Ocean Ambient Noise for Seabed Characterization

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Outline

- Introduction
- Inversion methods
- Ocean ambient noise
- Geoacoustic inversion
- Summary

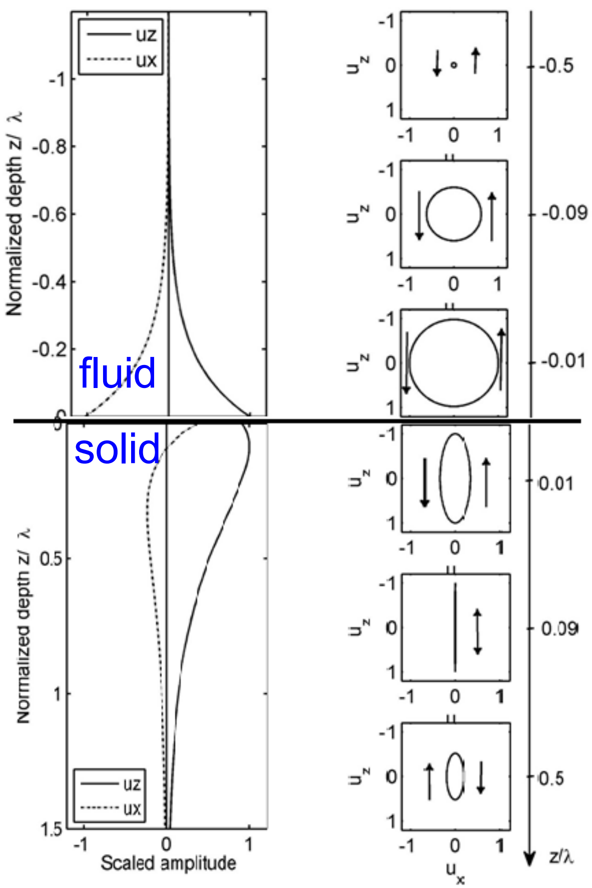
Shear-wave velocity

- Directly related to shear modulus, a critical parameter for offshore geotechnical engineering
- Direct indicator for geohazard
- Provide constraint for migrations for reservoir characterization and production monitoring
- Provide constrain for seismic inversion
- Contribute to propagation loss for sonar performance especially in shallow water
- Related to interface wave dispersion.

Interface waves

- **Rayleigh/Love wave** at air/solid interface
- [Scholte wave at fluid/solid interface]
- **Stoneley wave** at solid/solid interface
- Cylindrical propagation along the interface
- Exponential decaying away from the interface
- Elliptical particle motion
- Dispersive for layered media
- Lower frequency components travelling faster

Hodograph of the particle motion



Inversion methods

- Linearized inversion
  - Singular value decomposition
- Nonlinear inversion
  - Optimization

    ASSA (adaptive simplex simulated annealing)

    DE (differential evolution)

    GA (genetic algorithms)
  - Bayesian approach

Bayes' Theorem

Let: $\mathbf{m}$ be model parameterization

$\mathbf{d}$ be observed data

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

Bayes' Theorem

Let: $\mathbf{m}$ be model parameterization

$\mathbf{d}$ be observed data

Prior information

Data information: Interpreted as likelihood of $\mathbf{m}$ for measured $\mathbf{d}$

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

Posterior probability density (PPD)

Constant for given $\mathbf{d}$

The likelihood: $\mathrm{P}(\mathbf{d} | \mathbf{m}) = L(\mathbf{m}) \propto \exp(-E(\mathbf{m}))$

PPD: $$\mathrm{P}(\mathbf{m} | \mathbf{d}) = \frac{\exp(-\phi(\mathbf{m}))}{\int \exp(-\phi(\mathbf{m}'))d\mathbf{m}'}$$

Model parameterization

Bayesian information criterion (BIC)

$$\mathrm{BIC} = 2E(\hat{\mathbf{m}}) + M \log_e N$$

Data misfit   # parameters   # data

- Minimizing the BIC trades off fitting the data against over-parameterizing the model
- Providing the simplest parameterization consistent with the data resolution

Passive acoustics

- One man's noise is another man's signal
- Treating noise as the signal
- Extracting coherent information from noise
  - Senor-sensor correlation
  - Beamforming (beam-beam) correlation
- Using correlation from noise for inversion

