MODELING STRATEGY OF A LARGE FIELD OF SHALLOW BOREHOLE HEAT EXCHANGERS

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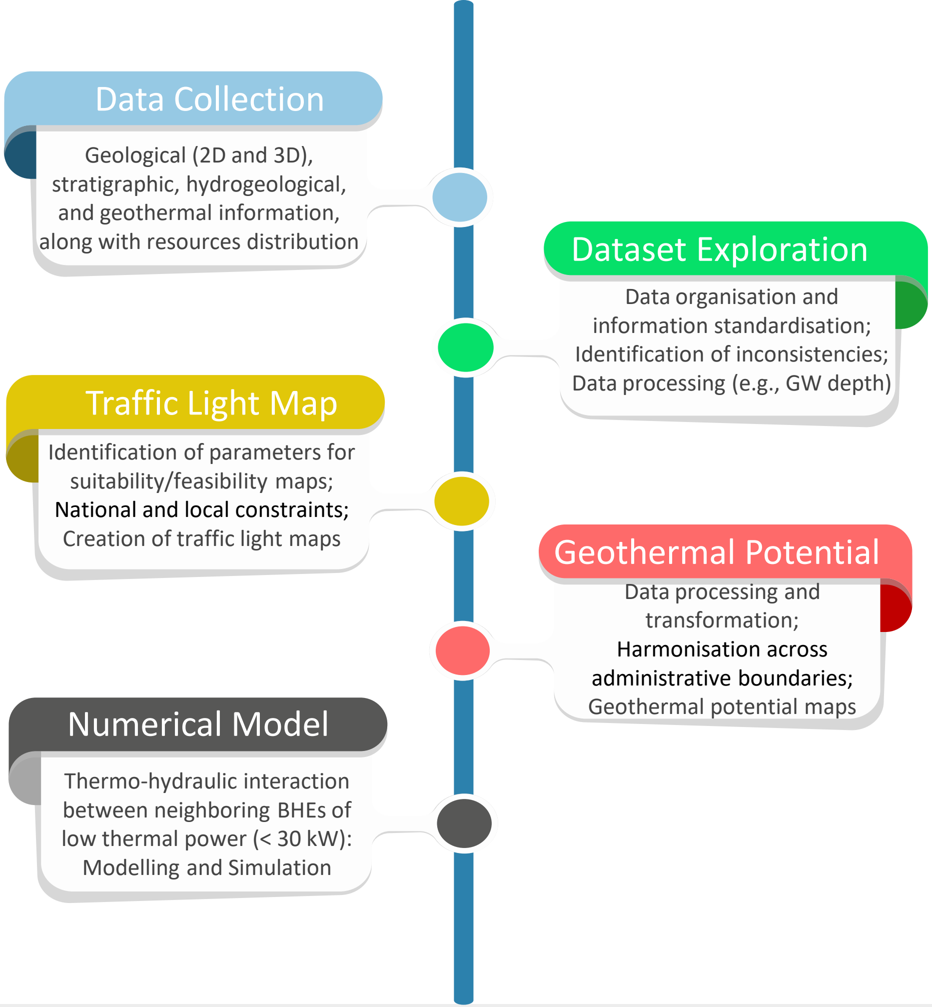
WärmeGut (UGOE)

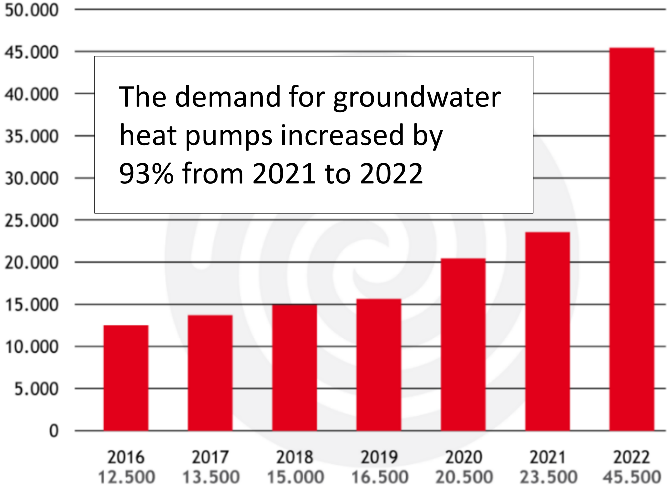
Today's talk

- ✓ Motivation & Problem definition
- ✓ Model setup (technical and geologic)
- ✓ Numerical experimental design
- ✓ Preliminary simulation results

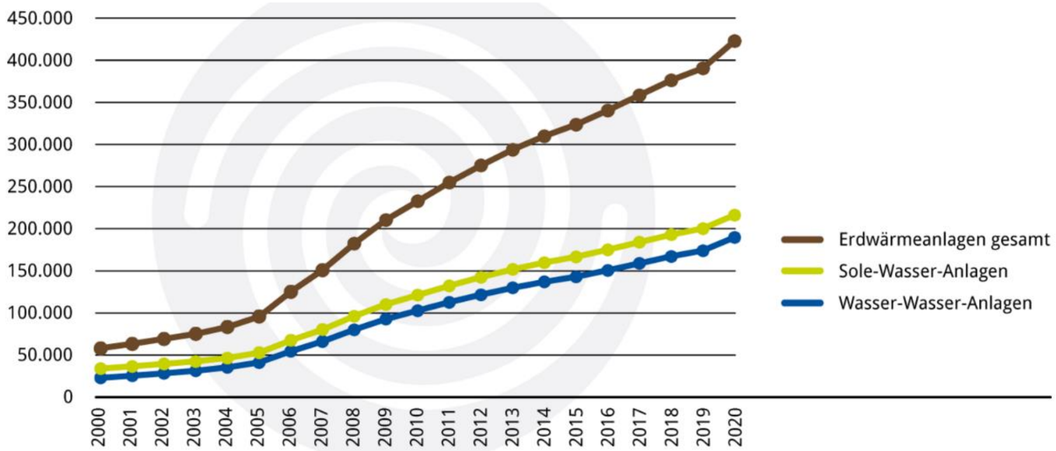


In the last decades, the utilization of shallow-geothermal energy in Germany has steadily risen

Geothermal heat pump sales from 2016 to 2022



Near-surface geothermal energy projects in Germany (number of heat pumps 2000-2020)



