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

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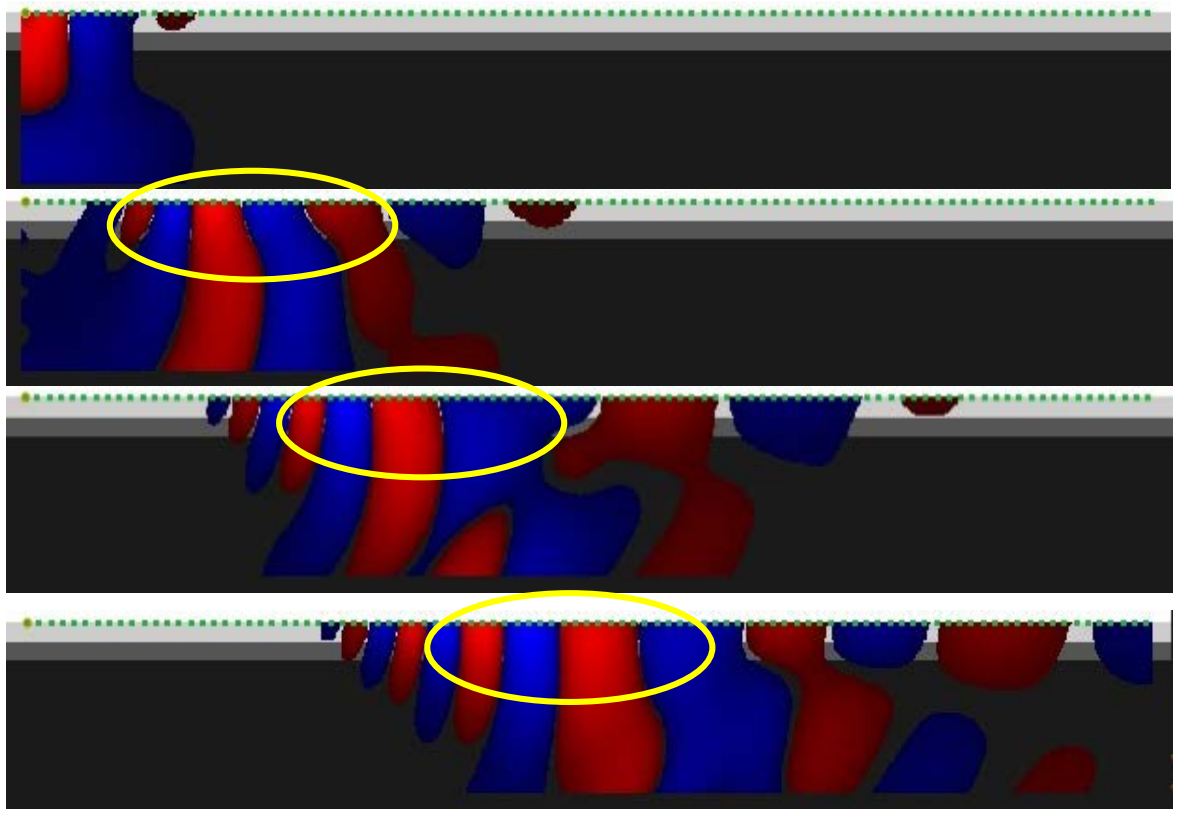
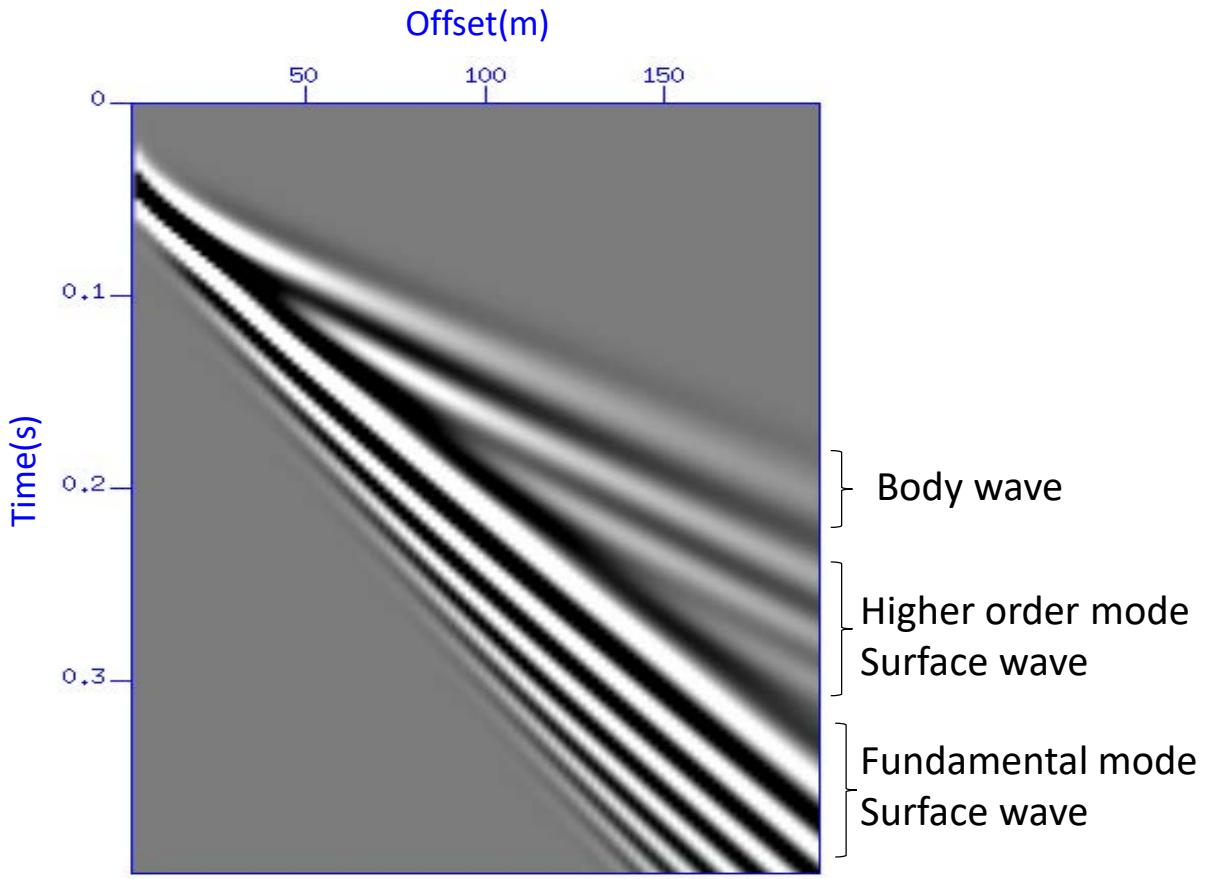
Introduction

