Reduction of scenario uncertainties through climate models (REDUKLIM)

4. URS Workshop – 12.06.2024

Aachen

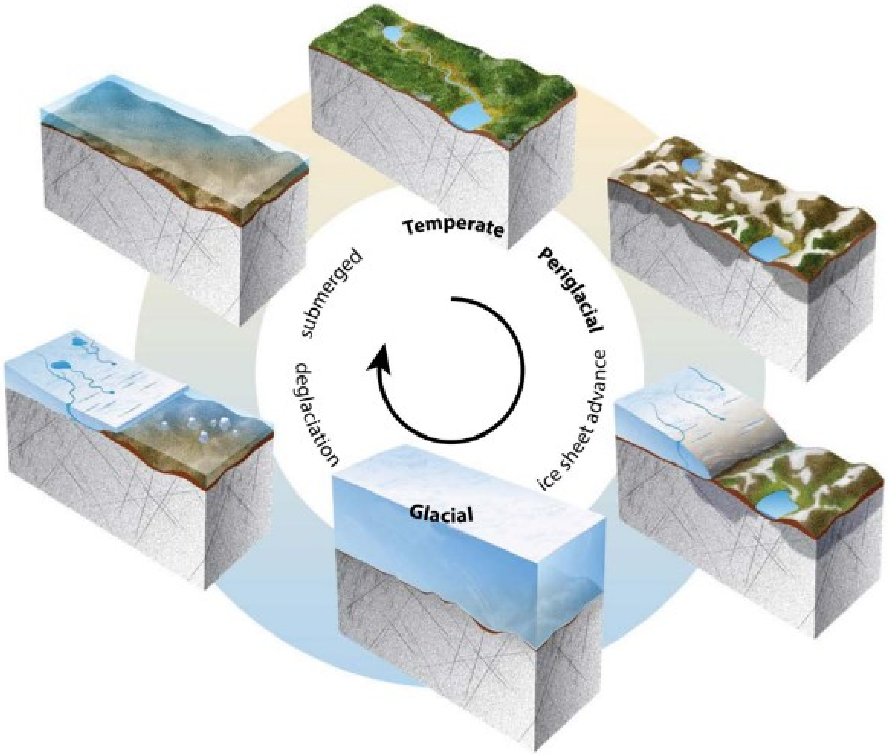
Marc Johnen

Research aims

- Identify climate developments in the long term safety and their uncertainties
- Consideration of geological and climatic situation due to the assessment period of one million years in the German law
- Flow- and Transport simulations to show the potential influence of climate developments on the geosphere
- Assessment of transport paths and lengths over the assessment period of one million years for possible contamination of radionuclides
- Consideration of uncertainties in the context of the site selection and long term safety analysis

Climatic developments

- Over the assessment period of one million years, changes in climatic conditions can be expected in Germany
- These can occur once or several times as part of climate cycles
- In this project, climate developments are represented as stylized states
  - Climate developments are implemented by changing parameters and boundary conditions

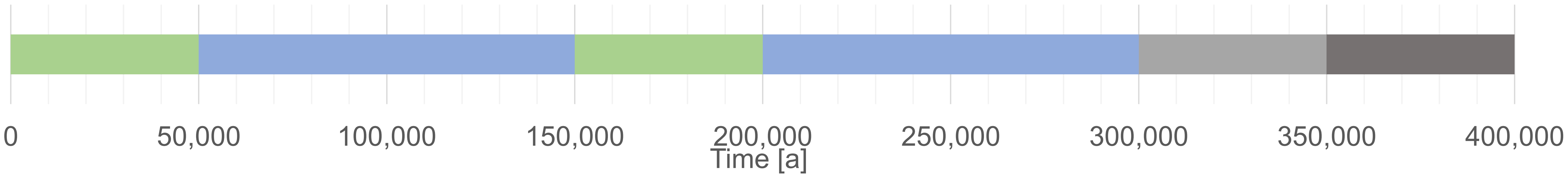


Brandefelt et al. 2019 /SKB TR-19-04

- Glaciation
- Permafrost
- Erosion
- Sea level changes

Climate developments

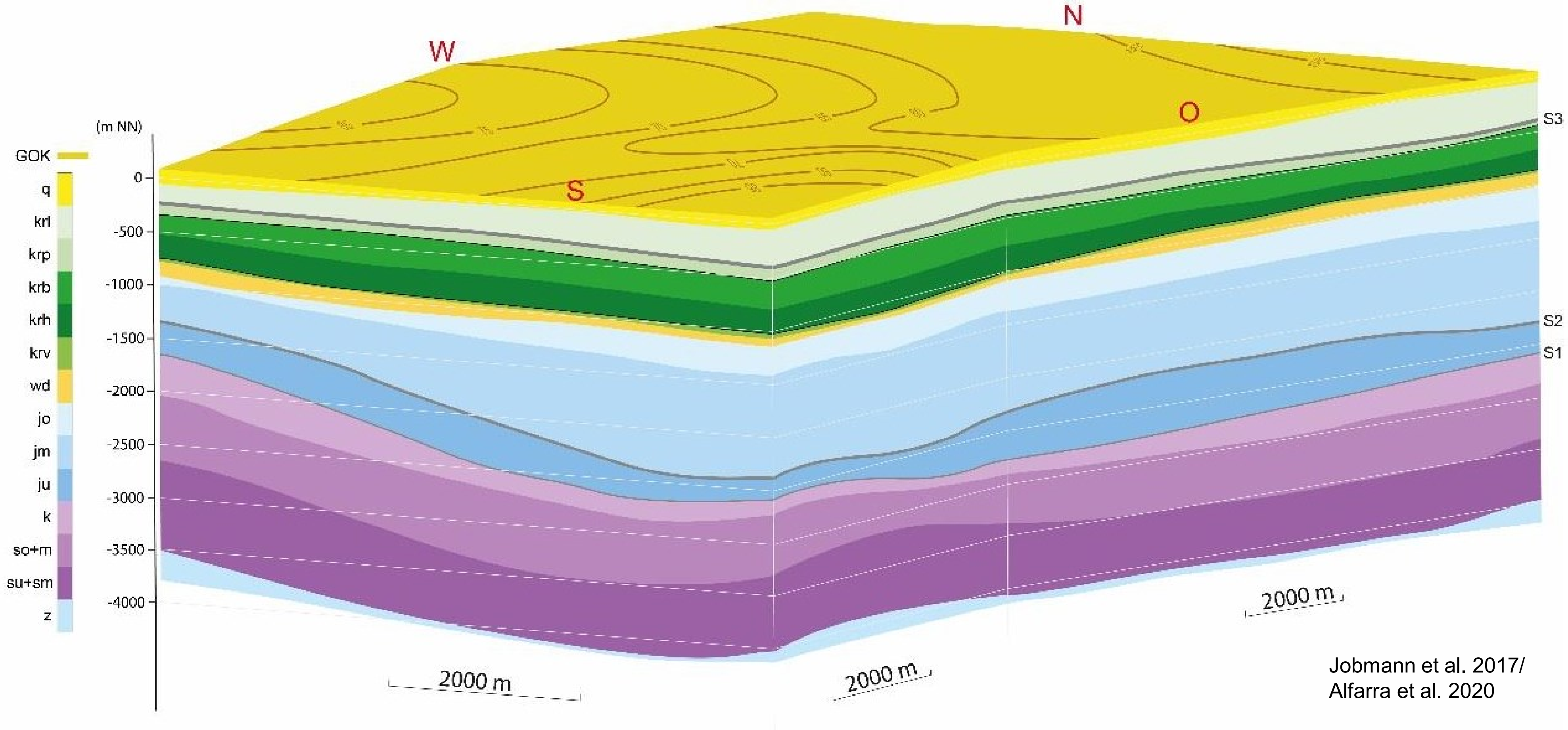
- Actual work from GRS with possible climate scenario for Germany (abstracted here)
  - No separation into scenarios for northern and southern Germany
- No change of model geometry while simulation possible in d³f++



Temperate climate
Continuous permafrost
Glacier front with permafrost in front of the glacier
Glacier over repository area

Model region – ANSICHT North

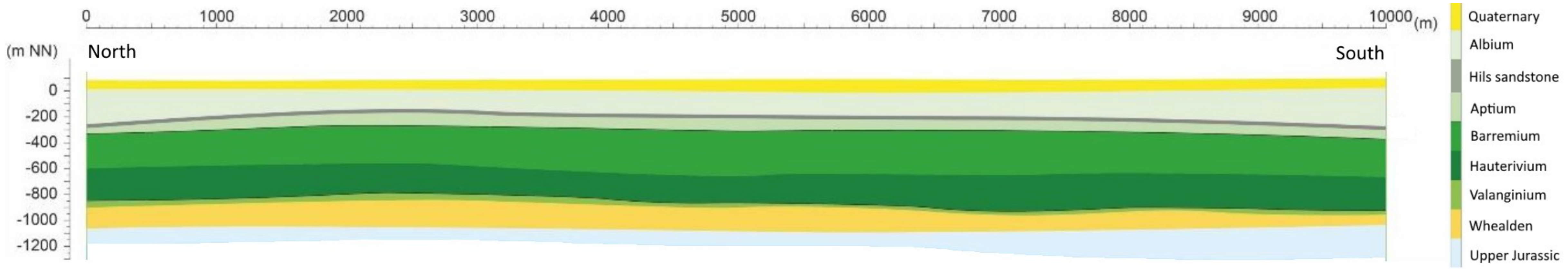
- Generic geological site model with relation to geological units which are investigated in Germany



Jobmann et al. 2017/
Alfarra et al. 2020

Model region – ANSICHT North

- Model area with smaller amount of lithostratigraphic units
  - Upper Jurassic as lowest unit
    - No further influence from underlying units – impermeable Middle Jurassic
- 9 lithostratigraphic units with different characteristics
- The dimensions of the model area are approximately 10 km in width by up to 1.400 m in height.



