On inferring noise in probabilistic seismic AVO inversion using Hierarchical Bayes

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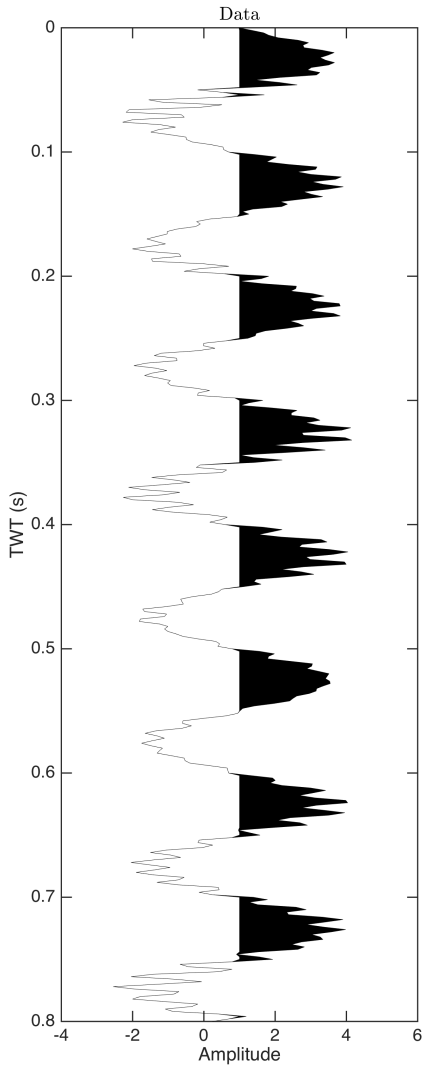
Seismic noise

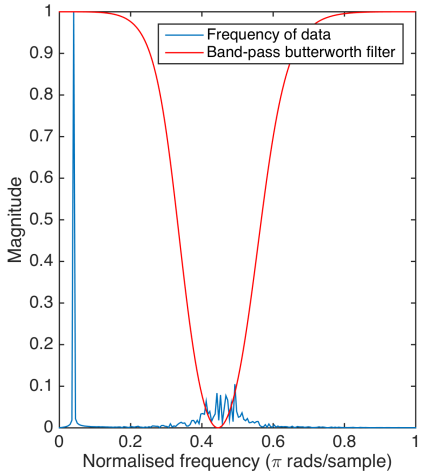
- What is the uncertainty on seismic data?

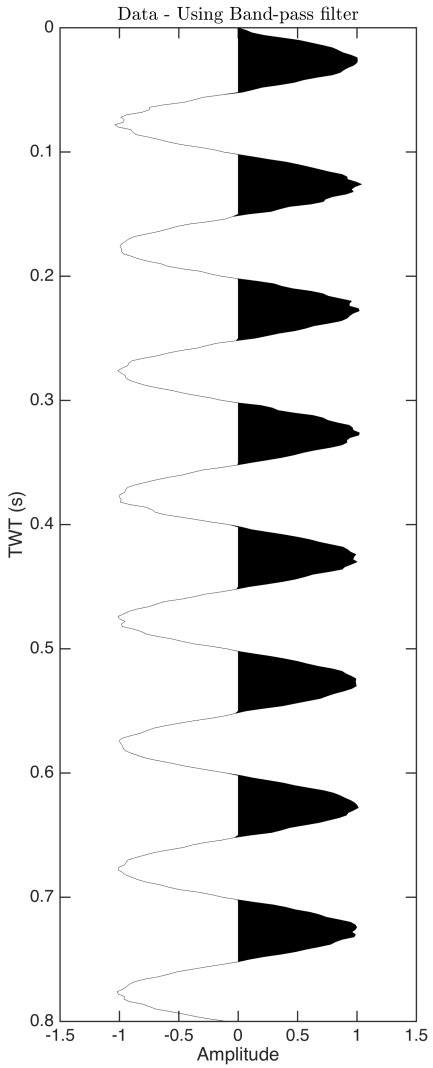
Seismic noise

- What is the uncertainty on seismic data?
- Simple example:

