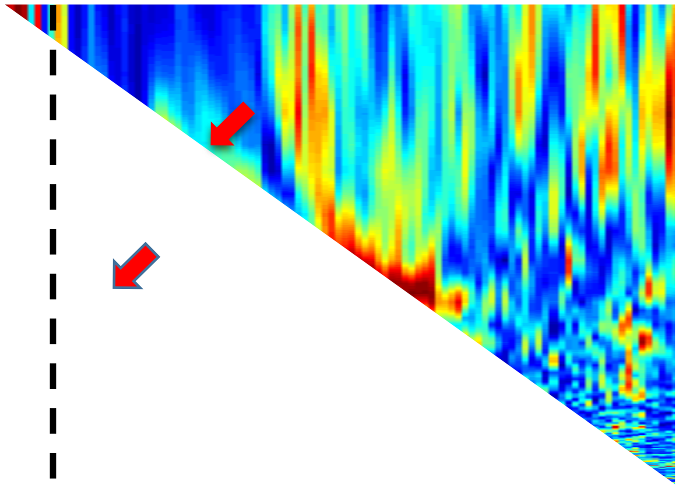
(Hall and Lawton, 2



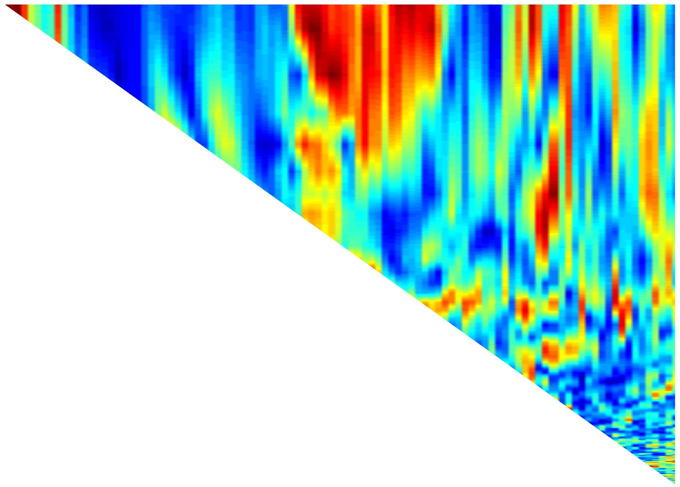
Wavefield sensing
No alias with dense sam

DAS data

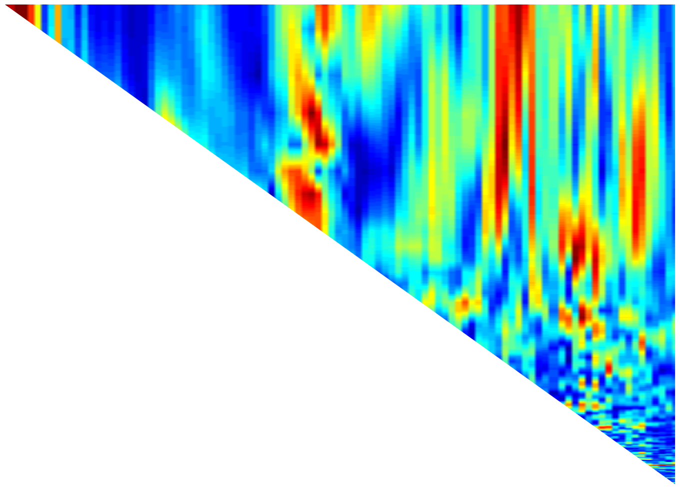
Shot 4151(Straight line fiber)



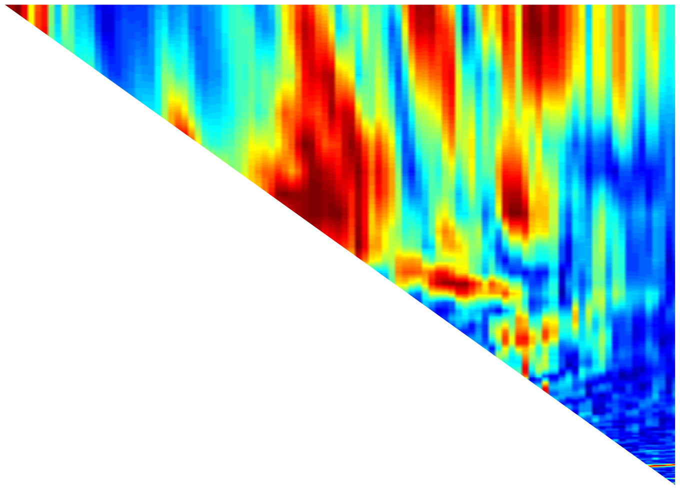
Shot 4152(Straight line fiber)



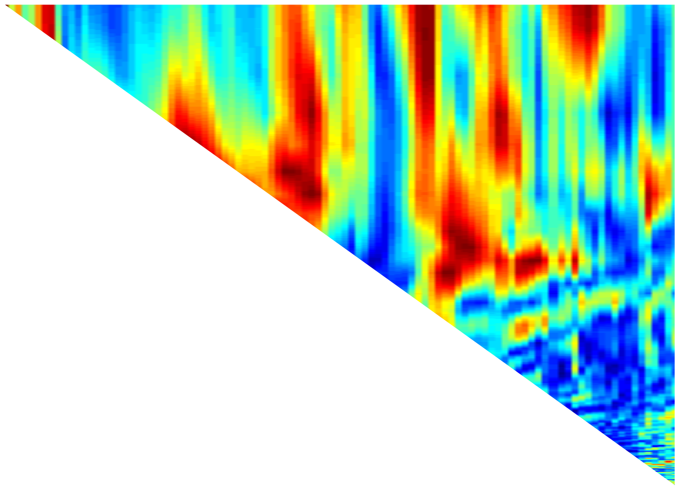
Shot 4153(Straight line fiber)



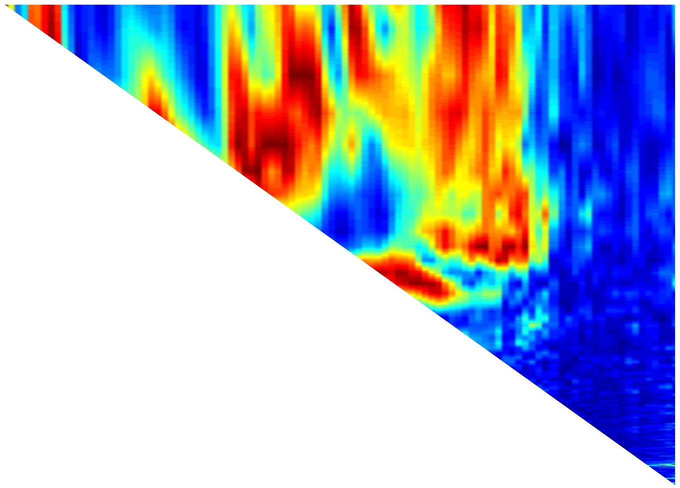
Shot 4155(Straight line fiber)



Shot 4156(Straight line fiber)

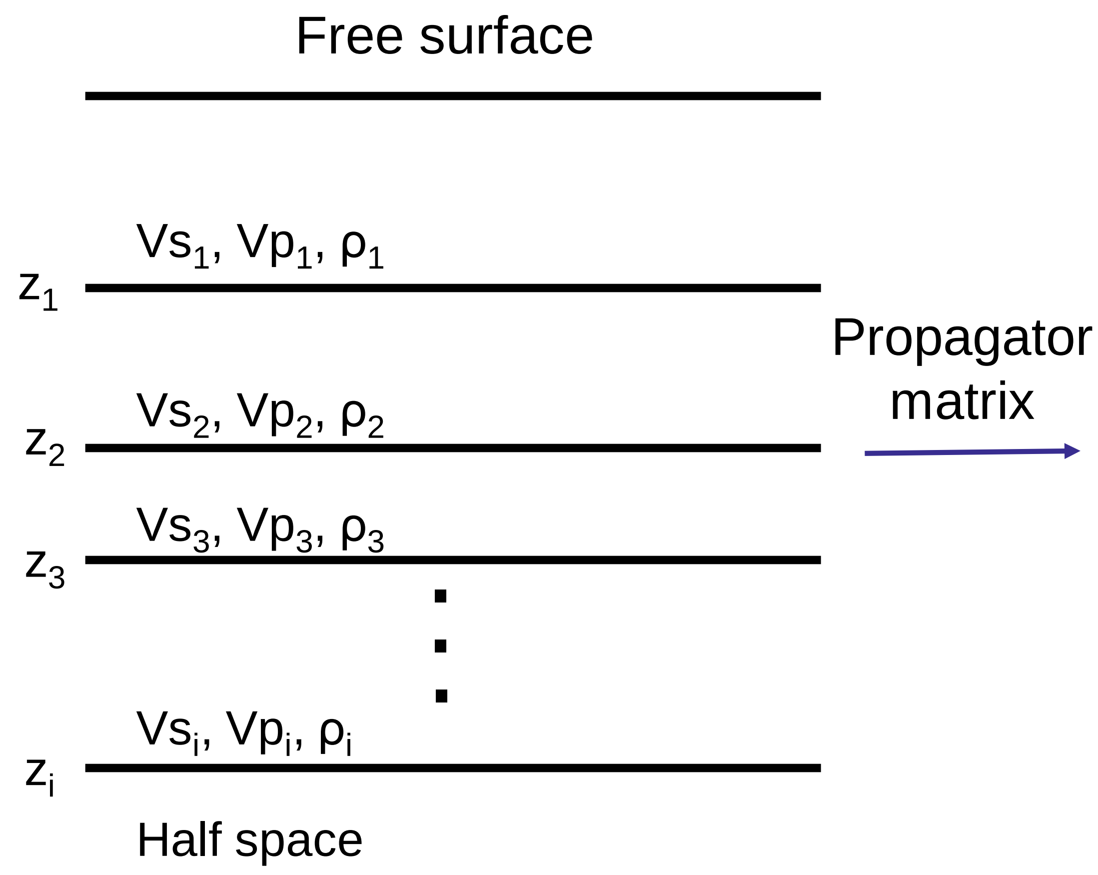


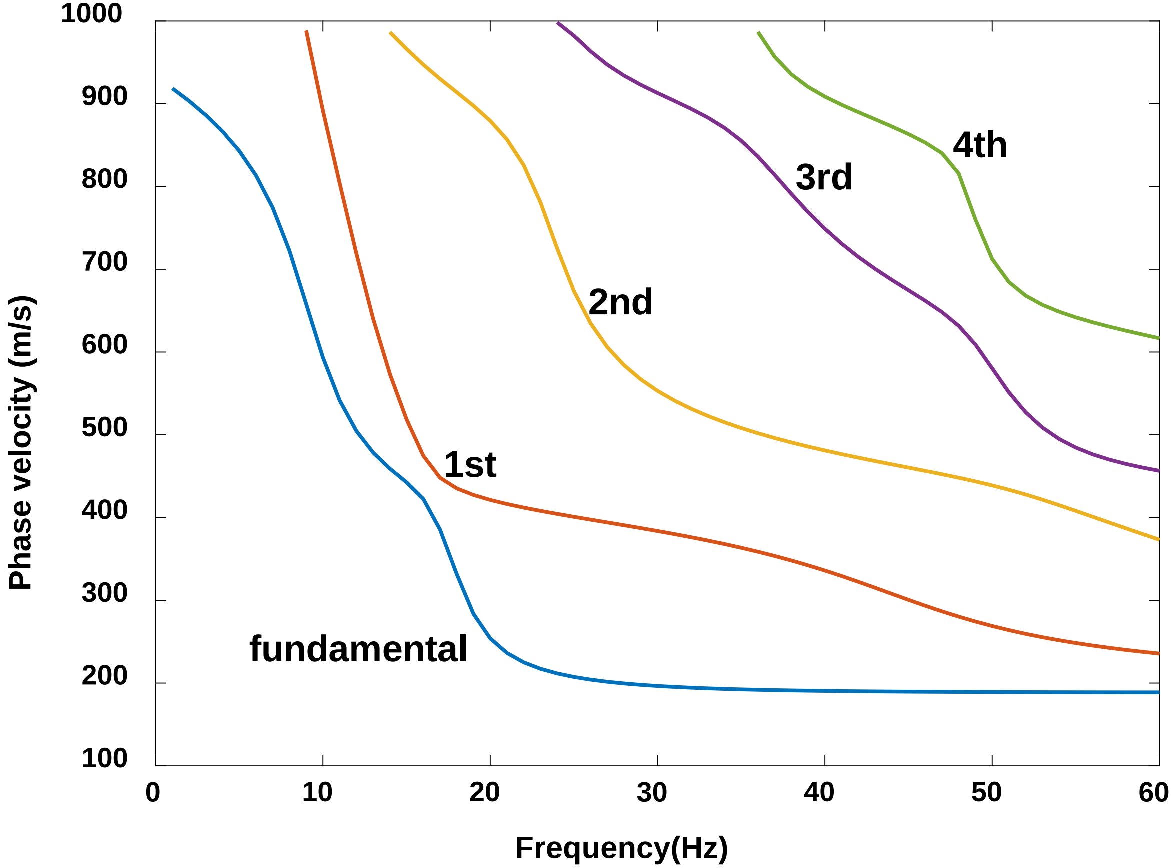
Shot 7150(Straight line fiber)



