KarboEx2

Project Meeting,
13.10.2025

AP4: Geologische und markscheiderische Neuinterpretation aller Daten im Hinblick auf eine geothermische Nutzung

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Chair of Computational Geoscience, Geothermics and Reservoir Geophysics (CG3)

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Ministerium für Wirtschaft, Industrie, Klimaschutz und Energie des Landes Nordrhein-Westfalen
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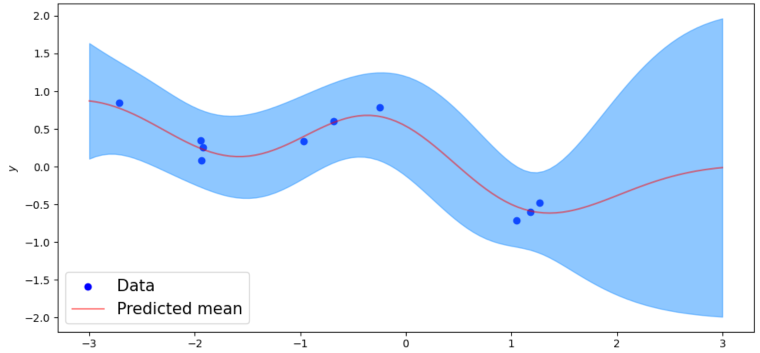
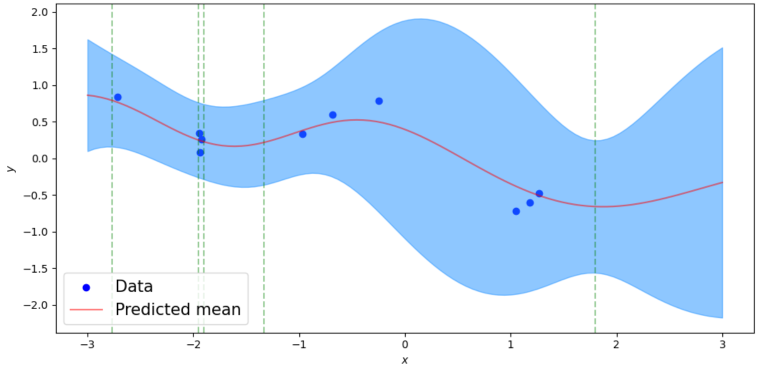
Gaussian Processes | Bias – Variance Trade Off

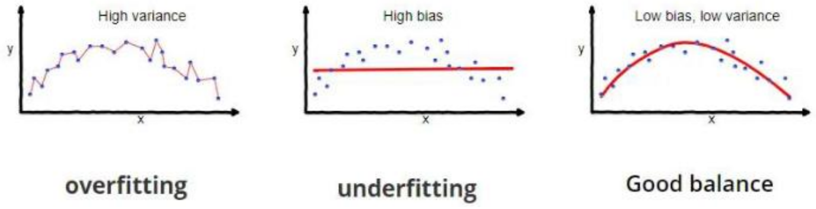
- **Gaussian Processes** allow us to make probabilistic predictions about our data by solving regressions and probabilistic classification problems
- For a given set of training points, there are potentially infinitely many functions that fit the data.
- Gaussian Processes assign a probability to each of these functions which allows to incorporate a **confidence interval (uncertainty)**.
- **Inducing Points** lower the computational cost of Gaussian Process prediction by closely modeling only a subset of the input space.

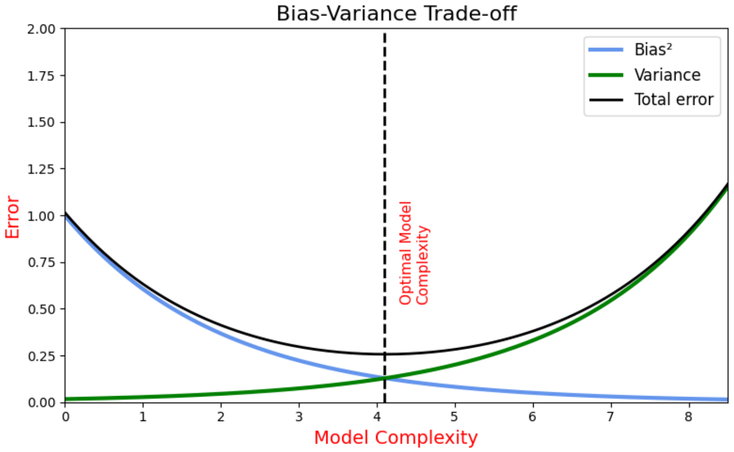


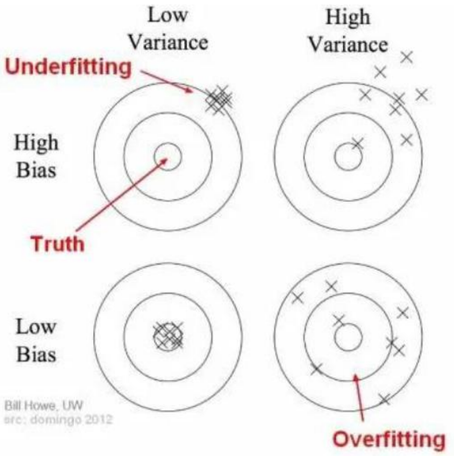


- **Bias:** an estimator (or interpolation method) is biased if the expected value deviates from the true value.

- **Variance:** indicates on average how far the estimates are from the expected value of the estimates.







