A Dynamic Three-Dimensional (3D) Numerical Borehole Heat Exchanger (BHE) Model

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Applications of BHEs Models

1. To design of BHEs
2. To analyze in-situ ground thermal conductivity test data
3. To integrate with building system simulation

Limitations of Existing Models

- Lack of detailed representation of BHE
- Variations in fluid temperature with depth cannot be considered explicitly in 2D models: assumptions have to be made to associate inlet and outlet temperatures with borehole temperatures
- Transient transport of the fluid and thermal mass of the fluid are neglected in all models

Model Development – GEMS3D

Built upon a finite volume solver – General Elliptical Multi-block Solver in 3 Dimensions (GEMS3D)

Partial Differential Equation for Heat Transfer

$$\frac{\partial T}{\partial t} + u_j \frac{\partial T}{\partial x} = \frac{\partial}{\partial x}\left(\frac{k}{\rho c_p}\frac{\partial T}{\partial x}\right) + S$$

where u_j: velocity

k: thermal conductivity

ρc_p: volumetric heat capacity

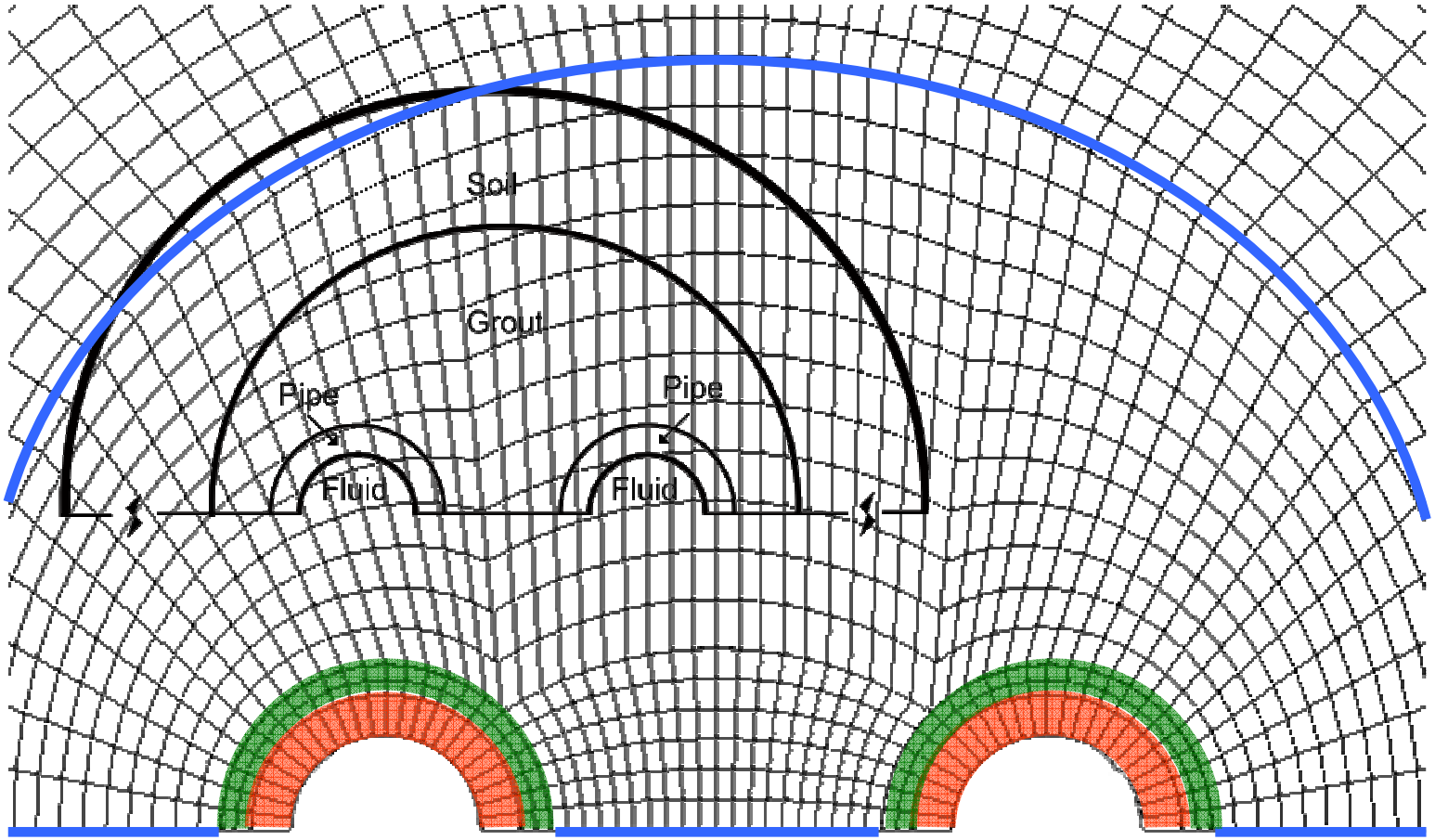
S: source term

$|u_j| > 0$ in fluid cells

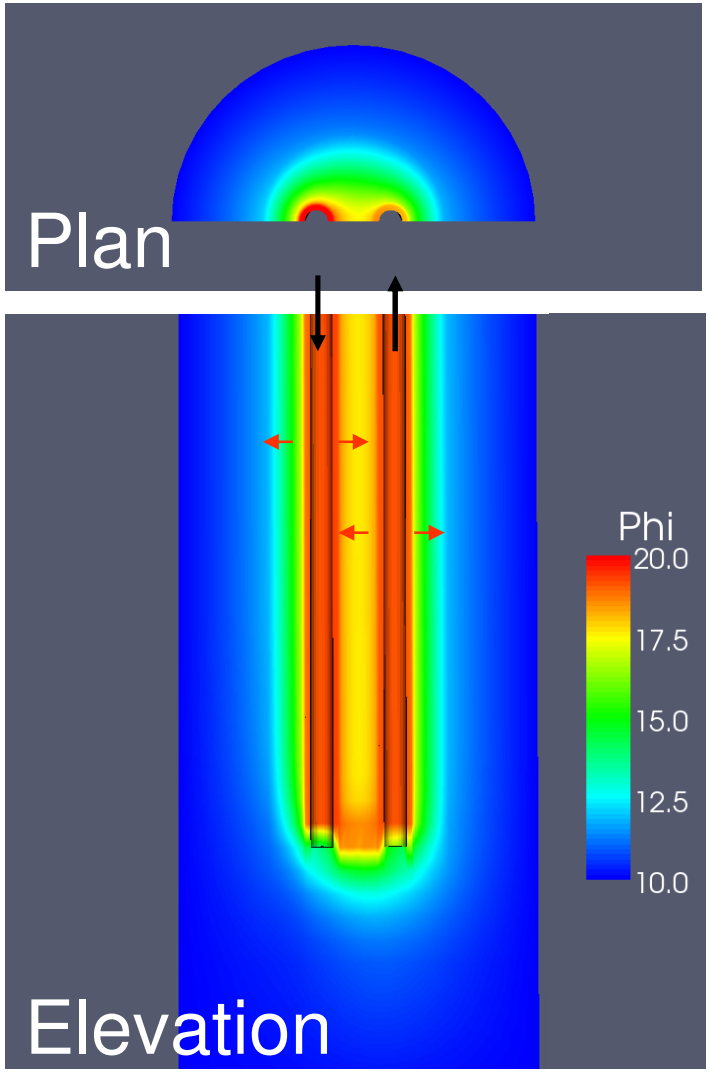
$|u_j| = 0$ else where

Model Development – Mesh

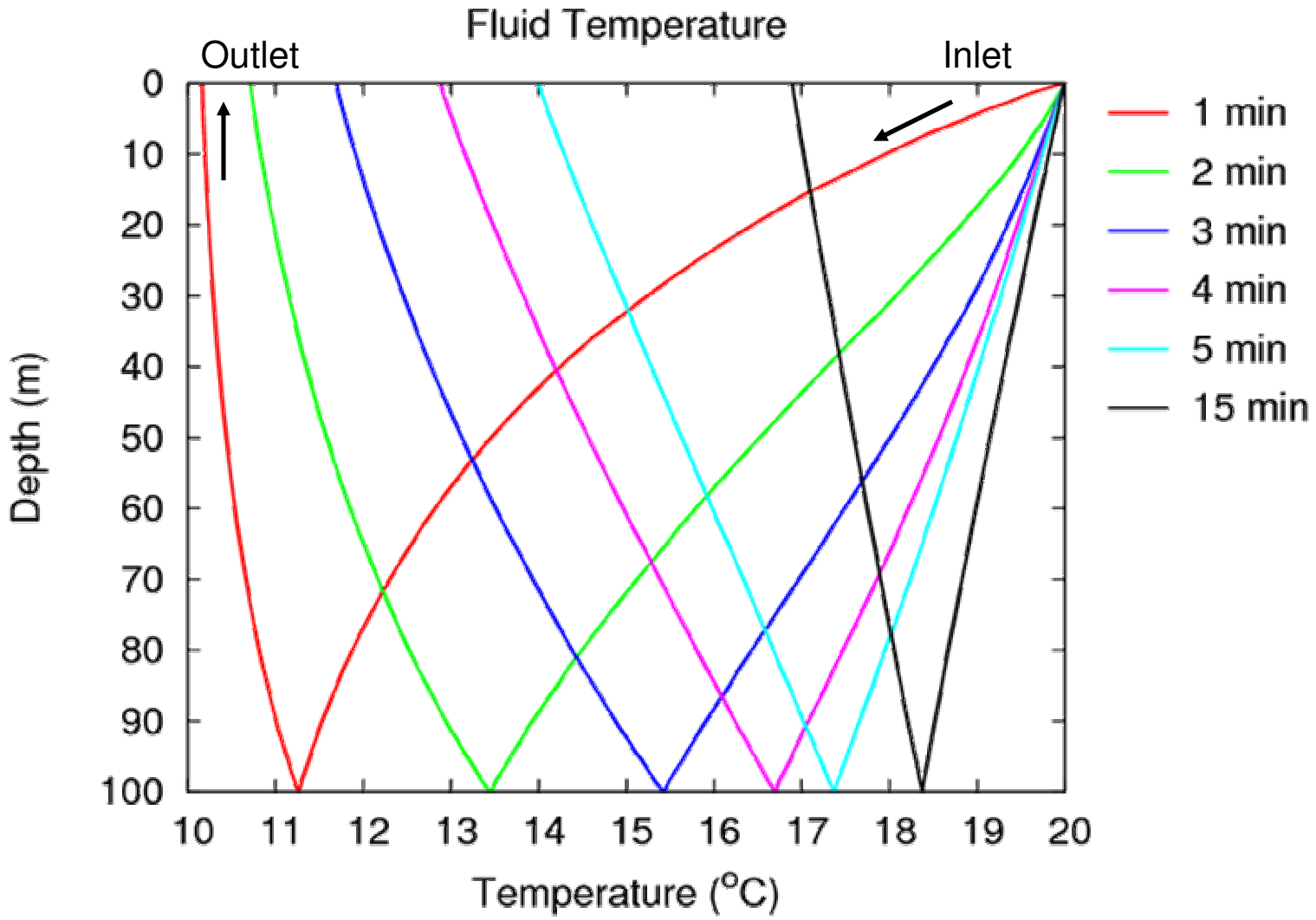
Multi-block structured boundary fitted mesh



