Well-log parameterized full waveform inversion

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NSERC CRSNG
UNIVERSITY OF CALGARY
FACULTY OF SCIENCE
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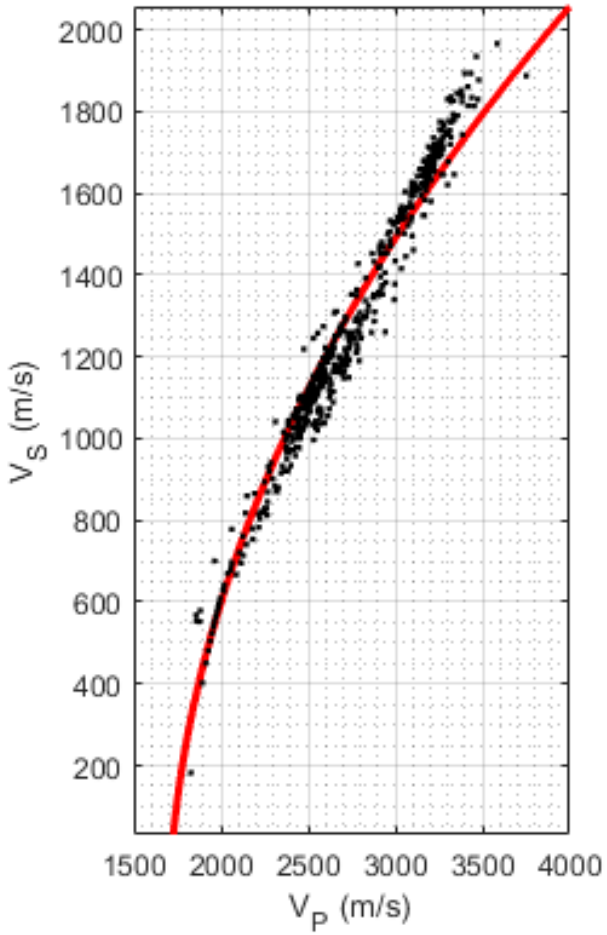
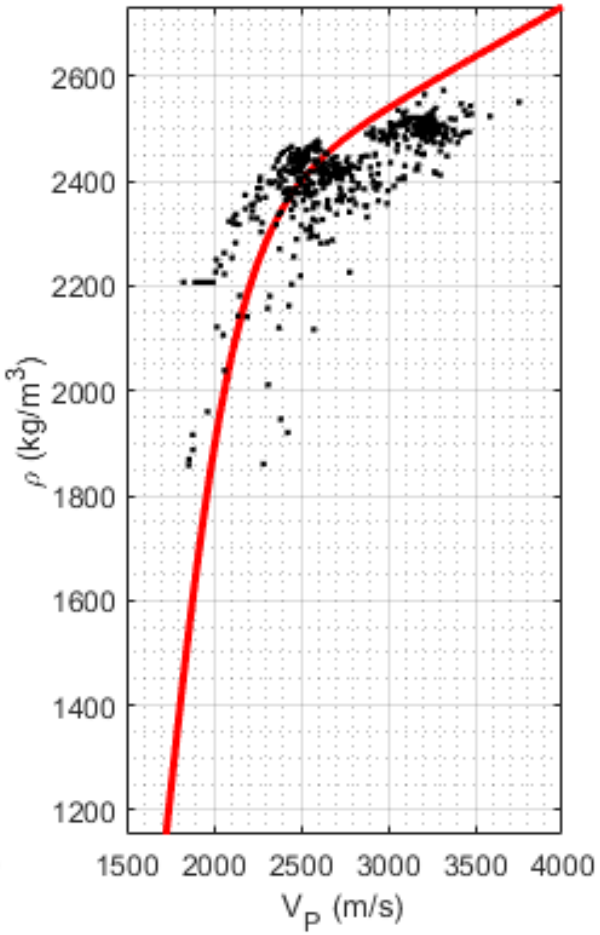
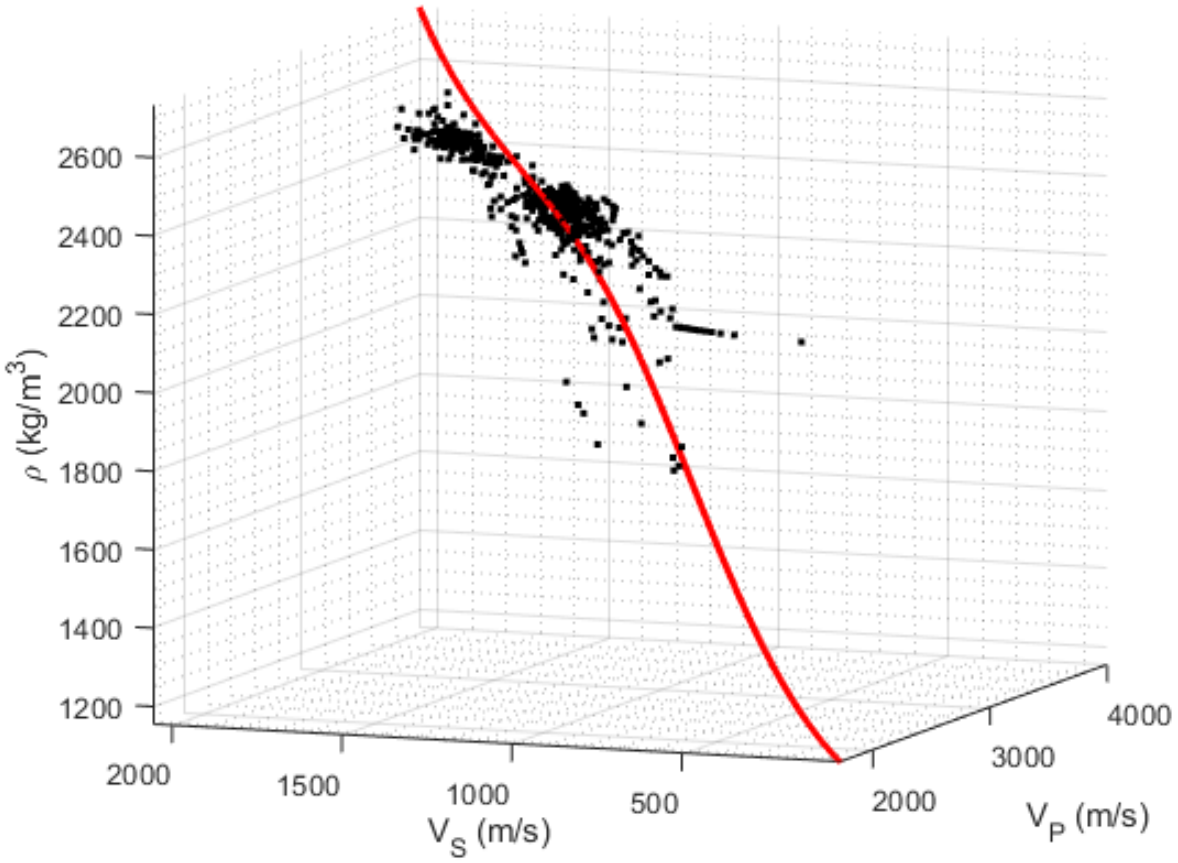
Motivation

