Kick off meeting of INTERFROST, 18/10/14 Paris

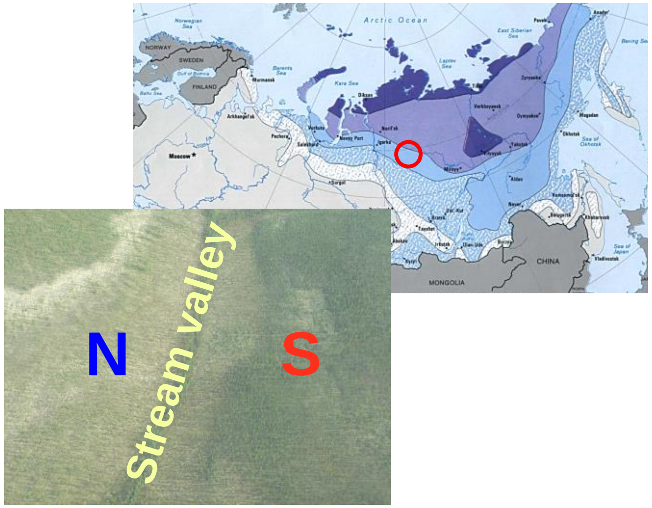
Thermo-hydrologic modelling of permafrost with OpenFOAM®

Laurent Orgogozo[1], Oleg S. Pokrovsky[1], Yves Goddéris[1], Jérôme Viers[1], David Labat[1], Stéphane Audry[1], Anatoly Prokushkin[2].

[1]Geosciences Environment Toulouse, Toulouse, France

[2]V.N. Sukachev Institute of Forest, SB RAS, Akademgorodok, Russia

Study of the transfers in the permafrost affected regions : Numerical modelling of thermo-hydrologic dynamics



Problematic :

Climate change and weathering in boreal areas with a continuos permafrost

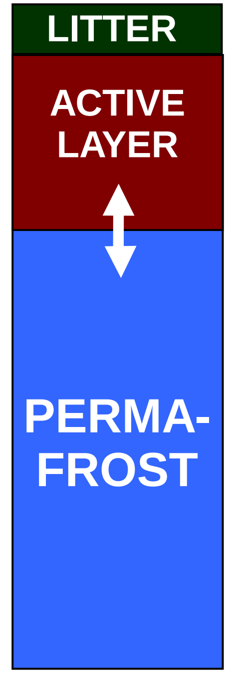
Studied area :

Central SIberia, <atersheds of the Nizhnaya Tungunska, homogeneous vegetation cover and lithology ; main spatial variability : south aspected / north aspected slopes

Goals :

(i) Influence of seasonnal freeze/thaw of the active layer on the geochemical fluxes related to weathering

(ii) Impact of the interannual variations of these cycles du to anthropogenic climate change



Methodological approach :

Mechanistic modeling of thermal and hydrological transfers from the plot scale to the experimental watershed scale