GEMS3D Visualization - ParaView

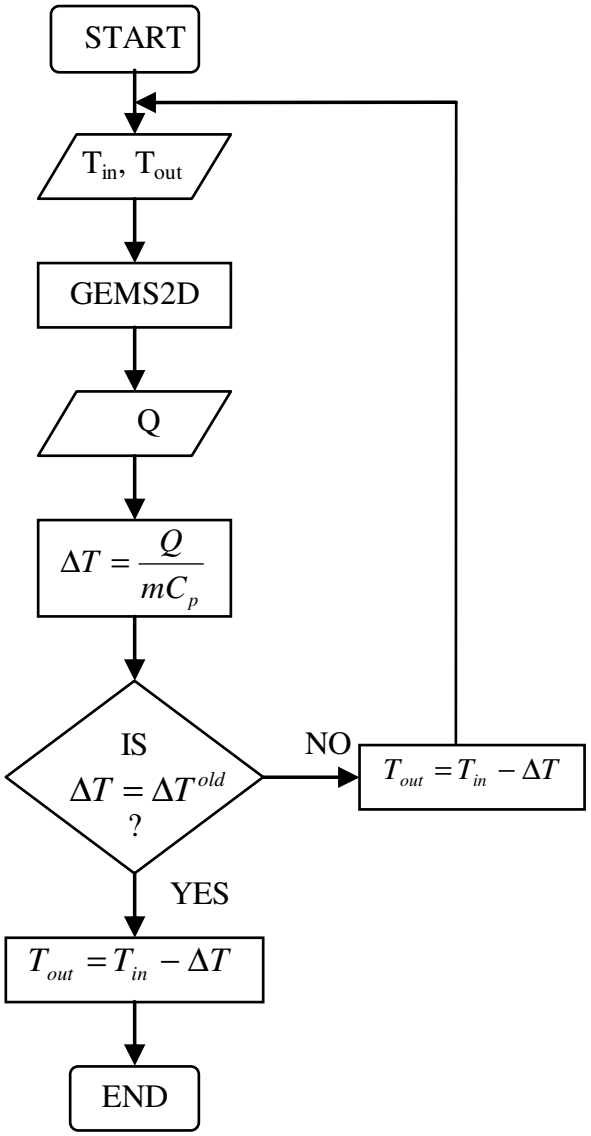


Fluid Temperature along the Depth



A 2D Model Development

- Equivalent to GEMS3D model of one cell depth
- One pipe assumed to be the inlet; the other pipe assumed to be the outlet
- The outlet temperature calculated by iteration to reach the energy balance of the borehole



Outlet Temperature 2D & 3D

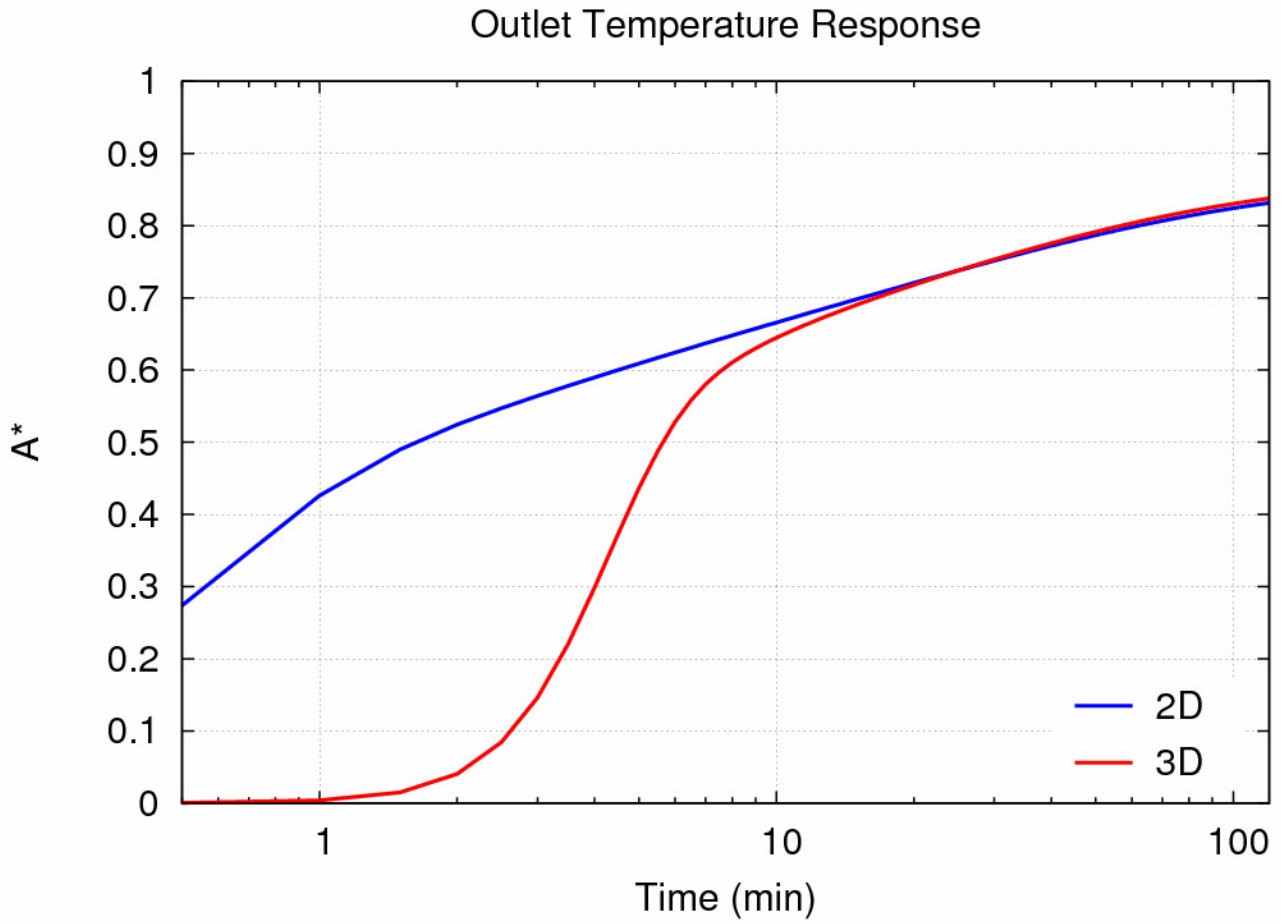
$$A^* = \frac{T_{out} - T_0}{T_{in} - T_0}$$