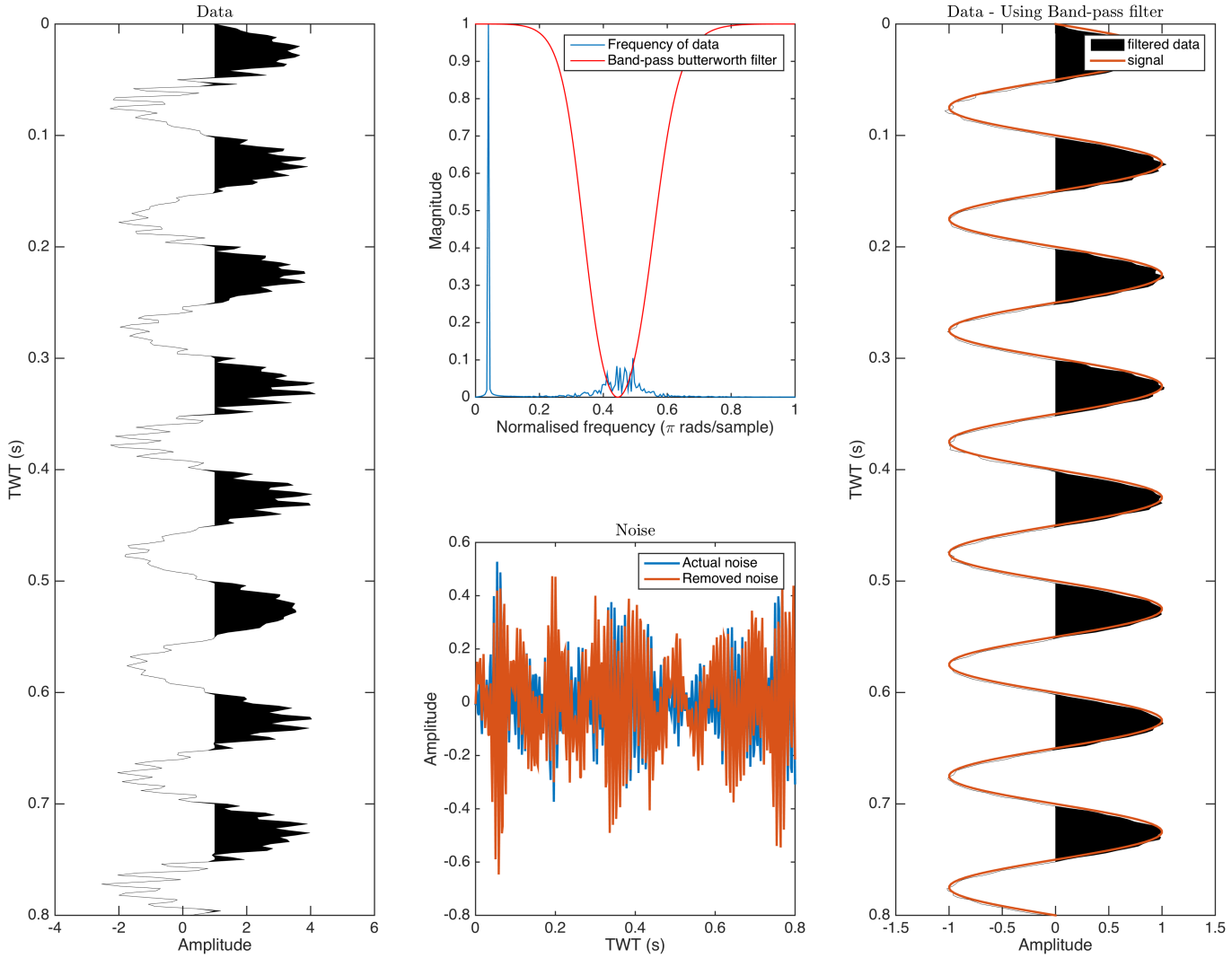
Seismic noise



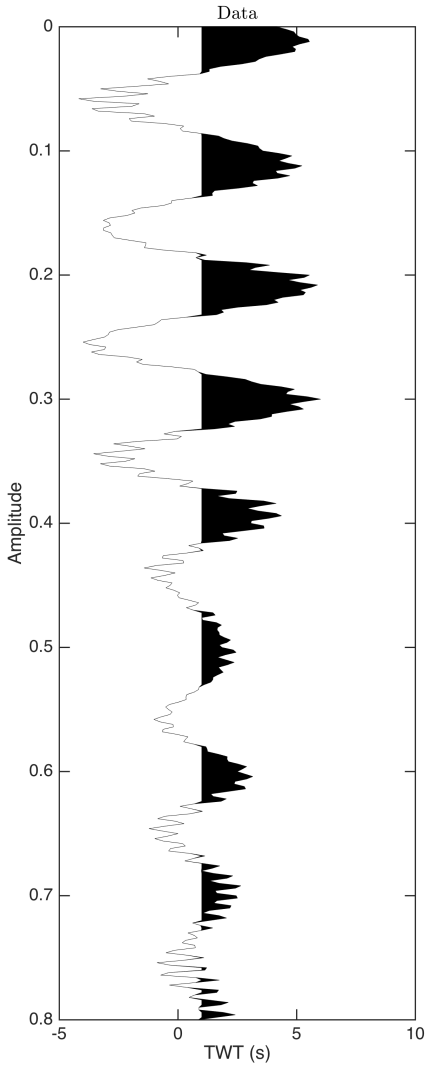


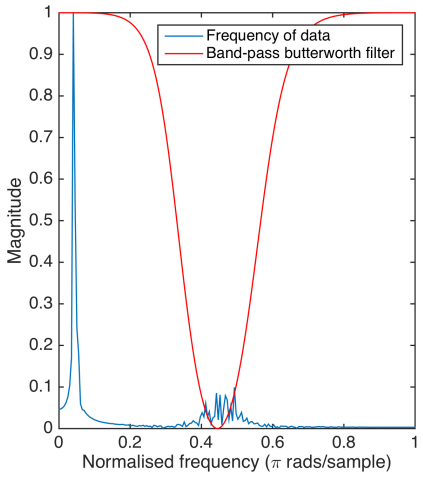


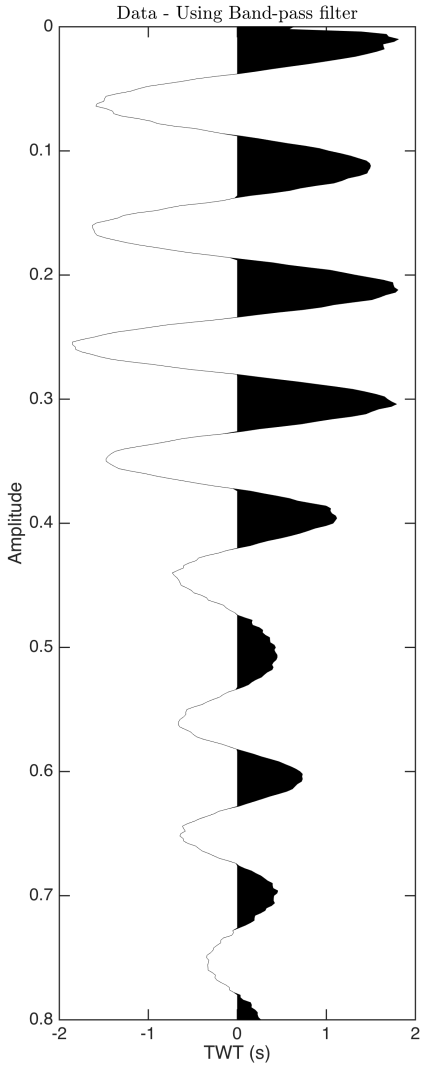
Seismic noise



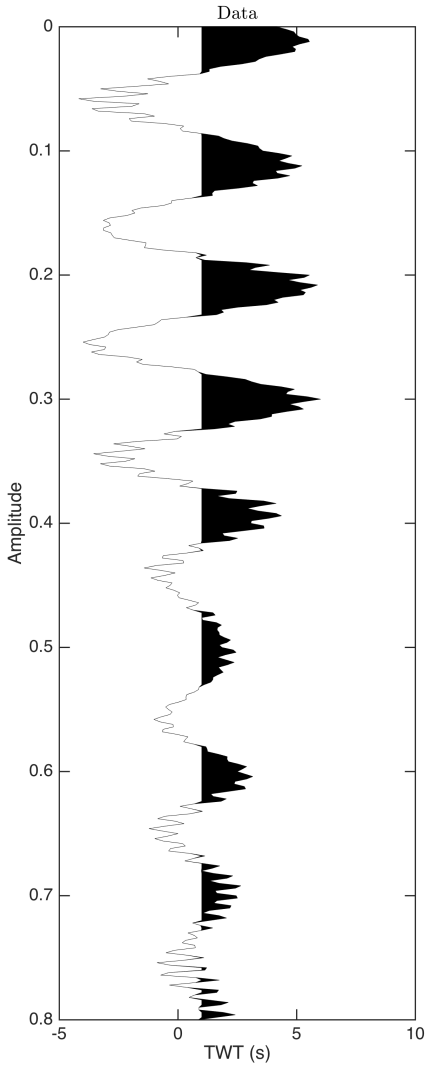
Seismic noise

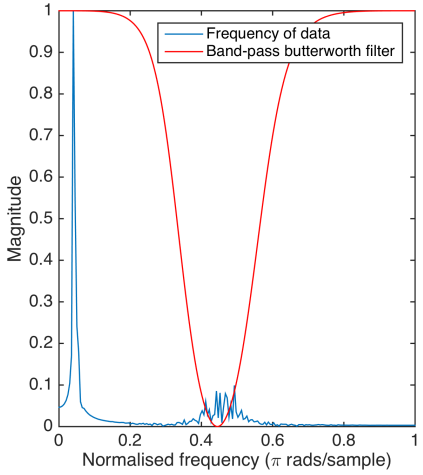


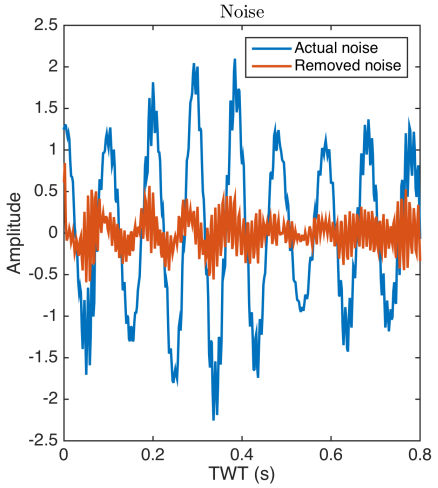


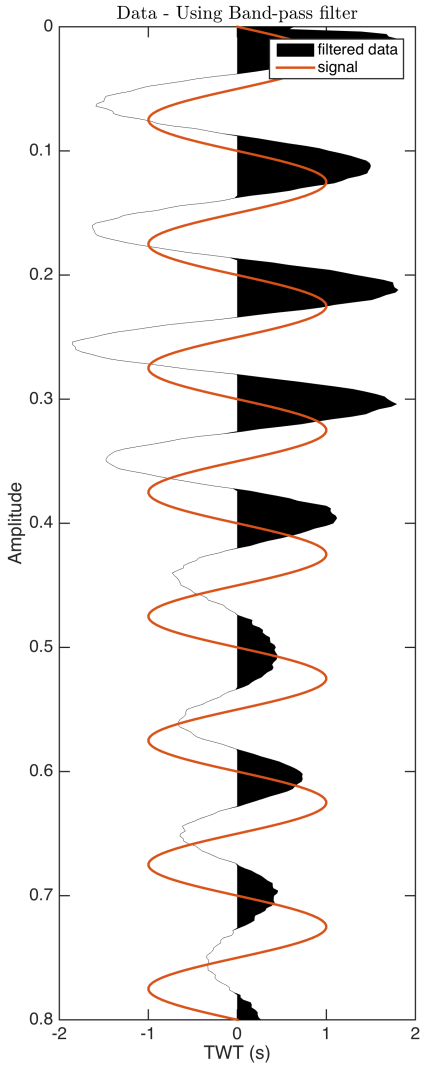


Seismic noise









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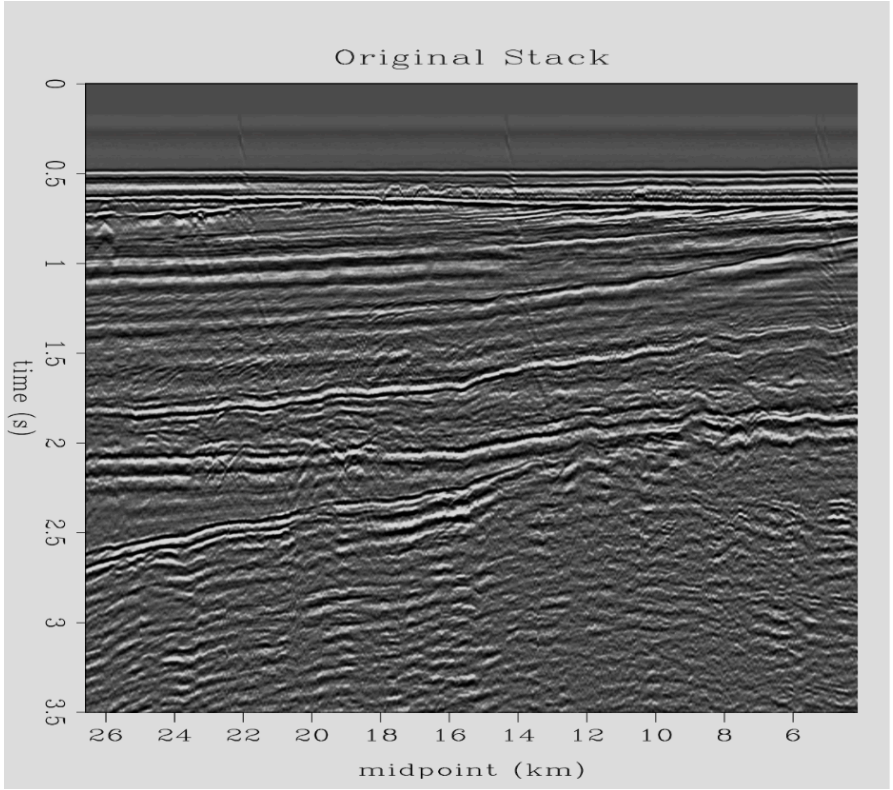
Seismic noise

- What is seismic noise (uncertainty)?
  - Multiples
  - Background noise
  - Measurement errors
  - Artifacts from processing
  - Etc.