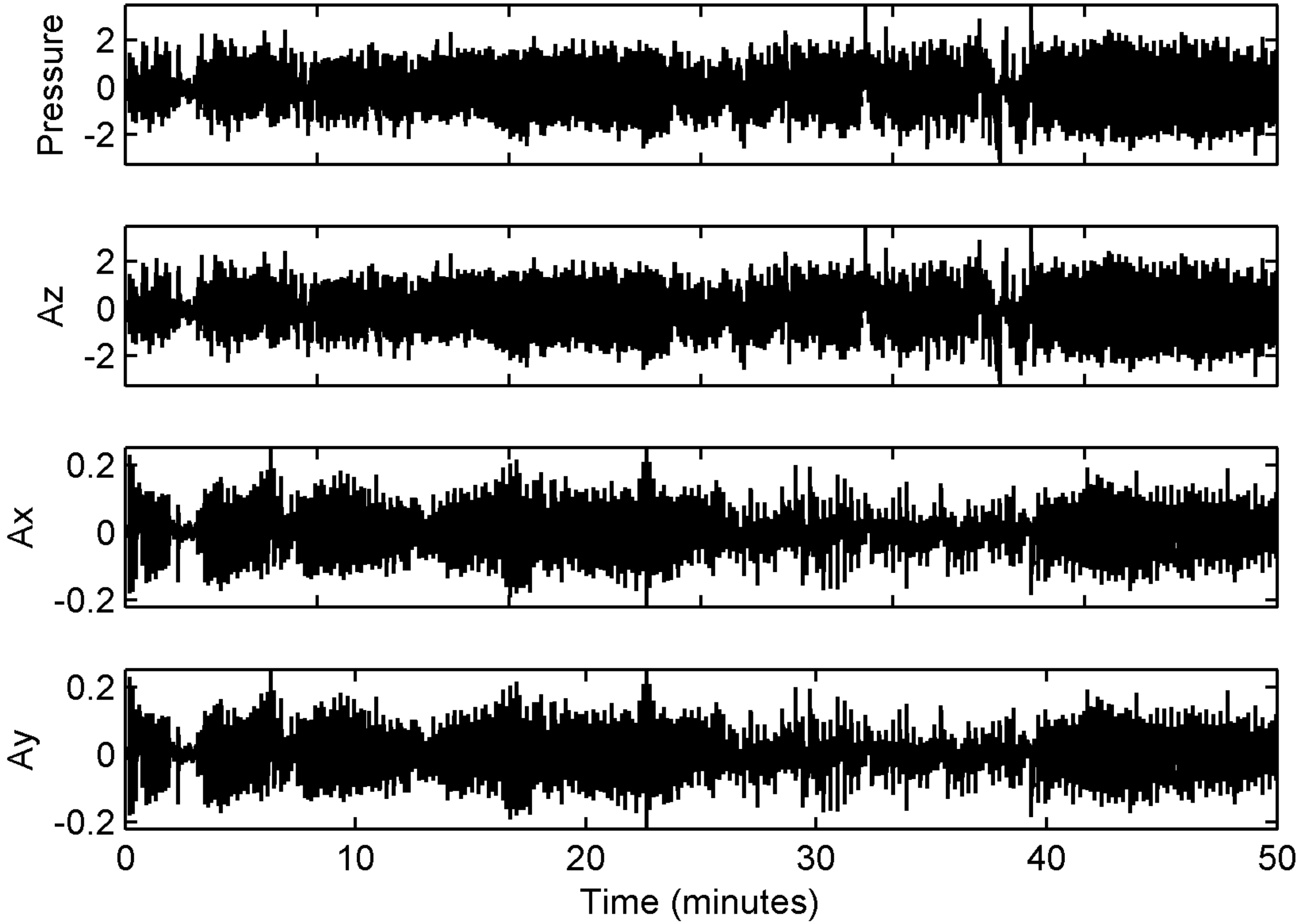
Ocean ambient noise

- Ambient noise from both land and ocean has been used to infer the earth or ocean bottom structure.
- Applications for seismic exploration and earthquakes have used **days or years of ambient noise records.**
- In this study **2.3 hours** of noise records are analysed.
- Green's functions by cross-correlation of the noise records between all receiver pairs are retrieved.
- Interface wave dispersion curves are extracted from the Green's functions by time-frequency analysis.
- Shear-wave velocity profile in the sea bottom is estimated by inverting the dispersion curves of the interface waves.

Ocean ambient noise recording

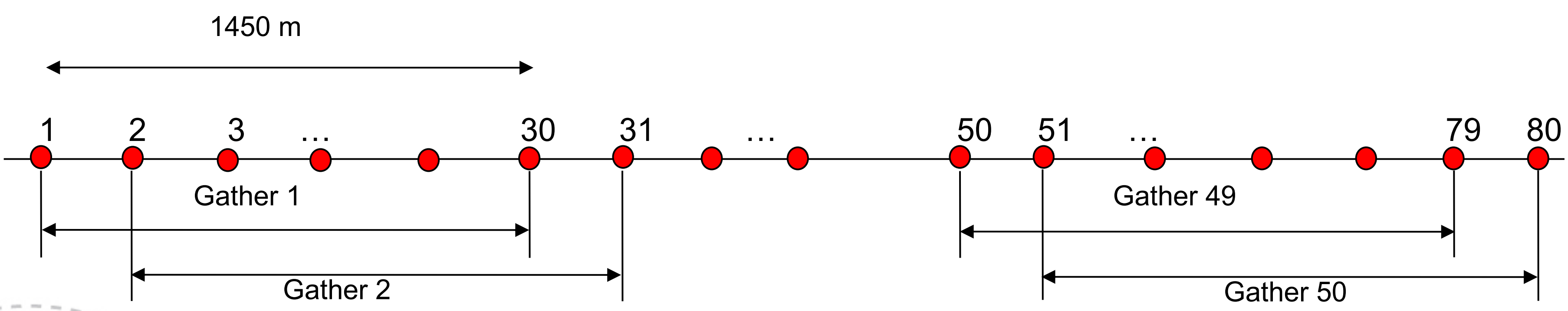
- OBC sensor : 4 components (Ax, Ay, Az, P)
- OBC orientation : EW
- Sensor spacing : 50 m
- Cable length : Two 5-km/196 sensors
- Recording time : 2.38 hours
- Sampling interval : 2 ms
- Water depth : 300-350 m