Methodology

Forward modeling





- Dispersion curves are sensitive to S wave velocity and thickness parameters, but not sensitive to P wave velocity and density parameters.
- GPDC(Wathelet, 2002)

Inversion method

Bayesian based **Trans-Dimensional** inversion method

Model size (Layer number ***k***) is unknown and perturbed in the inversion,

$$P(\mathbf{m}|\mathbf{d}) = \frac{P(\mathbf{d}|\mathbf{m})\,P(\mathbf{m})}{P(\mathbf{d})}.$$

$$P(k, \mathbf{m}_k|\mathbf{d}) = \frac{P(k)\,P(\mathbf{d}|k, \mathbf{m}_k)\,P(\mathbf{m}_k|k)}{\sum_{k' \in \mathcal{K}} \int_{\mathcal{G}} P(k')\,P(\mathbf{d}|k', \mathbf{m}'_{k'})\,P(\mathbf{m}'_{k'}|k')\,d\mathbf{m}'_{k'}}.$$

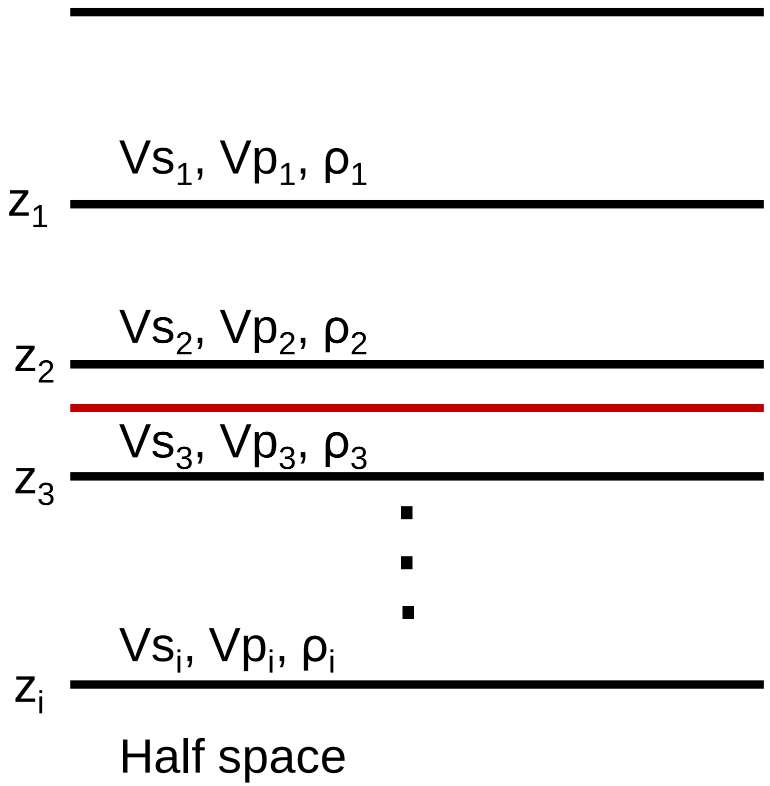
A **birth-death scheme** is used to perturb the layer number ***k.***

(Dettmer, 2012)

Inversion method

Bayesian based **Trans-Dimensional** inversion method

Model size (Layer number ***k***) is unknown and perturbed in the inversion,



Perturb: *k'=k;* 1/6

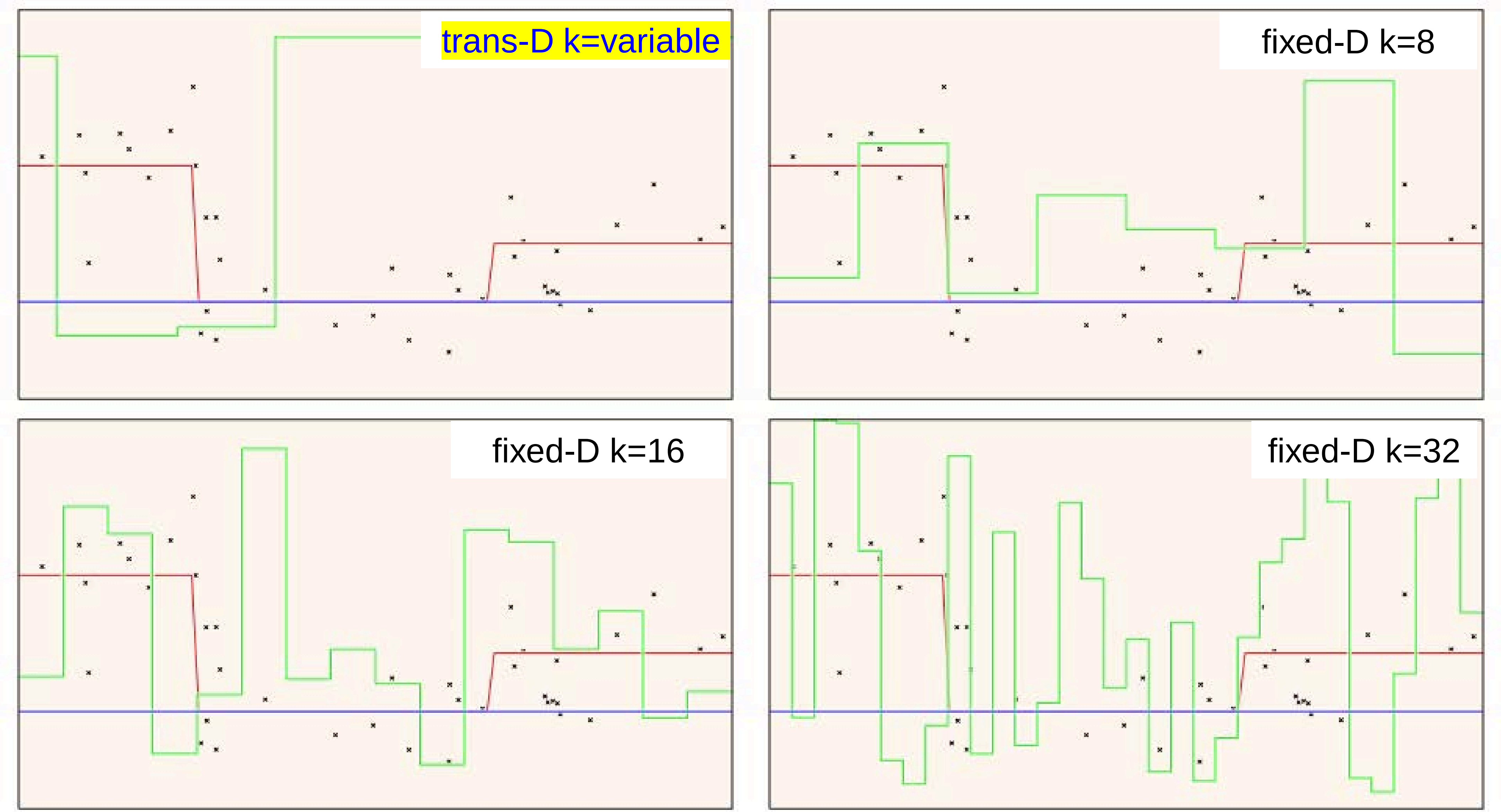
Birth: *k'=k+1;* 1/6

Death: *k'=k-1;* 1/6

A **birth-death scheme** is used to perturb the layer number ***k.***

Inversion method

Trans-dimensional MCMC vs. Fixed-dimensional MCMC



Inversion method

Likelihood formulation for multimode inversion

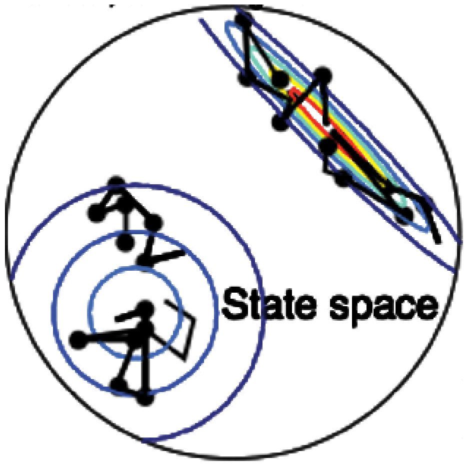
$$L(\mathbf{m}) = \prod_{i=1}^{S} \frac{1}{\sqrt{(2\pi)^{N_i} |\mathbf{C}_{\mathbf{d}i}|}} \exp\left(-\frac{1}{2} \mathbf{r}_i^T \mathbf{C}_{\mathbf{d}i}^{-1} \mathbf{r}_i) \right) .$$

Product is used instead of addition.

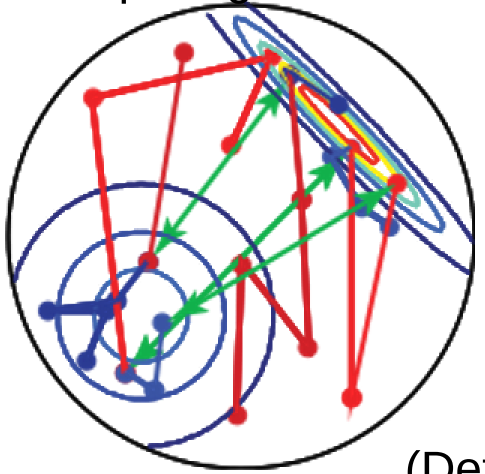
- The unknown **layer number k** is included in the posterior.
- The **error** is included in the posterior.
- All the model parameters are **quantitatively characterized**.
- Higher resolution is obtained with incorporation of **higher order modes**.

