Developing numerical models for investigating talik forming and stability from scratch

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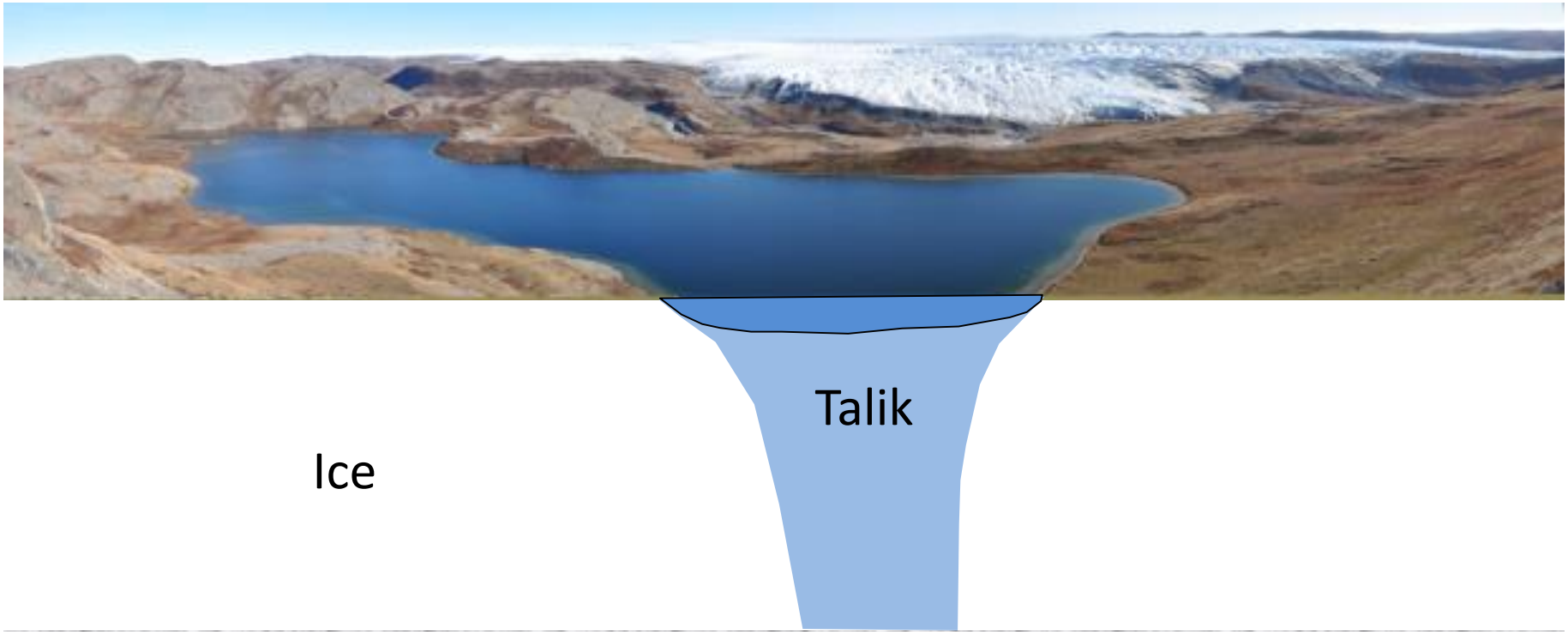
CatchNet annual meeting

