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Uncertainties in geomechanical models – exhaustive vs. feasible approach

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Uncertainties in geomechanical models Exhaustive vs. feasible approach

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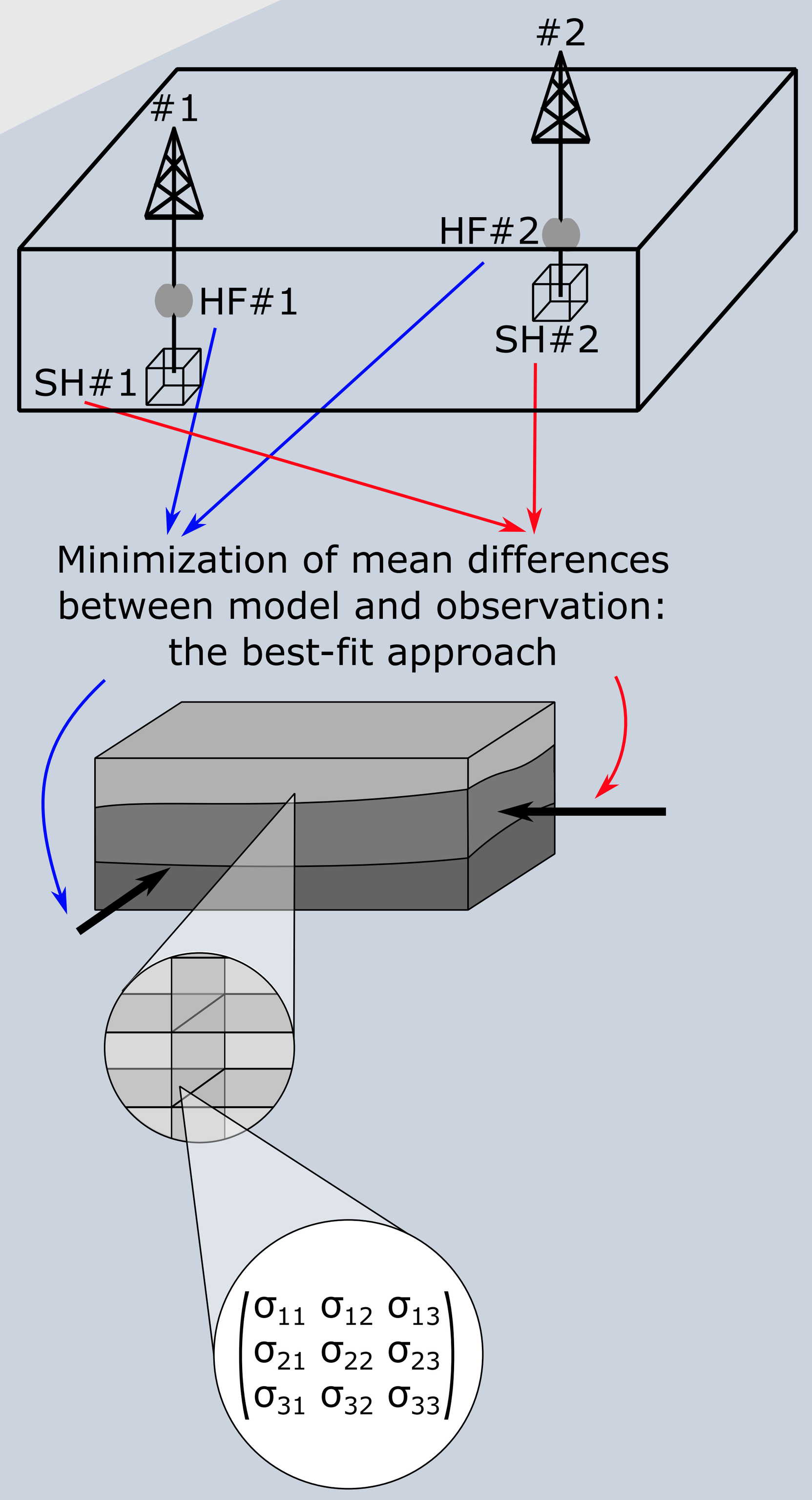
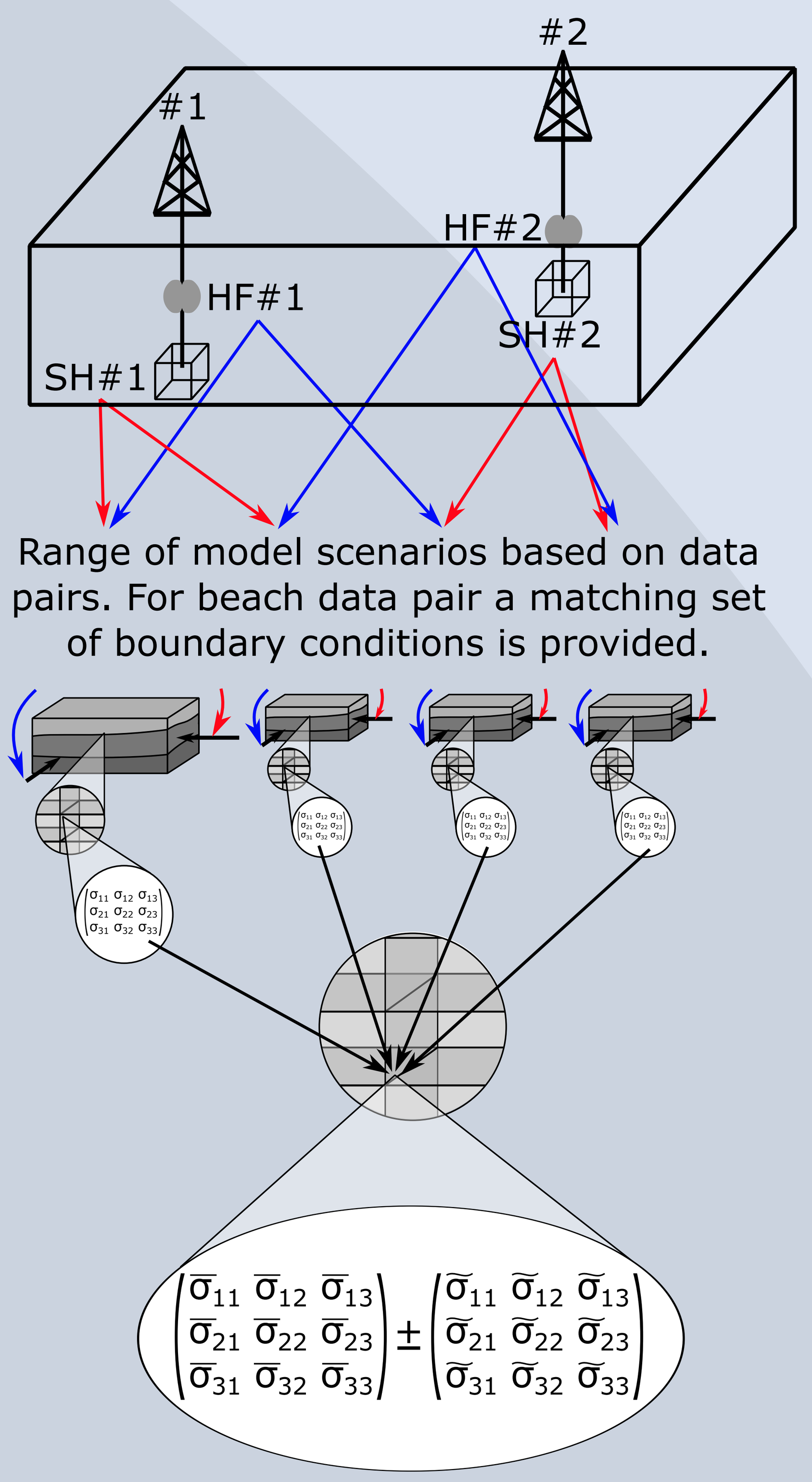
Abstract