where

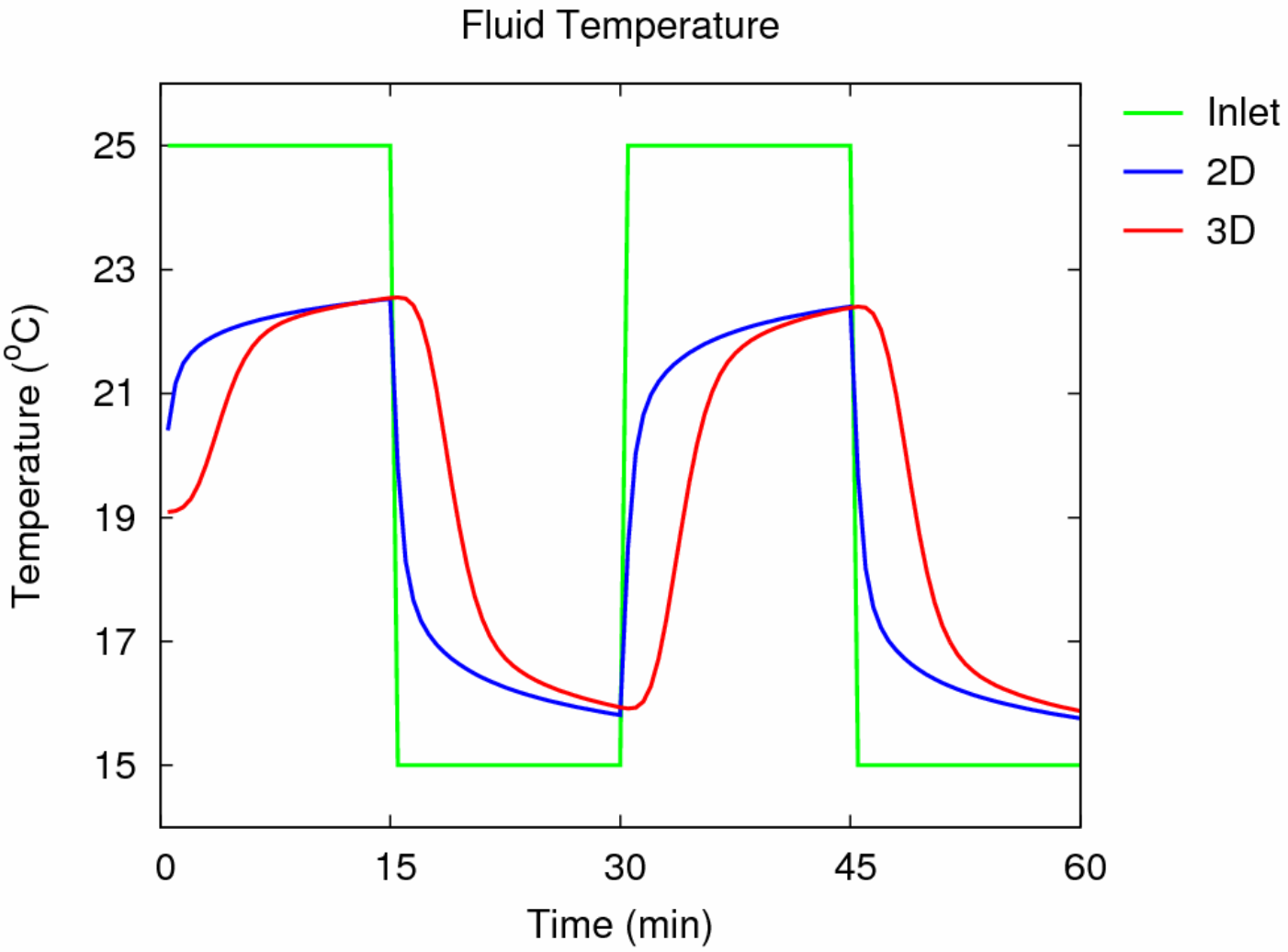
T_{in}: inlet temp

T_{out}: outlet temp

T_0: initial temp



Outlet Temperature 2D & 3D

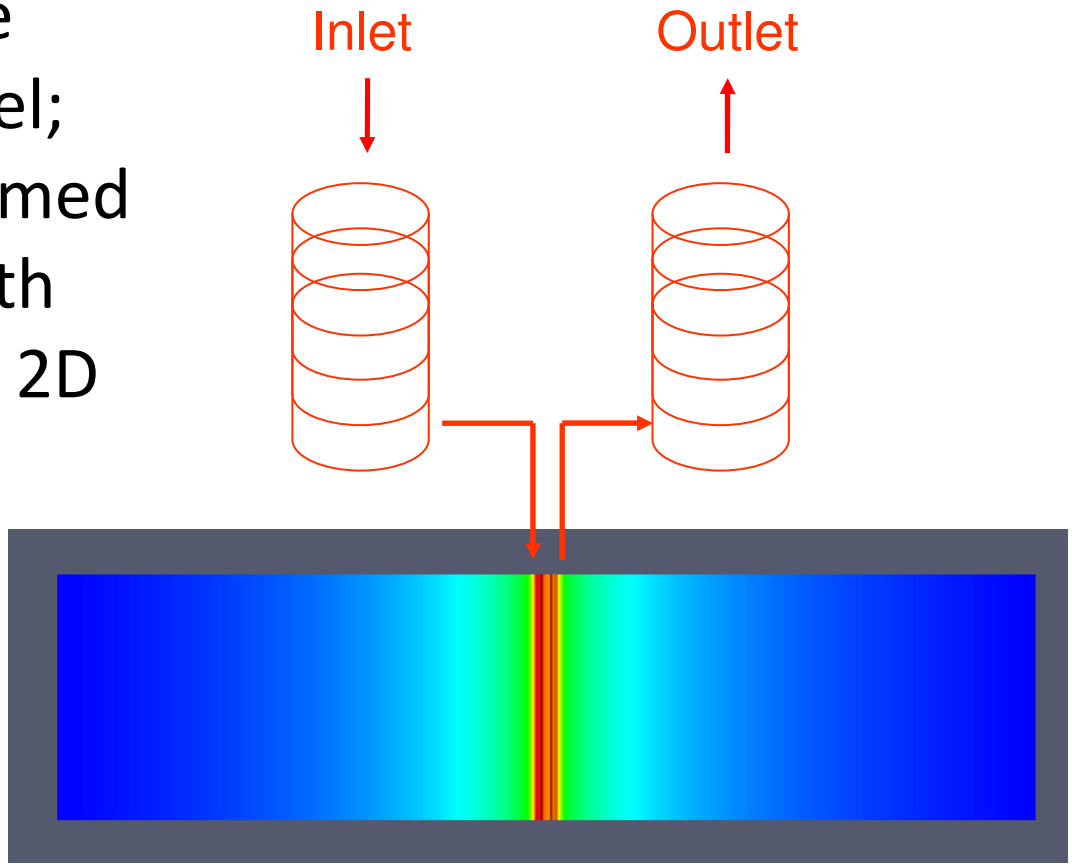