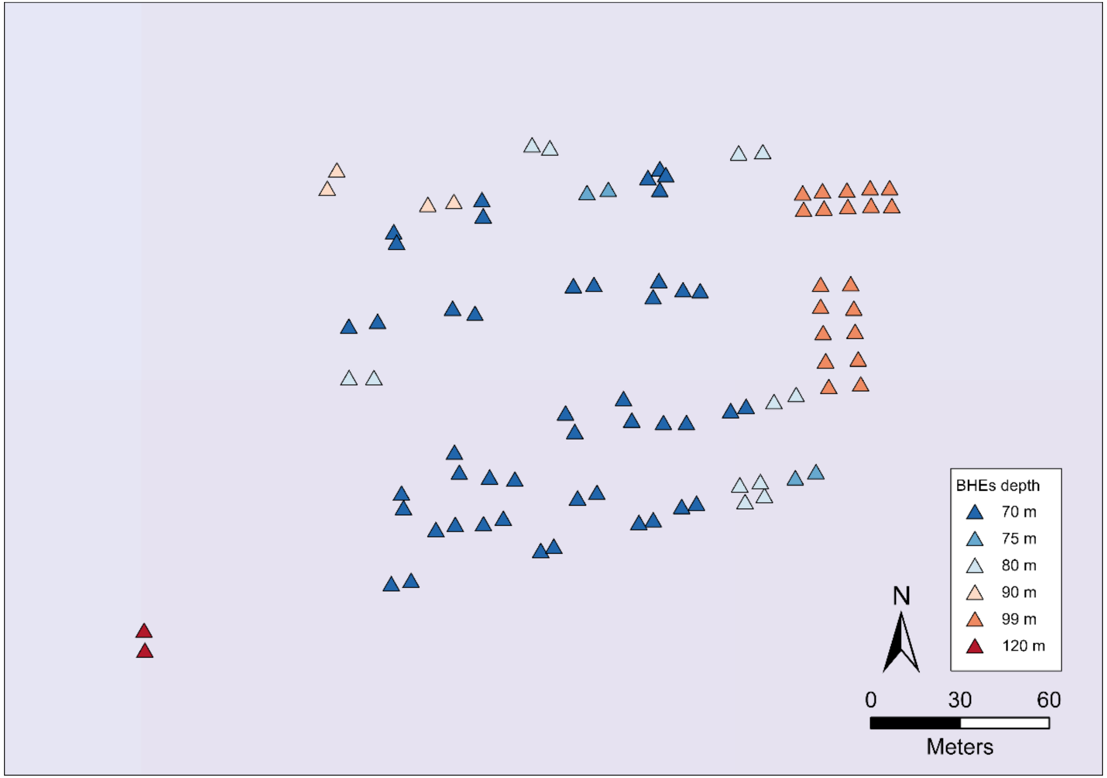
Bundesverband Wärmepumpe (BWP)

MOTIVATION

SHALLOW GEOTHERMAL INSTALLATIONS OF SMALL THERMAL POWER (<30KW) FOR SINGLE HOUSES AND GENERALLY SMALL-SCALE HEATING PURPOSES DO NOT REQUIRE DETAILED THERMAL-HYDRAULIC MODELLING BY STATE GEOLOGICAL SURVEYS IN GERMANY.

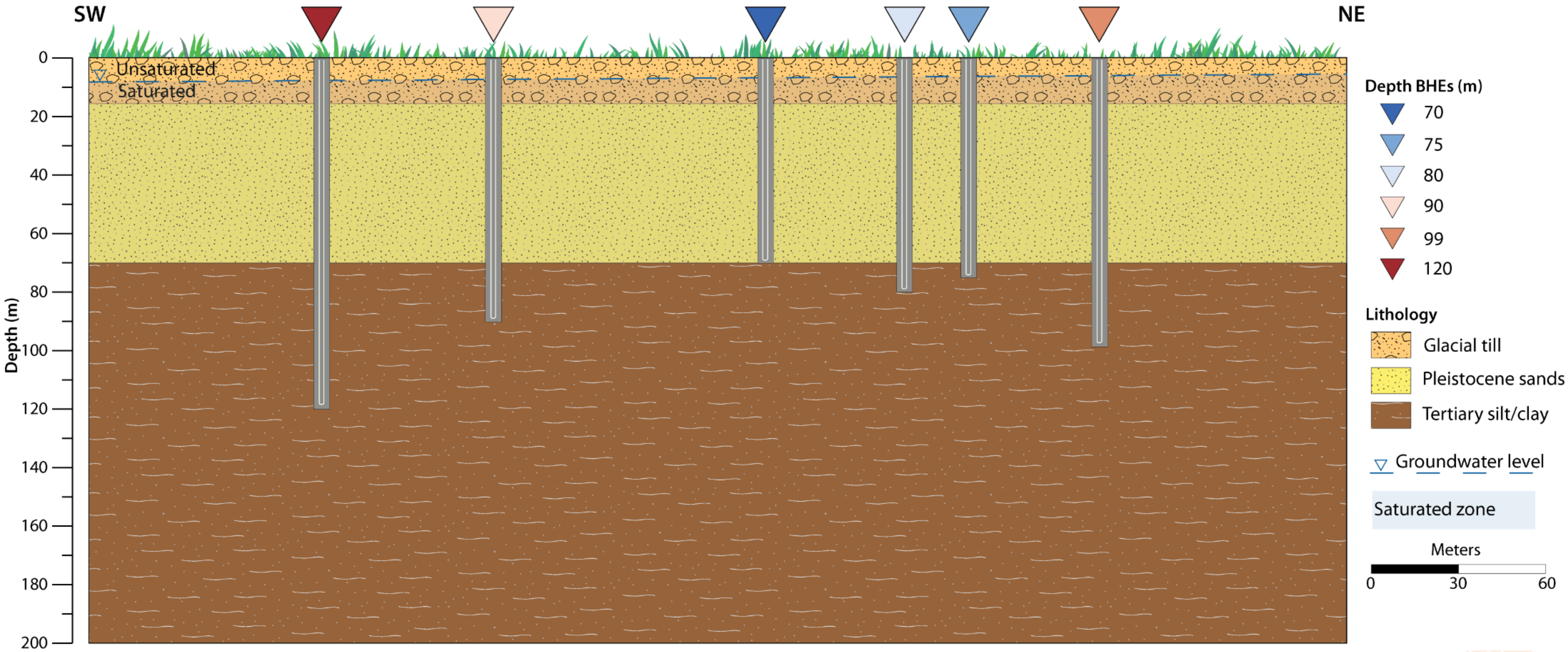
- WHAT ABOUT THE **LONG-TERM** THERMO-HYDRAULIC INTERACTION BETWEEN BHEs UNDER DIFFERENT GEOTHERMAL AND HYDROGEOLOGICAL CONDITIONS?
- WHAT ARE THE **CONTROLS ON THE LONG-TERM PERFORMANCE** OF SUCH FIELD OF INDIVIDUAL, SMALL-THERMAL-POWER BHE-UNITS?
- OPTIMIZATION?

