# Rock physics properties from seismic attributes with global optimization methods

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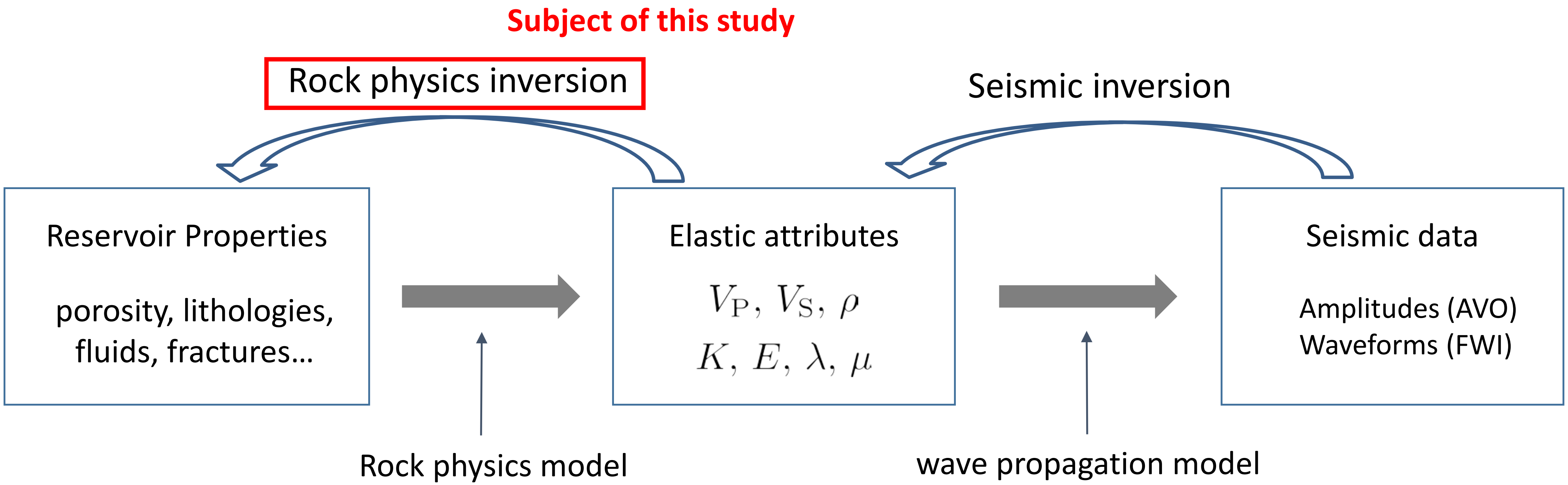
Sponsors Meeting

## ■ Quantitative seismic interpretation



## ■ Nonlinear inverse problems

- **Local optimization methods**: make use of local slope or curvature or both of the cost function to compute an update to the current model.

  e.g., steepest descent, conjugate gradient, Newton's method

- **Global optimization methods**
  - **Enumerative or grid-search method**: involve the systematic search through each point in a predefined model space to locate the bestfit models.
  - **Monte Carlo-type random-search techniques**: stochastic in nature

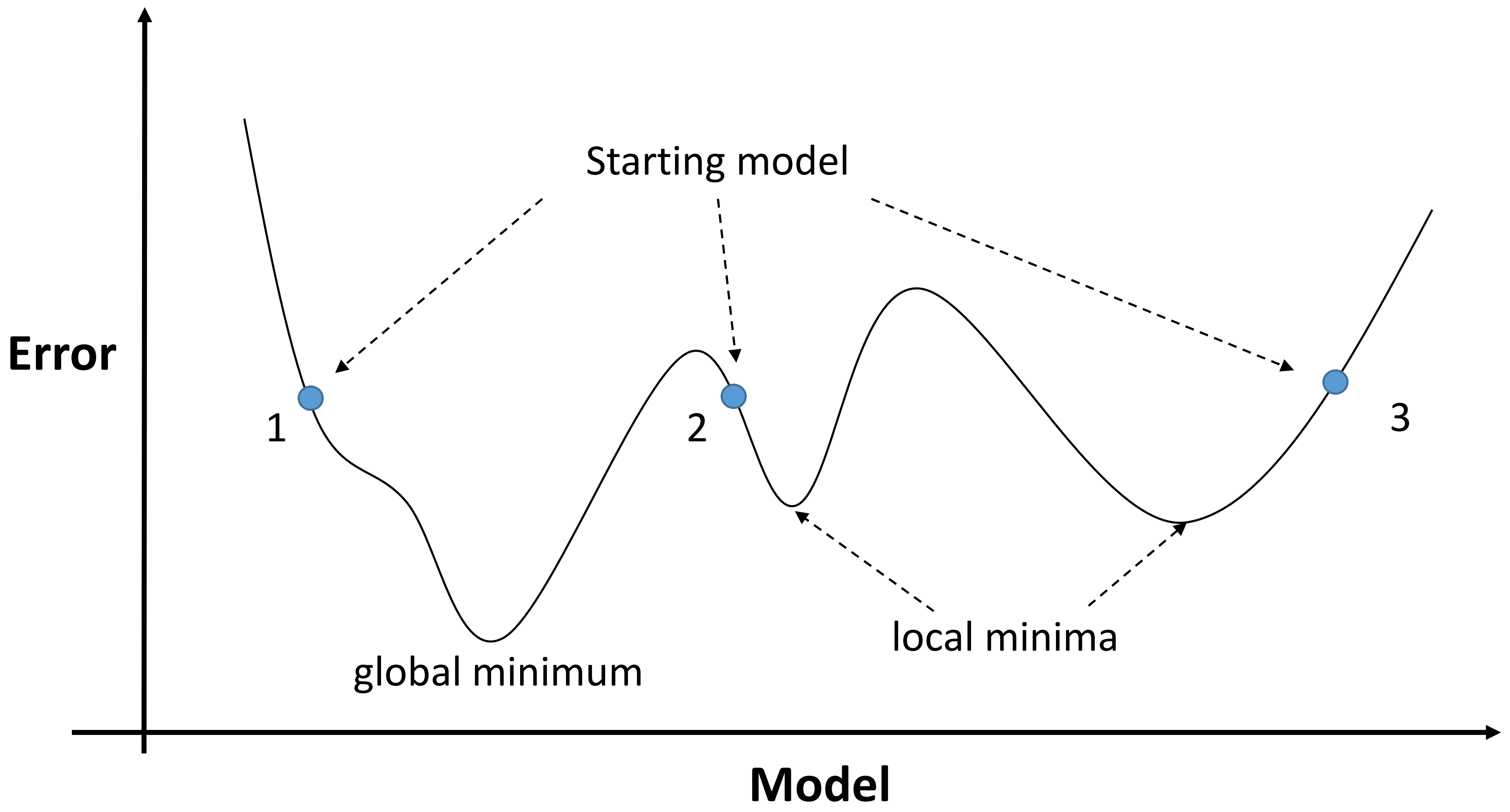
    a). **Pure Monte Carlo method**: models are drawn uniformly at random

    b). **Directed Monte Carlo methods**: make use of previous samples to guide their search

    e.g., Simulated annealing, Genetic algorithms, Neighborhood algorithm

*adopted largely from Sen and Stoffa, 2013*

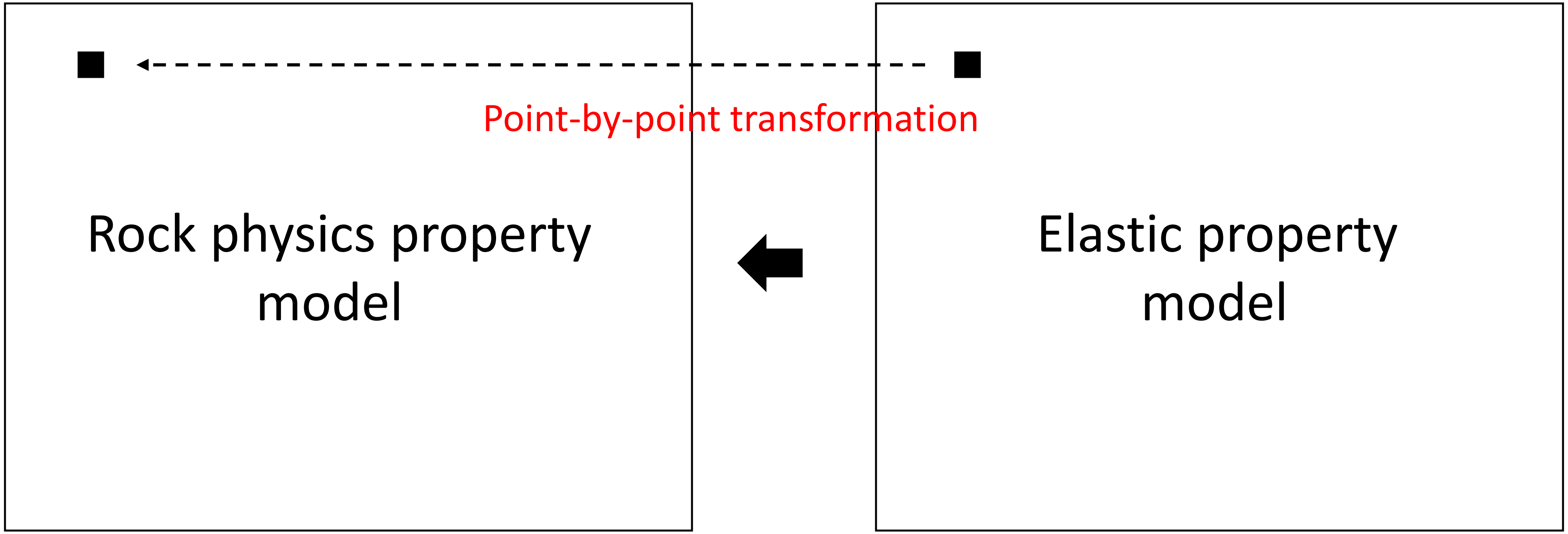
**Why global optimization?**



# Background

**Why global optimization can be used for rock physics inversion?**

- Model space is small: point by point
- Forward calculation is fast: most rock physics models are analytic