22nd September 2022, Solna

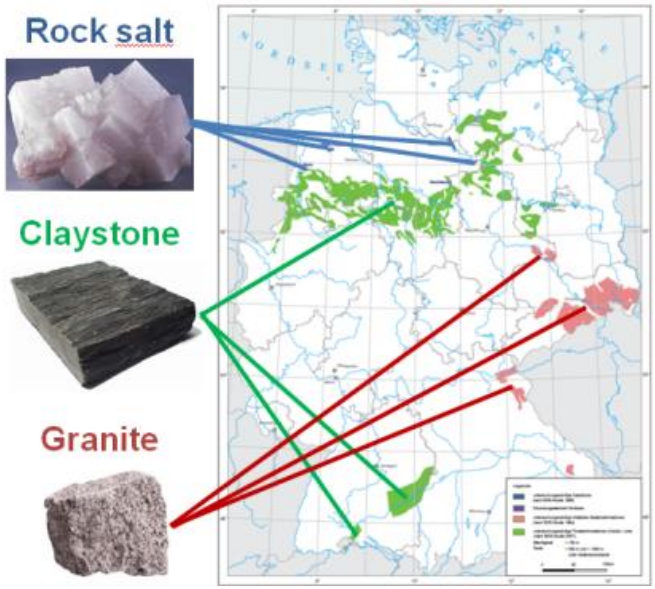
My personal starting point



Taliki

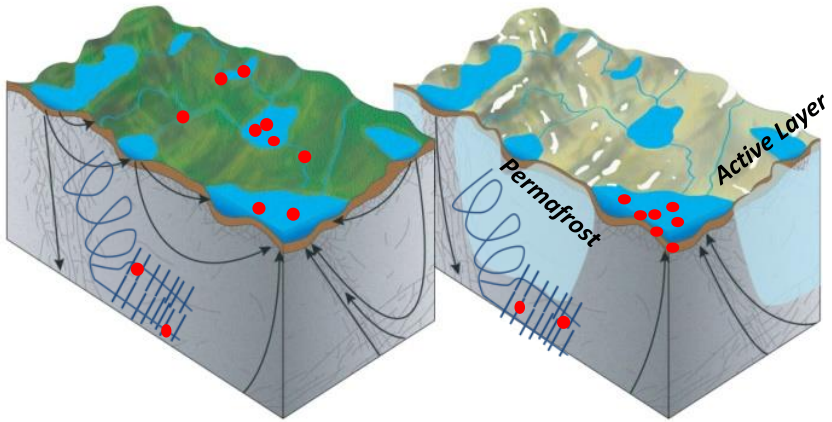
- Cool features
- Obviously based on physical principles
- Totally counterintuitiv

Reasons to investigate



(BGR, 2011)

After: Vandenberghe, J. and Pissart, A., 1993: Permafrost changes in Europe during the Last Glacial. Permafrost and Periglacial Processes 4, 121–135.
Renssen, H. and Vandenberghe, J., 2003: Investigation of the relationship between permafrost distribution in NW Europe and extensive winter sea-ice cover in the North Atlantic Ocean during the cold phases of the Last Glaciation. Quaternary Science Reviews 22, 209-223.



(Emma Lindborg, SKB)

Safety assessment requires knowledge on

- Talik forming
- Talik stability

The way to go

Numerical modelling

- within the range of our financial resources
- allows for investigating an awful lot of conditions

Checking the literature

- Confusing and seemingly contradictory formulations

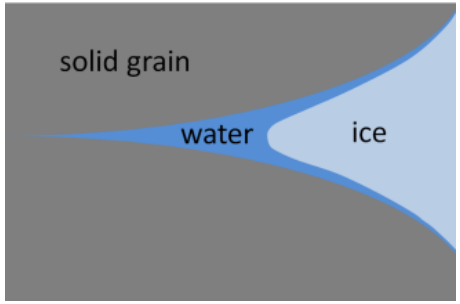
→ from scratch:

- conceptual model
- mathematical model
- data on material behaviour

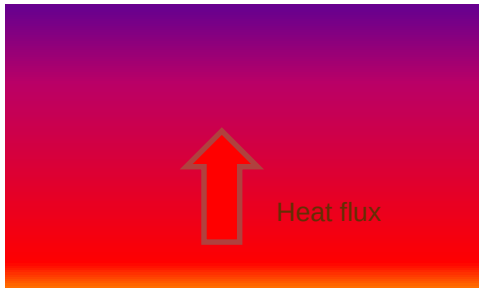
Relevant physical processes

Surprisingly small in number

- Groundwater flow including
  - phase changes of the water
  - density-driven flow



- Heat flow in a porous medium

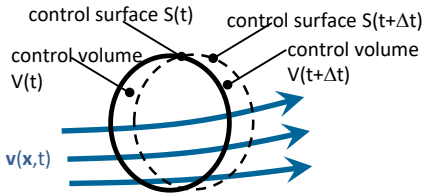


But there is coupling!