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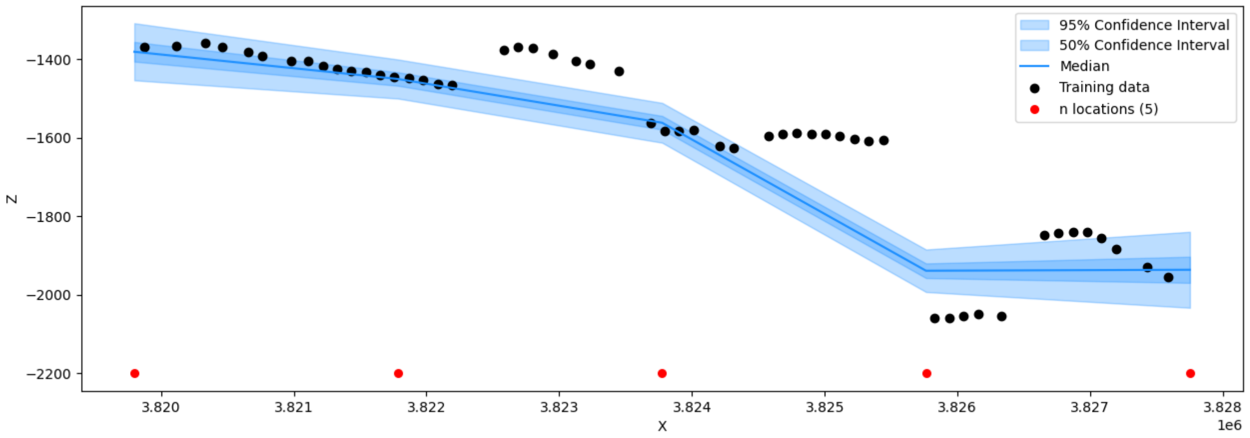
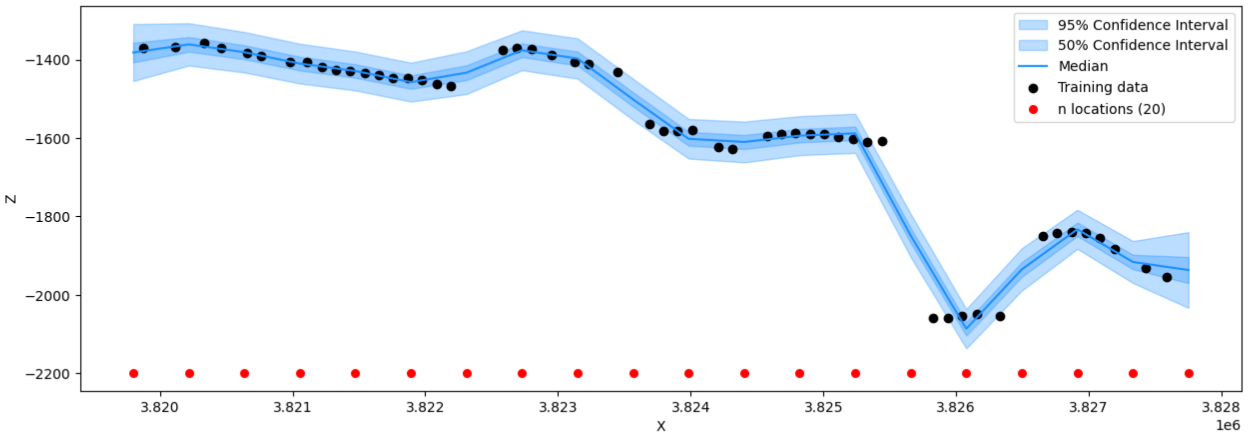
1-D Case

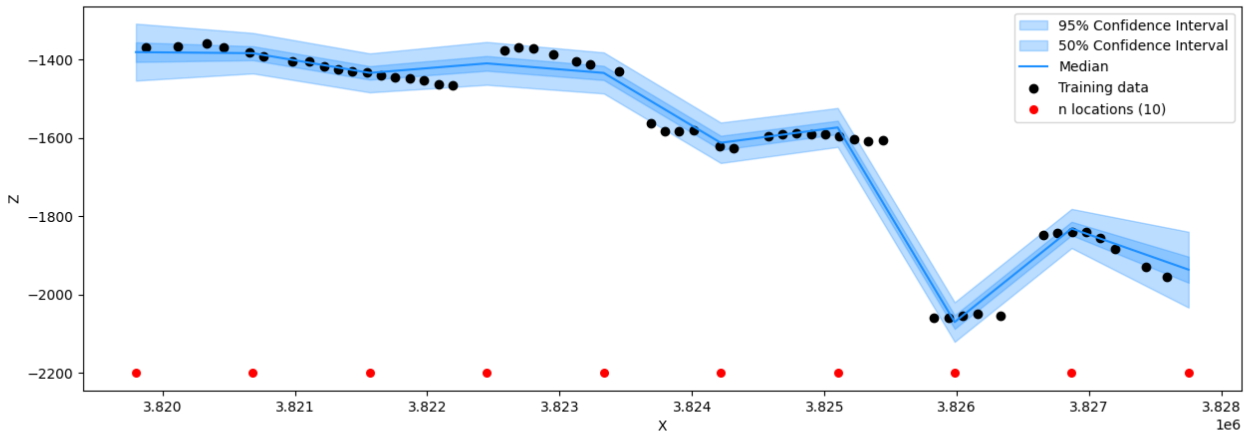
Seismic Section Inline | Inducing Points n=5



