Smart Monitoring –Optimized Experimental Design (OED) methods for (geo)physical data acquisition

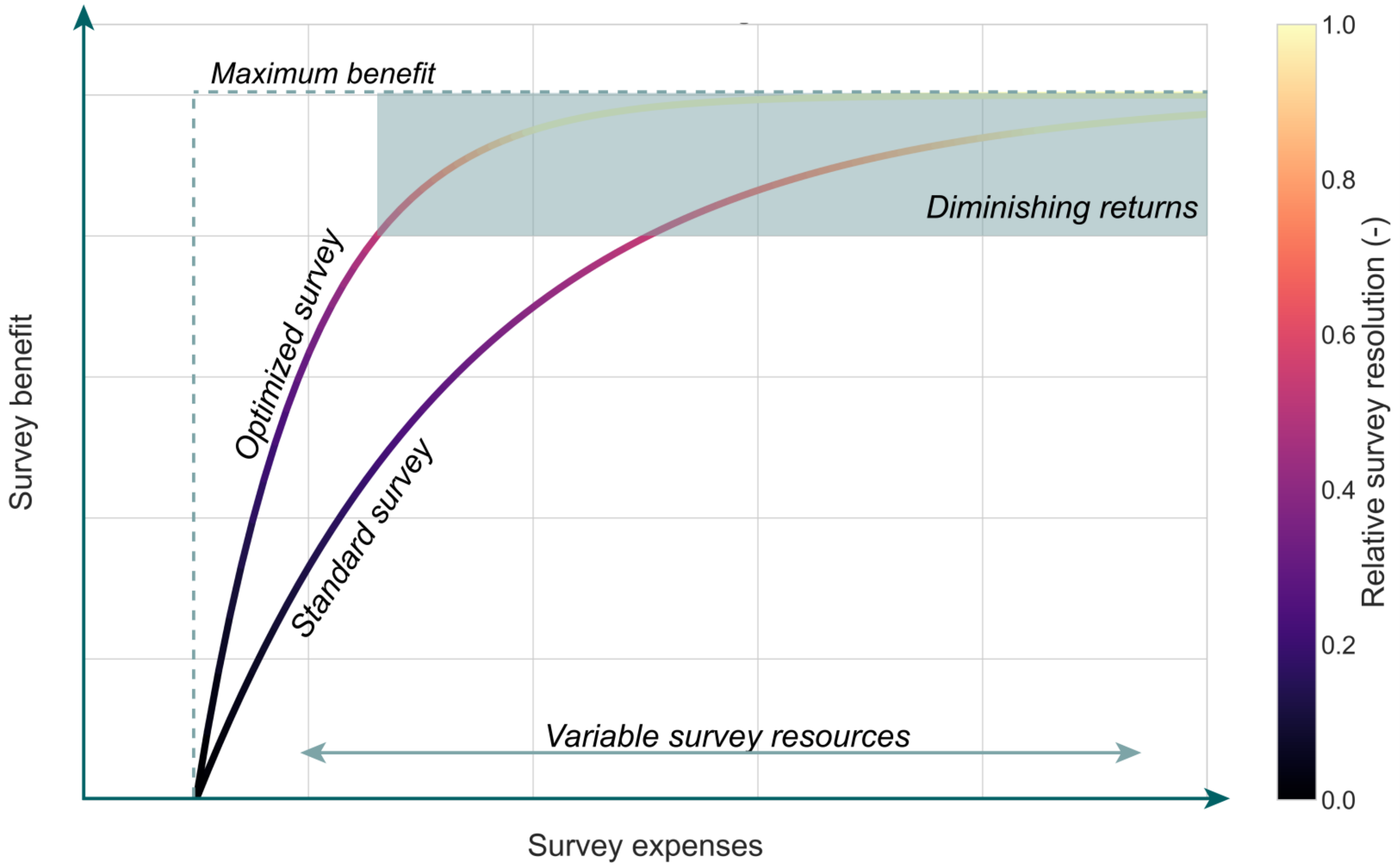
Nino Menzel

URS Smart Monitoring Group Meeting

13.06.2024

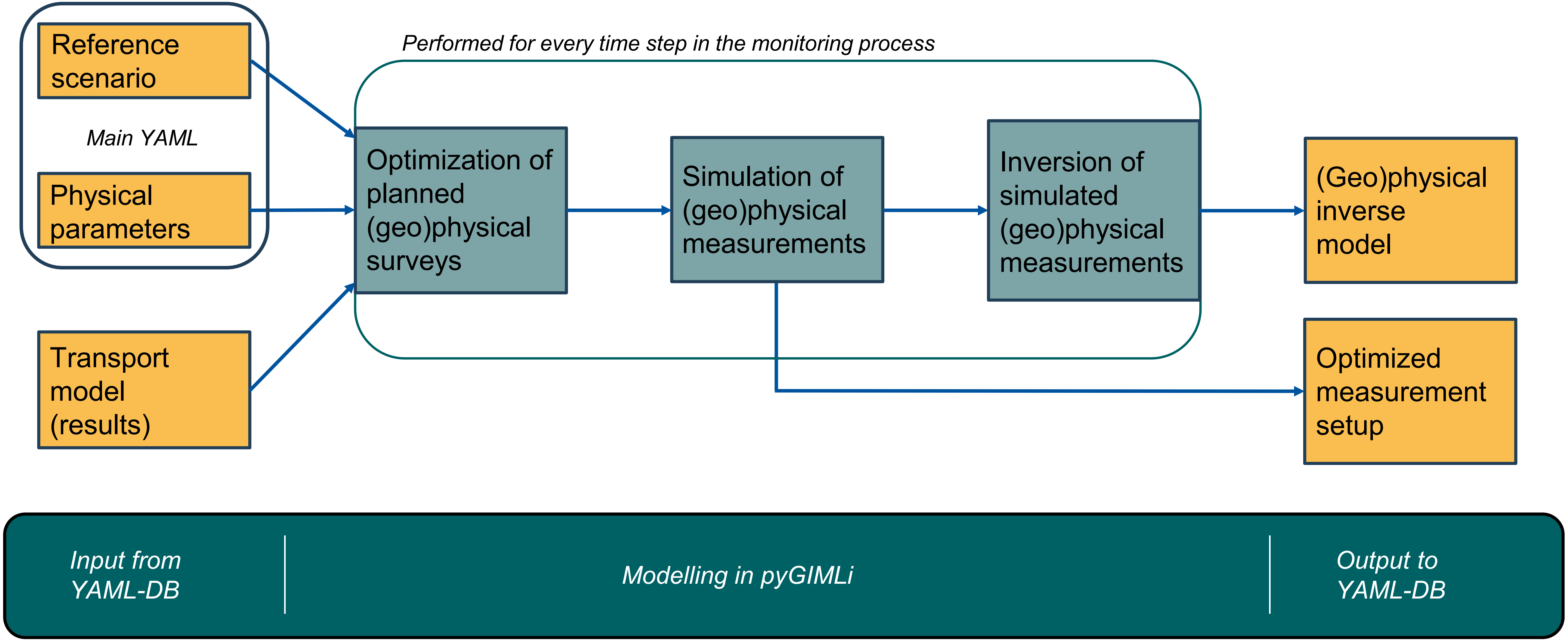
Geophysical Imaging and Monitoring
RWTH AACHEN UNIVERSITY

Recap – Optimized Experimental Design



- "**smart**" data acquisition aims at reaching the point of **maximum benefit as fast as possible**
- **Benefit** of a survey: resulting **net increase in resolution** of model parameters of interest
- Overall goal: **limit** the amount of acquired data (and **variable survey cost**) without drastically reducing information content
- In our case: **effective monitoring of fluid transport processes** using (geo-)physical surveys