Mathematical model

Mass balance

$$\int_V \left[\frac{\partial}{\partial t}\left(S_w \Phi \rho_w + S_i \Phi \rho_i\right) + \nabla \cdot \left(\mathbf{v_w} \rho_w + \mathbf{v_i} \rho_i\right) - \rho_w q_w \right] dV = 0$$



Reynolds transport theorem

Heat balance

$$\int_V \left[\begin{array}{l} \frac{\partial}{\partial t}\left(S_w \Phi c_{sw} \rho_w T_w + S_i \Phi c_{si} \rho_i T_i + (1-\Phi) c_{sm} \rho_m T_m\right) \\ + \nabla \cdot \left(\mathbf{v_w} S_w \Phi\, c_{sw} \rho_w T_w + \mathbf{v}_i S_i\, \Phi\, c_{si} \rho_i T_i + \mathbf{v}_m (1-\Phi)\, c_{sm} \rho_m T_m\right) + \left(\mathbf{J_w} + \mathbf{J_i} + \mathbf{J_m}\right) \\ - r_Q - L \frac{\partial}{\partial t}\left(S_i\, \Phi\, \rho_i\right) \end{array} \right] dV$$

State variables*

- Density
- Viscosity
- Thermal conductivity
- Heat capacity

Flow → Darcy's law

Heat conduction
→ Fouries's first law

Constitutive relations*

- Relative permeability
- Saturation (SFCC)
- Porosity

* for water, ice, and matrix, where applicable

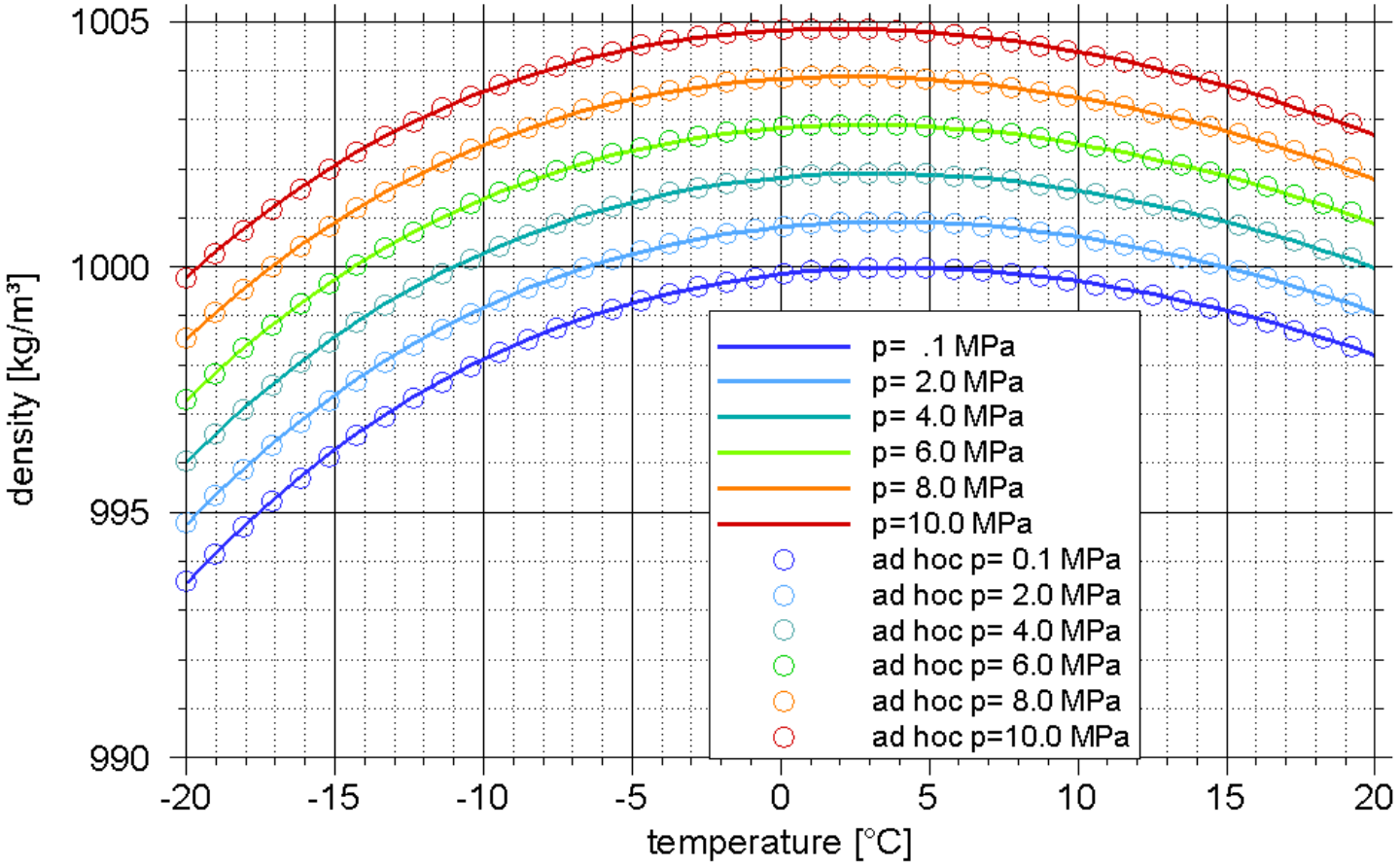
Equations of state (EOS)