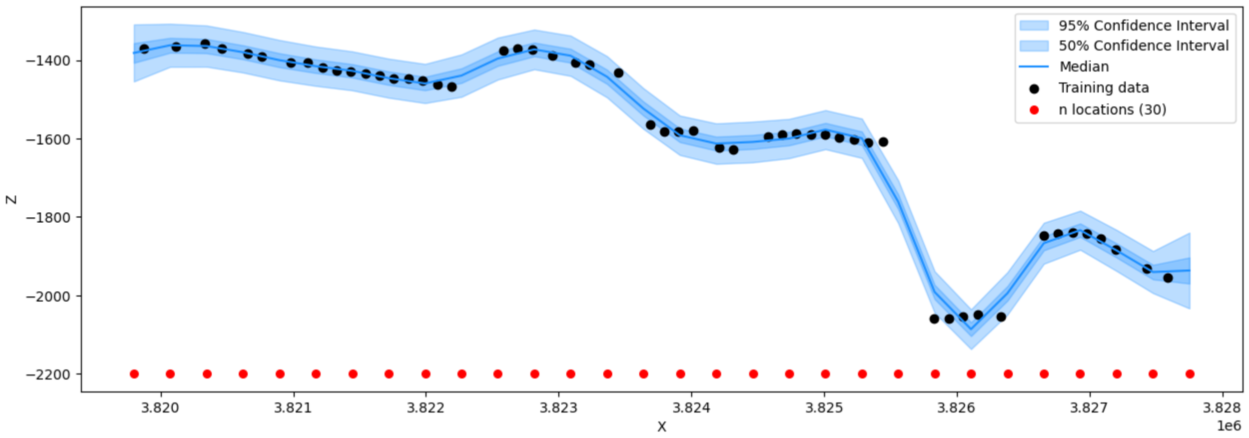
Seismic Section Inline | Inducing Points n=20