The stress state is a key component for the safety and stability for deep geological repositories for the storage of nuclear waste. For the stability assessment and prediction over the repository lifetime the stress state is put in relation to the rock strength. This assessment requires knowledge of both, the future stress changes and the current in-situ stress state. Due to limited number of in-situ stress data records 3D geomechanical models are used to obtain a continuous stress field prediction. However, a meaningful interpretation of the stress state model requires the quantification of the associated uncertainties that result from the geological, stress, and rock property data. This would require thousands of simulations which in a high resolution model is called an exhaustive approach. Here we present a feasible approach to reduce computation time significantly.
The exhaustive approach quantifies uncertainties that are due to variabilities in stress data records. Therefore, all available data records within a model volume are used individually in separate simulations. Due to the inherent variability in available data, each simulation presents one of many possible stress states supported by data. A combination of these simulations allows estimation of an individual probability density function for each component of the stress tensor represented by an average value and a standard deviation. If a weighting of the data records can be performed, the standard deviation usually can be reduced and the significance of the model result is improved. Alternatively, a range of different stress states supported by the data can be provided with the benefit that no outliers are disregarded, but this comes at the cost of a loss in precision.
Both approaches are only feasible since the number of stress data records is limited. However, it is indicated that large uncertainties are also introduced by variabilities in rock properties due to natural intra-lithological lateral variations that are not represented in the geomechanical model or due to measurement errors. The quantification of these uncertainties would result in an exhaustive approach with a high number of simulations. Therefore we use an alternative, feasible approach.We use a generic model to quantify the stress state uncertainties from the model due to rock property variabilities. The main contributor is the Young's module followed by the density and the Poisson ratio. They affect primarily the σ_{xx} and σ_{yy} components of the stress tensor except for the density that mainly affects the σ_{zz} component. Furthermore, a relative influence of the stress magnitudes, the tectonic stress regime, and the absolute magnitude of rock properties are observed. We propose to use this information in a post-computation assignment of uncertainties to the individual components of the stress tensor. A range of lookup tables need to be generated that compile information on the effect of different variabilities in the rock properties on the components of the stress tensor in different tectonic settings. This allows to feasibly quantifying uncertainties in a geomechanical model and to increases the significance of the model results significantly.

