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Subsurface Temperature Distribution of Germany

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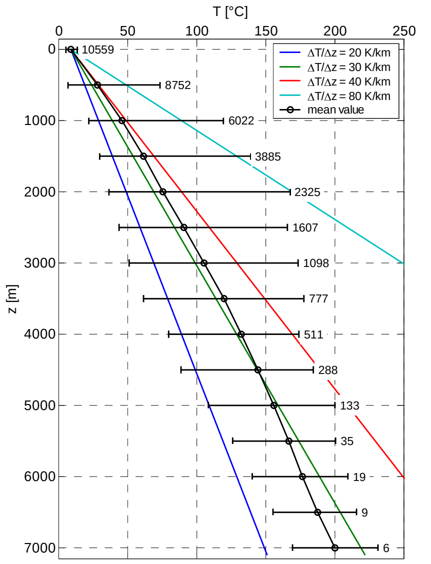
Data from approximately 10 500 wells and more than 700 ground level data sets were used to develop a consistent 3D-estimate of the subsurface temperature distribution in Germany. The temperature model was realized with universal kriging and extends from ground level to 5000 m below sea level. Conventional 2D-mapping algorithms estimate subsurface temperature at certain depth levels. The major limitation of any 2D-mapping is the possibility of inconsistencies between different depth levels due to the loss of information from shallower levels. Aspects of varying data density and quality were considered. The developed temperature model is part of the Geothermal Information System for Germany (GeotIS) and can be accessed via the internet (http://www.geotis.de/).



Temperature-depth profile of Germany: The circles denote the mean temperature values, the bars indicate the variation of the measured values (minimum and maximum temperature), and the figures give the number of boreholes at the respective depth. The plotted lines correspond to temperature gradients of 20 K/km, 30 K/km, 40 K/km and 80 K/km.

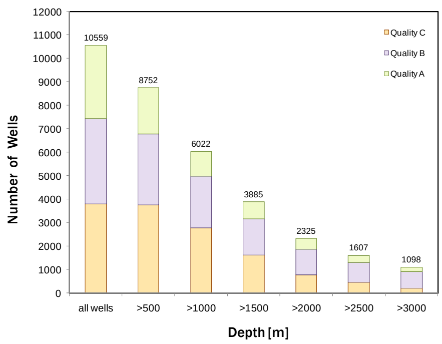
In order to estimate the geothermal potential of a geologic body at any depth level it is necessary to determine the temperature at any point in a consistent 3D-temperature model. In this study we applied 3D universal kriging. Generally, kriging estimates are weighted linear or non-linear combinations of the available data. It is the only method which allows to configure the estimation process according to the measured spatial variability. The geostatistical approach does not only produce estimates for unsampled regions but also the uncertainty associated with the predicted values. This is a distinct advantage over more conventional techniques. Another advantage is the possibility to account for random variability by smoothing.

We grouped subsurface temperature data in categories of low, medium and high reliability. Low quality data were used for further processing where no data of a higher quality are available at a maximum distance of 5 km and a maximum depth level of 300 m above sample location. Medium quality data in the vicinity of high quality data were rejected in the same way. This filtering improves mapping and mitigates small-scale temperature variability.

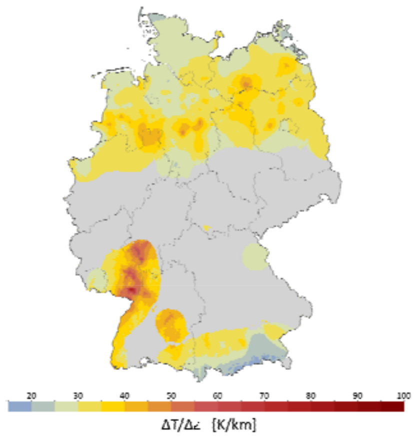
Additional input data were derived by vertical interpolation between single sample locations and surface temperature. This procedure allows us to apply kriging with high lateral mapping ranges. These “virtual temperature logs” follow a linear temperature/depth relationship. The influence of varying heat conductivity on subsurface temperature has been neglected.

All sample data were transformed to normal-score for kriging. This is necessary because the complete data set exhibits a non-normal distribution and does not satisfy the basic assumption of statistical normality. The maps A to D on the right side show the results of this 3D multi-Gaussian universal kriging for four depth levels.