Advantages of a 3D Model – GEMS3D

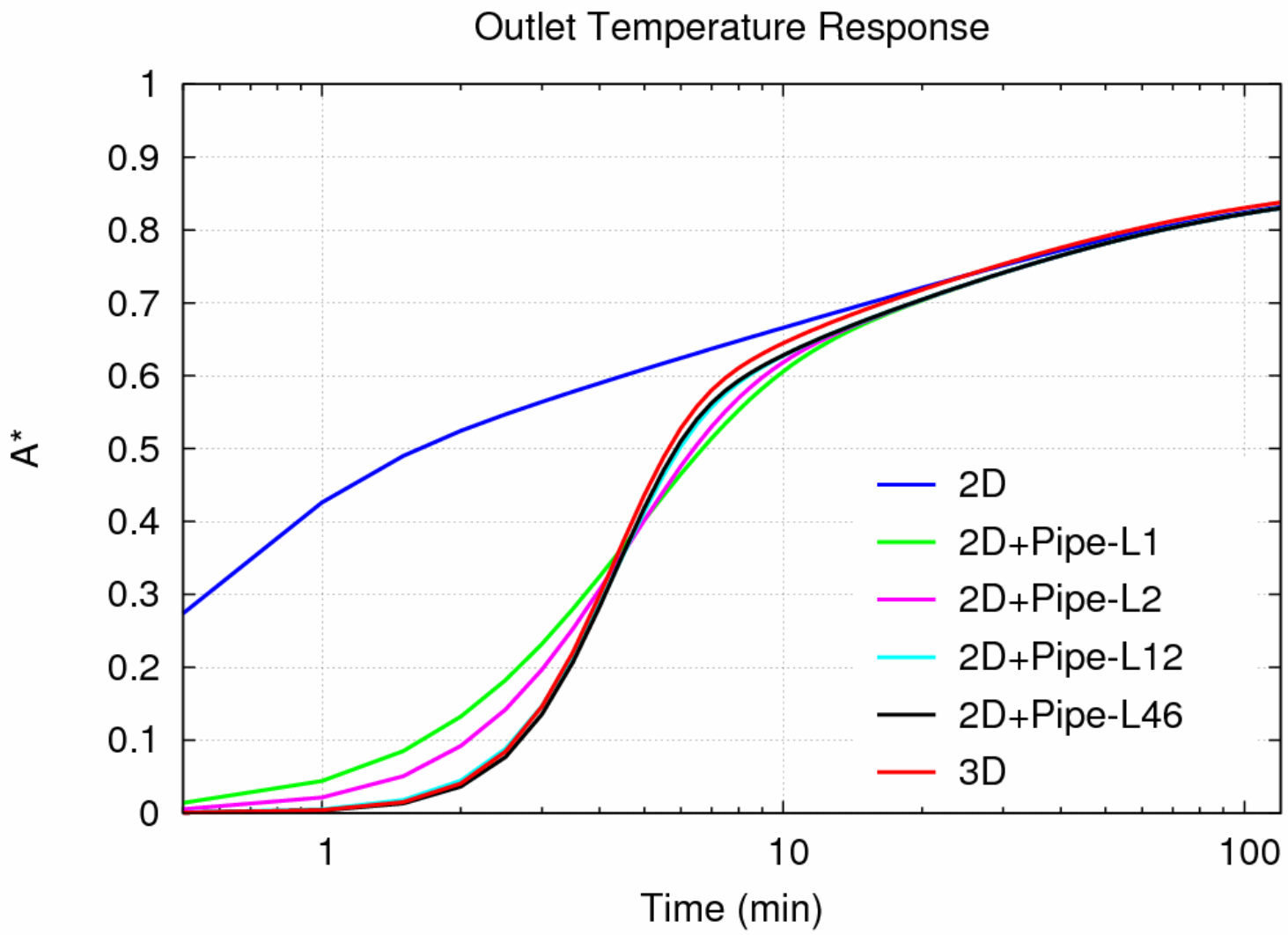
- Simulate dynamics of fluid transport along pipe loop
- Apply various boundary conditions at surface
- Impose initial vertical ground temperature gradients
- Simulate different layers of rock and soil
- Obtain temperature distribution along borehole depth (fluid, borehole and ground)
- Examine heat transfer below borehole

