How well do we know our models?

Denise Degen[1], Karen Veroy[2,3], Mauro Cacace[4,5], Magdalena Scheck-Wenderoth[4,5], Florian Wellmann[1]

[1] Computational Geoscience and Reservoir Engineering (CGRE), RWTH Aachen University, Wüllnerstr. 2, 52062 Aachen, Germany
[2] Centre for Analysis, Scientific Computing, and Applications, Faculty of Mathematics and Computer Science, TU Eindhoven, Eindhoven, The Netherlands
[3] Faculty of Civil Engineering, RWTH Aachen University, Aachen, Germany
[4] Faculty of Georesources and Materials Engineering, RWTH Aachen University, Aachen, Germany
[5] GFZ German Research Centre for Geosciences, Telegrafenberg, 14473 Potsdam Germany

Introduction / Motivation

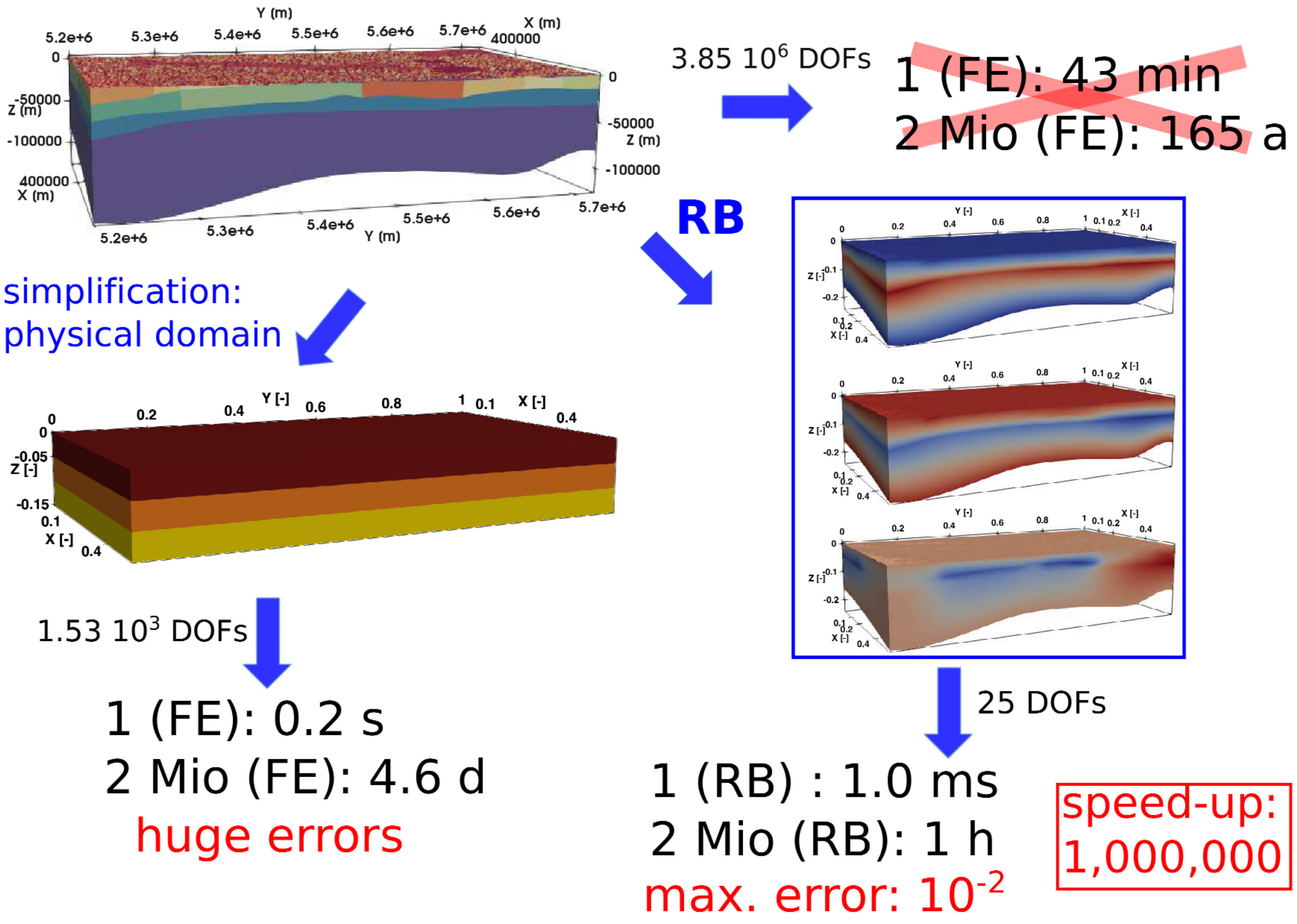


Figure 1: Illustrating the benefits of the RB method for geophysical inverse problems.

