Geomechanical Assessment of Potential for Induced Seismicity

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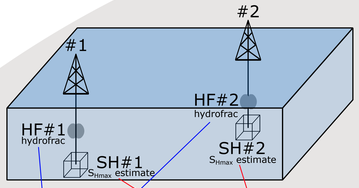
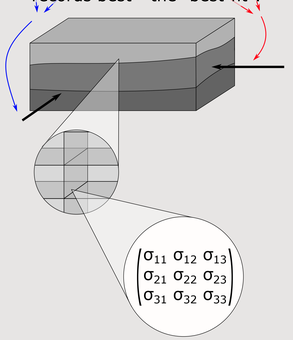
The undisturbed stress state is of key importance for all kinds of subsurface applications as well as for seismic hazard assessment but information on stress magnitudes is rare and unevenly distributed. Thus, 3D geomechanical-numerical modelling is used to estimate the stress state in an area of interest. However, due to the limitation of available data, the modelled stress state has a large uncertainty which has not been rigorously quantified yet. We present an approach to quantify the uncertainties in a 3D geomechanical-numerical modelled stress field. We combine the available SHmax and Shmin data records to pairs. For each pair we compute an individual model scenario. At each location in the model each scenario contains the full stress tensor. Then, from all model scenarios we compute an average value and a standard deviation for each component of the full stress tensor at each location within the model.
We compute an average stress state with uncertainties for the Bavarian Molasse Basin. In order to assess the potential of this approach, we compare the modelled stress state with seismological observations of induced seismicity in the vicinity of geothermal operations. The two power plants Aschheim/Feldkirchen/Kirchheim and Poing are in close proximity and in operation for almost the same time. Yet, no seismicity has been observed in Aschheim/Feldkirchen/Kirchheim, while significant events have been recorded in Poing. Our model shows these characteristics and thus its value for the geomechanical assessment of the potential for induced seismicity is confirmed.

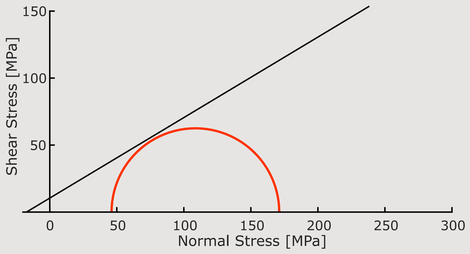
"Best-Fit" approach



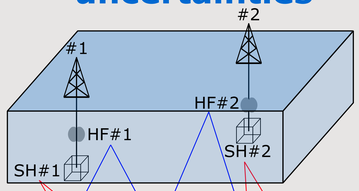
Mean difference between modelled and observed stress states are minimized. The resulting stress state fits all stress data records best - the "best-fit".



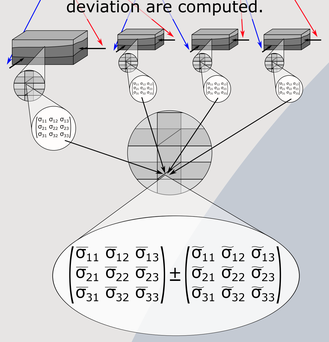
$$\begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{pmatrix}$$



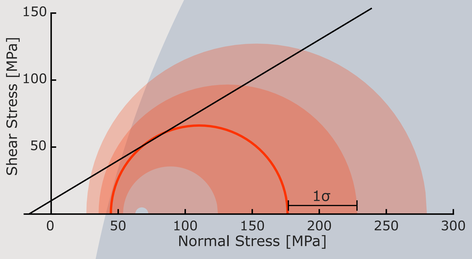
Quantification of uncertainties



Model scenarios from pairs of data records result in perfect fit for each pair. From all resulting modelled stress states the average and standard deviation are computed.



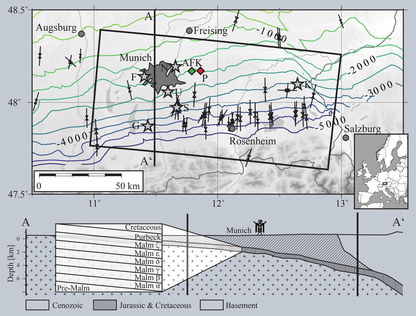
$$\begin{pmatrix} \overline{\sigma}_{11} & \overline{\sigma}_{12} & \overline{\sigma}_{13} \\ \overline{\sigma}_{21} & \overline{\sigma}_{22} & \overline{\sigma}_{23} \\ \overline{\sigma}_{31} & \overline{\sigma}_{32} & \overline{\sigma}_{33} \end{pmatrix} \pm \begin{pmatrix} \overline{\sigma}_{11} & \overline{\sigma}_{12} & \overline{\sigma}_{13} \\ \overline{\sigma}_{21} & \overline{\sigma}_{22} & \overline{\sigma}_{23} \\ \overline{\sigma}_{31} & \overline{\sigma}_{32} & \overline{\sigma}_{33} \end{pmatrix}$$