Rayleigh wave

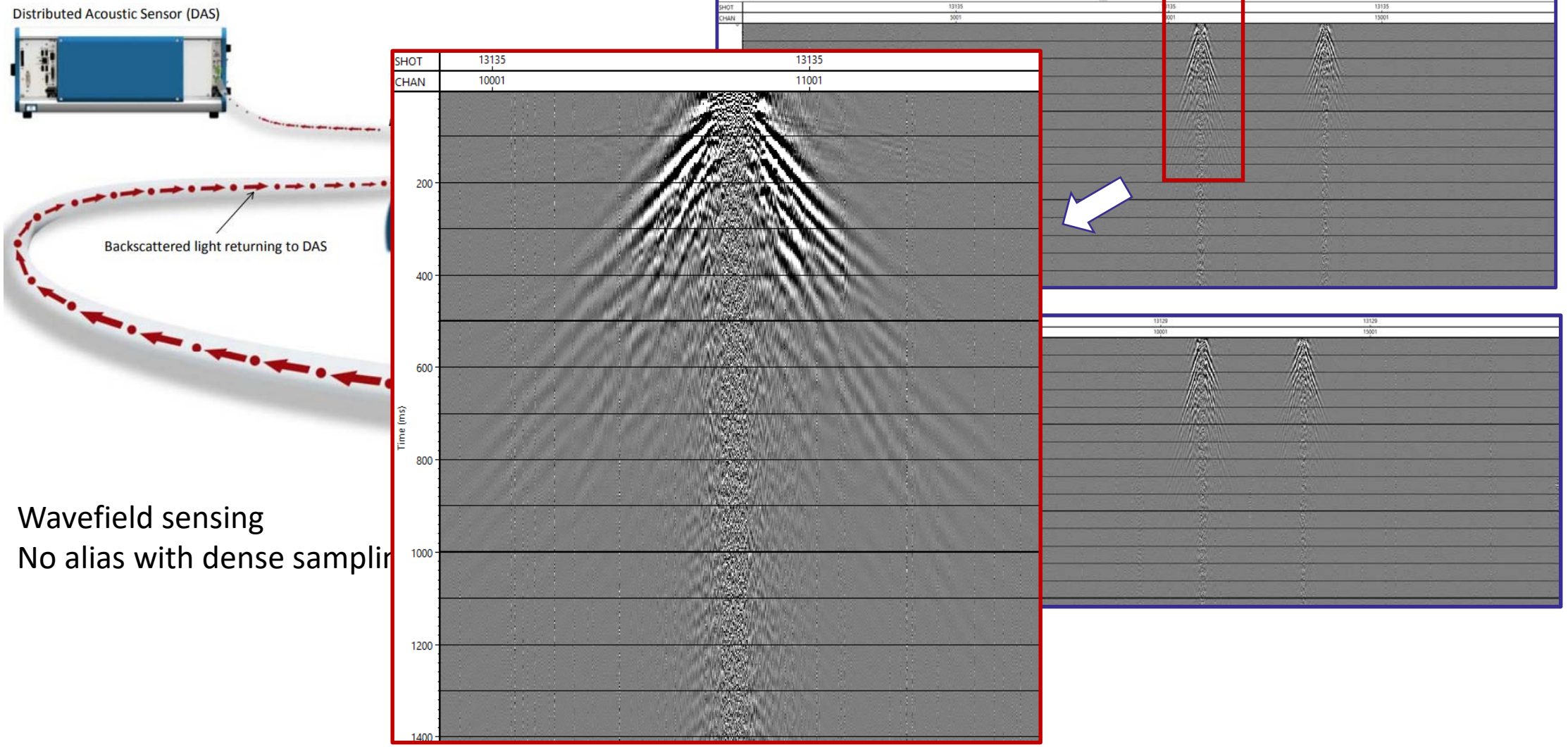




- Surface wave removal
- Invert shear wave velocity in shallow site

DAS data

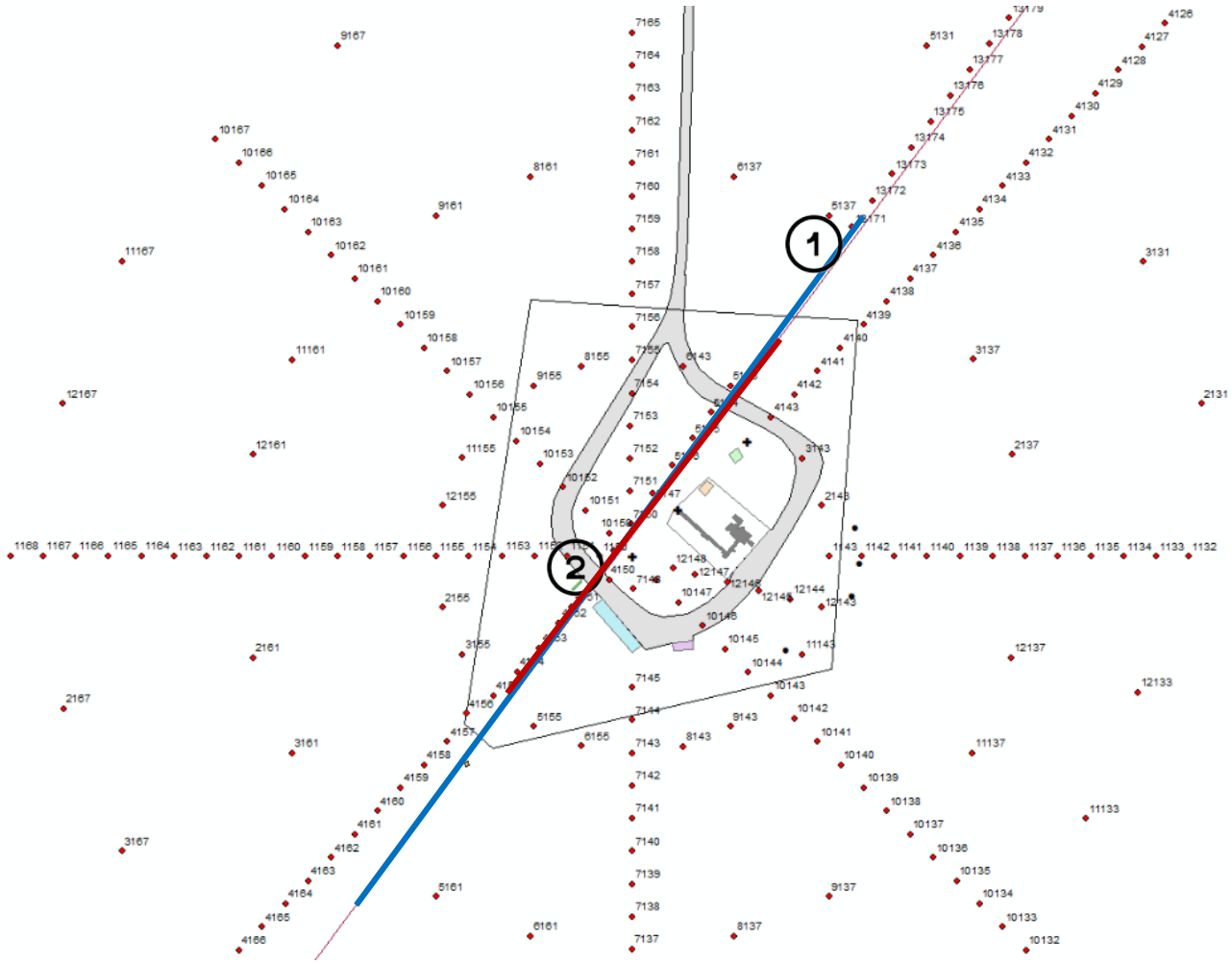
Principle

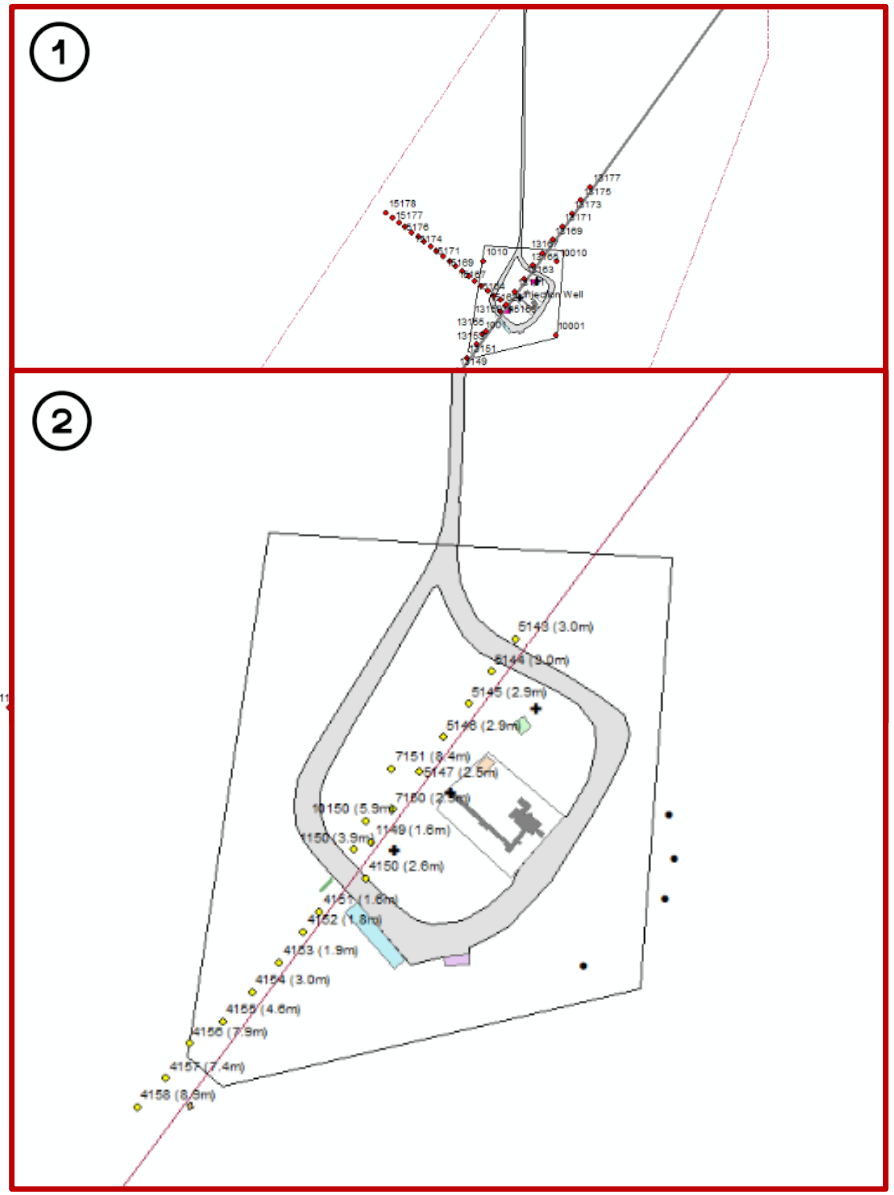


Wavefield sensing

No alias with dense samplir

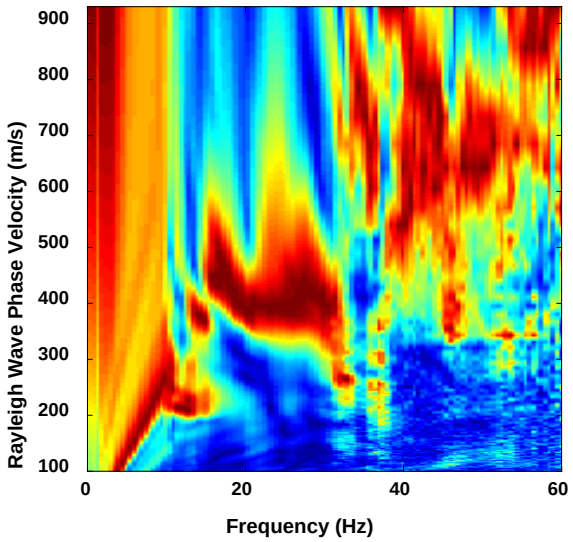
DAS data


1
2

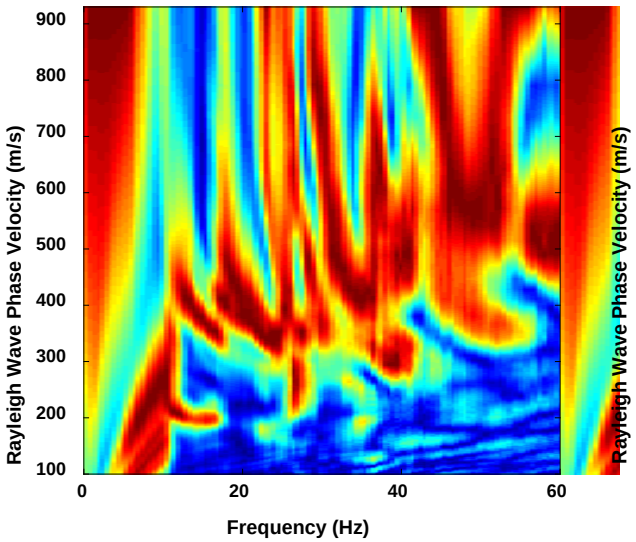

1
2
5143 (3.0m)
5144 (3.0m)
5145 (2.9m)
5146 (2.9m)
7151 (8.4m)
5147 (2.5m)
10150 (5.9m)
1149 (1.8m)
1150 (3.9m)
4150 (2.6m)
4151 (1.6m)
4152 (1.8m)
4153 (1.9m)
4154 (3.0m)
4155 (4.6m)
4156 (7.9m)
4157 (7.4m)
4158 (8.9m)