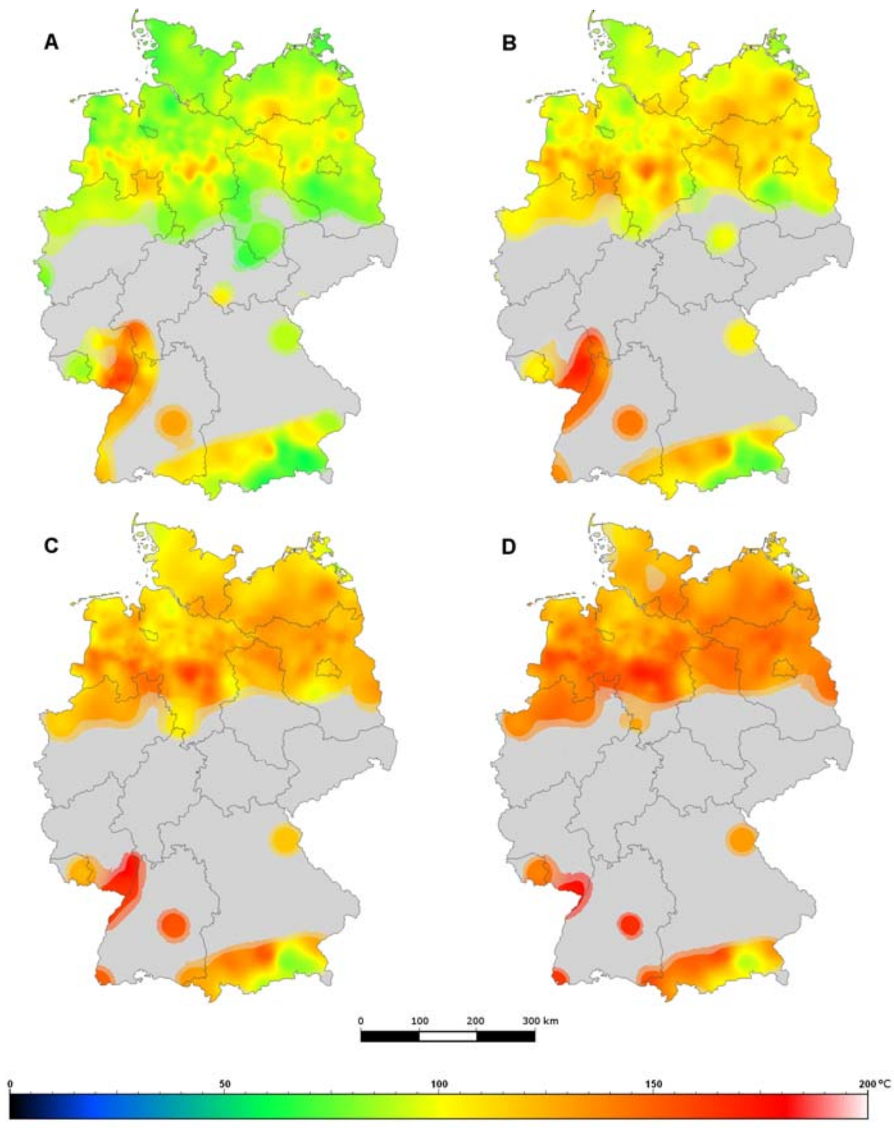
The average depth level of a temperature 100 K above surface temperature is 3125 m. This corresponds to an average geothermal gradient of 32 K/km.



Number of wells with temperature records penetrating certain depth levels. Highest quality A includes undisturbed logs, continuous reservoir measurements, drill stem test data and measurements from mines and tunnels. Medium quality B includes disturbed logs and comprehensive bottom hole temperature records. Low quality C comprises bottom hole temperature records with little or no additional information.



Spatial variation of the geothermal gradient in Germany. The geothermal gradient is expressed as the ΔT/Δz ratio where ΔT = 100 K and Δz is the depth from ground level.



Subsurface temperature in Germany at 2500 m (A), 3000 m (B), 3500 m (C) and 4000 m (D) below sea level.
The blanked areas (for the most part Central German Uplands) cannot be mapped due to the lack of data.