Model Improvement – 2D + Pipe Model

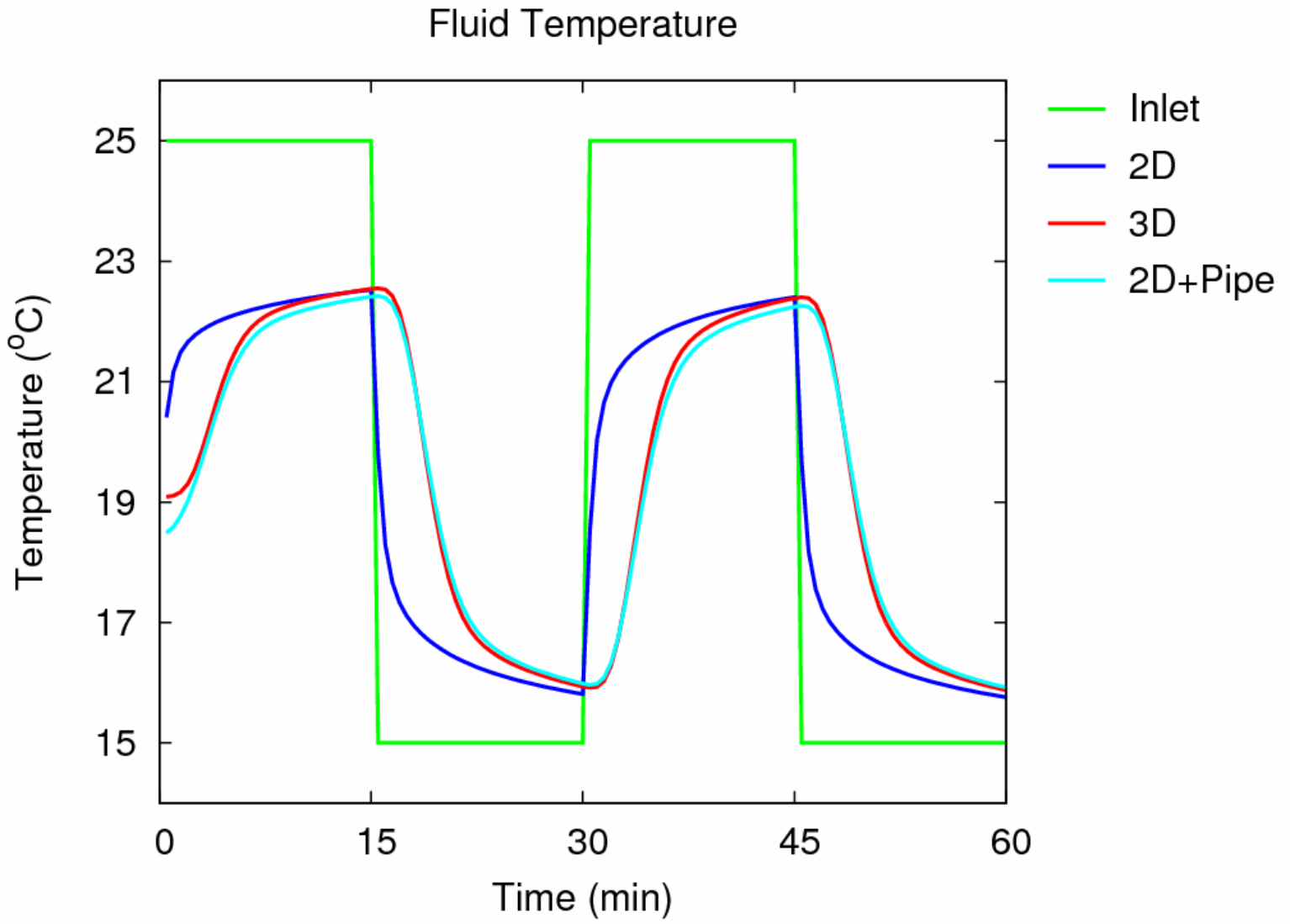
- Two external pipes, one assumed to be connected with one pipe in the 2D model; the other pipe assumed to be connected with another pipe of the 2D model
- Same numerical method as the 2D model



Outlet Temperature – 2D + Pipe Model



Outlet Temperature – 2D + Pipe Model



Summary

- Development of a dynamic three-dimensional numerical model for BHEs
- Investigation of dynamics of fluid transport and transient response of a BHE
- Delayed response associated with fluid transport along pipe loop
- Improvement of a two-dimensional model