Parameter encapsulating V_P, V_S, and ρ relationship





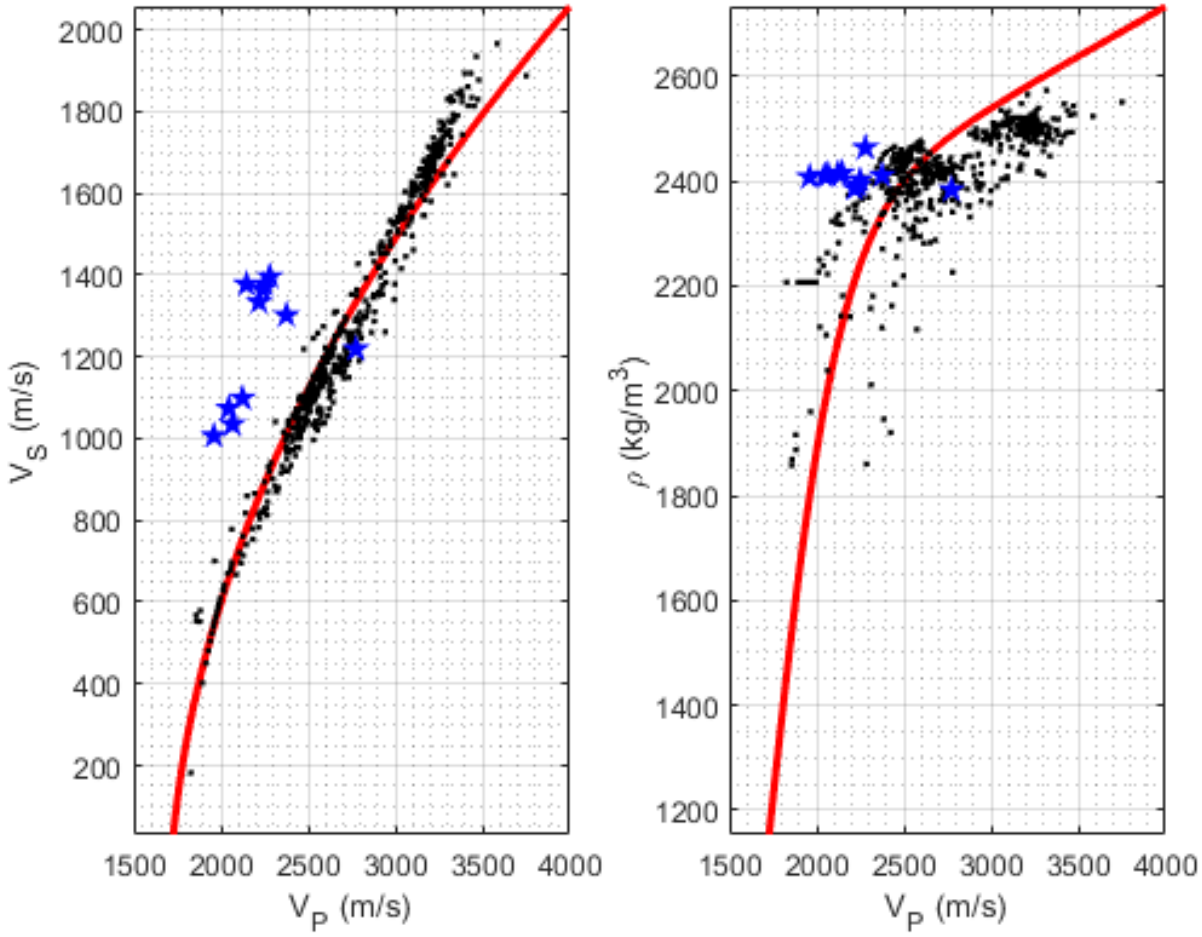


Legend
- Baseline
- Trendline

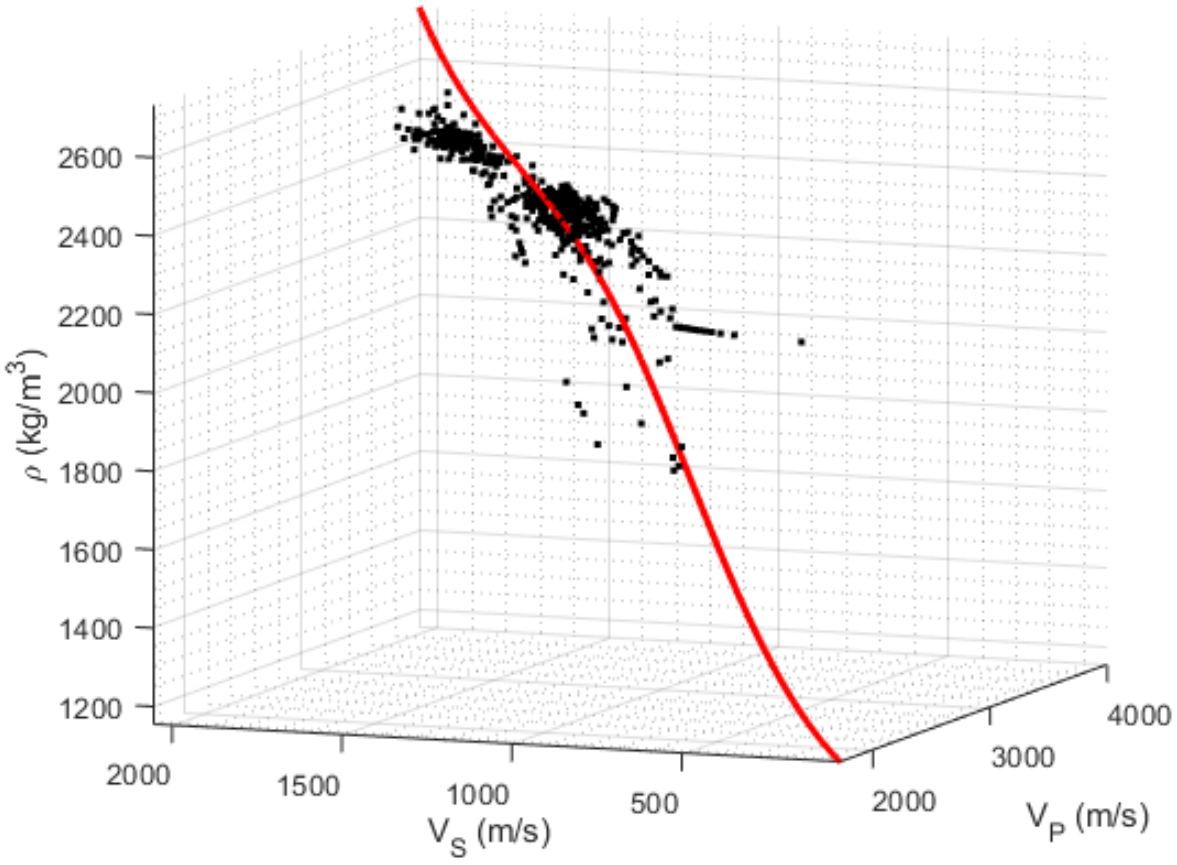
(Eaid, Keating and Innanen, 2021)

Motivation

Parameter encapsulating V_P, V_S, and ρ relationship

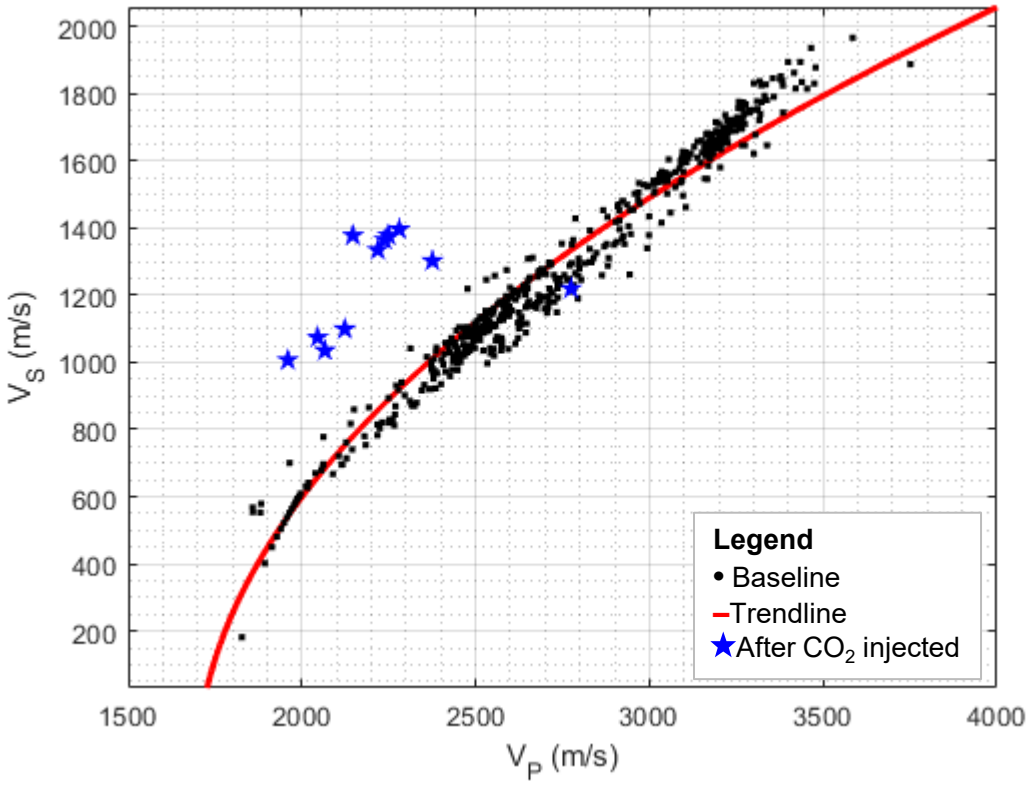


(CO_2 modeling from Macquet et al., 2019)



(Eaid, Keating and Innanen, 2021)

Introduction



(CO_2 modeling from Macquet et al., 2019)

Pros of the single parameter inversion:

- Uses prior information
- Prevents nonphysical combinations of Vp, Vs, ρ
- Prevents cross-talk

Cons of the single parameter inversion:

- Restrict isotropic-elastic model
- Excludes data variations

Objective:
Incorporate a second parameter, which captures much of the remaining data variability

Steps for well-log reparameterization

1. Map log values

2. Update FWI sensitivities

3. Apply FWI

$$\left(\frac{\partial \rho}{\partial Par_1} + \frac{\partial \rho}{\partial Par_2}\right), \left(\frac{\partial c_{11}}{\partial Par_1} + \ldots\right), \ldots$$

4. Return to original space

Assumption: trendline must be well behaved and differentiable

Proposed method

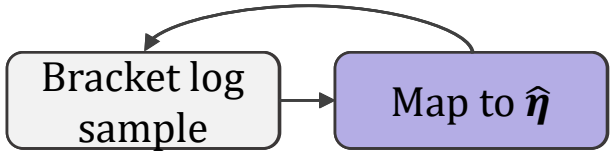
Position in V_P-V_S-ρ space = **Position <u>along</u> trendline** + **Distance in a <u>perpendicular</u> plane from trendline**

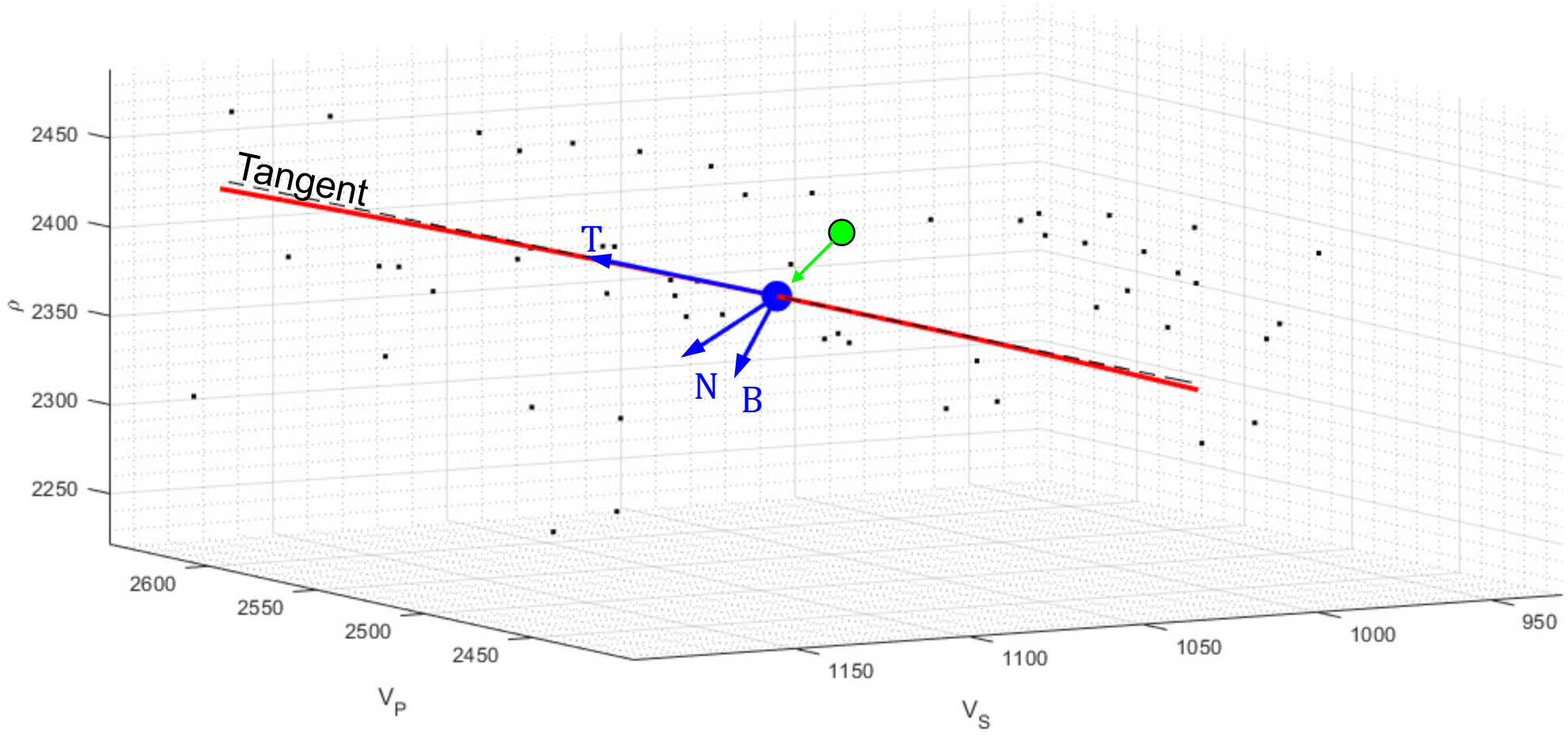
$$(\boldsymbol{P_{LOG}} = \hat{\boldsymbol{\eta}} + \boldsymbol{a}\hat{\boldsymbol{\kappa}})$$