DAS data

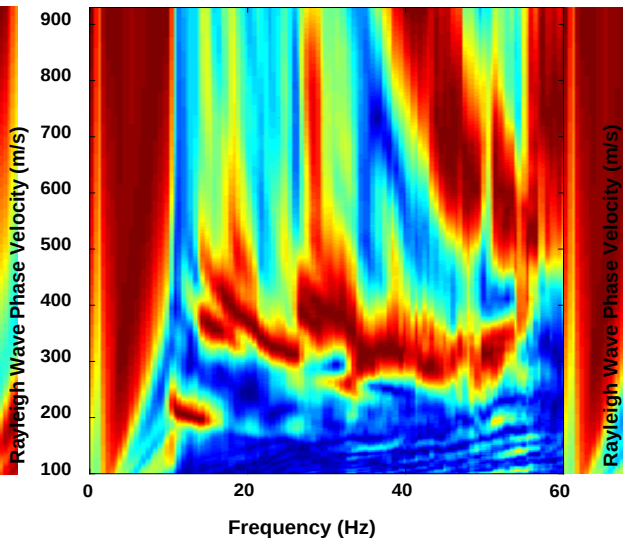
Straight line 13117



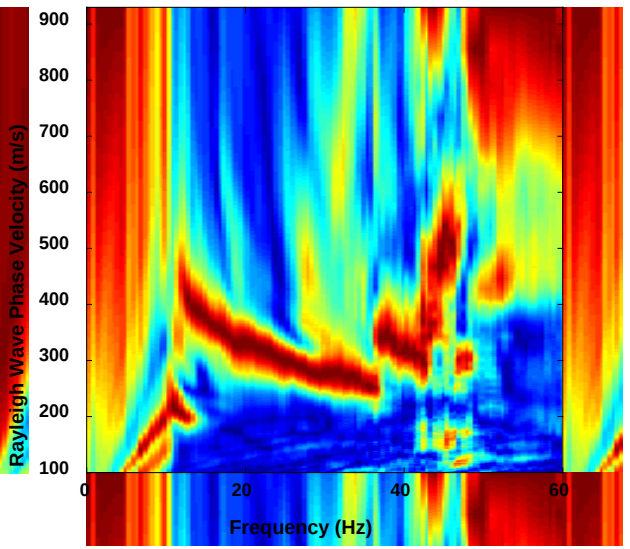
Straight line 13121



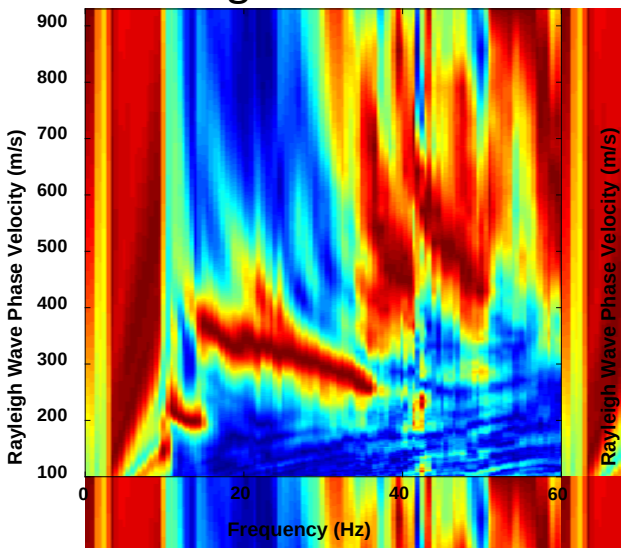
Straight line 13125



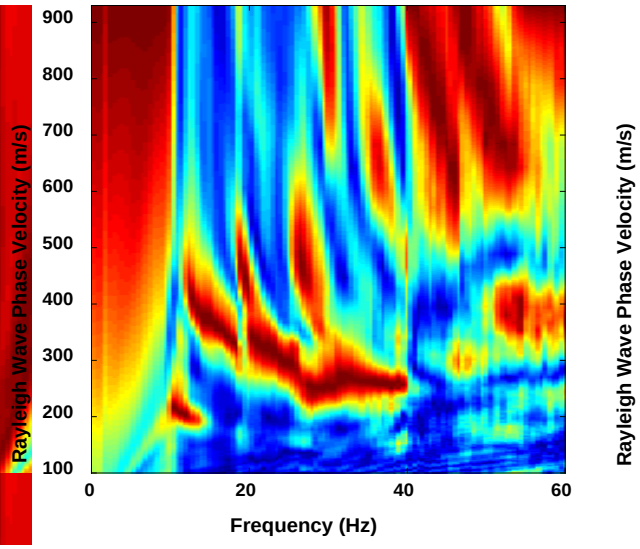
Straight line 13129



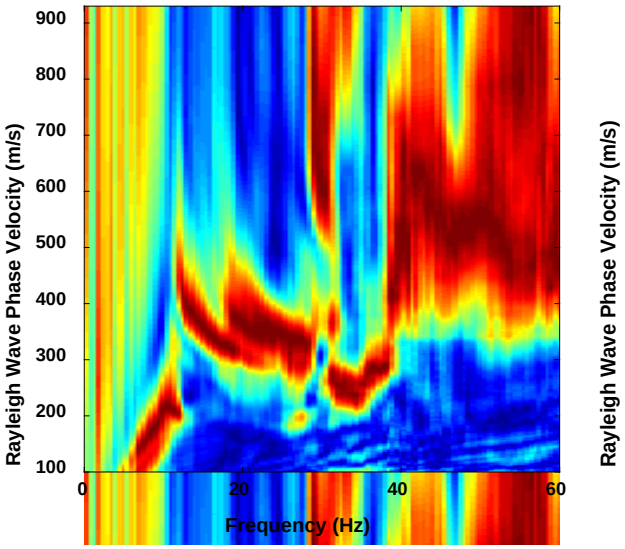
Straight line 13133



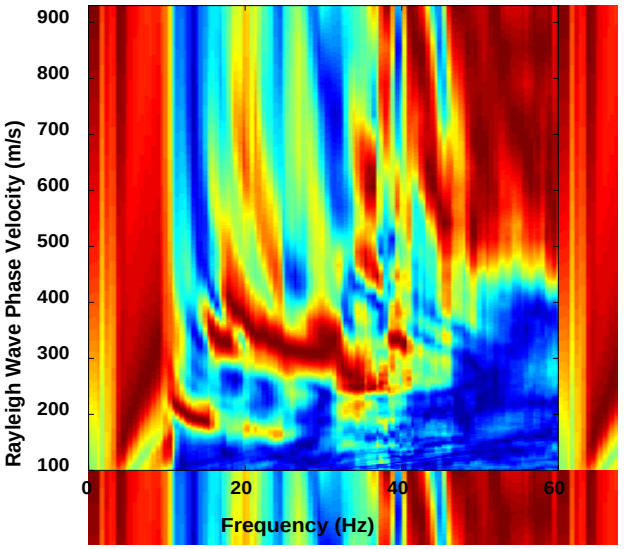
Straight line 13137



Straight line 13141



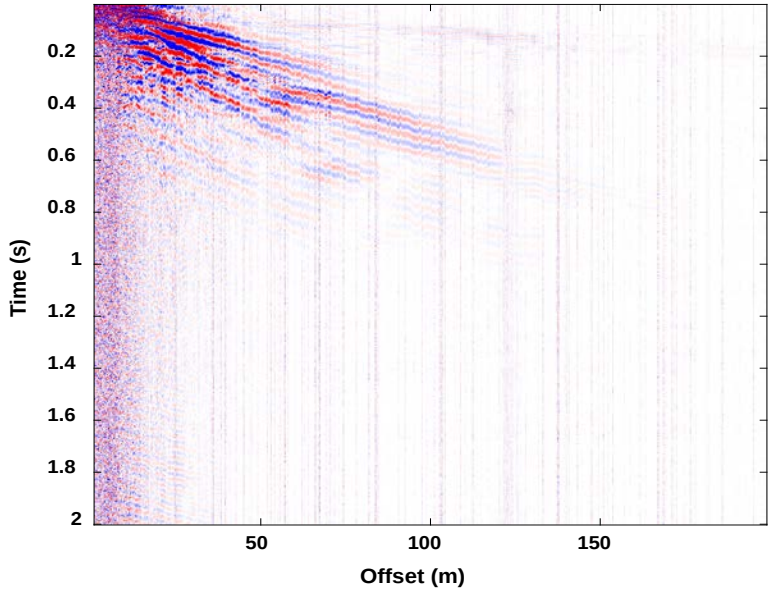
Straight line 13145



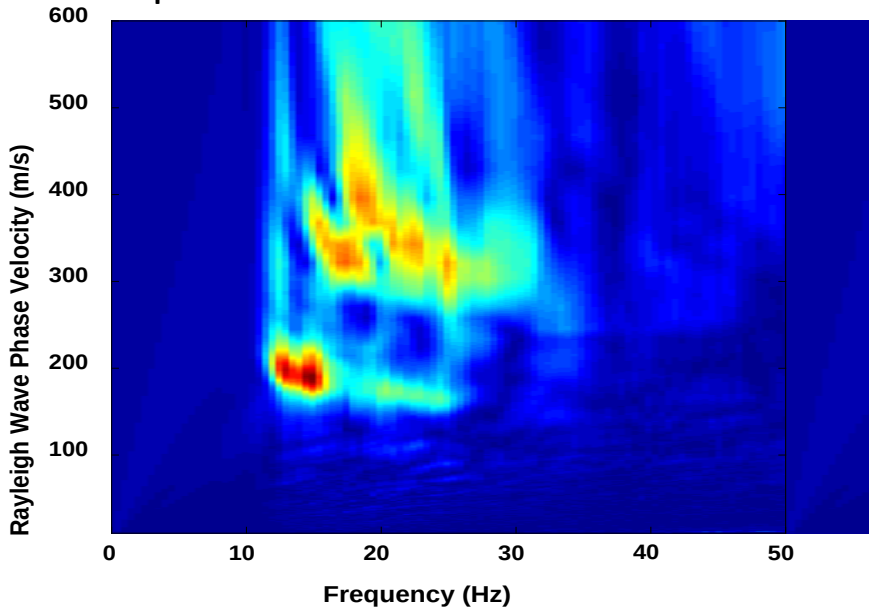
DAS data

Line 13
2017May
13145
Sweep
10~150Hz

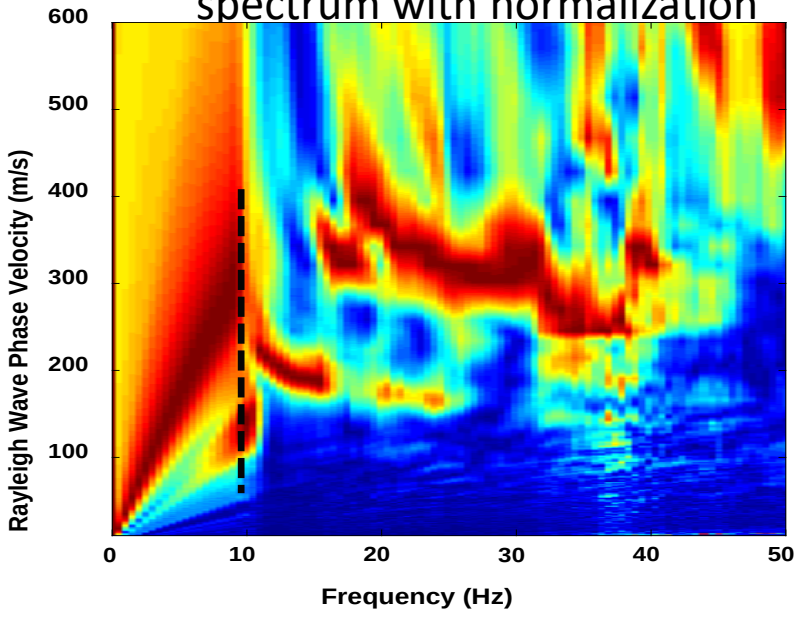
Shot record



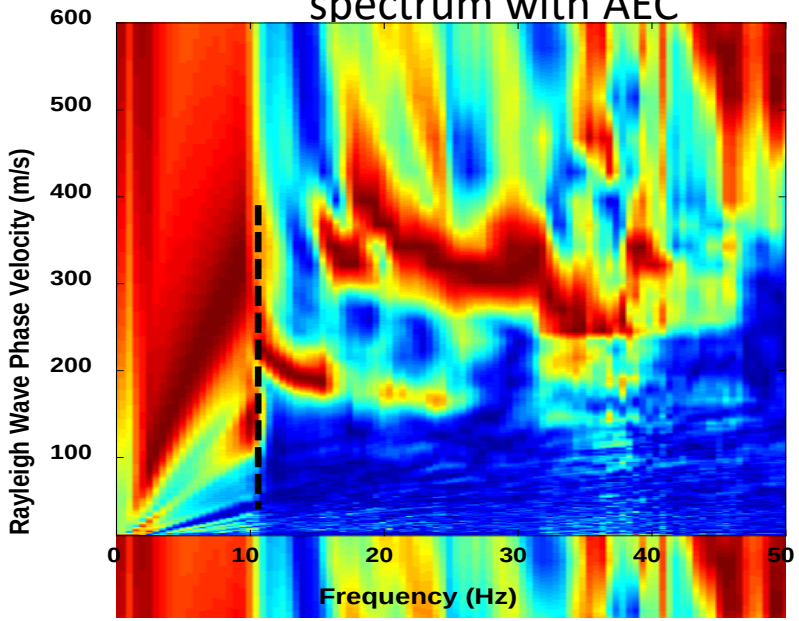
spectrum without normalization



spectrum with normalization

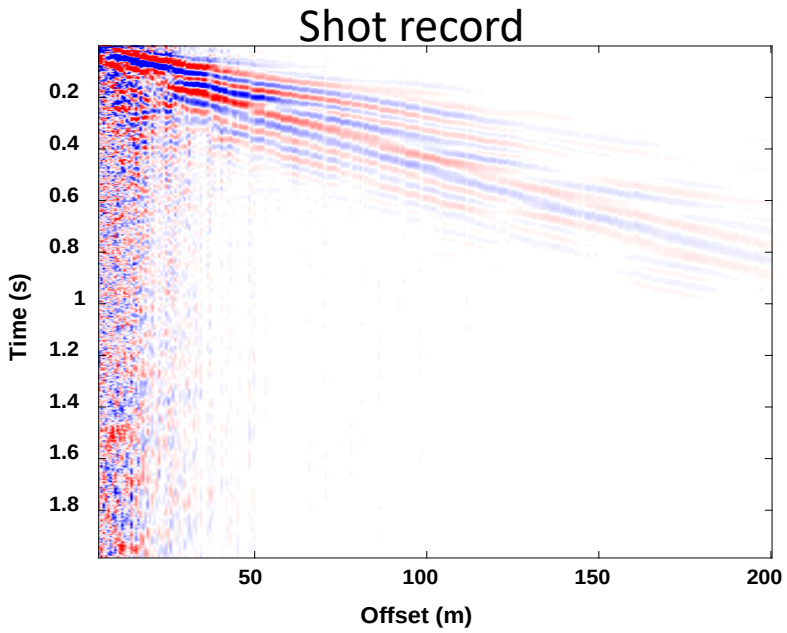


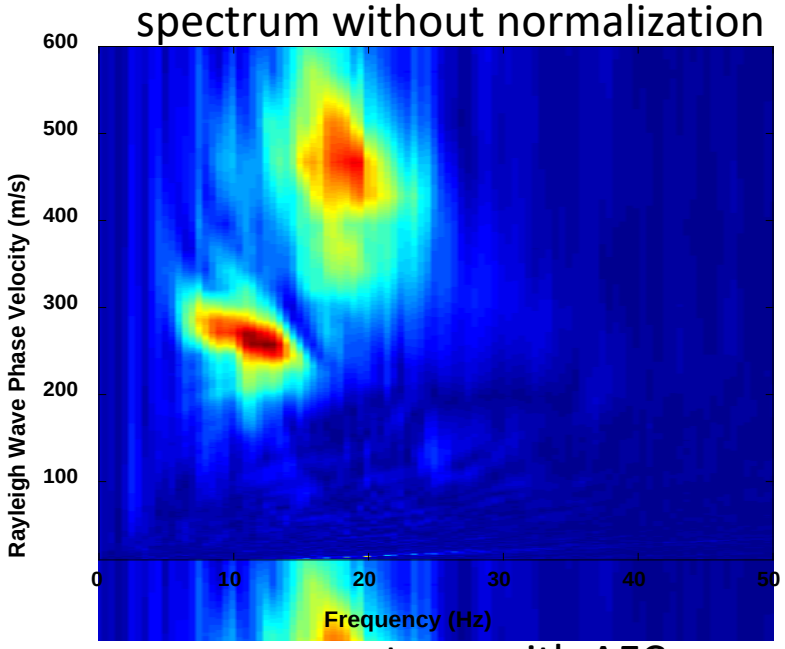
spectrum with AEC

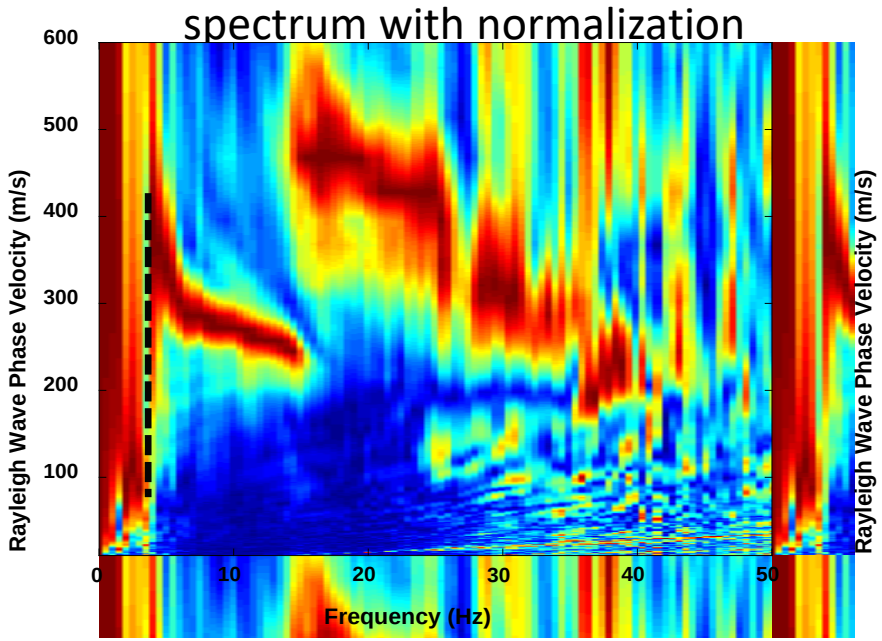


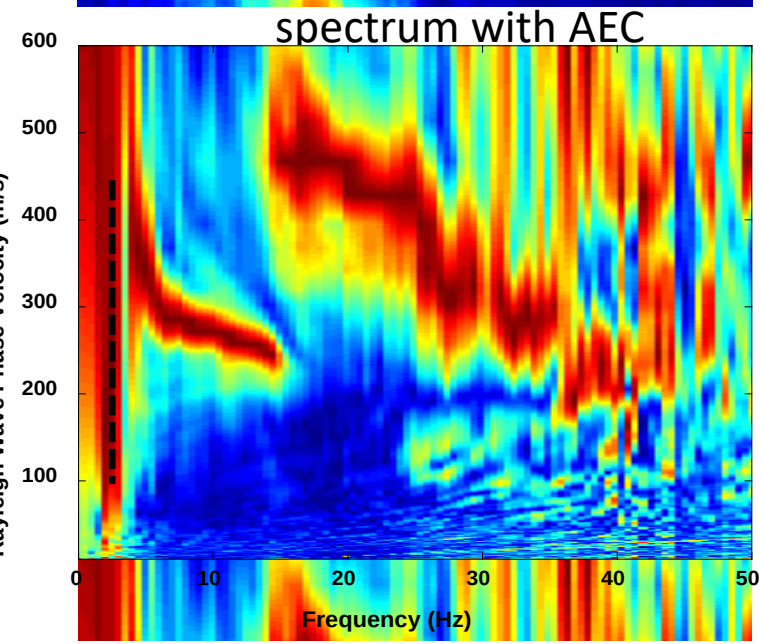
DAS data

2018 DAS data
Sweep
1~150Hz









Forward modeling

- Disper96(Saito)
- Surf96(Herrmann)