Inversion method

Without Parallel Tempering

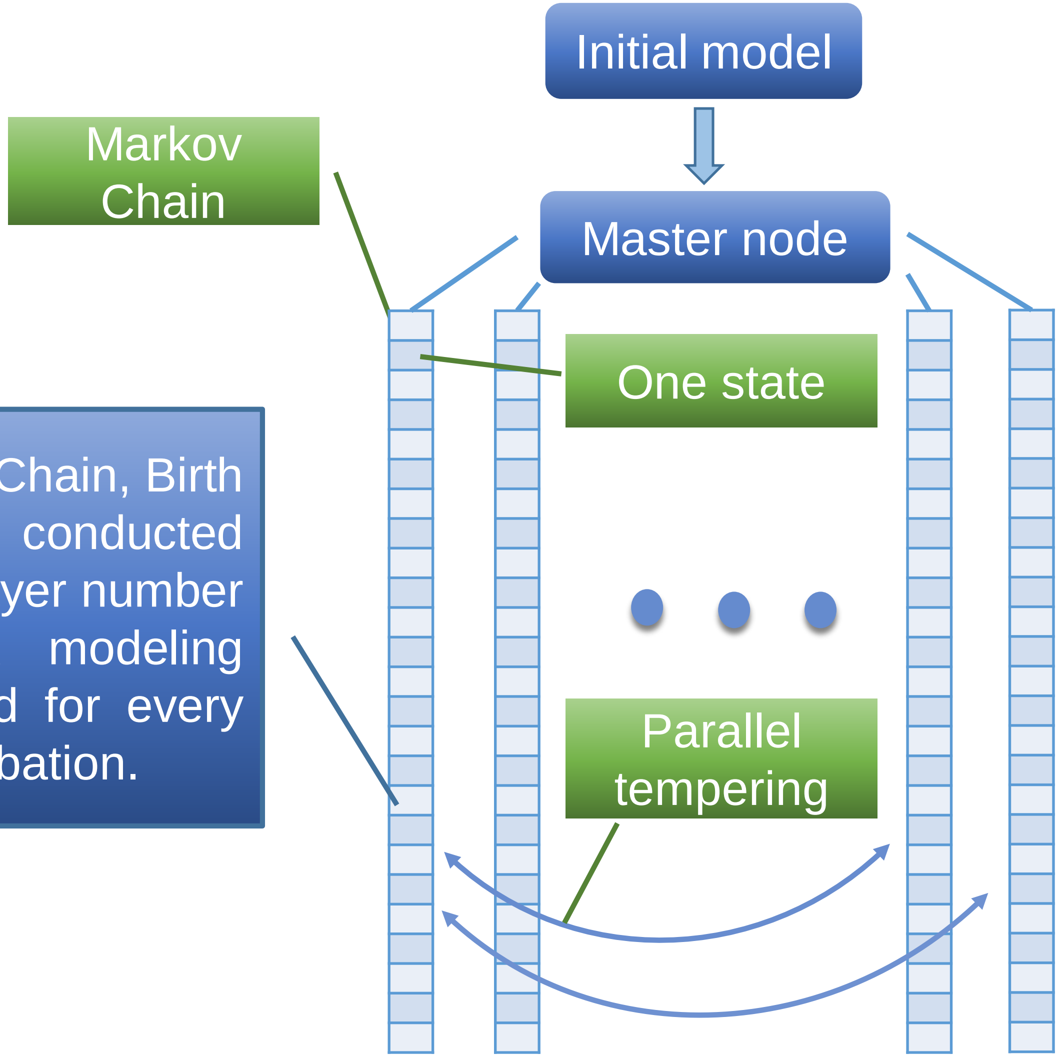


Parallel Tempering



(Dettmer, 2018)

In every Markov Chain, Birth death scheme is conducted to find suitable layer number k, and forward modeling (GPDC) is called for every parameter perturbation.

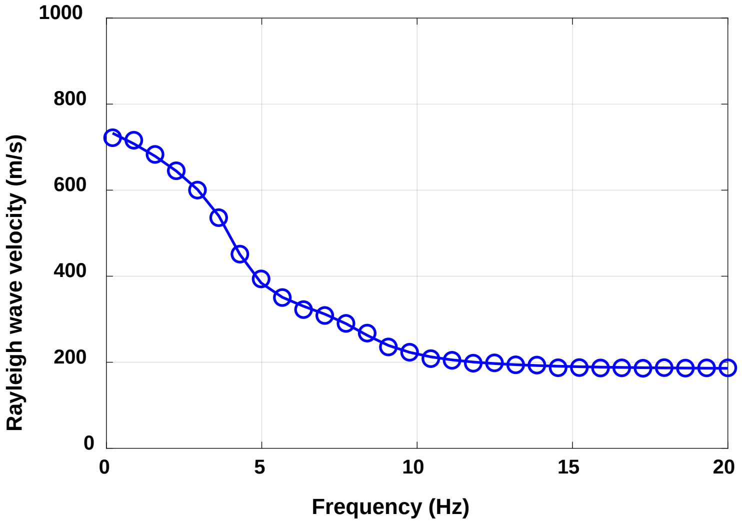


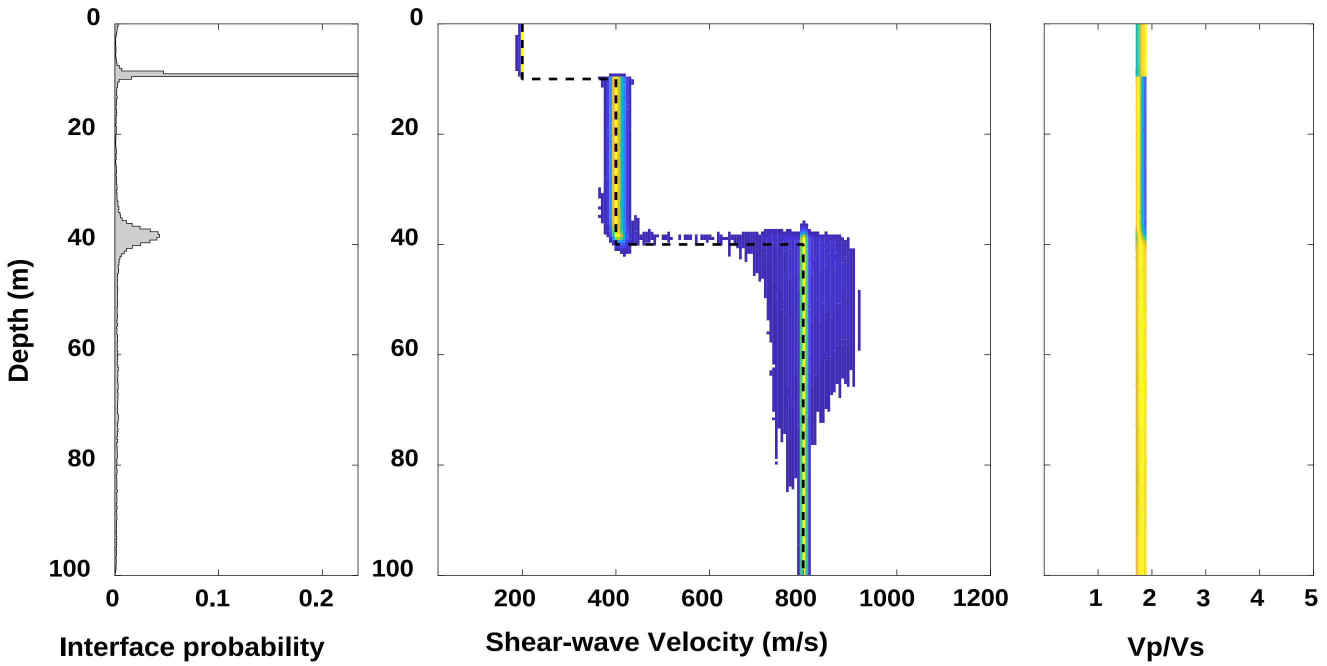
Parallel tempering to explore wide, exchange information between Markov Chains, converge efficiently.

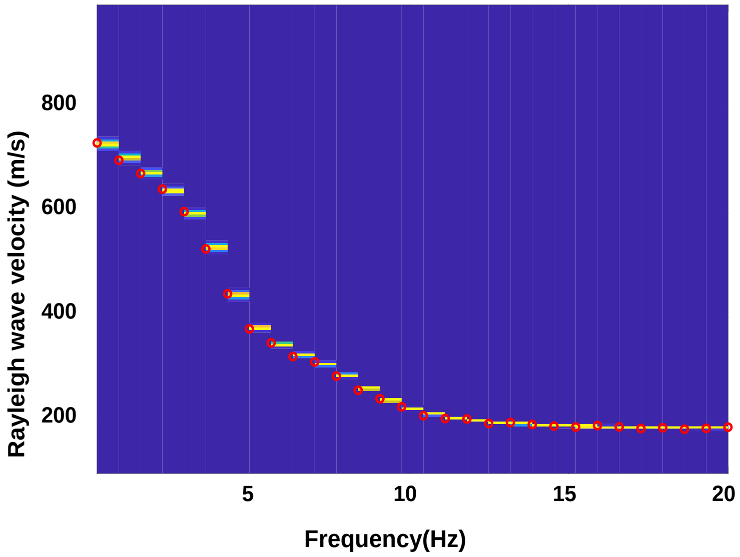
Synthetic models

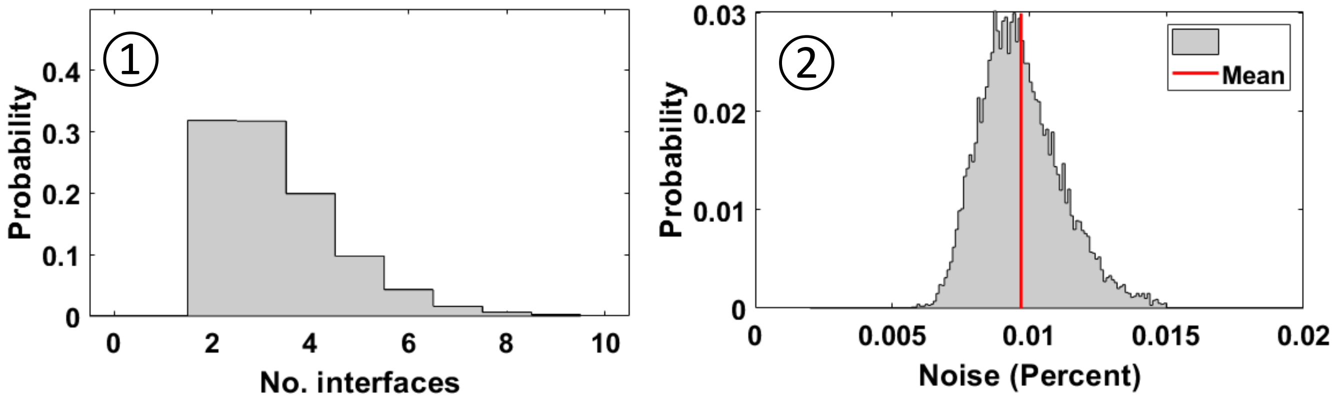
Synthetic models

Three-layered model with 1% magnitude scaled normal random noise using only fundamental mode