Mapping well-log values

Legend
- Log value
- Trendline
- Bracket point
-- Tangent

$$P_{LOG} = \hat{\eta}^{1} + a\hat{\kappa}$$



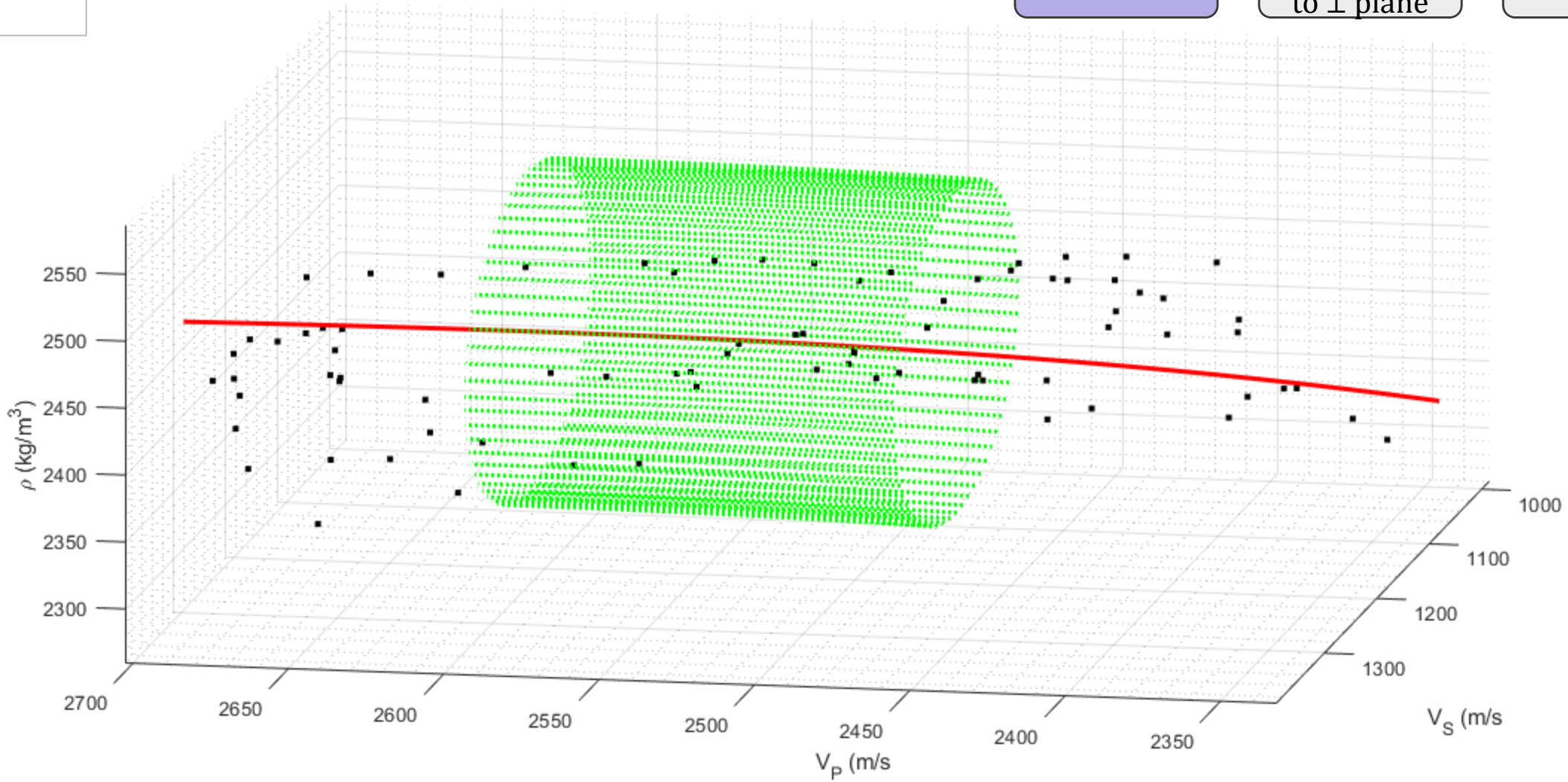


[1]: Eaid, Keating and Innanen, 2021

Mapping well-log values

$$P_{LOG} = \hat{\eta} + \boldsymbol{a}\hat{\boldsymbol{\kappa}}$$

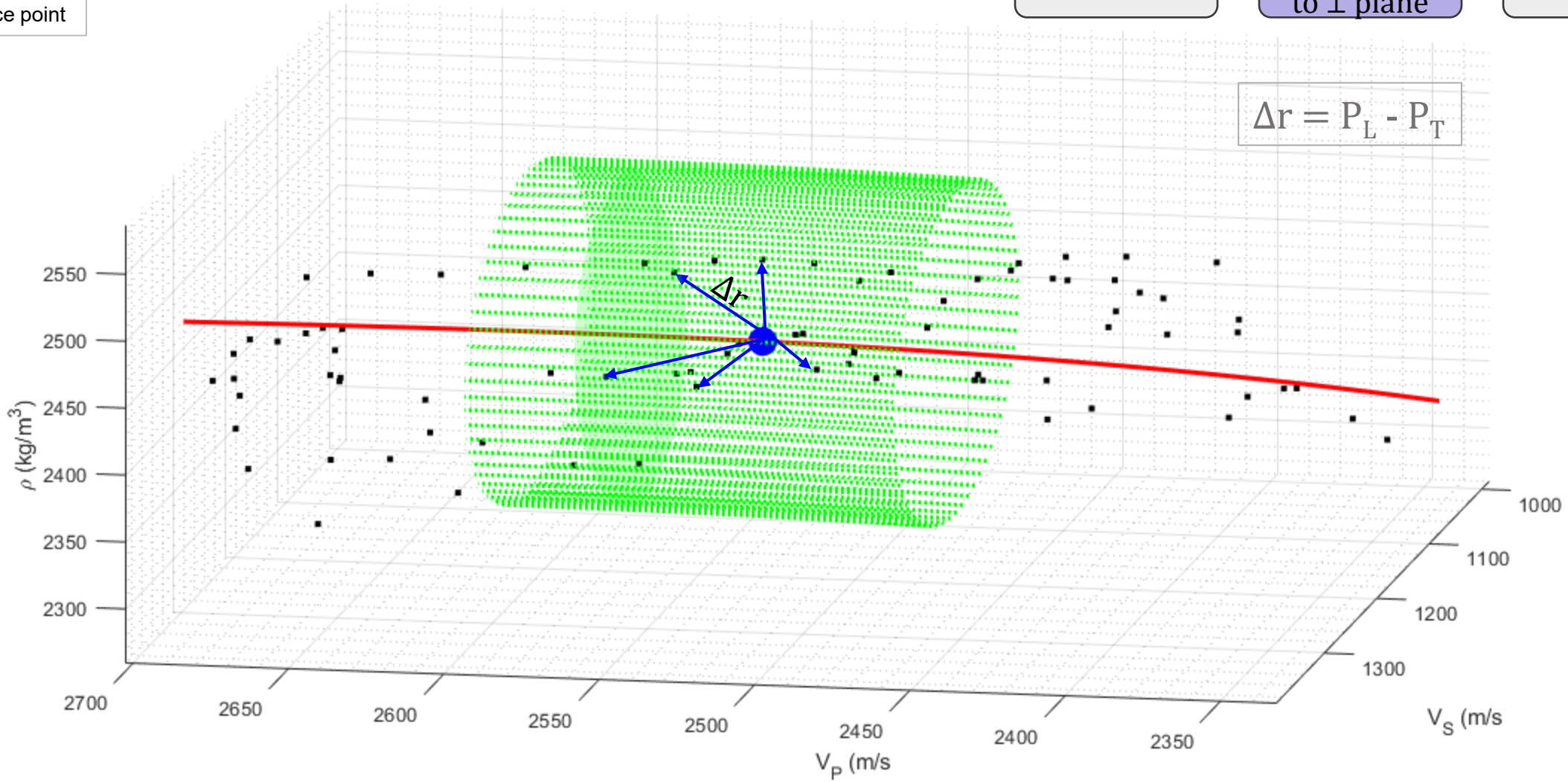
Def. vicinity → Project Δr to ⊥ plane → Apply PCA



Mapping well-log values

$$P_{LOG} = \hat{\eta} + \boldsymbol{a\hat{\kappa}}$$

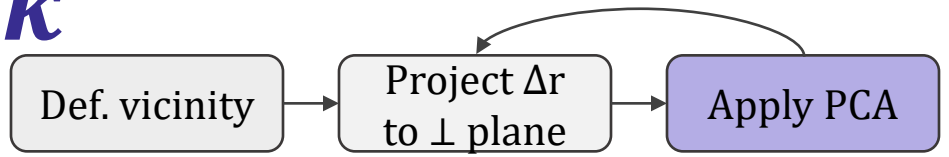
Def. vicinity → Project Δr to ⊥ plane → Apply PCA