Inversion method

Dispersion Curve Inversion methods:

Gradient based inversion methods: Gaussian-newton, Conjugate gradient…

Non-gradient based:
- Genetic algorithm
- Neighborhood algorithm
- MCMC

Strong surface wave → surface wave inversion

Data media is stratified → 1 D inversion, GPDC

Layer number is unknown → Trans-dimensional Inversion(Reversible Jump MCMC)

MCMC is computational expensive → MPI, Parallel Tempering

Inversion method

Bayesian inversion

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

$$\alpha = \min\left[1, \frac{P(\mathbf{m}'_{k'})}{P(\mathbf{m}_k)} \frac{P(\mathbf{d}|\mathbf{m}'_{k'})}{P(\mathbf{d}|\mathbf{m}_k)} \frac{Q(\mathbf{m}_k|\mathbf{m}'_{k'})}{Q(\mathbf{m}'_{k'}|\mathbf{m}_k)}\right]$$

$$P(\mathbf{d}|\mathbf{m}) = \frac{1}{(2\pi)^{N/2}|\mathbf{C}_d|^{1/2}} \times \exp\left(-\frac{1}{2}(\mathbf{d}-\mathbf{d}(\mathbf{m}))^T \mathbf{C}_d^{-1}(\mathbf{d}-\mathbf{d}(\mathbf{m}))\right)$$

$$E = (\mathbf{d}-\mathbf{d}(\mathbf{m}))^T \mathbf{C}_d^{-1}(\mathbf{d}-\mathbf{d}(\mathbf{m}))$$

Trans-dimensional Bayesian inversion

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

$$\alpha = \min\left[1, \frac{P(k', \mathbf{m}'_{k'})}{P(k, \mathbf{m}_k)} \frac{P(d|k', \mathbf{m}'_{k'})}{P(d|k, \mathbf{m}_k)} \frac{Q(k, \mathbf{m}_k|k', \mathbf{m}'_{k'})}{Q(k', \mathbf{m}'_{k'}|k, \mathbf{m}_k)} |\mathbf{J}|\right]$$

$$|\mathbf{J}| = \left|\frac{\partial h(k, \mathbf{m}_k, \mathbf{u})}{\partial(k, \mathbf{m}_k, \mathbf{u})}\right| \qquad (k', \mathbf{m}'_{k'}, \mathbf{u}') = h(k, \mathbf{m}_k, \mathbf{u})$$

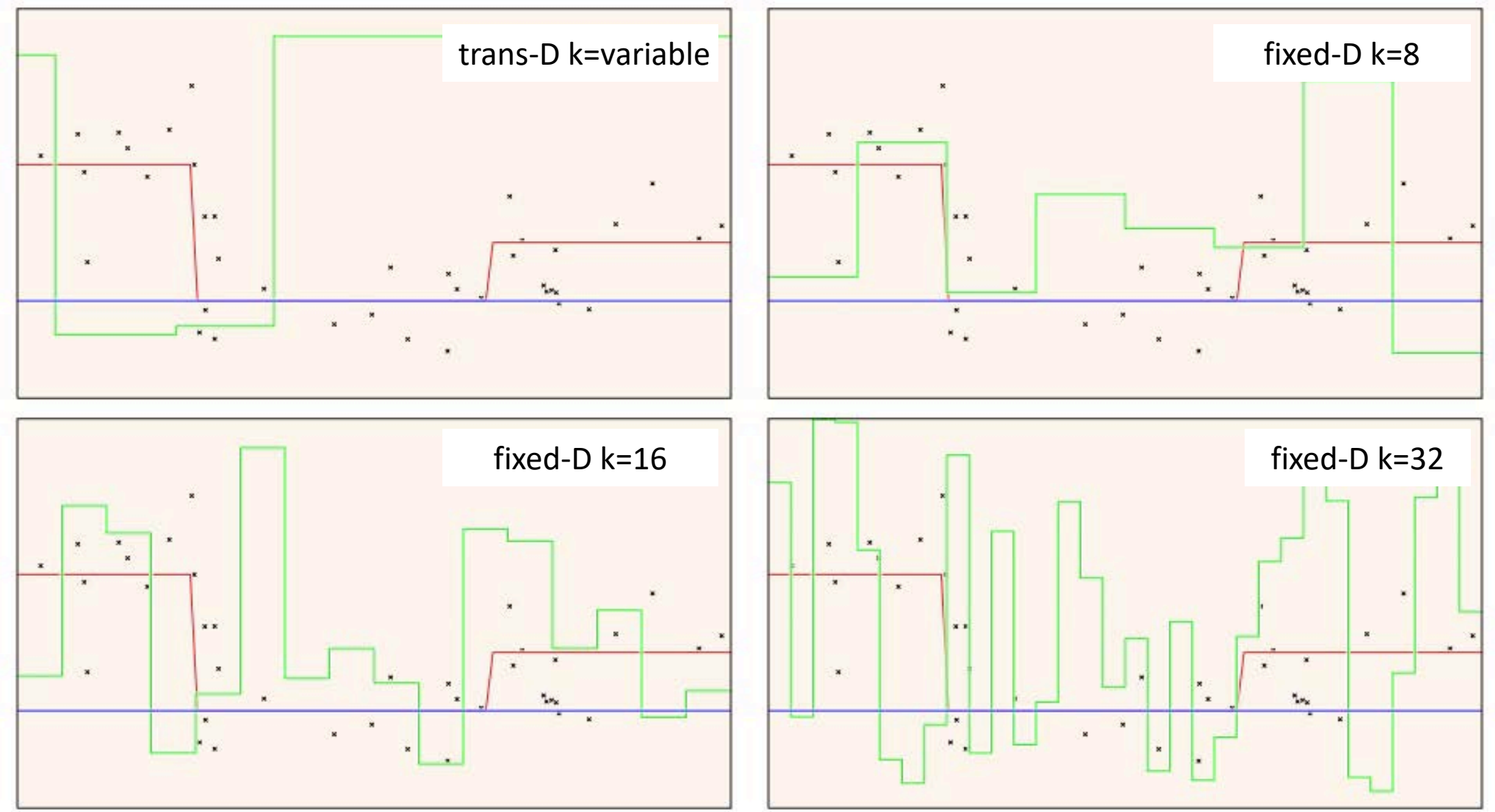
$$(k, \mathbf{m}_k, \mathbf{u}) = h^{-1}(k', \mathbf{m}'_{k'}, \mathbf{u}')$$

$$\frac{Q(k, \mathbf{m}_k|k', \mathbf{m}'_{k'})}{Q(k', \mathbf{m}'_{k'}|k, \mathbf{m}_k)} = \frac{Q(k|k', \mathbf{m}'_{k'})}{Q(k'|k, \mathbf{m}_k)} \frac{Q(h|k', \mathbf{m}'_{k'})}{Q(h'|k, \mathbf{m}_k)} \frac{Q(vs|k', \mathbf{m}'_{k'})}{Q(vs'|k, \mathbf{m}_k)} \frac{Q(\gamma|k', \mathbf{m}'_{k'})}{Q(\gamma'|k, \mathbf{m}_k)}$$

