The InterFrost benchmark of Thermo-Hydraulic codes for cold regions hydrology – first inter-comparison results

Christophe Grenier (1), Nicolas Roux (1), Hauke Anbergen (2), Nathaniel Collier (3), Francois Costard (4), Michel Ferry (5), Andrew Frampton (6), Jennifer Frederick (7), Johan Holmen (8), Anne Jost (9), Samuel Kokh (10), Barret Kurylyk (11), Jeffrey McKenzie (12), John Molson (13), Laurent Orgogozo (14), Agnès Rivière (15), Wolfram Rühaak (16), Jan-Olof Selroos (17), René Therrien (13), and Patrik Vidstrand (17)

(1) LSCE (CNRS - CEA - UVSQ), LSCE, Gif sur Yvette, France (christophe.grenier@lsce.ipsl.fr), (2) Frank GeoConsult GmbH, Hamburg, Germany, (3) ORNL Climate Change Science Institute, One Bethel Valley Road, PO BOX 2800, MS-6301, Oak Ridge, TN 37831-6301, (4) GEOPS, UMR 8148 CNRS – Université Paris Sud, 91405 Orsay Cedex, France, (5) MFRDC, 6 rue de la Perche 44700 Orvault, France, (6) Department of Quaternary Geology and Physical Geography, Stockholm University, Stockholm, Sweden, (7) Desert Research Institute, Division of Hydrologic Sciences, 2215 Raggio Parkway Reno, NV 89512, (8) Golder Associates Kapellgrund 7, 11625 Stockholm, Sweden, (9) METIS, UMR 7619, Sorbonne Universités, UPMC Univ. Paris 6, 75005 Paris, France, (10) Maison de la Simulation USR 3441, Bâtiment 565 - Digiteo - PC 190, CEA Saclay, 91191 Gif-sur-Yvette cedex, France, (11) Department of Geoscience, University of Calgary, ES118, 2500 University Drive NW, Calgary, AB, T2N 1N4, Canada, (12) Department of Earth and Planetary Sciences, McGill University, 3450 University Street, Montreal, PQ, Canada H3A 0E8, (13) Département de géologie et de géologie géologique, Université Laval, 1065 avenue de la Médecine, Québec, Canada, G1V 0A6, (14) GET, UMR 5563 CNRS-IRD-UPS, Université Toulouse, 14 avenue Edouard Belin, 31400 Toulouse, France, (15) MINES ParisTech - Centre de Géosciences, 35 rue Saint Honoré 77305 Fontenay-sous-Bois, France, (16) Darmstadt Graduate School of Excellence Energy Science and Engineering, Technische Universität Darmstadt, Germany, (17) Swedish Nuclear Fuel and Waste Management Company, Box 250, 101 24 Stockholm, Sweden

The impacts of climate change in boreal regions has received considerable attention recently due to the warming trends that have been experienced in recent decades and are expected to intensify in the future. Large portions of these regions, corresponding to permafrost areas, are covered by water bodies (lakes, rivers) that interact with the surrounding permafrost. For example, the thermal state of the surrounding soil influences the energy and water budget of the surface water bodies. Also, these water bodies generate taliks (unfrozen zones below) that disturb the thermal regimes of permafrost and may play a key role in the context of climate change.

Recent field studies and modeling exercises indicate that a fully coupled 2D or 3D Thermo-Hydraulic (TH) approach is required to understand and model the past and future evolution of landscapes, rivers, lakes and associated groundwater systems in a changing climate. However, there is presently a paucity of 3D numerical studies of permafrost thaw and associated hydrological changes, and the lack of study can be partly attributed to the difficulty in verifying multi-dimensional results produced by numerical models.

Numerical approaches can only be validated against analytical solutions for a purely thermic 1D equation with phase change (e.g. Neumann, Lunardini). When it comes to the coupled TH system (coupling two highly non-linear equations), the only possible approach is to compare the results from different codes to provided test cases and/or to have controlled experiments for validation. Such inter-code comparisons can propel discussions to try to improve code performances.

A benchmark exercise was initialized in 2014 with a kick-off meeting in Paris in November. Participants from USA, Canada, Germany, Sweden and France convened, representing altogether 13 simulation codes. The benchmark exercises consist of several test cases inspired by existing literature (e.g. McKenzie et al., 2007) as well as new ones. They range from simpler, purely thermal cases (benchmark T1) to more complex, coupled 2D TH cases (benchmarks TH1, TH2, and TH3). Some experimental cases conducted in cold room complement the validation approach. A web site hosted by LSCE (Laboratoire des Sciences du Climat et de l’Environnement) is an interaction platform for the participants and hosts the test cases database at the following address: https://wiki.lsce.ipsl.fr/interfrost.

The results of the first stage of the benchmark exercise will be presented. We will mainly focus on the
inter-comparison of participant results for the coupled cases (TH1, TH2 & TH3).

Further perspectives of the exercise will also be presented. Extensions to more complex physical conditions (e.g. unsaturated conditions and geometrical deformations) are contemplated. In addition, 1D vertical cases of interest to the Climate Modeling community will be proposed.

Keywords: Permafrost; Numerical modeling; River-soil interaction; Arctic systems; soil freeze-thaw