Multi-component noise data

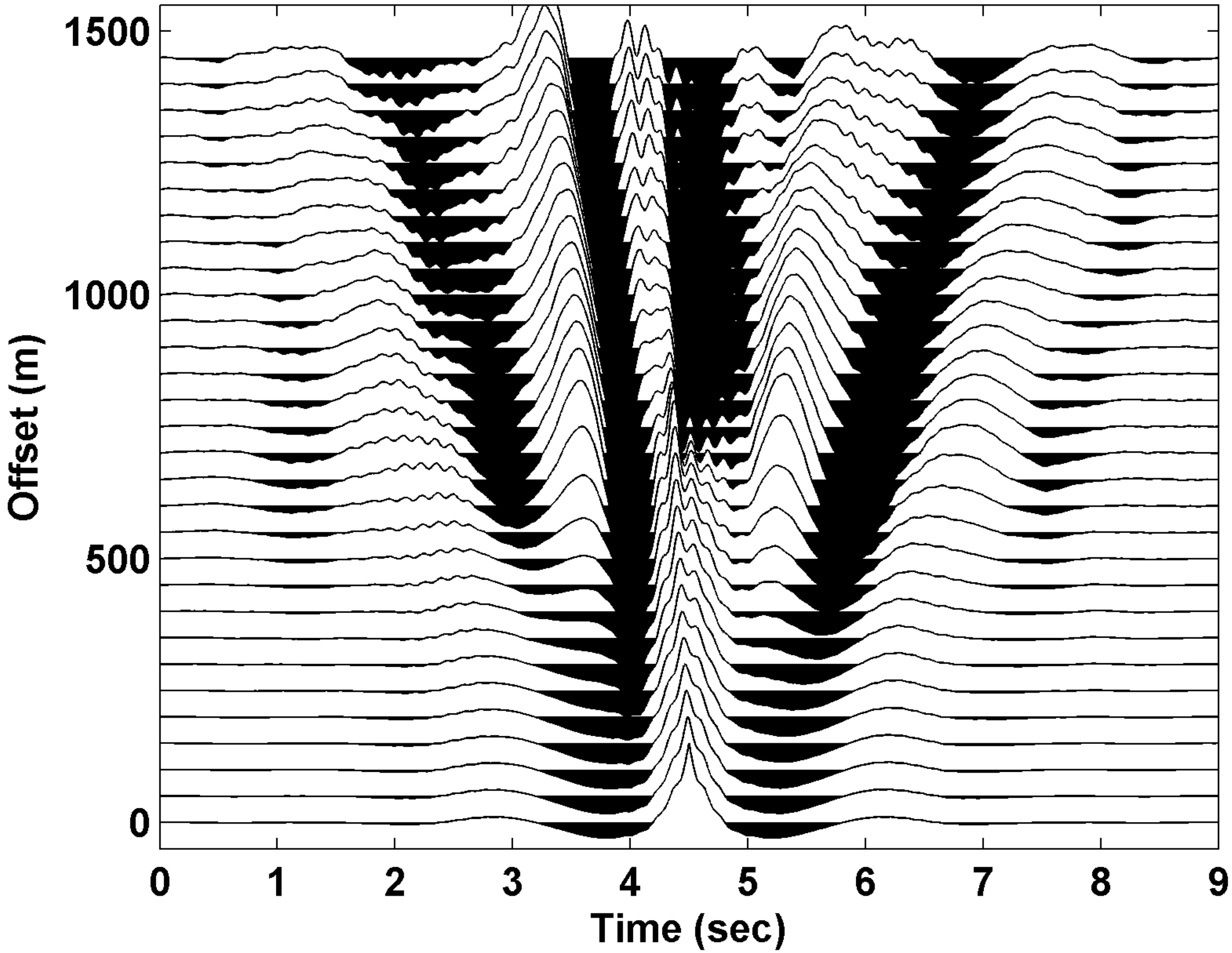


Data processing

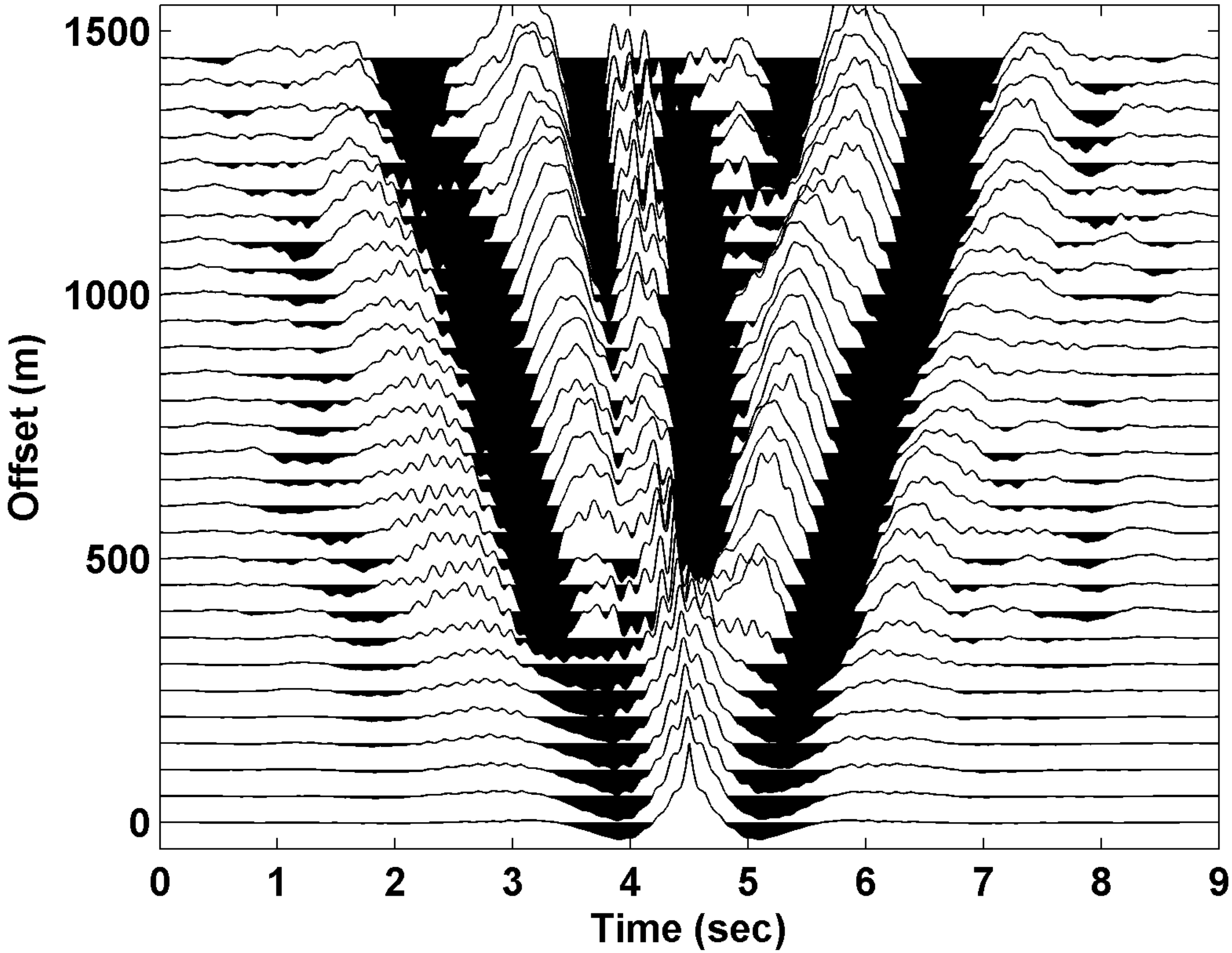
- Low-pass filtering (0.68-6 Hz)
- One-bit normalization
- Segmentation (4.5s each segment)
- Cross-correlation and stacking
- Gathers (30 Green's functions each gather)