Field of BHEs of small thermal power (< 30kW) - irregularly distributed

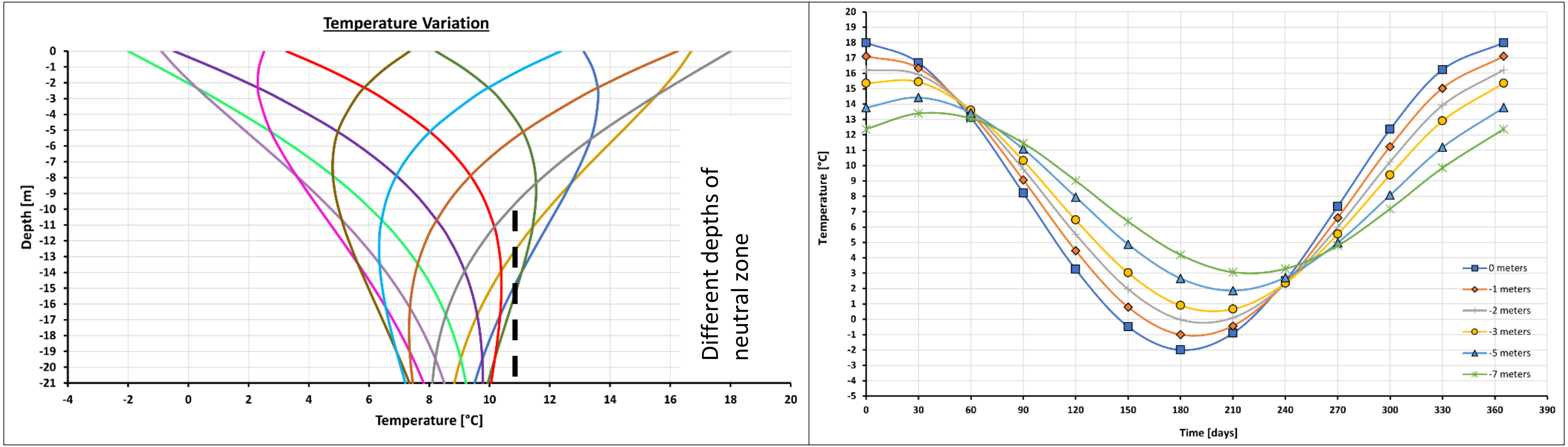


- **Collaboration with LBEG** (State Authority for Mining, Energy and Geology) in Lower Saxony
- Real field comprising 88 BHEs

VERTICAL PROFILE – IMPACT ON HYDRAULIC AND **THERMAL PROPERTIES**

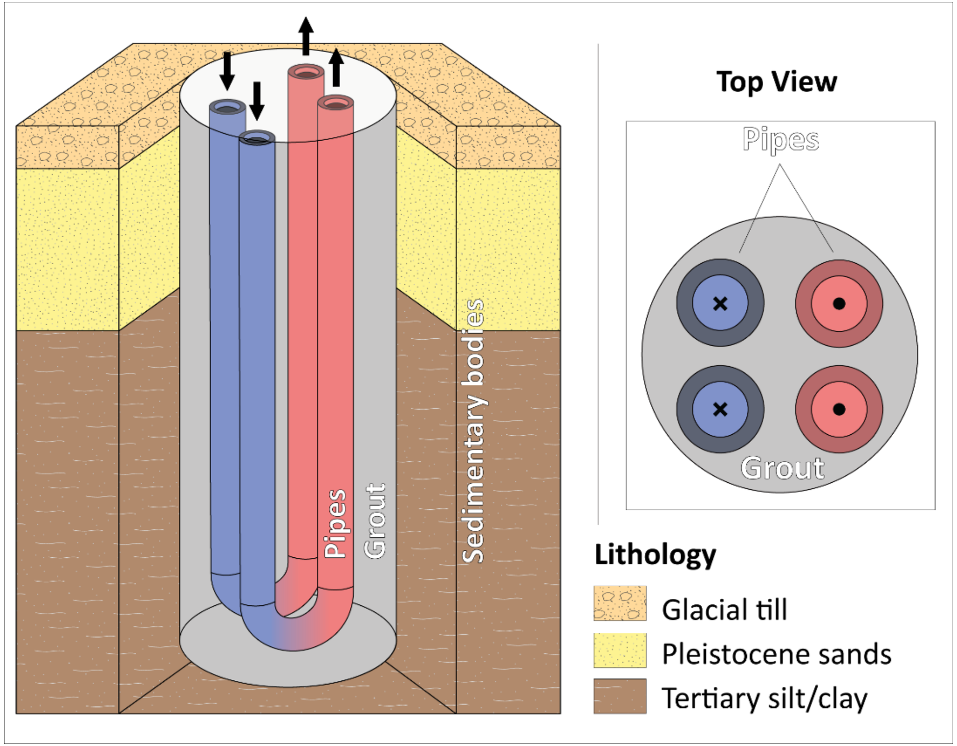


Geothermal – Theoretical Temperature distribution over depth and time



Different subsurface temperature scenarios

Model setup and physical processes



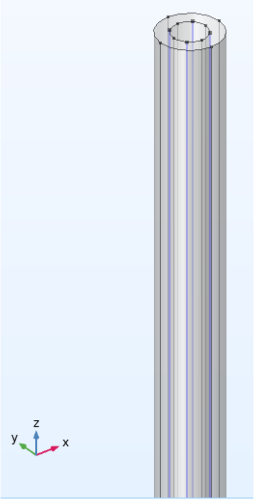
- Double U-tube pipe assemblage, high-density polythylene pipes
- Working fluid (mixture of water and 20-25% antifreeze) – pressurised to 2-3 bar
- Vertical borehole (cylinder) – Bentonite-cement mixture
- Porous material