Birth-death scheme

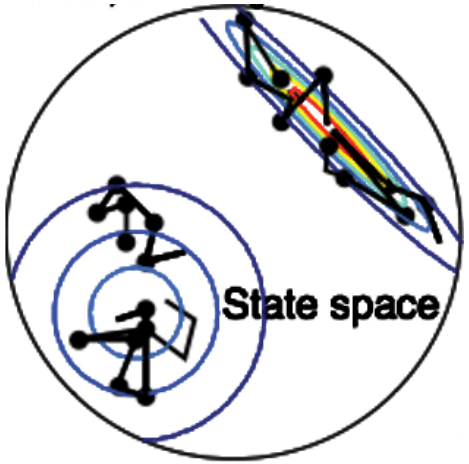
Inversion method

Trans-dimensional MCMC vs. Conventional MCMC

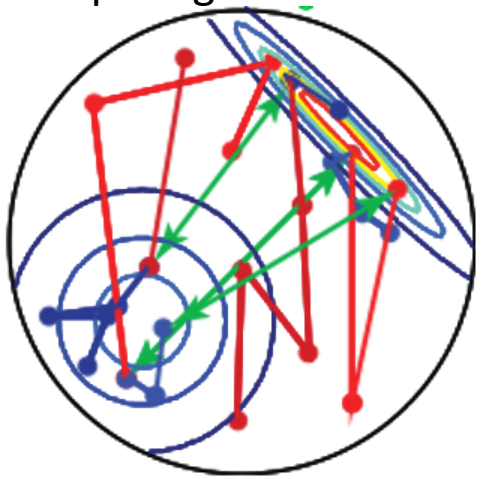


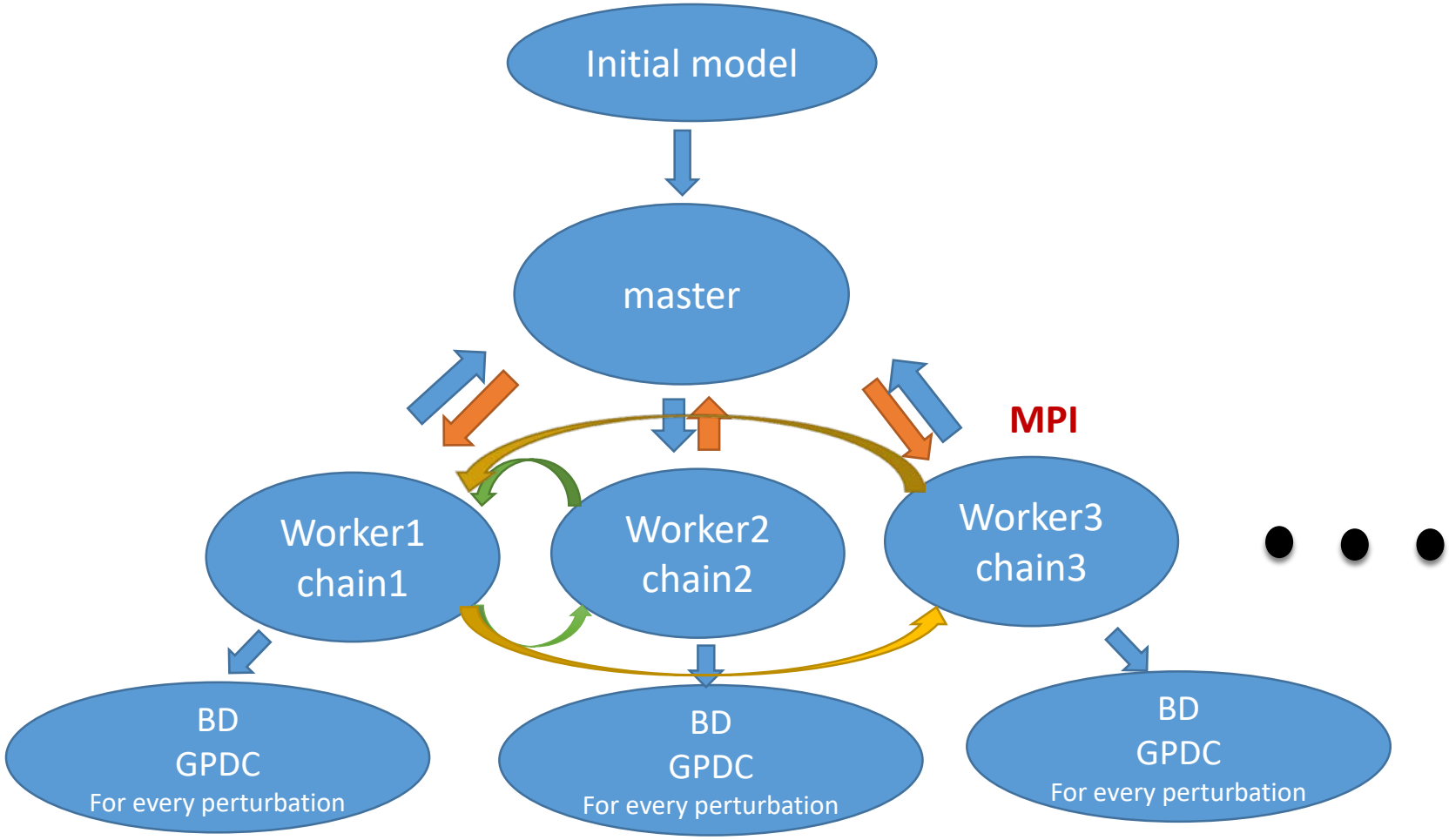
Inversion method

Conventional MCMC



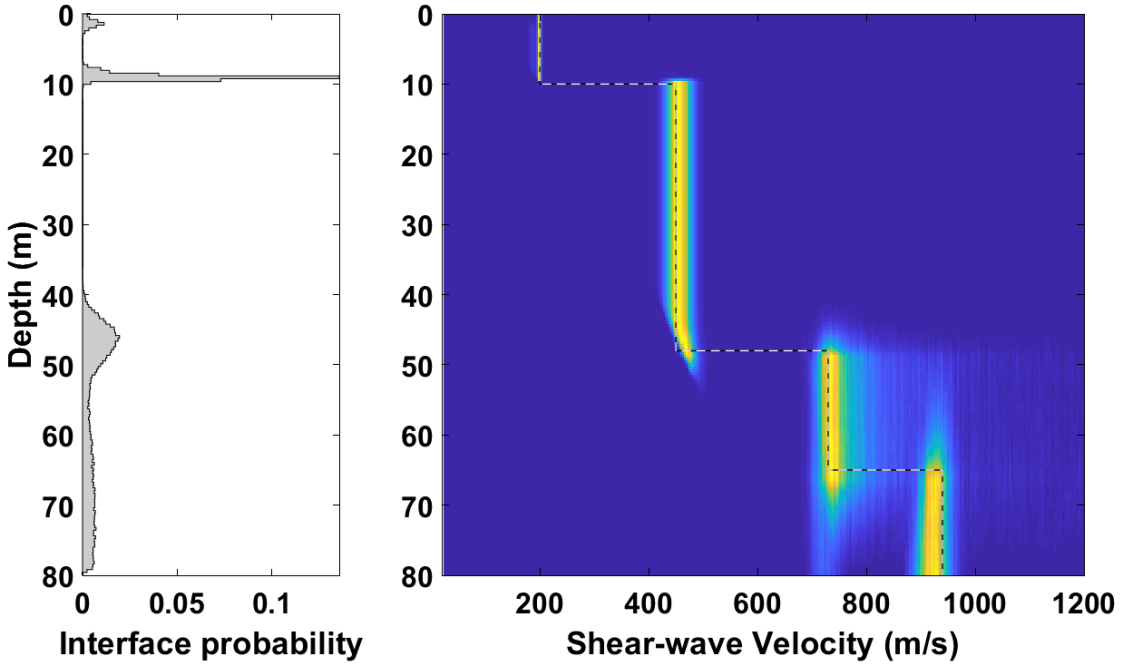
Parallel Tempering

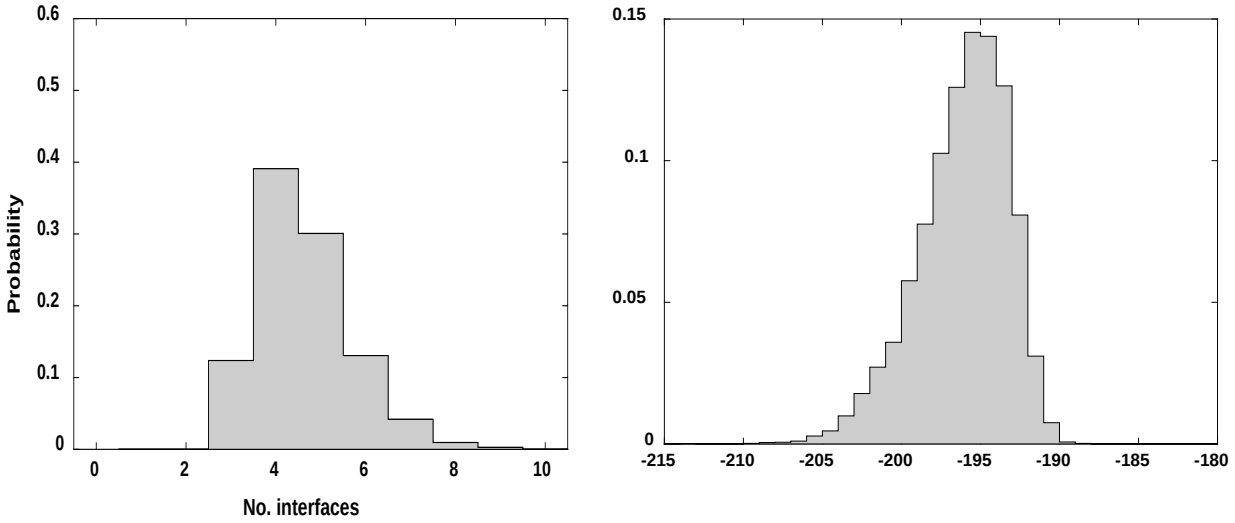


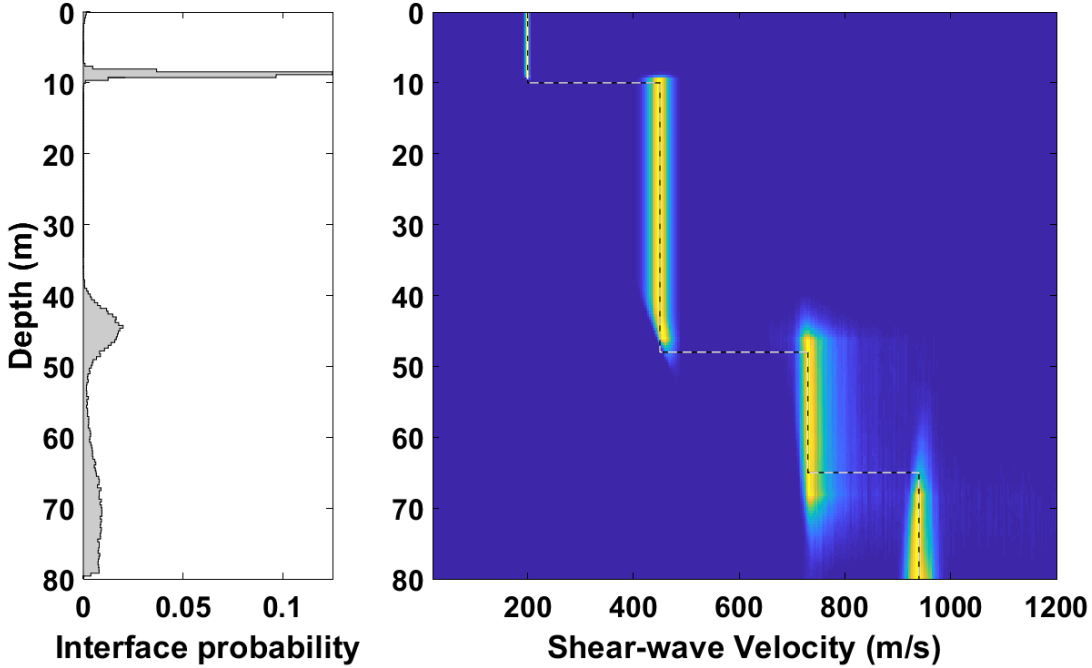


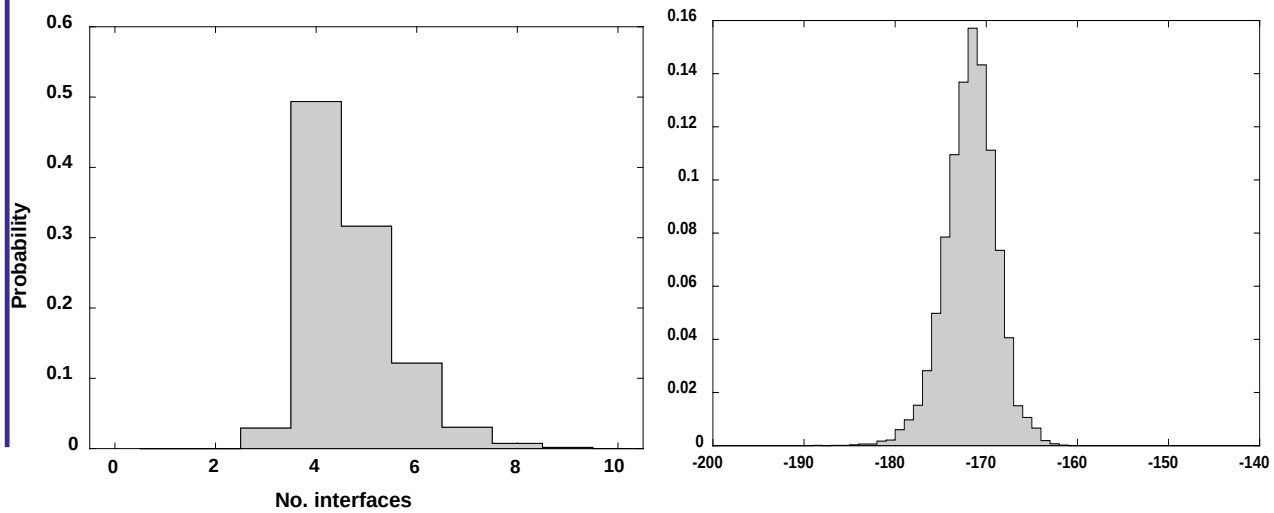
Parallel tempering to explore wide, exchange information between Markov Chains, converge efficiently.