Recap – Optimized Experimental Design



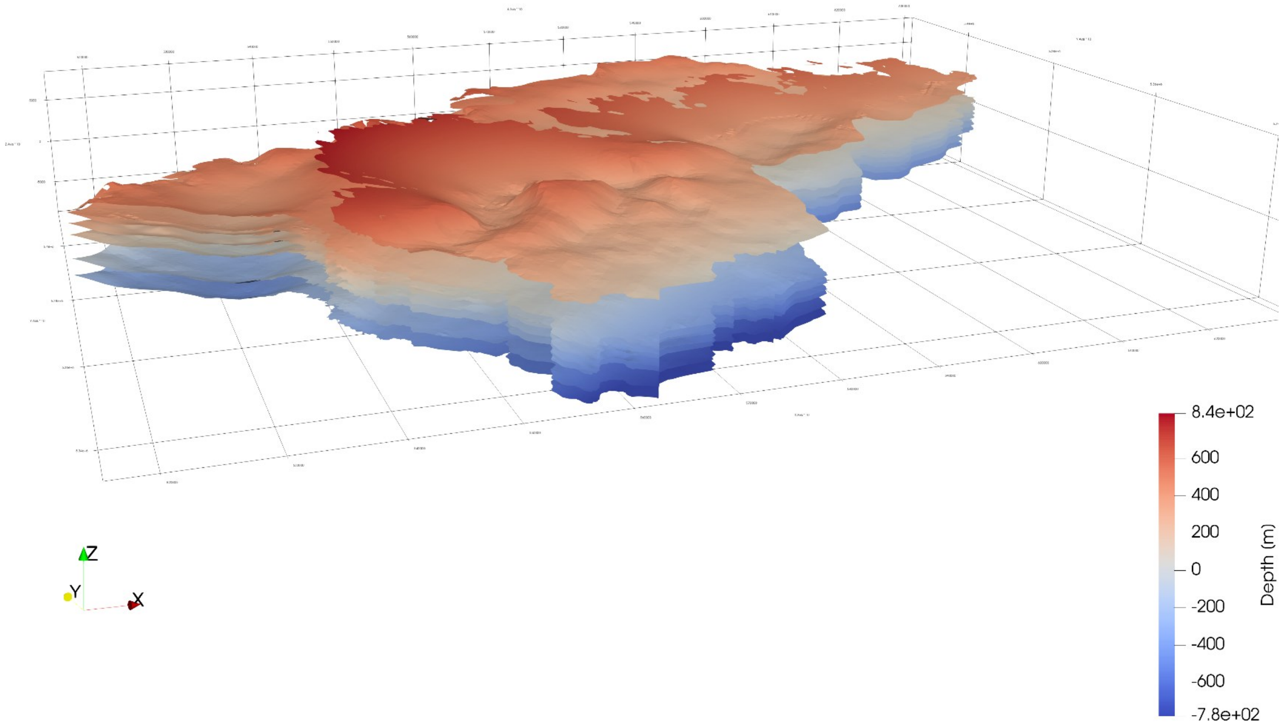
OED - Inputs

Inputs:

- **A-priori information** of the **target area** in the subsurface (transport process: *hydr. parameters*; geological structure: *geometrical parameters*)

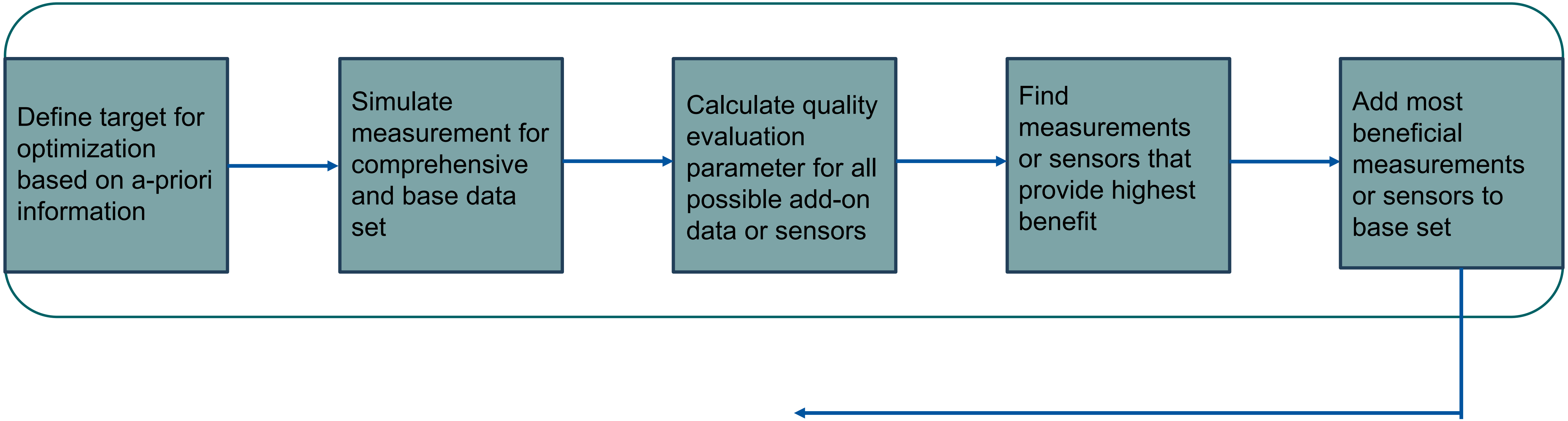
- “Small” **base measurement** setup
  - Seismic survey with *40* recievers and *5* shot points
  - Geoelectric survey using *20* electrodes

- **Densest** possible **measurement setup** (*comprehensive dataset*)
  - Seismic survey with *n* recievers and *m* shot points
  - Geoelectric survey with *n* electrodes