Application in the Bavarian Molasse Basin

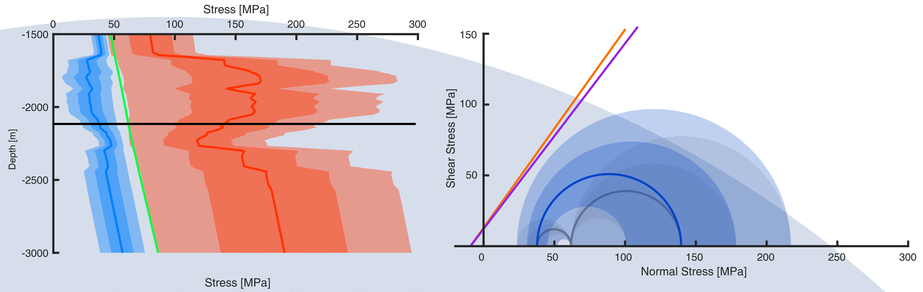
The modelled stress state at the geothermal power plant Aschheim/Feldkirchen/Kirchheim (AFK) east of Munich, where no seismicity has been observed yet (top) and at the geothermal power plant Poing (P) east of Munich, where significant seismicity has been observed (middle). A depth-stress plot (left) indicates the three principal stress components S_{Hmax} (red), S_{hmin} (blue), and S_v (green). The according average magnitudes (bold line) and a standard deviation of 1 sigma (bold shaded area) and 2 sigma (lightly shaded area) are indicated. The reservoir depth is indicated by the bold black horizontal line.
The stress state in reservoir depths is displayed in a Moh-Coulomb diagram with according failure criteria (Hedtmann & Alber, 2018).

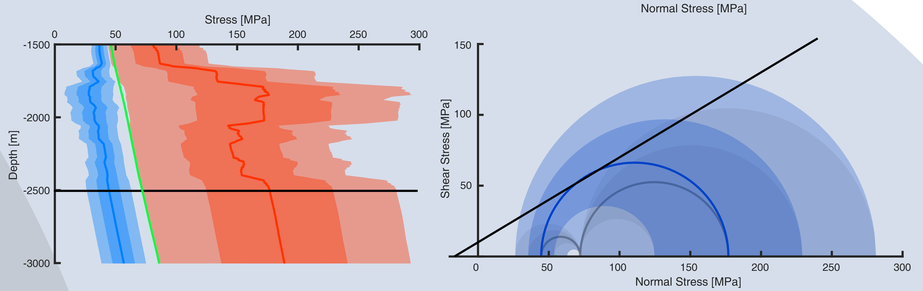
The differences between the best-fit model results and the average stress state according to the novel technique to quantify model uncertainties is displayed in the bottom figure on a horizontal plane in a depth of 3500m (left) and on a profile.

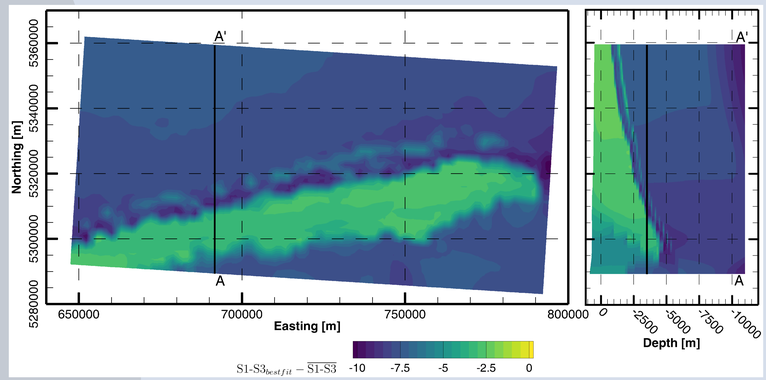


Please refer to the published results for more details:

Ziegler, M.O., Heidbach, O. The 3D stress state from geomechanical–numerical modelling and its uncertainties: a case study in the Bavarian Molasse Basin. Geotherm Energy 8, 11 (2020). https://doi.org/10.1186/s40517-020-00162-z







Download a full paper discussing the poster:

Watch a video of the entire model:

www.gfz-potsdam.de

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