Data and formulations for

- -20°C < T < +200°C
- 0.1 MPa < p < 10 MPa

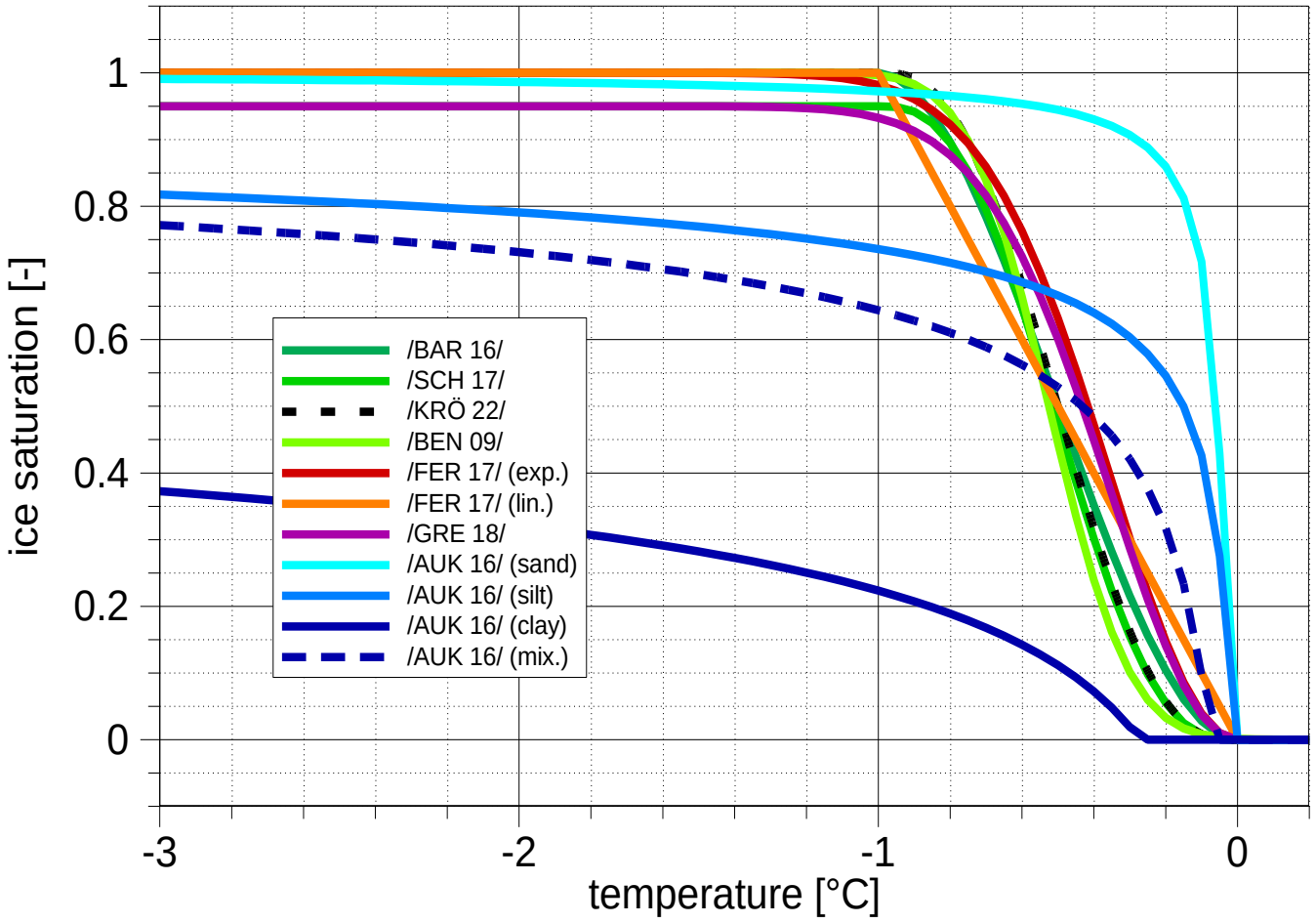
Simplified ad hoc formulations for

- -20°C < T < +20°C
- 0.1 MPa < p < 10MPa



Constitutive Equations (CE)