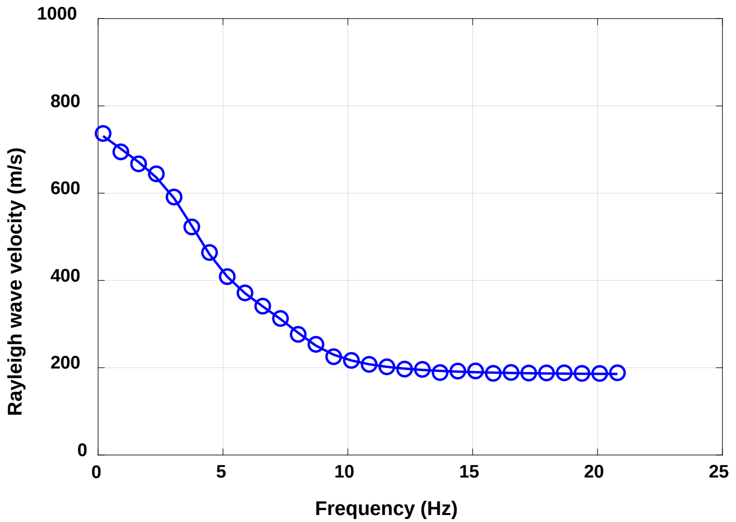


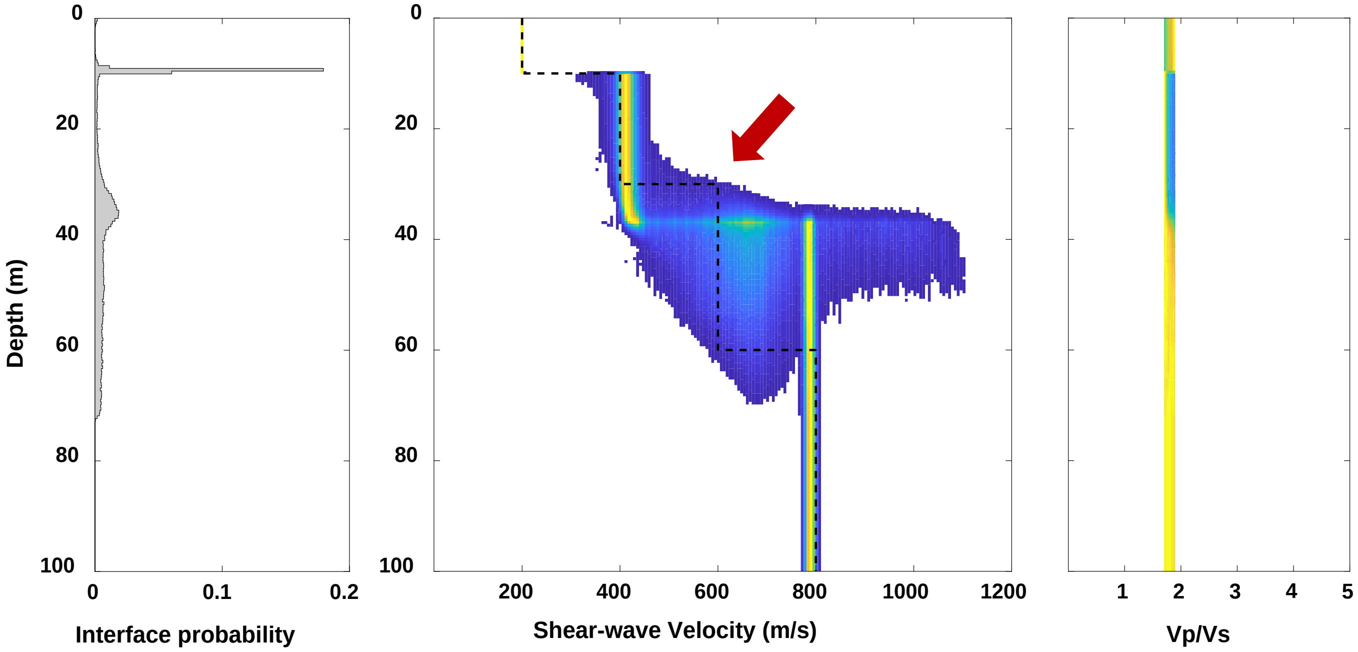


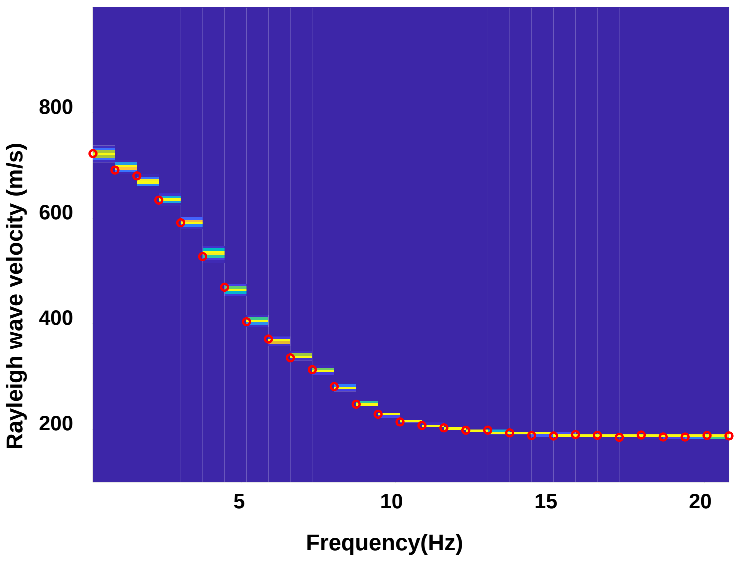


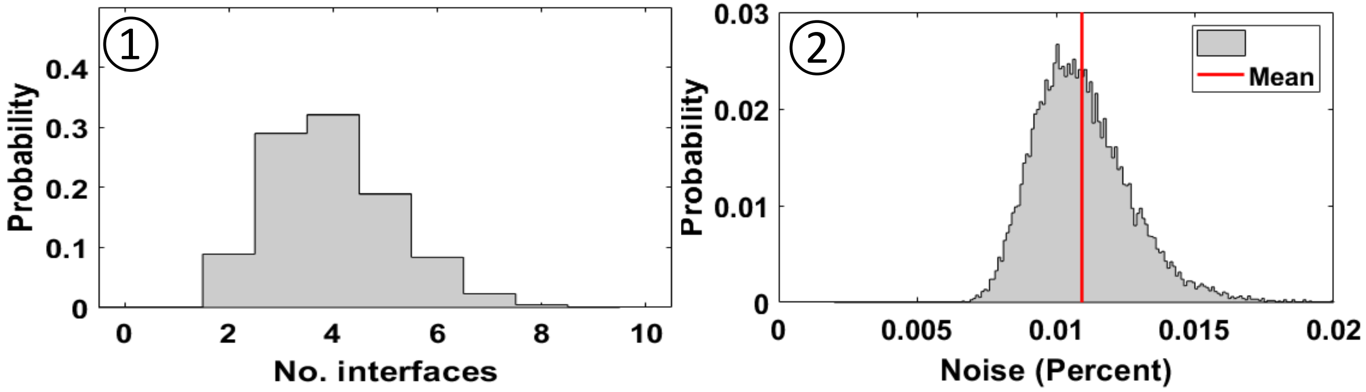
Synthetic models

Dispersion inversion using only the fundamental mode suffers from non-uniqueness.



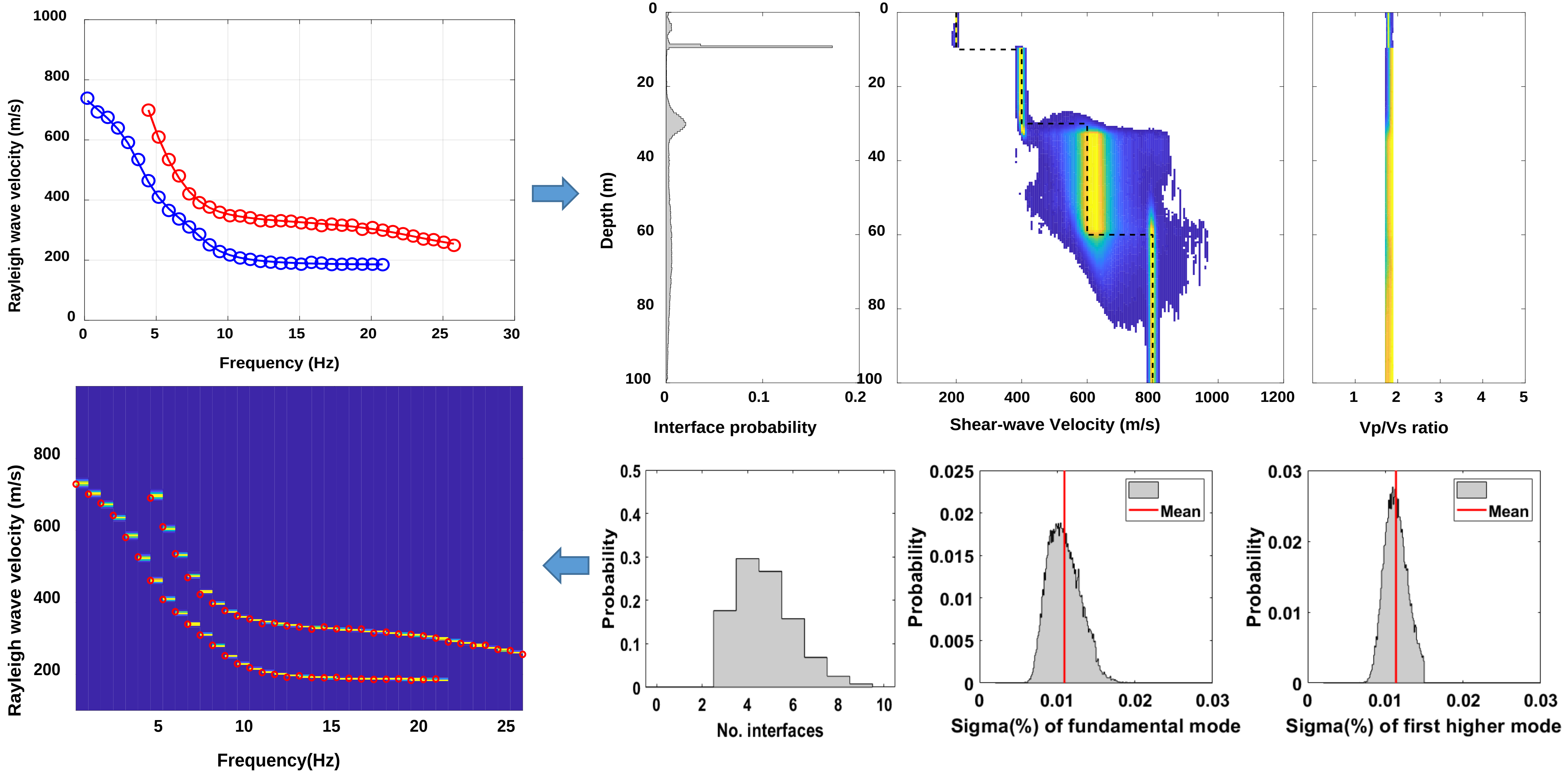






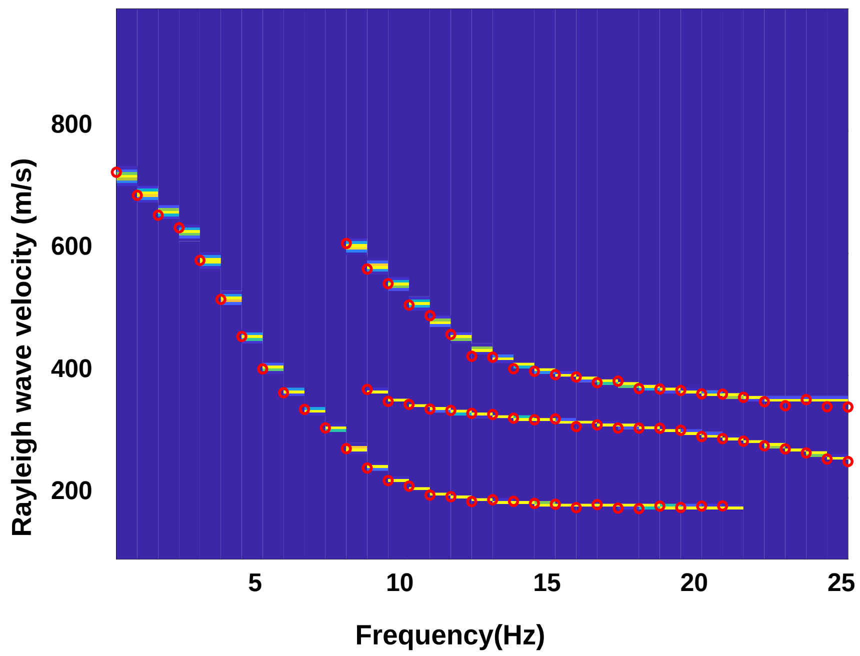
Synthetic models

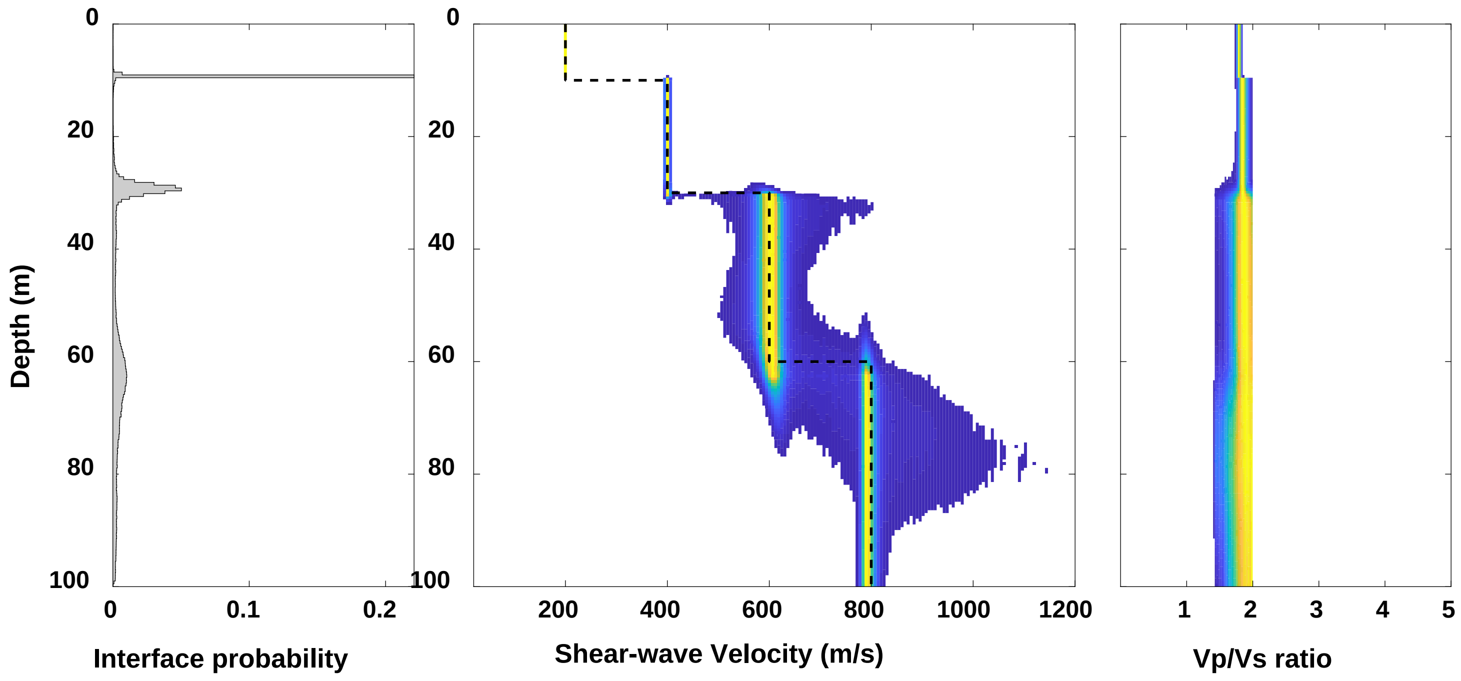
Incorporation of first higher order mode.

