# The geothermal 3D model for the pilot area Upper Austria/Upper Bavaria within the project GeoMol

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**ABSTRACT:** The scope of the project GeoMol is to promote the efficient use and sustainable management of a multitude of natural subsurface interests (i.e. deep geothermal potentials, storage capacities and existing oil and gas claims as well as groundwater rights) in the Molasse basin, a deep sedimentary Alpine Foreland basin stretching along the Alpine mountain range. Mainly financed by the Alpine Space Program, the geophysical and geological information (mostly wells and seismic data) from several European countries (Austria, France, Germany, Italy, Slovenia and Switzerland) on the Molasse Basin and on the Po Plain has been gathered to build up geological 3D models.
Based on the geological 3D model of a predefined pilot area covering parts of Bavaria and Upper Austria, the Geological Survey of Austria set up a numerical 3D steady-state model in Feflow to simulate the geothermal conditions.
The calculated geothermal model supports conductive heat transport and steady state conditions in the pilot area. The thermal properties of the geological units are derived by parameter estimation using the FePest module. The results of the steady-state numerical model are temperature distribution maps in various depths as wells as calculated residuals based on the modelled temperature information and measured formation temperature to interpret areas of convective influence.

## INTRODUCTION

### The project GeoMol

The GeoMol project was executed within the European Territorial Cooperation Alpine Space Program and ended in June 2015 after 3 years running. 14 institutions from 6 member states (Austria, France, Germany, Italy, Slovenia, Switzerland) took part in the project.

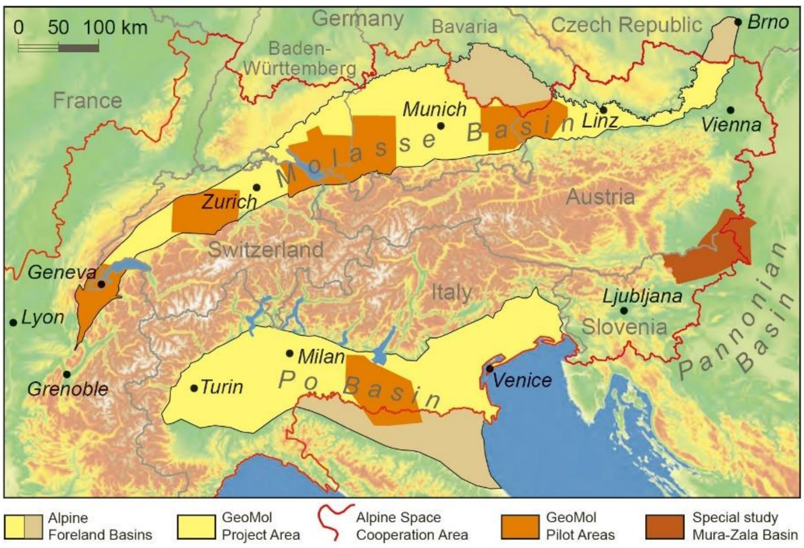


**Figure 1: Investigation area of the project GeoMol** (GEOMOL TEAM (2015)

The GeoMol project area is located within the Northern and Southern Alpine Foreland basins of the European Alps. The Southern Alpine Foreland Basin (SAFB), the Po basin, extends about 500km in northern Italy. The Northern Alpine Foreland Basin (NAFB), the Molasse basin, stretches over more than 1,000 km from Chambery (France) to the southwest of Brno (Czech Republic). Within the Molasse basin 4 pilot areas for detailed 3D modelling and assessment of geopotentials with respect to current issues in the region were defined. Figure 1 shows the GeoMol project area and the pilot areas within the Northern and Southern Foreland basins.

The main objective of GeoMol was to provide transnationally harmonized, digital and up-to-date knowledge and databases of the geology of the basins, which is a prerequisite for various applications in spatial planning and decision-making. The unbiased and agreed transnational interpretation of the geology serves as basis for the assessment of the geopotentials in the pilot areas. Table 1 gives a summary on the different geopotential types. The geopotentials considered in GeoMol are shown in Italics.

| Natural (geo-genetic) potentials | | Man-made geopotential |
|---|---|---|
| **Utilisable geopotential** | **Unfavourable geopotential** | |
| Earth's surface | Volcanism | Dumps and landfill |
| Soil | *Earthquakes (seismicity)* | Cavities |
| Building ground | Mass movement and landslides | Accumulation of substances |
| *Groundwater* | Swamp formation | |
| *Geothermal energy* | Salinisation | |
| Mineral resources | Sand drift | |
| Oil and gas | Flooding | |
| *Storage formations* | | |
| incl. *karst as a reservoir* | Karstification (sink-holes) | |