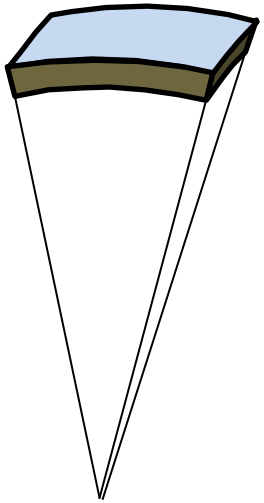
Many approaches for the SFCC



Simplifications: domain geometry (3D)

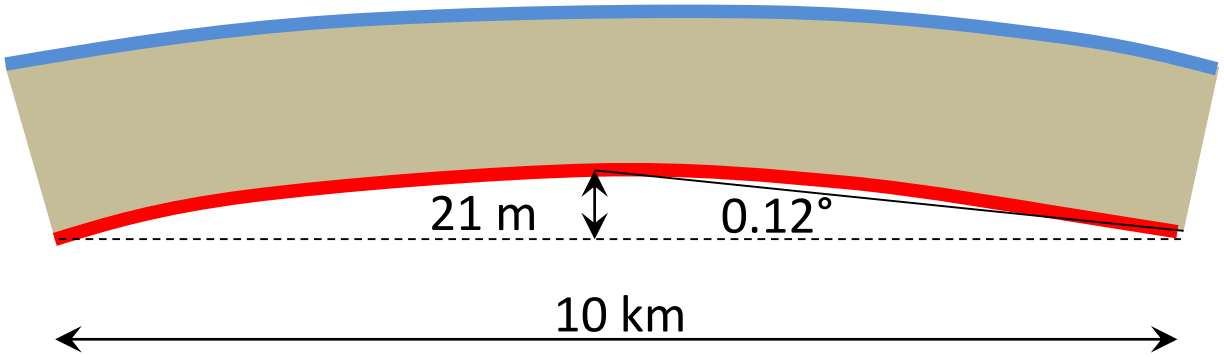
in principle

- the crust
  of a sphere segment



⇨ good approximation

- brick shape



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Thermal boundary conditions: bottom

heat flux from inner earth

- caused by different processes → complex evolution
- but changing only by ~ 0.18 %/Ma(*)
- → constant flow rate

present mean heat flow rate over Germany

- 65 mW/m² (**)
- large variance

depth

- below any possible temperature signal from the top

(*) (Loyd et. al, 2007)

(**) (Bundesverband Geothermie, 2021)