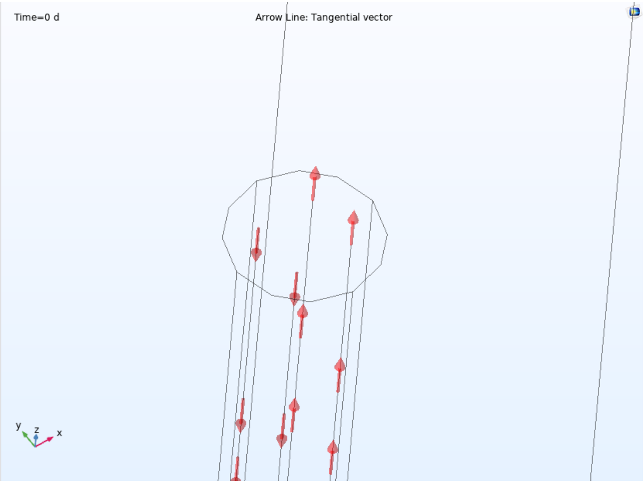
COMSOL MULTIPHYSICS – PROBLEM SETTING

- HEAT TRANSFER IN PIPES
- HEAT TRANSFER IN SOLIDS / POROUS MEDIA
- PIPE WALL HEAT TRANSFER (MULTIPHYSICS)
- DARCY LAW AND RICHARD‘S EQUATION
- UNCERTAINTY QUANTIFICATION AND OPTIMIZATION

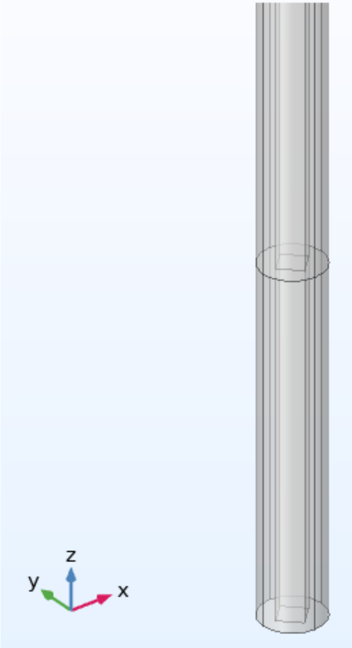
BUILDING THE BHEs- SELECTION OF INLET AND OUTLET TEMPERATURE IN COMSOL MULTIPHYSICS