Inverse Processes, for instance, uncertainty quantification, have a major impact in many both scientific and economic fields of Geosciences.

Here, we investigate the importance of **global sensitivity analyses (SA)** as a required pre-step for inverse processes.

To compensate for the computationally intensive nature of the SA, we employ the **reduced basis method (RB)** to construct highly accurate surrogate models (Fig. 1).

The RB method (Hesthaven et al., 2016; Prud'homme et al., 2002) is a model order reduction technique that aims at constructing low order approximations of, for instance, finite element simulations. For an introduction to the method in a geoscientific context, we refer to Degen et al. (2020a).

Local vs. Global Sensitivity Analysis – Case Study Upper Rhine Graben

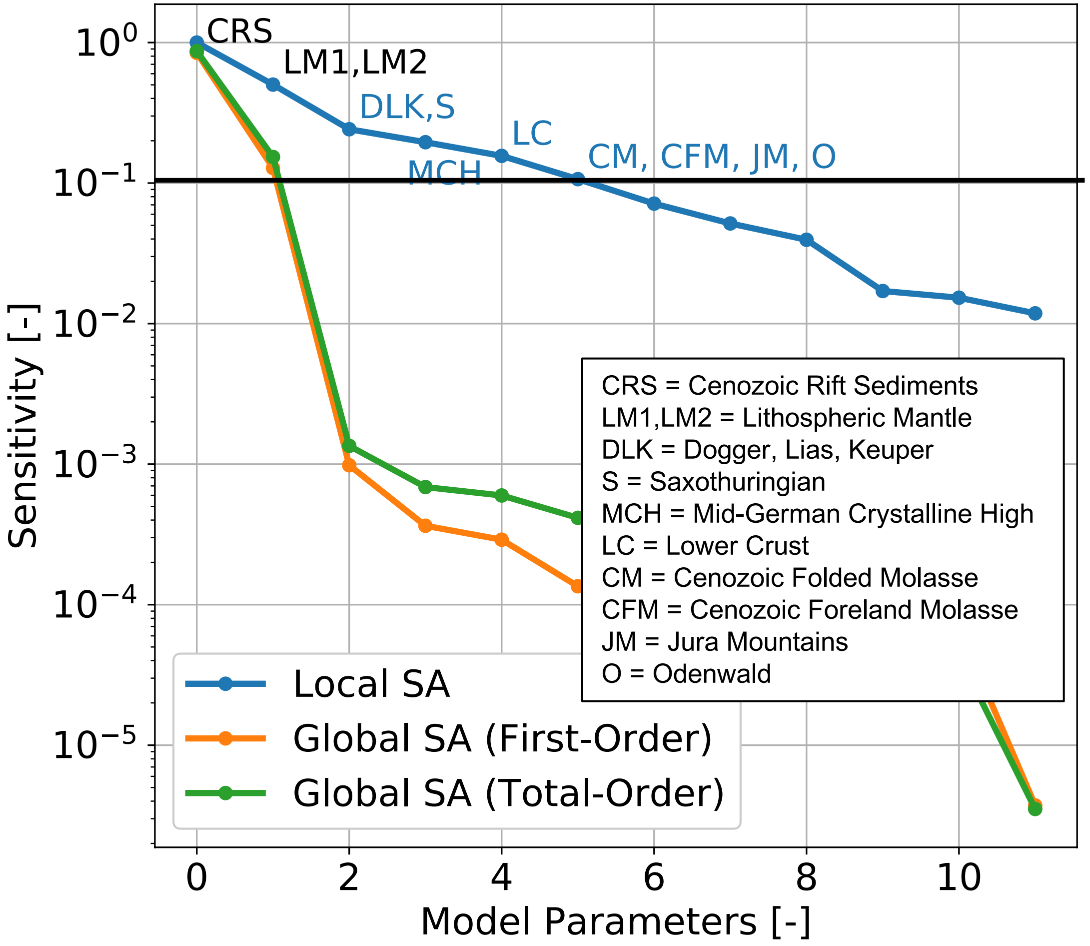


Figure 2: Comparison of local and global SA for the Upper Rhine Graben model

Aim: Determine the influence of the model parameters on the model response

Theory:

- Local SA:
  - Local influence → with respect to pre-defined reference
  - Vicinity of the input parameters
  - No correlations considered
- Global SA:
  - Sobol sensitivity analysis → variance-based
  - Parameter distribution does not need to be know a priori
  - Correlations considered

Take Away:
Local SA **overestimates** the influence of the model parameters and does not efficiently reduce the parameter space. Therefore, only the global SA is beneficial as a pre-step for inverse processes. For more information, refer to Degen (2020b).

For more information regarding the geological model we refer to Freymark et al. (2017).

Influence of the Boundary Condition – Case Study Brandenburg

Case Study Brandenburg

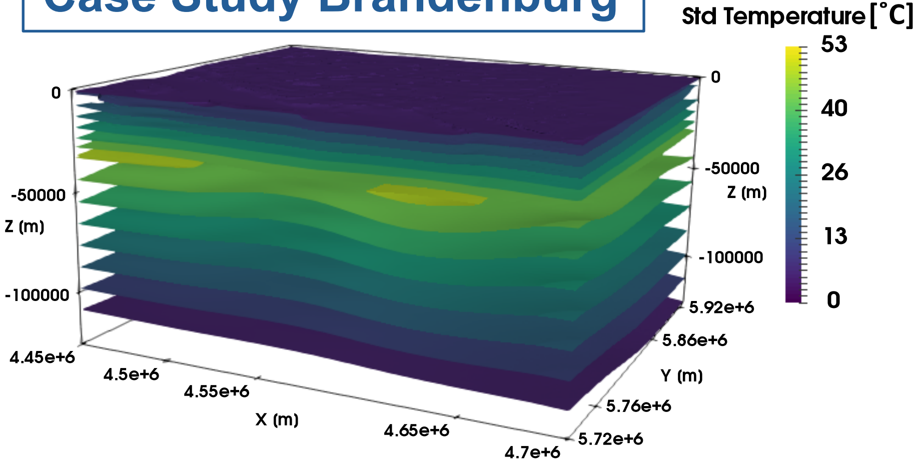
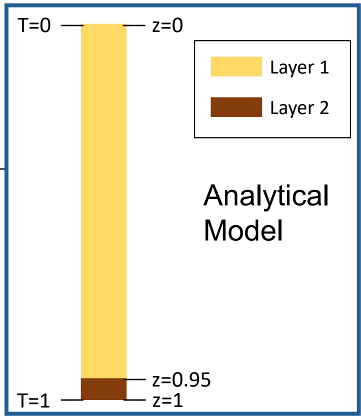


Figure 3: Posterior standard deviation for the Brandenburg Model

Take Away:
Both the uncertainty quantification (Fig. 3) and the sensitivity analysis for the analytical solution (Fig. 4) show that we have a **high influence of the upper boundary condition** on our area of interest (target depth 5 km).

For more information regarding the geological model we refer to Noack et al. (2012;2013) and for information about the uncertainty quantification we refer to Degen et al. (2020c).