Thermal boundary conditions: sides and top

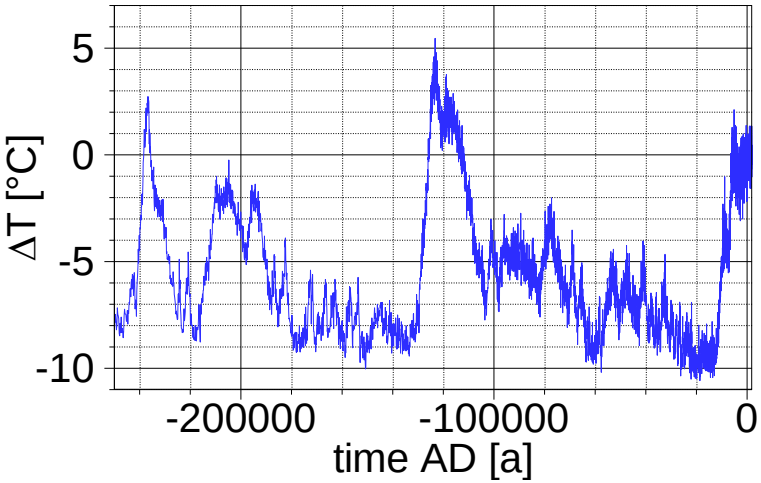
Side boundaries

- Impermeable for heat flow → sufficient lateral model size

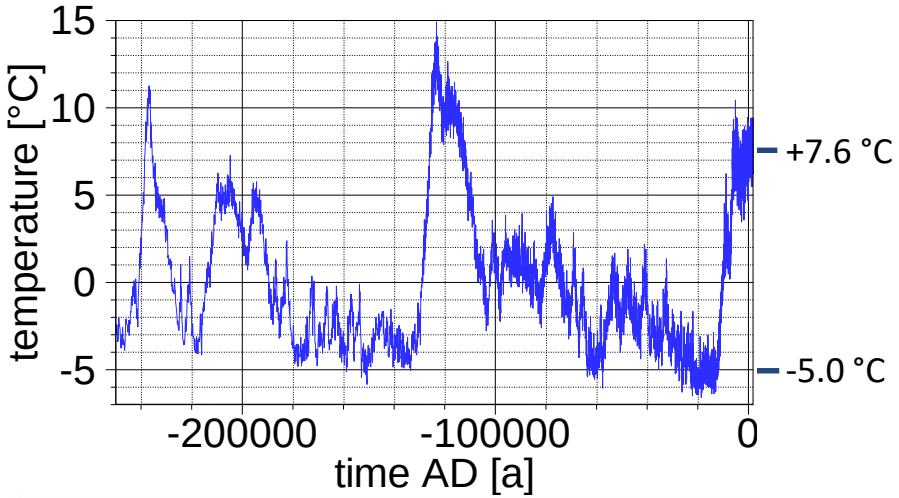
Top

- Prescribed temperature
  - Global temperature evolution
    - Ice core data from Antarctica (*)
  - Global temperature distribution at the last glacial maximum (**)
    - adapting global trends to location of (future) Germany

(**) (Tierne et al., 2020)

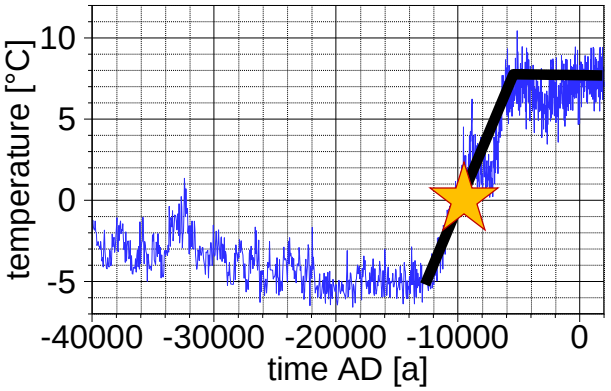


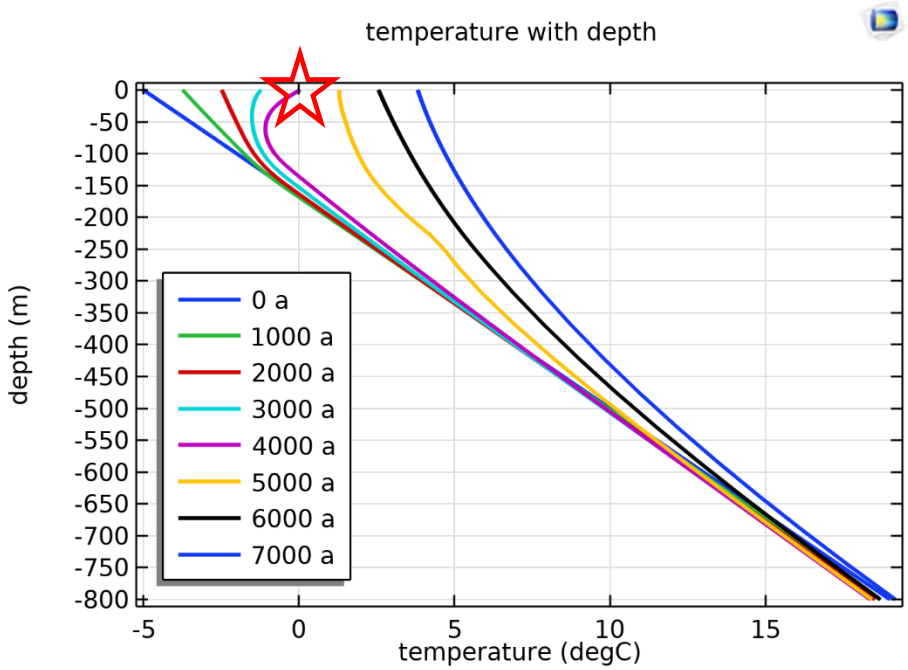
(*) (Jouzel et al., 2004)