# Methods

**Inverse problem:**

$$\mathbf{d} = g(\mathbf{m})$$

porosity, clay content, water saturation

$$\mathbf{d} = [V_{\mathrm{P}}\ V_{\mathrm{S}}\ \rho],\ \mathbf{m} = [P\ C\ Sw],$$ $g$ : Rock physics model

**Misfit function:**

$$E(\mathbf{m}) = \|\mathbf{d}_{obs} - g(\mathbf{m})\|^2$$

- Simulated Annealing (SA)
- Genetic algorithm (GA)
- Neighborhood algorithm (NA)

# Methods

## ■ Simulated Annealing (SA)

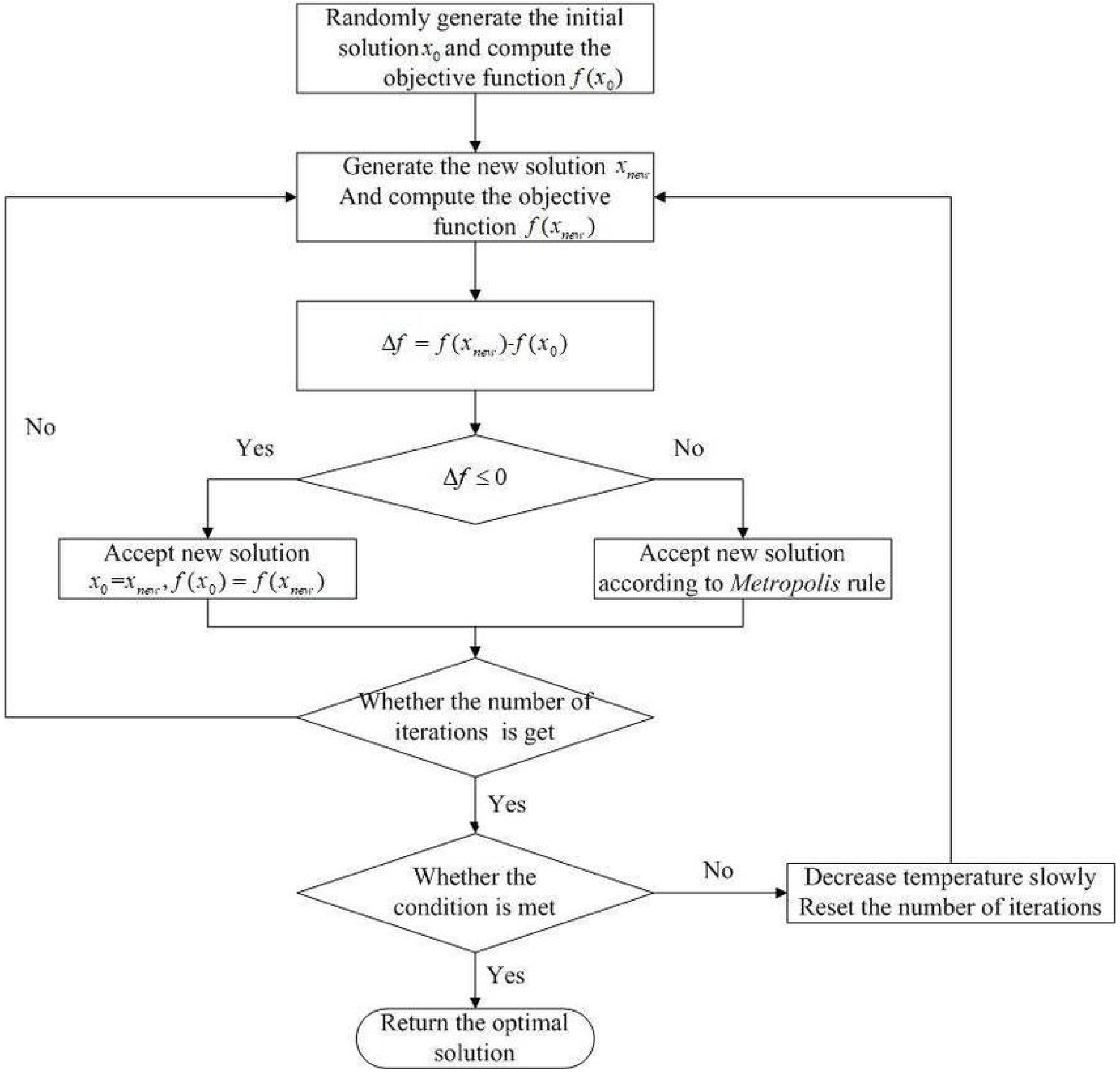
simulates the physical annealing process

Perturb **m** to **m'**, $\Delta E = E(\mathbf{m}') - E(\mathbf{m})$

**Metropolis algorithm:**

1. Always accept a downhill step $\Delta E < 0$ ;
2. Accept an uphill step $\Delta E > 0$ with a probability:

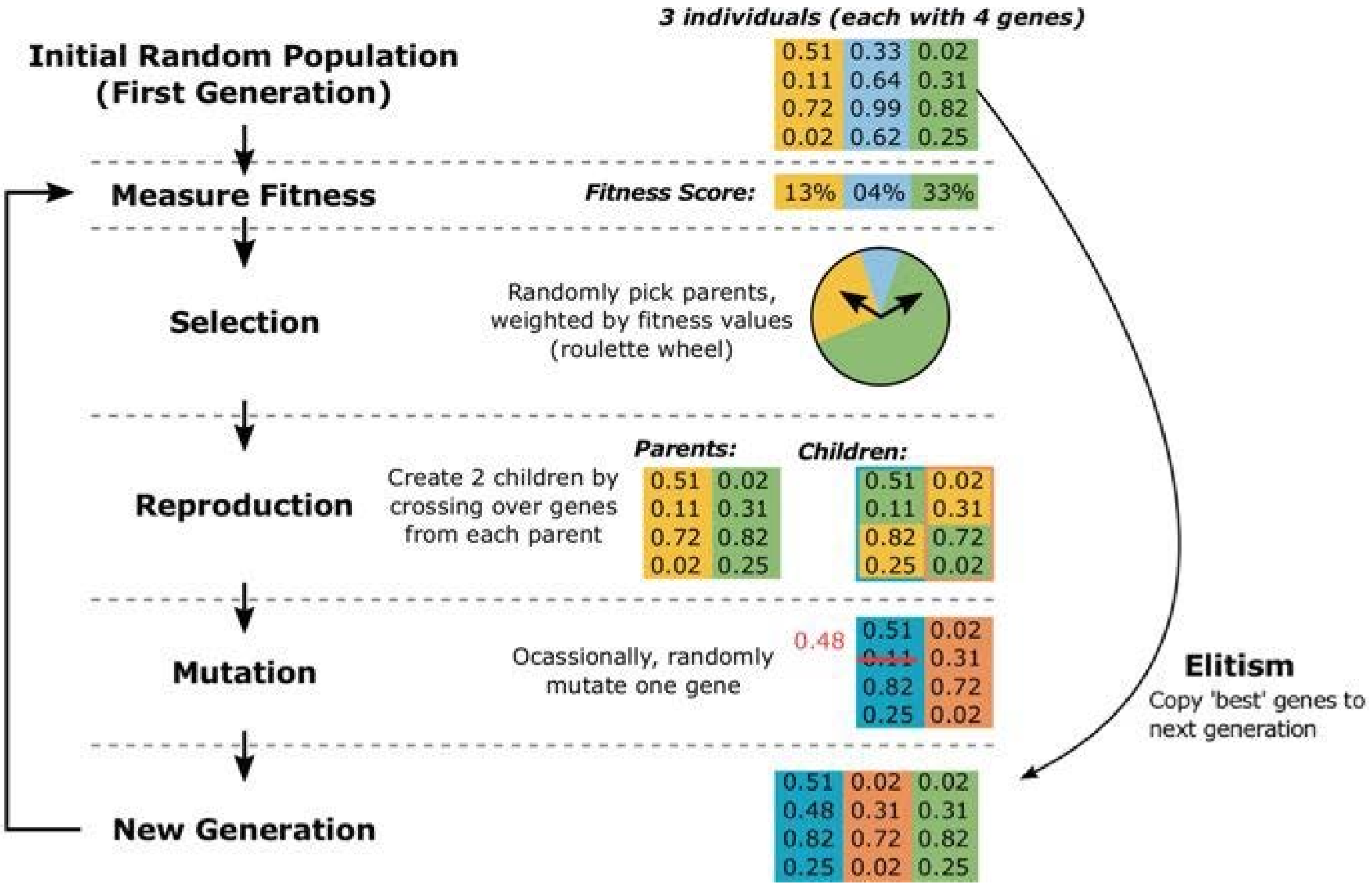
$$P = \exp(-\frac{\Delta E}{T})$$




A flowchart of SA algorithm (Zhou, 2019)