Analytic Comparison



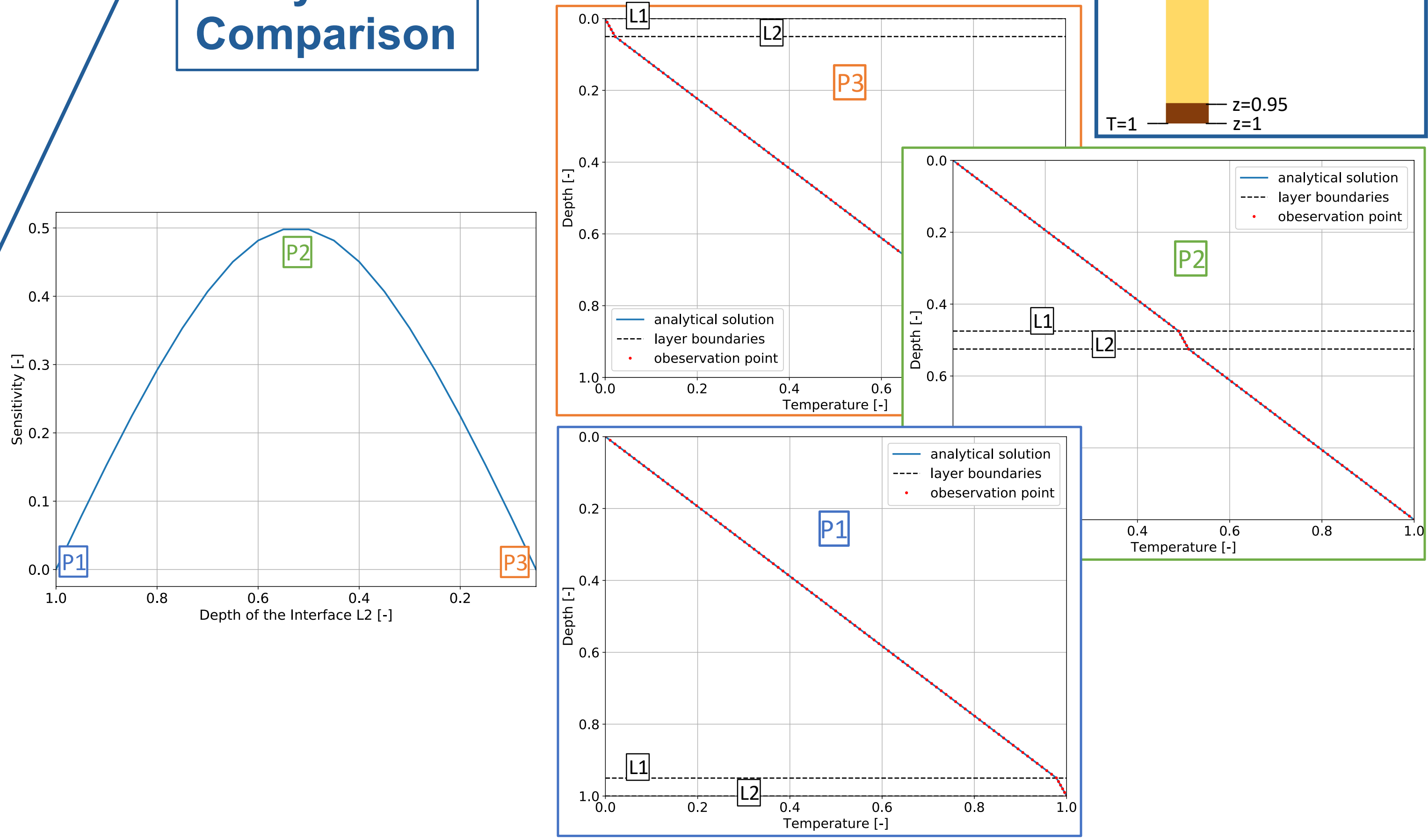
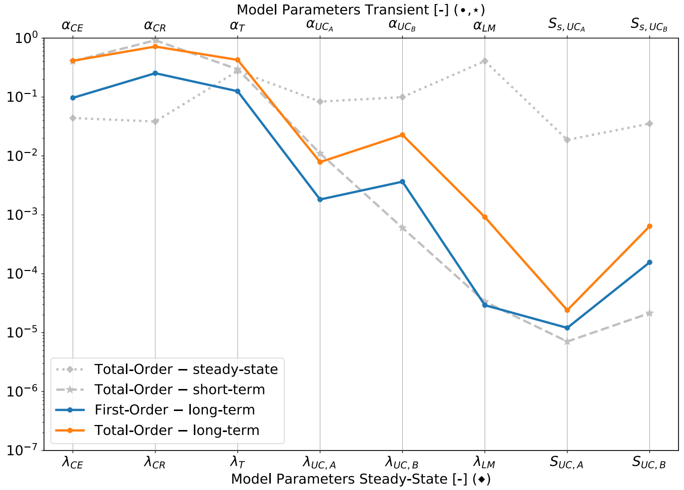


Figure 4: Sensitivity of the thermal conductivity of the thin lower layer (Layer 2) with respect to the distance from the boundaries. The interfaces of this layer are denoted with L.