Green functions - pressure



Green functions - Inline



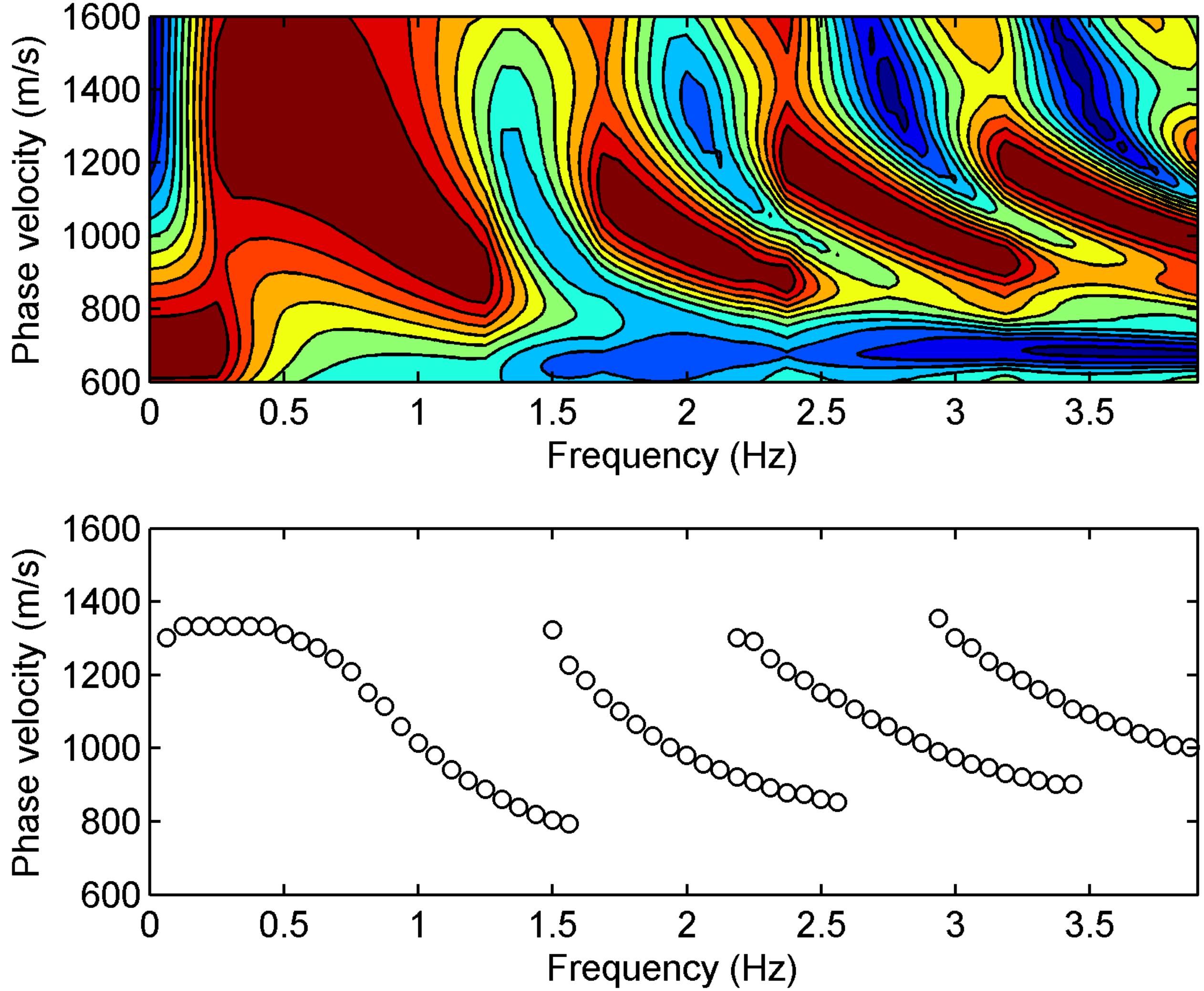
τ – *p* transform

Linearly invertible transforms between (*t, x*) ↔ (τ, *p*)

$$t = \tau + px$$

$$\begin{cases} u(x,t) = \iint_{-\infty}^{\infty} \frac{N(k,\omega)}{D(k,\omega)} \mathrm{e}^{i(kx-\omega t)}\, dk d\omega \\ U(p,\tau) = \int_{-\infty}^{\infty} u(x,\tau+px)dx = \int_{-\infty}^{\infty} \frac{N(\omega p,\omega)}{D(\omega p,\omega)} \mathrm{e}^{-i\omega\tau}\, d\omega \\ U(p,\omega) = \frac{N(\omega p,\omega)}{D(\omega p,\omega)} \end{cases}$$