- Genetic algorithm (GA)

based on an analogy with the processes of biologic evolution




Working of a genetic algorithm (Bal, 2019)

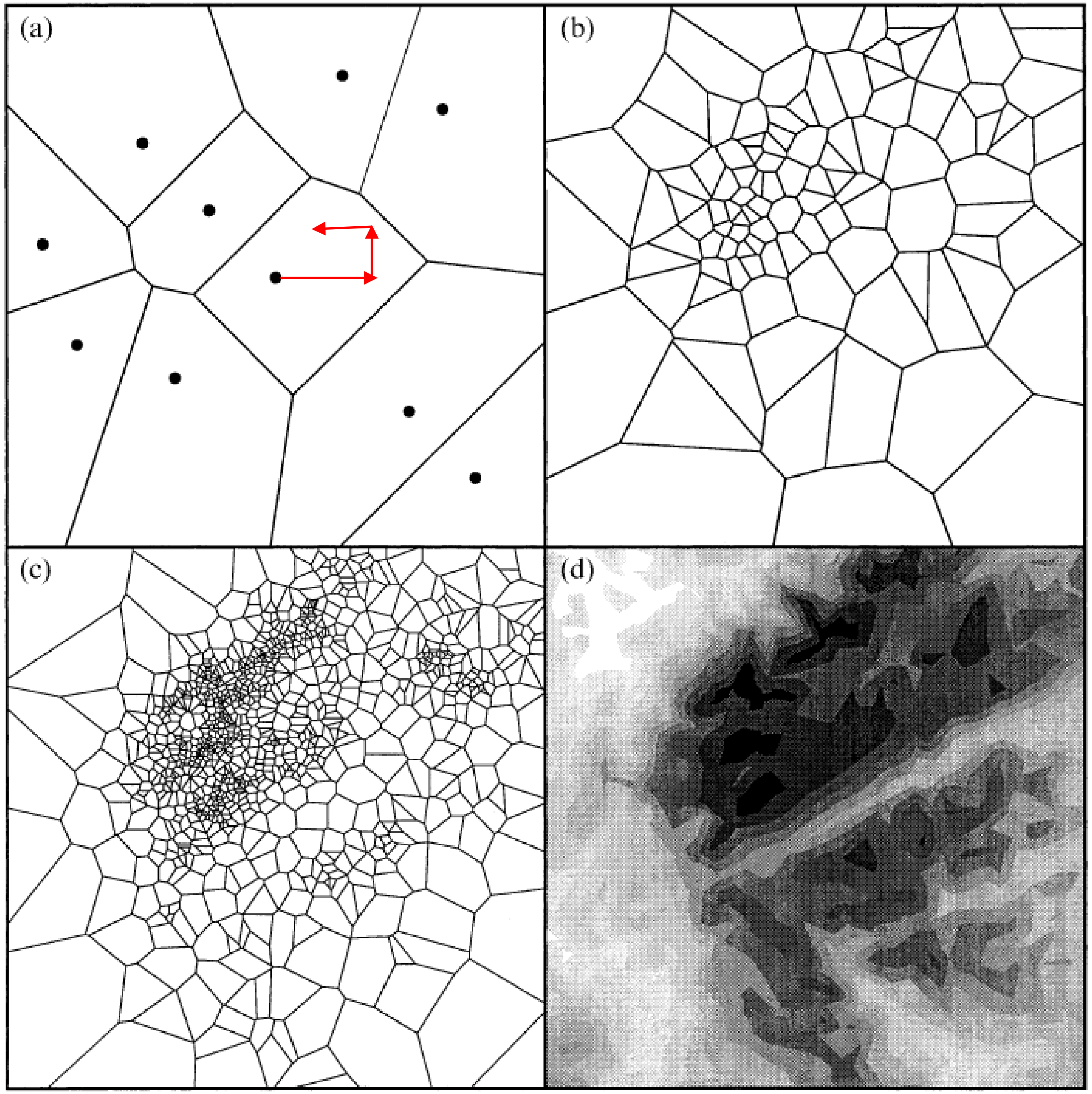
# Methods

- Neighborhood algorithm (NA)

Voronoi cell: nearest neighbor region

a. 10 random points and their Voronoi cells.
b. 100 samples
c. 1000 samples
d. Approximate misfit surface

