InterFrost meeting in Paris
Nov 18 – 2014

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Presentation by Johan Holmén

Golder Associates

Permafrost modelling

Article:

Holmén J., Benabderrahmane H., Buoro A. and Brulhet J.

“Modelling of permafrost freezing and melting and the impact of a climatic cycle on groundwater flow at the Meuse/Haute-Marne site. ”

J. Phys. Chem. Earth (2011), doi:10.1016/j.pce.2011.10.021

Heat equation with permafrost

$$H = \underbrace{\rho v\, c_{p_w} T}_{a} - \underbrace{\lambda_A \frac{\partial T}{\partial l}}_{b}$$

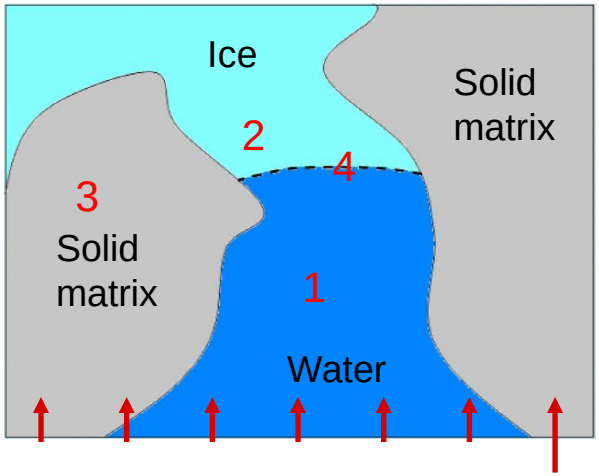
a= convection
b= conduction

Heat transport equation

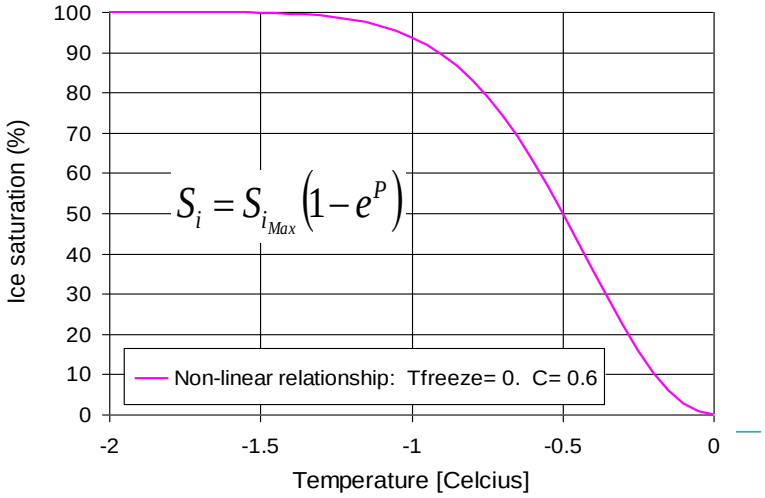
$$\frac{\partial H_x}{\partial x} + \frac{\partial H_y}{\partial y} + \frac{\partial H_z}{\partial z} - U_{spec} = \frac{\partial T}{\partial t}\left(\underbrace{\varepsilon_w \rho_w c_{p_w}}_{1} + \underbrace{\varepsilon_i c_i}_{2} + \underbrace{\varepsilon_s c_s}_{3} - \underbrace{\rho_i(\varepsilon_i + \varepsilon_w) L \frac{d S_i}{d T}}_{4} \right)$$

Heat continuity equation

$$T_{t-\Delta t} \rightarrow \frac{d S_i}{d T}$$



Amount of ice in computational cell →



Formulations of the heat equation that includes ice and phase transitions, very similar to the equation presented above, goes back at least to the mid nineteen-seventies, see for example Tayler and Luthin (1976), Holden (1979).