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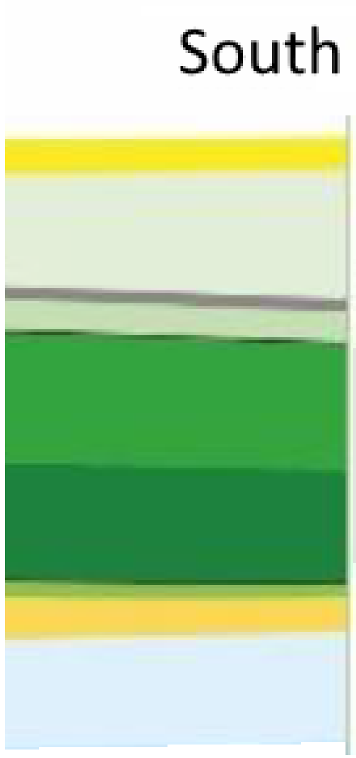
Model region – ANSICHT North



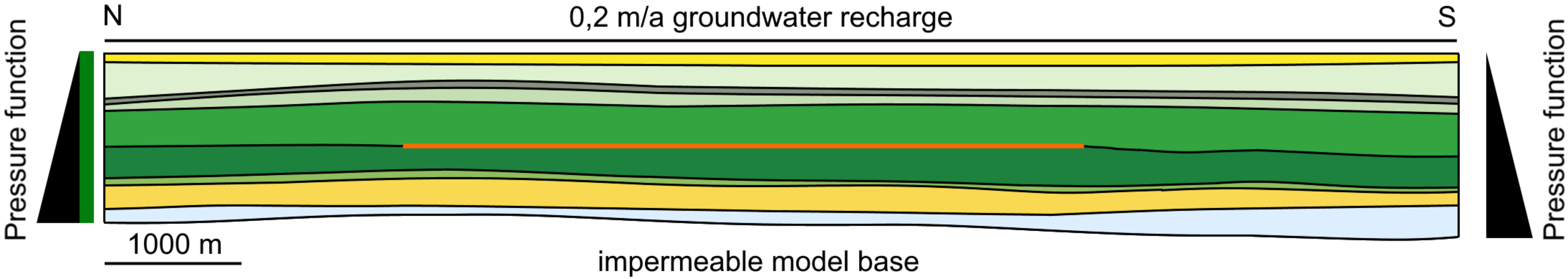
	Permeability [m²]	Effective porosity [-]
Quaternary	$1 \cdot 10^{-14}$	0,2
Albium	$1 \cdot 10^{-18}$	0,05
Hils sandstone	$1 \cdot 10^{-14}$	0,1
Aptium	$1 \cdot 10^{-18}$	0,05
Barremium	$1 \cdot 10^{-19}$*	0,05
Hauterivium	$1 \cdot 10^{-19}$*	0,05
Valanginium	$1 \cdot 10^{-16}$	0,05
Whealden	$1 \cdot 10^{-14}$	0,075
Upper Jurassic	$1 \cdot 10^{-15}$	0,01

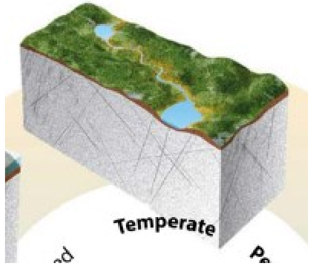
Einschlusswirksamer Gebirgsbereich (ewG)
containment providing rock zone (CRZ)

*vertical $1 \cdot 10^{-20}$ [m²]

Boundary conditions "present climate"

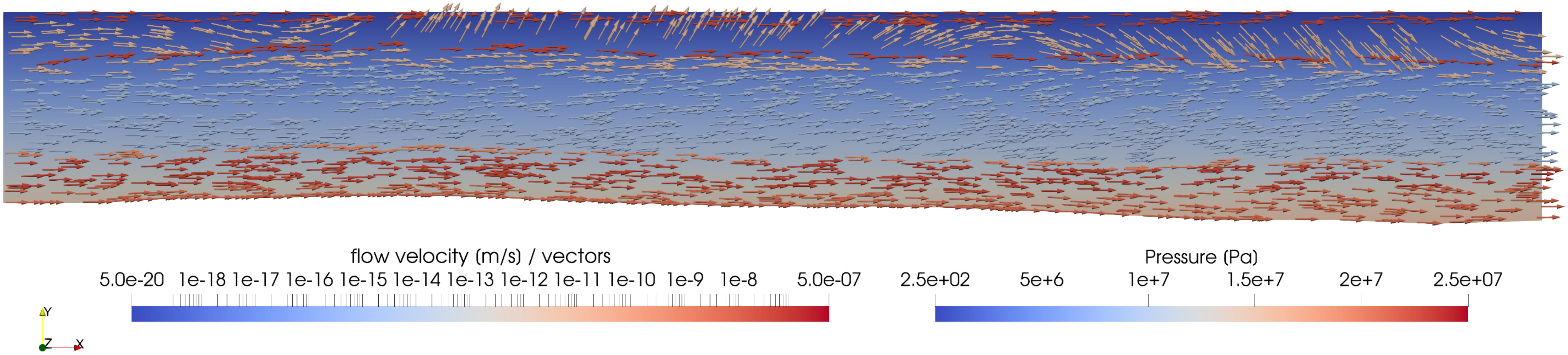
- Defined base case with parameters after Alfarra et al. 2020
- Hydraulic gradient of 0.002 m/m added to the depth depended pressure function





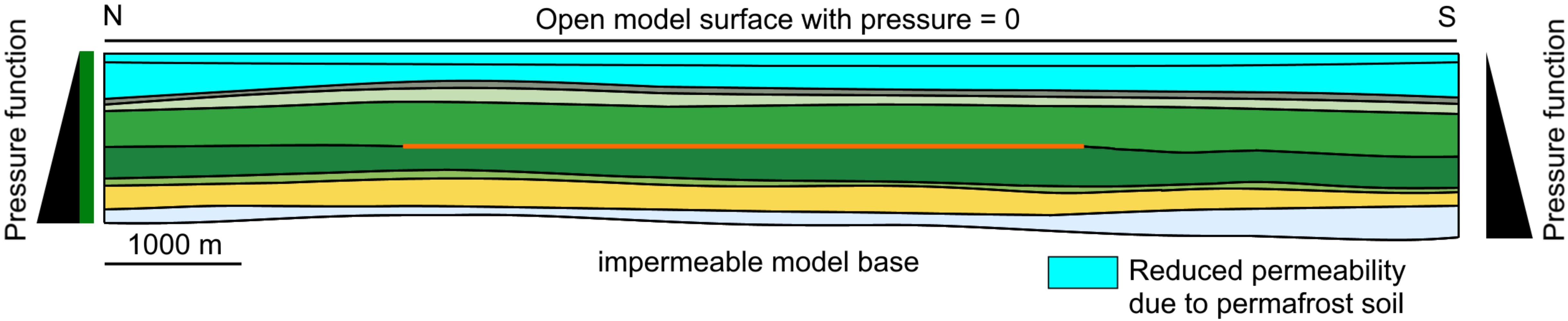
Brandefelt et al. 2019 /SKB TR-19-04

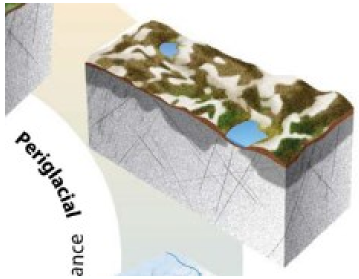
Flow velocities “present climate”



Boundary conditions “permafrost”

