EGU22-11934
https://doi.org/10.5194/egusphere-egu22-11934
EGU General Assembly 2022

Numerical modelling of Aquifer Thermal Energy Storage systems with Surface-Based Geologic modelling and Dynamic Mesh Optimisation

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Aquifer Thermal Energy Storage (ATES) has significant potential to provide large-scale seasonal cooling and heating in the built environment, offering a low-carbon alternative to fossil fuels. To deliver safe and sustainable ATES deployments, accurate numerical modelling tools must be used to predict flow and heat transport in the targeted aquifers. However, numerical simulation of ATES systems is very challenging, due to the associated high computational cost of capturing fluid flow and heat transport at a high resolution and importance of accurately modelling complex geological heterogeneity.

Here, we present a novel approach to simulate ATES, based on the use of surface-based geologic models (SBGM), a double control-volume finite element method, and unstructured tetrahedral meshes with dynamic mesh optimisation (DMO). Previous use of DMO for a range of porous media flow applications has allowed an important reduction in the cost of numerical simulations. DMO allows the resolution of the mesh to vary over time and space to satisfy a user-defined solution precision for selected fields, refining where the solution fields are complex and coarsening elsewhere. SBGM allows accurate representation of complex geological heterogeneity and efficient application of DMO, essential for accurate simulation of ATES without excessive computational cost.

We demonstrate application of these methods in two low-temperature ATES scenarios: a homogeneous aquifer, and a heterogeneous fluvial aquifer containing meandering, channelised sandbodies separated by mudstones. For both cases, cold and warm water are injected alternatively over 6-month periods via a well doublet. We demonstrate that DMO reduces the required number of mesh elements by a factor of up to 22 and simulation time by a factor of up to 15, whilst maintaining the same accuracy as an equivalent fixed mesh. DMO significantly reduces the computational cost of ATES simulations in both homogeneous and heterogeneous aquifers. This offers significant advantages compared to conventional methods in assessing the impact of uncertain geologic heterogeneity on ATES operation and efficiency, and in optimising individual and multiple ATES deployments.