Sambridge, 1999



# Numerical examples

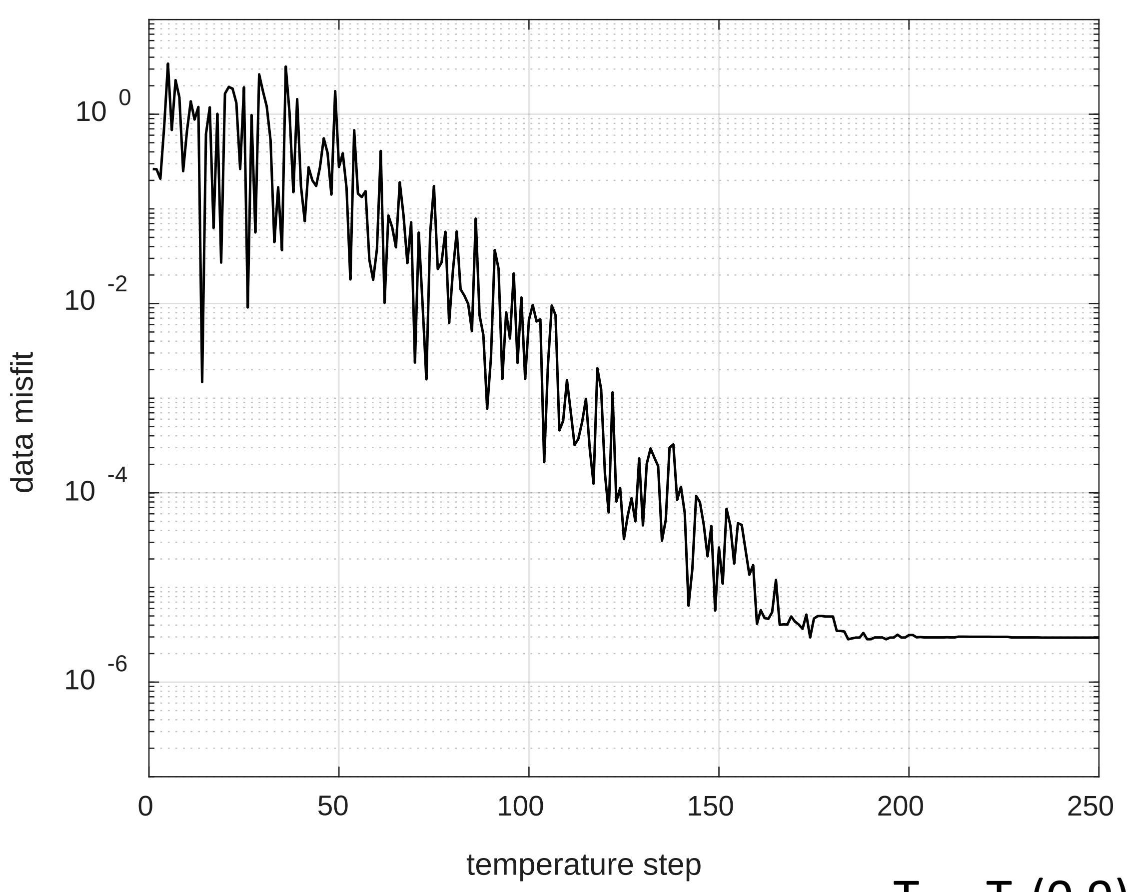
- Single-point test

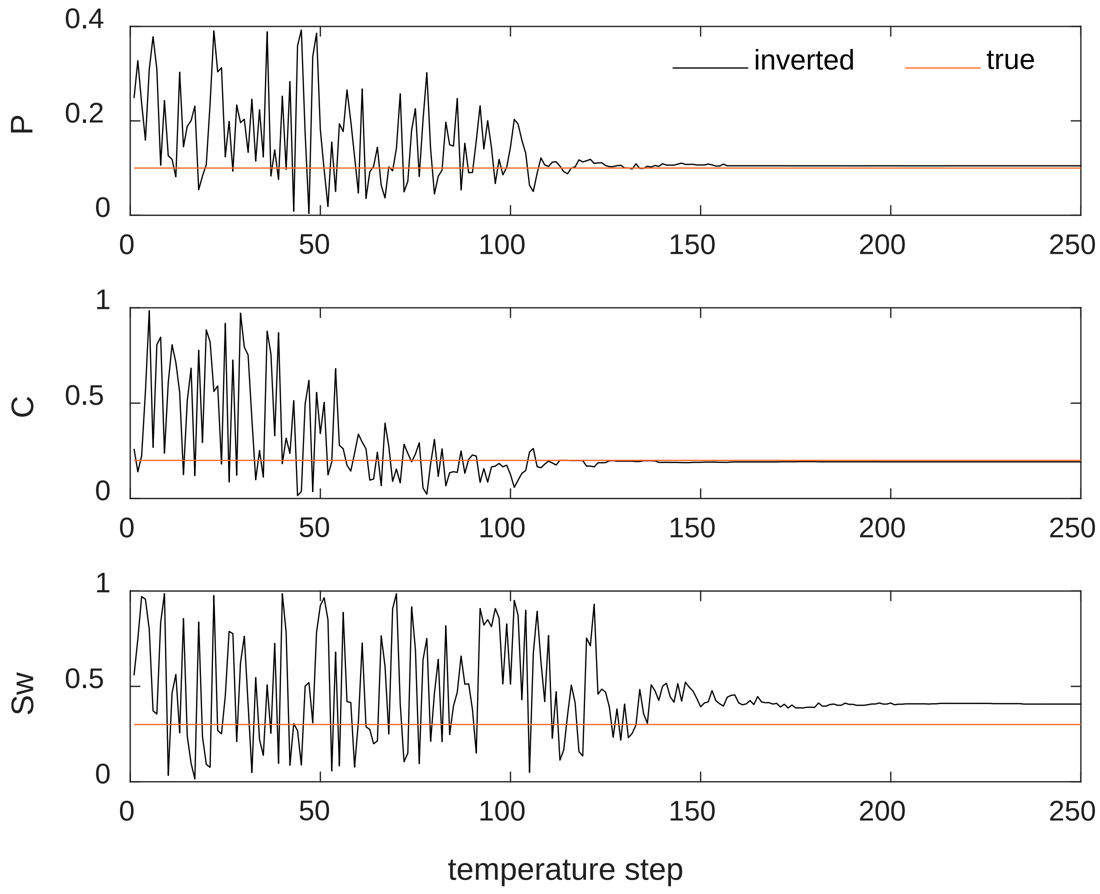
$$(V_\mathrm{P}, V_\mathrm{S}, \rho) = \mathrm{KT}(P = 0.1, C = 0.2, Sw = 0.3)$$

- Noise test using synthetic well logs
- Rock physics inversion using EFWI results