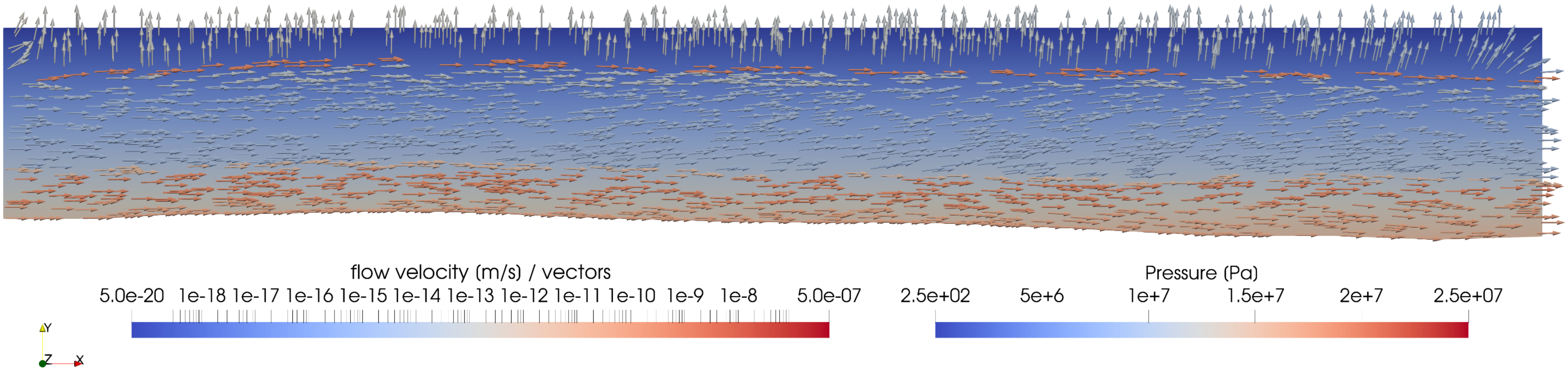
- Reduced permeability in first two lithological units
- No groundwater recharge





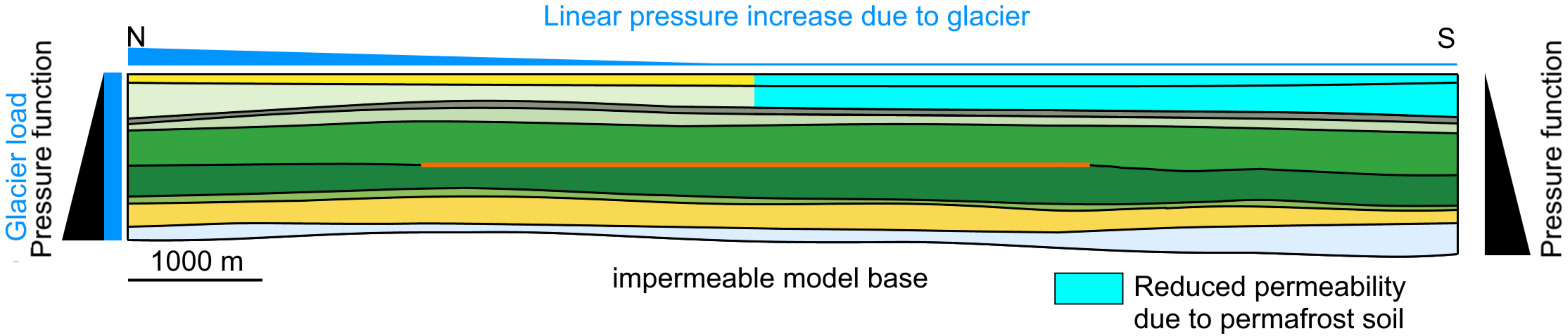
Brandefelt et al. 2019 /SKB TR-19-04

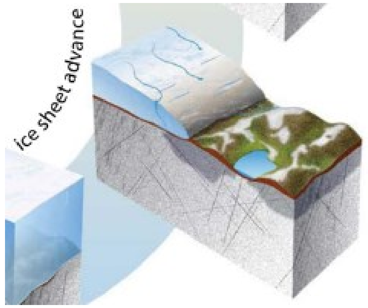
Flow velocities “permafrost”



Boundary conditions "permafrost and glacier"

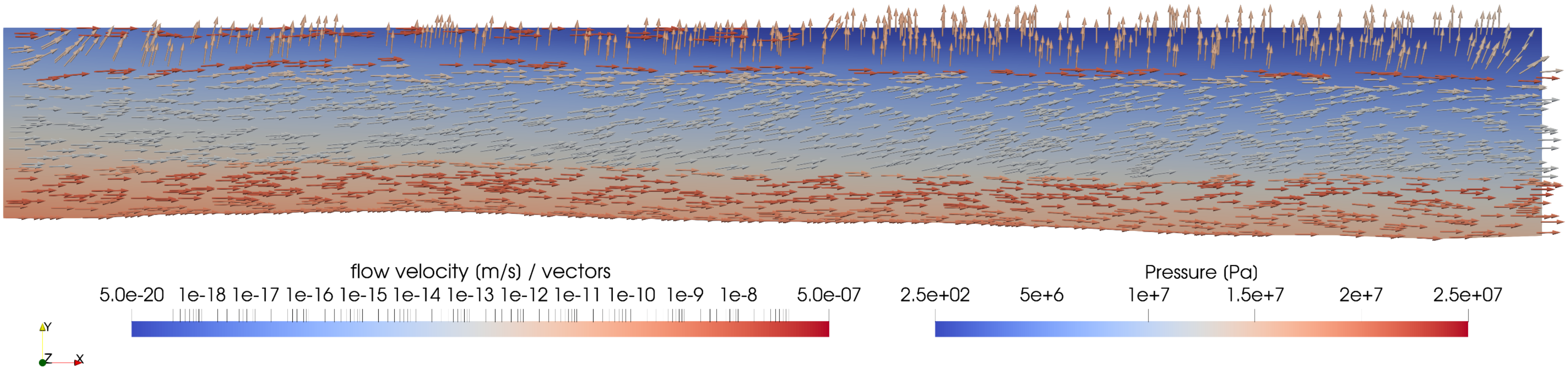
- Model boundary conditions representing the transition from a permafrost area to a glacier
- Overlap between glacier and permafrost of 100 m





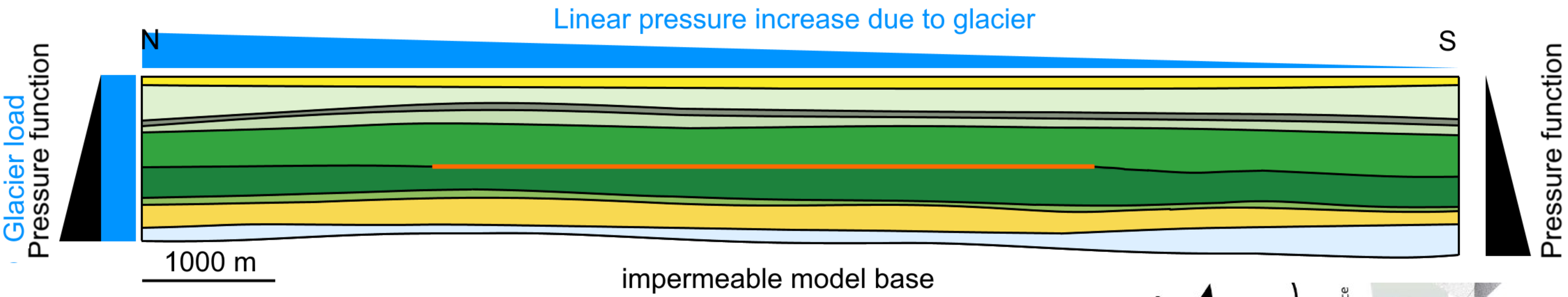
Brandefelt et al. 2019 /SKB TR-19-04

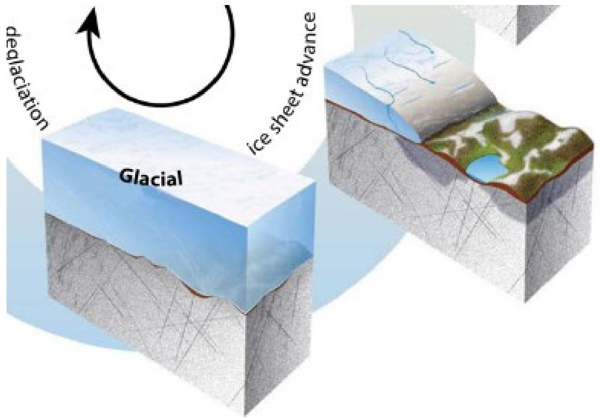
Flow velocities “permafrost and glacier”



Boundary conditions "glacier"

- Glacier covers whole model area
- Model area still represents the area of a glacier front