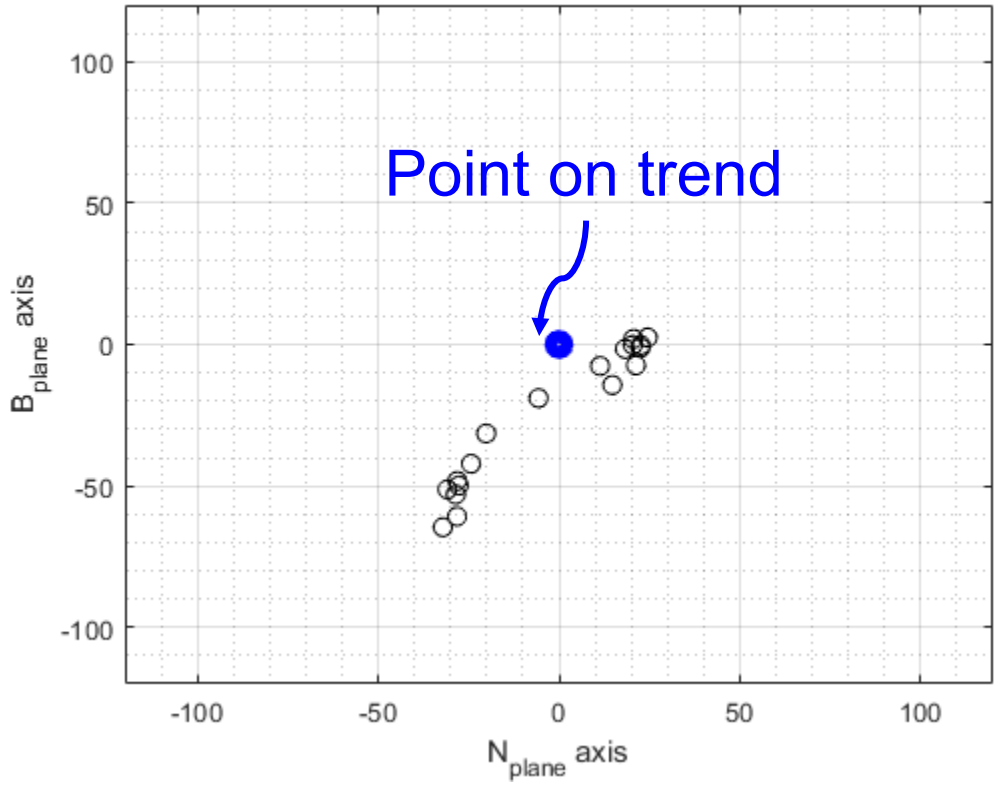


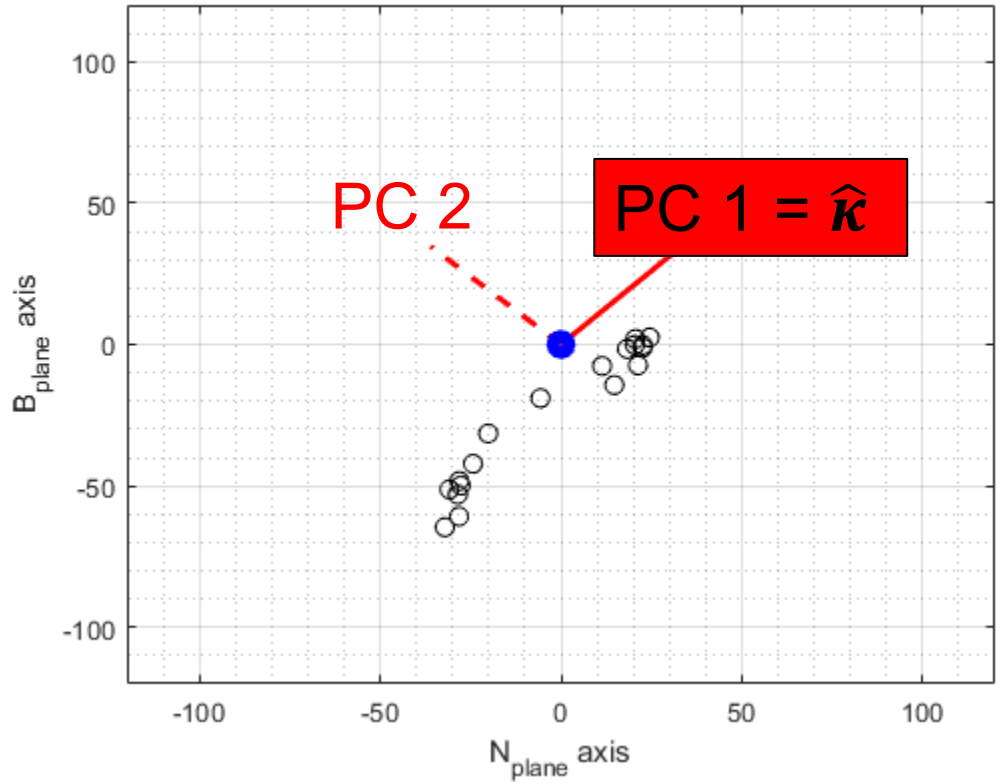
Mapping well-log values

Legend
- Projected Δr
- Reference point
- PCA comp.

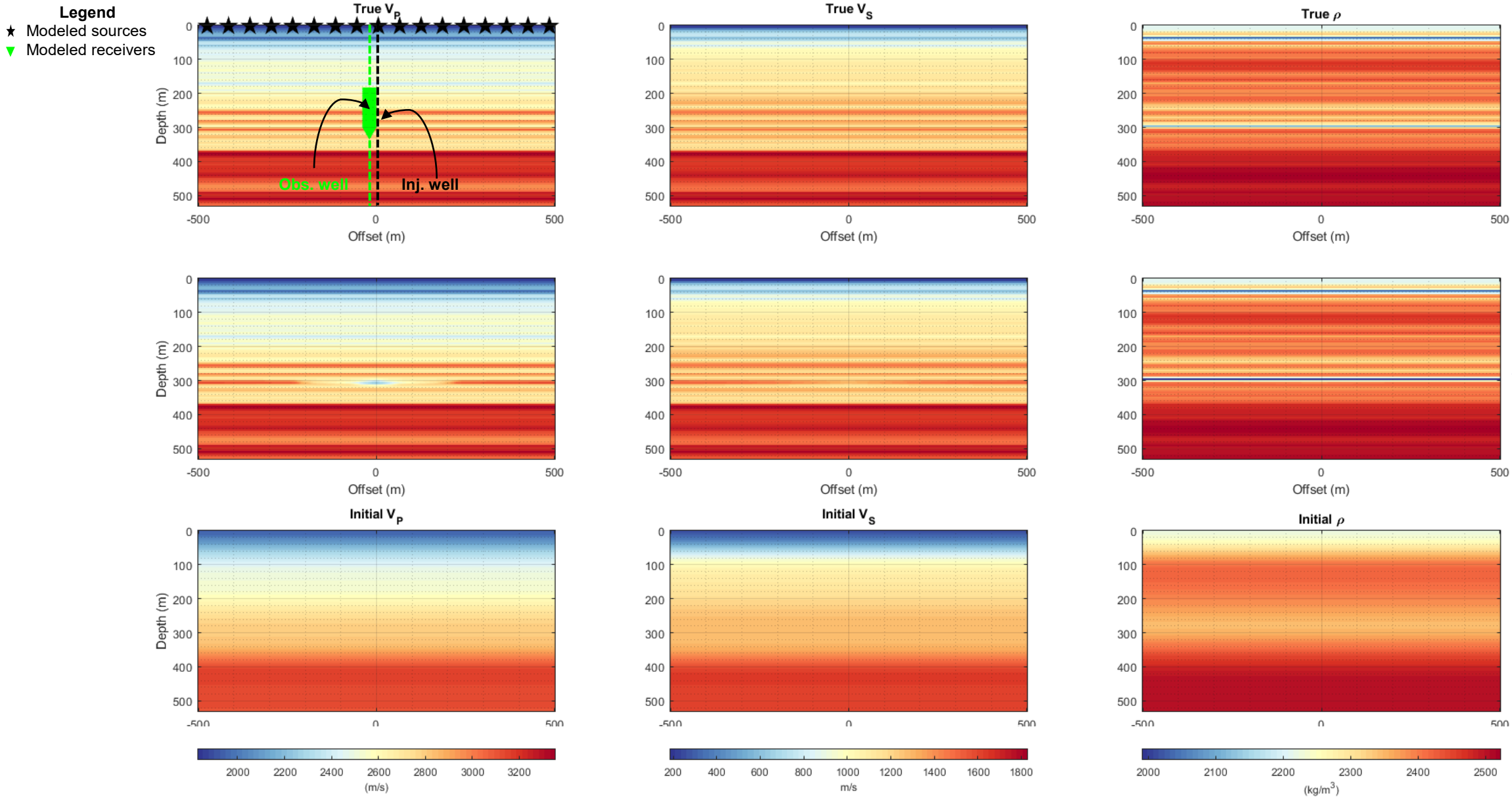
$$P_{LOG} = \hat{\eta} + \boldsymbol{a\hat{\kappa}}$$