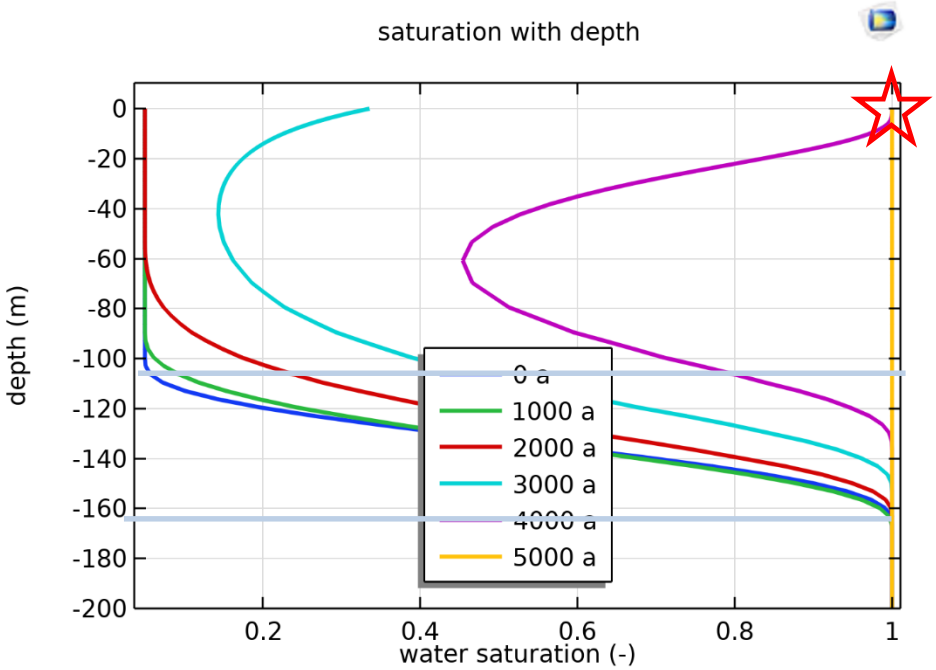


Tentative application: Temperature changes in the underground

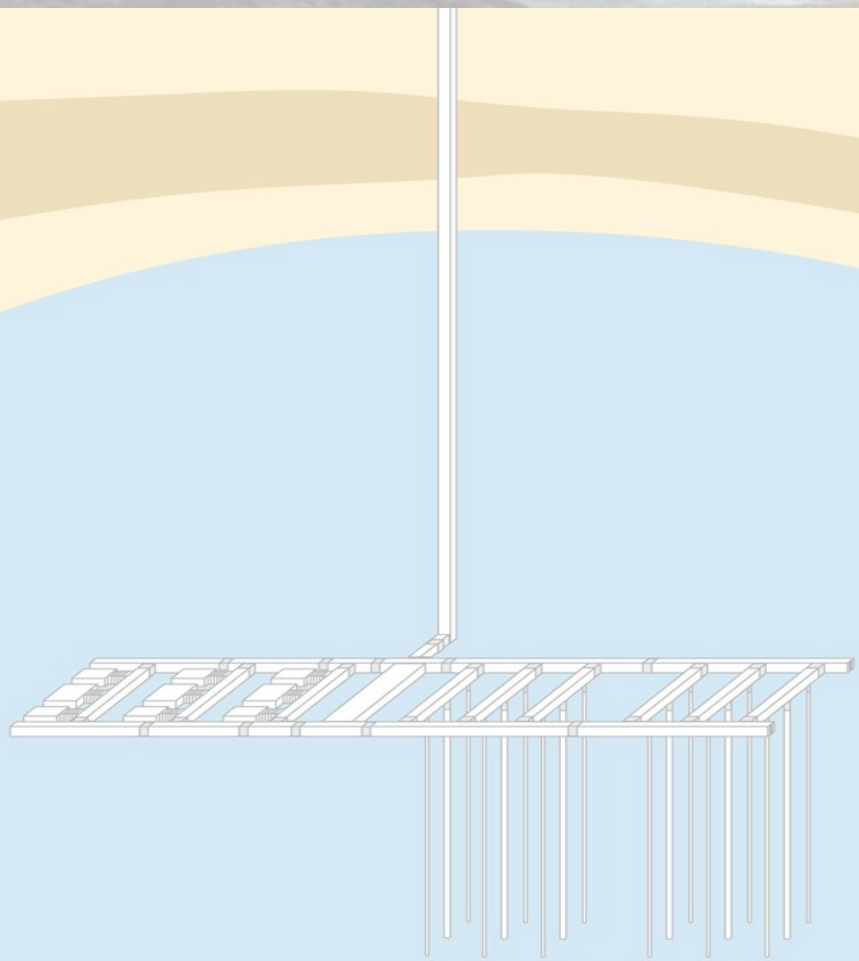
Warming at the end of the Weichselian glacial