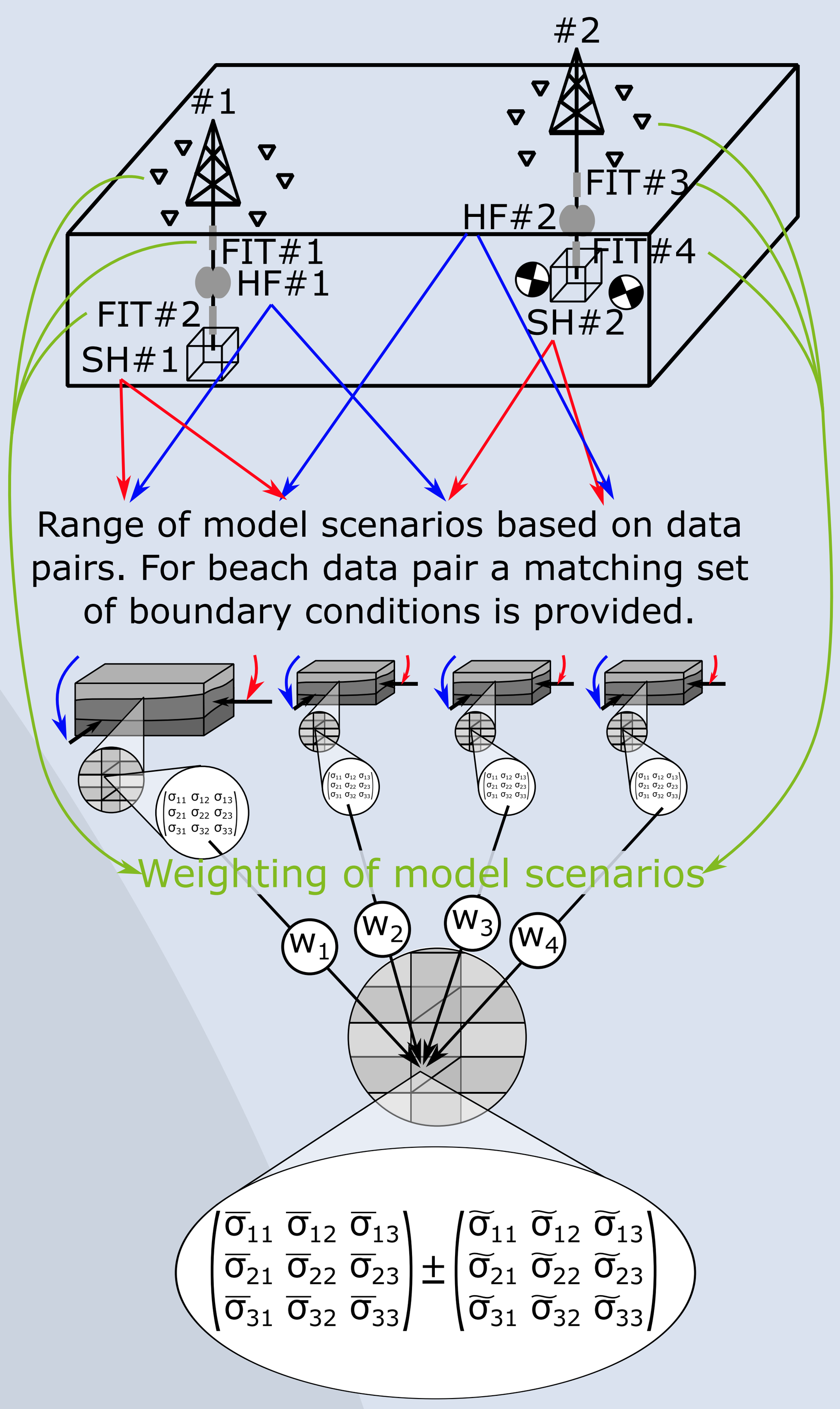
Best-fit approach



Quantification of uncertainties



Reduction of uncertainties