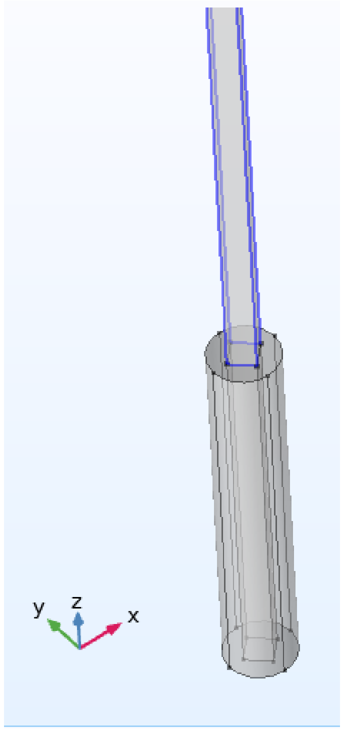
UPPER PART





LOWER PART



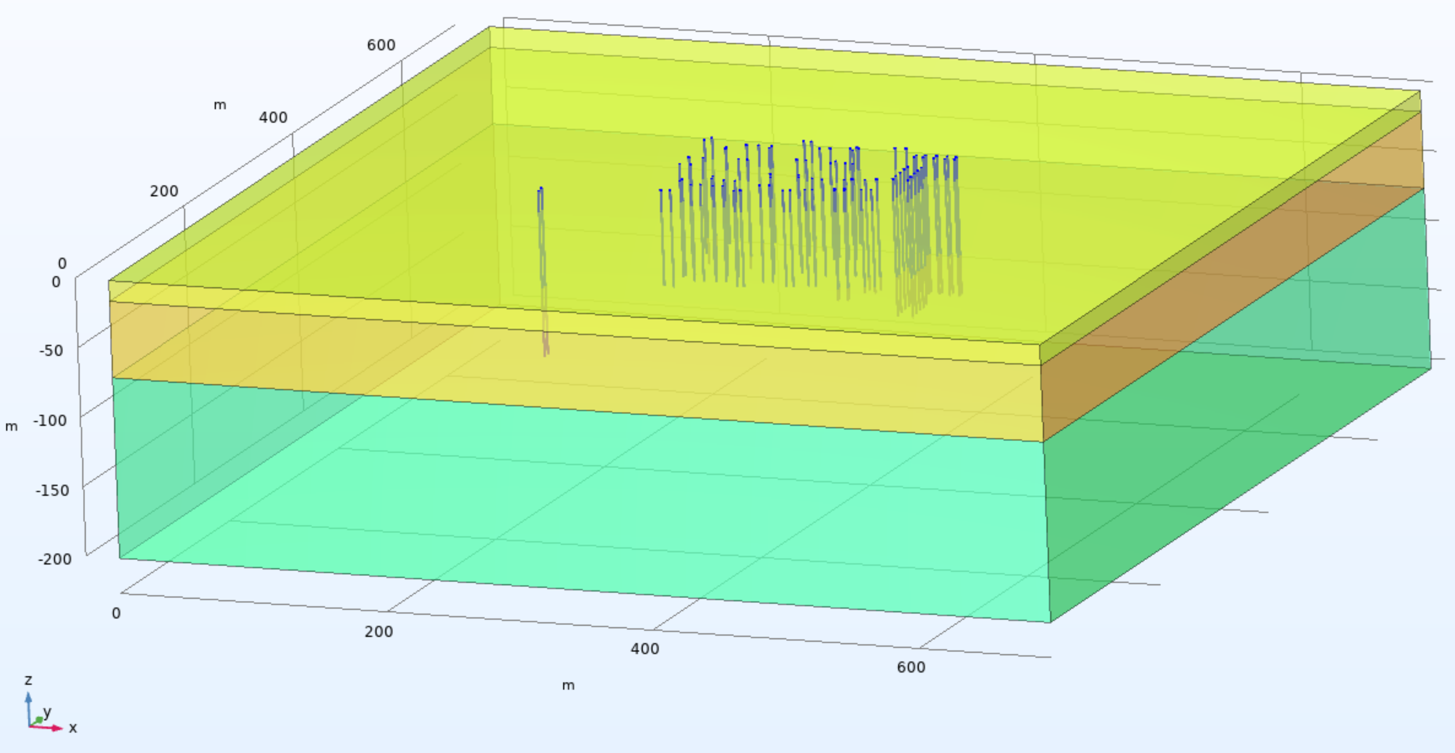


Automatisation of BHE construction and selections via coding

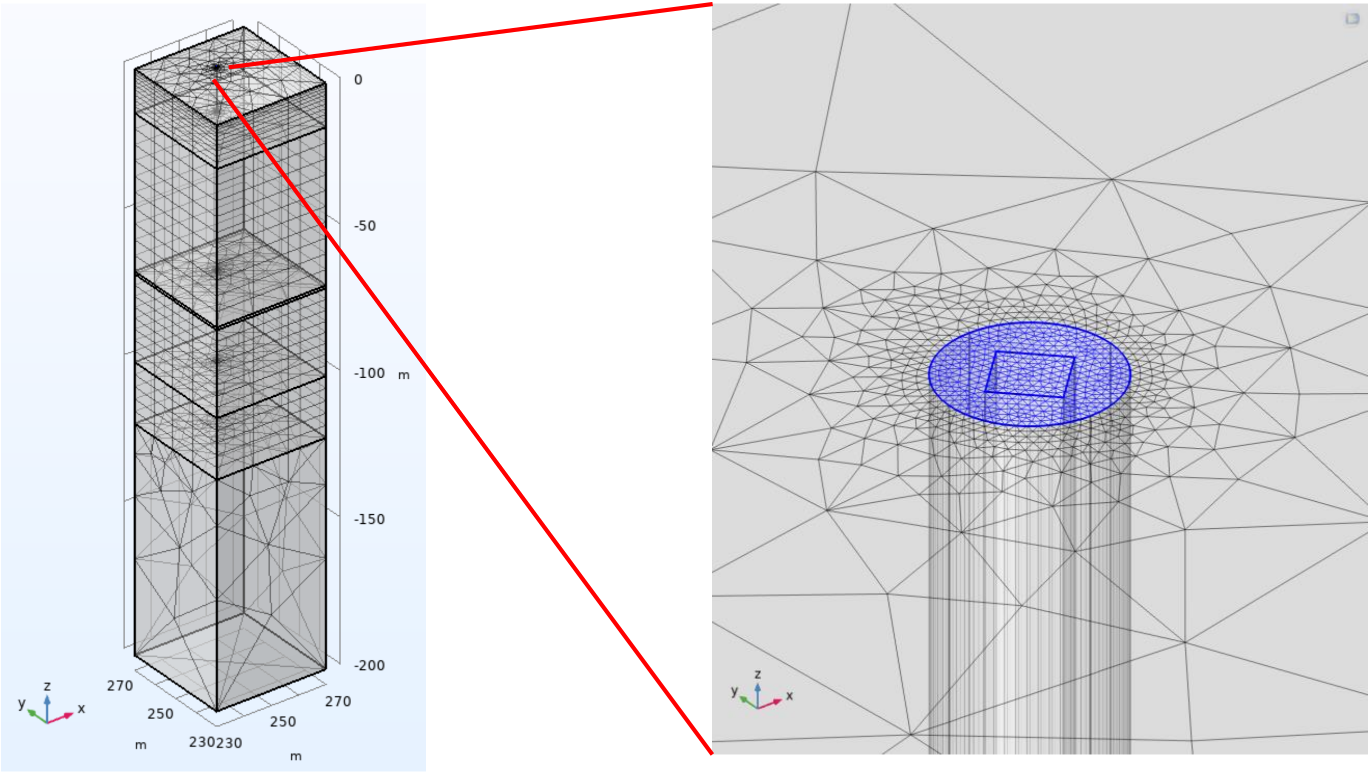
Preview | method2 | method3 | redefineSelections

```java
double[][] coord = readMatrixFromFile("PositionenundTiefen.prn");
int[] size = matrixSize(coord);
int N = size[0];

for (int i = 0; i < N; ++i) {

  double x = coord[i][0];
  double y = coord[i][1];
  double depth = coord[i][2];
  model.component("comp1").geom("geom1").create("pi"+i, "PartInstance");
  model.component("comp1").geom("geom1").feature("pi"+i).set("part",
                                                             "part1");
  // Input Parameter setzen:
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("inputexpr",
                                                                  "xPart", x);
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("inputexpr",
                                                                  "yPart", y);
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("inputexpr",
                                                                  "zPart", depth);

  //Selections einstellen
  model.component("comp1").geom("geom1").feature("pi"+i).set("selkeepnoncontr", false);
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("selkeeppnt", "pi"+i+"_sel1", true); //Explicit Selections für In/Outlets einzeln behalten
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("selkeeppnt", "pi"+i+"_sel2", true);

  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("selcontributetopnt", "pi"+i+"_sel1", "csel1"); //Explicit Selections aus PI in kumulative aus geom1 einfügen
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("selcontributetopnt", "pi"+i+"_sel2", "csel2");
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("selcontributetoedg", "pi"+i+"_sel3", "csel3");
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("selcontributetodom", "pi"+i+"_sel4", "csel4");
  model.component("comp1").geom("geom1").feature("pi"+i).setEntry("selcontributetobnd", "pi"+i+"_sel5", "csel5");
  model.component("comp1").geom("geom1").feature("pi0").setEntry("selcontributetoedg", "pi"+i+"_sel6", "csel6");


  //Create Operators
  model.component("comp1").cpl().create("outlet"+i+"_avg", "Average");
  model.component("comp1").cpl("outlet"+i+"_avg").selection().named("geom1_pi"+i+"_sel2"); //Explicit Selection aus PI
  model.nodeGroup("grp2").add("cpl", "outlet"+i+"_avg");
  model.component("comp1").cpl().create("outlet"+i+"_int", "Integration");
  model.component("comp1").cpl("outlet"+i+"_int").selection().named("geom1_pi"+i+"_sel2"); //Explicit Selection aus PI
  model.nodeGroup("grp3").add("cpl", "outlet"+i+"_int");

  //Set Variables
  model.component("comp1").variable().create("variables"+i);
  model.component("comp1").variable("variables"+i).selection().named("geom1_pi"+i+"_sel1"); //Explicit Selection aus PI

  model.component("comp1").variable("variables"+i).set("T_out", "outlet"+i+"_avg(T2)");
  model.component("comp1").variable("variables"+i).descr("T_out", "");

  model.component("comp1").variable("variables"+i).set("dT", "P_local/htp.Cp/Q_local");
  model.component("comp1").variable("variables"+i).descr("dT", "");

  model.component("comp1").variable("variables"+i).set("P_local", "localPower("+i+",t)");
  model.component("comp1").variable("variables"+i).descr("P_local", "");

  model.component("comp1").variable("variables"+i).set("Q_local", "outlet"+i+"_int(htp.A*htp.u*htp.rho)");
  model.component("comp1").variable("variables"+i).descr("Q_local", "");

  model.component("comp1").variable("variables"+i).set("T_in", "T_out+dT");
  model.component("comp1").variable("variables"+i).descr("T_in", "");

  model.nodeGroup("grp4").add("variable", "variables"+i);

}
```