Seismic Section Inline | Inducing Points n=10

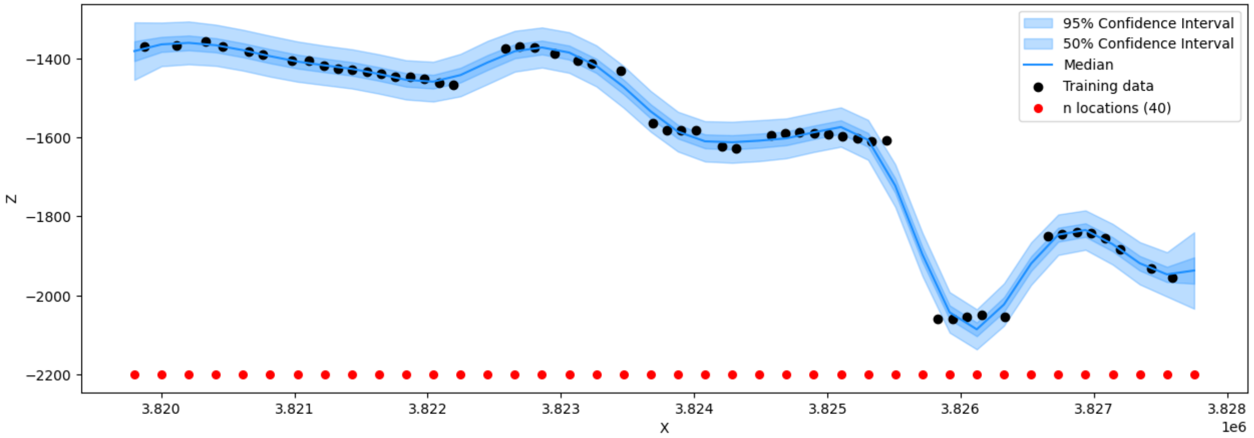


Seismic Section Inline | Inducing Points n=30

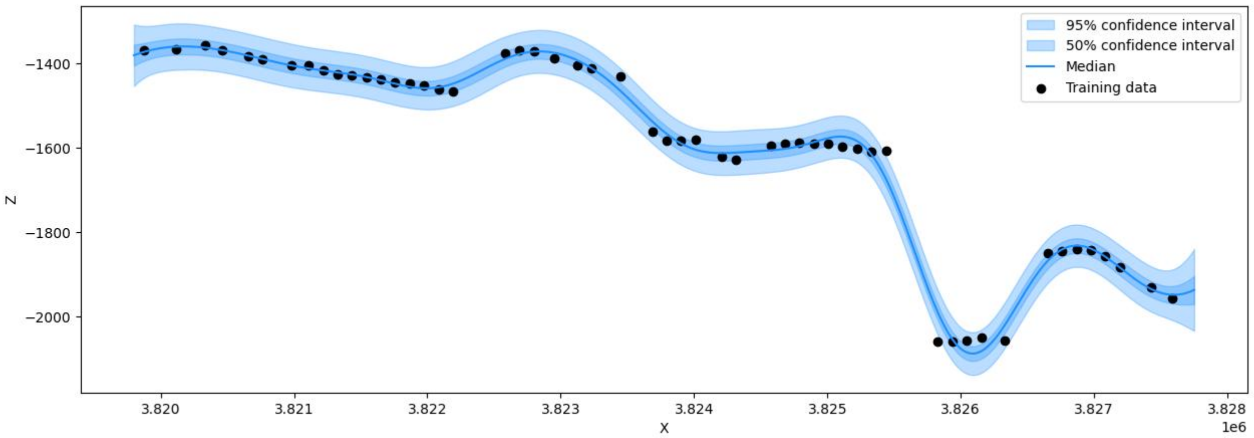


1-D Case

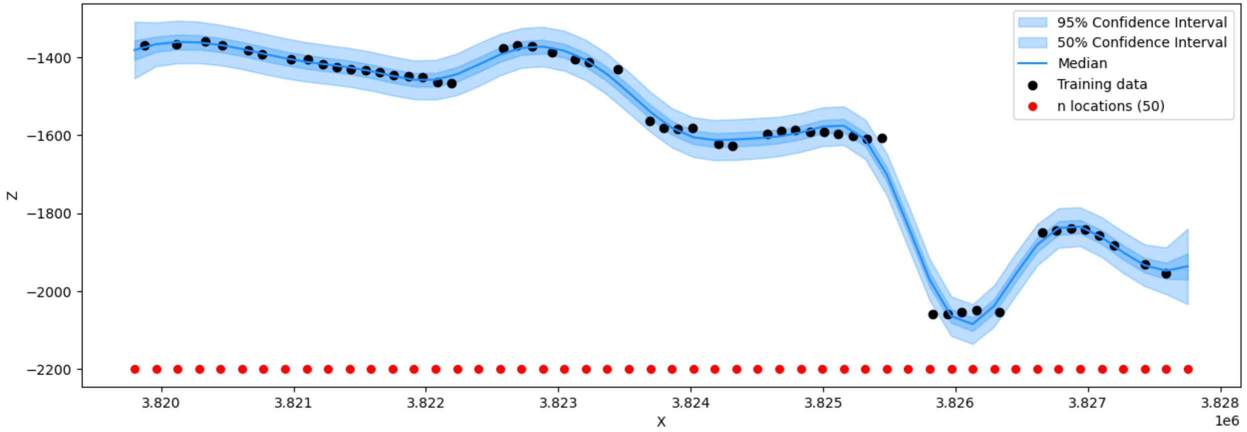
Seismic Section Inline | Inducing Points n=40



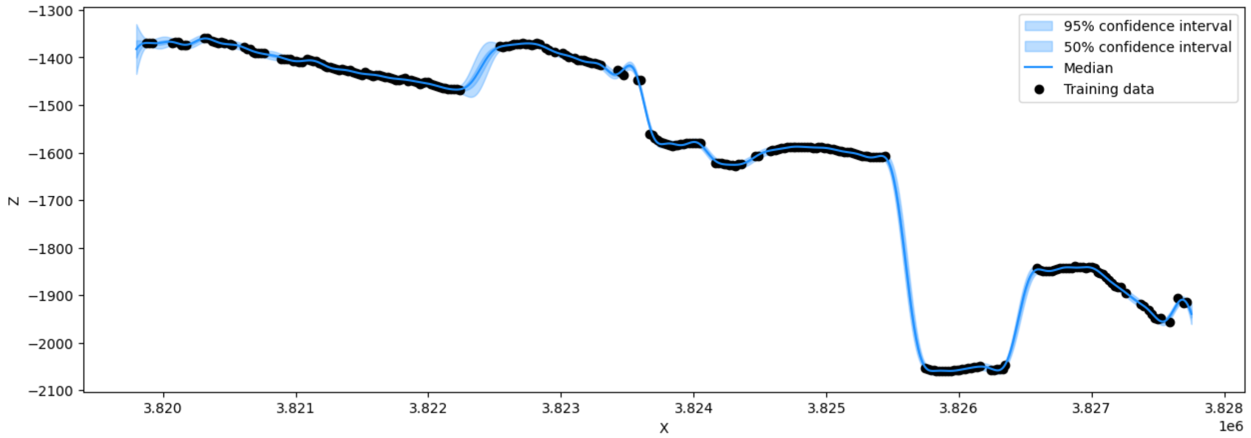
Seismic Section Inline | Inducing Points n=1000