BGE, 2023

OED – General structure



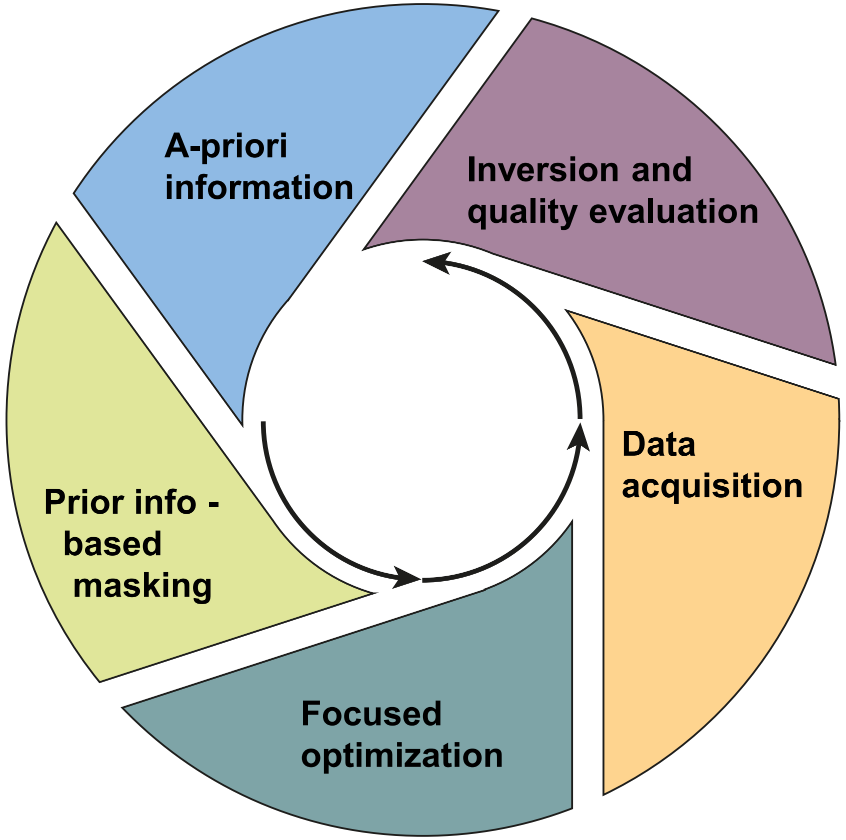
Modelling in Python / pyGIMLi

OED – General structure

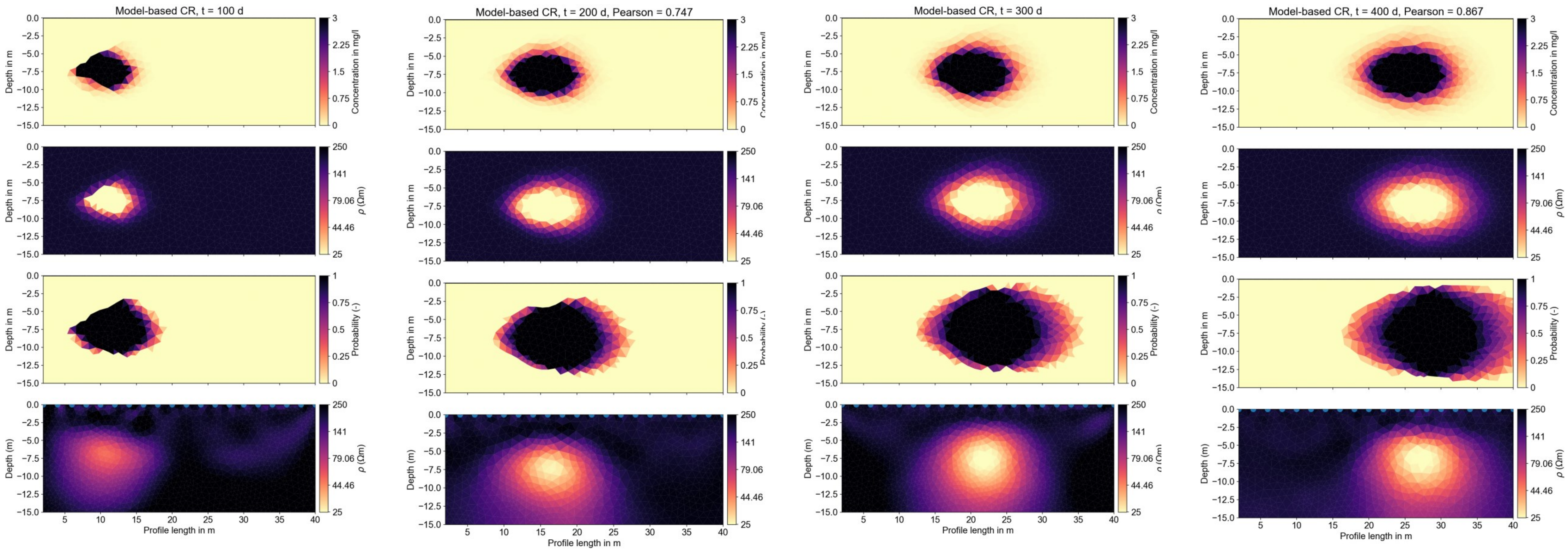
OED – Approaches for transport process monitoring