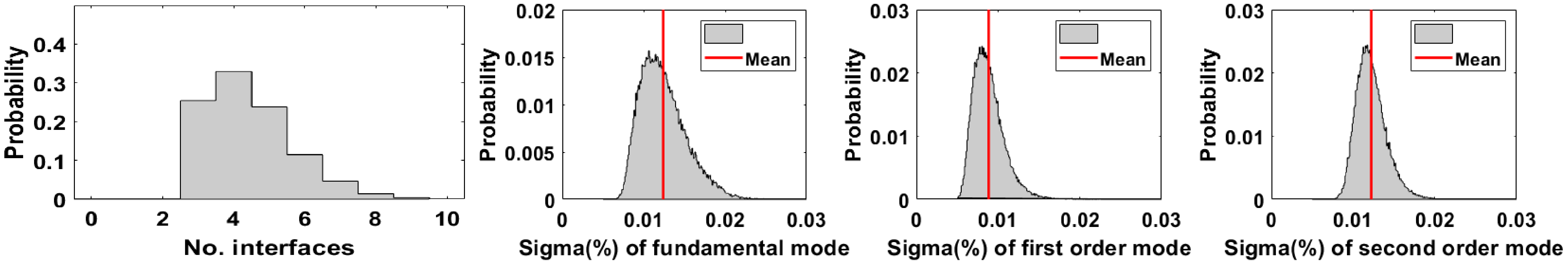


Synthetic models

Incorporation of first higher order mode and second higher order mode.





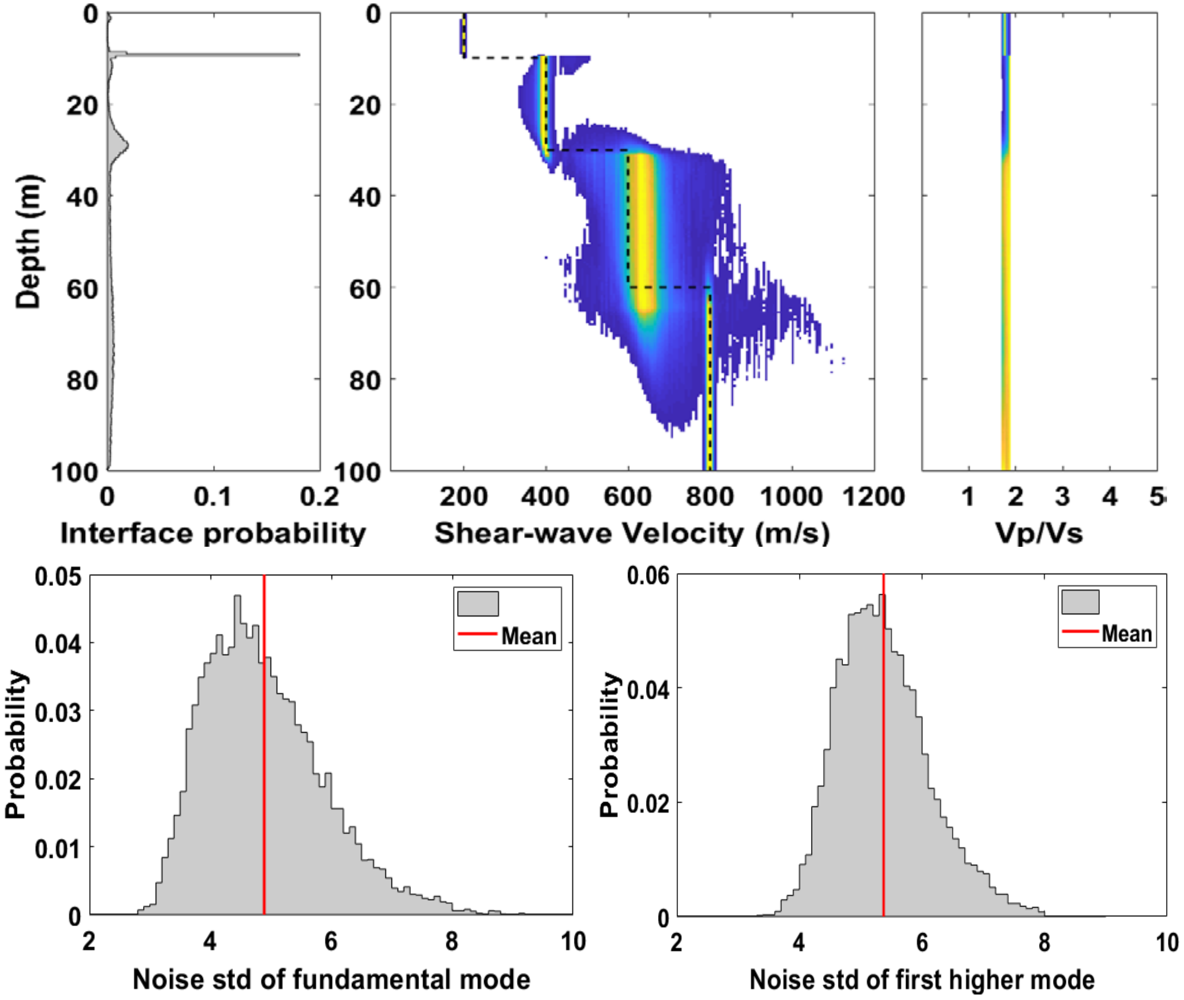


Synthetic models

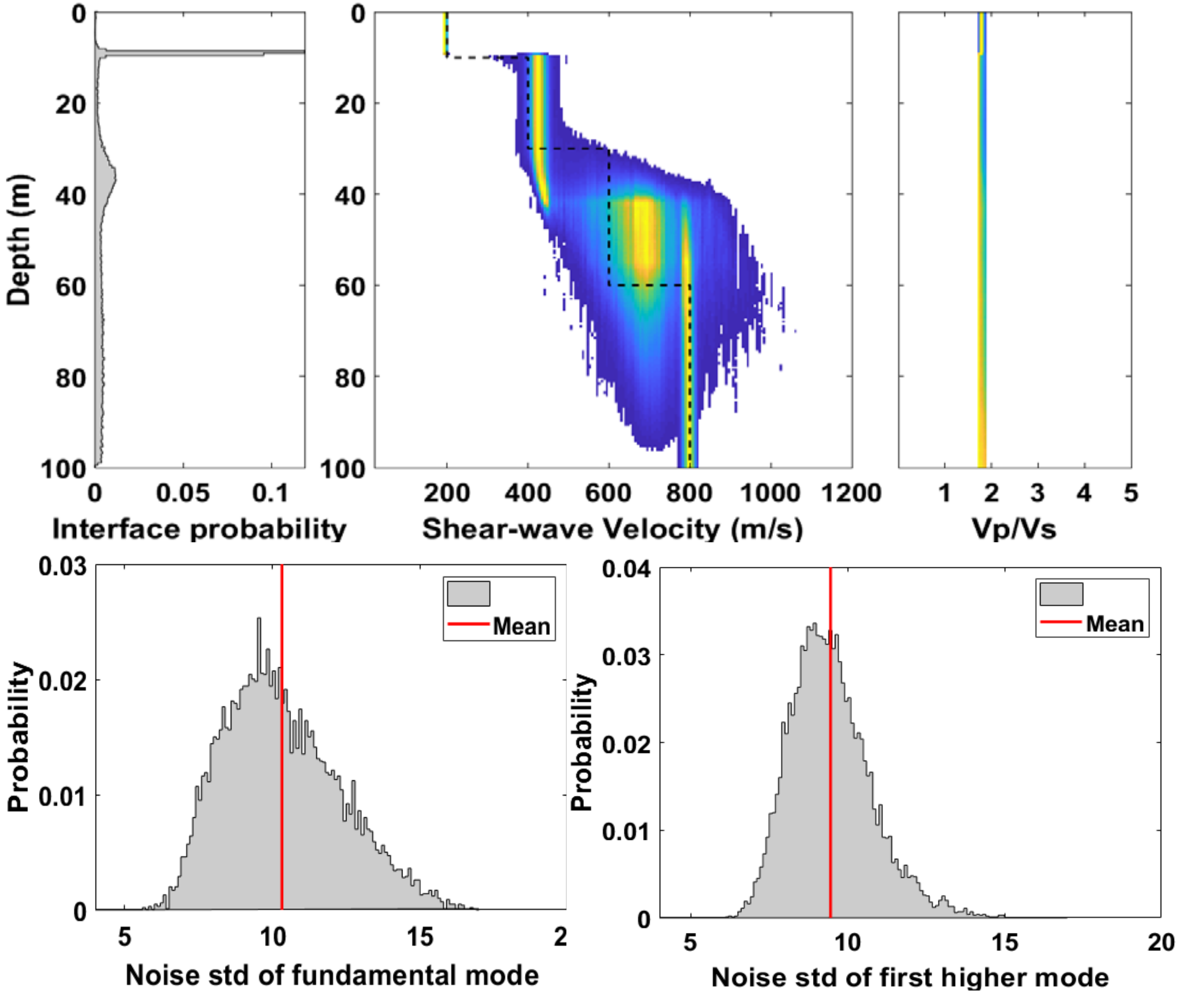
Models with different types of errors(likelihood function, initial value, prior)

(1) Gaussian distributed noise with a certain standard deviation, not magnitude scaled