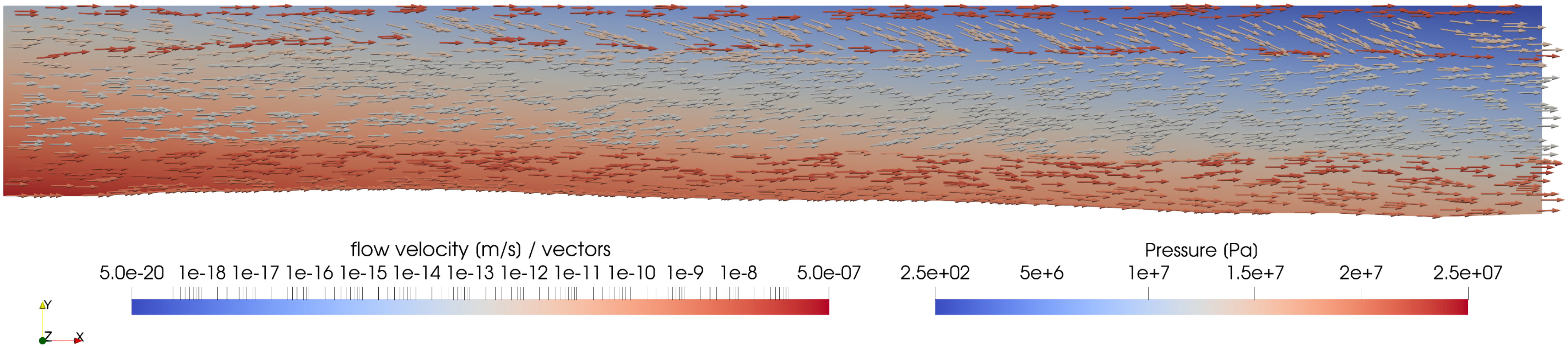




Brandefelt et al. 2019 /SKB TR-19-04

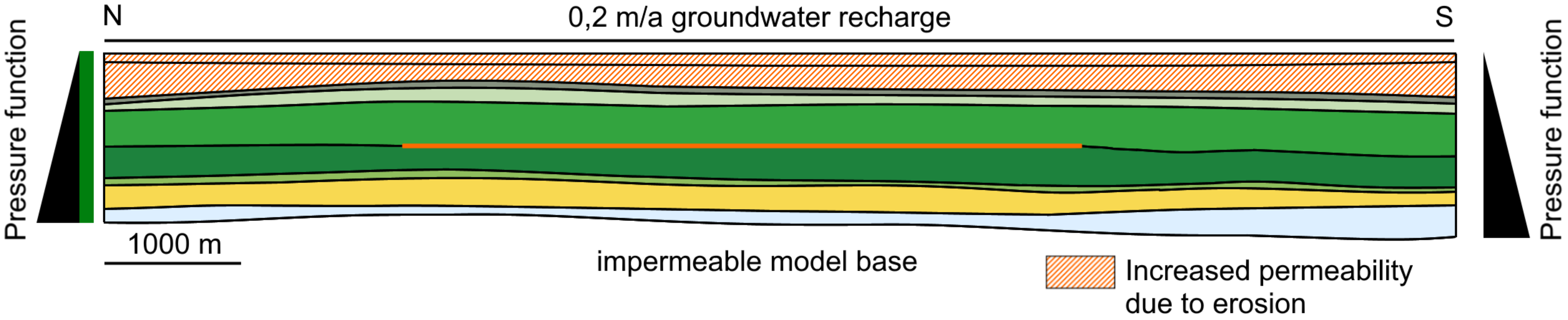
Flow velocities "glacier"

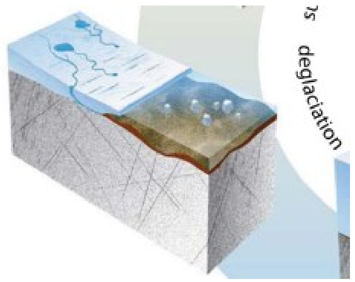
- High pressure and pressure gradient with higher flow velocities



Boundary conditions "erosion"

- Within a glacial cycle material can be eroded at the surface
- Eroded areas can be filled with sediments with increased permeabilities

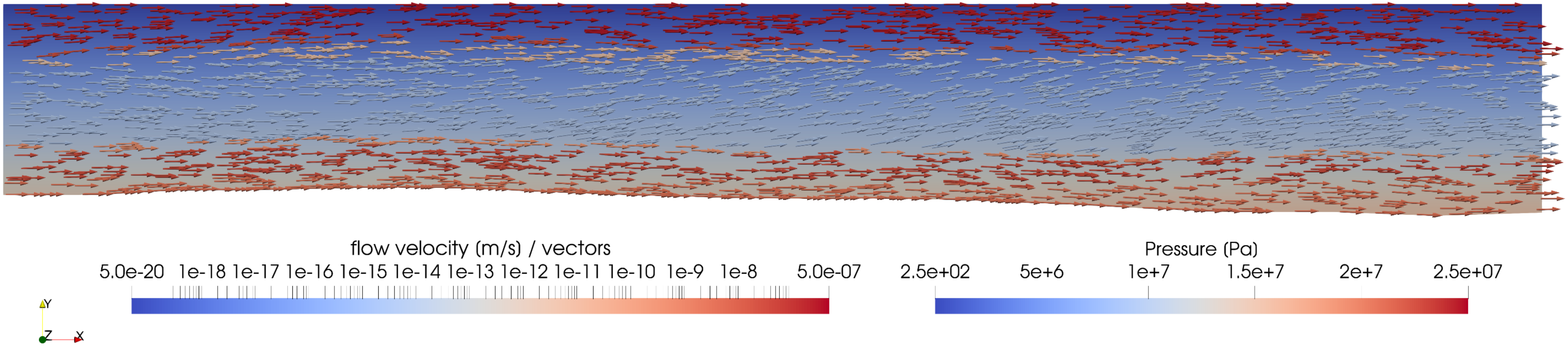




Brandefelt et al. 2019 /SKB TR-19-04

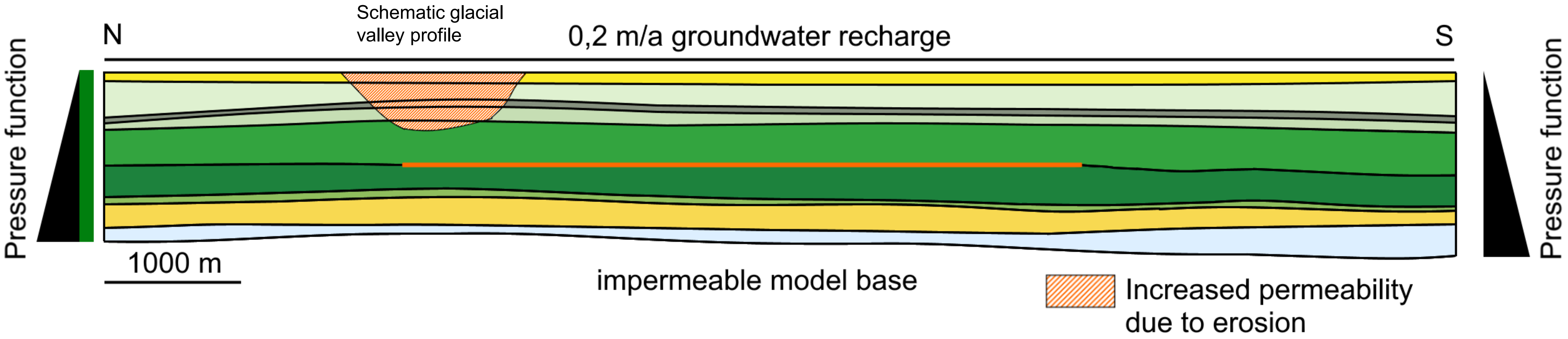
Flow velocities “erosion”

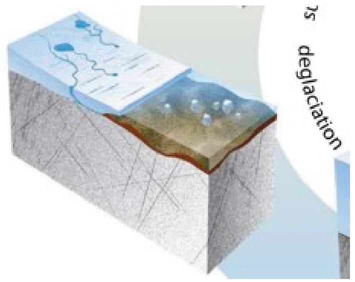
- Highest flow velocities in comparison to the other scenarios in the near surface units



Boundary conditions “erosion” (vertical valley)

- Within a glacial cycle material can be eroded at the surface
- Eroded areas can be filled with sediments with increased permeabilities