**Table 1: Classification of geopotentials (**MANHENKE (1999) **modified by** GEOMOL TEAM (2015)**)**

**Geothermal energy potential within GeoMol**

Among the deep geopotentials of the Foreland Basins, the geothermal potential is one of the most important and widely deployed. The Molasse basin features the highest geothermal potential in central Europe – due to highly productive aquifers within the Upper Jurassic. Since the 1990s the utilization of the thermal waters developed from balneological exploitation to energy generation. For example: the Greater Munich area at present features 15 deep geothermal installations for district heating or combined heat and power generation.

Geothermal energy potential within GeoMol basically refers to hydrothermal resources, where heat is extracted from deep aquifer systems. Geothermal exploration generally is still a high risk investment, particularly the low-enthalpy system of the NAFB with varying hydraulic characteristics of the reservoir (aquifer permeability) and a complex fault network influencing the preferential flow path of the thermal water and causing possible compartmentalizing of the thermal aquifer.

The evaluation of geothermal energy potential in the GeoMol pilot areas is based on 2 principal reservoir features: the spatial interpretation of fault networks and the temperature distribution in the subsurface. As the fault networks were already a part of the geological 3D modeling, an improved spatial temperature model, based on the comparison of different methodologies and comprehensive review of all data available was set up.

Combining the information of the 3D geological model and the spatial temperature distribution a geothermal map series was elaborated featuring the following issues:

- Temperatures at the top of most important aquifer (Upper Jurassic (Malm) Karst)
- Temperature at certain depths
- Depths of the 60°C, the 100°C, and the 120°C isotherms

Subsequently geothermal potential gradation maps for the pilot areas were elaborated, representing temperature intervals of commonly accepted technical and economic boundary conditions for geothermal installations.

The shallow geothermal potential is not considered in GeoMol.

**GEOTHERMAL 3D MODEL**

**Temperature data preparation**

In general the numerical 3D temperature model is based on the geological 3D model and measured subsurface temperatures.
These temperature data were, in the case of the pilot area Upper Austria/ Upper Bavaria (UA/UB), mostly acquired during hydrocarbon exploration. The most important temperature data sources are: Bottom Hole temperature (BHT) - data, Drill Stem Test (DST) - data, logs (temperature or cementation) and outflow temperatures at geothermal wells. Table 2 provides an overview on the available temperature data in the different pilot areas. For a qualitative comparison between the different areas, the evaluation method by CLAUSER ET AL. (2002) was applied, leading to "quality coefficients" for the temperature data.

| Pilot / Study Area | | Number of wells | | | | Number of individual datum points | | | | Sum of quality coefficients |
|---|---|---|---|---|---|---|---|---|---|---|
| Name | Area km² | Total | BHT | DST | Logs undist | Total | BHT uncorr | BHT corr | DST | |
| Lake Constance–Allgäu Area (LCA) w/o Swiss territories | 7,260 | **350** | 131 | 65 | 154 | **691** | 0 | 178 | 513 | **522.53** |
| Geneva-Savoy Area (GSA) | 2,000 | **14** | 13 | 1 | 0 | **43** | 0 | 40 | 3 | **16.1** |
| Upper Austria–Upper Bavaria Area (UA–UB) | 4,730 | **346** | 330 | 10 | 6 | **659** | 75 | 571 | 13 | **365.85** |
| Brescia-Mantova-Mirandola Area (BMMA) | 5,700 | **39** | 36 | 3 | 0 | **331** | 134 | 194 | 3 | **88.76** |
| Mura-Zala Basin | 5,400 | **275** | 225 | 10 | 40 | **339** | 211 | 107 | 21 | **121.69** |

**Table 2: Available temperature background data in the different pilot areas (**GEOMOL TEAM (2015)**)**

**Model set up**

The numerical temperature model for the pilot area UA/UB was set up as a FeFlow 3D model, based on the geological 3D model in the pilot area. Figure 2 shows the general outline of the model in FeFlow. The numerical model consists of 10 main formations and extends from ground level to a depth of 7,000 m b.s.l. The import and correct display of the complex structural maps was the most time consuming part of the model set-up, as the 10 different geological units mostly do not cover the whole pilot area but are intersecting with overlying horizons. The solution was to also import slices where geological units were pinching out for the whole pilot area by using minimum distance to the overlying slice when intersecting. Afterwards the thereby developed volumina were allocated to the correct geological formation using element selections. That way the material parameters for each unit could be assigned correctly.