Seismic Section Inline | Inducing Points n=50



Seismic Section Inline (Actual Data) | Inducing Points n=1000



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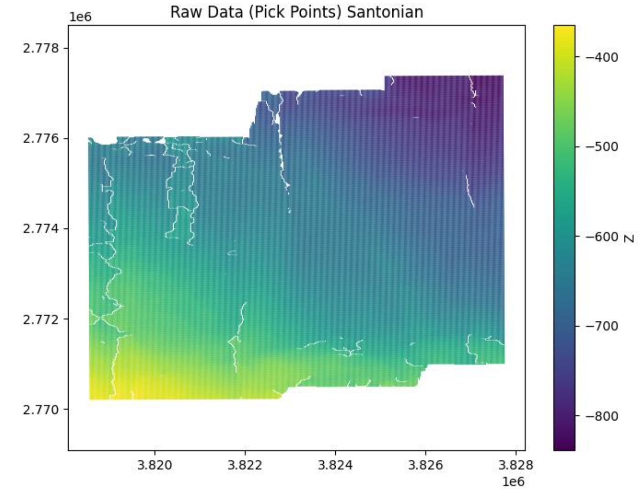
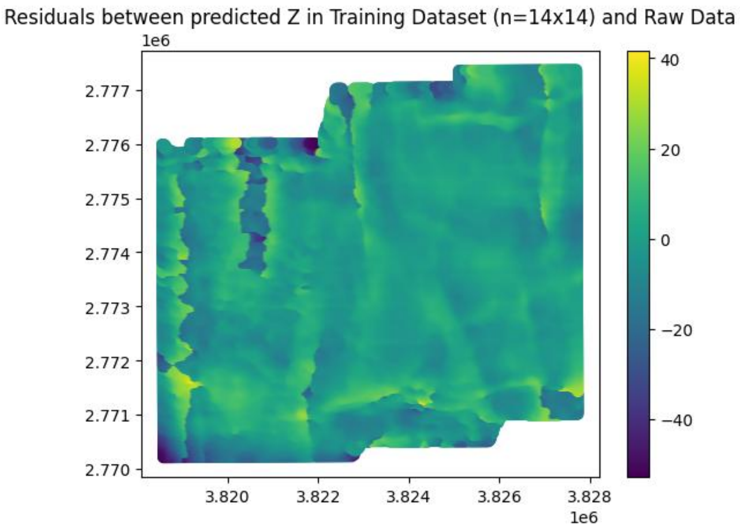
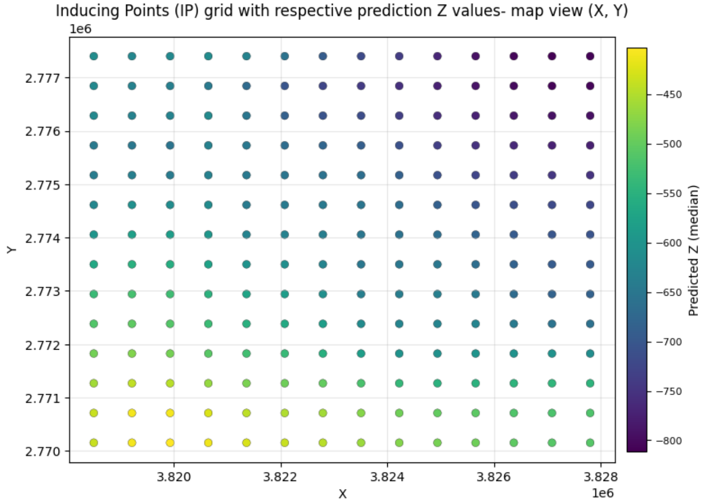
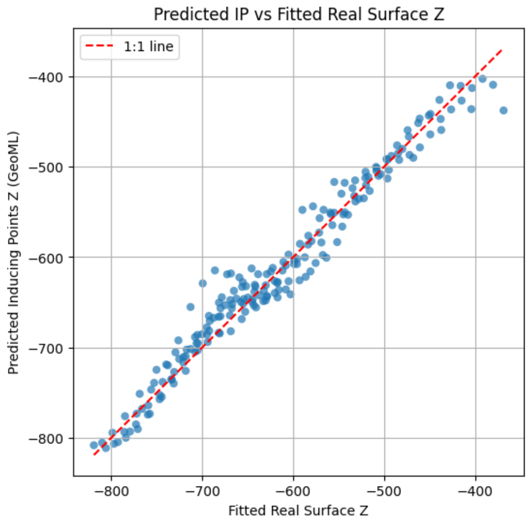
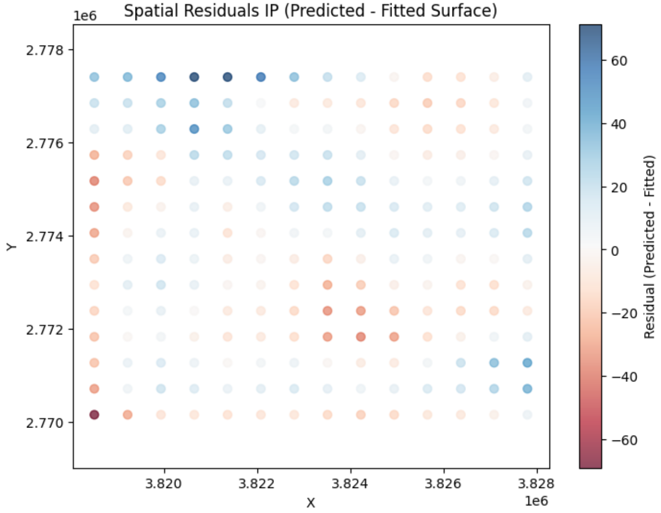
Simple Case: Santonian

