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Probabilistic Machine Learning for improved Decision-making with 3-D Geological Models

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Geological models, as 3-D representations of subsurface structures and property distributions, are used in many economic, scientific, and societal decision processes. These models are built on prior assumptions and imperfect information, and they often result from an integration of geological and geophysical data types with varying quality. These aspects result in uncertainties about the predicted subsurface structures and property distributions, which will affect the subsequent decision process.

We discuss approaches to evaluate uncertainties in geological models and to integrate geological and geophysical information in combined workflows. A first step is the consideration of uncertainties in prior model parameters on the basis of uncertainty propagation (forward uncertainty quantification). When applied to structural geological models with discrete classes, these methods result in a class probability for each point in space, often represented in tessellated grid cells. These results can then be visualized or forwarded to process simulations. Another option is to add risk functions for subsequent decision analyses. In recent work, these geological uncertainty fields have also been used as an input to subsequent geophysical inversions.

A logical extension to these existing approaches is the integration of geological forward operators into inverse frameworks, to enable a full flow of inference for a wider range of relevant parameters. We investigate here specifically the use of probabilistic machine learning tools in combination with geological and geophysical modeling. Challenges exist due to the hierarchical nature of the probabilistic models, but modern sampling strategies allow for efficient sampling in these complex settings. We showcase the application with examples combining geological modeling and geophysical potential field measurements in an integrated model for improved decision making.