Influence Transient Effects – Case Study Central European Basin System (CEBS)

Take Away:
Fig. 5 shows that the sensitivities for the thermal parameters **hugely differ between the steady-state and transient case**. That is also the case for transient simulations that reach equilibrium.



Take Away:
Subdividing the analysis into different time frames allows to investigate the travel path of the thermal signal.

For more information regarding the geological model we refer to Maystrenko et al. (2013), Scheck-Wenderoth and Maystrenko (2013), and Scheck-Wenderoth et al. (2014).

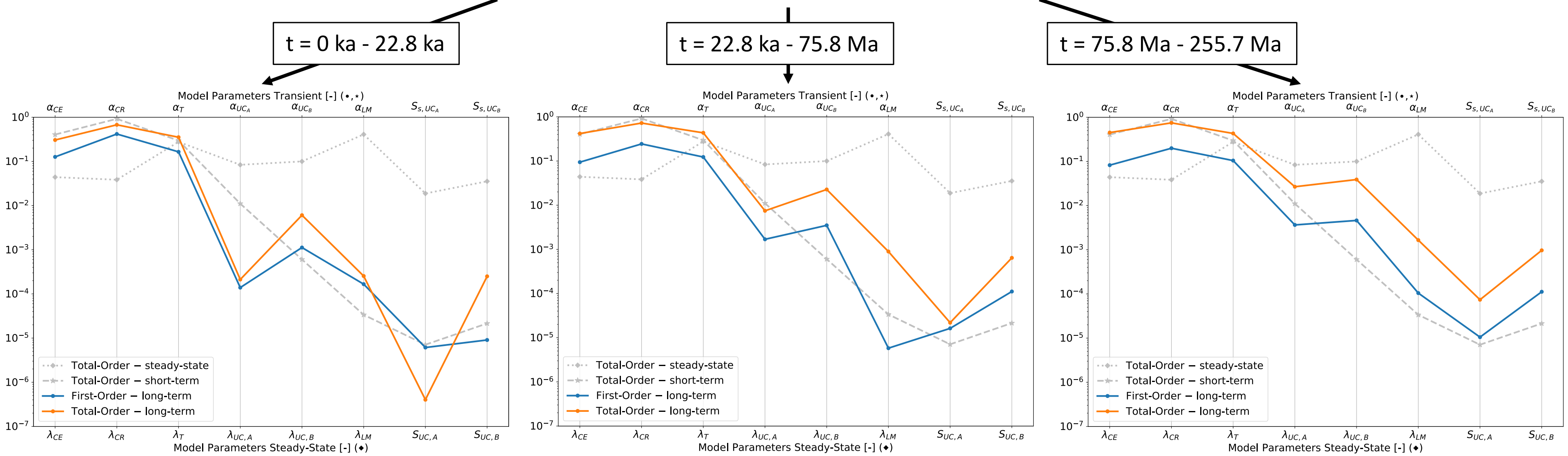


Figure 5: Global SA for the CEBS model. The first-order indices are denoted in blue and the total-order indices in orange. Additionally, the total-order indices of the short-term (dashed gray line) and steady-state analyses (doted gray line) are plotted.

Outlook and Conclusion

Outlook:

- Extension to coupled processes
- Coupling of Climate and Subsurface for the Boundary
- Incorporation of Optimal Experimental Design
  Collaboration with Karen Veroy (TU Eindhoven) and Nicole Nellesen (RWTH Aachen)

Conclusion:

- Sensitivity Analysis is important to reduce the parameter space for inverse processes
- SA enhances the model understanding
- Local sensitivity analyses overestimate the influence
- Only global sensitivity analysis yield robust and reliable model calibrations (both deterministic and stochastic)
- Computational demanding nature of the global SA requires a surrogate model
- RB yields ideal surrogate models since we
  - Obtain results **everywhere** in the model
  - Obtain Speed-ups between **10^4 to 10^6**
  - Preserve the physical laws
  - Have an objective evaluation of the approximation quality through the error bound

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* Federal Institute for Geosciences and Natural Resources (BGR), Wilhelmstraße 25-30, 13593 Berlin, Germany

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GFZ Helmholtz Centre Potsdam
Computational Geoscience and Reservoir Engineering
RWTH AACHEN UNIVERSITY