std=5



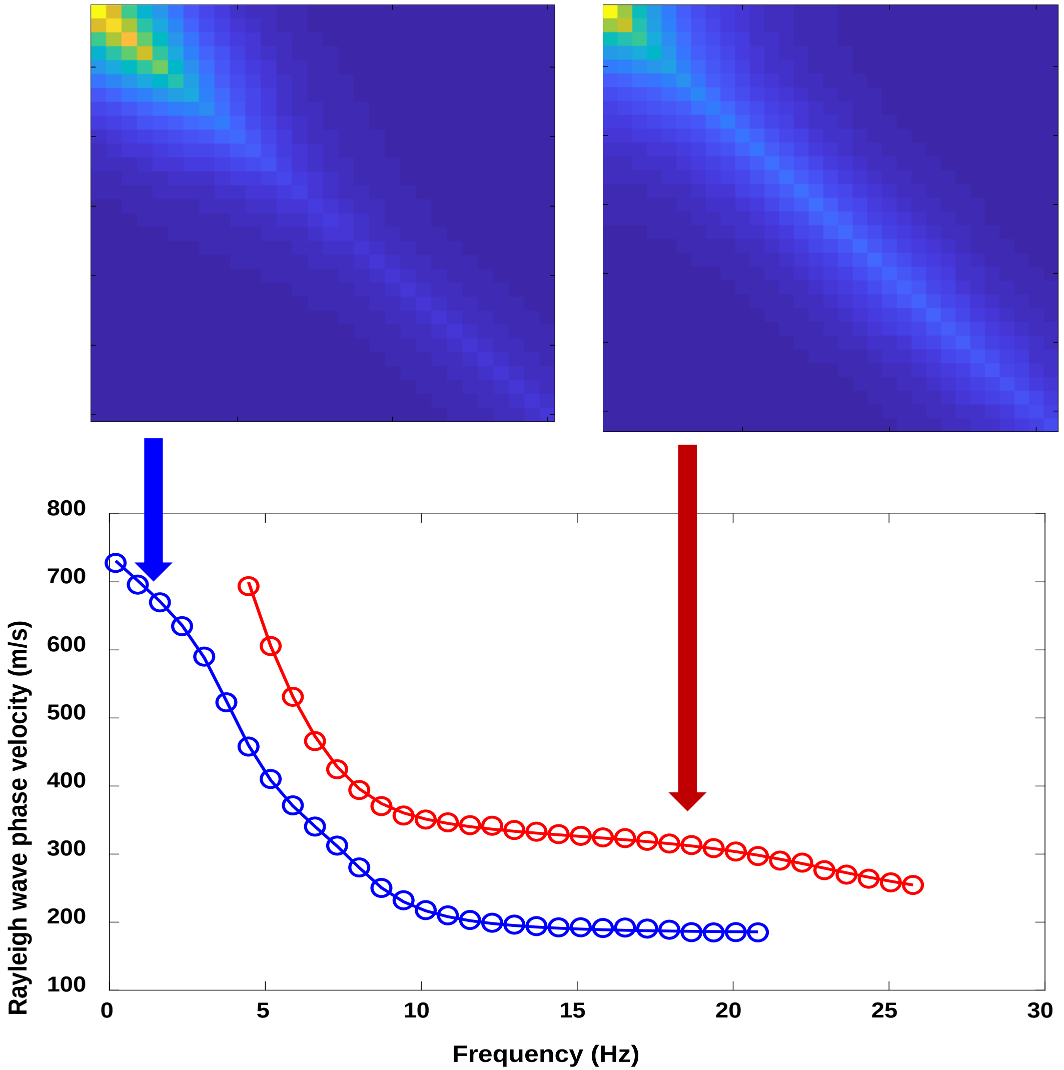
std=10

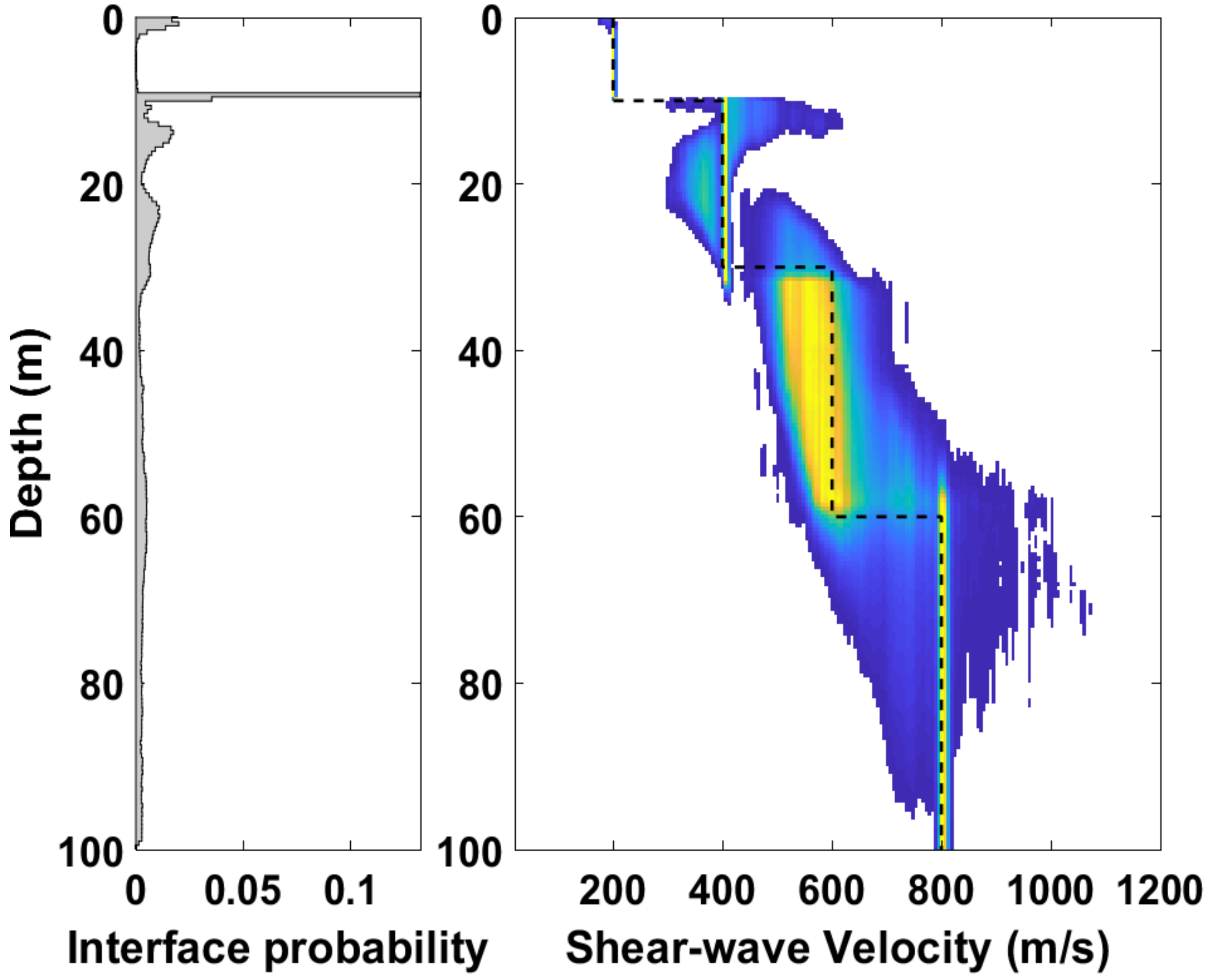


Synthetic models

Models with different types of errors(likelihood function, initial value, prior)