- Noise is important, yet difficult to describe



Probabilistic inverse problem

- Correct evaluation of the likelihood is essential
  - Requires a good model for the measurement and theory uncertainties
  - Assume some noise model (inferring from nearby wells?)

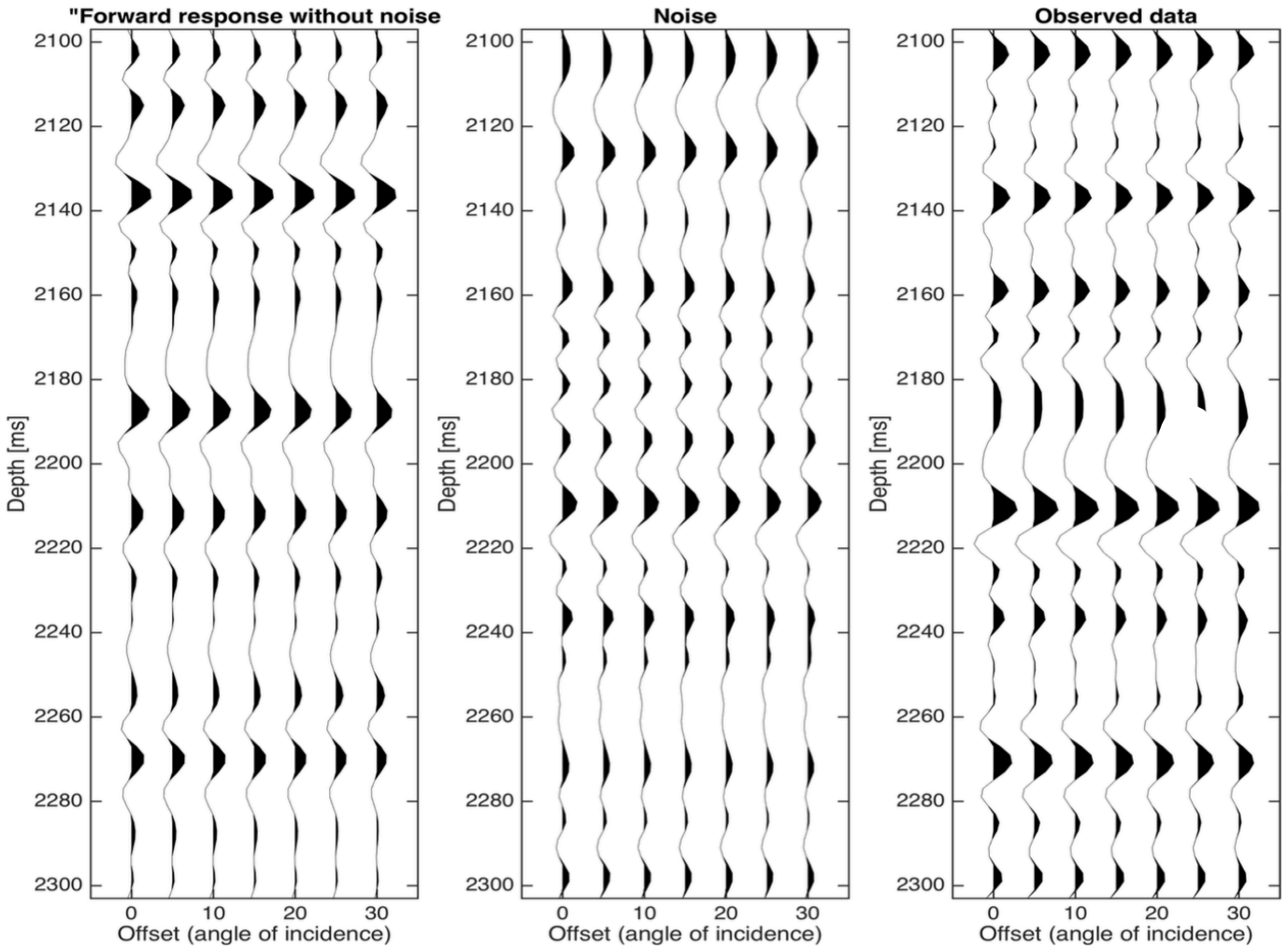
Inferring noise in probabilistic inversion

- Alternative approach
  - Estimate the noise as part of the inversion
  - Proposed to infer variance of noise using hierarchical Bayes inference scheme as part of the inversion[1,3,4,5,6,7]

Seismic noise

- Setup a simple synthetic case study to test this approach
  - Eliminate unknowns (if possible?)
  - Same forward model, same prior, etc.
  - Know the true solution (reference model)
  - Well-known (well-described) familiar test scenario
- Adapt Gaussian prior and linear seismic AVO forward model formulated from Buland & Omre (2003)[2]

Reference data



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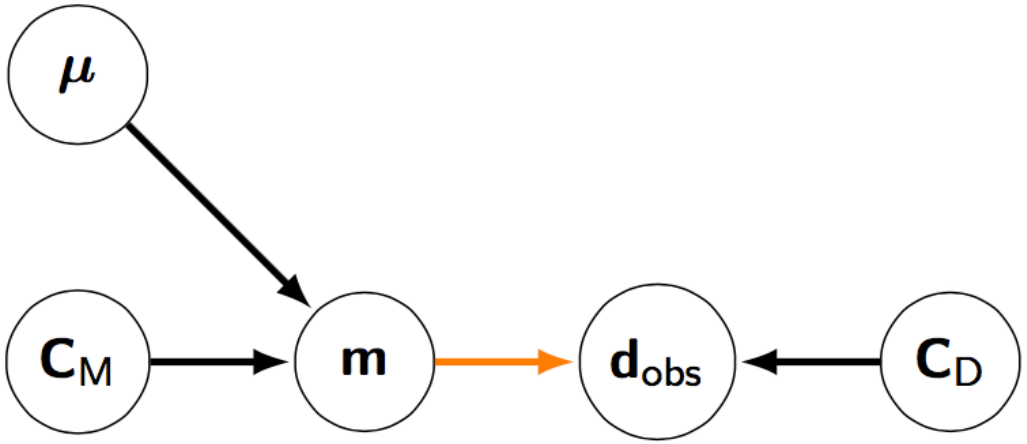
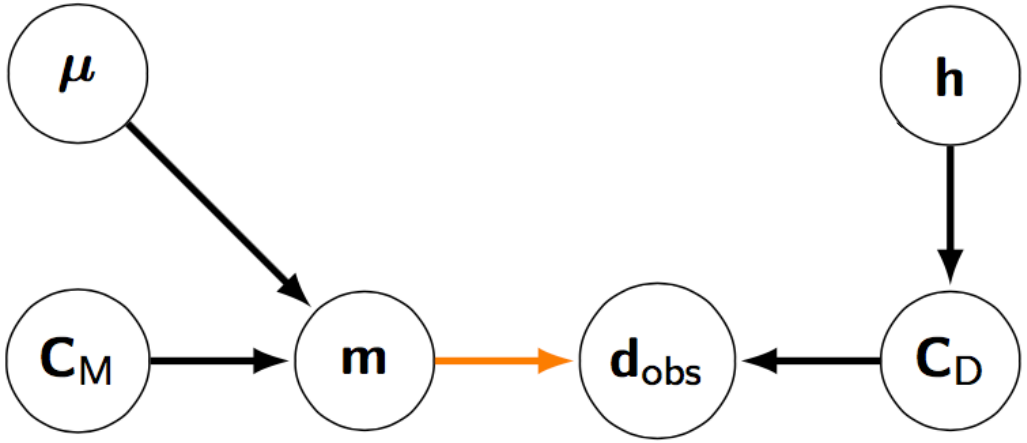
Stochastic model