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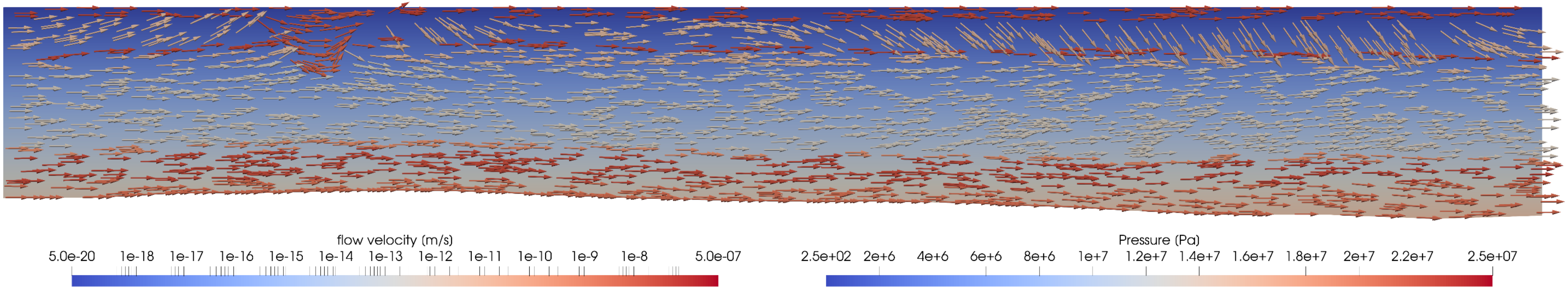
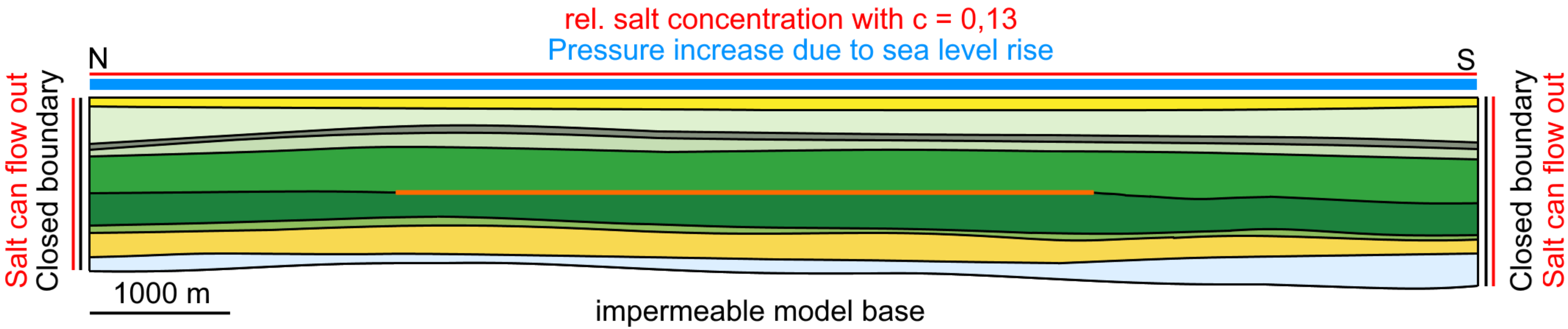
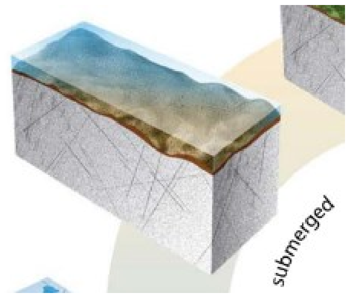


Boundary conditions “sea level rise”

- With the retreat of the glacier because of temperature increase, sea level rises can occur
- Seal level rise represented by higher pressure at model surface

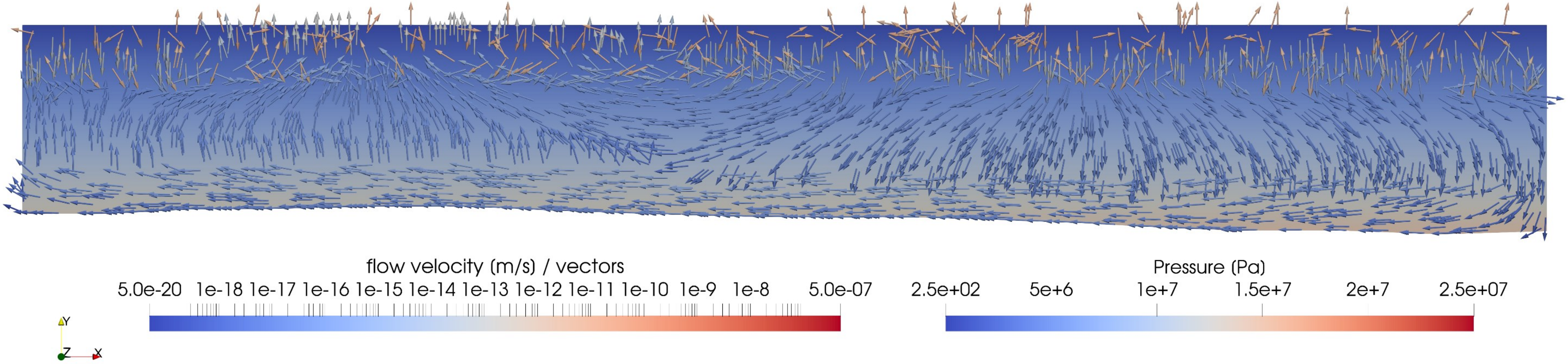




Brandefelt et al. 2019 /SKB TR-19-04

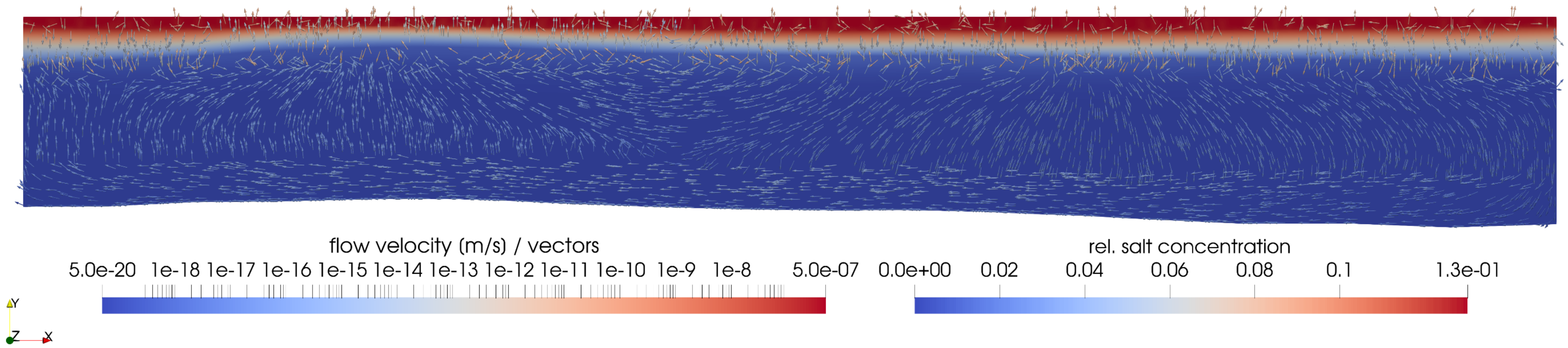
Flow velocities “sea level rise”

- Very low flow velocities
- Small convection cells at model surface



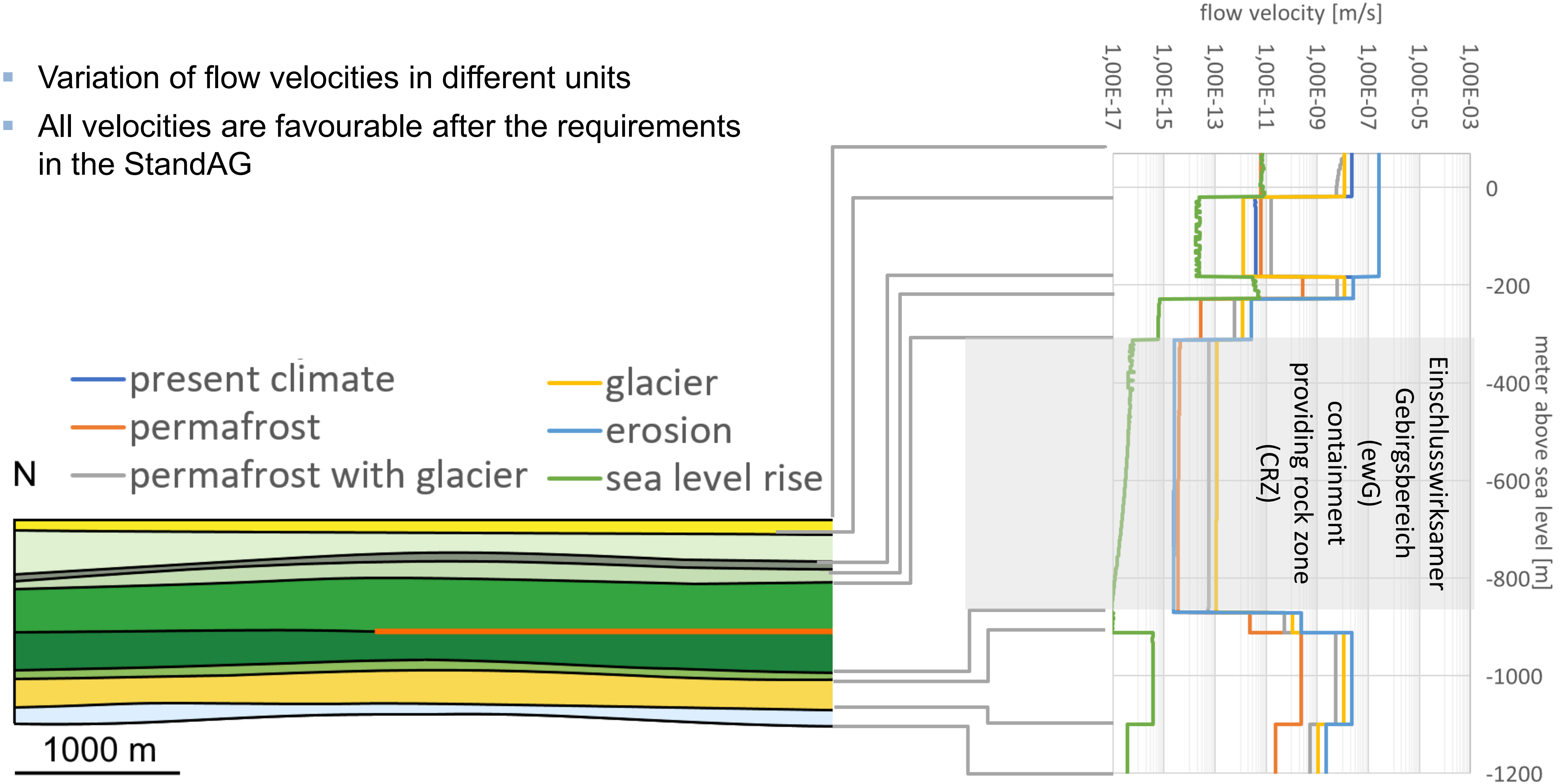
Flow velocities “sea level rise”