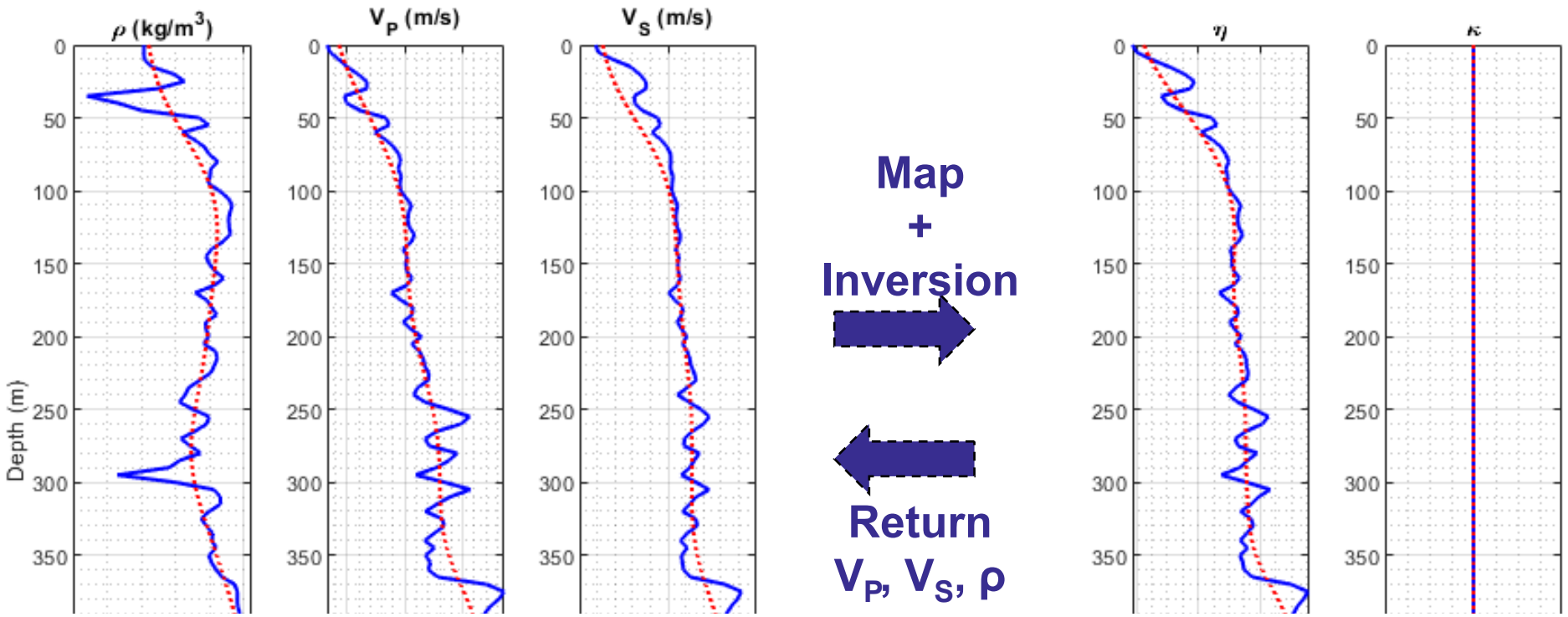
Modeled examples



Adapted from Macquet et al., 2019

Assumption: horizontal migration of the CO_2 effects centered in injection well at the reservoir level.

Modeled examples

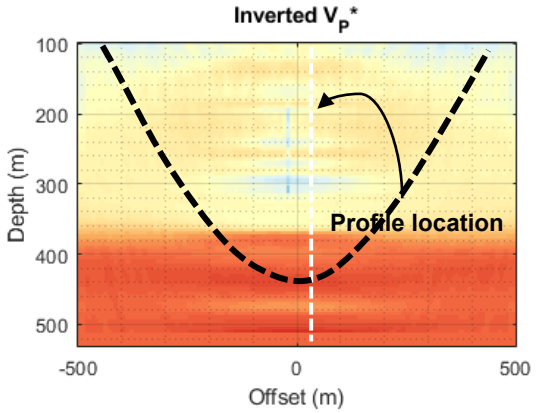


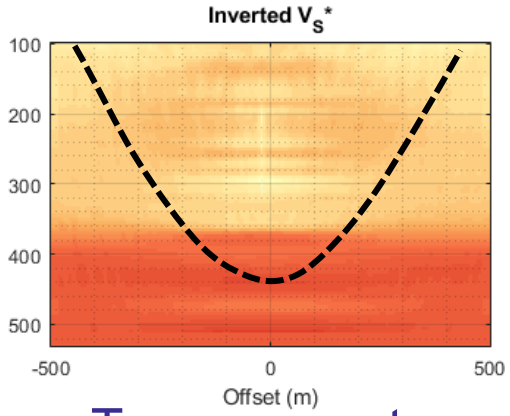
Parameterization	Case 1	Case 2
Single	η	η
Two-parameter	η $\kappa_{\text{fine-detailed}}$	η κ_{smooth}

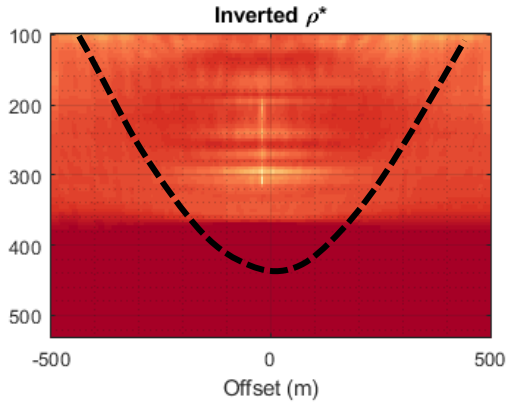
Case 1 comparison ($K_{fine\text{-}detailed}$)