# Single-point test

## Simulation results using SA

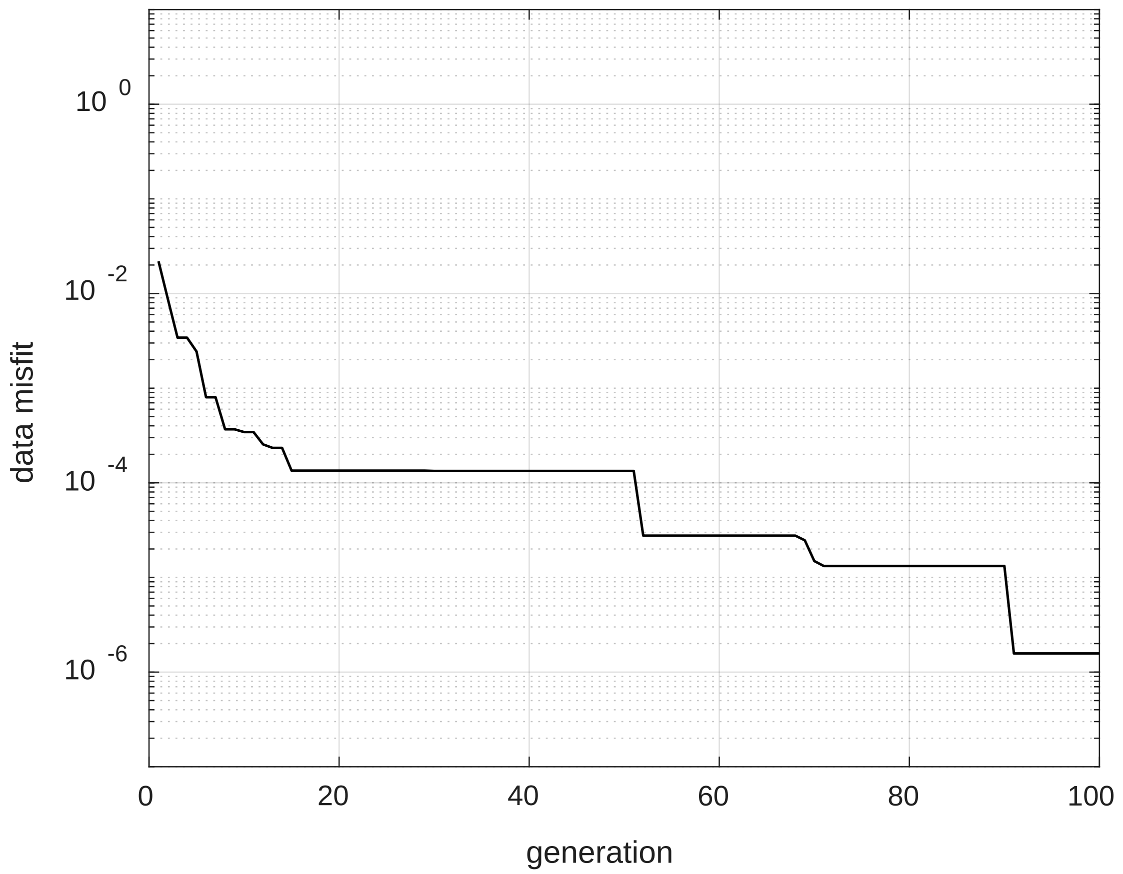


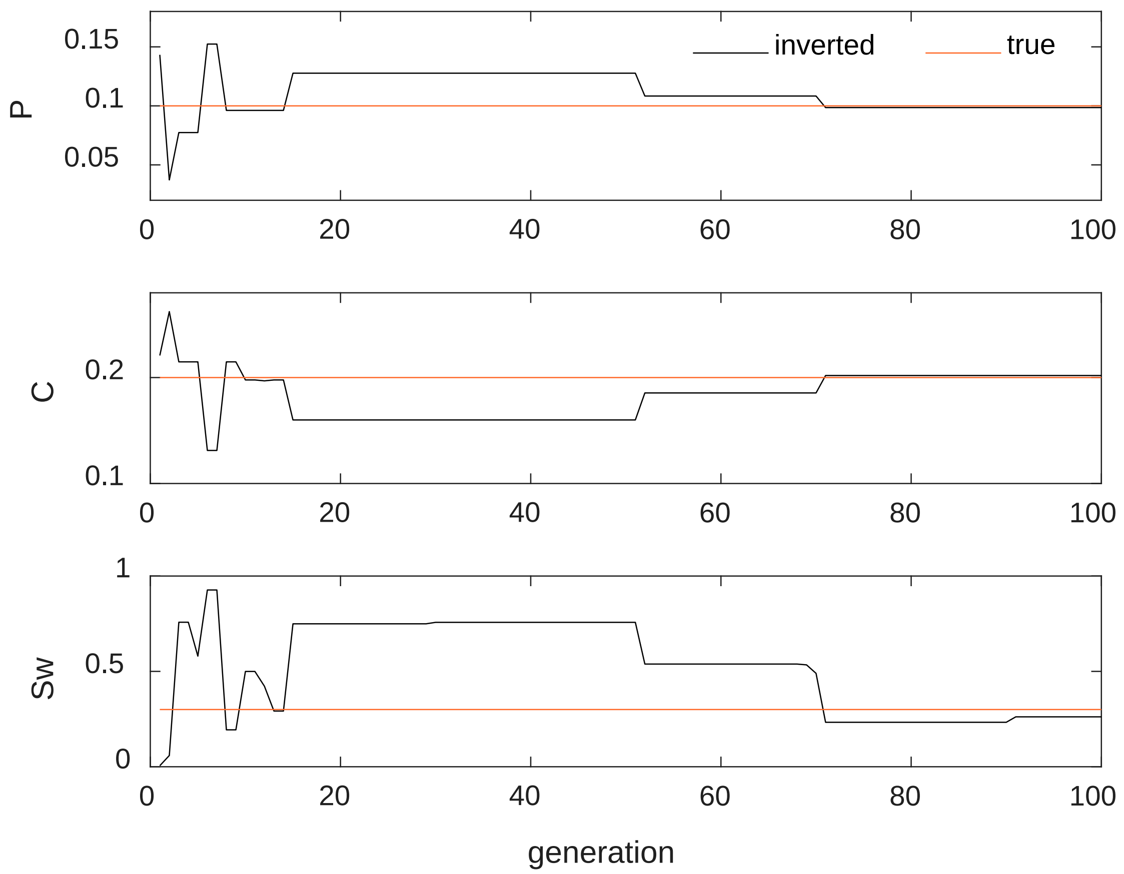




$T_k = T_0(0.9)^k$

# Single-point test

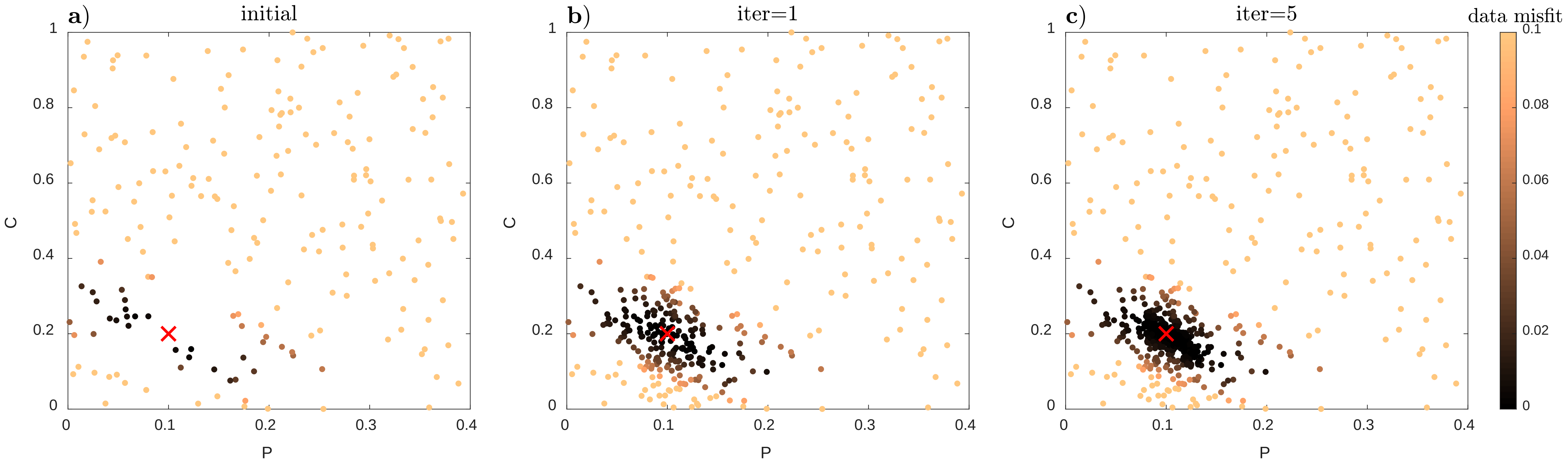
## Simulation results using GA



# Single-point test

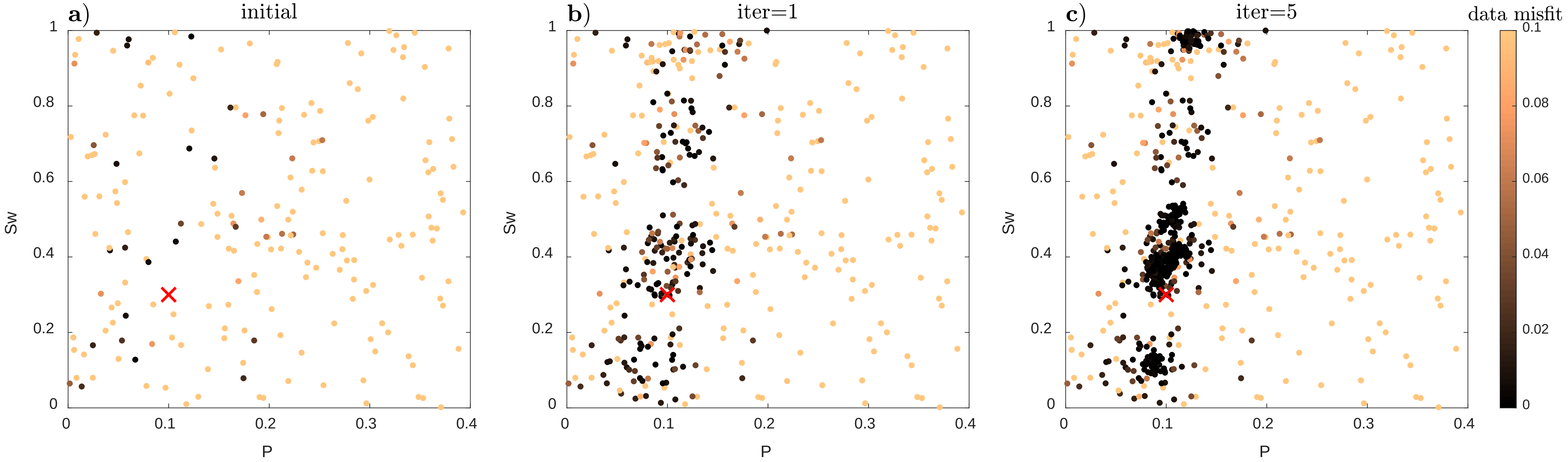
## Simulation results using NA




The information in the misfit-surface is exploited to concentrate sampling in the regions where the misfit is low