- Salt concentration is influenced by the lithostratigraphical model units



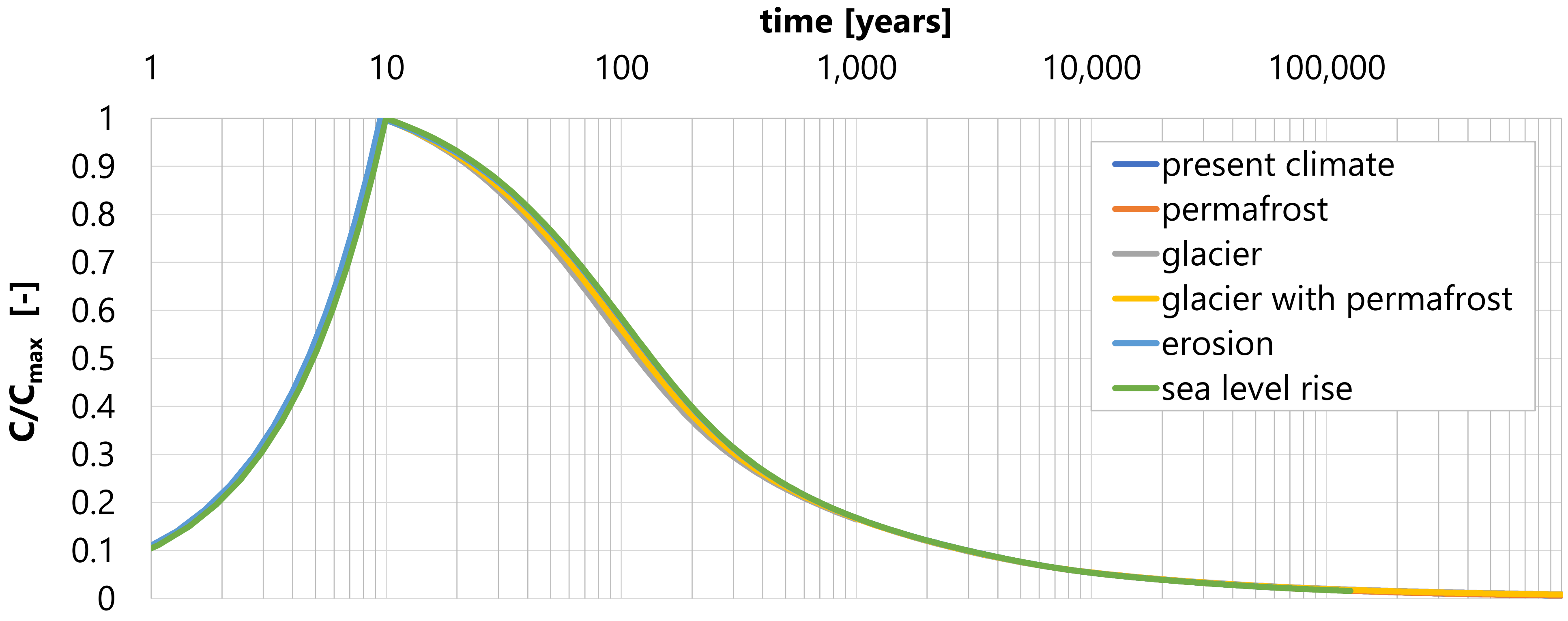
Results

- Variation of flow velocities in different units
- All velocities are favourable after the requirements in the StandAG



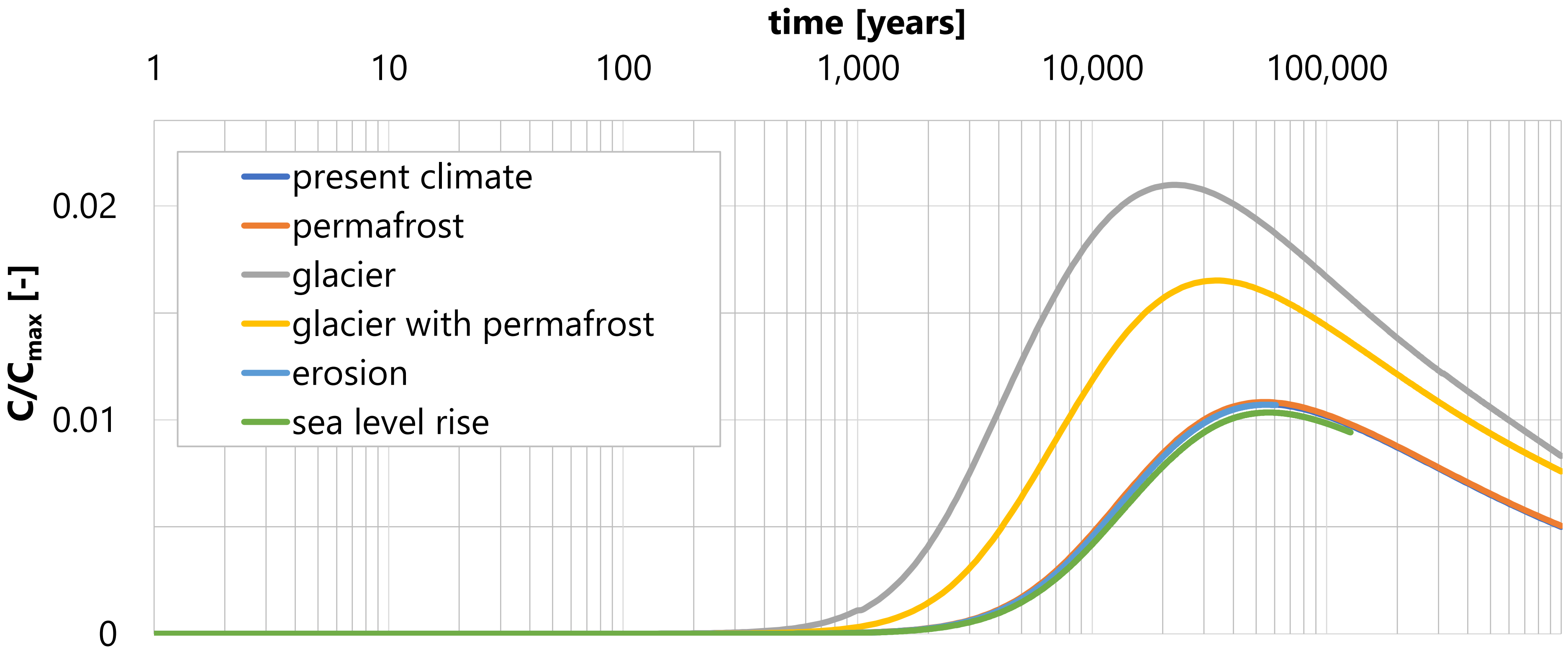
Results

- Climate state show comparable concentration curves at repository area
- Effects of climate developments seem small because the CRZ stays intact