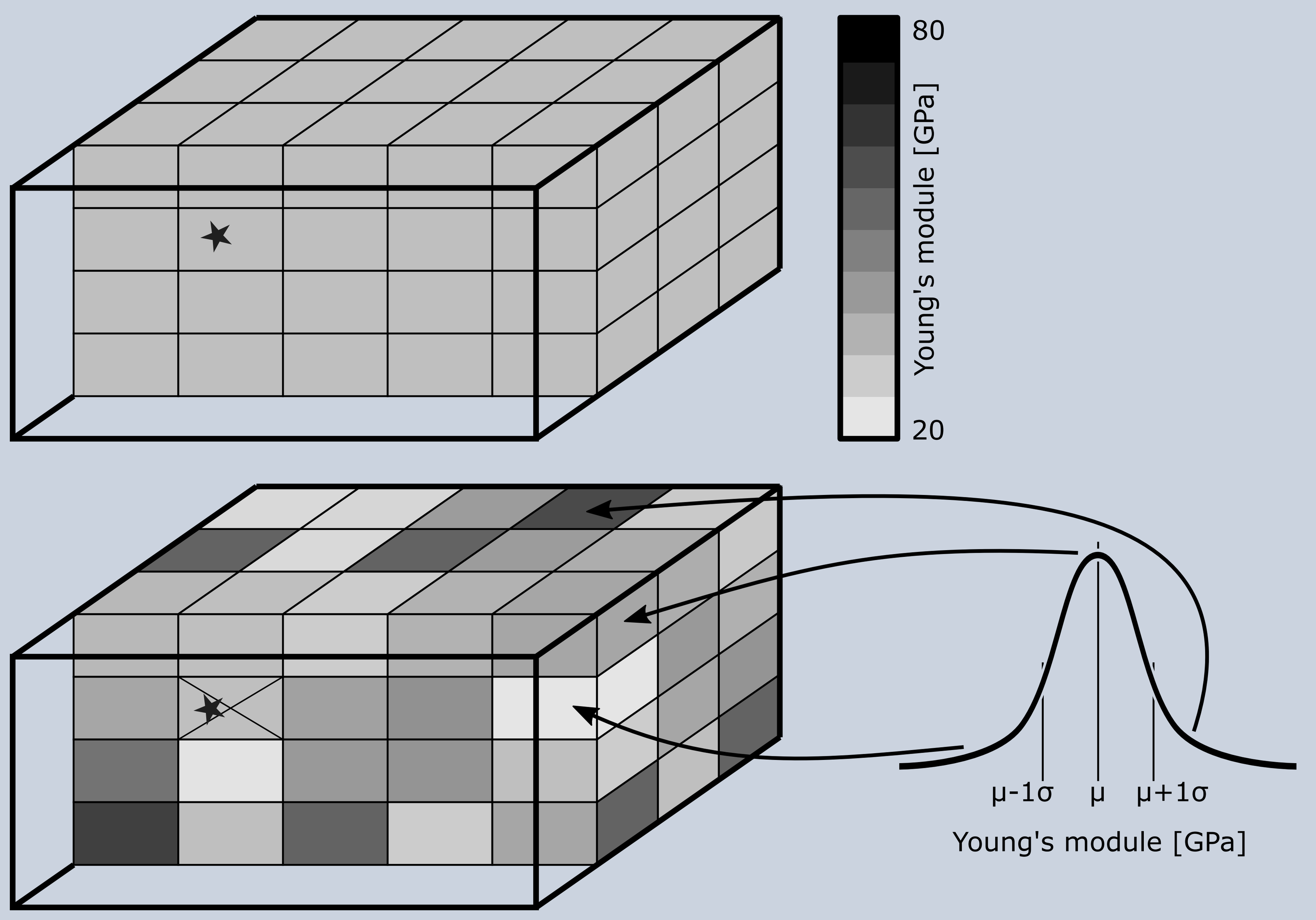


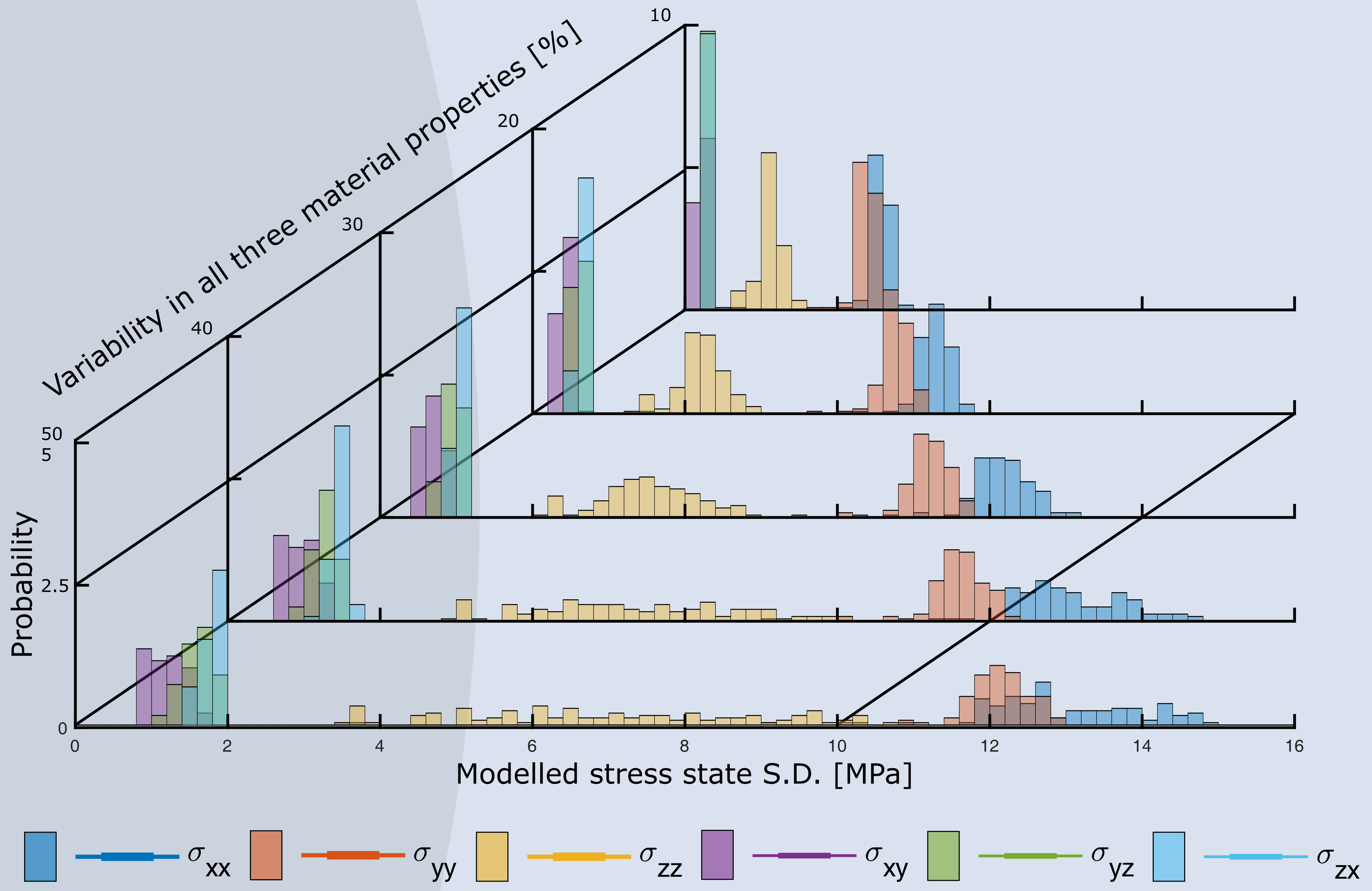
Synopsis in German Für interessierte Laien