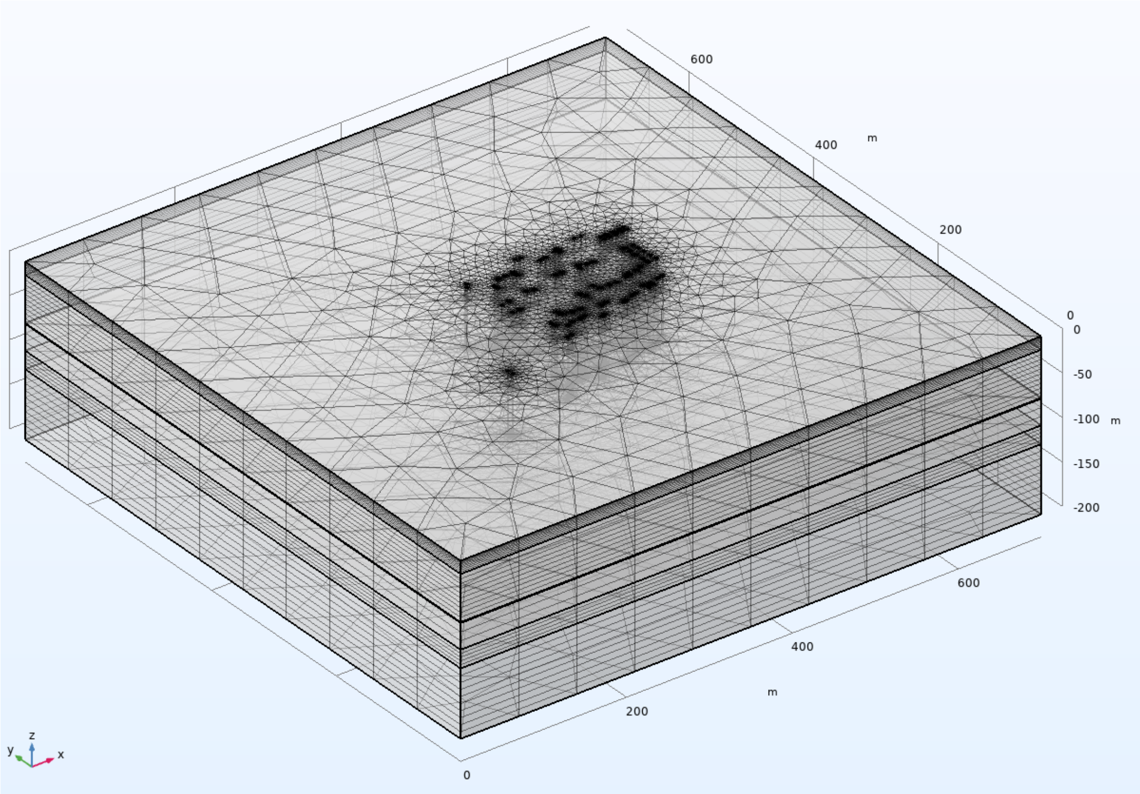
3-D IMPLEMENTATION IN COMSOL MULTIPHYSICS