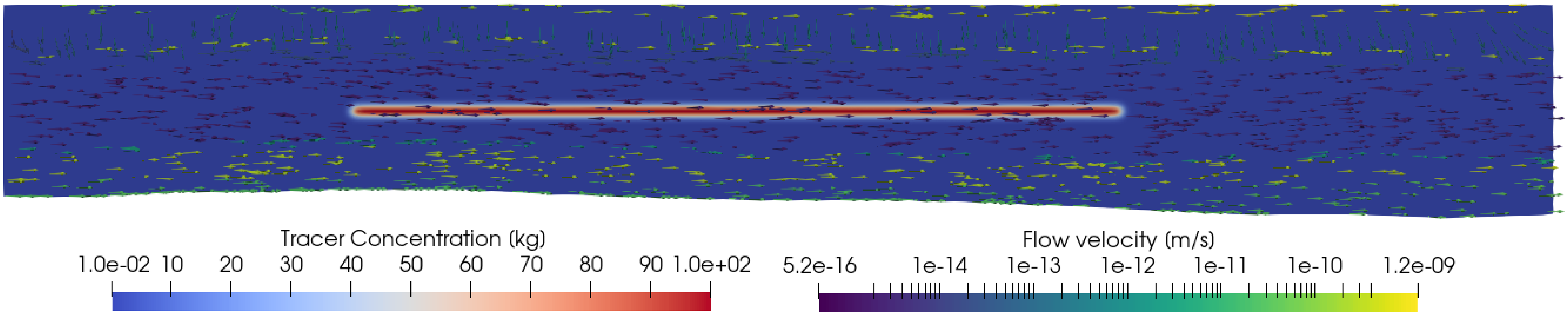
Results

- Downstream of the repository the relative concentration show some differences in the concentration distribution
- Higher flow velocities in the climate states “glacier” and “glacier and permafrost” results in higher concentrations in the downstream



Results – Parameter variation

- „Base case“
- No substance input into surrounding layers within the assessment period of 1 million years
- Diffusive transport dominates
- Almost no advective transport



Non logarithmic

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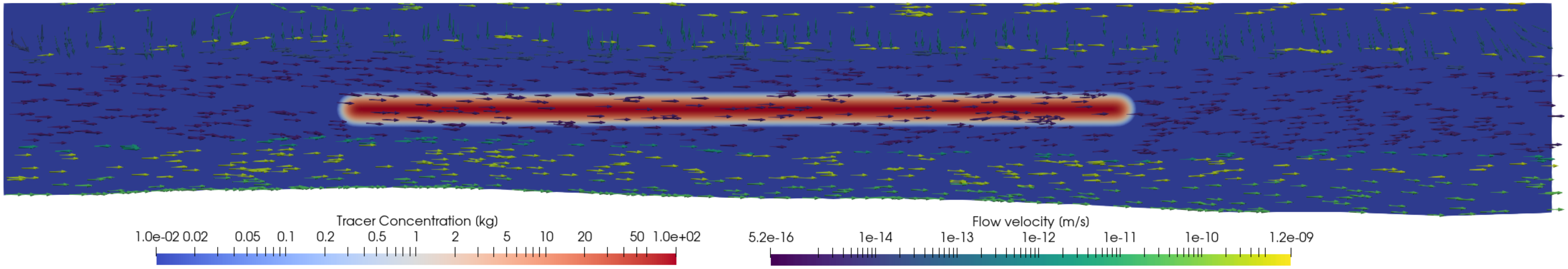
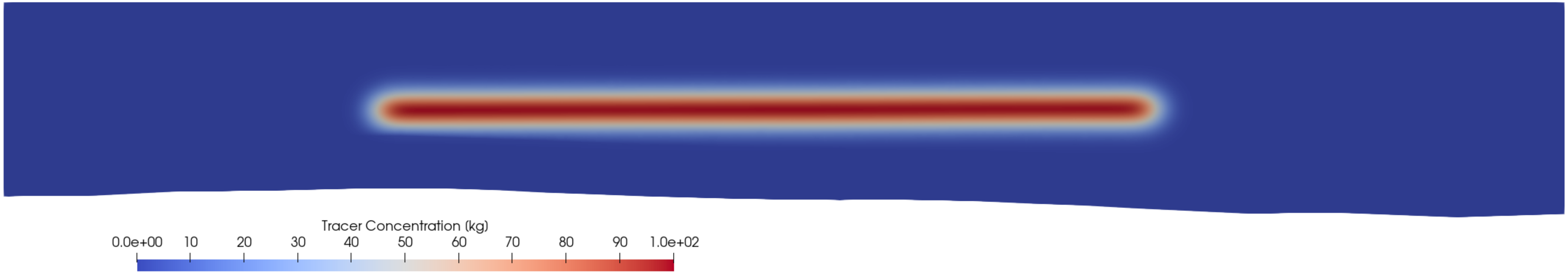


logarithmic

Results – Parameter variation

- Example for illustration of evaluation
- Figure with model case in which
  - the **diffusion coefficient** (10x) and **permeability** (100x) are **higher** compared to the "base case",
  - dispersion is chosen to correspond to the base case
- Tracer concentration after 1 million years



non logarithmic

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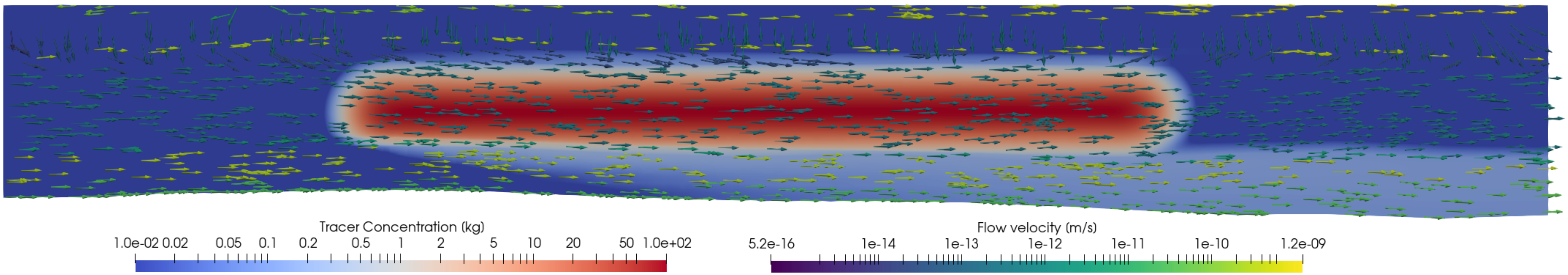


logarithmic

Evaluation of concentration

- Requirement for the long-term safety according to the Repository Safety Requirements Ordinance EndlSiAnfV:
  - §3 Assessment period; developments of the repository system: (1) Assessment period of 1 million years
  - §4 Safe enclosure of radioactive waste: (5) *"For the expected developments, it shall be examined and demonstrated that during the assessment period*

    1. a maximum total proportion of 10^{-4} and

    2. annually at most a proportion of 10^{-9}

    [...] is discharged from the area of the essential barriers.“

  - §3 Bewertungszeitraum; Entwicklungen des Endlagersystems: (1) Bewertungszeitraum von 1 Mio. Jahre
  - §4 Sicherer Einschluss der radioaktiven Abfälle: (5) *„für die zu erwartende Entwicklungen ist zu prüfen und darzustellen, dass im Bewertungszeitraum*