Model-driven OED for fluid transport monitoring:

- Survey focusing based on **a-priori information**
  - Geological model and corresponding parametrization
  - Transport process simulation
- Focusing **mask** is created **based on a-priori information**, e.g., several transport simulations with varying parameter sets
  - Accounts for parameter uncertainties by including probability-based weights for every model cell
- Approach relies on **sufficient a-priori information** with limited uncertainties



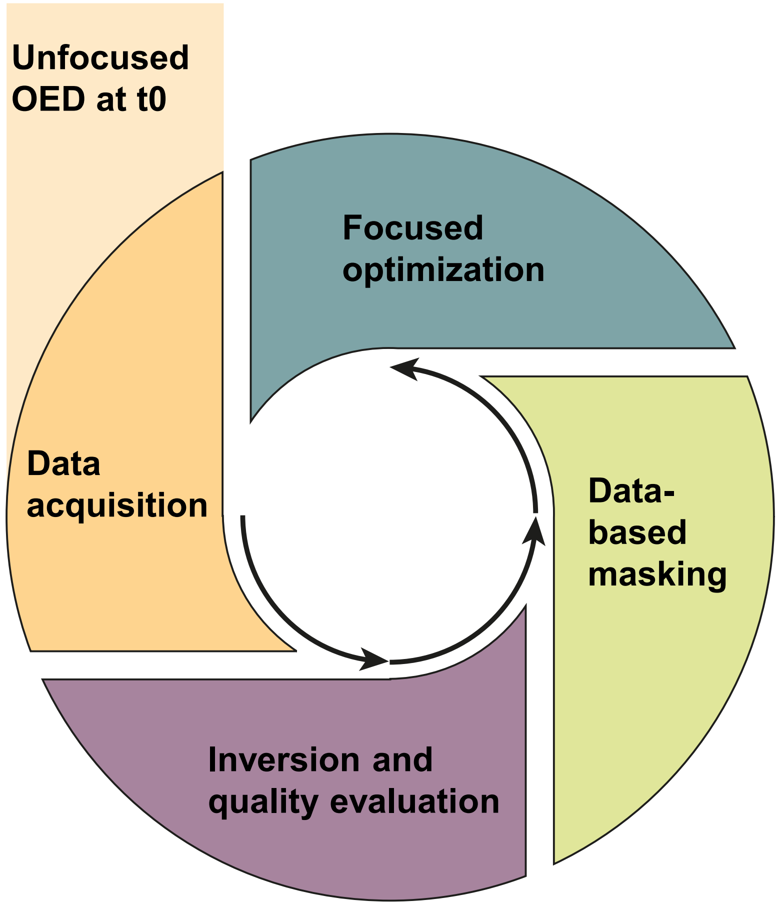
OED – Approaches for transport process monitoring