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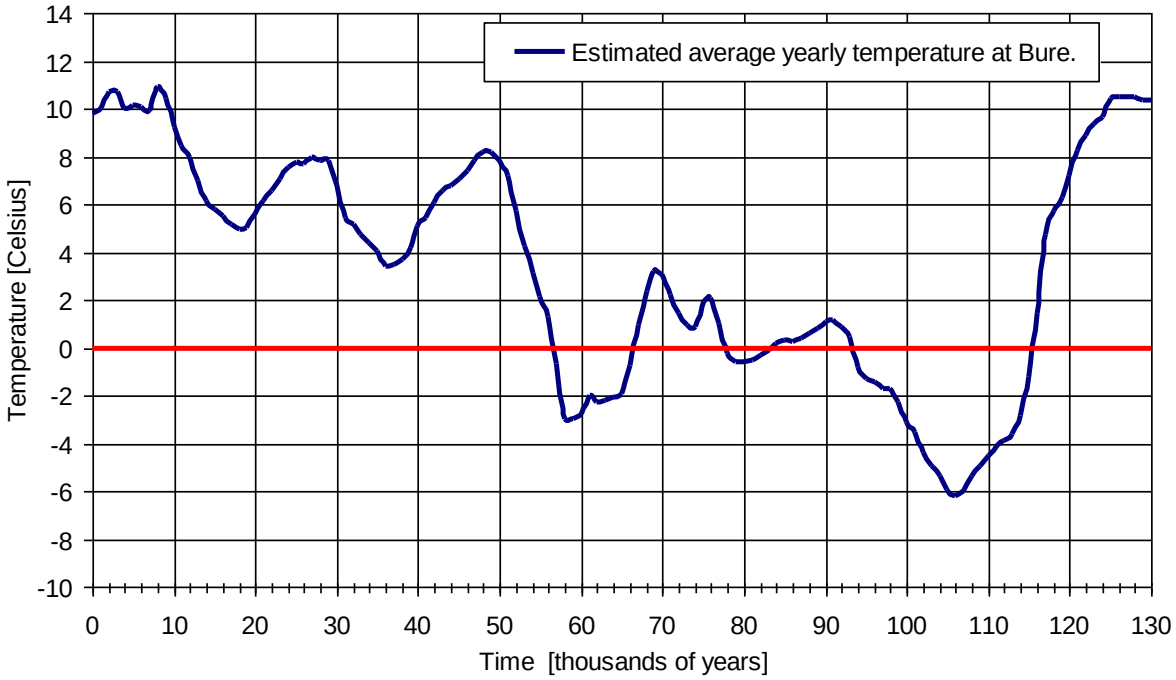

Estimated average yearly air temperatures at Bure during the studied climatic cycle.