Baseline

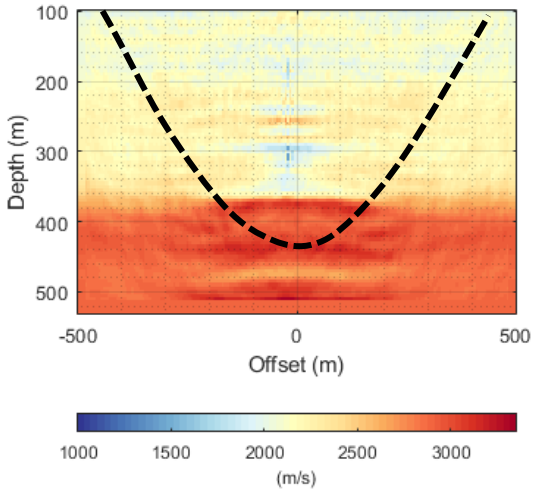
Single parameter

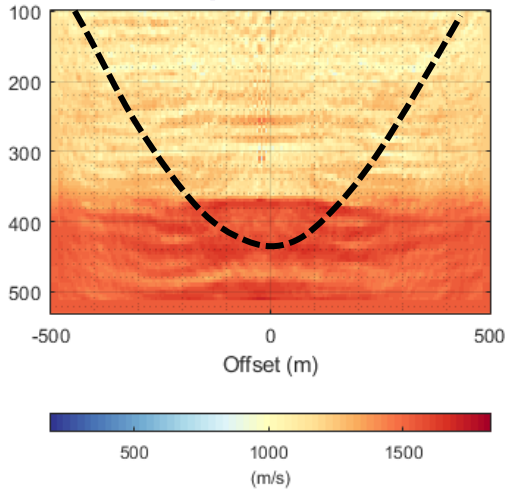


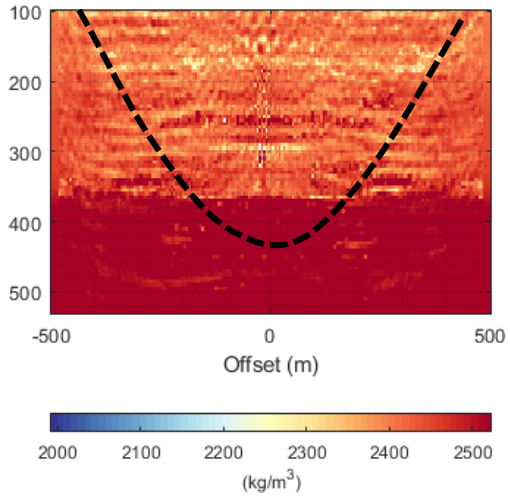


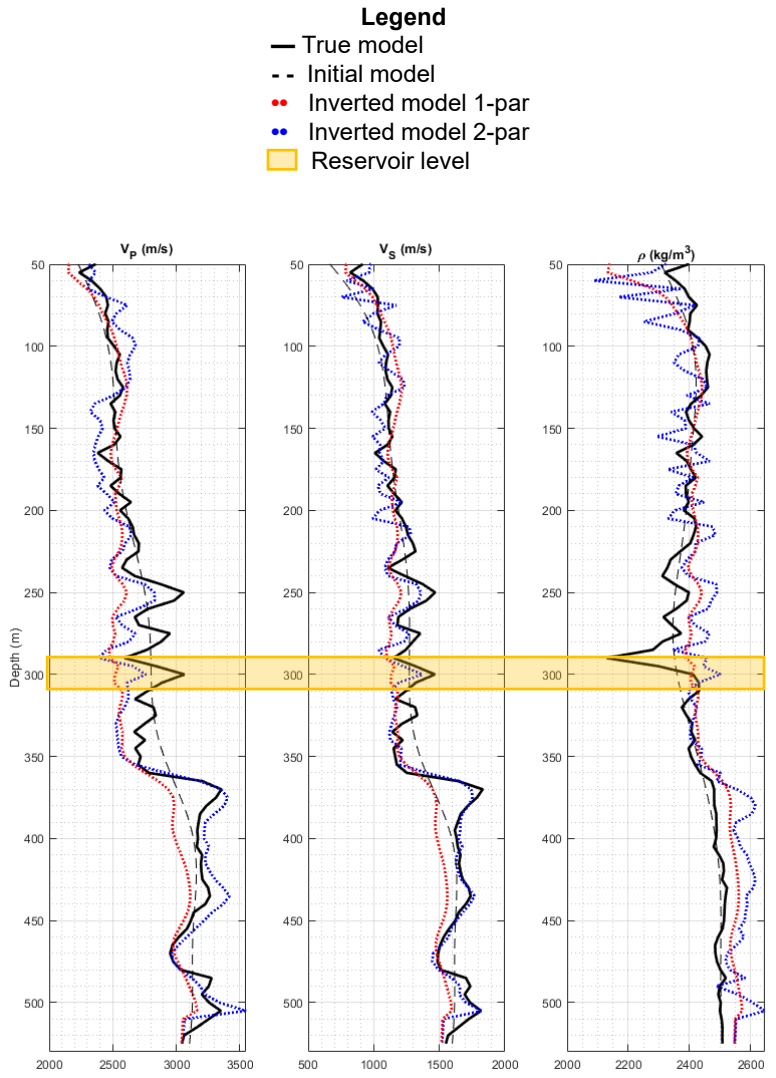


Two-parameter





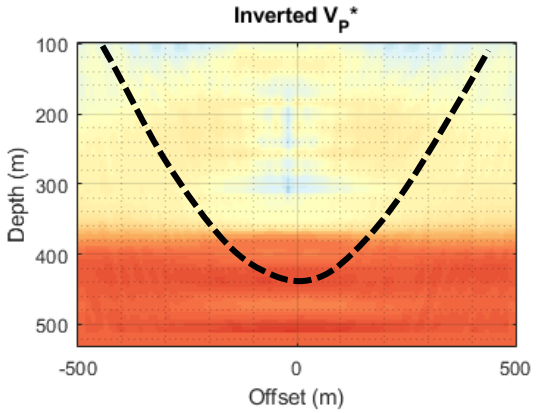


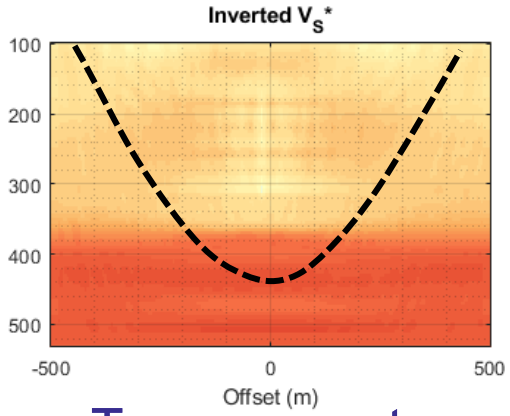


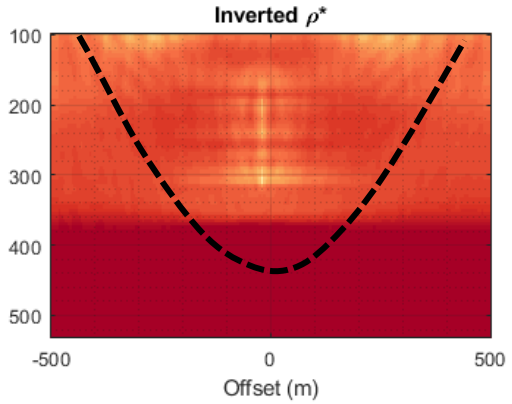
Case 1 comparison ($K_{fine\text{-}detailed}$)

Advanced stage

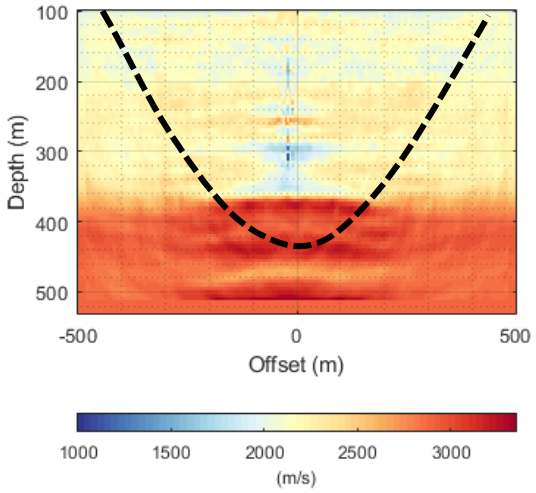
Single parameter

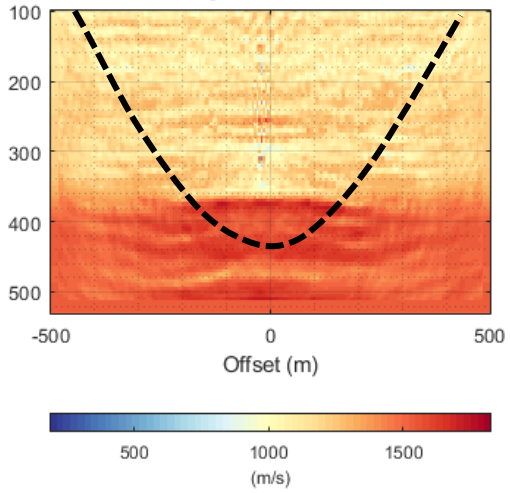


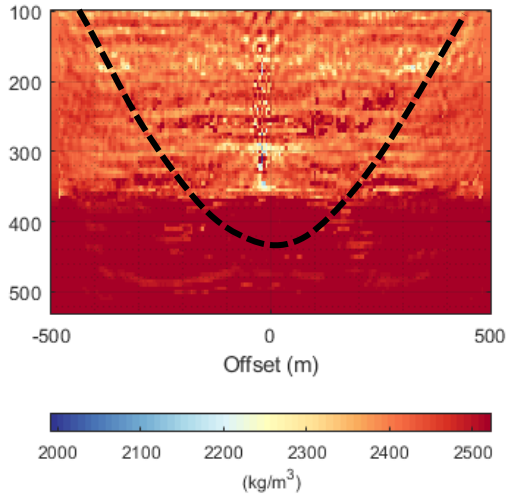


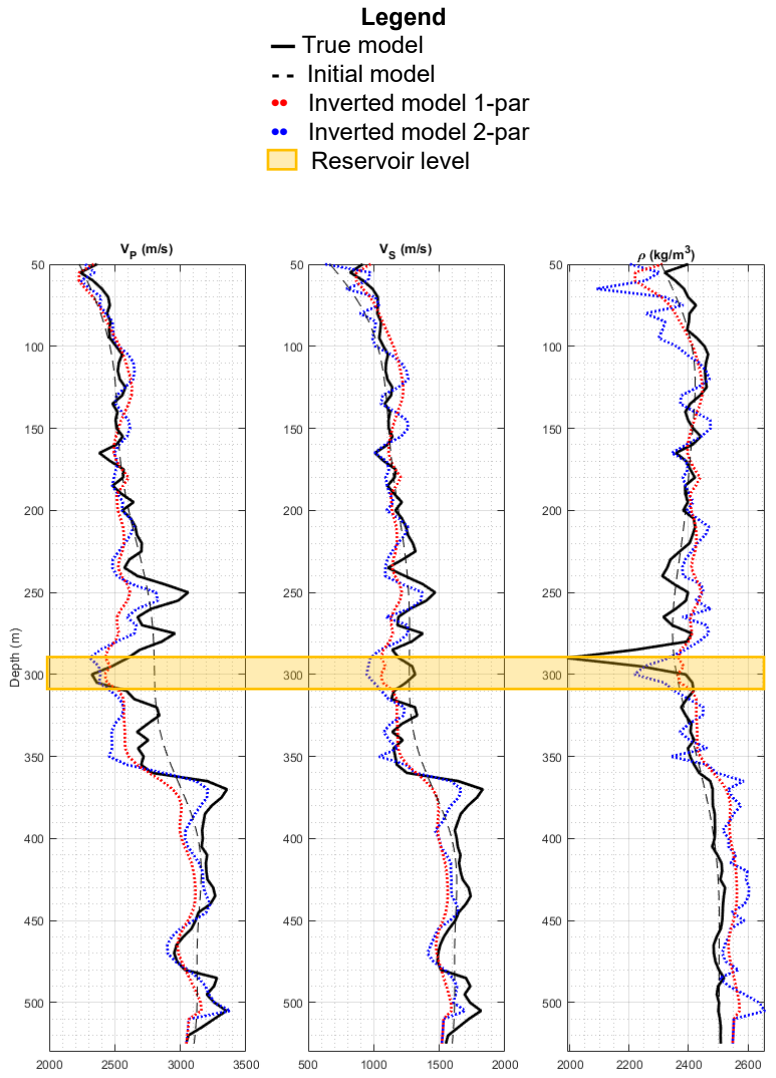


Two-parameter





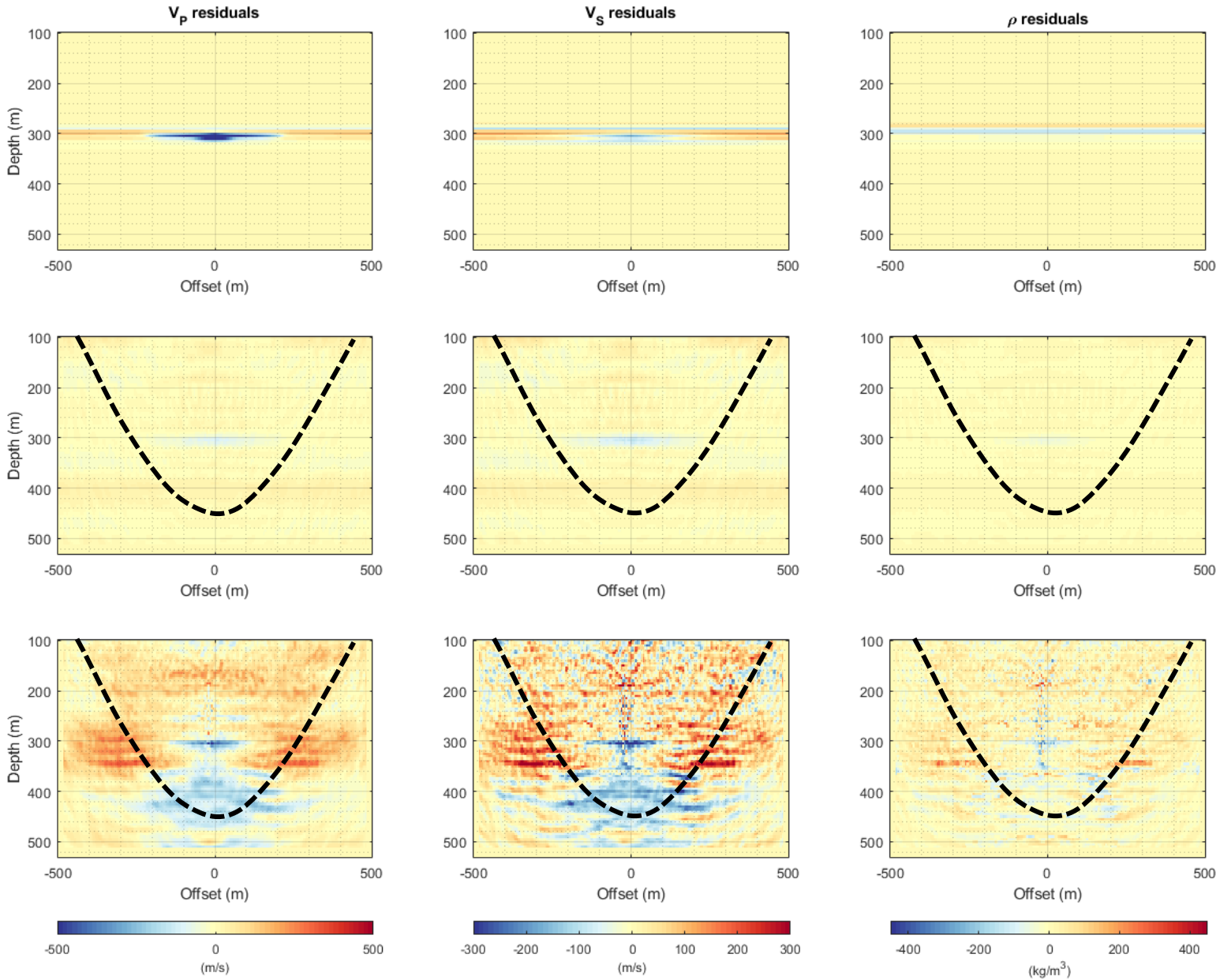




Case 1 comparison ($K_{fine\text{-}detailed}$)

$$m_{residual} = m_{advanced} - m_{baseline}$$

Model residuals



True V_P red = - 810 m/s
(at injection well)