⟶ Time scales : annual to multidecennal
Space scales : 1 m^2 to 10's of km^2

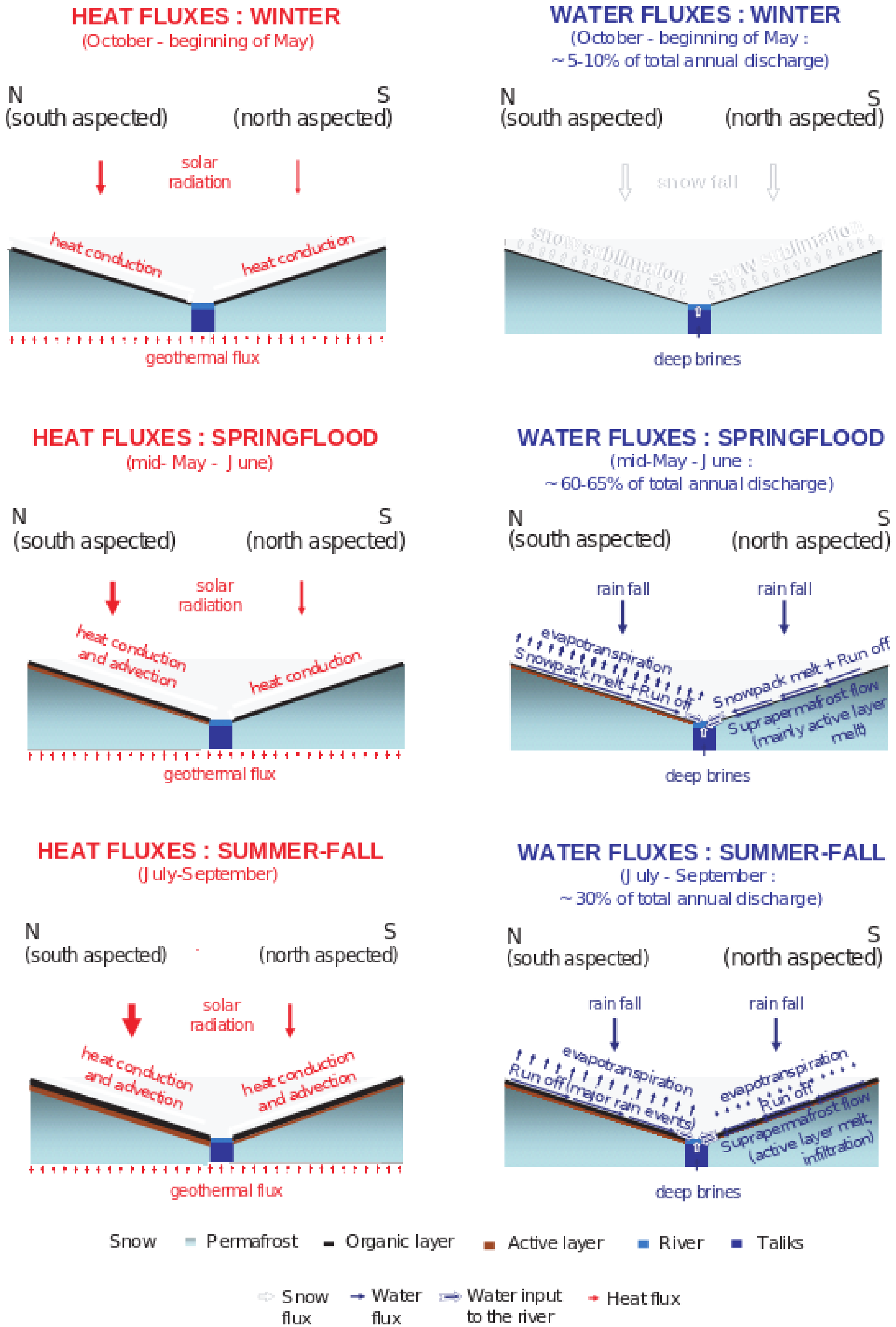
Other potential context of application: thermokarstic areas in Western Siberia

Insights on thermo hydrological dynamics obtained from study of the biogeochemical transfers

Qualitative thermo-hydrological seasonnal dynamics inferred from quantitative measurements of biogeochemsitry of litter, soil and stream waters in experimental watersheds of the Putorana Plateau (e.g.: Pokrovsky et al. 2005, 2006, Prokushkin et al. 2007, Bagard et al. 2011).

Figure extracted from Orgogozo et al. 2014
In "Permafrost : Distribution, Composition and Impacts on Infrastructure and Ecosystems », Ed. O.S. Pokrovsky, Nova Publisher, New York, 2014.

Future interplay: thermo-hydrological input for weathering modelling (e.g. : Goddéris et al. 2006, 2012) get from mechanistical modeling.