Mesh studies to adequately represent heat transport mechanism

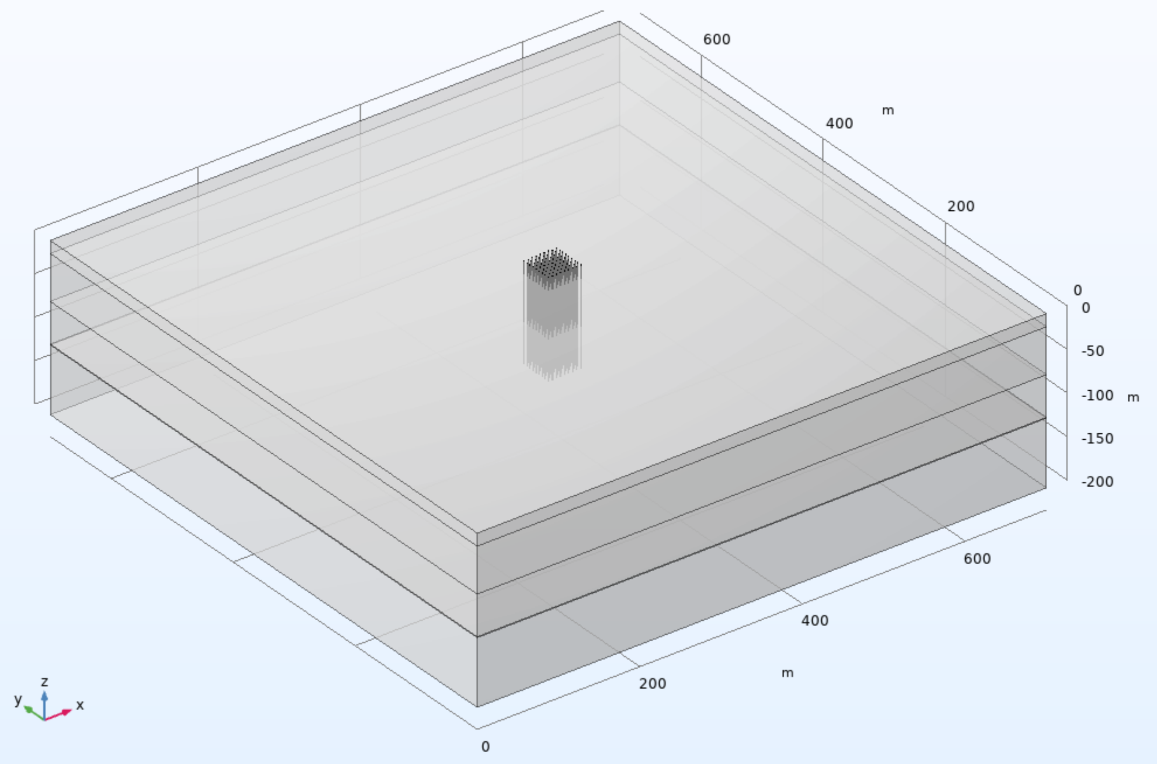


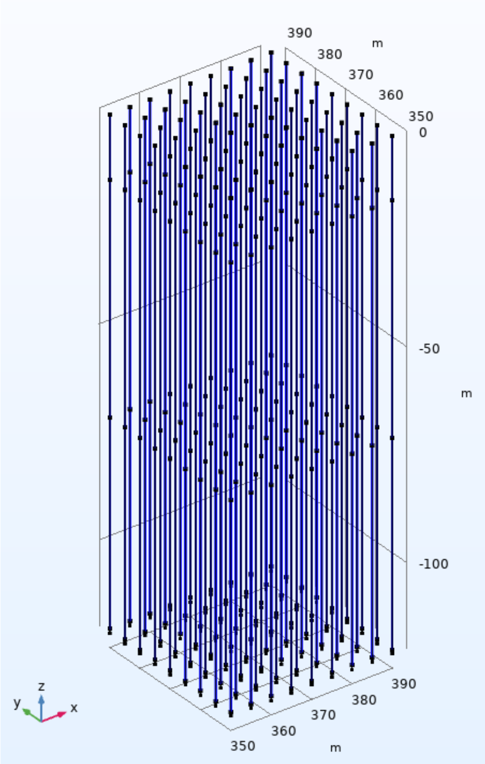
FINAL OPTIMIZED MESH



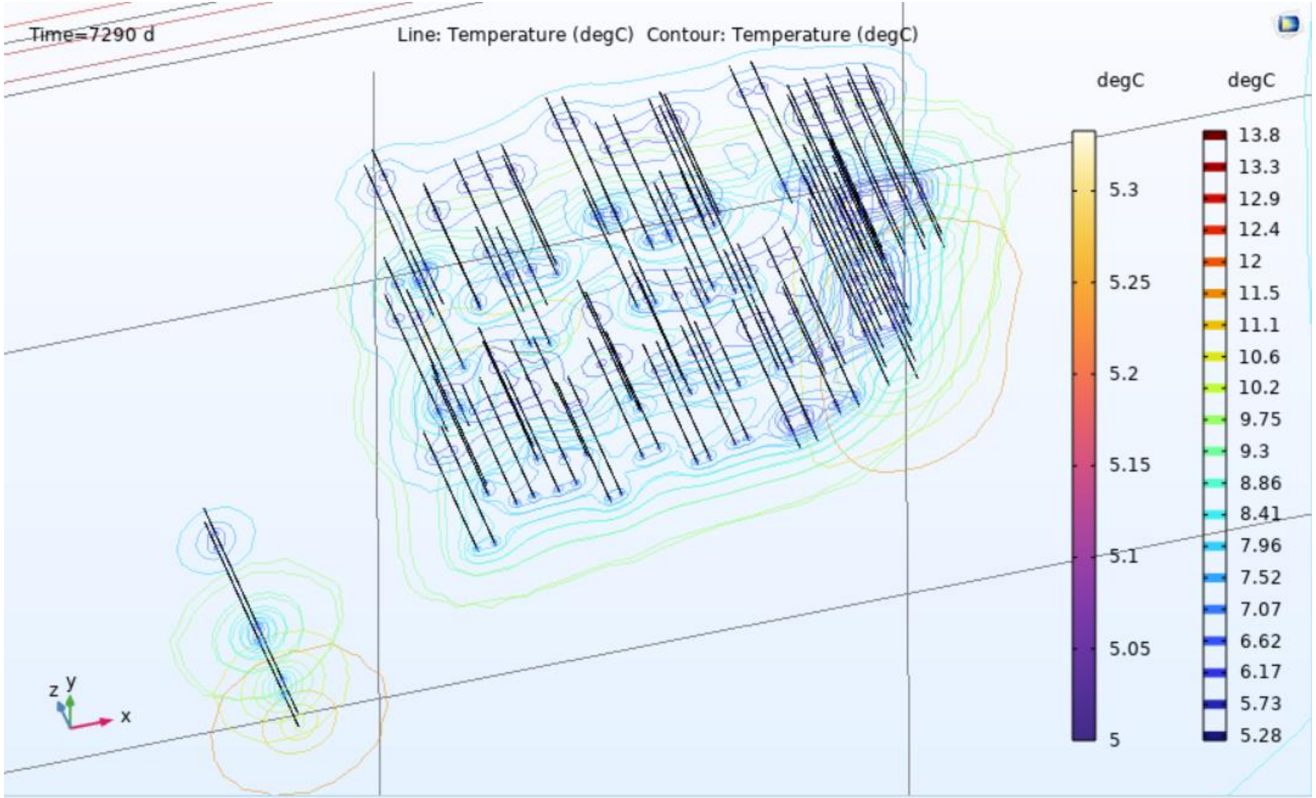
Mesh Elements	Statistics
Tetrahedra	250192
Pyramids	3746
Prisms	414440
Hexahedra	120
Triangles	77978
Quads	23384