kurz und einfach

Mechanische Gebirgsspannungen sind die Reaktion des Gesteins auf Plattentektonik, Gebirgsmassive, aber auch menschliche Eingriffe z.B. Tunnel oder Bergwerke. Wenn der Spannungzustand die Festigkeit des Gesteins überschreitet, bricht das Gestein. Im Großen geschieht das bei Erdbeben, wobei sich angestaute Spannungen entladen. Im Kleinen kann es zu einer Rissbildung kommen, durch welche Wasser strömen kann - etwas was im Endlagerbereich vermieden werden soll.
Da es nur wenige direkte Daten über die Spannung gibt, wird das Spannungsfeld am Computer modelliert. Hier zeigen wir eine Möglichkeit das Spannungsfeld zu modellieren und gleichzeitig auch die Unsicherheiten in den Ergebnissen darzustellen. Allerdings sind deren Unsicherheiten sehr groß. Daher benutzen wir weitere Informationen aus Bohrlöchern und beobachtete Seismizität (Erdbeben, hier sehr kleine, kaum spürbare) um die Unsicherheiten im Modellergebnis zu verkleinern.
Damit lässt sich die Aussagekraft von Spannungsmodellen deutlich steigern. Durch die berechneten Unsicherheiten lässt sich der nötige Sicherheitsspielraum definieren.

Heterogeneous rock properties: No time for an exhaustive quantification of uncertainties





A decisive factor for the manifestation of the stress state are the rock properties Young's module, Poisson ratio, and Density which are inherently heterogeneous to a variable degree. While a general range of rock properties may be known, the exact distribution is not known. Thus, the heterogeneity is reflected in the uncertainties in the stress state (see above).

Usually models assume a homogeneous distribution of rock properties throughout a lithological unit (Left top). In reality, heterogeneities to at least some degree have to be expected (Left bottom). Their influence on the uncertainties in the modelled stress state is indicated by the colour-coded standard deviations of the modelled stress states components (x-axis) throughout the model volume and its variability (y-axis) as a histogram (right). Different variabilities between 10% (back) and 50% (front) of all three rock properties are assumed.

These heterogeneities significantly increase the number of possible model scenarios. We propose to use a generic modelling to assess the additional uncertainties in each component of the stress tensor and add them to the uncertainties of the high resolution model.

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