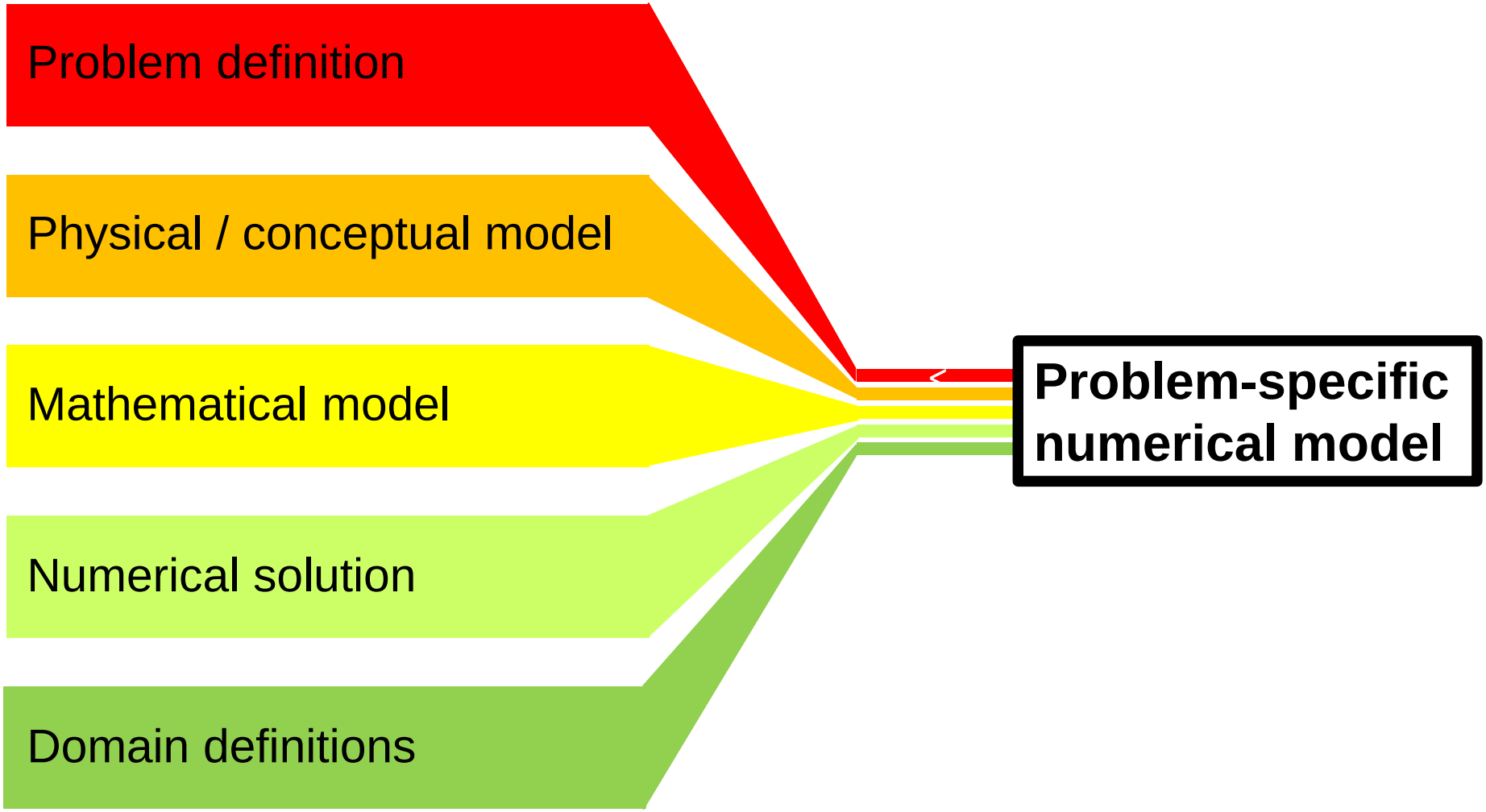




Summary and outlook



Summary


Problem definition
Physical / conceptual model
Mathematical model
Numerical solution
Domain definitions
Problem-specific numerical model

Outlook

Draft report on model development still about to be completed

Revision of EOS-formulations → reasonable model size and b.c.

Commencing systematic model investigation → taliks

Many thanks for listening!

Comments, hints, maybe even discussions are welcome!

Federal Ministry of Economics and Technology