Simulated model

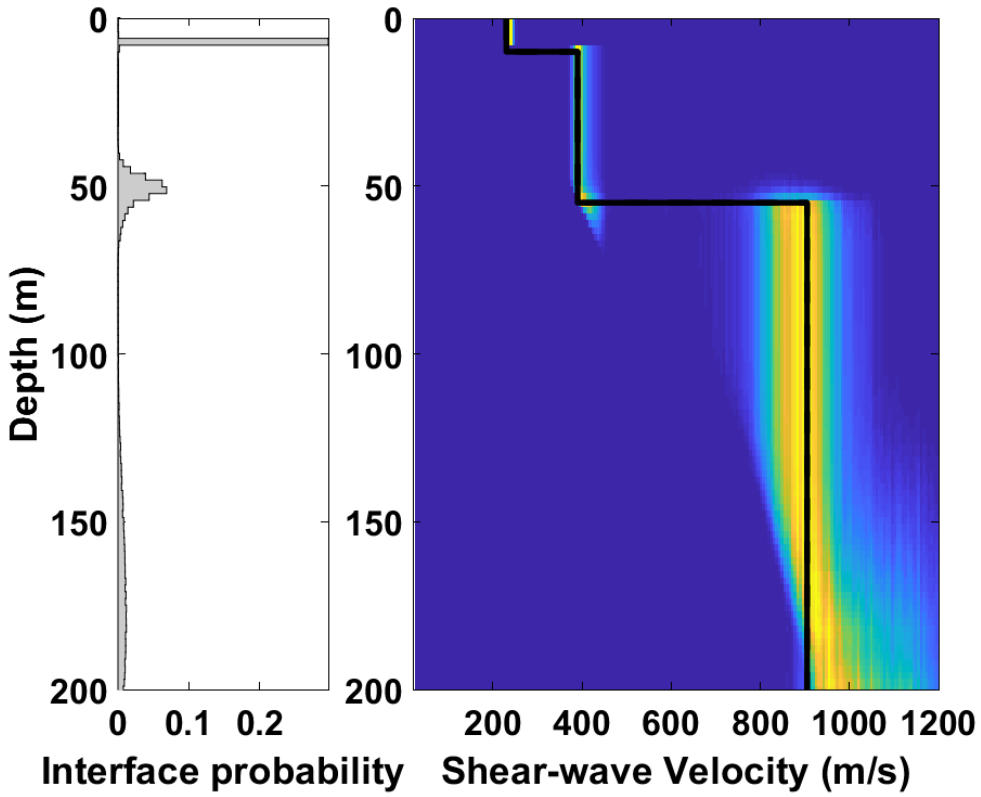


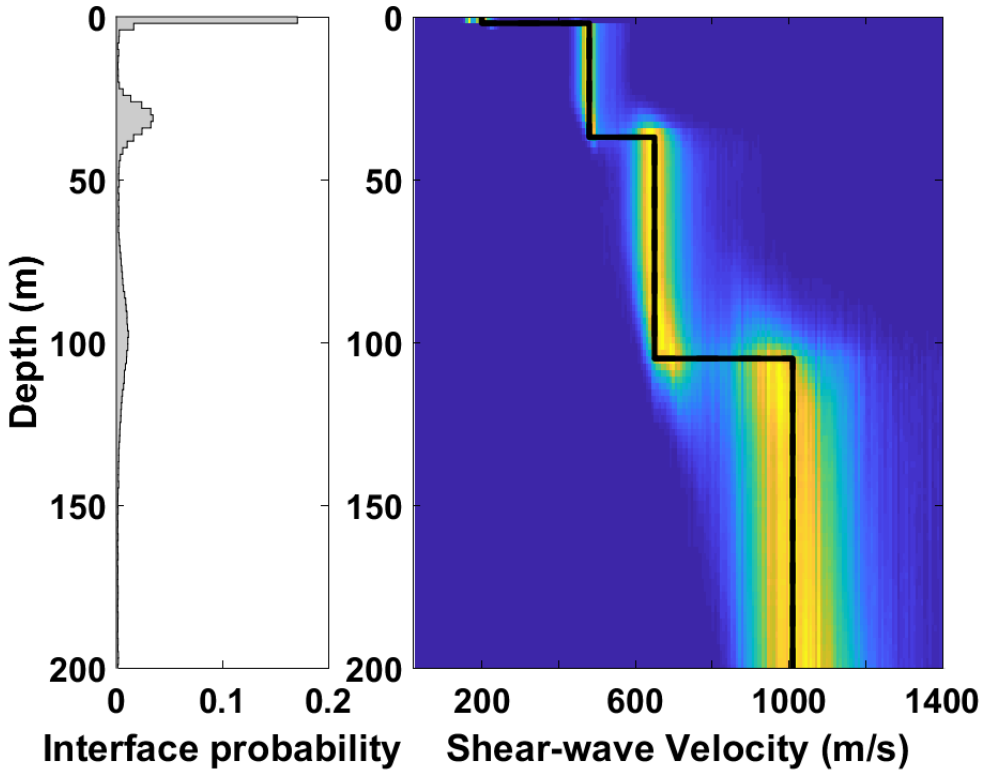


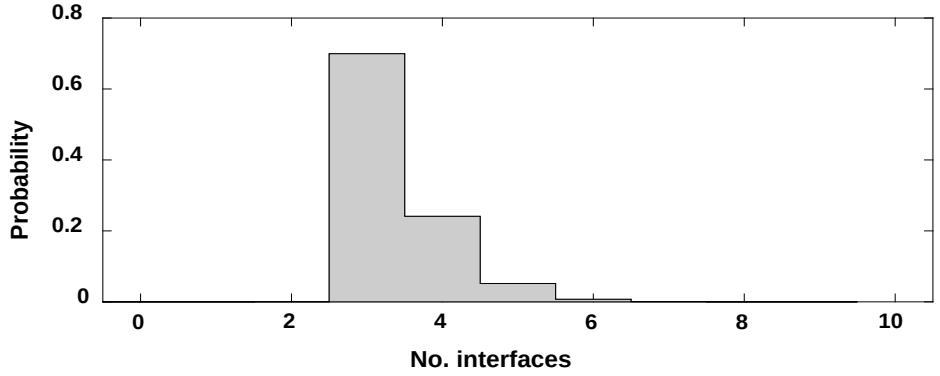


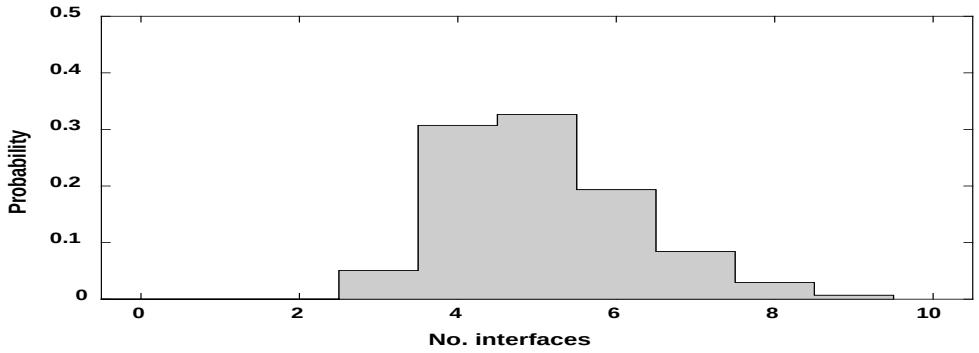


Simulated model



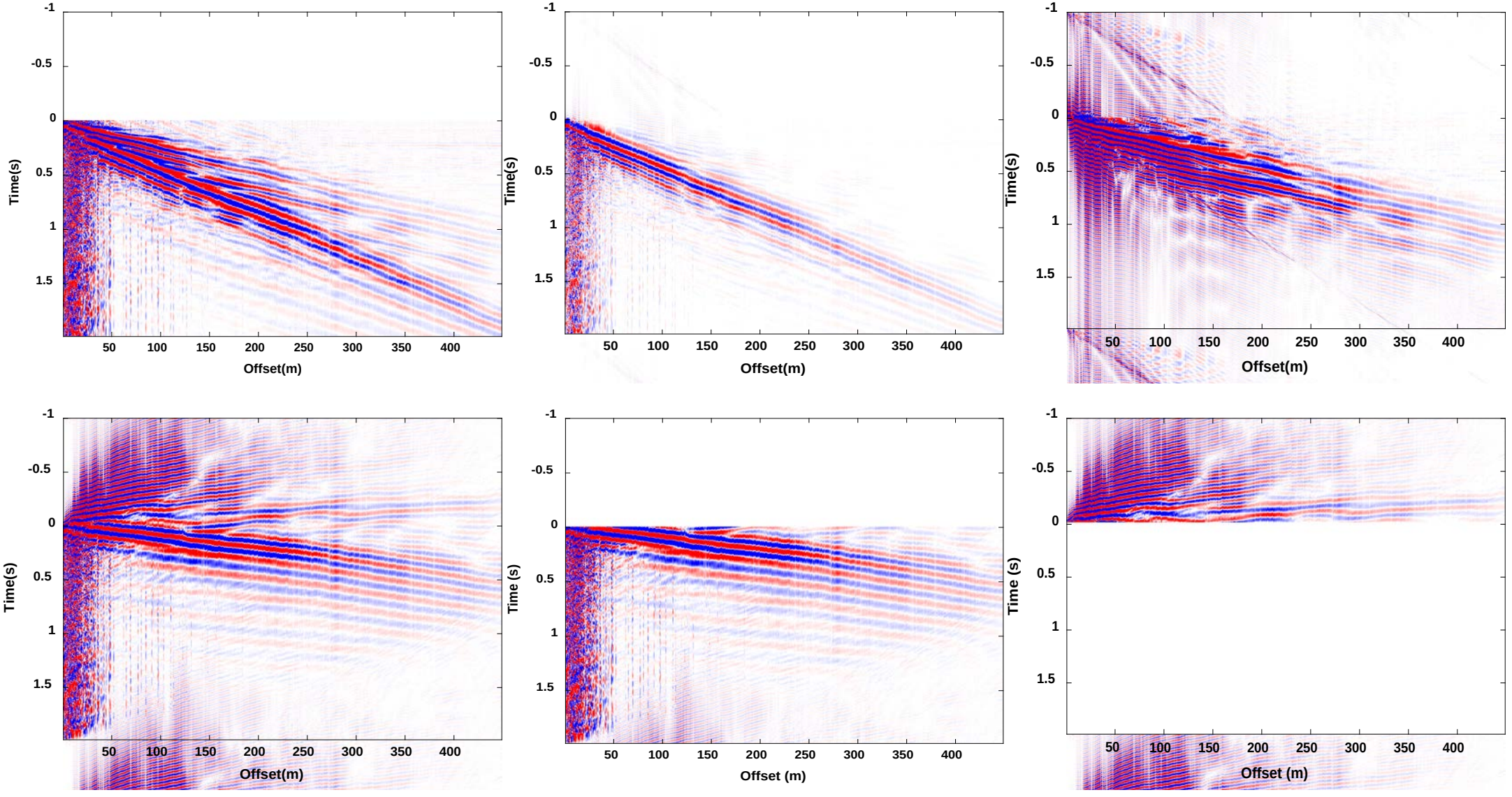




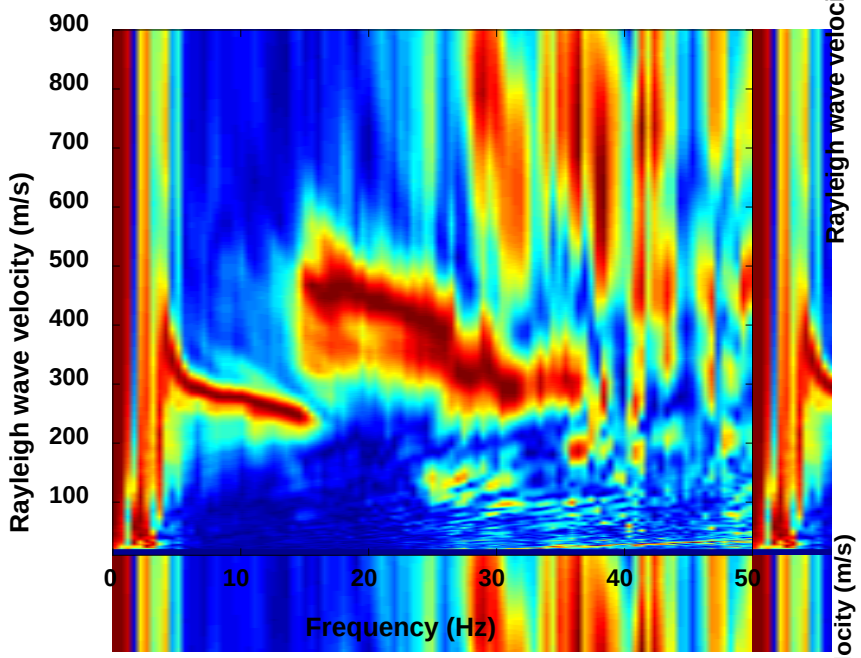


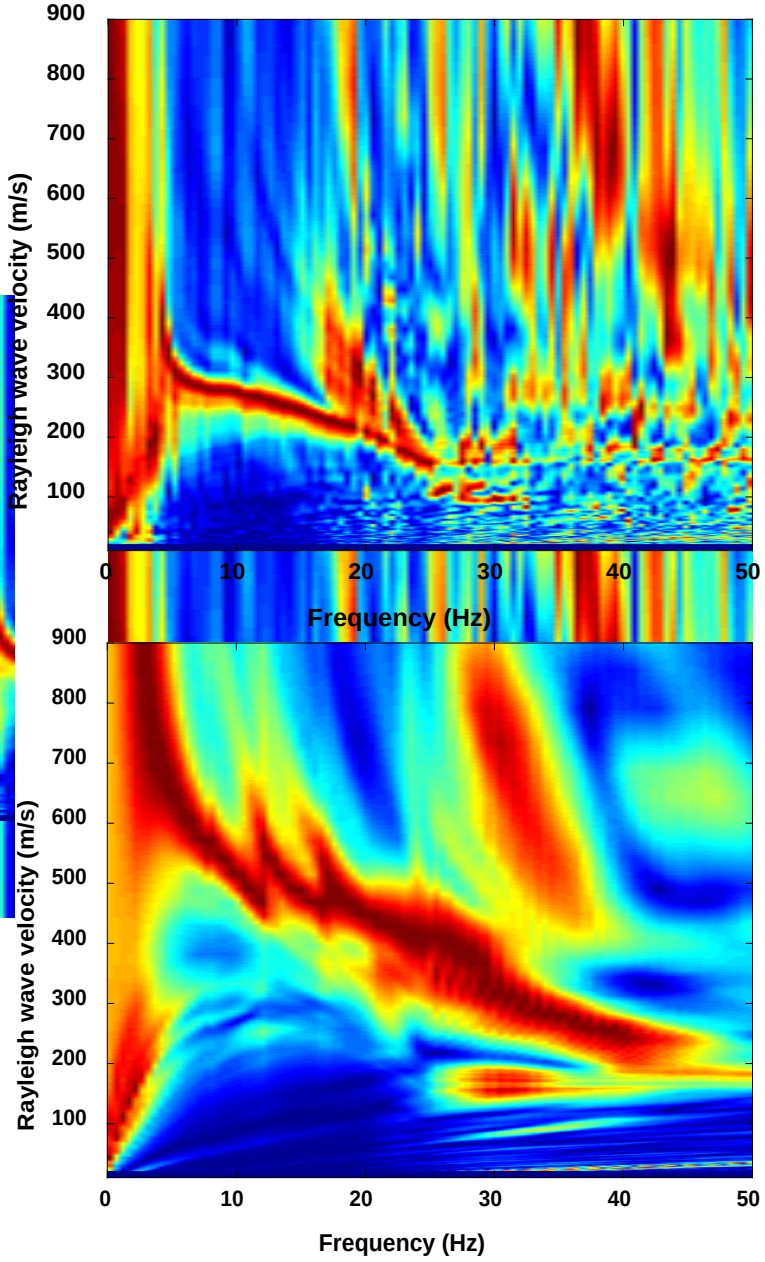
Mode separation

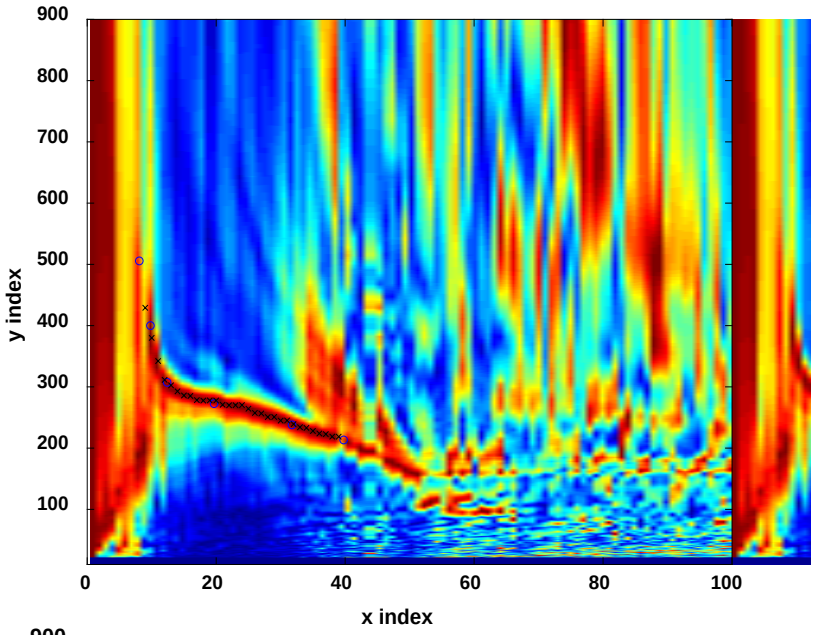
Mode separation ⟶ Dispersion Compensation