Stochastic model



Sampling algorithm

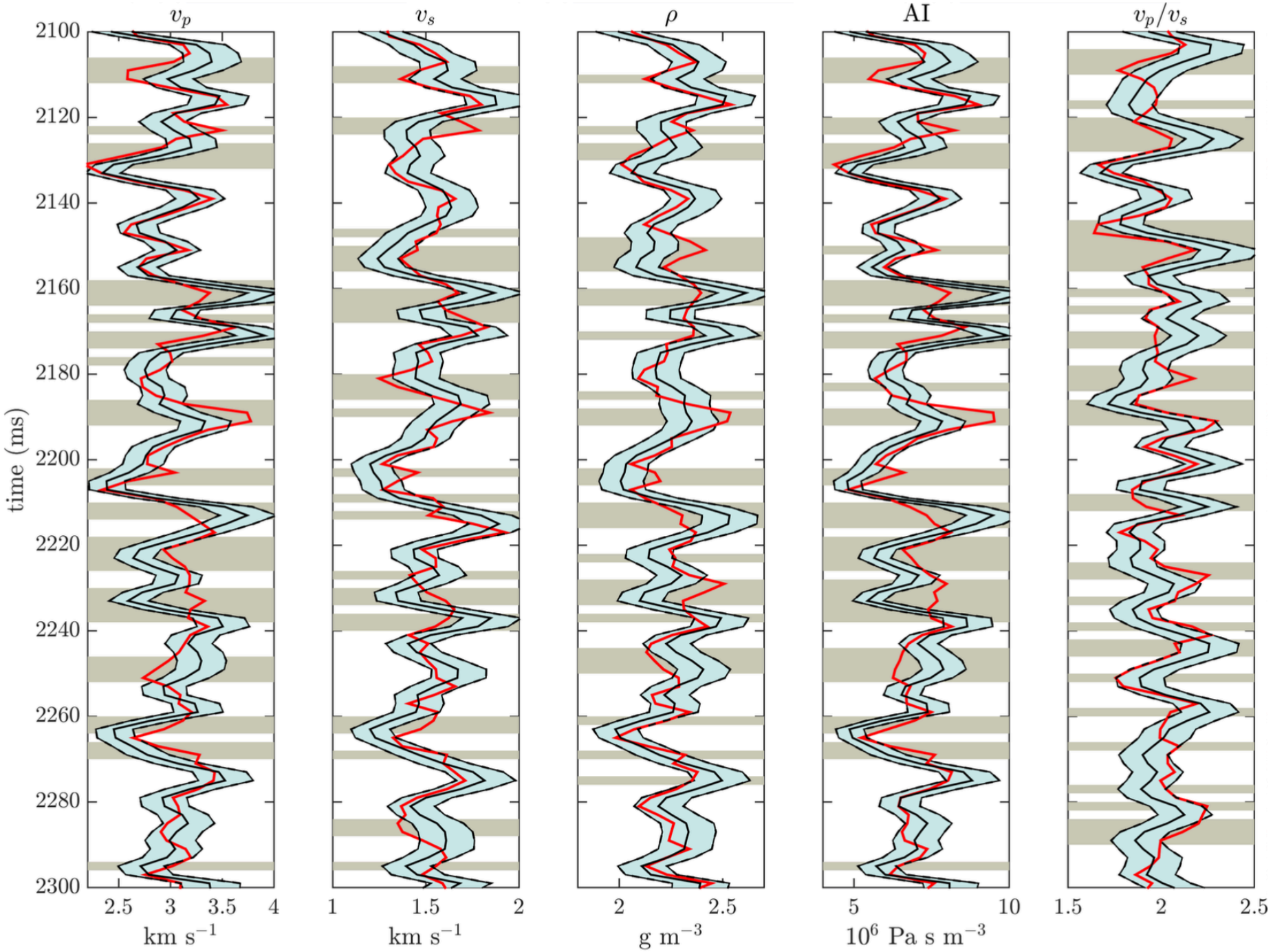
- Sampling algorithm adapted from Malinverno & Briggs (2004)[5]

Test case 1

- A common practice for inferring noise is to assume an uncorrelated noise model:
  - Highest possible entropy (Unpredictability)

$$\mathbf{h} = \mathrm{h}_1 = \sigma_{\mathrm{d}}$$

$$\mathrm{h}_1 \sim \mathrm{Uniform}(0.00001, 1)$$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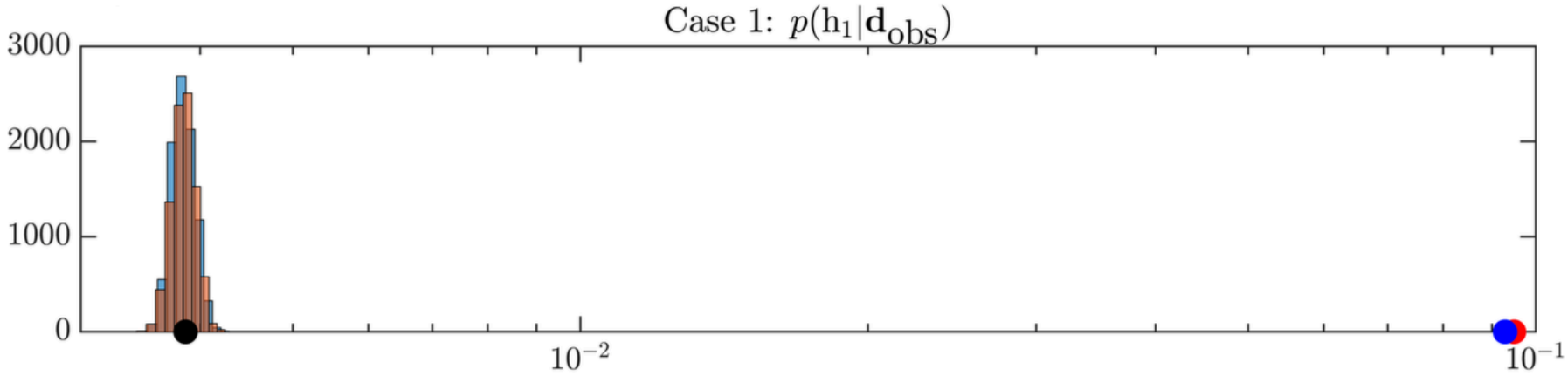
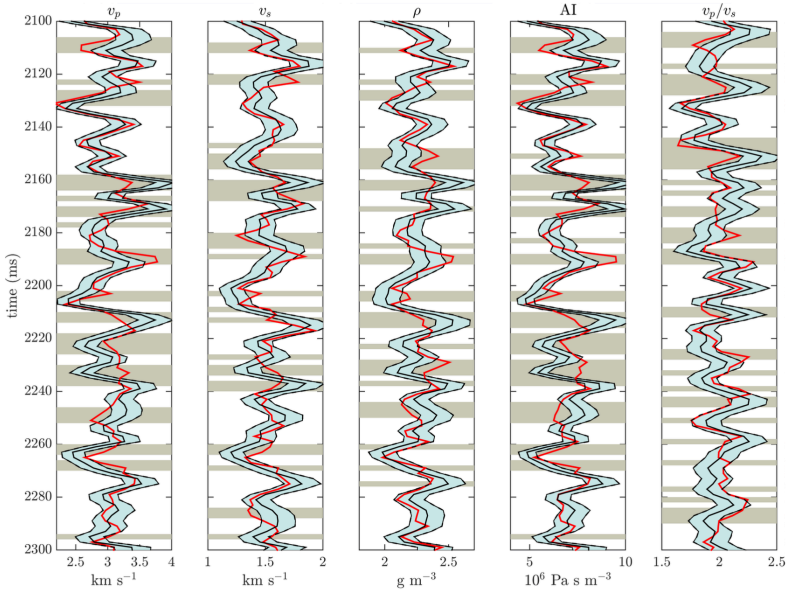
Results case 1