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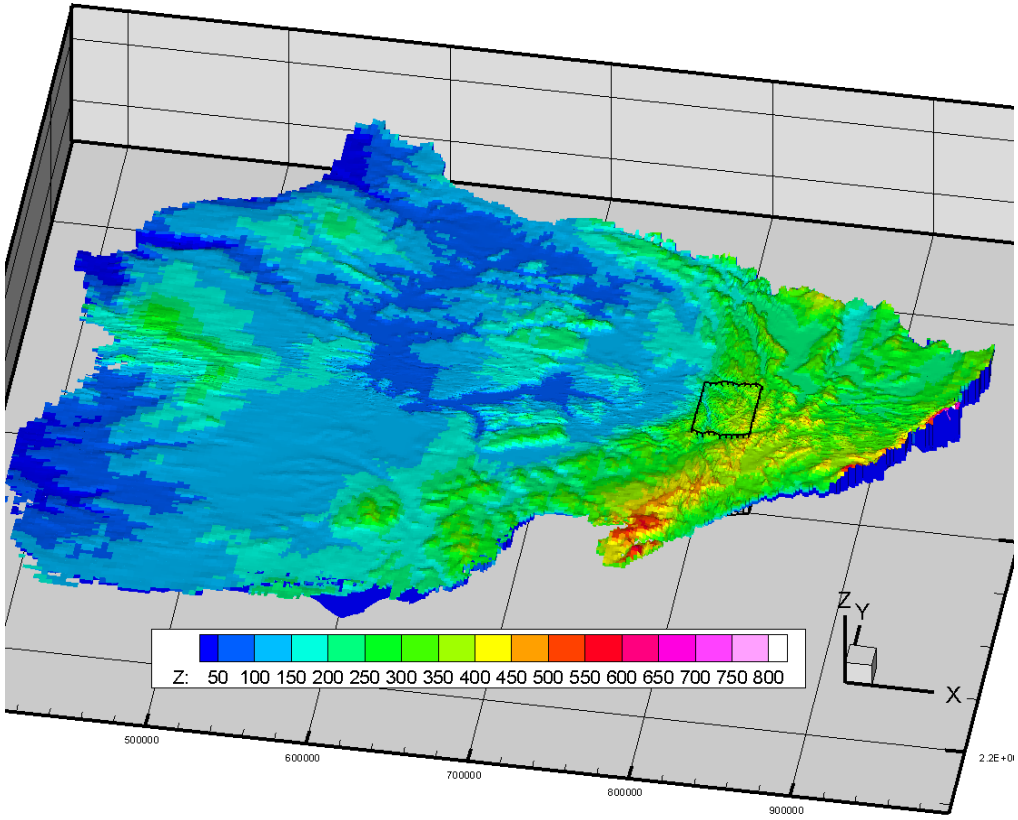

Perspective view (from South) of the topography of the established model of the Paris basin, as defined by the cells of the model. The vertical exaggeration is 25 times. The black rectangle denotes the Meuse/Haute-Marne Sector area. The Bure site is located within the Sector area. The model covers the entire Paris basin, an area of 163 400 km2 (approx. 660km x 528km). The model includes geological layers from Triassic to Tertiary stage; in all 34 geological layers.

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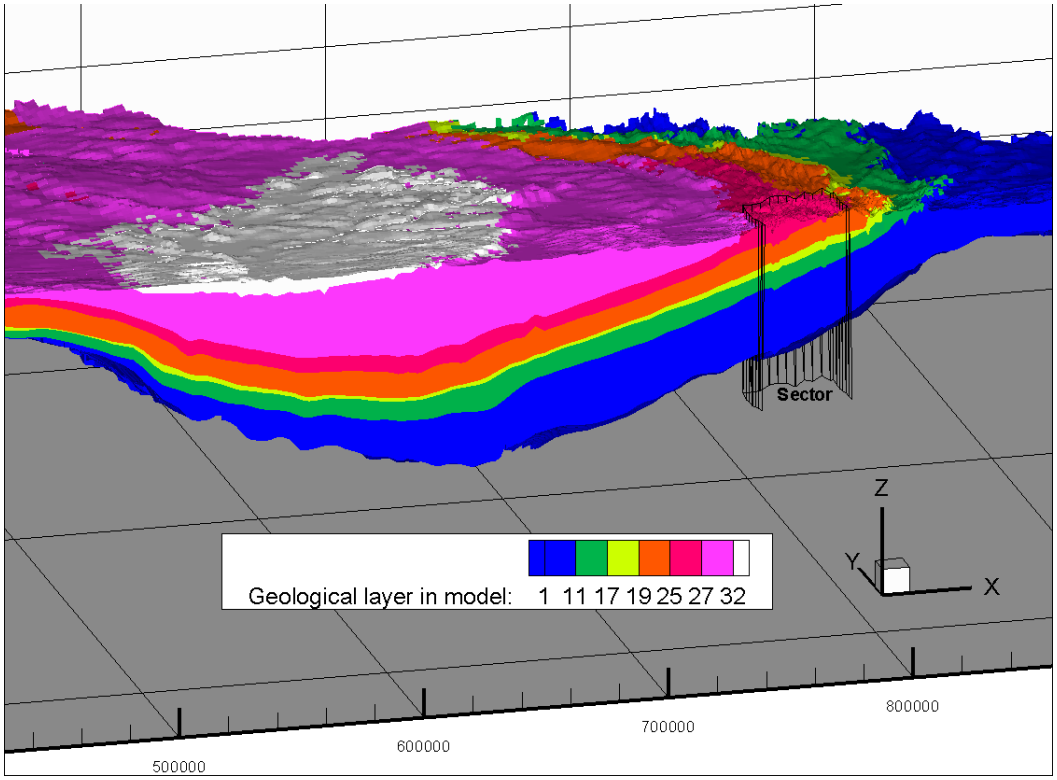