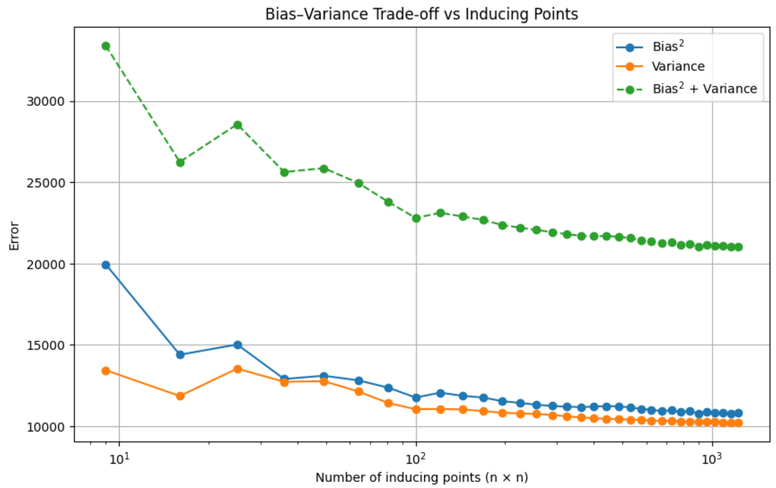












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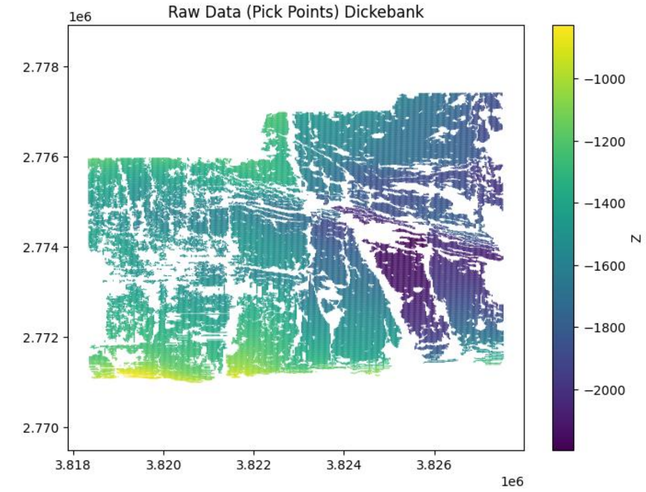
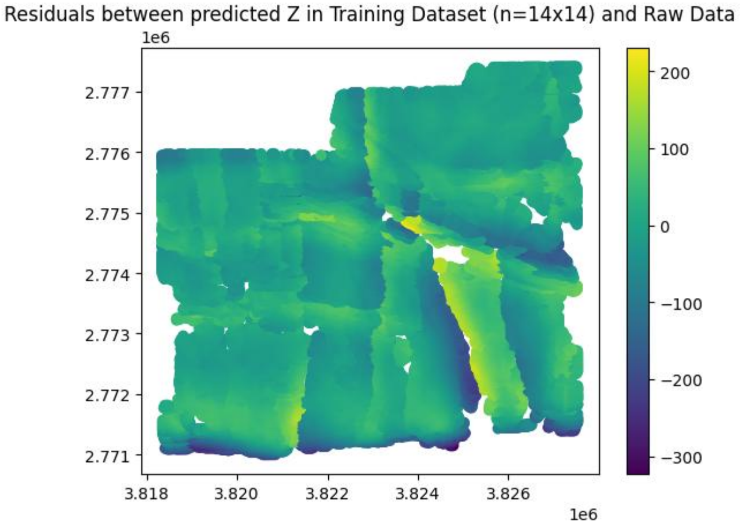
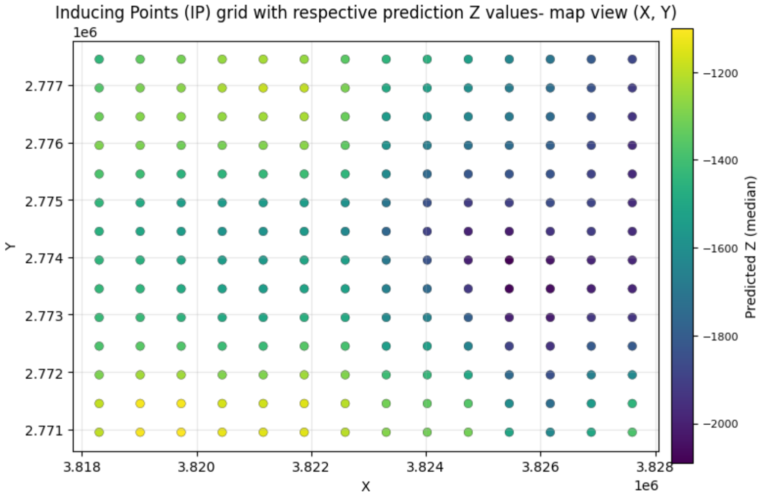
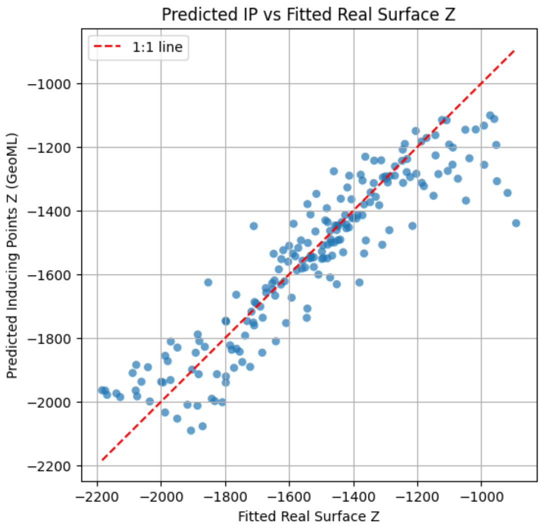
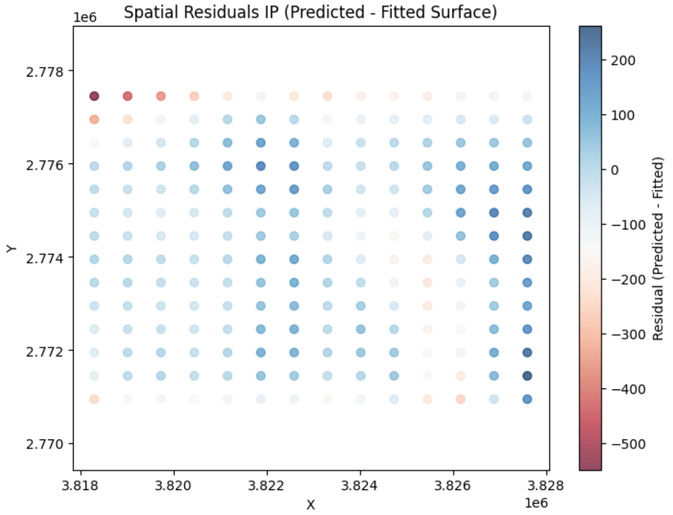
Complex Case: Dickebank