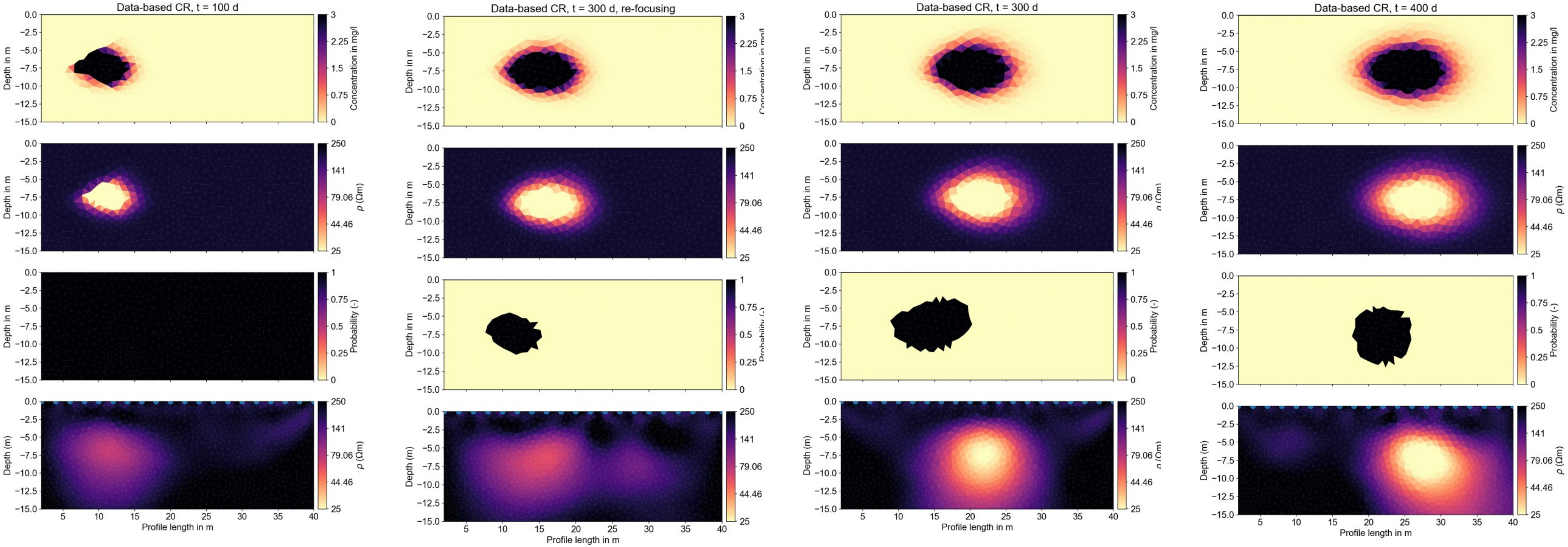
OED – Approaches for transport process monitoring

Data-driven OED for fluid transport monitoring:

- Survey focusing based on acquired data of **previous time step**
  - No focusing for first time step – unfocused OED
- Robust approach that does **not include** any additional sources of **uncertainty**
- However, approach only sufficient for **small monitoring intervals**



OED – Approaches for transport process monitoring



OED – Approaches for transport process monitoring

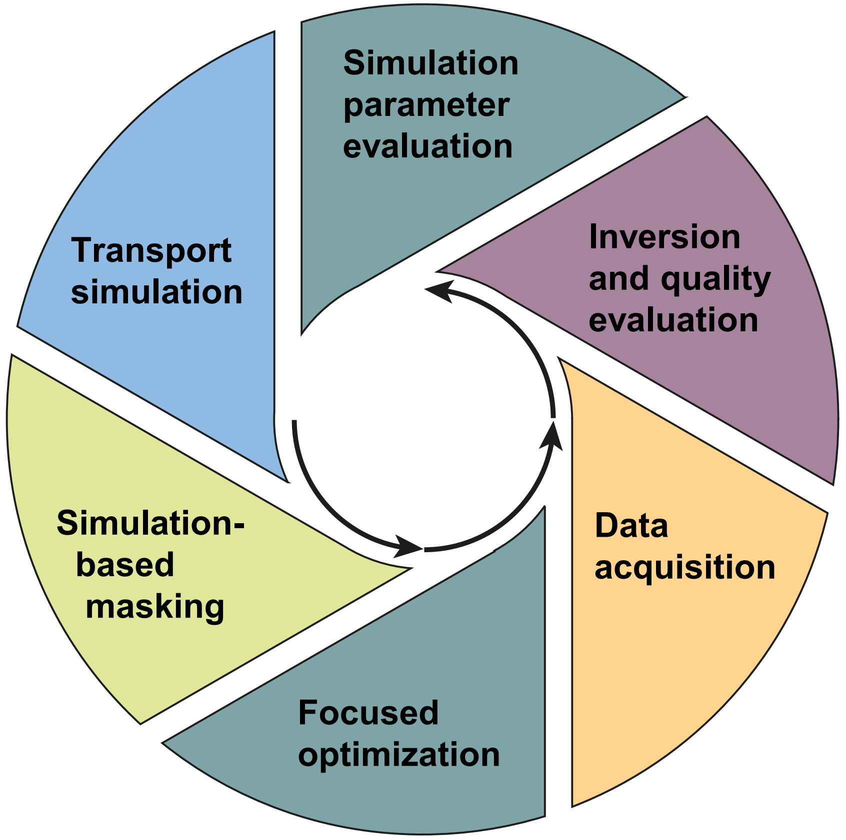
Hybrid OED for fluid transport monitoring:

- Survey focusing based on **synthetic fluid transport model** and resulting concentration distribution

- Similar to model-based approach, but with additional step:
  - After each iteration, **simulated and acquired data** of time step t_n are **compared** to evaluate accuracy of transport simulation