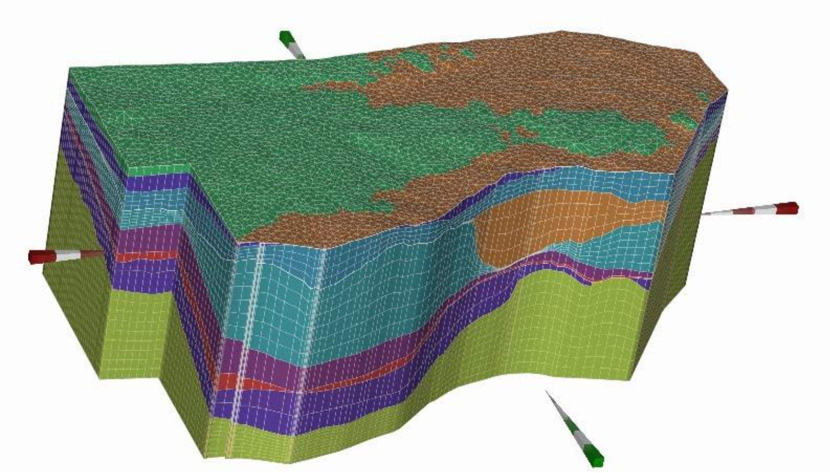

**Figure 2: Extent of the 3D model of the pilot area UA/UB in FeFlow**

Due to the paucity of information on the hydrological flow-paths and the complexity of the theoretical hydrothermal groundwater flow system only conductive heat transport processes were taken into account. Therefore a constant water level was set at 100 m a.s.l. as boundary condition to prevent groundwater flow.

As there is hardly any information on the thermal rock properties in the UA/UB pilot area, a FePest model was set up to estimate the thermal conductivity for the involved formations. Based on starting values taken from literature data, the thermal conductivity was then re-evaluated using measured temperature data within the different formations.

Main boundary conditions for the numerical model are a relief depending mean annual surface temperature at the uppermost slice and a temperature distribution at 7000 m b.s.l., taken from PRZYBYCIN AT AL. (2014), as basal heat flow boundary condition at the lowest slice.

## RESULTS

### Temperature distribution and error estimation

Figure 3 shows the main result of the steady-state simulation in the pilot area UA/UB, which is the temperature distribution due to conductive heat transport. There is clearly an increased temperature gradient along the southern part of the pilot area.

