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The geothermal field of Denmark from borehole measurements and 3D numerical modelling

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We present a 3D numerical crustal temperature model and analyze the present-day geothermal field of onshore Denmark, including parts of the Danish Basin, the northernmost part of the North German Basin and the Sorgenfrei-Tornquist Zone. An extensive analysis of borehole and well-log data on a basin scale is conducted to derive the model parameterization with a spatial distribution of rock thermal conductivity as well as new, regionally variable heat-flow values. A new structural geological model with lithological layers is provided by the Geological Survey of Denmark and Greenland (GEUS). Measured heat flow and borehole temperature observations (102 values from 47 wells) are used to constrain the modelling results in terms of calibration and validation. The prediction uncertainties between modelled and observed temperatures at deep borehole sites are small (rms = 1.3°C). For 22 deep boreholes, new values of terrestrial surface heat flow are derived ranging between 64 and 84 mW/m^2 (mean of 77 $\pm$ 5 mW/m^2) for the Danish Basin, between 60 and 95 mW/m^2 (mean of 80 $\pm$ 10 mW/m^2) for the very northern part of North German Basin, and between 63 and 66 mW/m^2 (mean of 65 $\pm$ 2 mW/m^2) in the Sorgenfrei-Tornquist Zone, respectively. Heat flow from the mantle is estimated to be between 31 and 39 mW/m^2 (q1–q3; mean of 34 $\pm$ 7 mW/m^2). Lateral temperature variations found by 3D modelling are caused by complex geological structures, like salt structures, lateral variations in the thickness of basin sediments or tectonic features. The variations in rock thermal conductivity associated with different lithological units generate significant variations in temperature gradients and heat flow. Major geothermal sandstone reservoirs show significantly different temperatures according to a large variation in reservoir depth and different thermal conductivity of overlying lithologies. For example, temperatures of the Gassum Formation, covering most of the Danish onshore areas, are within the range of 20–140°C (top depth). The presented temperature model constitutes a very valuable base for planning and management the subsurface geothermal resources in Denmark. It is available online at http://data.geus.dk/geoterm/.