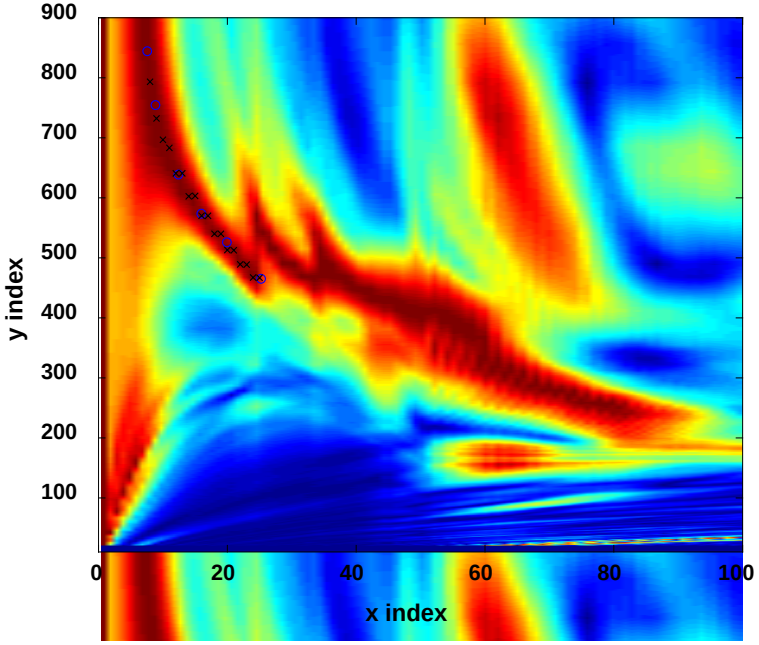


Mode separation

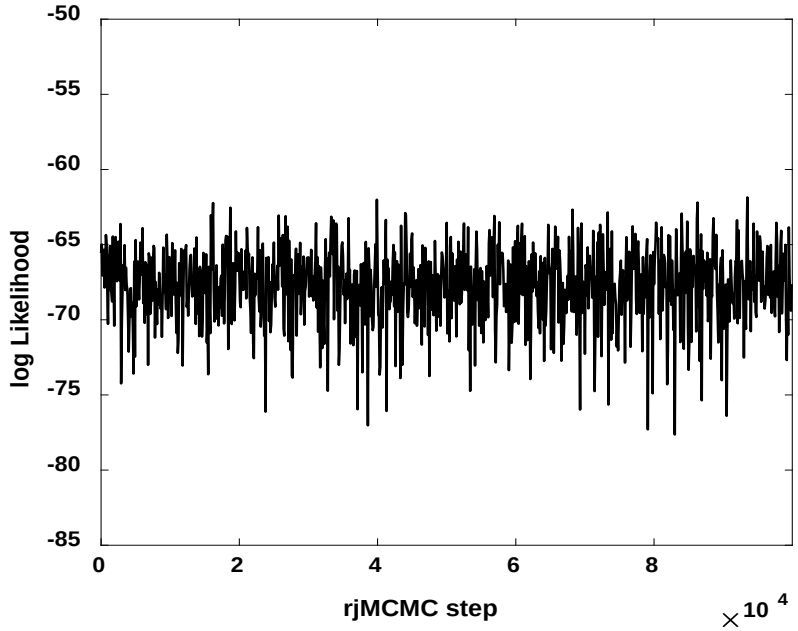


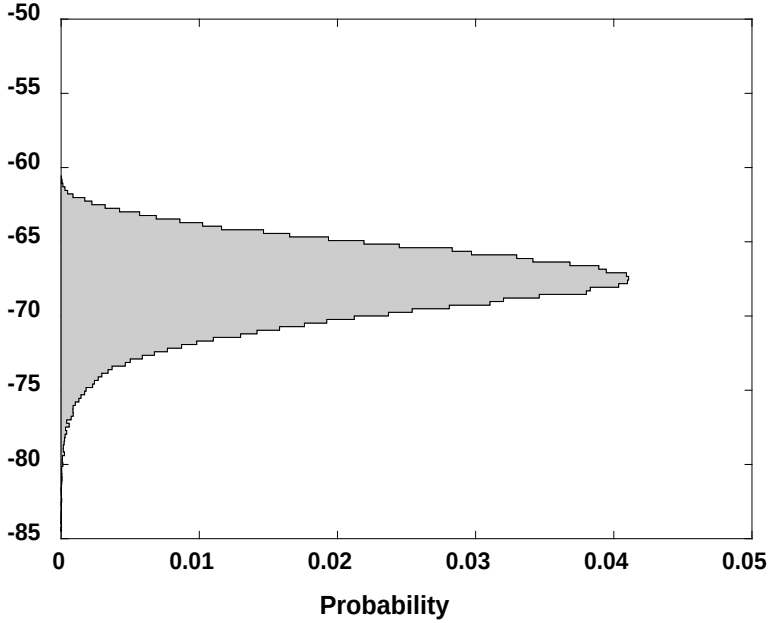


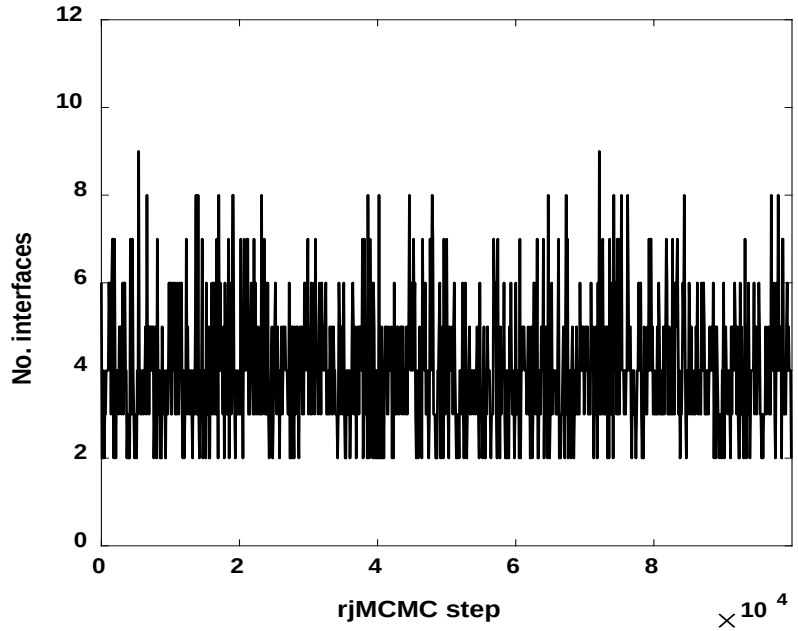


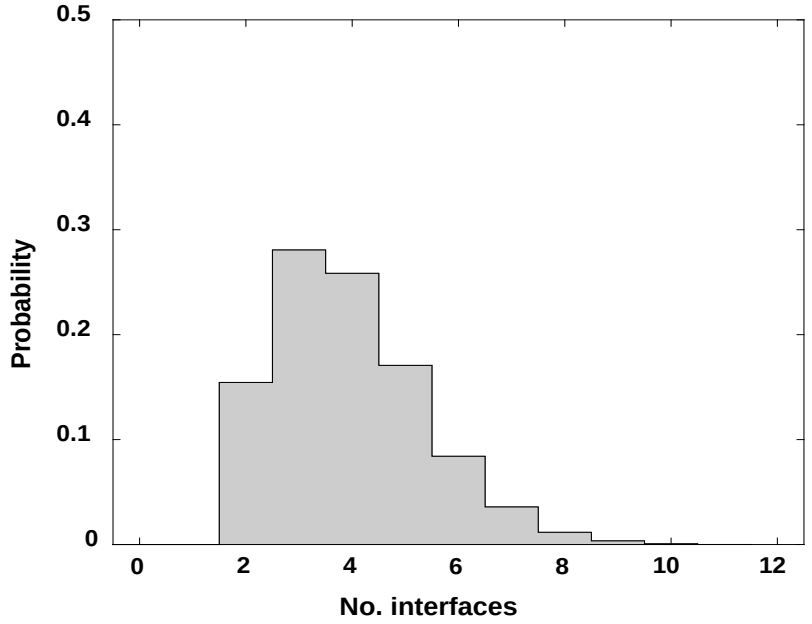


DAS data inversion



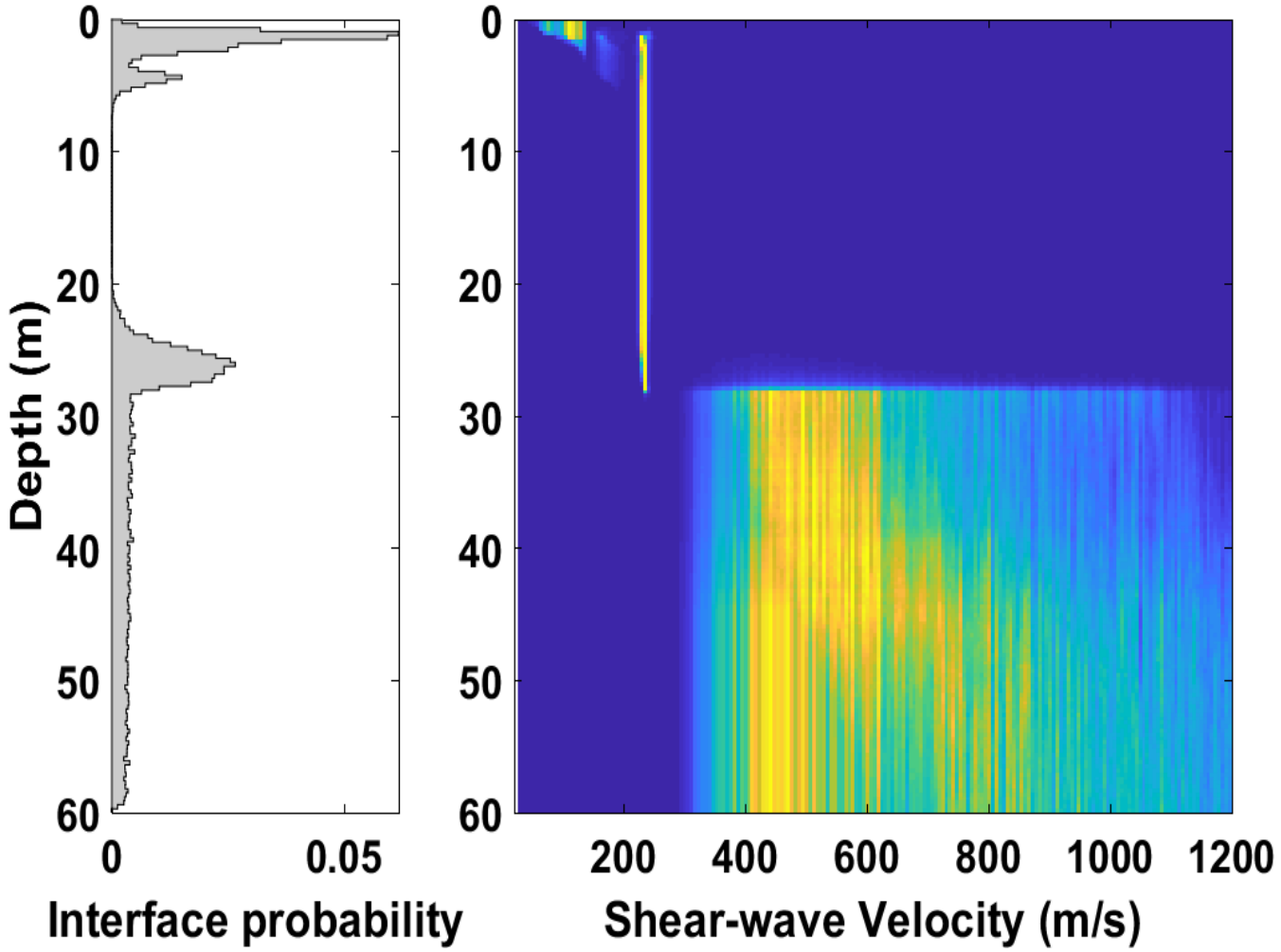




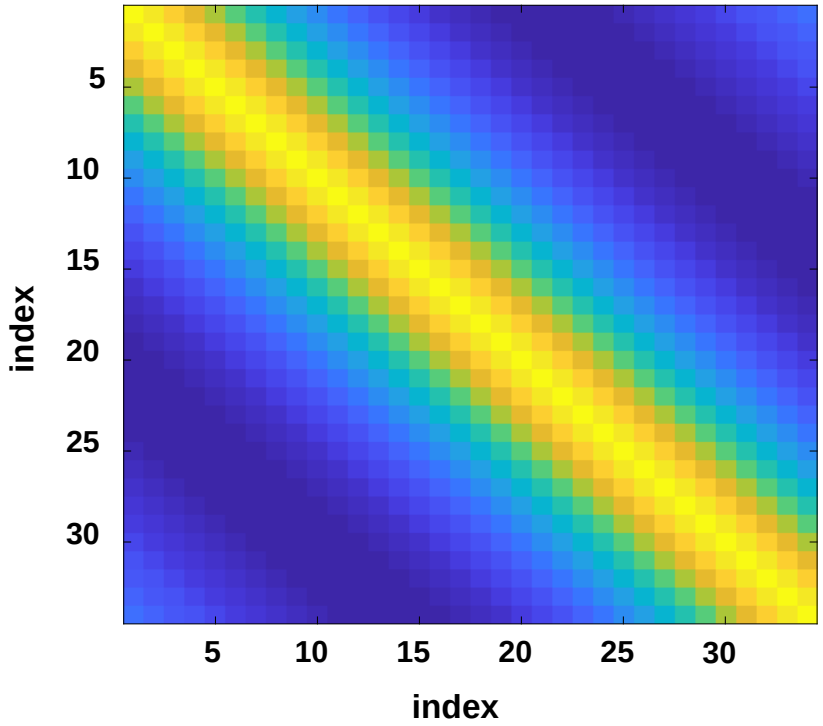


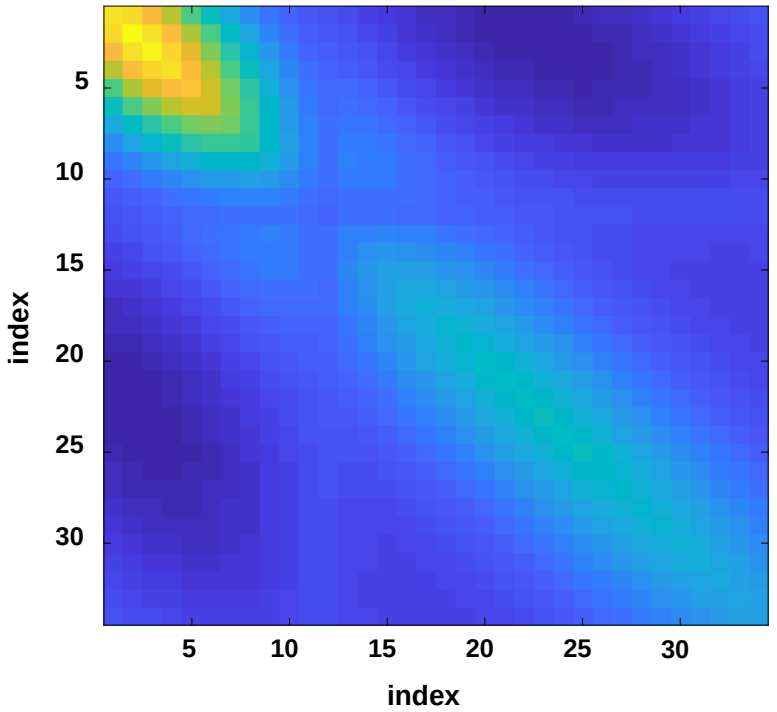
DAS inversion

Fundamental mode dispersion curve inversion



DAS data analysis



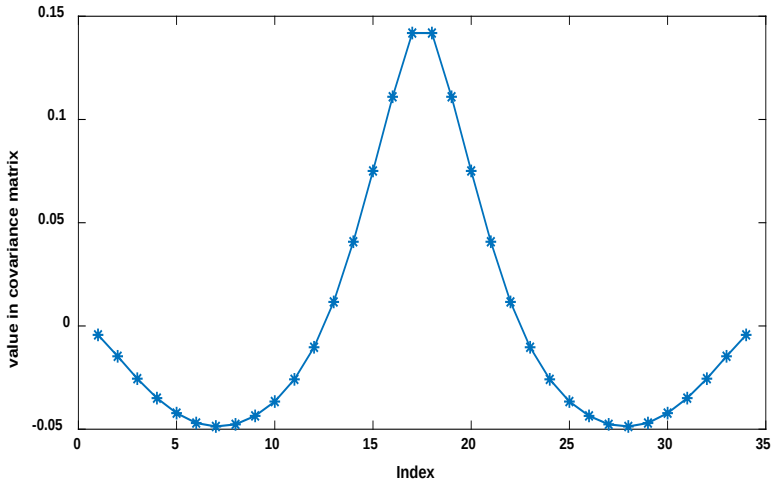


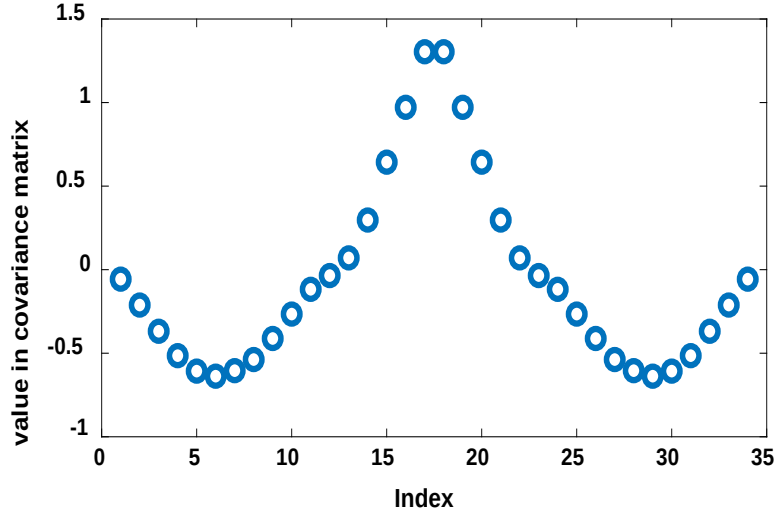
$$E = (\mathbf{d} - \mathbf{d}(\mathbf{m}))^T \mathbf{C}_d^{-1} (\mathbf{d} - \mathbf{d}(\mathbf{m}))$$