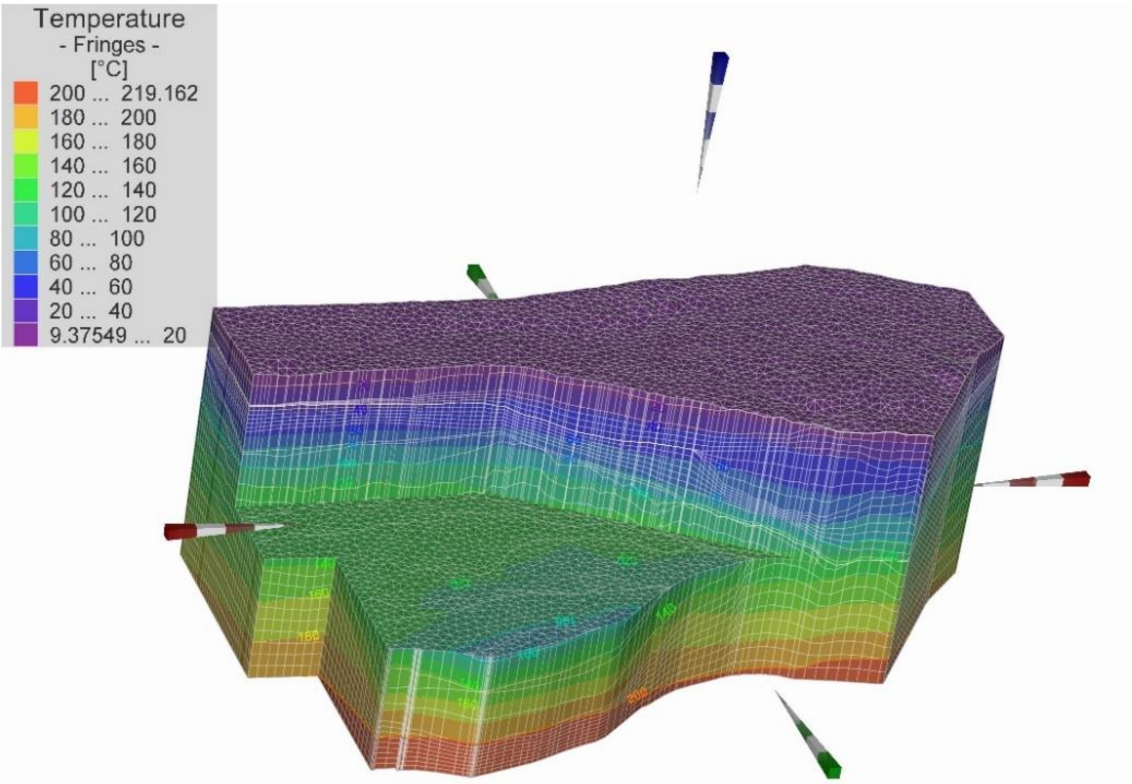


**Figure 3: Temperature distribution in the pilot area UA/UB**

Based on the temperature distribution of the steady-state model, temperature maps in certain depths below surface (500 m, 1000 m, 2000 m, 3000 m, 4000 m) and on top of the most import aquifer (Upper Jurassic) were elaborated by exporting the nodes and calculating the depth-slices using Matlab.
Figure 4 shows the depth profile of the 100 °C isotherm in the model area. The distribution of the isotherms (60 °C, 100 °C and 120 °C) was taken directly from FeFlow.

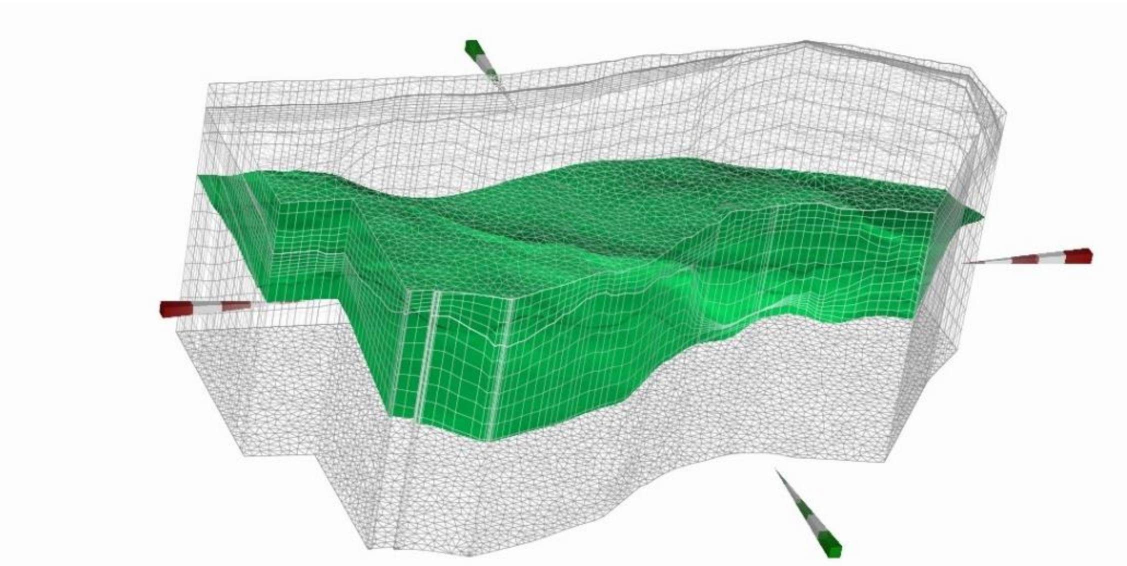

**Figure 4: 100°C isotherm in the pilot area UA/UB**

The temperature maps from the conductive steady-state model were then compared with available measurements within a tolerance range of +/- 200m respectively +/- 6°C. The residuals between the observed and the numerical model are also illustrated in maps, i.e. Figure 5 displaying the temperature residuals at the Top of the Upper Jurassic formation. As the numerical model only supports the conductive heat transport, these residual maps mainly reflect zones of heat transport by convection (on condition that the measured temperature data represent equilibrium temperature with no errors due to applied correction methods). The temperature residual maps were also used for hydrological interpretations. Red colors indicate areas, where the conductive model underestimates the subsurface temperature due to convective heat transport by thermal groundwater flow.