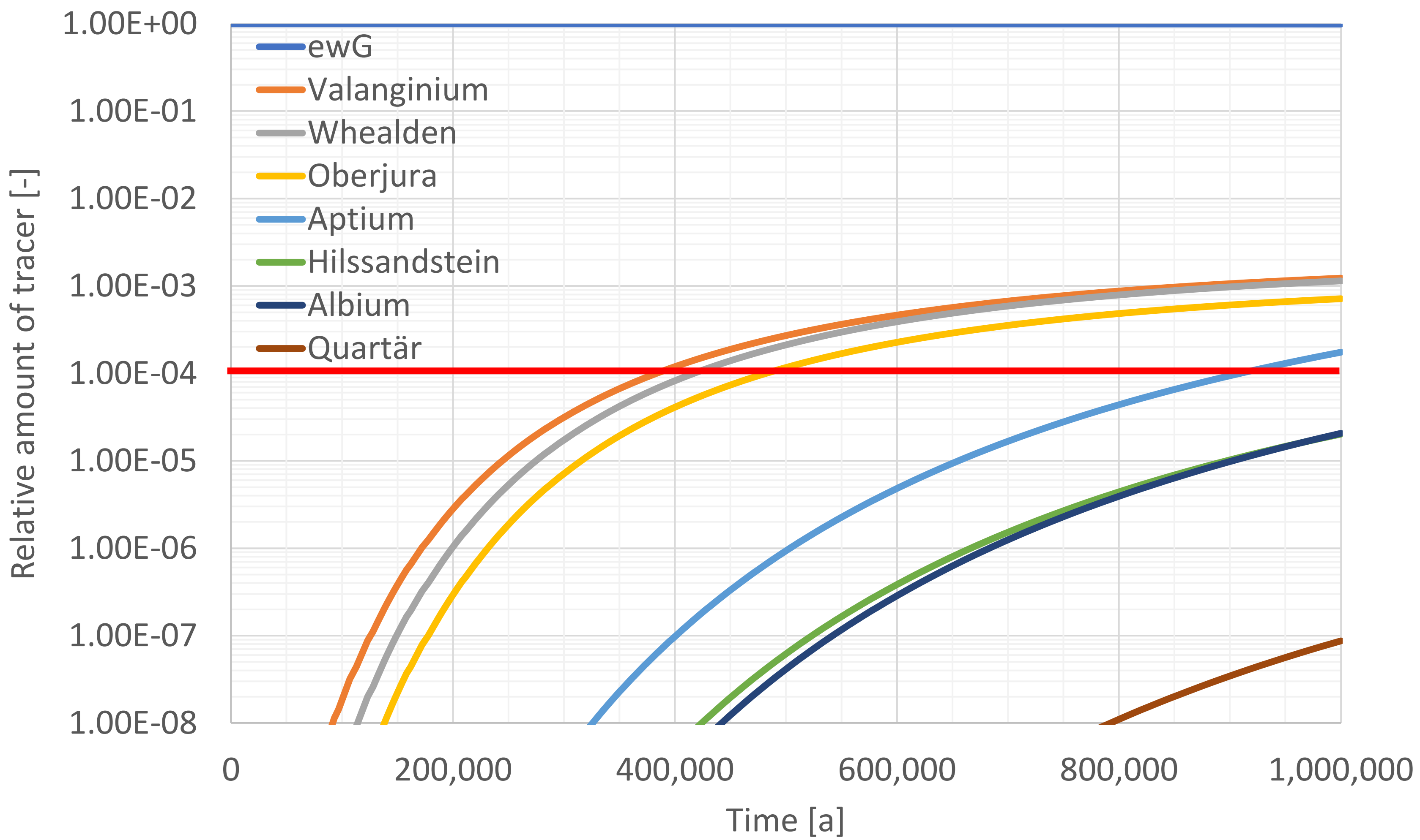
    1. insgesamt höchstens ein Anteil von 10^{-4} und

    2. jährlich höchstens ein Anteil von 10^{-9}

    […] aus dem Bereich der wesentlichen Barrieren ausgetragen wird.“

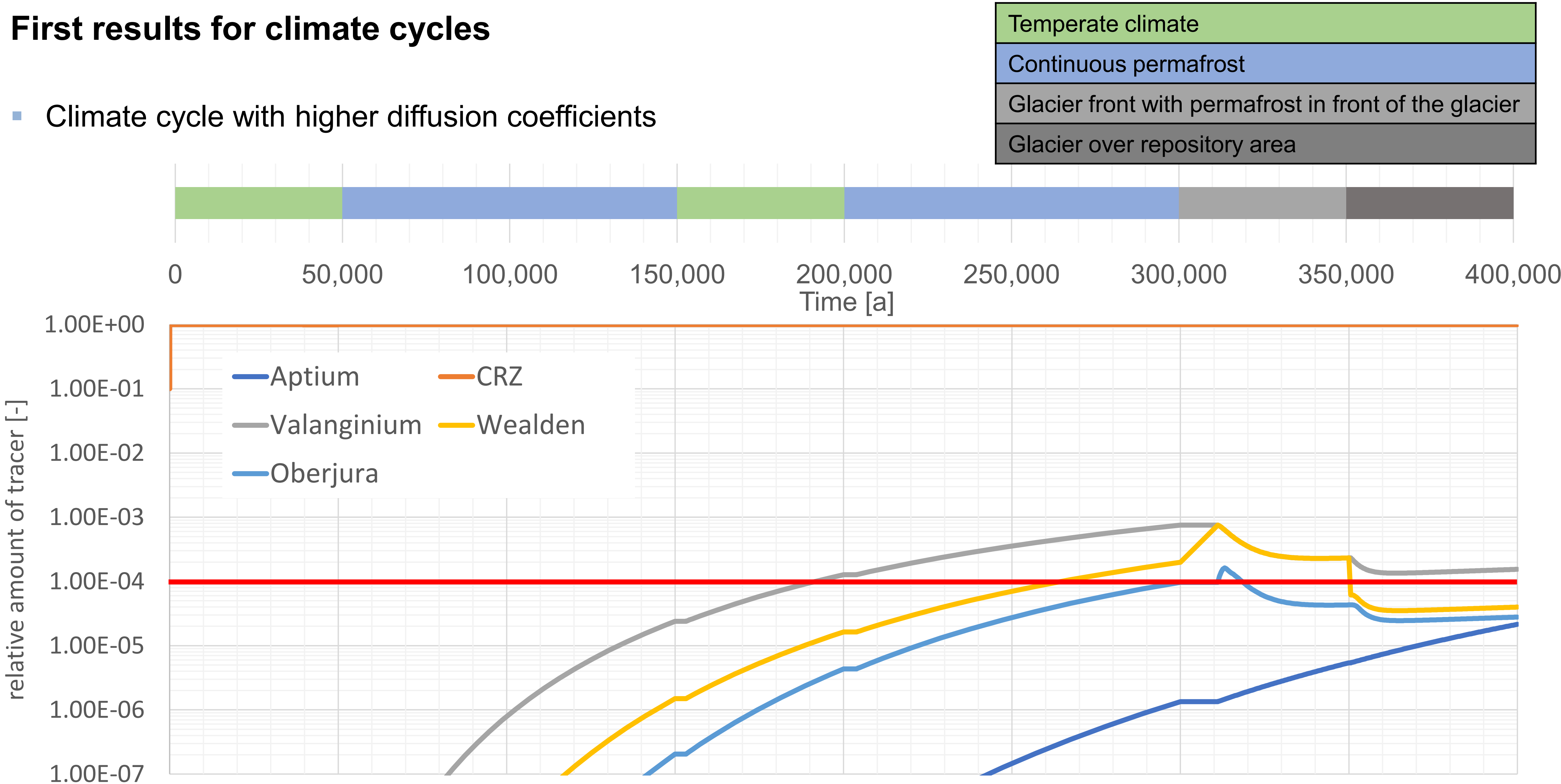
Parameter variation – diffusion coefficient (10x) and permeability (100x)

- d³f++ writes out the integrals of the substance quantities of the different units



First results for climate cycles

- Climate cycle with higher diffusion coefficients



Evaluation - summary

- Diffusive transport dominates
- Tracer transport distances are small
- Relative amount of tracer is below a proportion of $1 \cdot 10^{-4}$ outside of the CRZ/ewG
- Higher diffusion coefficients are very sensitive to the safety criteria of the StandAG
  - Proportion can be higher than $1 \cdot 10^{-4}$ due to diffusion processes
- Effects of climate states do not change the concentration distribution in the CRZ/ewG area in a relevant extend

Categories of uncertainties

Parameter uncertainties	Model uncertainties	Scenario uncertainties
• Missing data • Reliability of the data • Applicability of the data • Error ranges • Spatial and temporal variability	• System understanding • Simplifications • Model assumptions • Model boundaries	• System understanding • Uncertainty of future developments

- Generic RESUS/ANSICHT model
- Some representative data for typical stratigraphical units in Germany
- Bandwidths for lithostratigraphical units → Partial wide bandwidths

➢ Change model parameters to get information about the sensitivity of different parameters

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Parameter uncertainties	Model uncertainties	Scenario uncertainties
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- Absolute and relative error
  - Simulations with different grid refinements to address the error
- Repository area as line source for radionuclides
- Complexity of processes on smaller scale

Categories of uncertainties

Parameter uncertainties

- Missing data
- Reliability of the data
- Applicability of the data
- Error ranges
- Spatial and temporal variability

Model uncertainties

- System understanding
- Simplifications
- Model assumptions
- Model boundaries

Scenario uncertainties

- System understanding
- Uncertainty of future developments

- Broad range of possible scenarios
- Higher probability for “temperate climate” in the future

Summary

- Flow velocities changes through different considered climate states
- Groundwater models helps to understand the sensitivity of parameters and different climate scenarios
  - In low permeable claystone the concentration front does not reach the top of the CRZ in assessment period with parameters from ANSICHT model
  - Higher diffusion coefficient and Glacier load lead to transport in the Lower Cretaceous/Upper Jurassic units
    - ➢ Diffusion coefficient is an important parameter for host rock clay
  - Choice of parameters or differences in rock characteristics can have larger influence on model results than different climate states
  - ➢ Good exploration and choice of parameters will be very important in the site selection because of high sensitive parameters identified in simulations
  - ➢ Reduction of knowledge uncertainties of parameter sensitivity

Outlook

Model cases

- Further simulations with different parameter settings
  - Implement Taliki (unfrozen soil) in permafrost simulations
  - Different diffusion coefficient values (highest sensitivity up to now)
  - Use the data from CLIMBER-X for climate state cycles

Thank you for your attention!

Further information on the research project and the participating institutions can be found at https://urs.ifgt.tu-freiberg.de/en/home

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Research order number: STAFuE-21-4-Klei

Literature

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