Study of the transfers in the permafrost affected regions : Numerical modelling of thermo-hydrologic dynamics

Coupled transfers within soils of water and energy with phase change :

e.g.: Kennedy and Lielmezs, 1973, Harlan 1973, Guymon and Luthin 1974, Jame and Norum 1980, Seregina 1989, Boike et al. 2003, Hansson et al. 2004, McKenzie et al. 2007, Painter 2011, Frampton et al. 2011, Grenier et al. 2012, Rivière 2012, Kurylyk et al. 2014, ...

Large computation times may be encountered : use of parallel computation is expected to be necessary (Painter et al. 2013).

=> Our approach : develloping a devoted solver with OpenFOAM®

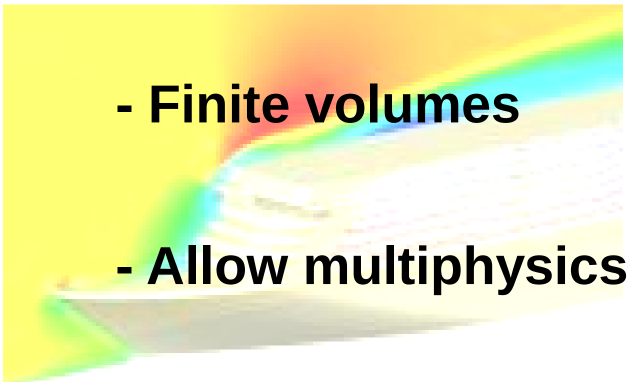
Steef problems, non-linearities, couplings, few references solutions :

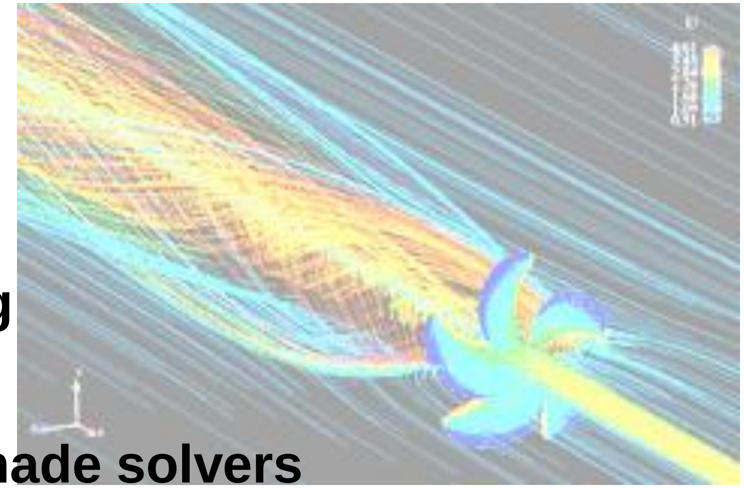
INTERFROST Benchmark, C. Grenier (LSCE, Continental Hydrology)

First test cases : Lunardini cases, in collaboration with N. Roux (Ph.D. LSCE) and Q. Chanzy (master degree student, LSCE)

OpenFOAM® (www.openfoam.com)