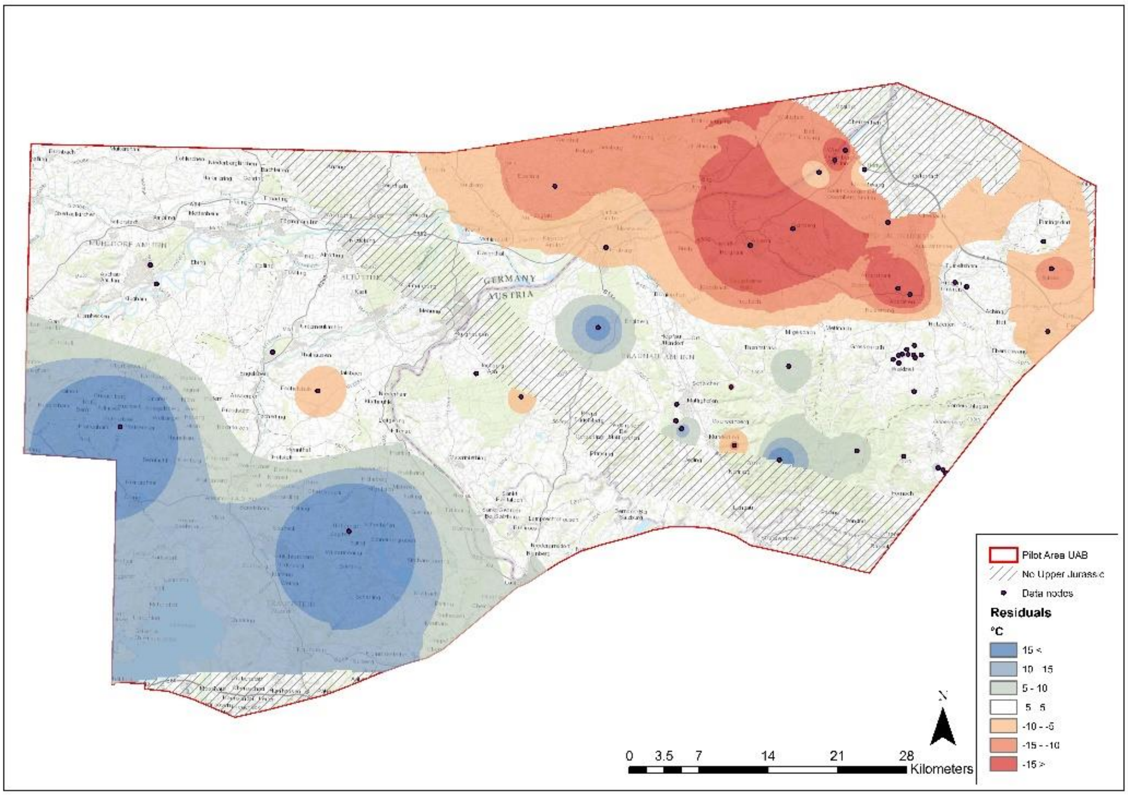


**Figure 5: Temperature residuals on top of the Upper Jurassic formation**

**Visualization**

One of the aims of the GeoMol project was to make the achieved knowledge and models available to the public. Several web-based channels are provided to disseminate GeoMol-products, for example a MapViewer for visualization and analysis of thematic 2D maps as well as a web map service for the integration of 2D thematic map information into Desktop GIS.
To elaborate the thematic 2D temperature maps the temperature from the conductive model was combined with the residuals. For example Figure 6 and Figure 7 show the temperature distribution at Top of Upper Jurassic, the most important thermal aquifer. Figure 6 shows the temperature distribution without considering the residuals. Figure 7 illustrates the combined temperature distribution by taking into account the residuals and the conductive model results. The broader lateral extent of the high temperature area in the north-eastern part of the pilot area is clearly due to convection, as proven by the various balneological utilizations in this area.