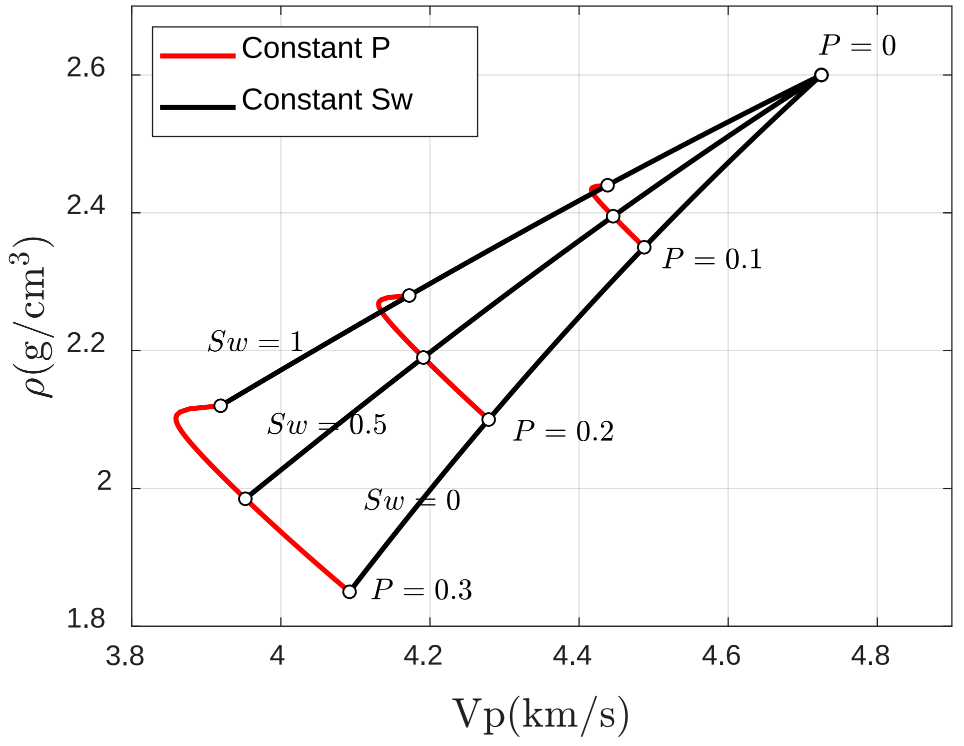
# Single-point test

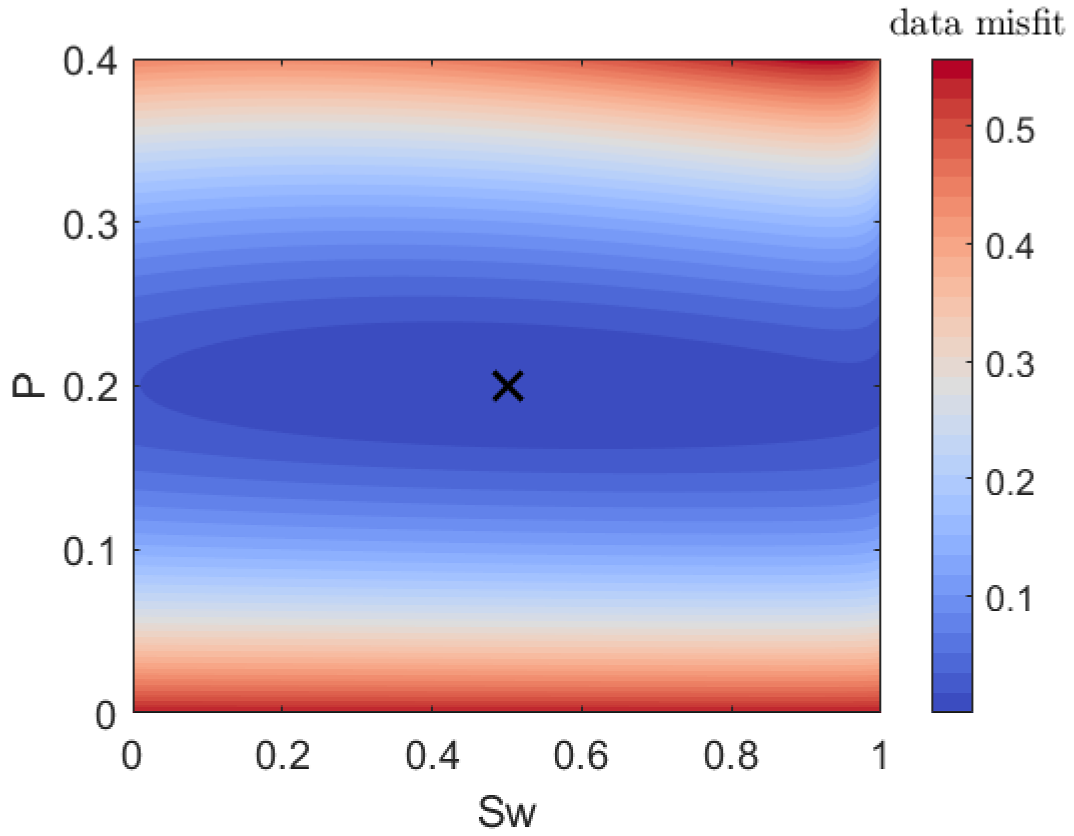
## Simulation results using NA




Sw displays several local minimum.