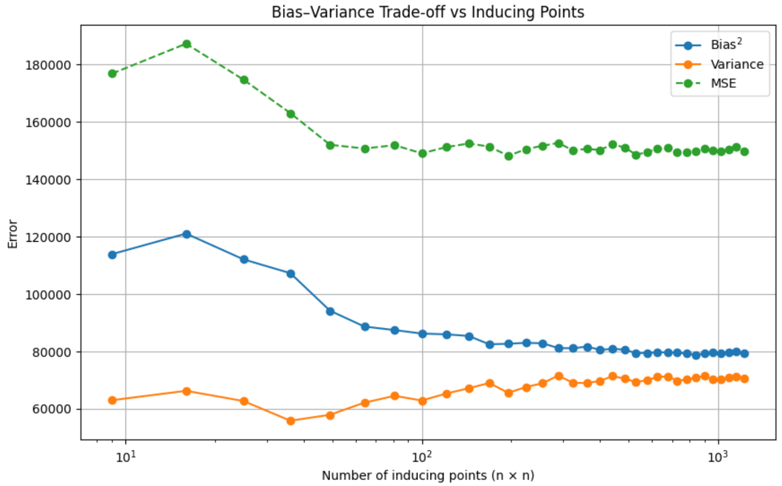












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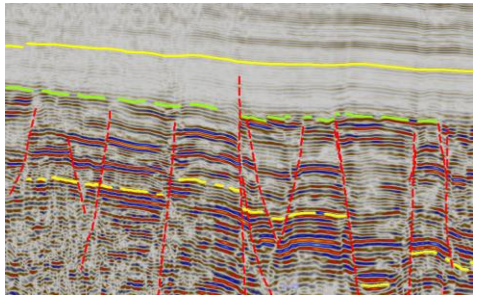
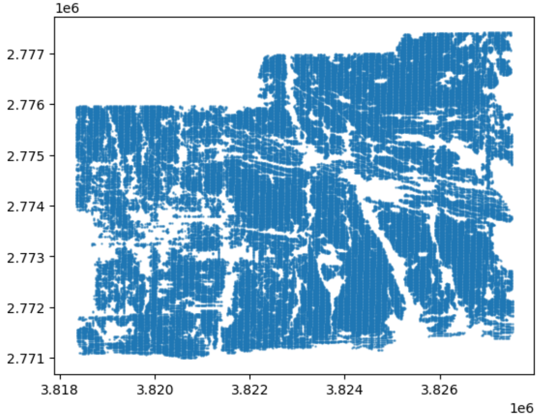
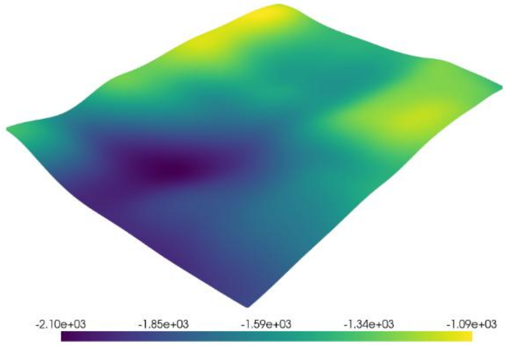
General Workflow – Down sampling of Data

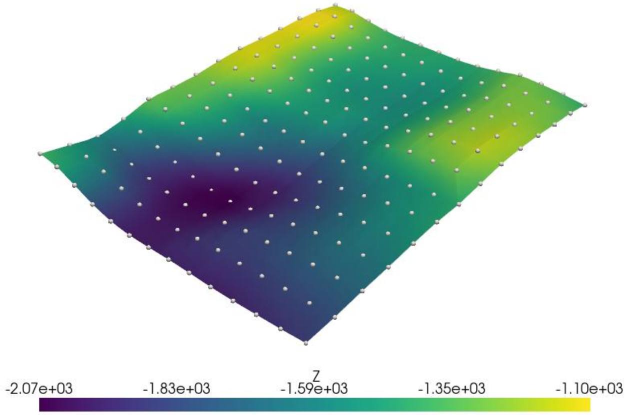


Seismic Interpretation

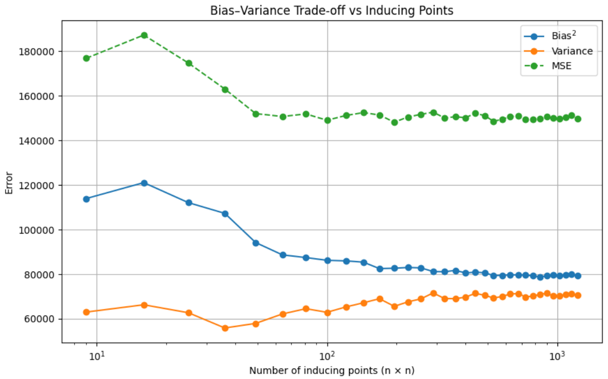


Pick Points (Seismic Horizons)