Phase-velocity dispersion

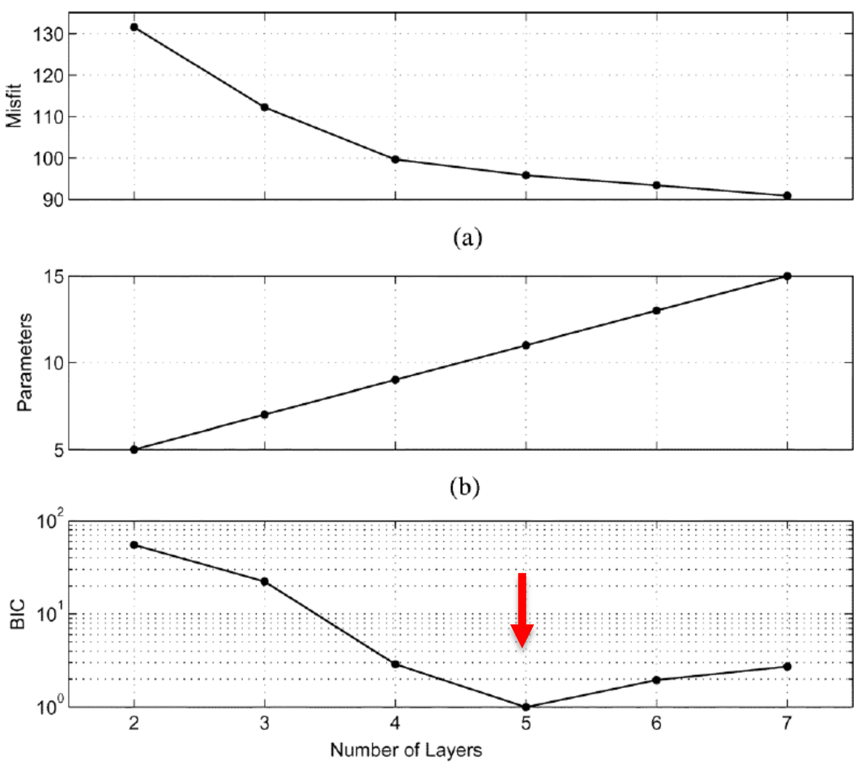


Model selection

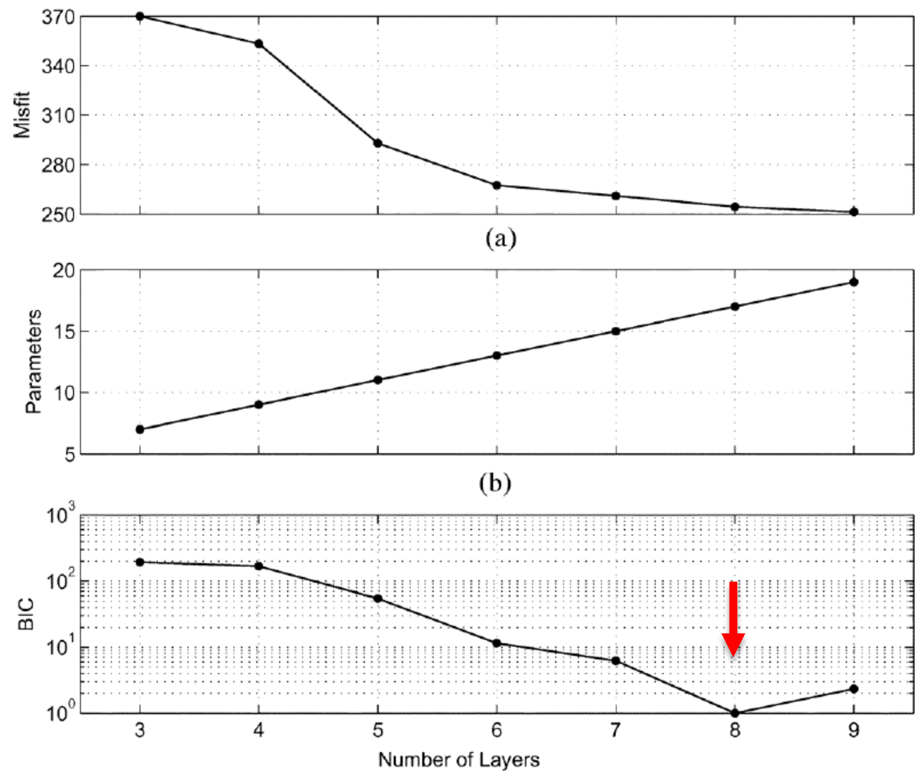
$$\mathrm{BIC} = 2E(\hat{\mathbf{m}}) + M \log_e N$$

It is assumed that the seabed consists of homogeneous horizontal layers.