Regularly distributed BHE array for optimization purposes

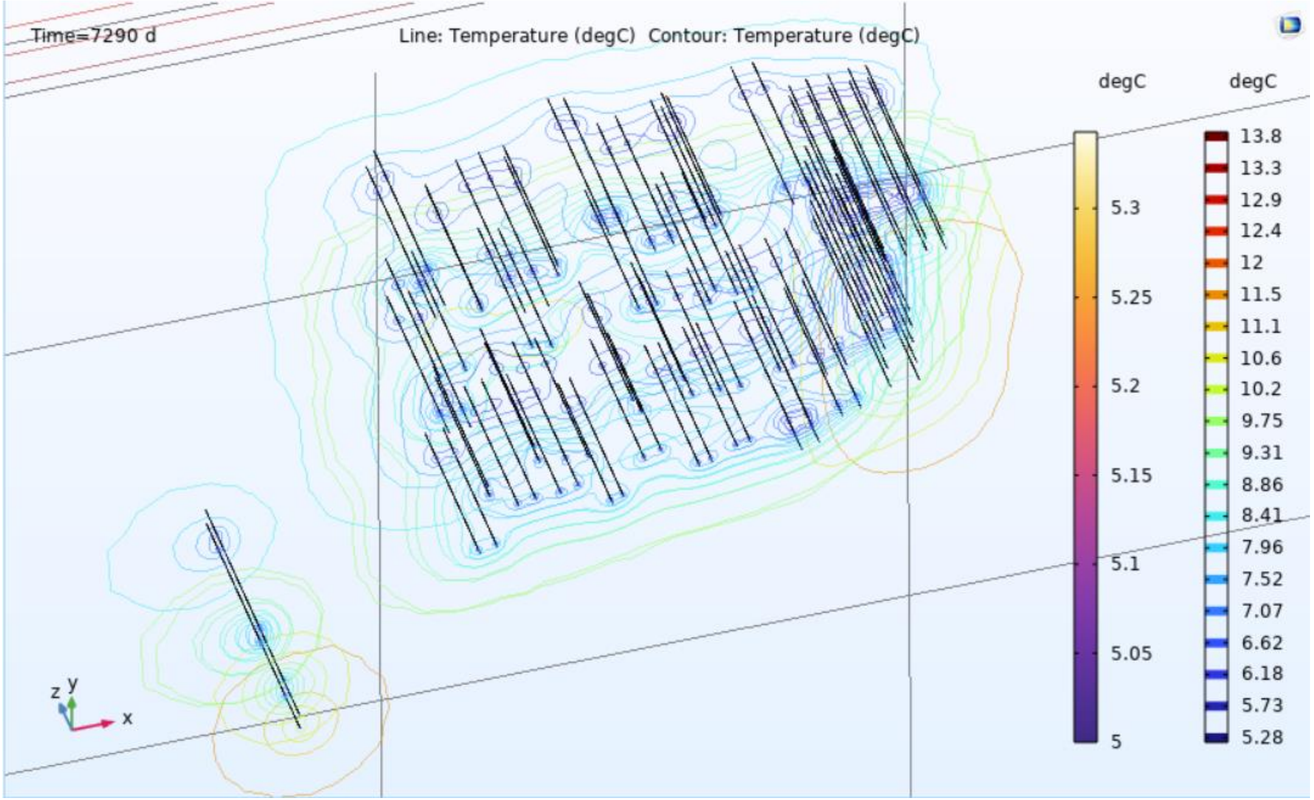




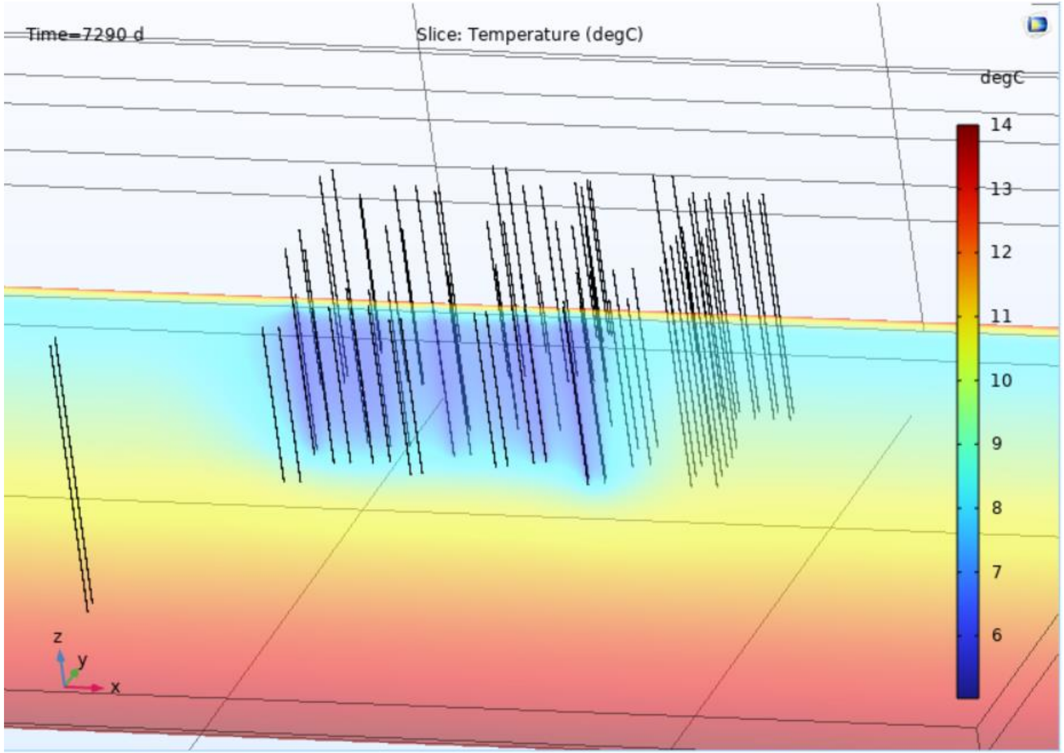
Area of thermal influence without groundwater flow



AREA OF THERMAL INFLUENCE WITH GROUNDWATER FLOW



Domain of thermal influence with groundwater flow



Summarizing Remarks & Outlook

- Several numerical experimental designs have been considered
- Detailed implementation of a complex, real field of individual BHEs under different geothermal and hydrogeological conditions
- Field of regularly distributed BHEs has been setup for optimization and geothermal potential assessment
- Preliminary simulation results show long-term thermo-hydraulic performance of real field of low-thermal-power BHEs
- Future consideration of cyclic recharge and fluctuation of water table
- Upscaling to large regions in Germany

Thank you for your attention!

WärmeGut

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