OpenFOAM® : an open source CFD tool box, developed in c++

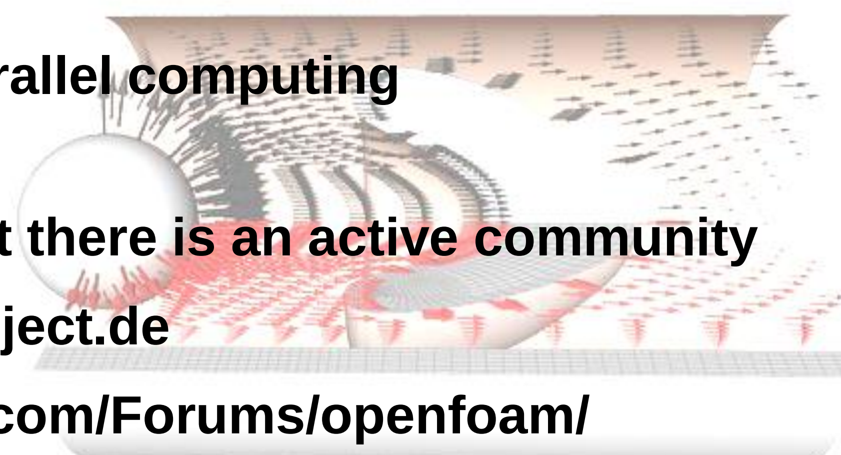




- **Finite volumes**

- **Allow multiphysics modelling**

- **Enable to implement home-made solvers**



- **Designed for massively parallel computing**

- **Lack of documentation, but there is an active community**

(e.g.: http://www.extend-project.de

http://www.cfd-online.com/Forums/openfoam/

http://openfoamwiki.net)

Massively parallel computation for geosciences with OpenFOAM®

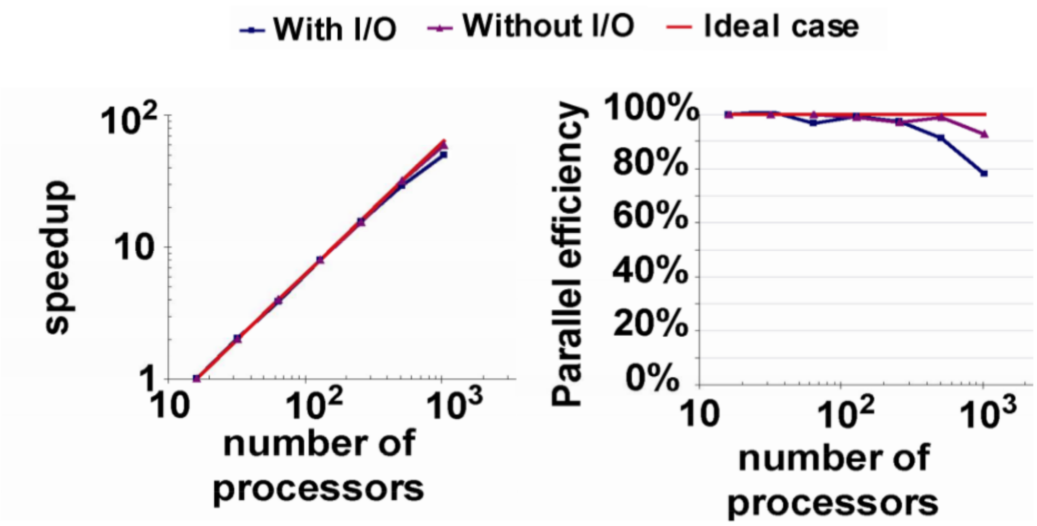
A massively parallel solver for Richards equation, RichardsFOAM has been implemented in OpenFOAM®, and its parallel performances has been studied in details : strong scaling (for both homogeneous and heterogeneous porous media), weak scaling, impact of the I/O's

The parallel performances are satisfactory (Orgogozo et al., CPC 2014):

3 km2, 10 m thick loam slope

36 millions mesh cells

10 days of infiltration



Computation times between ~1h30 (16 cores) and ~2 mn (1024 cores).

=> Our approach : coupling RichardsFOAM with a solver for thermal transfer with phase change also develloped with OpenFOAM®

Also recently develloped with OpenFOAM® : a massively parallel solver for two-phase flow in porous media (Horgue et al., CPC 2014)

Conclusion

Benefiting from the good parallel performances of OpenFOAM®

Idea : coupling RichardsFOAM (Orgogozo et al. CPC 2014) with a devoted solver for thermal transfer with phase change in porous media

Already done: soilFrostFOAM

Conductive thermal transfer with phase change in porous medium
(Lunardini solution, purely conductive cases – MacKenzie et al. 2007)

Conductive and advective thermal transfer with phase change in porous medium (Lunardini solution, advective test cases – Kurylyk et al. 2014)

Work in progress : permaFOAM = soilFrostFOAM + RichardsFOAM

Kick off meeting of INTERFROST, 18/10/14 Paris

Thank you for your attention.

Contact: laurent.orgogozo@get.obs-mip.fr