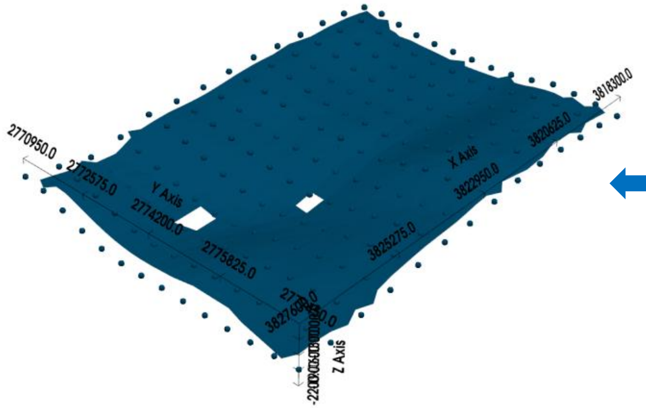




Gaussian Process (GeoML) with Inducing Points



Evaluate ML Model



Inducing Points used as input data for GemPy model

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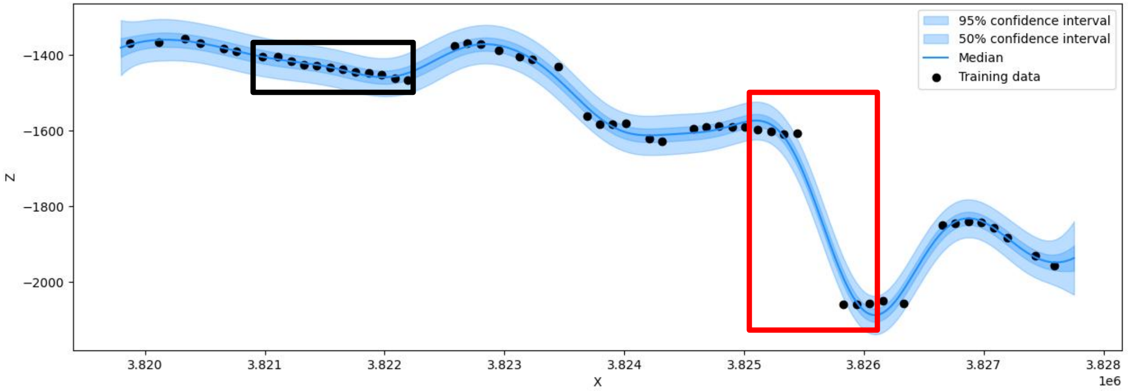
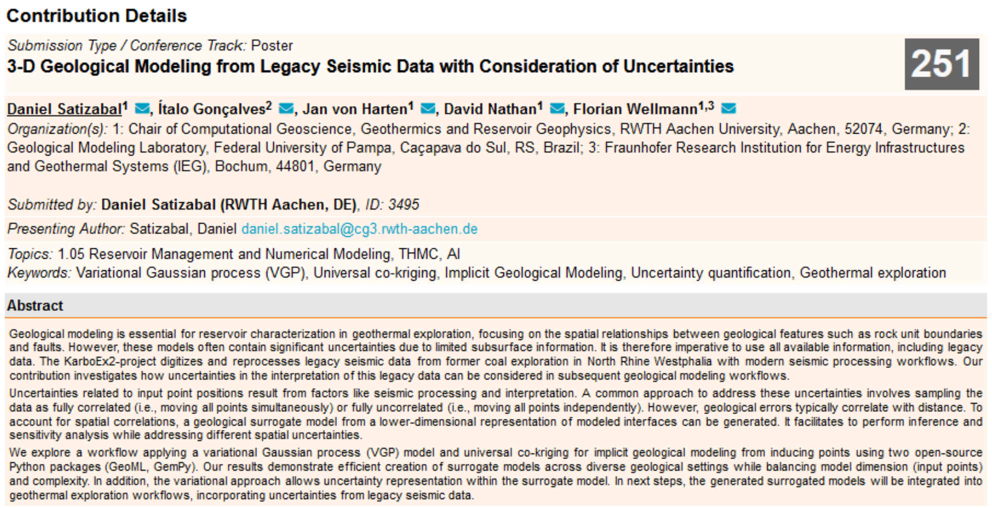
Next Steps

- Increase number of Inducing Points where there are complex structures (red rectangle - e.g. faults).
- Where there are no complex structures decrease number of Inducing Points (black rectangle).
- Apply Gaussian Processes regression with Inducing Points on KarboEx2 seismic data (interpreted horizons once available)
- Perform geological modeling using GemPy (mesh)
- Contribution as a Poster in **Der Geothermie Kongress 2025**





Contribution Details

Submission Type / Conference Track: Poster

3-D Geological Modeling from Legacy Seismic Data with Consideration of Uncertainties

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Submitted by: **Daniel Satizabal (RWTH Aachen, DE)**, *ID: 3495*

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Topics: 1.05 Reservoir Management and Numerical Modeling, THMC, AI

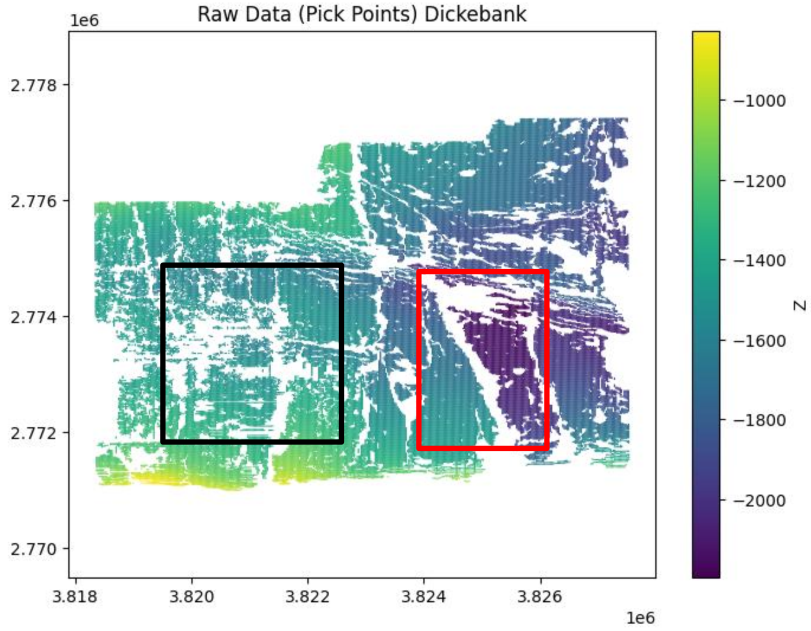
Keywords: Variational Gaussian process (VGP), Universal co-kriging, Implicit Geological Modeling, Uncertainty quantification, Geothermal exploration

Abstract

Geological modeling is essential for reservoir characterization in geothermal exploration, focusing on the spatial relationships between geological features such as rock unit boundaries and faults. However, these models often contain significant uncertainties due to limited subsurface information. It is therefore imperative to use all available information, including legacy data. The KarboEx2-project digitizes and reprocesses legacy seismic data from former coal exploration in North Rhine Westphalia with modern seismic processing workflows. Our contribution investigates how uncertainties in the interpretation of this legacy data can be considered in subsequent geological modeling workflows.

Uncertainties related to input point positions result from factors like seismic processing and interpretation. A common approach to address these uncertainties involves sampling the data as fully correlated (i.e., moving all points simultaneously) or fully uncorrelated (i.e., moving all points independently). However, geological errors typically correlate with distance. To account for spatial correlations, a geological surrogate model from a lower-dimensional representation of modeled interfaces can be generated. It facilitates to perform inference and sensitivity analysis while addressing different spatial uncertainties.

We explore a workflow applying a variational Gaussian process (VGP) model and universal co-kriging for implicit geological modeling from inducing points using two open-source Python packages (GeoML, GemPy). Our results demonstrate efficient creation of surrogate models across diverse geological settings while balancing model dimension (input points) and complexity. In addition, the variational approach allows uncertainty representation within the surrogate model. In next steps, the generated surrogated models will be integrated into geothermal exploration workflows, incorporating uncertainties from legacy seismic data.



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