# Sensitivity analysis



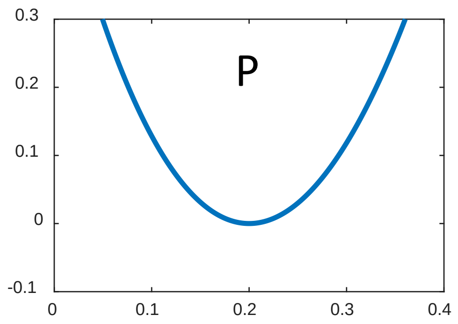

Vp and den are not sensitive to Sw

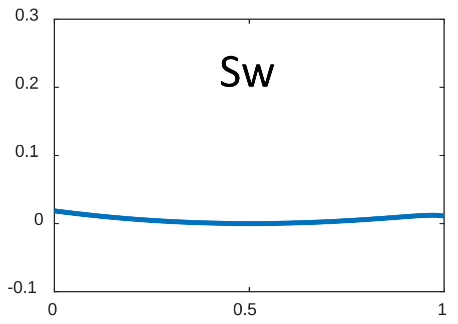
↓

Misfit function has a flat trough with respect to Sw

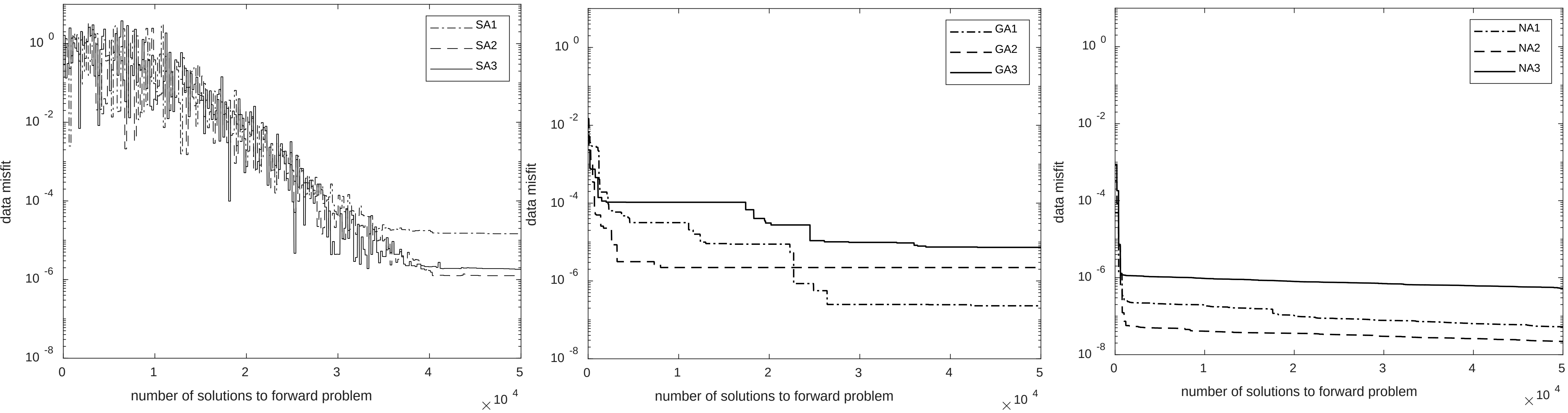
↓

Larger uncertainty in Sw estimate



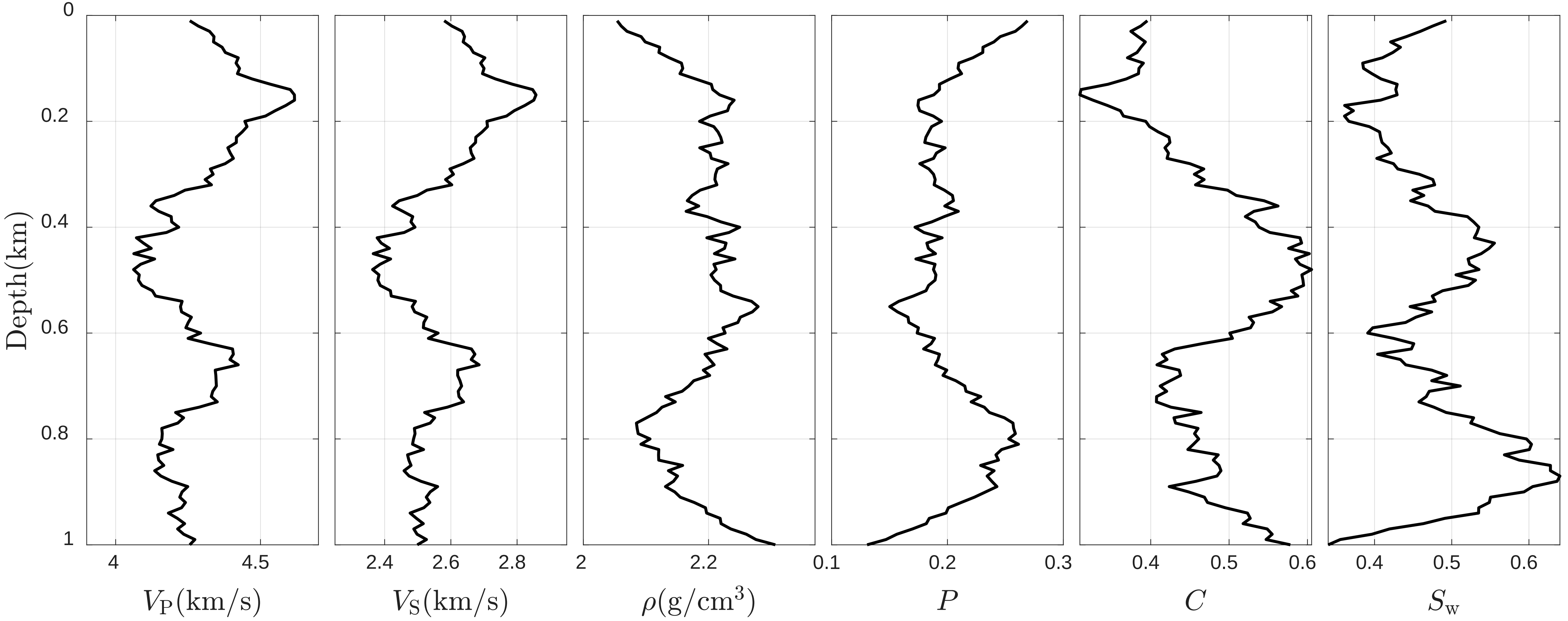



# Data misfit reduction for three runs of SA, GA, and NA



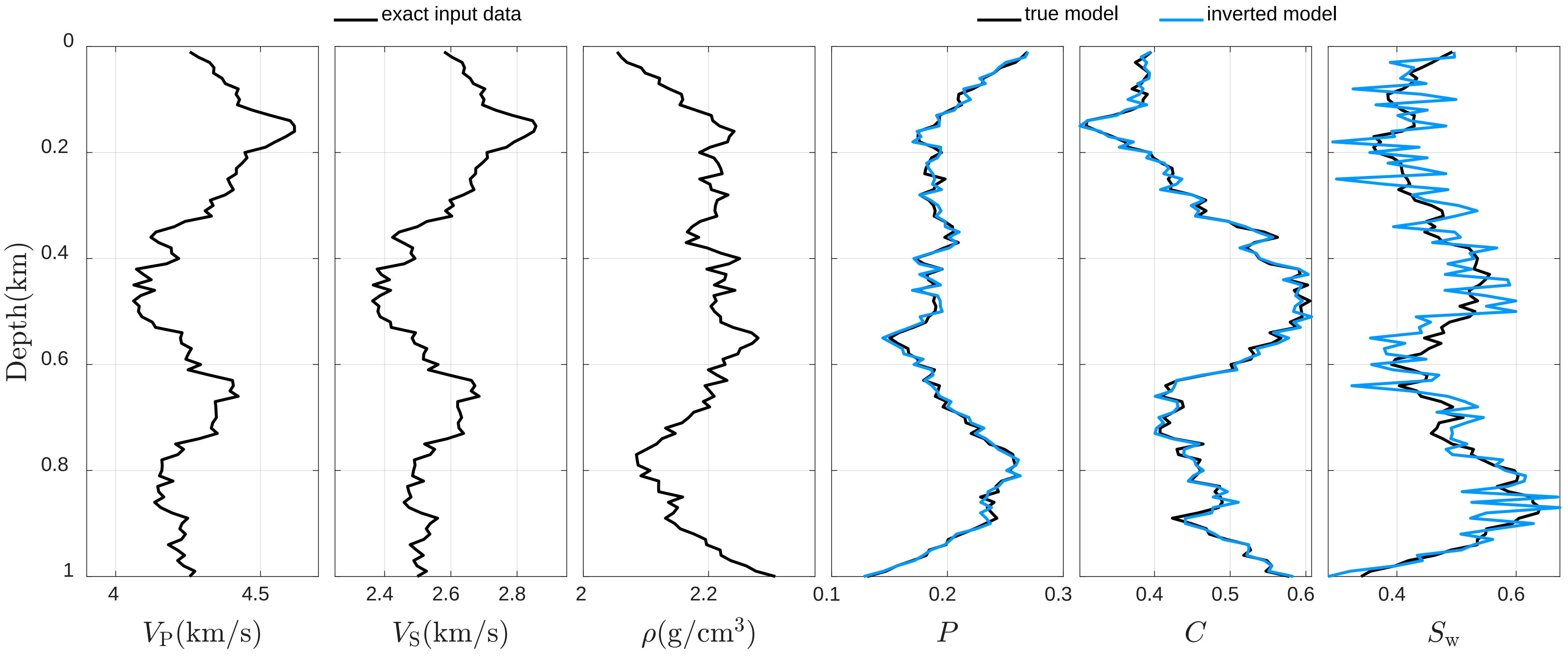
# Noise test

Synthetic well logs. $(V_\mathrm{P}\ V_\mathrm{S}\ \rho)$ are computed from $(P, C, Sw)$ via the KT model