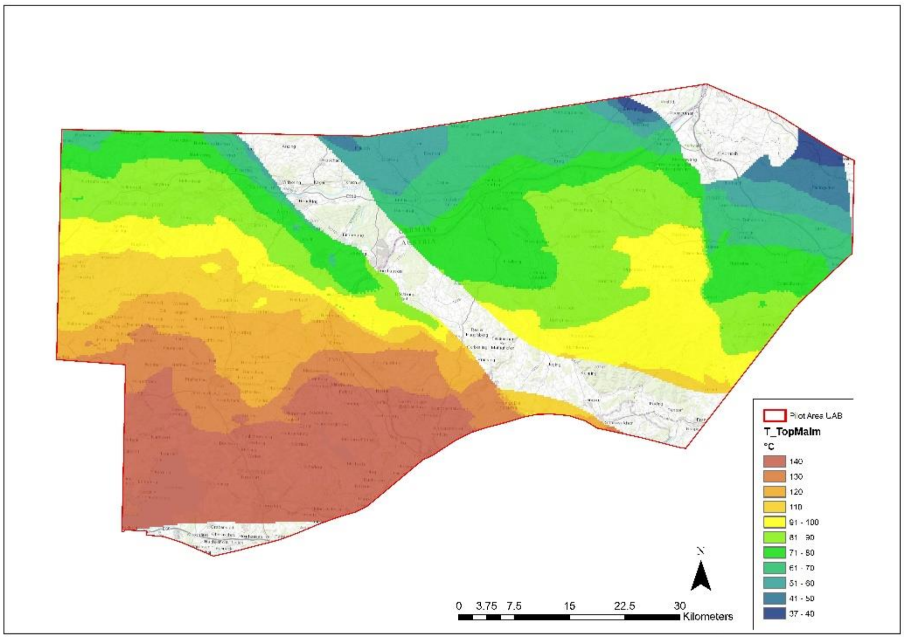


**Figure 6: Temperature map without Residuals for the Top of the Upper Jurassic formation in the pilot area UA/UB, as presented in the GeoMol Webmap-Service**

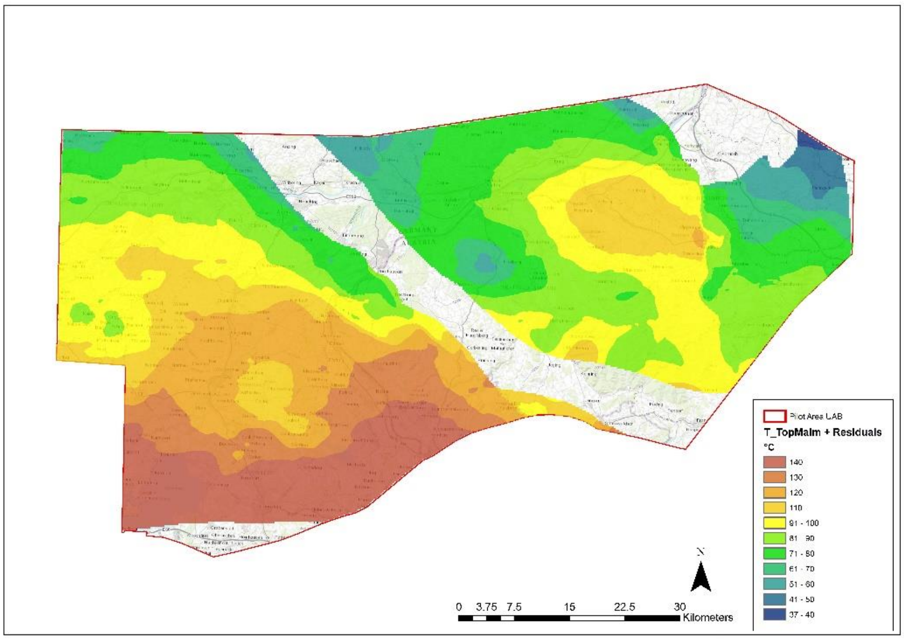


**Figure 7: Temperature map considering residuals for the Top of the Upper Jurassic formation in the pilot area UA/UB, as presented in the GeoMol Webmap-Service**

## SUMMARY

The project GeoMol provided a great opportunity to gather transnationally the available geological and thermal information and to build up an improved 3D underground model. Although most temperature measurements were acquired during hydrocarbon exploration and required data correction, the temperature model is corresponding quite well with observed measurements. Areas where the modelled temperature data was not corresponding with measured temperature represent regions with increased convective heat transport and were corrected using temperature residuals.

A numerical 3D model featuring conductive and convective heat transport is favorable, but will require improved understanding of the hydraulic characteristics of the aquifer. An improved understanding of the thermal parameters of the involved geological units, i.e. thermal conductivity, is also necessary for a better and more realistic temperature model.

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