(2) Correlated noise

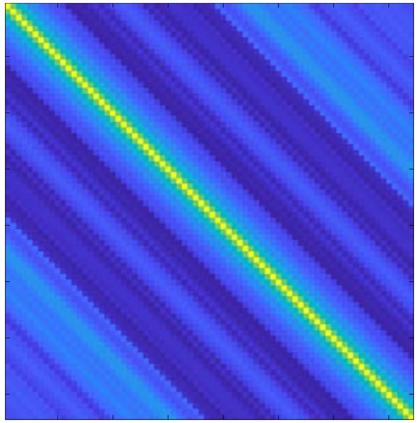


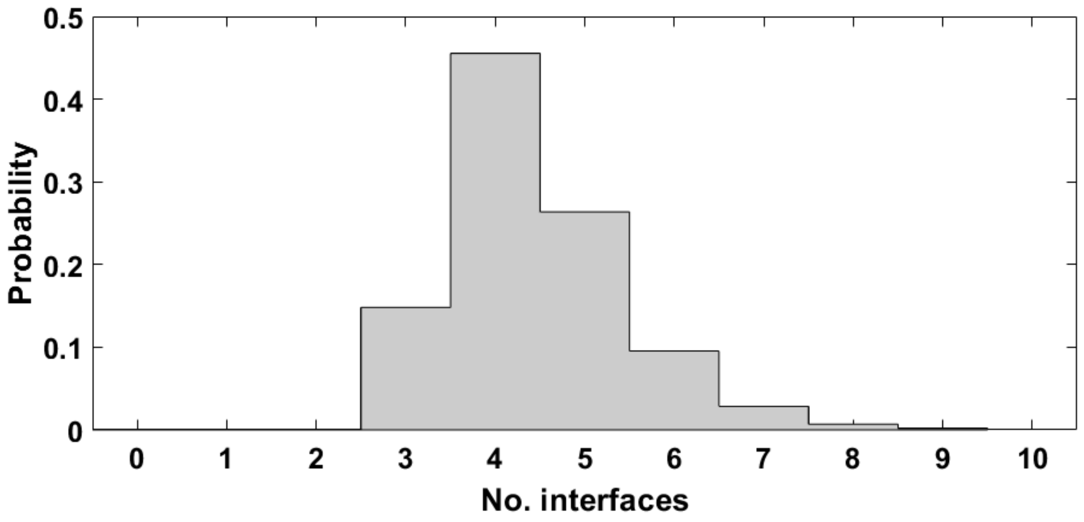


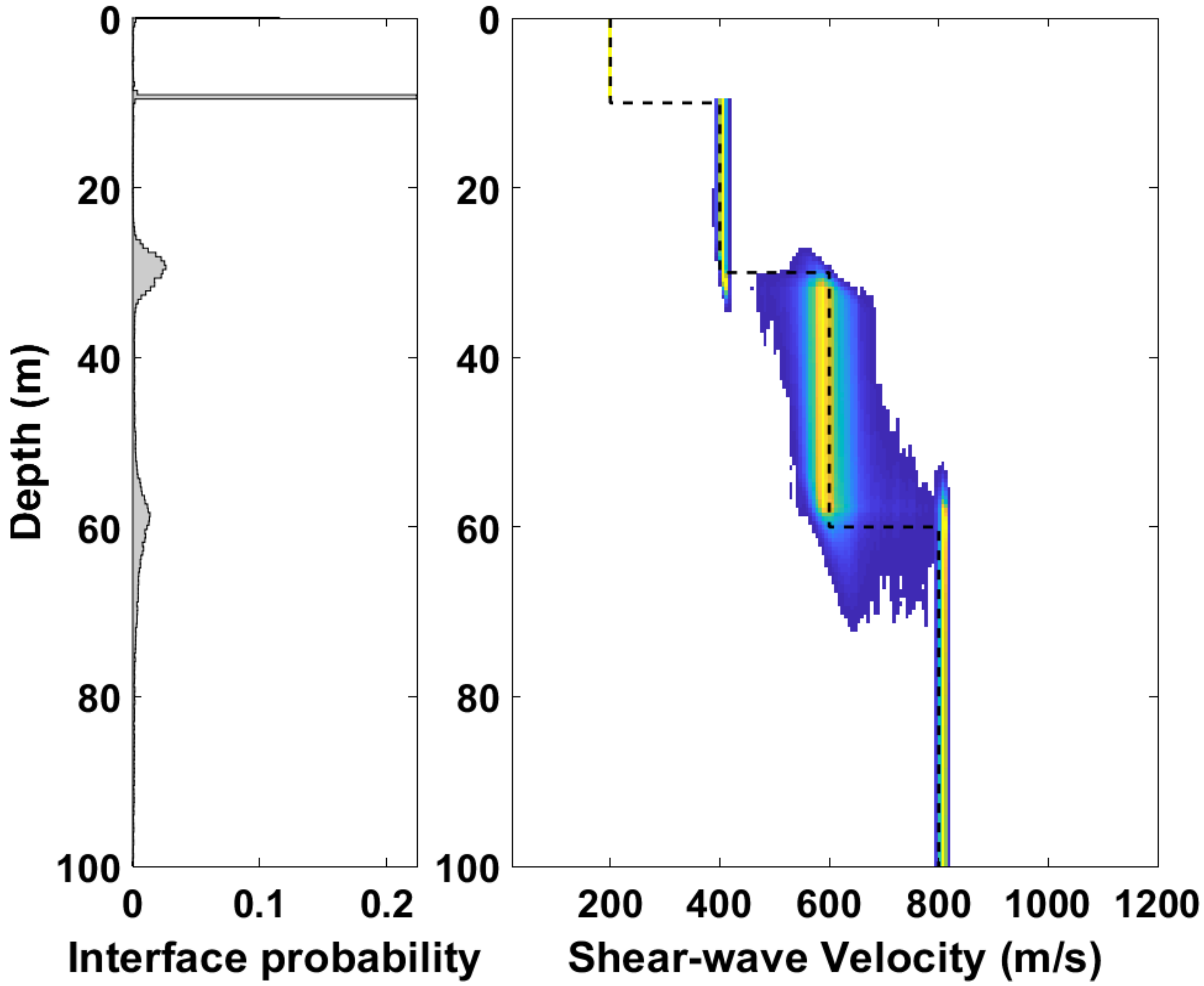
Synthetic models

Final inversion result

Nonstat covmat before scaling



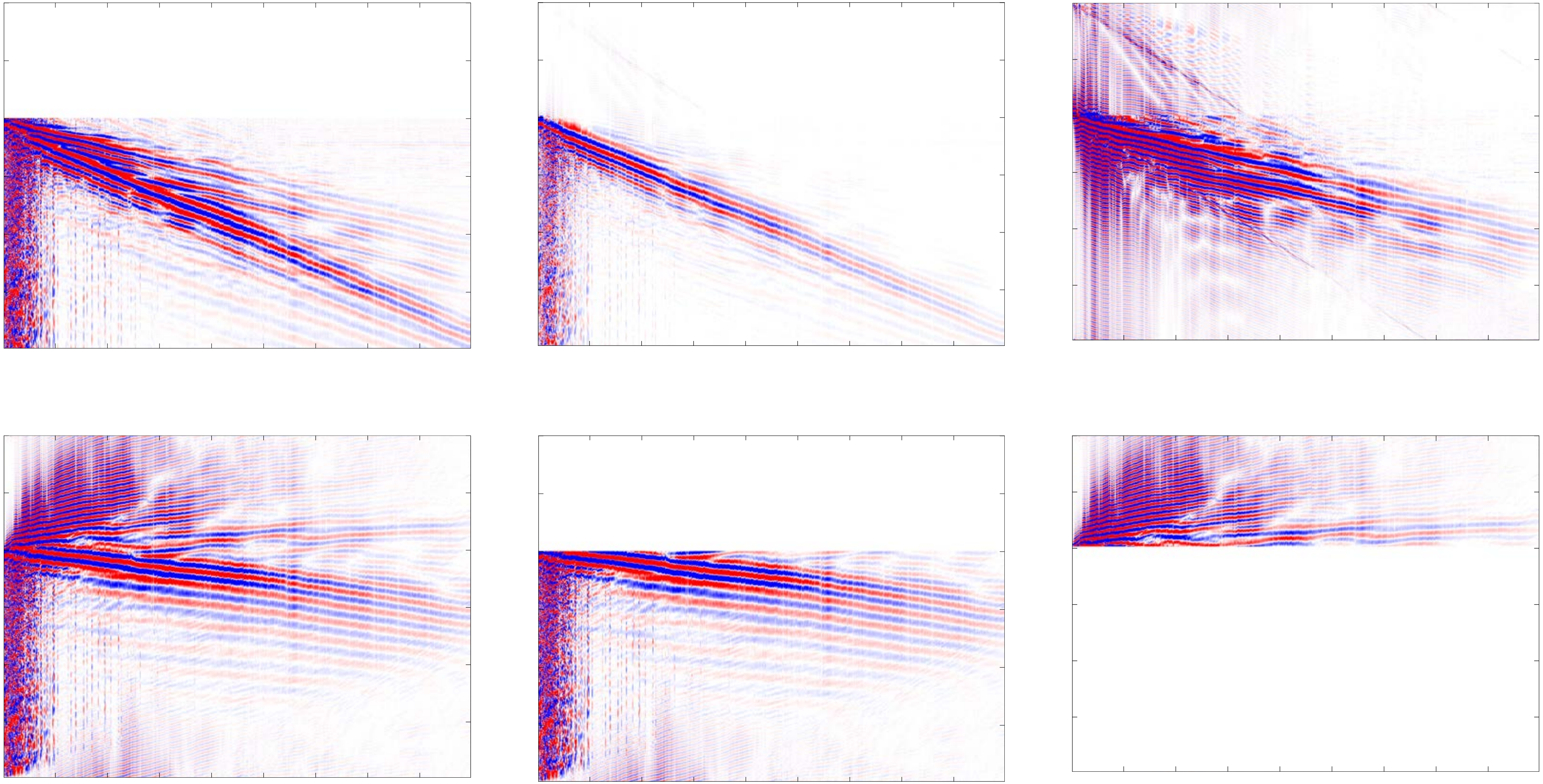




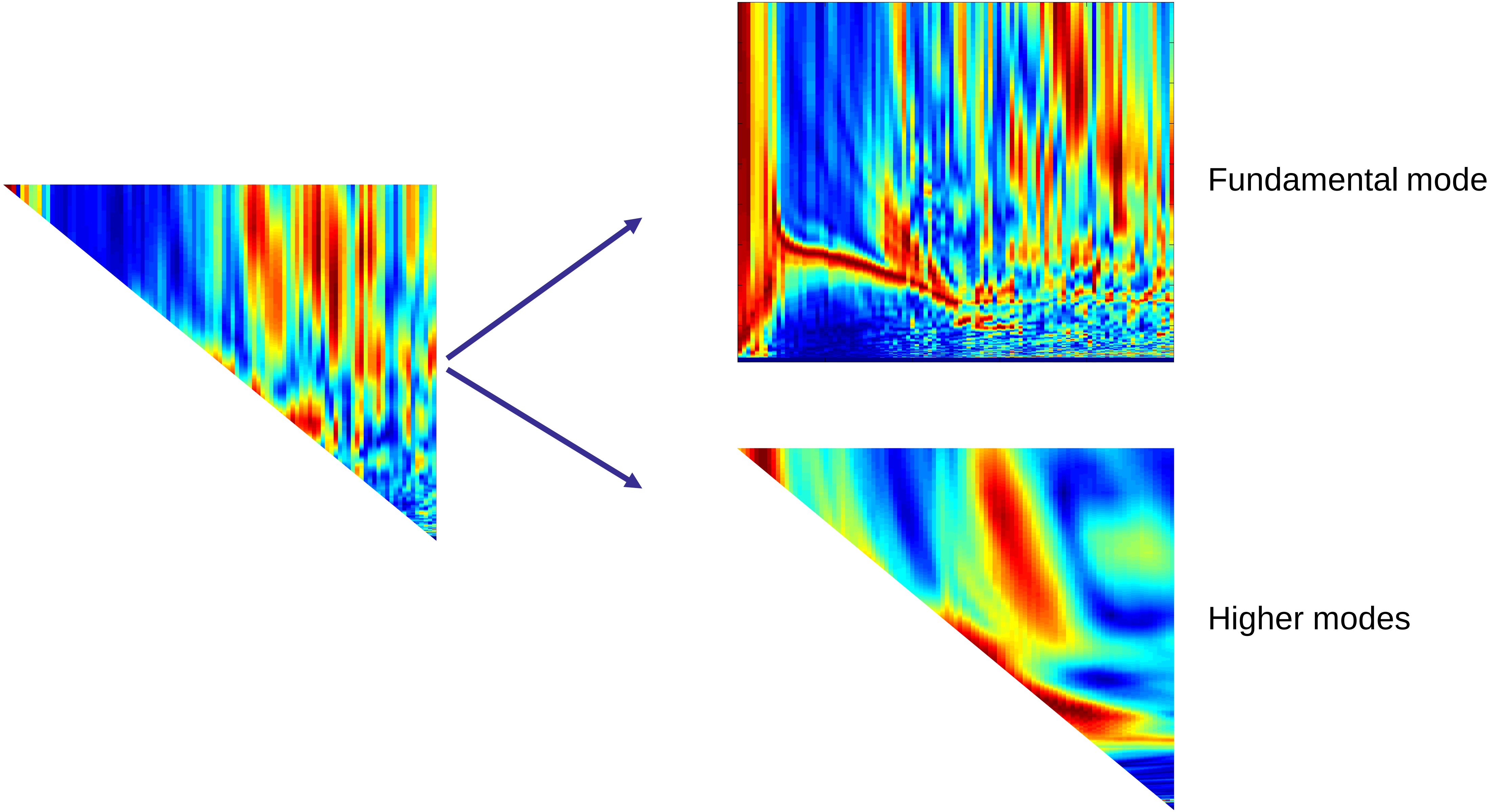
DAS data tests

Mode separation

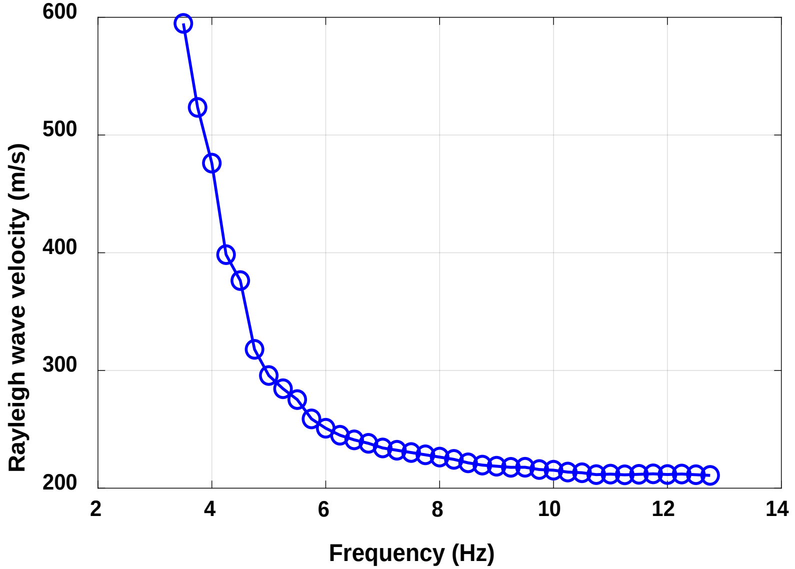
Mode separation ⟶ Dispersion Compensation

