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Information Theory and the Analysis of Uncertainties in a Spatial Geological Context

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The interpretation of uncertainties in a spatial context is of fundamental importance for the generation of structural geological models; this applies to models for mineral exploration, to scientific structural geological studies and fundamental geological evaluations. With our work, we are addressing uncertainties in this spatial geological context. Encouraged by the interdisciplinary and interactive aspect of the session, we would like to present our method to other branches of geosciences.

Structural geological models, here understood as structural representations of the dominant geological units in the subsurface, always contain uncertainties. The analysis of these uncertainties is intricate as these models are usually constructed on the basis of greatly varying data quality and spatial distribution. An additional complication is that, in most cases, the general distribution of uncertainties in space is of interest, and not a single outcome as, for example, the flow at a well. In the context of structural geological uncertainties, we therefore face two problems: (i) how can we estimate uncertainties in a complex 3-D geological model, and (ii) what is a meaningful measure to visualise and analyse these uncertainties quantitatively?

In recent years, several approaches have been developed to solve the first problem. We show here an approach based on implicit stochastic geological modelling techniques, capable of handling complex geological settings. To address the second problem, we apply measures from information theory. We consider each subspace in a discretised model domain as a random variable. Based on the probability functions estimated from a suite of generated models, we evaluate the information entropy at each location in the subsurface as a measure of uncertainty. We subsequently estimate multivariate conditional entropy and mutual information between a set of locations and other regions in space, to determine spatial uncertainty correlations, and the potential reduction of uncertainty with additional information.

We apply these information theoretic measures to a case study where uncertainties exist about the structure, and shape, of a bounded geological unit at depth. The results yield some, at first, surprising, but very reasonable results for the interpretation of uncertainties. The case study highlights the fact that information theoretic measures provide very intuitive measures of uncertainty, but, due to the relation of the measure to Bayesian theory, also combine them with a powerful quantitative meaning.