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Coupled permafrost-groundwater simulation applied to a spent fuel nuclear waste repository

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The Olkiluoto spent nuclear fuel repository in Eurajoki, Finland, is the first one on the planet that will go operational in foreseeable future. The long-term safety of this repository with respect to future ice-age conditions and the consequently occurring permafrost and altered groundwater flow conditions needs to be evaluated. To this end, a Darcy model for saturated aquifer groundwater flow combined with a heat transfer module accounting for phase change (i.e. freezing) as well as a solute and a bedrock deformation model have been implemented in the multi-physics Finite Element Method code Elmer. The set of equations is based on continuum thermo-mechanic principles. The application of this newly developed model to Olkiluoto aims to simulate the evolution of permafrost thickness, talik development, and groundwater flow and salinity changes at and around the repository during the next 120,000 years. This is achieved by solving the aforementioned model components in a coupled way in three dimensions on the mesh that discretizes a rectangular block of 8.8 km by 6.8 km, stretching from the surface of Olkiluoto down to a depth of 10 km, where a geothermal heat flux is applied. The horizontal resolution of 30 m by 30 m in combination with – imposed by the thickness of different temporarily varying soil and rock layers imported from high resolution data - vertical resolutions of down to 10 cm result in a mesh containing 5 million nodes/elements on which the system of equations is solved using CSC's HPC cluster mahti. The high spacial gradients in permeability (e.g. from soil to granitic bedrock) impose numerical challenges for the simulations that are forced by RCP 4.5 climate scenario. The investigated time-span contains cold periods between AD 47,000 and AD 110,000. Surface conditions are provided using freezing/thawing n-factors based on monthly temperature variations and wetness index defining varying conditions of vegetation. Our scenario run is able to project permafrost development at high spatial resolution and shows clear impact of permeable soil layers and faults in the bedrock that focus groundwater flow and solute transport.