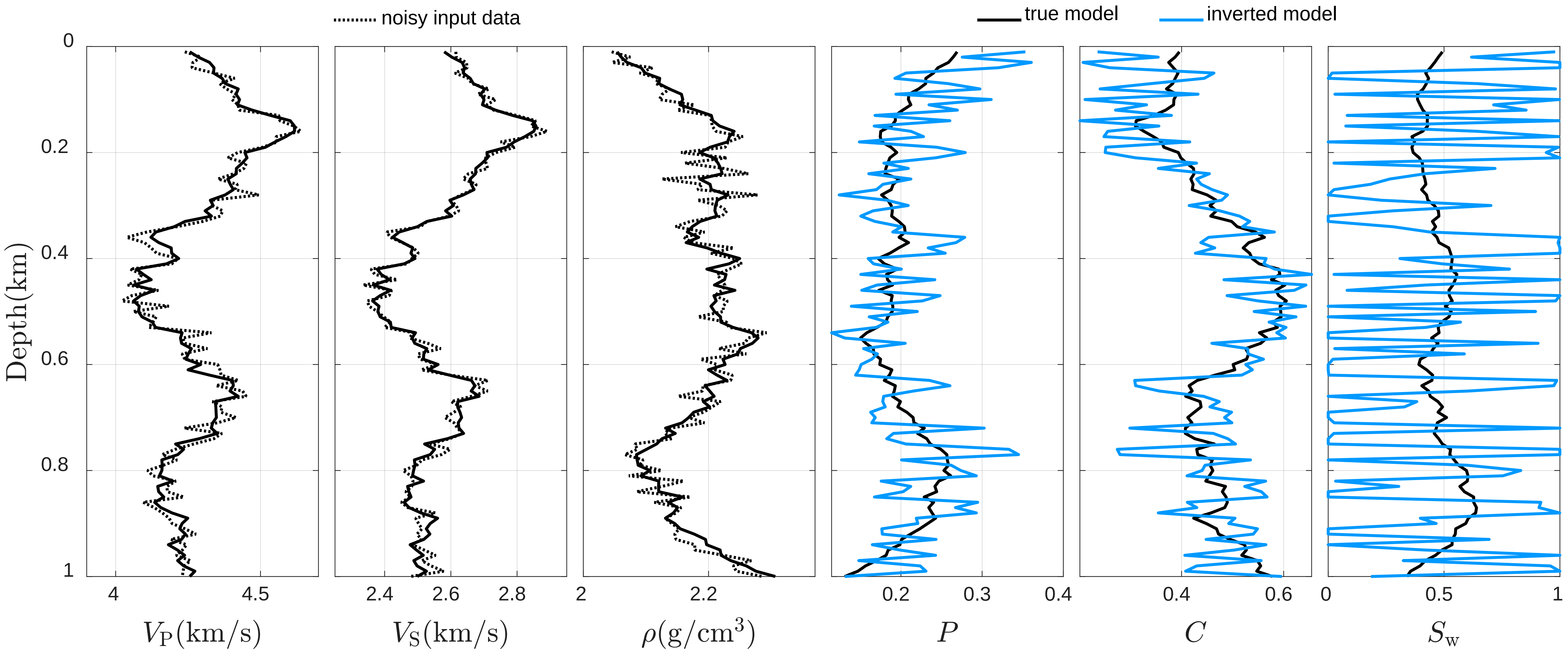
# Noise test

## Inversion with noise-free data



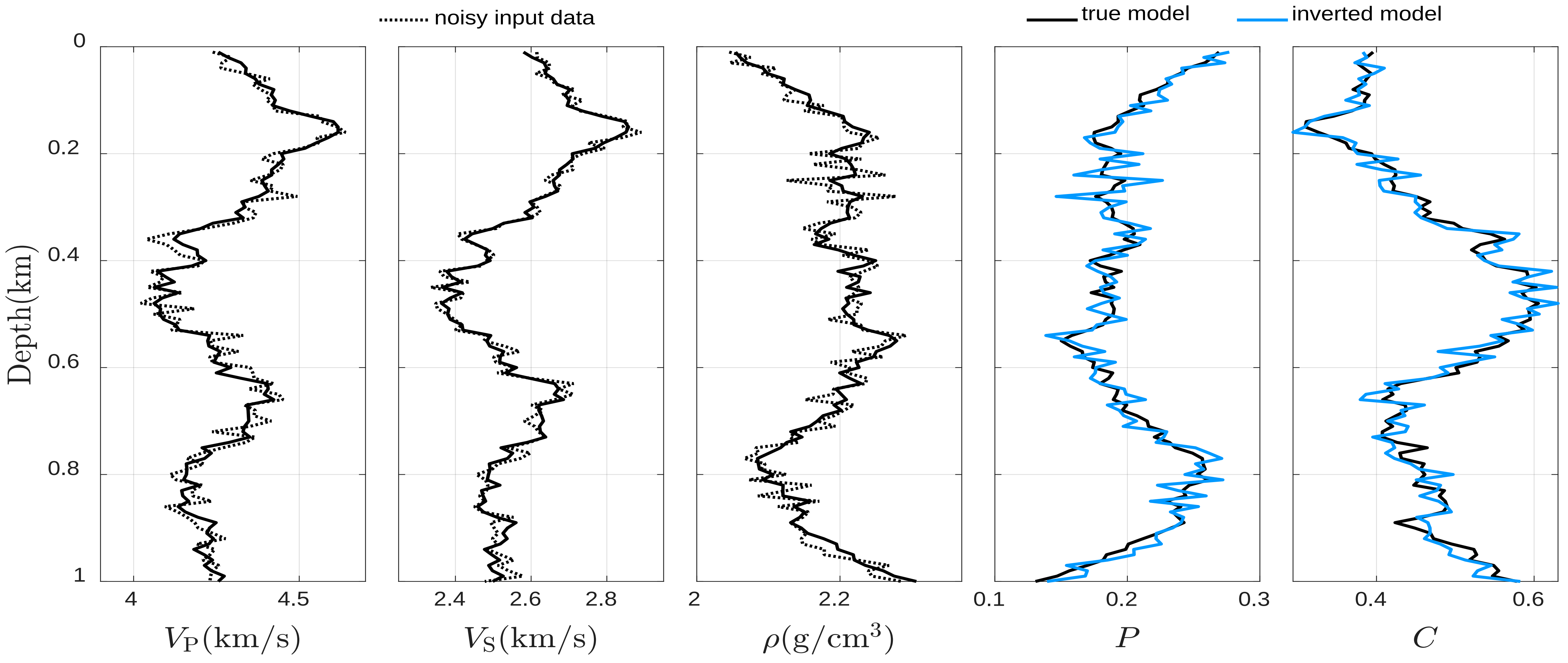
# Noise test

## Inversion with noisy data

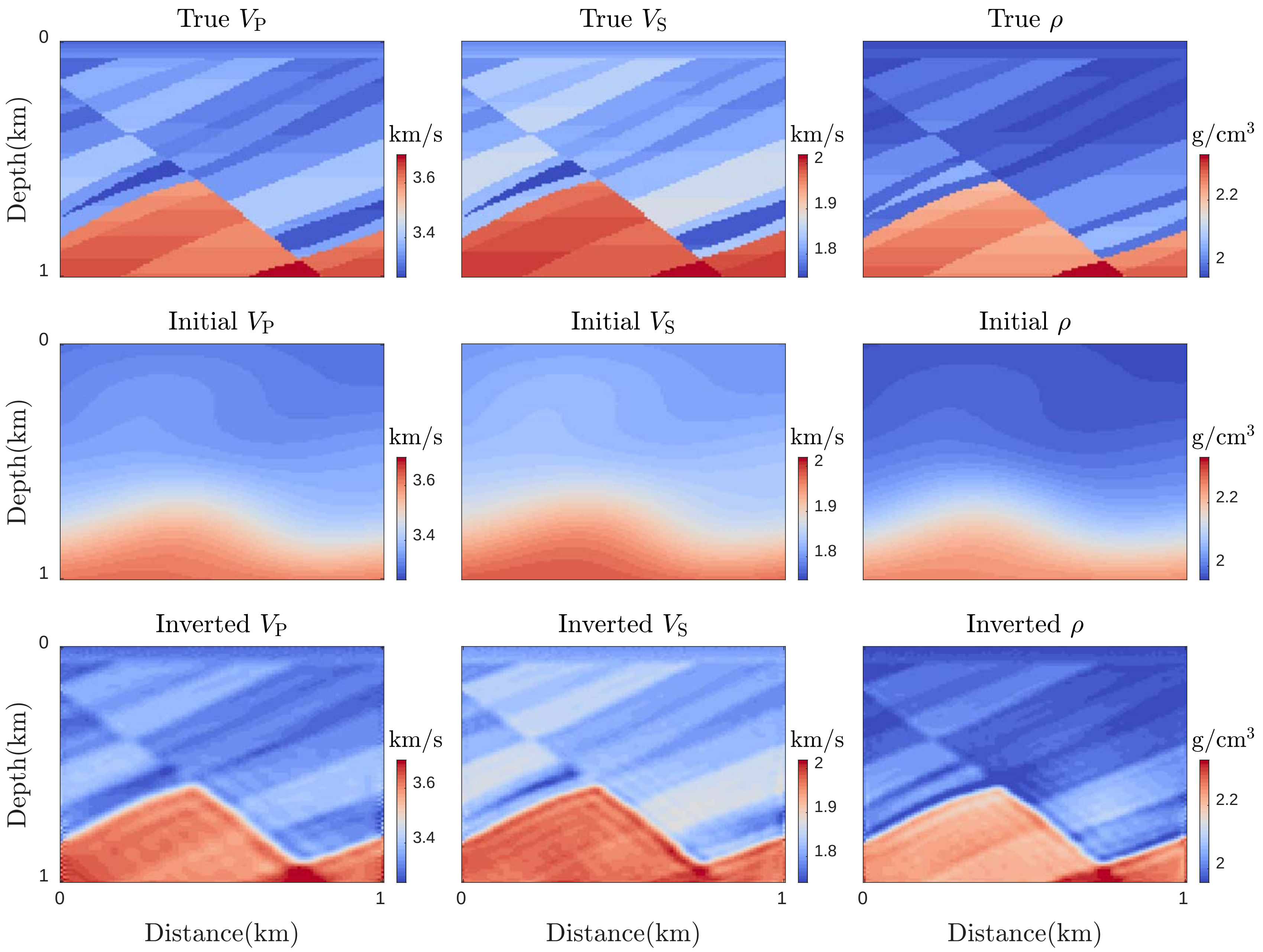


# Noise test

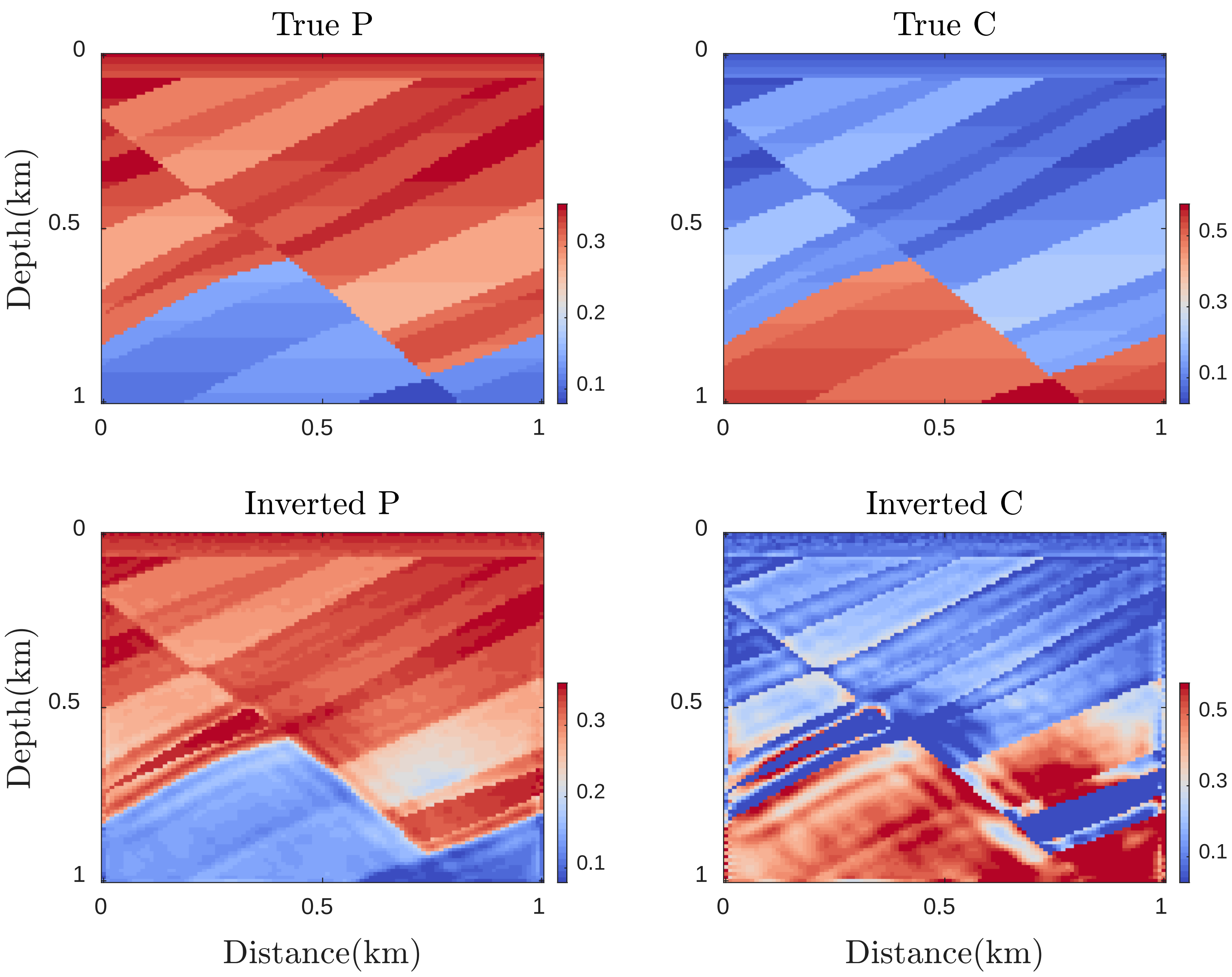
## Inversion with a prior information of the exact Sw



# Rock physics inversion using EFWI results



# Rock physics inversion using EFWI results



# Conclusions

- We have investigated global optimization methods for solving the rock physics inverse problem.

- The inversion of PCS from velocity and density is an ill-conditioned problem. Prior information is needed to make the inversion stable.

- The rock physics inversion using global optimization methods can be combined with EFWI for quantitative seismic interpretation.

# Acknowledgments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