Estimating the subsurface temperature of Hessen/Germany based on a GOCAD 3D structural model – a comparison of numerical and geostatistical approaches

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Introduction
Based on a 3D structural GOCAD model (Amth et al. 2011) and an extended geothermal database (Bär et al. 2011) of the federal state Hessen/Germany the subsurface temperature distribution is computed. Since subsurface temperature data for great depth are typically sparse, two different approaches for estimating the spatial subsurface temperature distribution are tested.

Numerical Modeling
One modified classical approach for estimating the subsurface temperature distribution is the numerical computation of a 3D purely conductive steady state temperature distribution (Rühaak et al. 2010). The numerical model is based on measured thermal conductivity data for all relevant geological units and surface temperatures (Sass et al. 2011). The numerical heat flow is estimated following the approach of Amth et al. (2011). It is spatially varying from 65 mW m\(^{-2}\) to 95 mW m\(^{-2}\) according to preserved Moho depth using data from Dökes & Ziegler (2001).

The model is calibrated using continuous temperature-logs. Only conductive heat transfer is considered as not enough data for convective heat transport at great depths are available. The fit of the modeled logs is very good in the areas that are not convective influenced (logs 1-19, 22), within such areas the fit is poor (logs 20-21).

3D Kriging of Temperature Measurements
The other approach to estimate the subsurface temperature distribution is by 3D ordinary Kriging. Here a modified approach is applied where the quality of the temperature measurements is taken into account (Rühaak 2006, Rühaak 2012). A difficult but important part is to derive good variograms for the horizontal and vertical direction. The variograms give necessary information about the spatial dependence of the data. The horizontal variogram is based on all data from the Odenwald and Sprendlinger Horst (ODW), Hanau Seligenstädter Senke (HSS), Hessen North-East (NE) and Schweinfurtgebirge (RH). Data from the Mainzer Becken (MZ) and the Oberhessischen Graben (ORG) are not used for this variogram as they are strongly convective disturbed. The vertical variogram is based on data from all regions but only high-quality measurements from continuous logs are used.

Discussion and Outlook
Differences in the predicted subsurface temperature distribution are mainly related to convective processes, which are reflected by the interpolation result, but not by the numerical model. Therefore, a comparison of the two results is a good way to obtain information about flow processes in such great depth. This way an improved understanding of the heat transport processes within this mid enthalpy geothermal reservoir (1000 m – 6000 m) is possible.

The computation of a fully coupled flow and heat transport model would be ideal. However, due to the small number of data any such result lacks of reliability.

To obtain the theoretical variogram necessary for the Kriging is a difficult task. Especially the quality of the horizontal semi-variogram is poor. However, it is sufficient for obtaining a reasonable spatial temperature distribution. Especially the inclusion of a weighting algorithm (Rühaak 2012) helps to improve the Kriging result as artefacts due to low quality measurement only have a small impact - where high quality data are available.

The combination of both approaches might result in a temperature model with a good fit to the given temperature measurements as well as a good extrapolation of subsurface temperatures in depths where no data is available. Such a model increases the quality of geothermal potential predictions compared to purely numerical or geostatistical approaches.

In this study the paleoclimate signal was not taken into account, which is relevant especially for depths up to approximately 1000 m. Also heat production was neglected for the numerical model. Both aspects as well as the influence of fault zones as conduits for convective heat transport should be addressed in future work. Additionally the impact of a temperature dependent thermal conductivity should be studied in future.

References
Dökes, M. & Ziegler, P. A. (2001): European Map of the Mohorovicic Discontinuity, (MZO) and unknown TSC with one temperature measurement, known radius and different times in the same depth; corrected with an explosion source ansatz - 16.

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