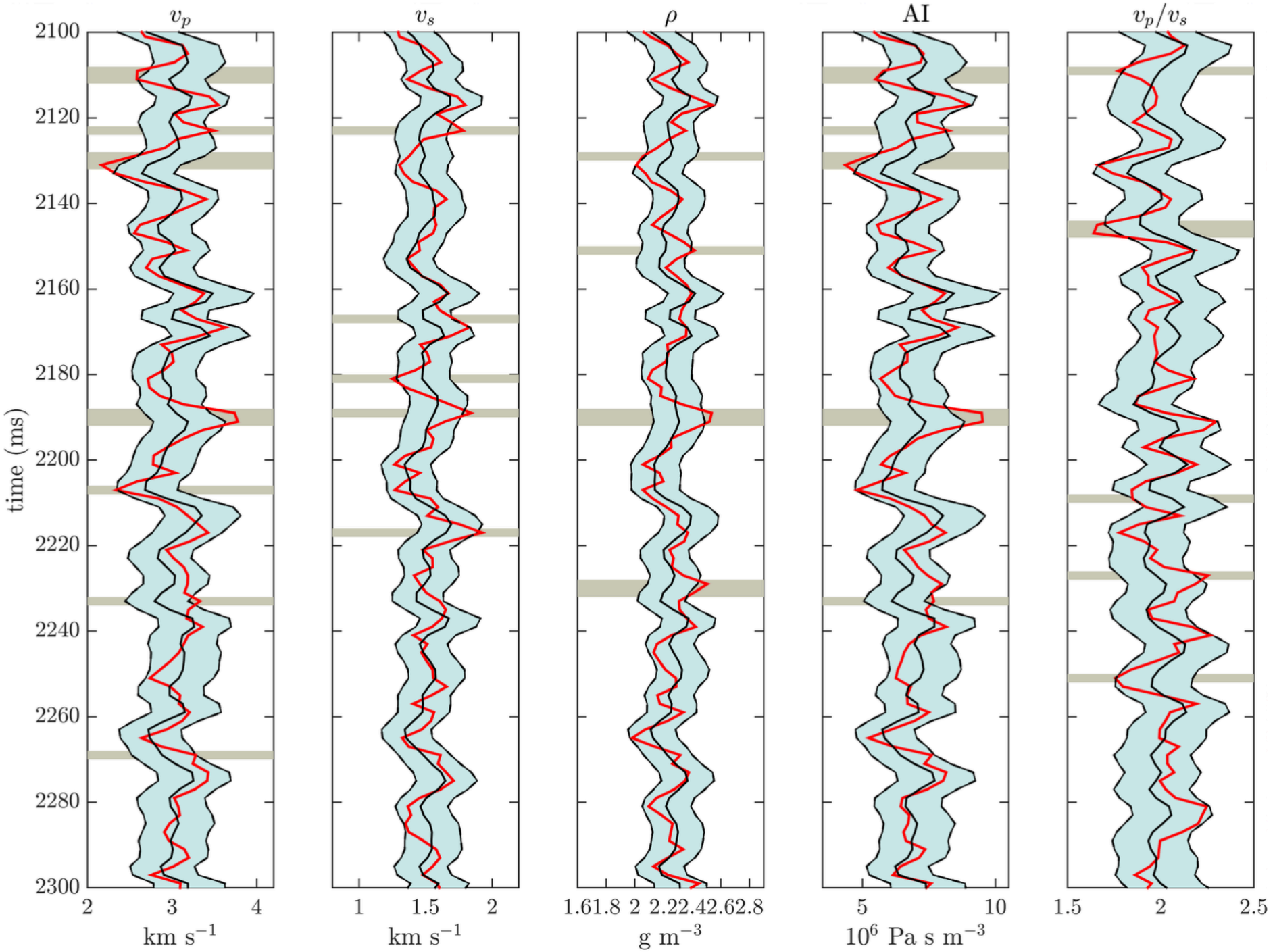
Run 1 Run 2 σ_{d} σ_{T} $\sigma_{\mathrm{d+T}}$

Test case 2

- Use the correct shape (same covariance) as used to generate noise

$$\mathbf{h} = [h_1, h_2] = [\sigma_d, \sigma_T]$$

$$h_1, h_2 \sim \text{Uniform}(0.00001, 1)$$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km s^{-1}
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g m^{-3}
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10^6 Pa s m^{-3}
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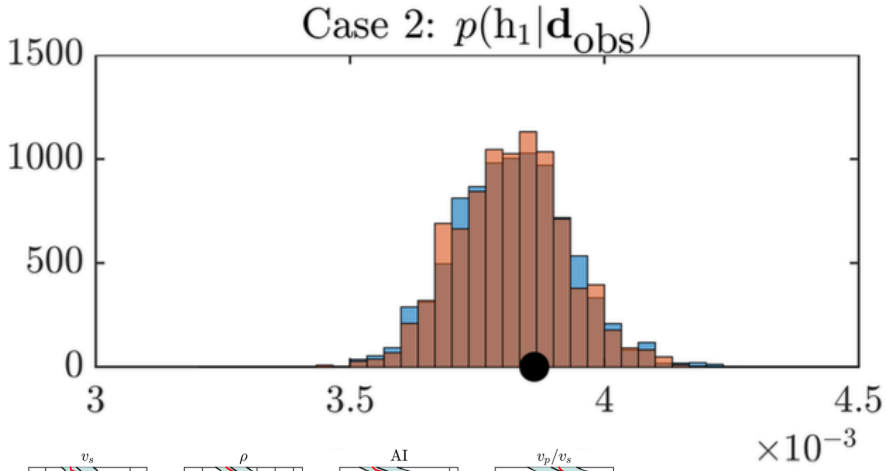
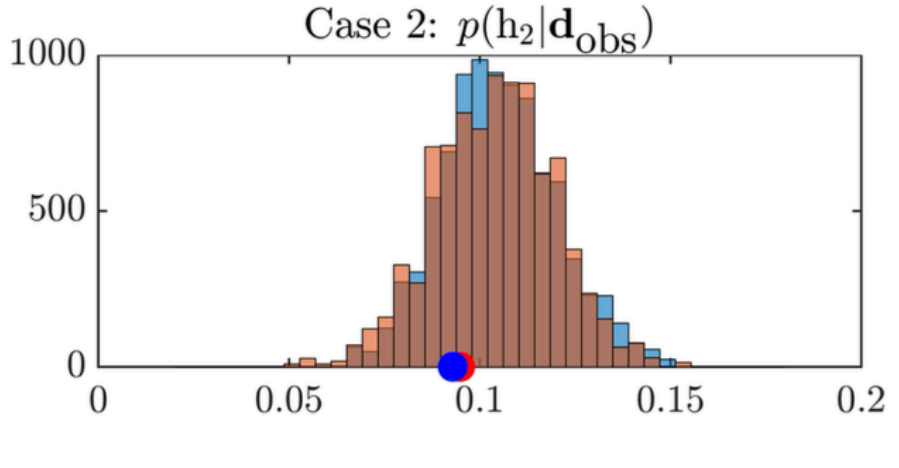
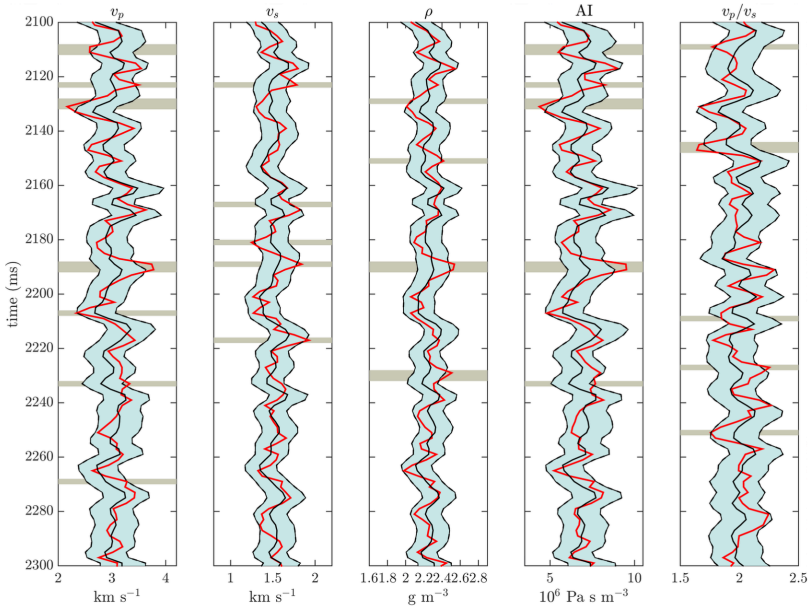
Results case 2







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Summary

1. The hierarchical Bayes approach was in all cases able to accurately estimate the variance of the uncorrelated noise on the data
2. Case 1 shows noise being fitted as data when assuming uncorrelated noise in a scenario with correlated noise
3. Case 2 shows that it is possible to infer the variance of the noise if the correct shape is known
4. Case 3 shows that some improvements can be gained by assuming some correlation of error. Still see biased results!