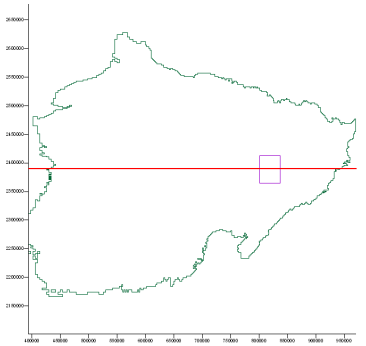

Perspective view (from south) of a cross-section (west-east) through the model, presenting different geological layers.
The vertical exaggeration is 30 times.
Blue = Trias and Lias. Green = Dogger. Yellow = the host formation, i.e the Callovo-Oxfordian. Orange = Oxfordian. Red = Kimmeridgian and Portlandian.
Purple = Cretaceous. White = Tertiaire. The black fence denotes the Meuse/Haute-Marne Sector area.

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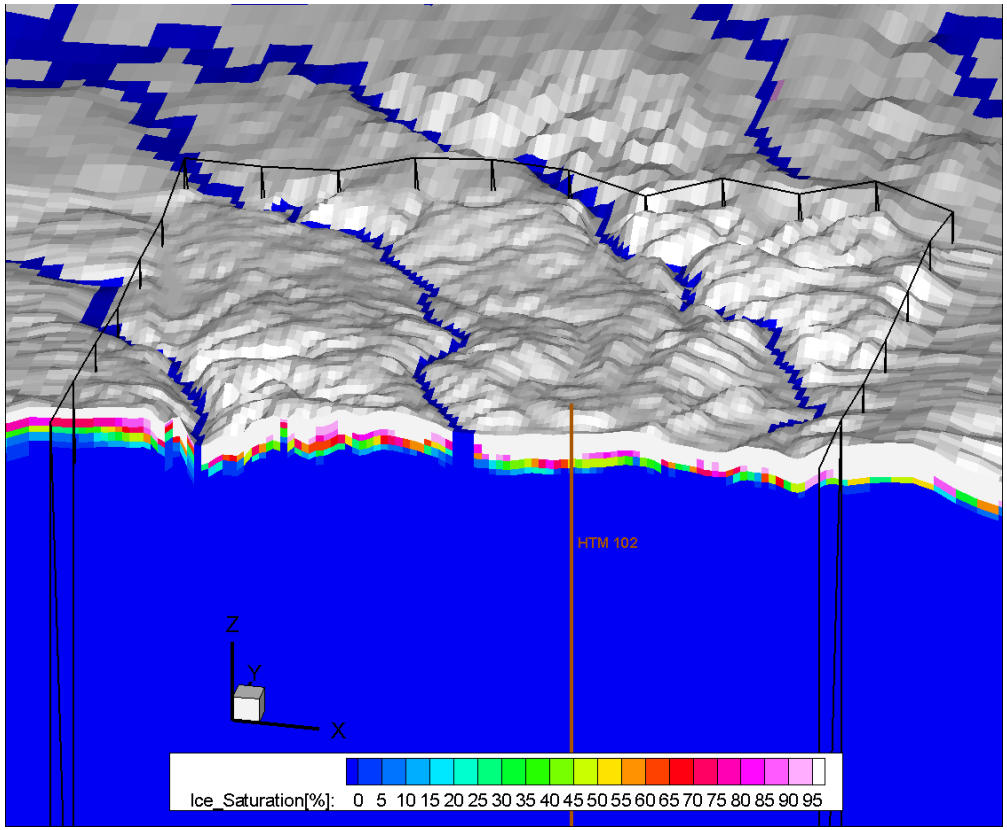