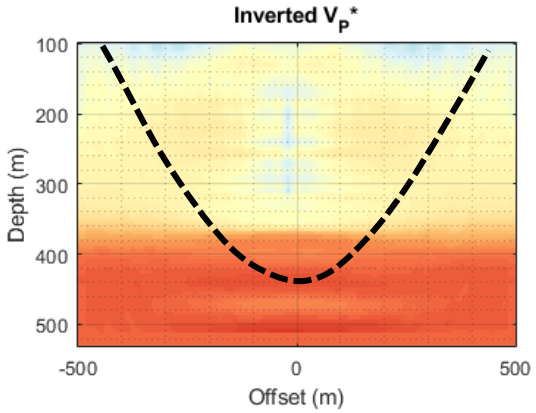
Single Parameter
V_P red = -109 m/s

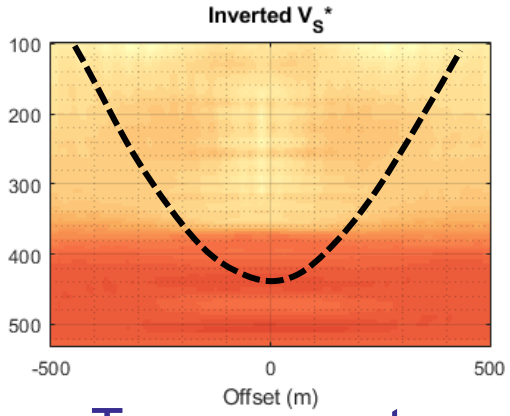
Two-Parameter
V_P red = -348 m/s

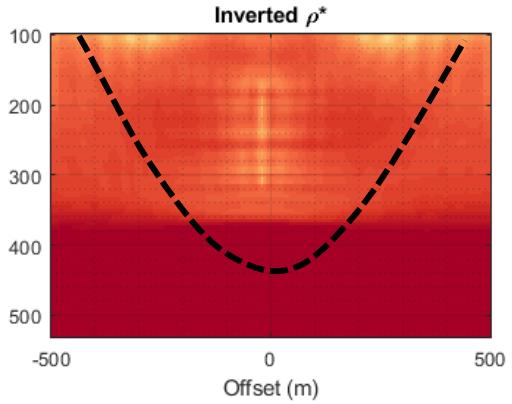
Case 2 comparison (κ_{smooth})

Baseline

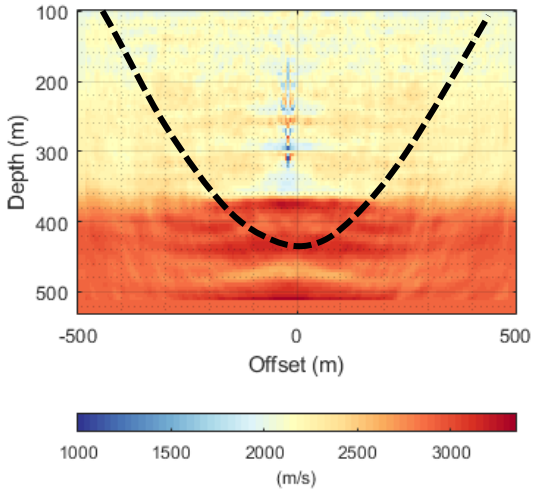
Single parameter

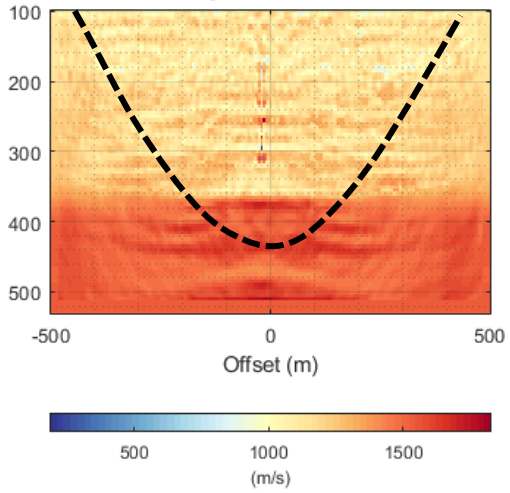


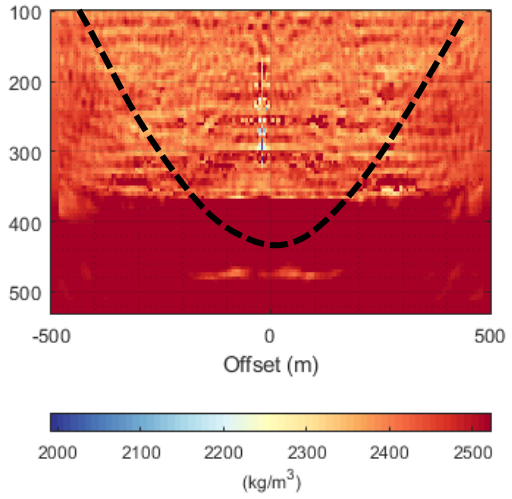


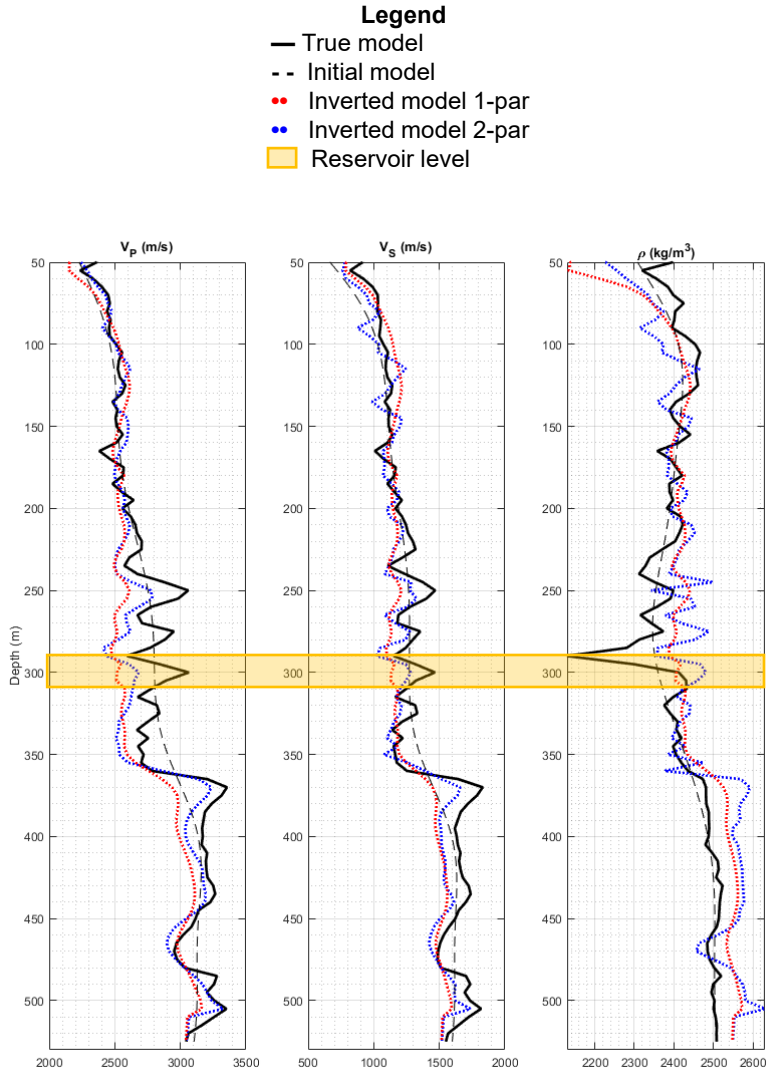


Two-parameter





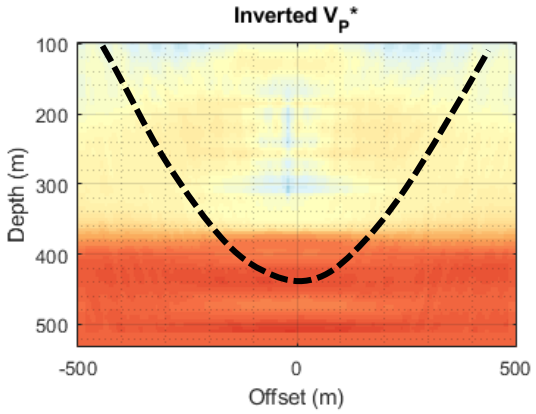


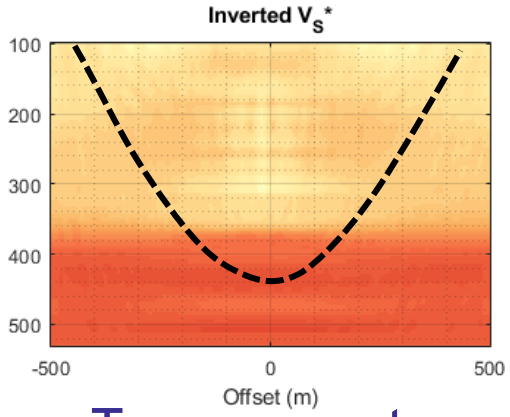


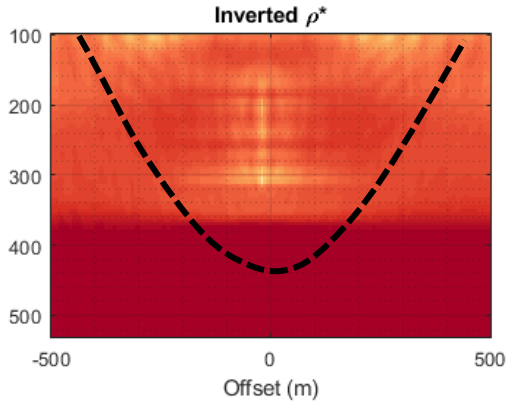
Case 2 comparison (κ_{smooth})