References

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2. Buland, A., & Omre, H. (2003). Joint AVO inversion, wavelet estimation and noise-level estimation using a spatially coupled hierarchical Bayesian model. *Geophysical Prospecting*, *51*(6), 531–550. http://doi.org/10.1046/j.1365-2478.2003.00390.x

3. Buland, A. & Omre, H. (2003). Bayesian linearized AVO inversion. GEOPHYSICS, 68(1), 185-198. https://doi.org/10.1190/1.1543206

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5. Malinverno, A., & Briggs, V. A. (2004). Expanded uncertainty quantification in inverse problems: Hierarchical Bayes and empirical Bayes. *Geophysics*, *69*(4), 1005–1016. http://doi.org/10.1190/1.1778243

6. Malinverno, A., & Parker, R. L. (2006). Two ways to quantify uncertainty in geophysical inverse problems. *Geophysics*, *71*(3), W15–W27. http://doi.org/10.1190/1.2194516

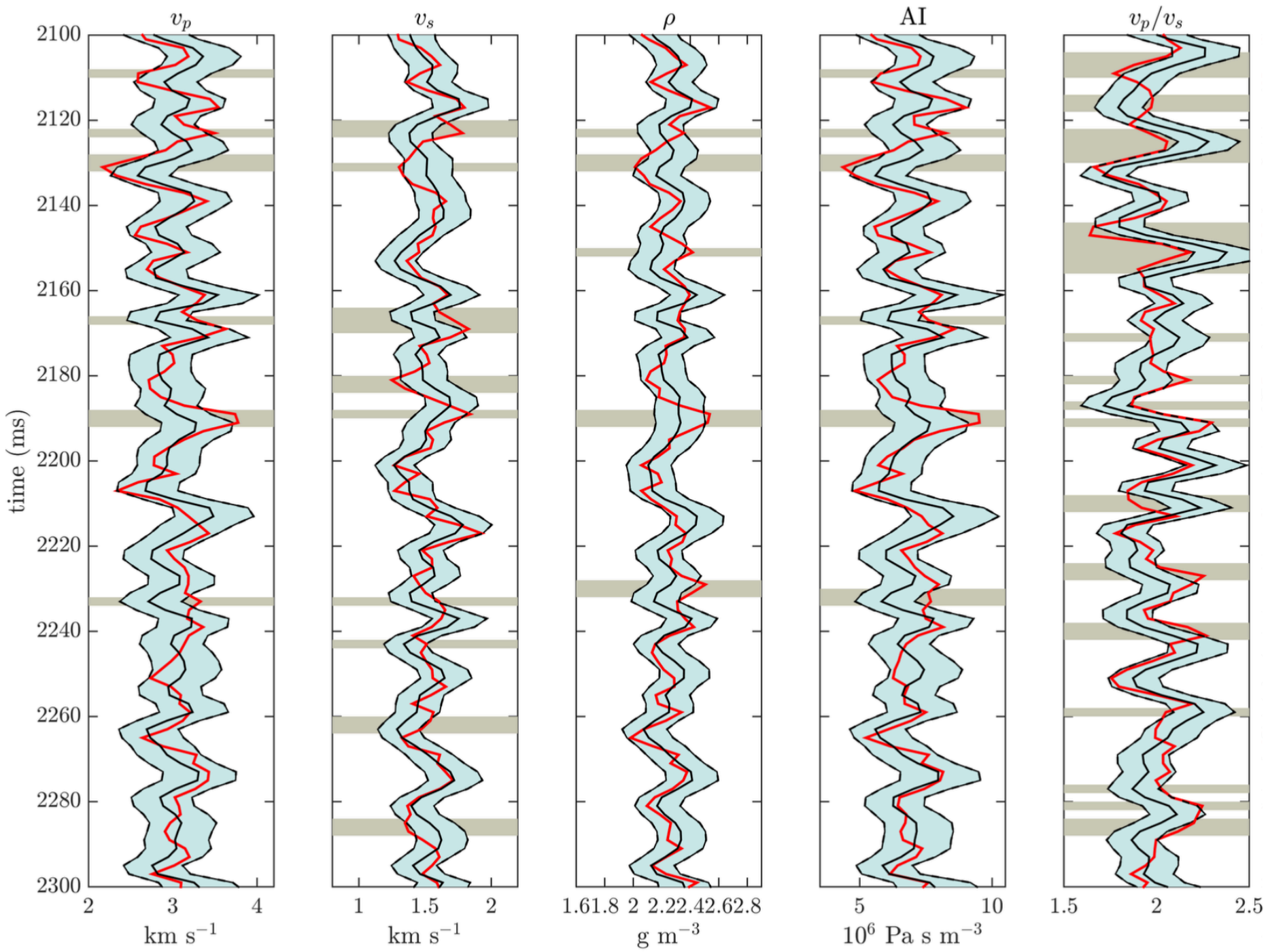
7. Ray, A., Key, K., & Bodin, T. (2013). Hierarchical Bayesian inversion of marine CSEM data over the Scarborough gas field — A lesson in correlated noise. *SEG Technical Program Expanded Abstracts*, (1), 723–727. http://doi.org/10.1190/segam2013-1439.1

Test case 3

- Use the estimated shape
  - wavelet with correlation between angles

$$\mathbf{h} = [h_1, h_2] = [\sigma_d, \sigma_w]$$

$$h_1, h_2 \sim \text{Uniform}(0.00001, 1)$$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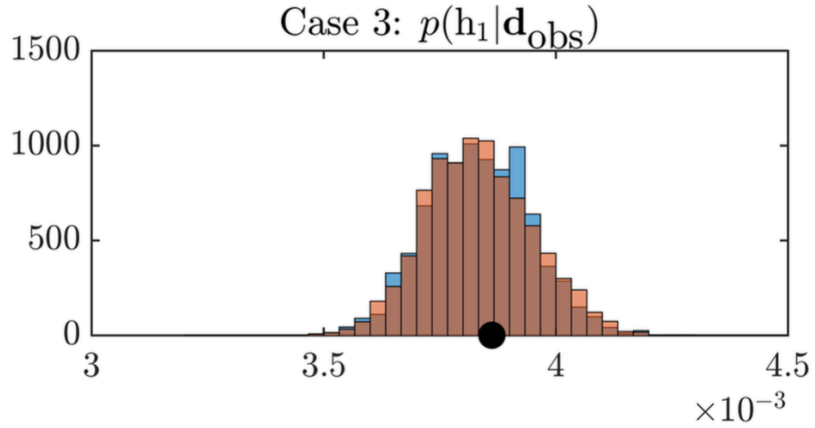
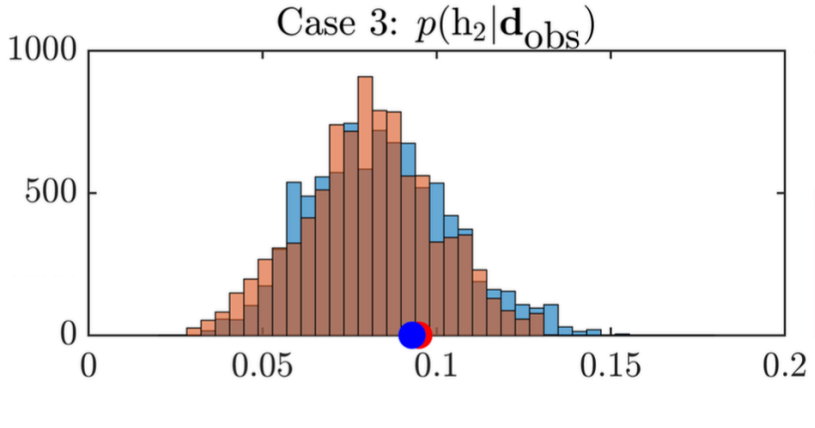
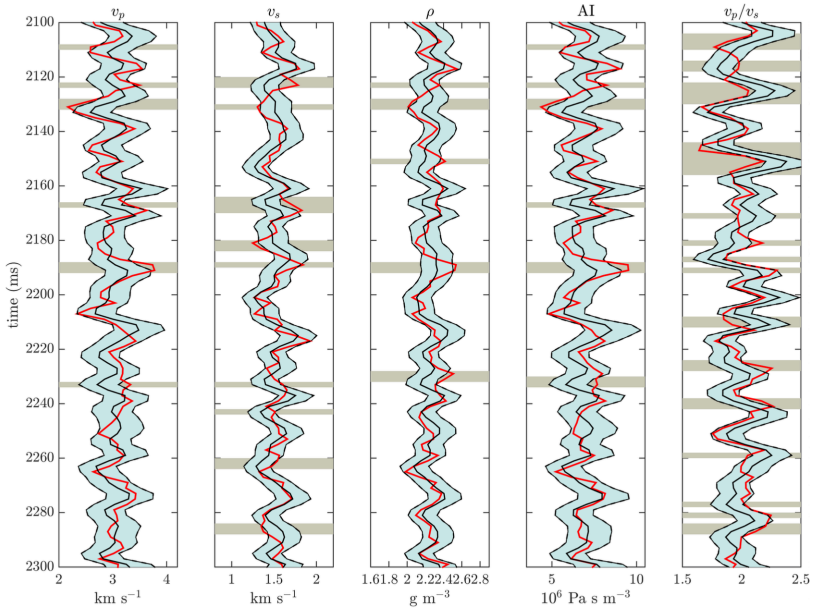
Results case 3