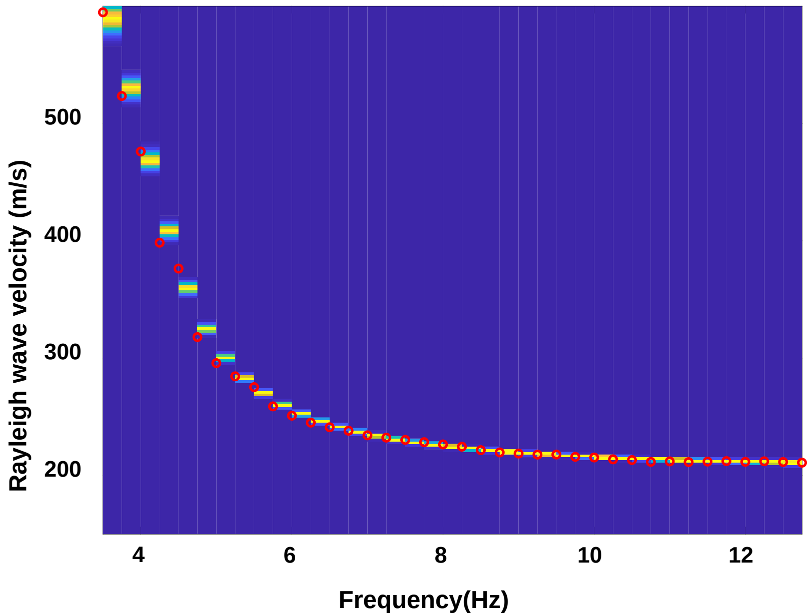


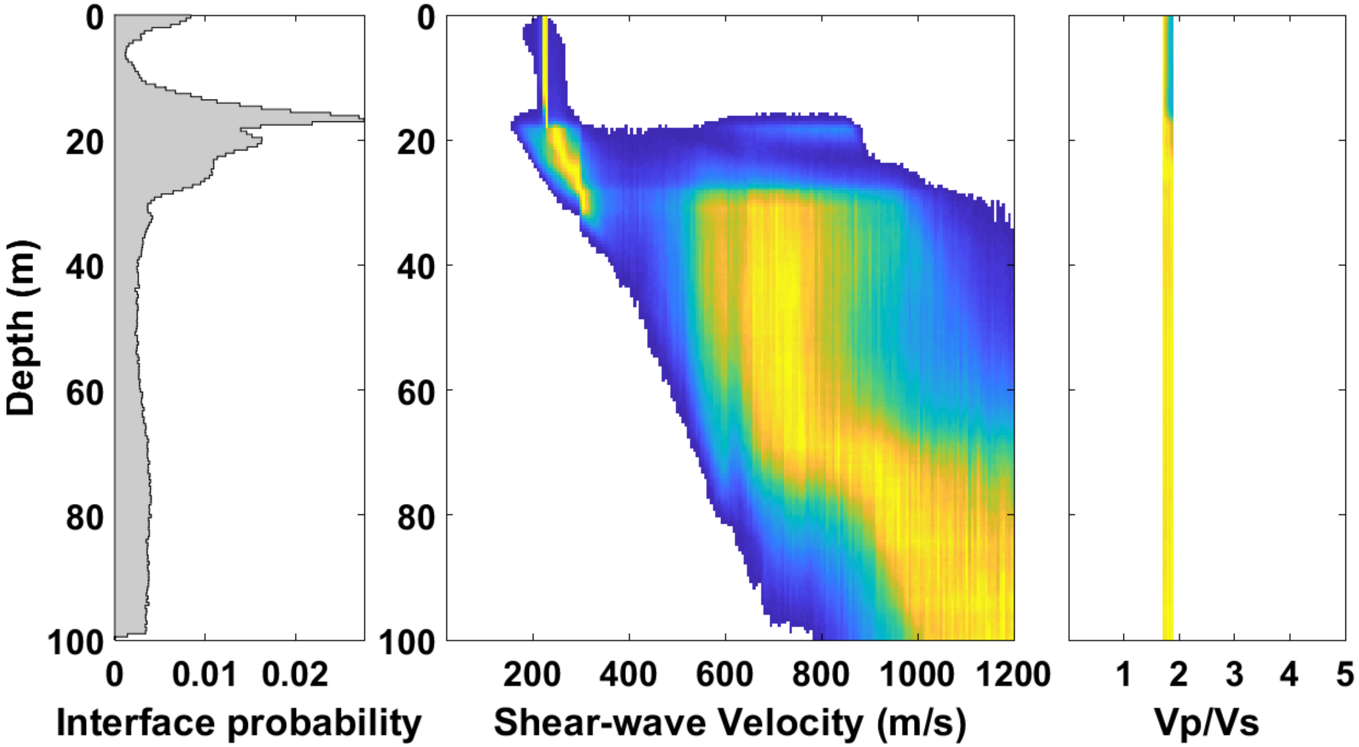
Mode separation

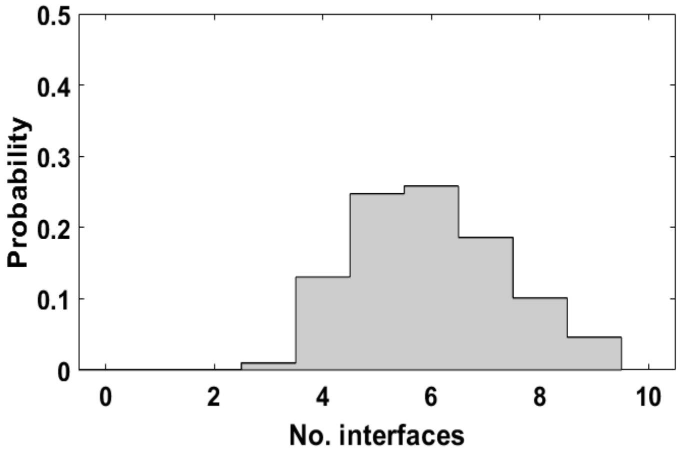


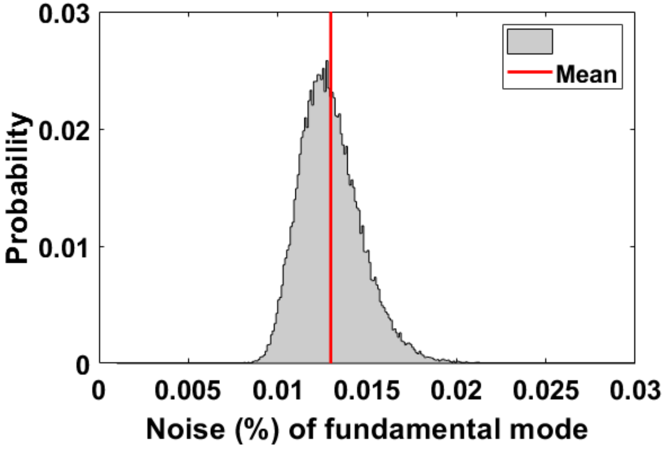
Fundamental mode inversion



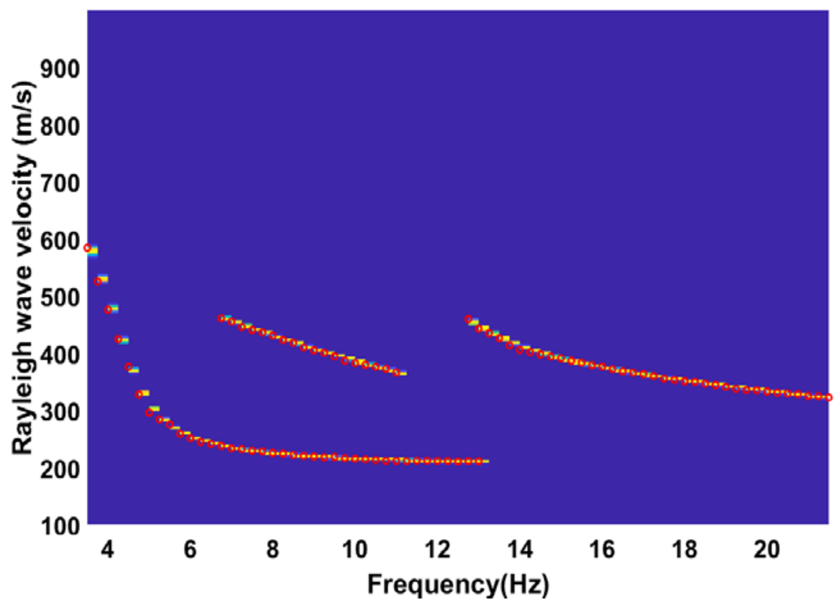


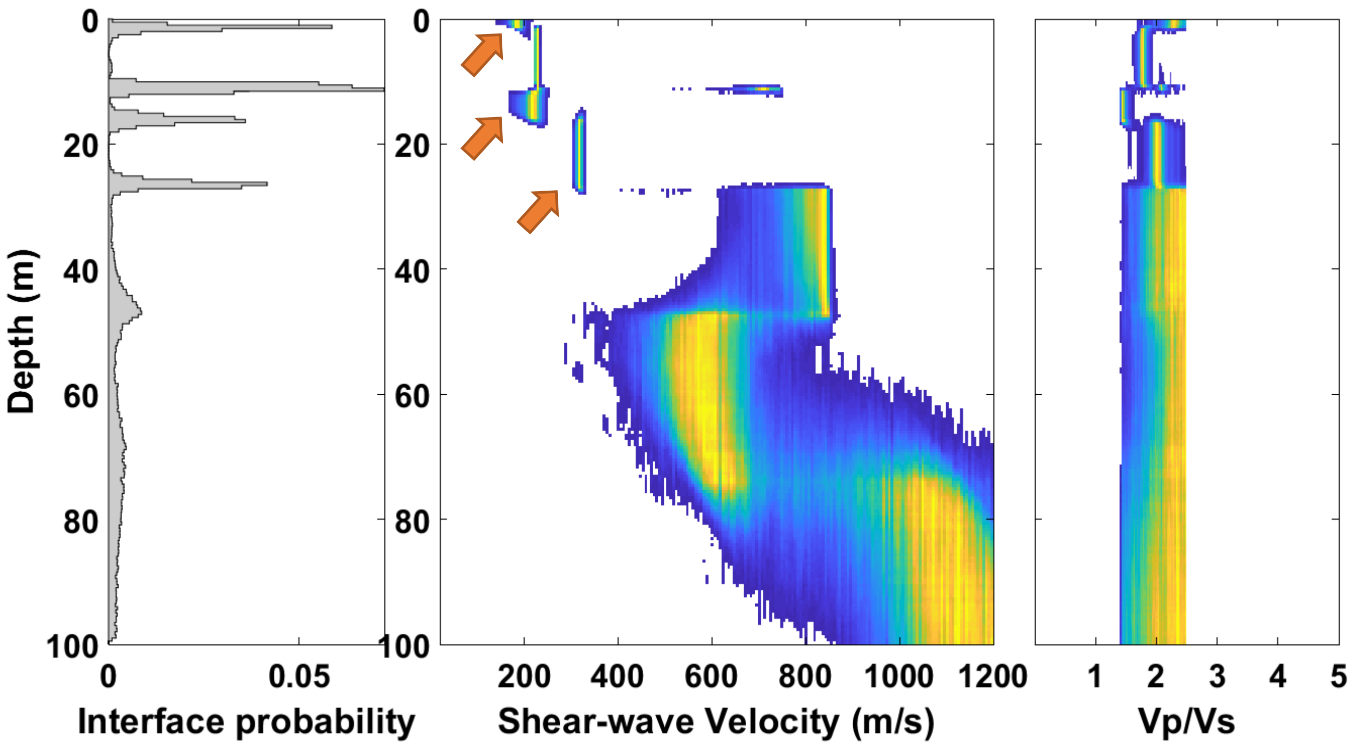


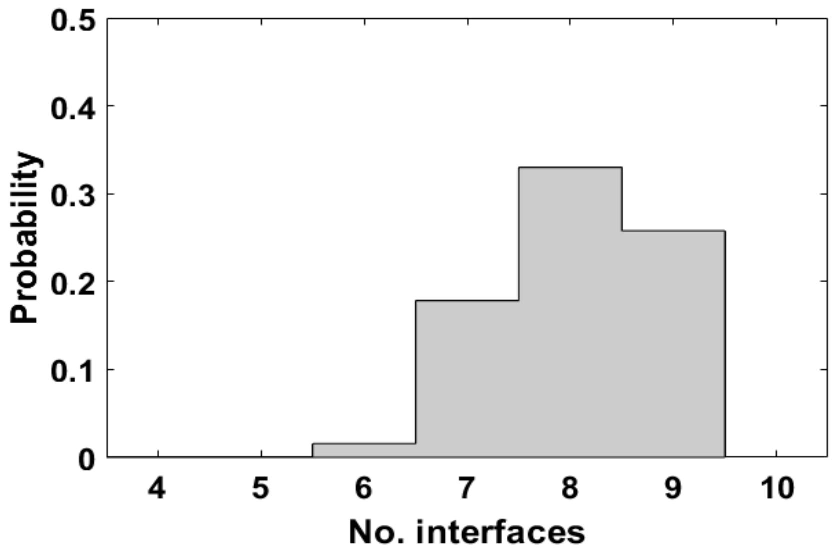


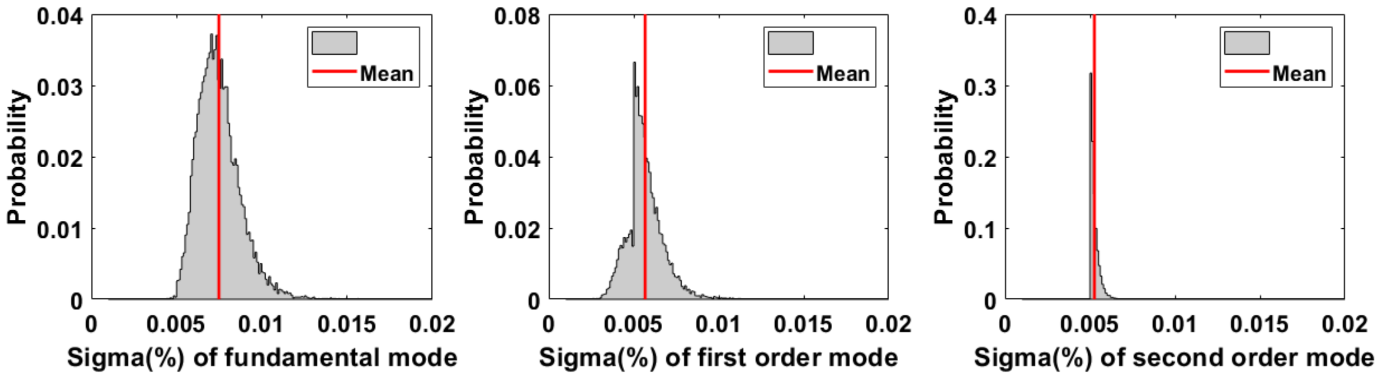


Higher order mode inversion









Conclusions and future work

Conclusions

- **Trans-Dimensional inversion** is utilized to implement the **multimode** surface wave dispersion inversion.
- Data **errors** are analyzed and involved in the posterior.
- The method is applied on trench **DAS** data, more detailed underground information is provided.

Future work

- **Joint inversion** of active source surface wave and ambient noise, refraction wave.
- **2D** surface wave dispersion inversion using trans-dimensional tree or Voronoi tesselation.

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