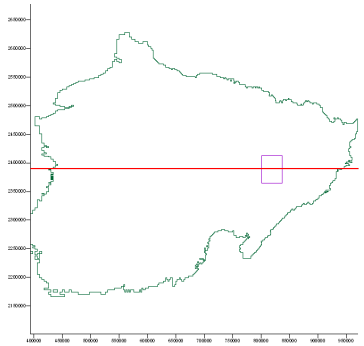

Base case. t= 107 000 years.
Ice saturation [%]. White colour represents ice-saturation above 95%.
Perspective view (from south) of a west-east cross-section through the Sector area and the close surroundings of the Sector area.
The cross sections cut through the HTM 102 borehole and the Bure site. The vertical exaggeration is 15 times. The black fence denotes the Sector area.

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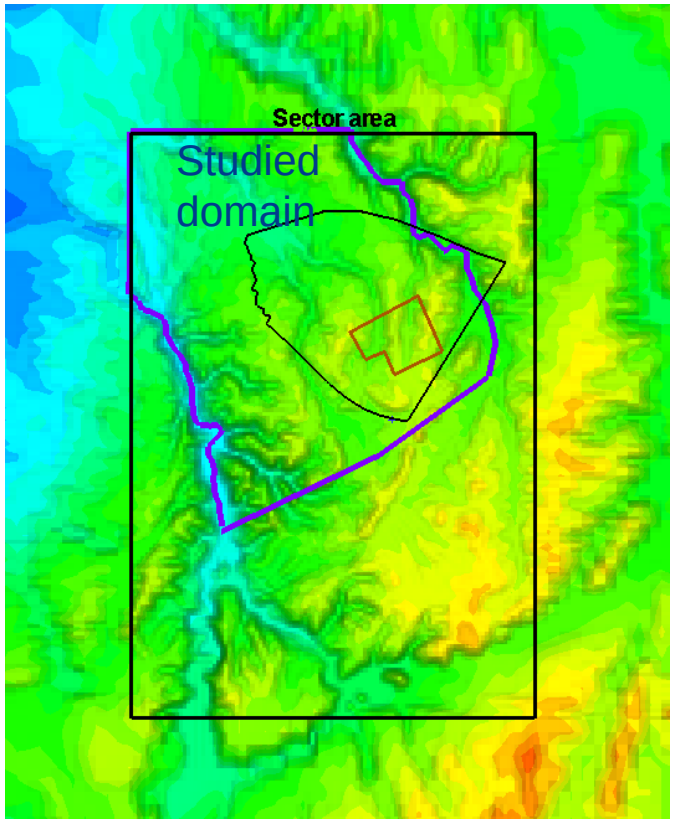
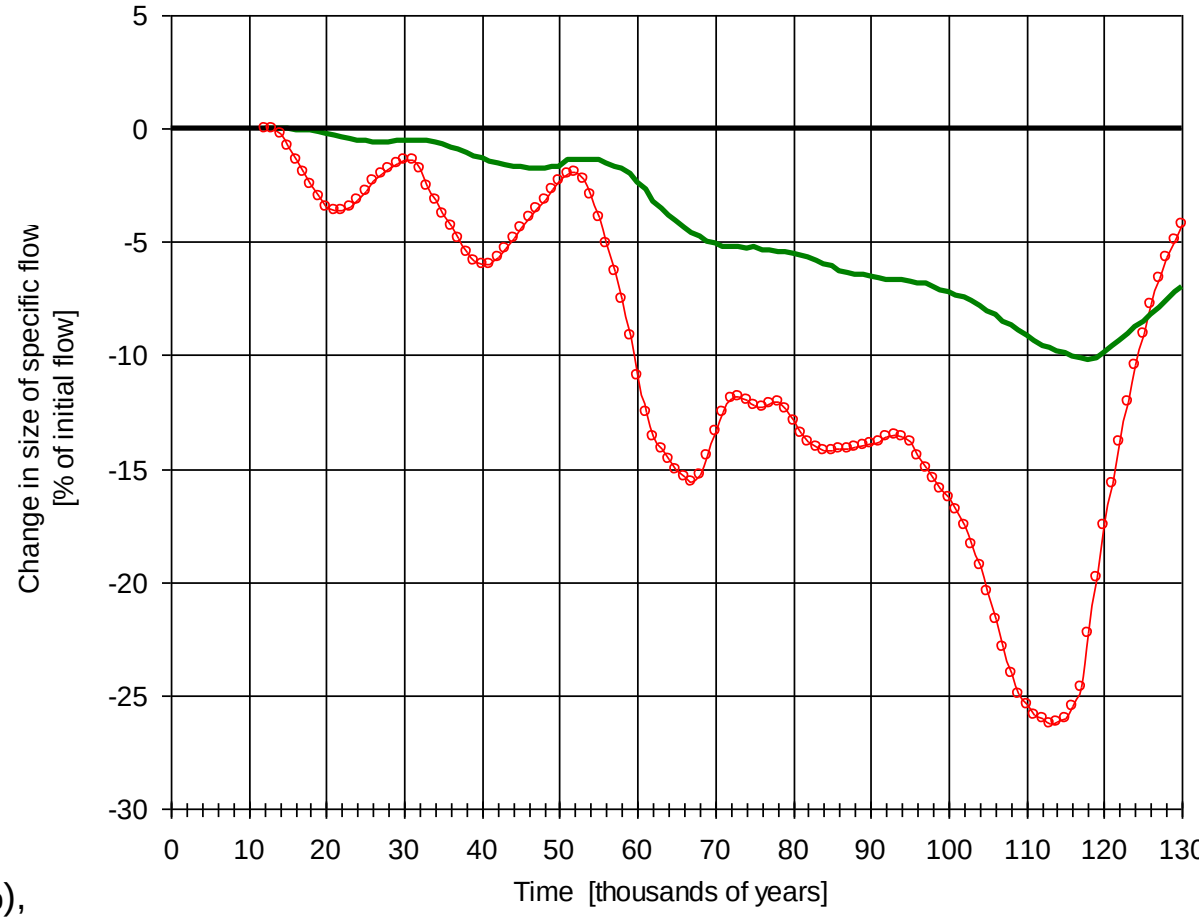
The depth of the permafrost varies in space and time during the glacial period studied. Within the Sector area, the largest depth reached by the permafrost is approx. 110m, this is a median depth considering the spatial distribution of the permafrost.

The lowest simulated temperature in the lower parts of the Callovo-Oxfordian, in the close surrounding of the Bure site, is 14.5 C, which is approximately 7.5 C lower than the initial temperature (22 C). A full reversion back to the initial temperatures will not occur during the studied climatic cycle.

There are no dramatic changes in size and direction of the groundwater flow, when considering the climatic cycle studied and the deeper geological layers directly above and below the Callovo-Oxfordian, downstream of the Bure site. The largest change will occur during periods with large extension of permafrost; the flow is reduced with approximately 10% through 25%, in relation to the initial flow (considering median values of the spatially varying flow field). The changes in the Dogger units are smaller than the changes in the Oxfordian units.

Simulated permafrost and change in groundwater flow





Change in groundwater specific flow (%), considering the medians of the distributions of values, during the studied glacial period.

Studied domain is downstream of the Bure site

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END

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