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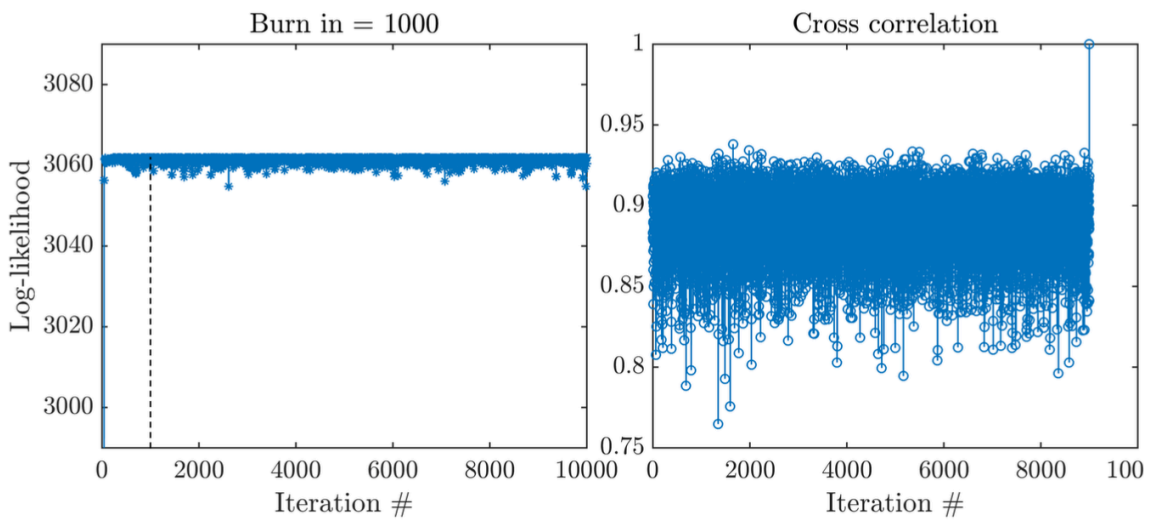
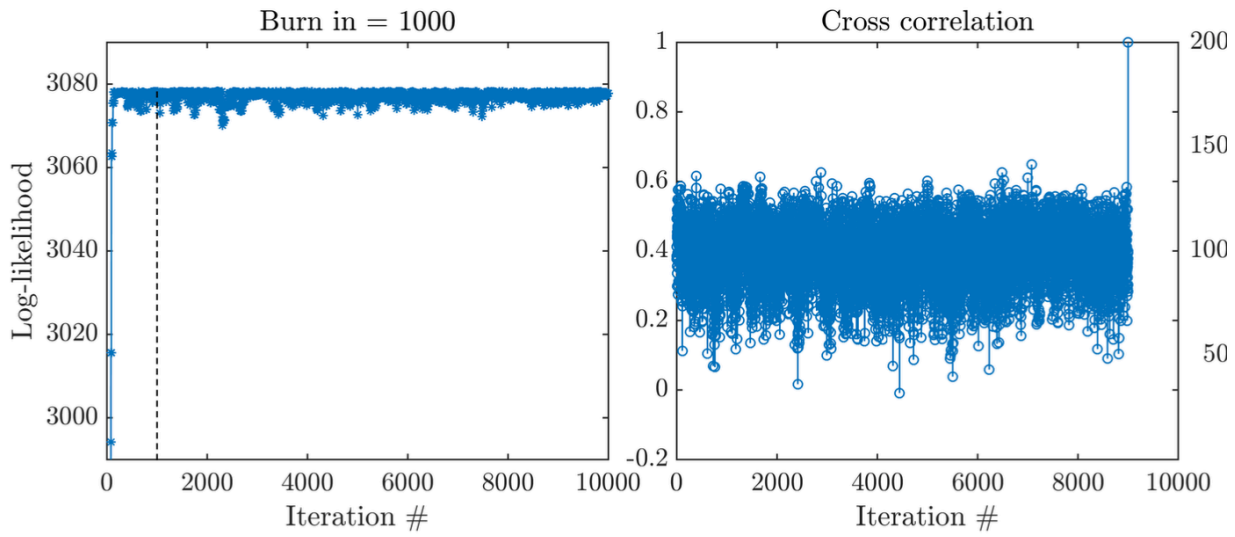
Log-likelikehood + Cross Correlation