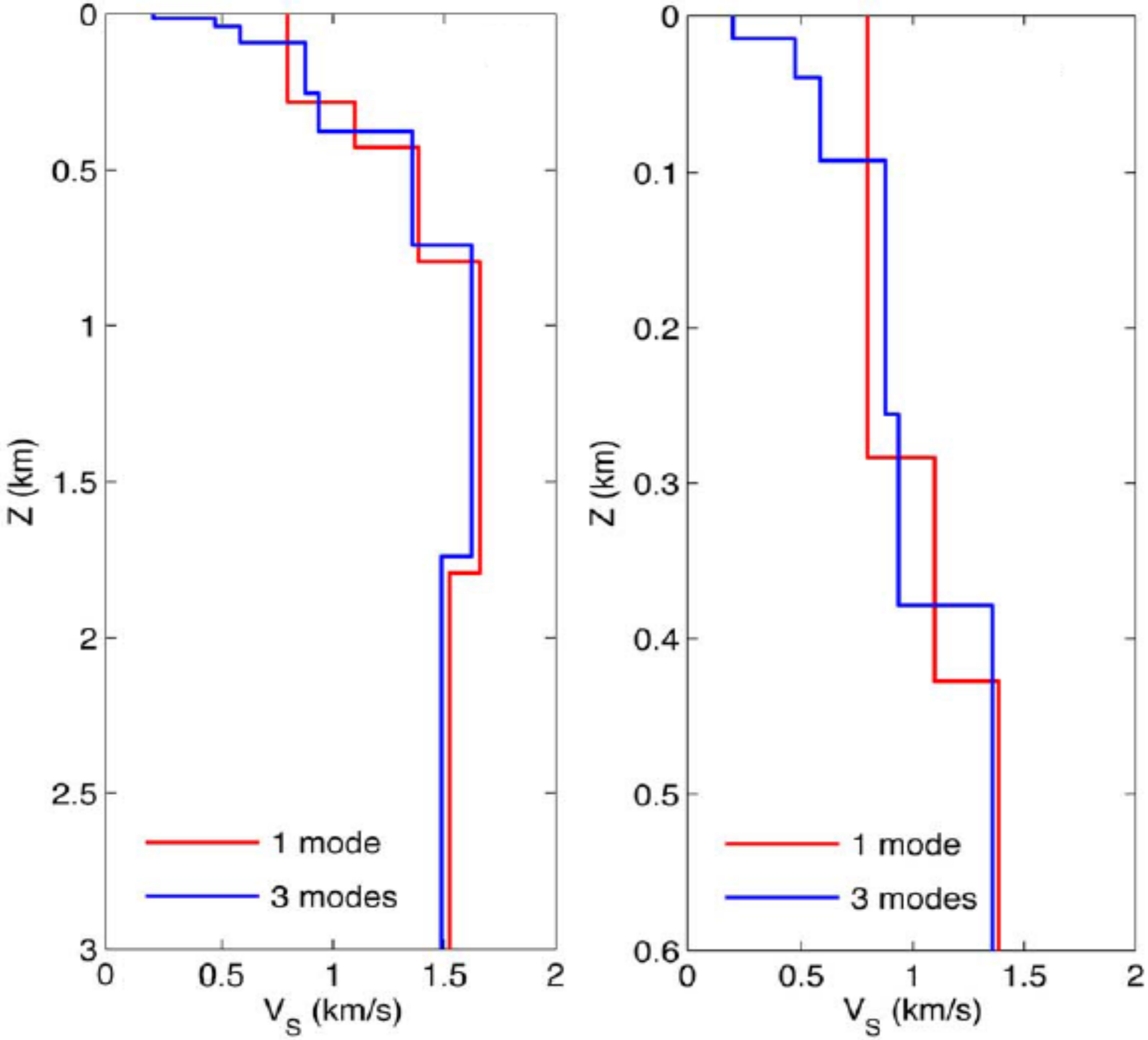
1 mode: 2 – 7 layers



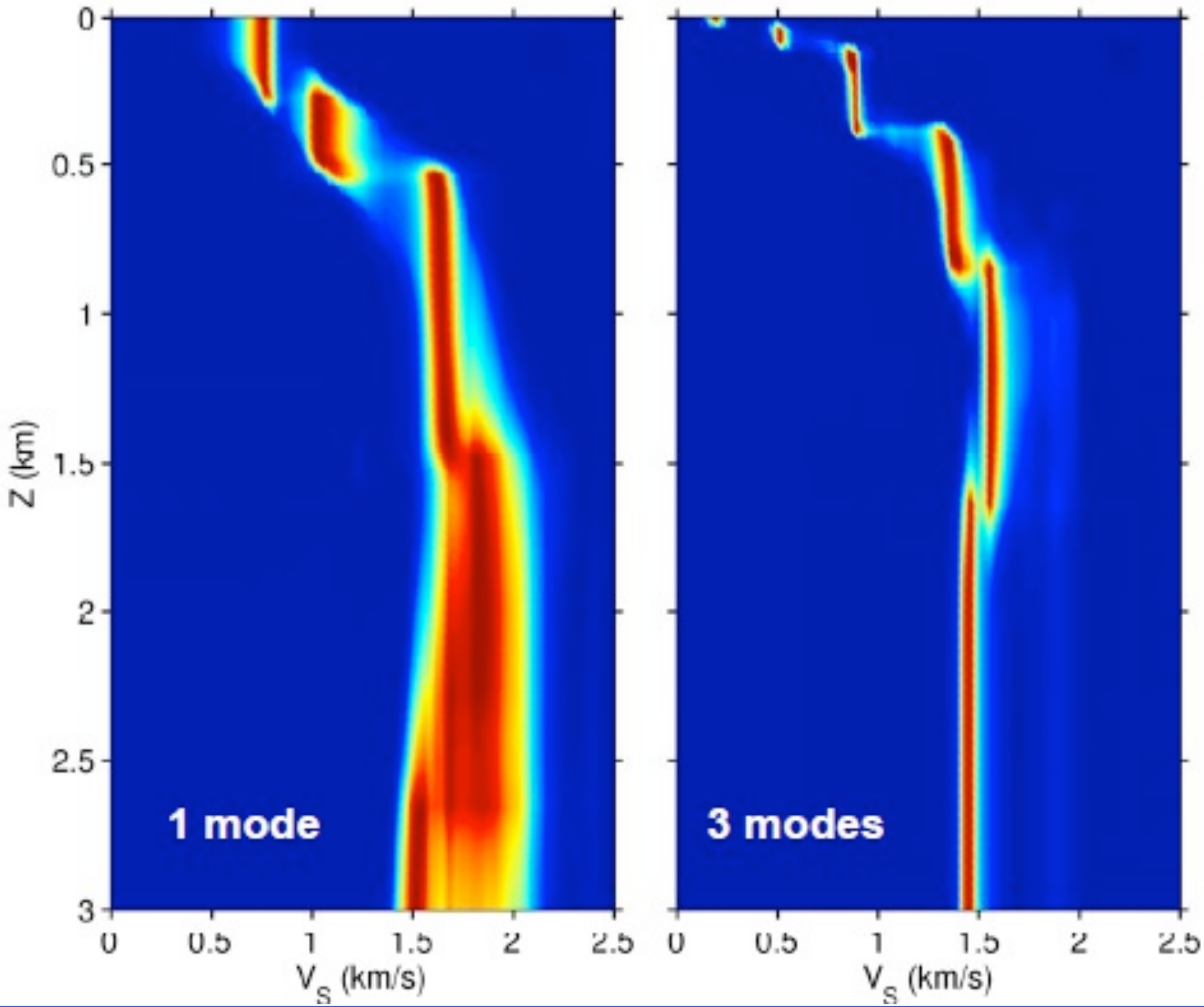
3 mode: 3 – 9 layers



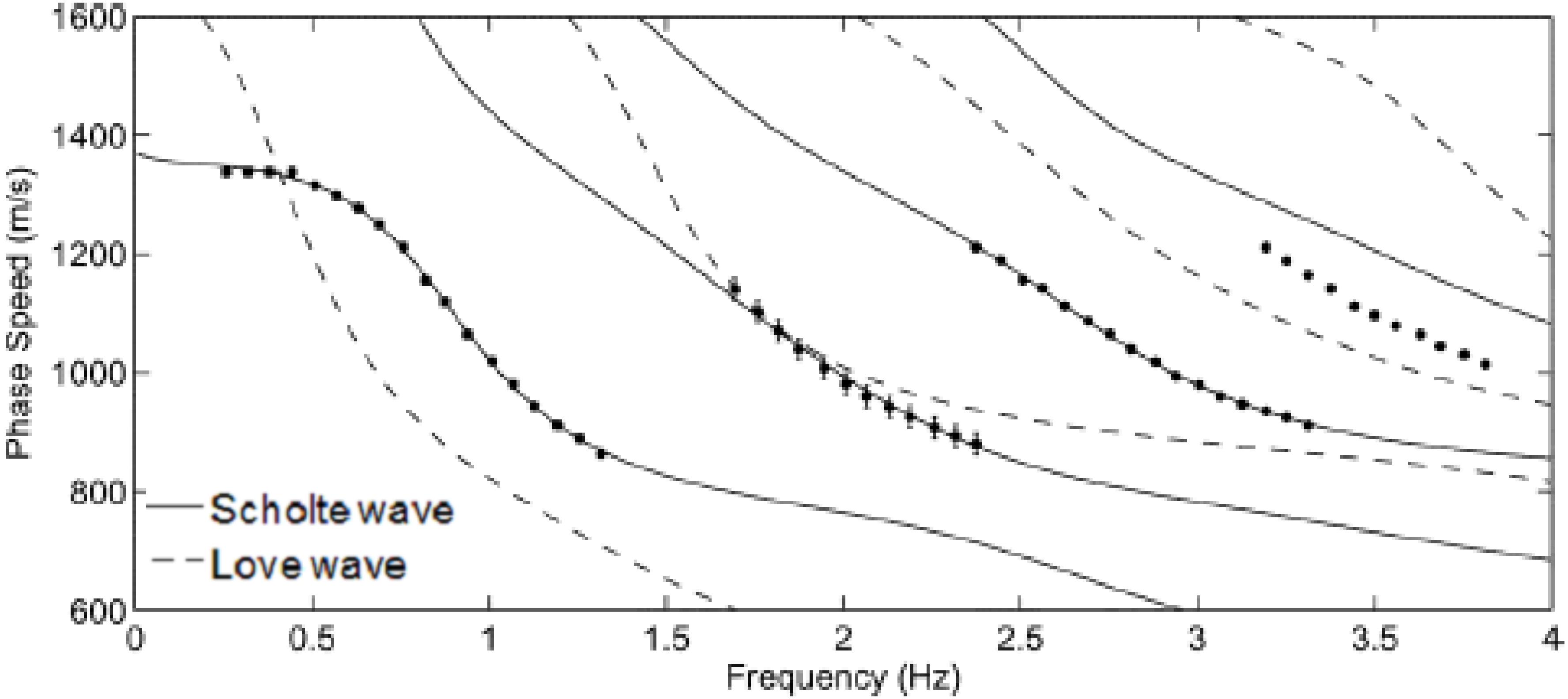
Estimated S-wave velocity profile



Marginal probability profile



Phase-velocity dispersion curves



Scholte- and Love-wave predicted from the 8-layer model.

Summary

- Bayesian approach used to estimate Vs(z) by inverting interface-wave dispersion curves extracted from ocean ambient noise.
- Higher-order modes provide greater near-surface resolution, small overall uncertainties.
- The study shows that it is possible to estimate geoacoustic parameters from short noise records in marine environment.
- This approach provides an alternate means to estimate seismic velocity that is valuable in offshore geotechnical engineering and reservoir monitoring.