$x(d_{sim}) \approx x(d_{acq})$: *No changes applied to transport simulation*

$x(d_{sim}) \neq x(d_{acq})$: *Adapt transport simulation parameters*

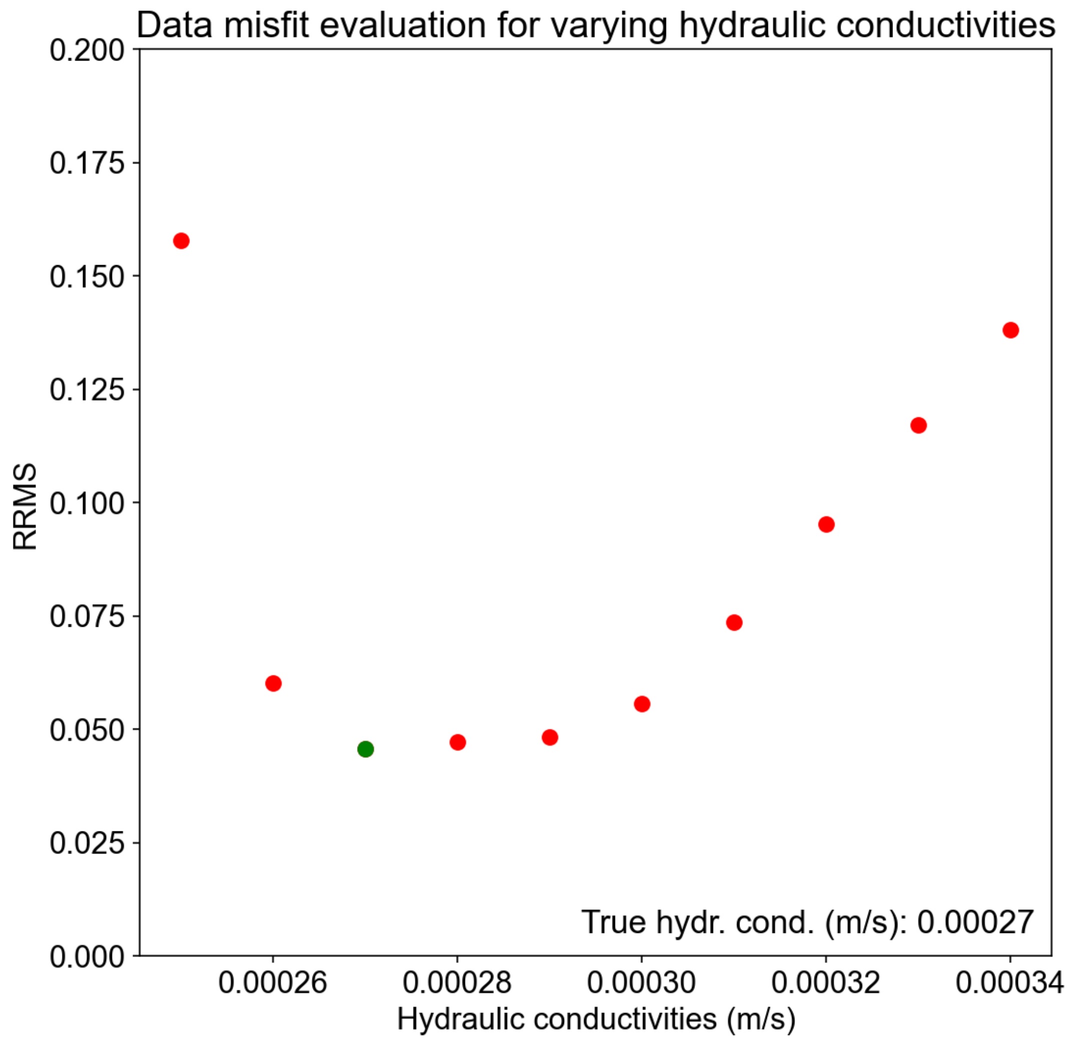


OED – Approaches for transport process monitoring

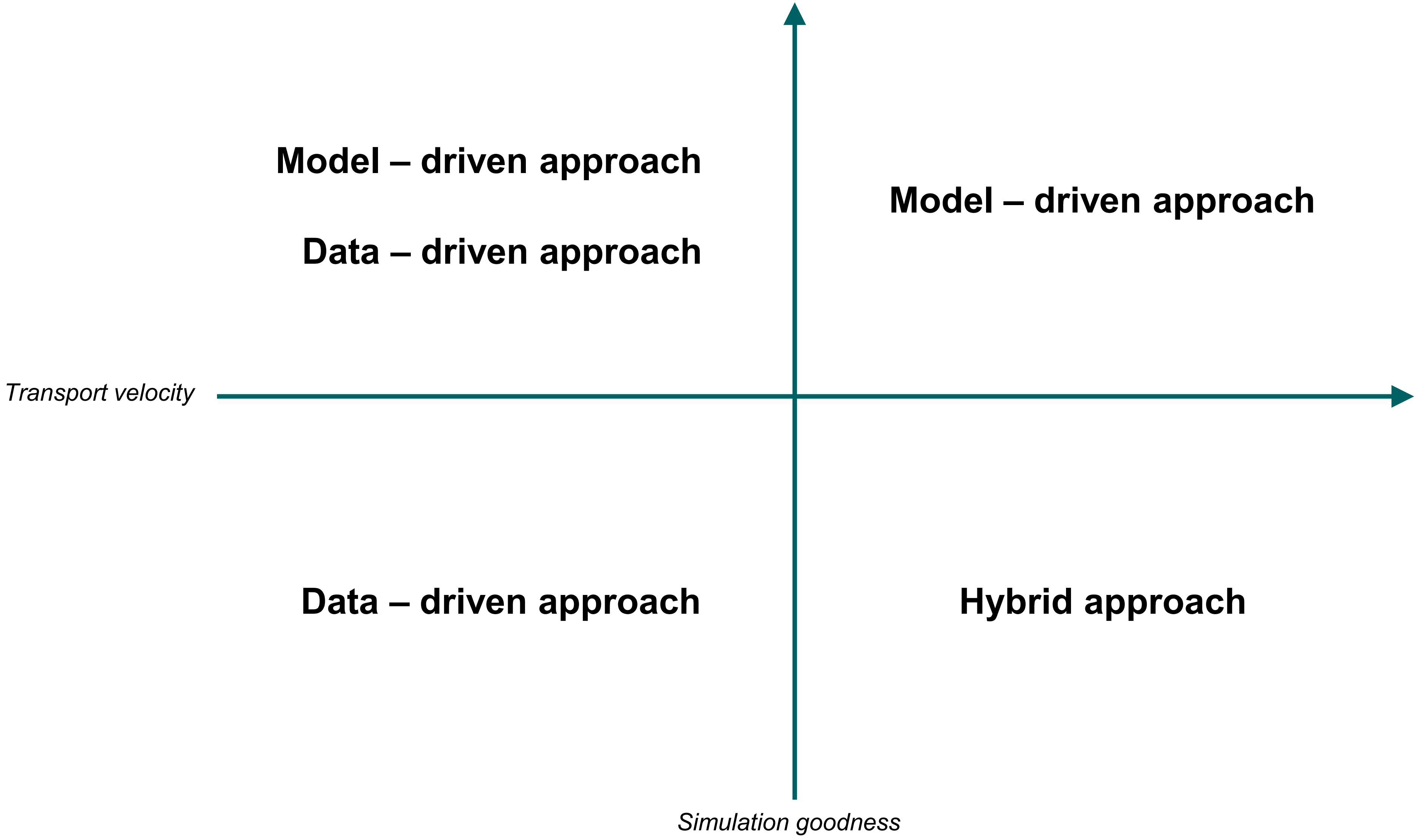
Hybrid OED for fluid transport monitoring:

- To **test** approach, we assumed transport process simulation that **deviates from true model**
- **Two transport models**: “true” model and wrong assumption to test whether hybrid approach is able to **correct transport parameters**

- Simulations for **several parameter sets** with **varying hydr. conductivities**
- **Calculate data misfit** of “*acquired*” and “*simulated*” data for all different data sets
- Data set with **lowest misfit** holds simulation **parameters** that are **closest to true model**



OED – Approaches for transport process monitoring



Thanks for your attention! Questions?

Optimal Experimental Design - Recap

Compare-R" method (Wilkinson et al., 2015)**:**

- Uses **resolution matrix** of linearized Gauss-Newton solution for ERT problem; defined as:

$$R = (G^T G + C)^{-1} G^T G$$

- Iterative optimization starts from a set of **base measurements** -> calculation of **change in resolution matrix** for each possible new measurement:

$$\Delta R_b = \frac{z}{1+(g*z)}(g^T - y^T) \qquad \text{where} \quad z = \left(G_b^T g_b + C\right)^{-1} g, \qquad y = \left(G_b^T G_b\right) z$$

- All additional measurements are **ranked according to improvement** of resolution matrix:

$$F_{CR} = \frac{1}{m} \sum_{j=1}^{m} \frac{w_{t,j} \, \Delta R_{b,j}}{R_{c,j}}$$

- Depending on chosen step size, **n measurements** with greatest benefit **are added to base set**