Case 1

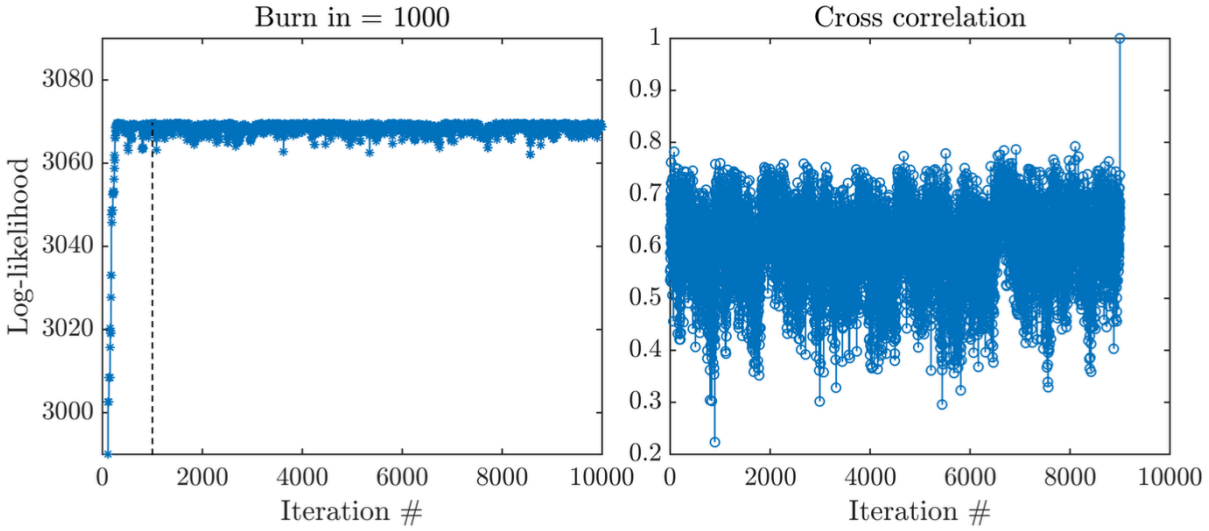


Case 2

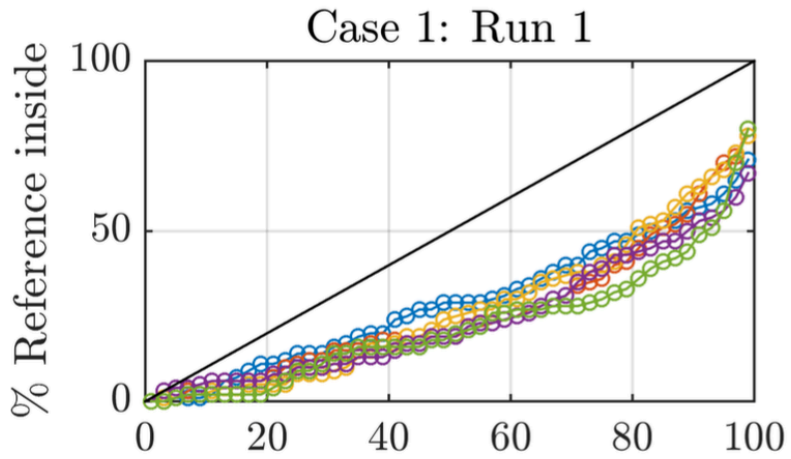


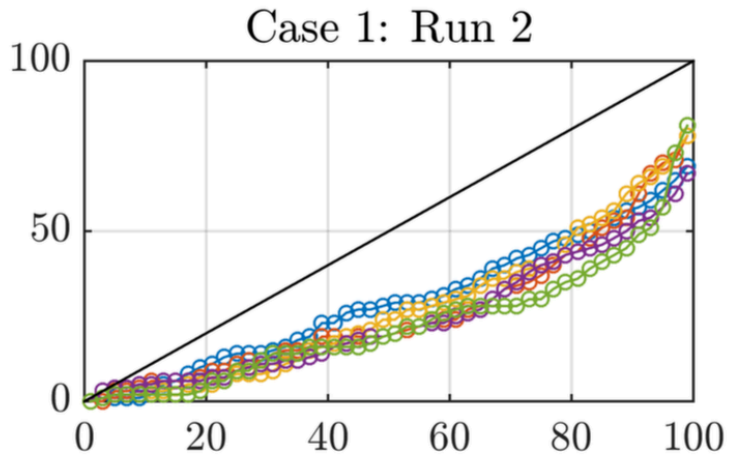
Log-likelikehood + Cross Correlation

Case 3

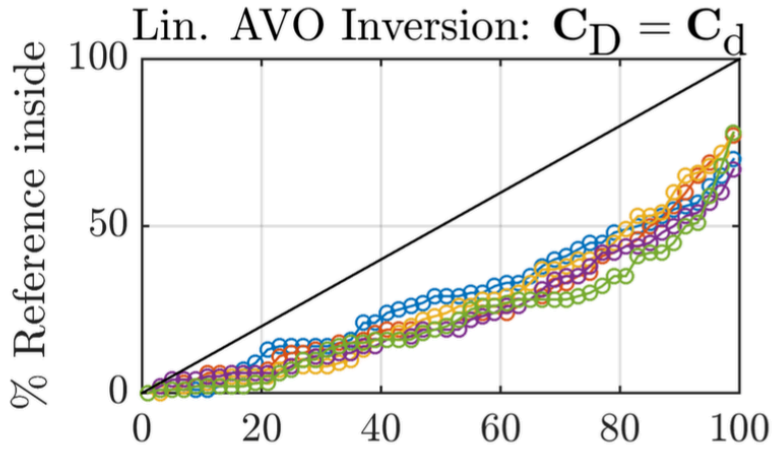


Comparison with non-hierarchical inversion





Non-hierarchical Bayesian linear AVO inversion for comparison:



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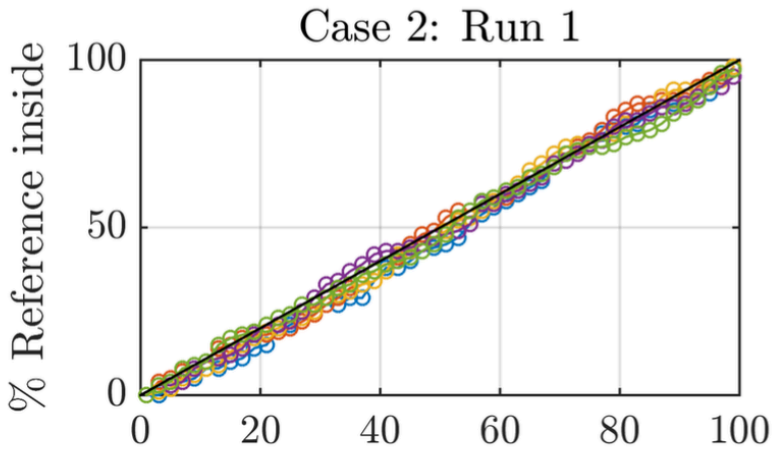

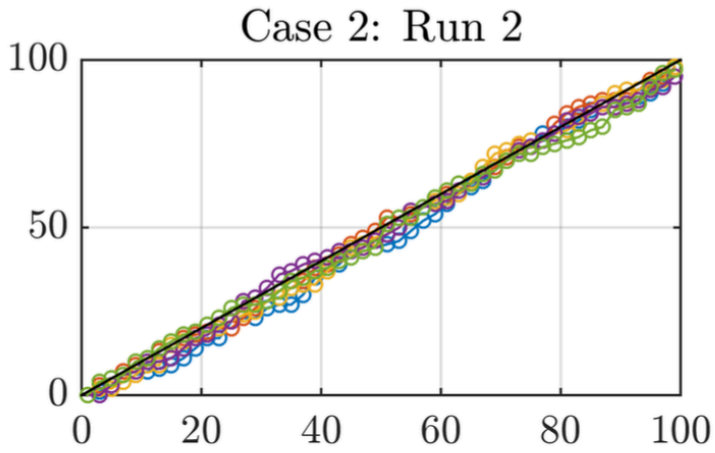

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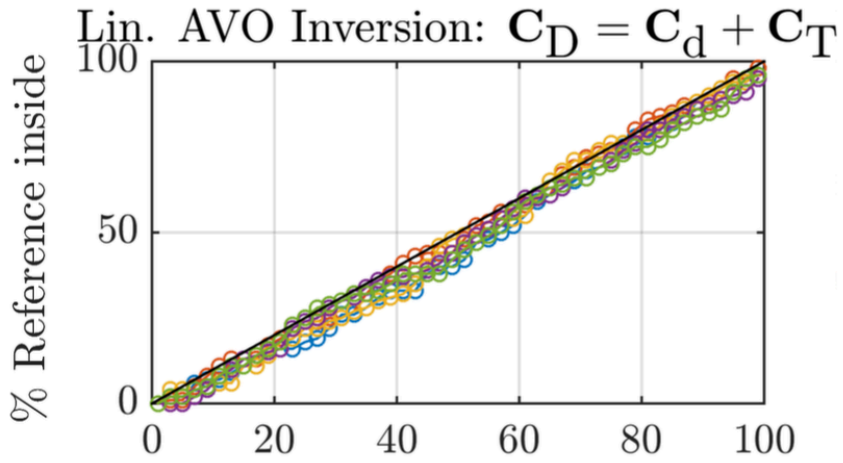
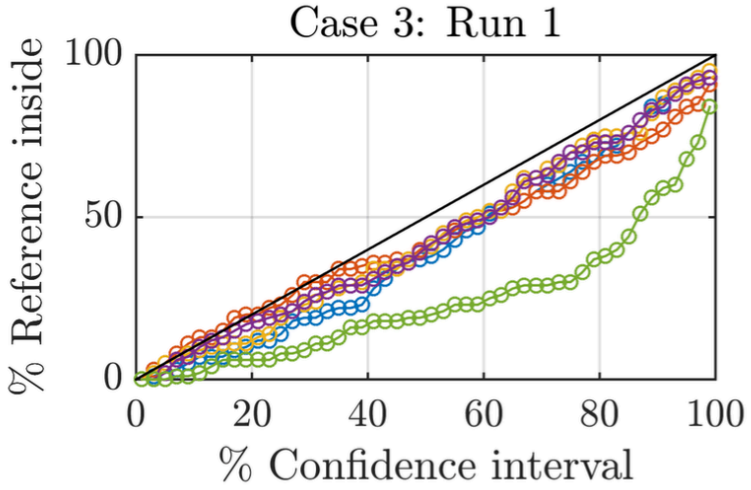
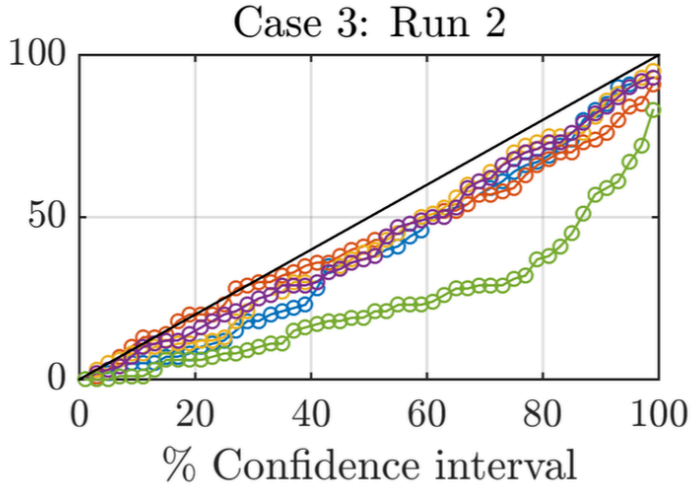


v_p v_s ρ AI v_p/v_s Ideal line

Comparison with non-hierarchical inversion





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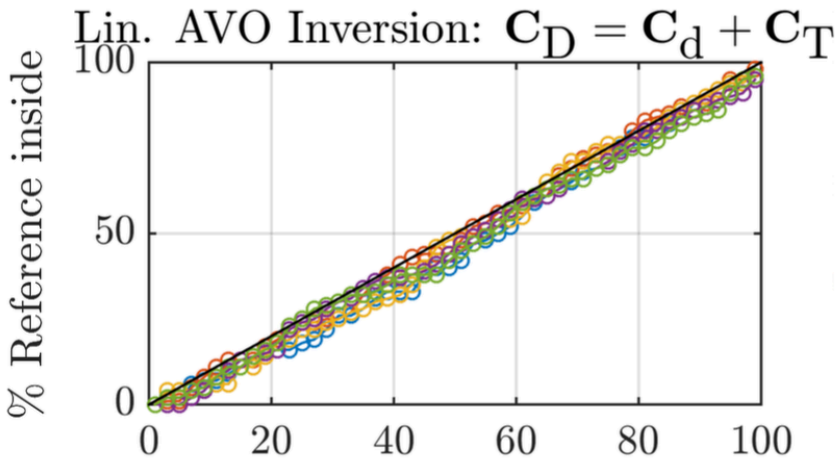

v_p v_s ρ AI v_p/v_s Ideal line