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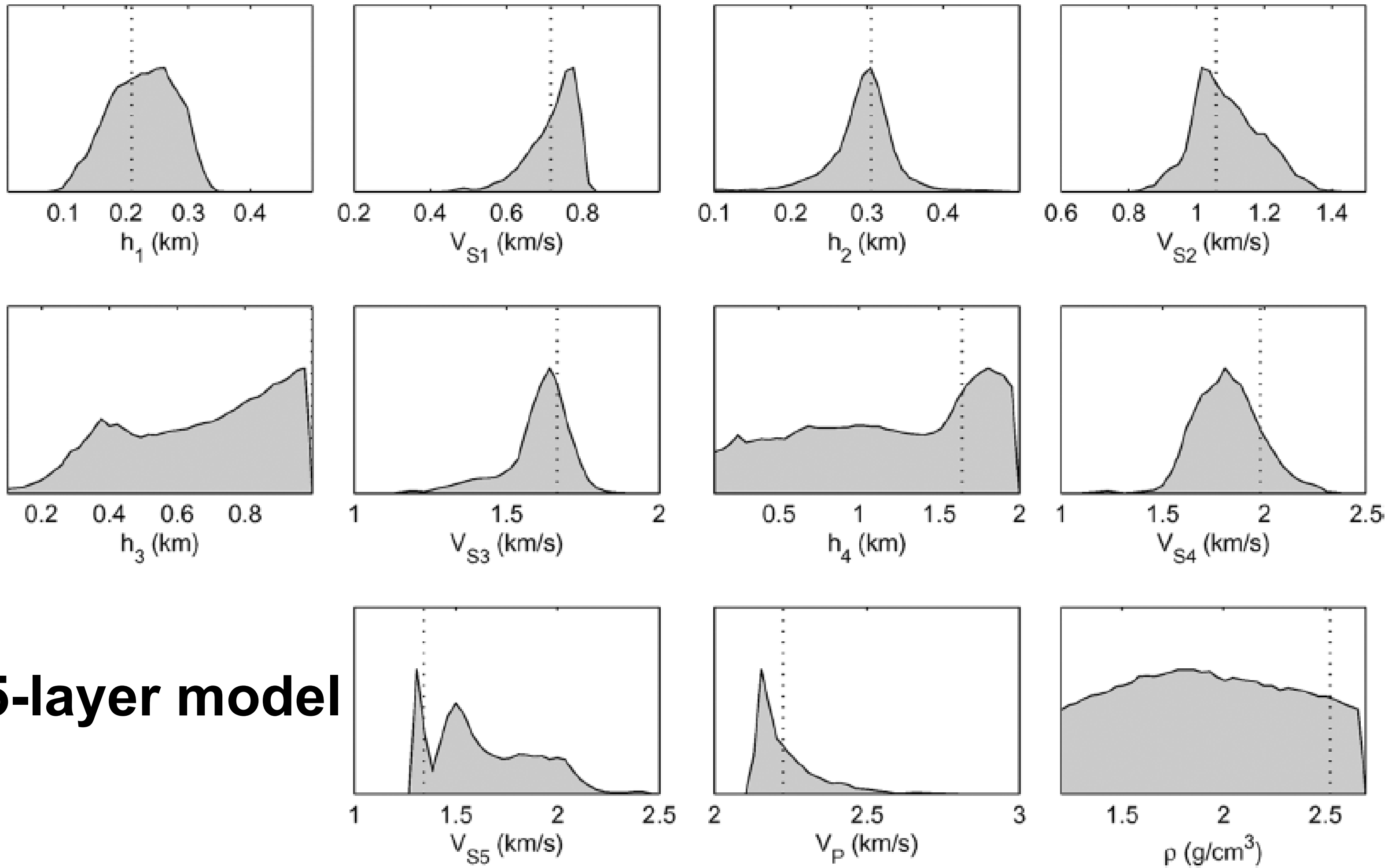
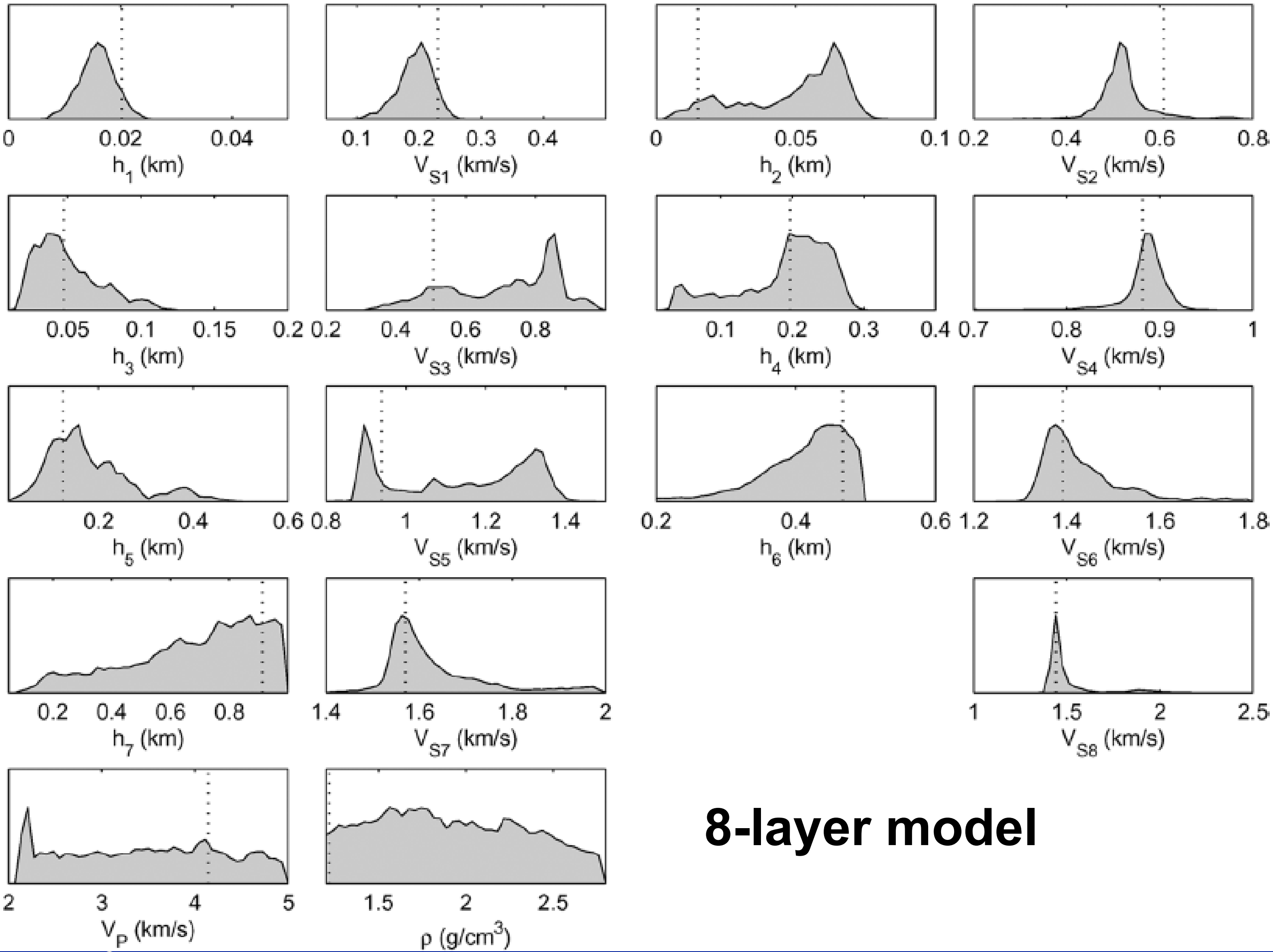
1D marginal probability distribution



5-layer model

1D marginal probability distribution



8-layer model