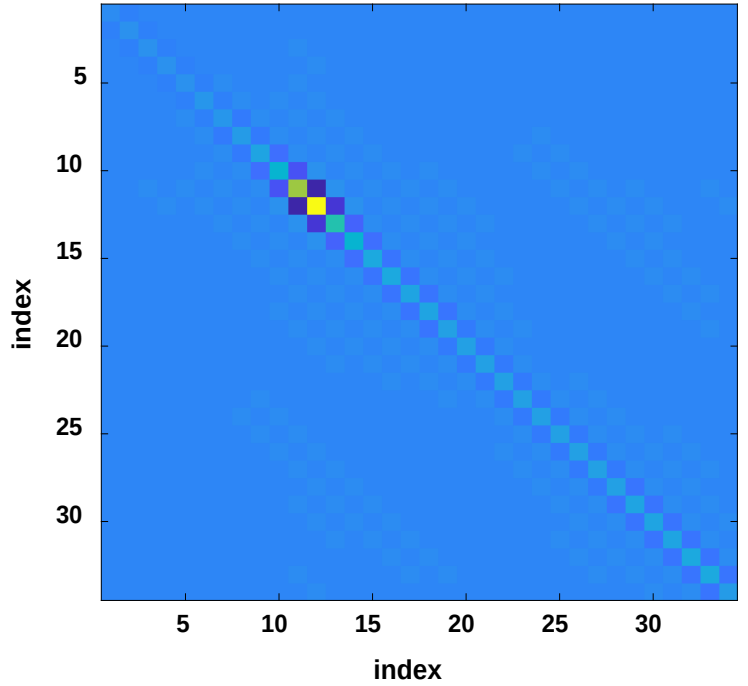
$$c_{ij} = \frac{1}{N} \sum_{k=0}^{N-j-1} (r_{ij+k} - \overline{r}_i)(r_{ik} - \overline{r}_i)$$

$$\sigma_j = \sqrt{\frac{1}{Q} \sum_{k=j-Q/2}^{j+Q/2} r_k^2}$$

$$n_j = \frac{r_i}{\sigma_j} \qquad C_{jl}^{(d)} = \tilde{C}_{jl} \sigma_j \sigma_l$$

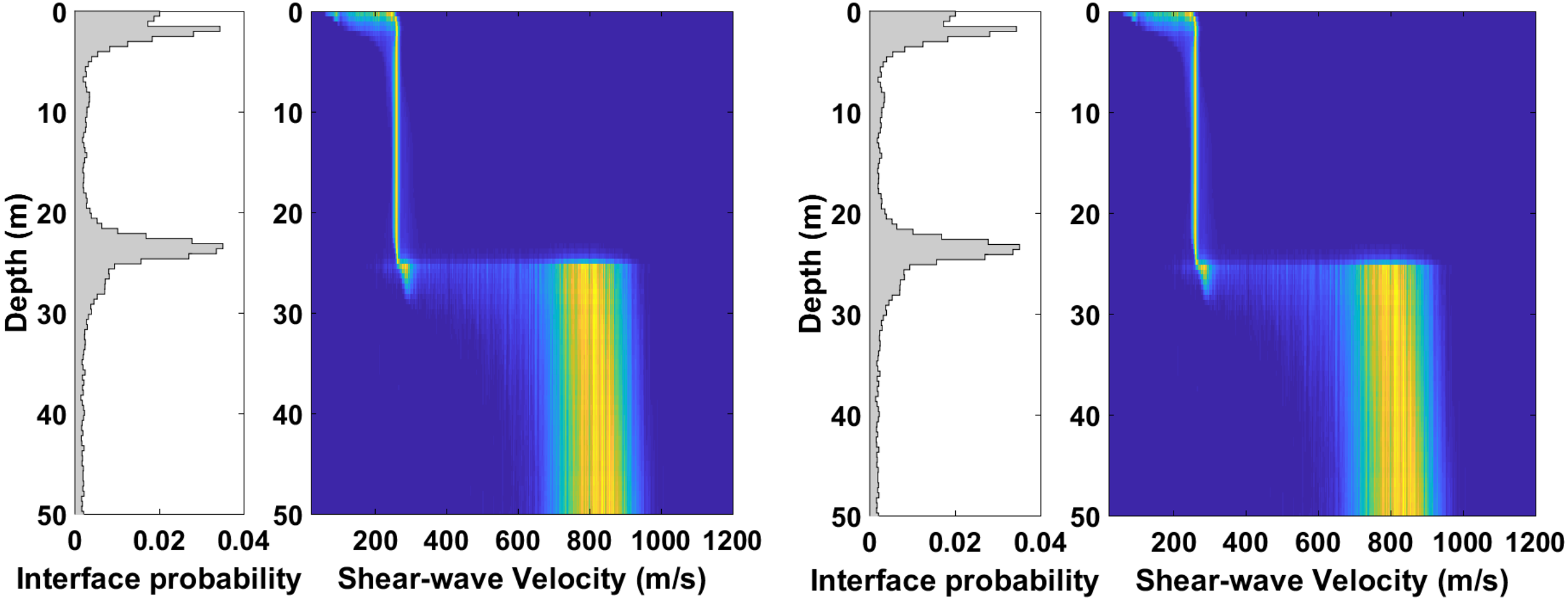






DAS data inversion

Second inversion result



Future work

- Multimode inversion
- Joint inversion(group velocity or ellipticity)
- 2D imaging through Bayesian inversion

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DAS data inversion