Advanced stage

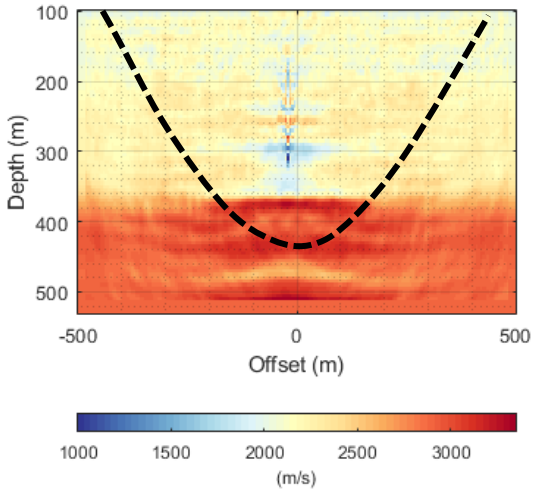
Single parameter

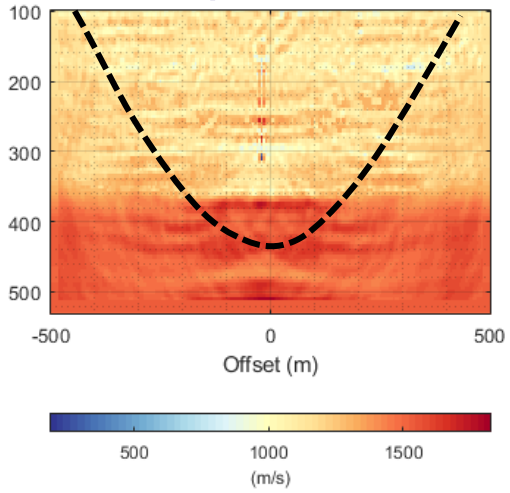


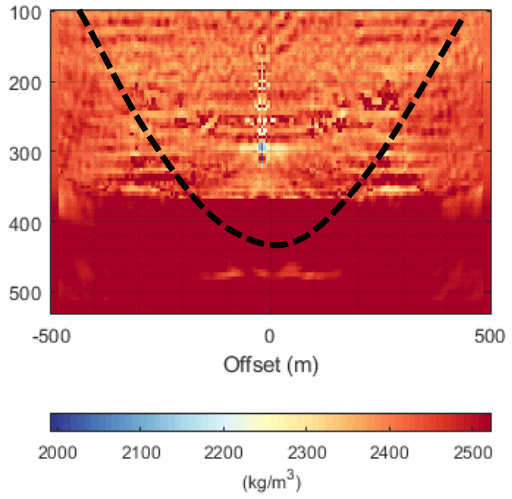


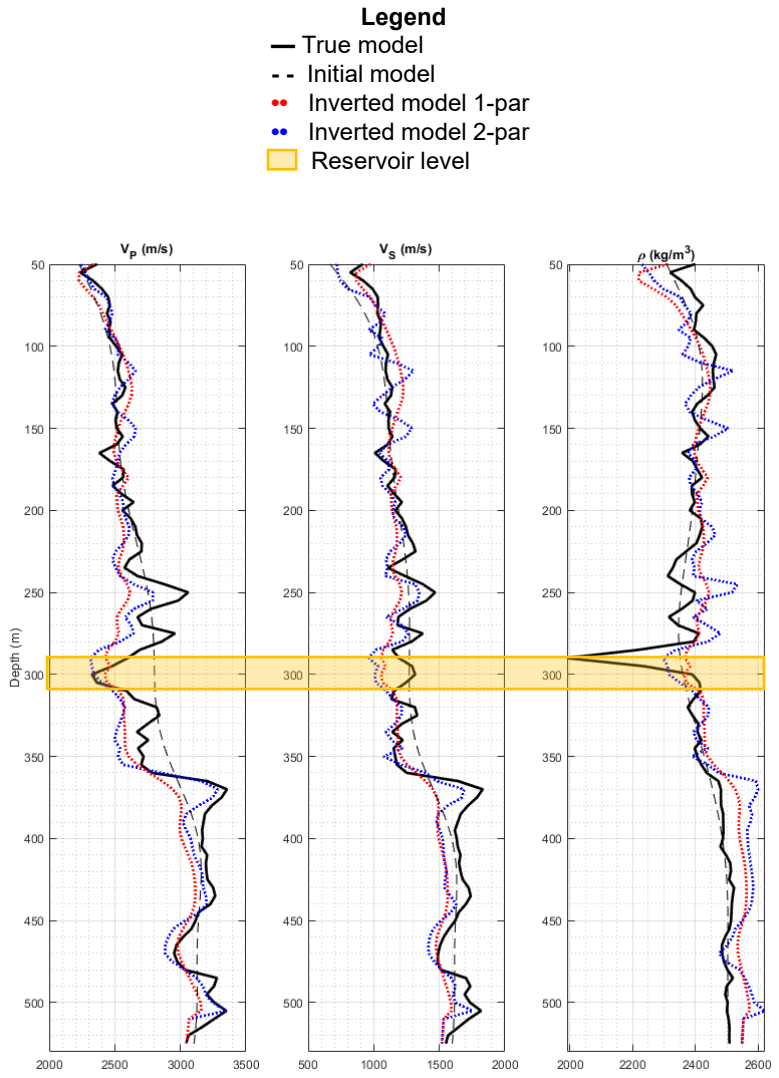


Two-parameter



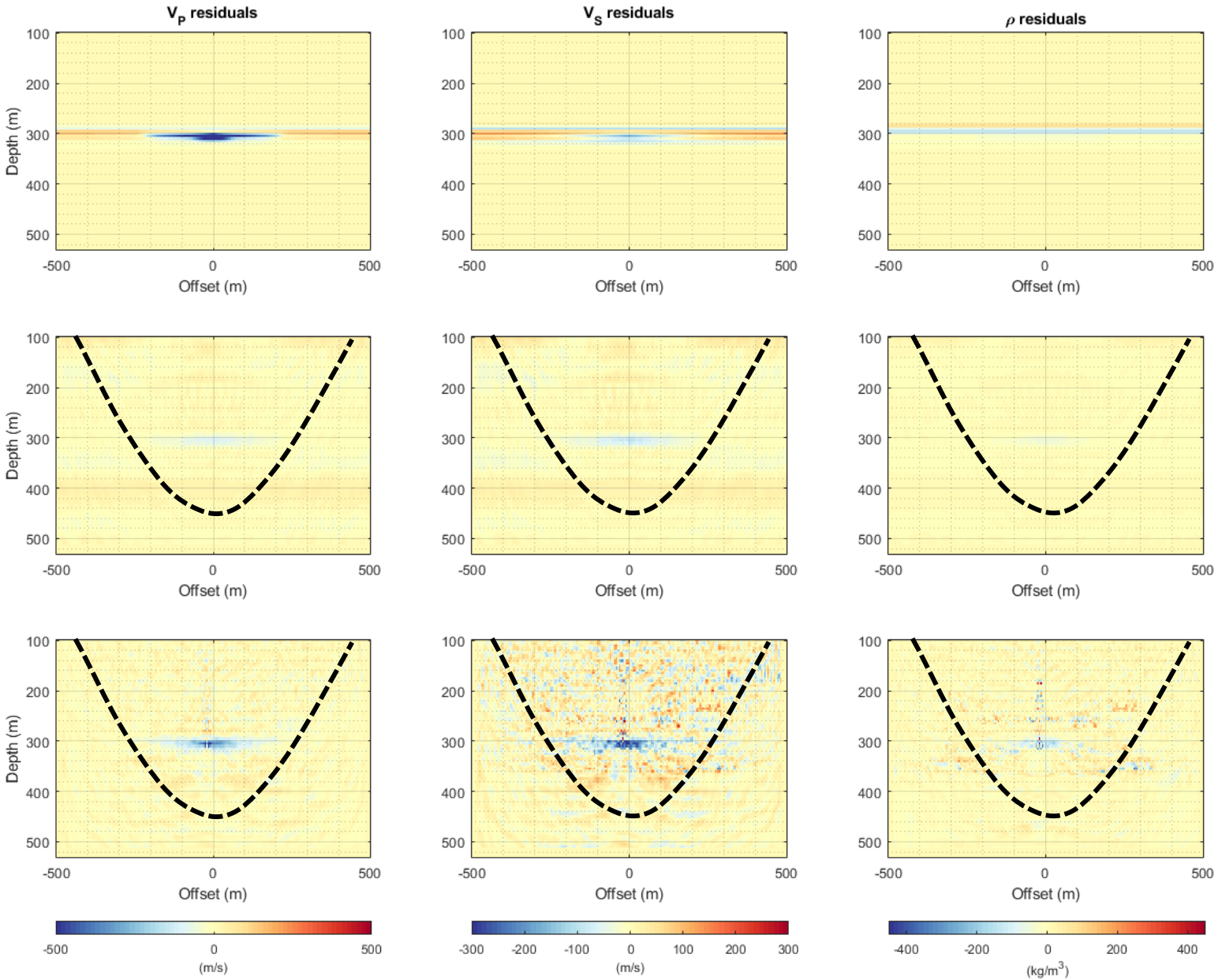






Case 2 comparison (κ_{smooth})

Model residuals



True V_P red = - 810 m/s
(at injection well)

Single Parameter
V_P red = -109 m/s

Two-Parameter
V_P red = -386 m/s

Summary and future work

- Second parameter aids:
  a) Better model convergence.
  b) Better delineation of gas effects.

- A ‘smooth’ normal distance introduces less artifact in inverted models.

- More analysis about parameter tuning is required to:
  a) Define penalty terms.
  b) Understand imaging effects of second parameter in V_P, V_S, ρ.

Acknowledgements

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Faculty, staff and students

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References

- Eaid, M., Keating, S., and Innanen, K. A., 2021, Full waveform inversion of DAS field data from the 2018 CaMI VSP survey: *CREWES Research Report*, vol 33, No. 7

- Macquet, M., Lawton, D. C., Saeedfar, A., and Osadetz, K. G., 2019, A feasibility study for detection for detections thresholds of co2 at shallow depths at the cami field research station, newell county, alberta, canada: *Petroleum Geoscience*, vol 25, No. 4, 509–518