Reduction of scenario uncertainties through climate models (REDUKLIM)

Compilation of the important impacts from climate development for long-term safety

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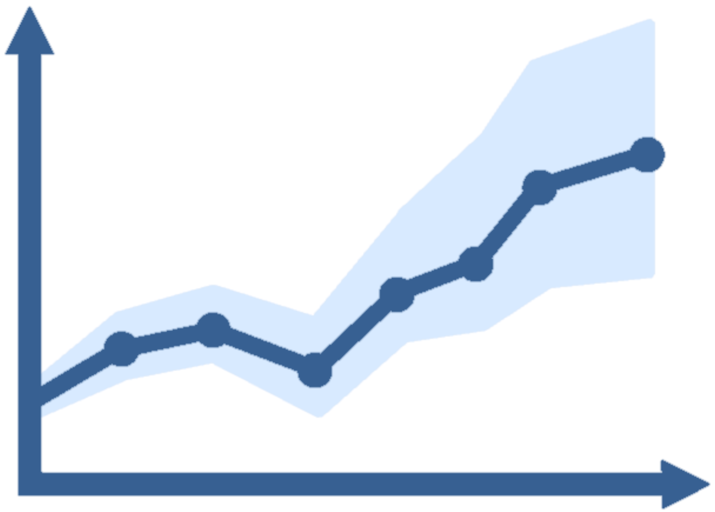
17th March 2023

Structure

1. Research aims
2. Climate triggers and factors
3. Implementation of climate factors
4. Climate Scenarios
5. Summary and upcoming work

Research aims

- Future climate developments in long-term safety and possible uncertainties
- Assessment period of one million years (EndSiAnfV § 3)
- Consideration of the geological and climatic situation
  - Developing a better understanding of potential future climate developments
  - Linking of climate modelling and groundwater processes for the safety assessment



Compilation of the important impacts from climate development for long-term safety

- Identify processes triggered by climate developments
  - Considering FEP catalogues
    - Filtering relevant processes with reference to climate developments
  - Considering international literature with reference to repository safety
    - Identify the most mentioned impacts of climate changes

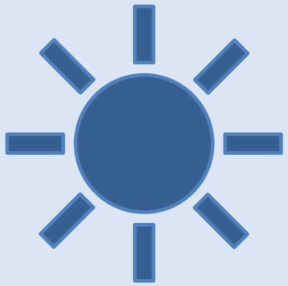
Compilation of international literature on climate modeling

and many more…

Triggers for climate changes

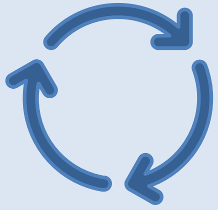
Extra terrestrial factors

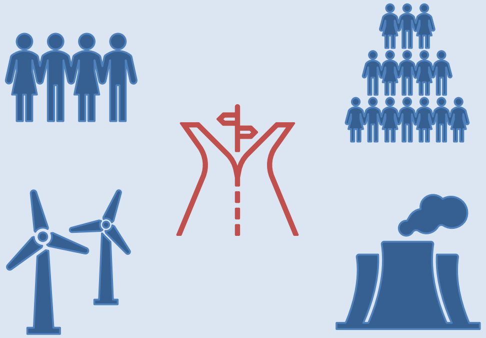
- Earth orbit parameters
- Solar radiation
- Meteorite impact



Terrestrial factors

- Plate tectonics
- Vulcanism
- (Material-) Cycles
  - Anthropogenic impacts





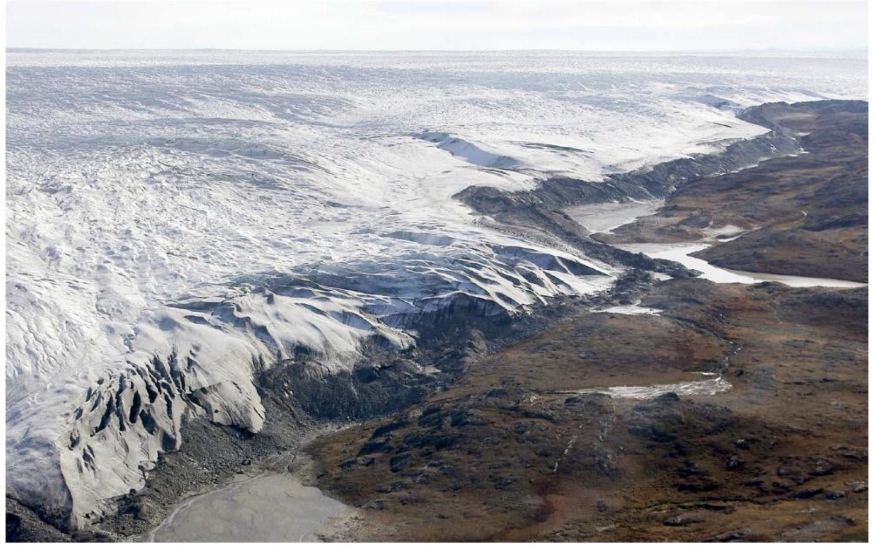
Possible impacts of climate changes

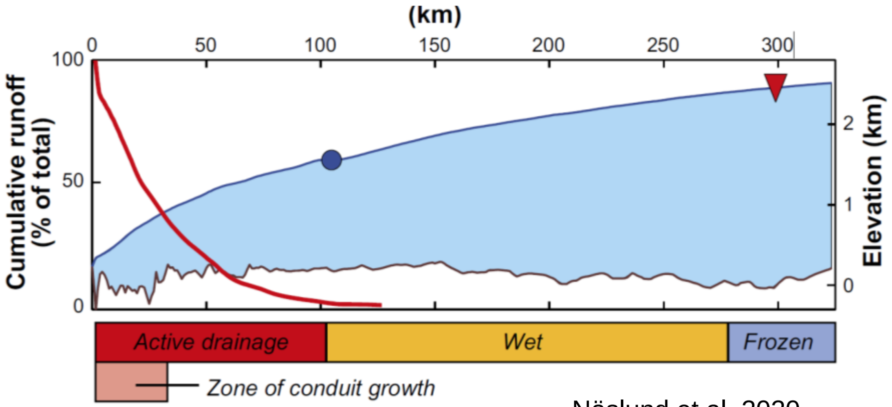
- Temperature and pressure conditions influence all subordinate developments

Temperature	Glaciation	Pressure
Isostatic Adjustment	Permafrost	Chemical reactions
Erosion / Subrosion	Sea level changes	Groundwater conditions

Glaciers / ice sheets

- Accumulations of snow
- Glaciers confined by topography / Ice sheets spread to all directions
- Never in a steady state, since climate is constantly changing
- Ice temperature → fundamental importance to behavior and characteristics
  - Temperate/ warm ice
  - Polar/ cold ice → harder, impermeable to water unless crevasses are present
- Ice sheet bed
  - Cold based → no free water on bed, no movement/sliding
  - Warm based → pressure melting point at bed → free water, possible sliding over substrate



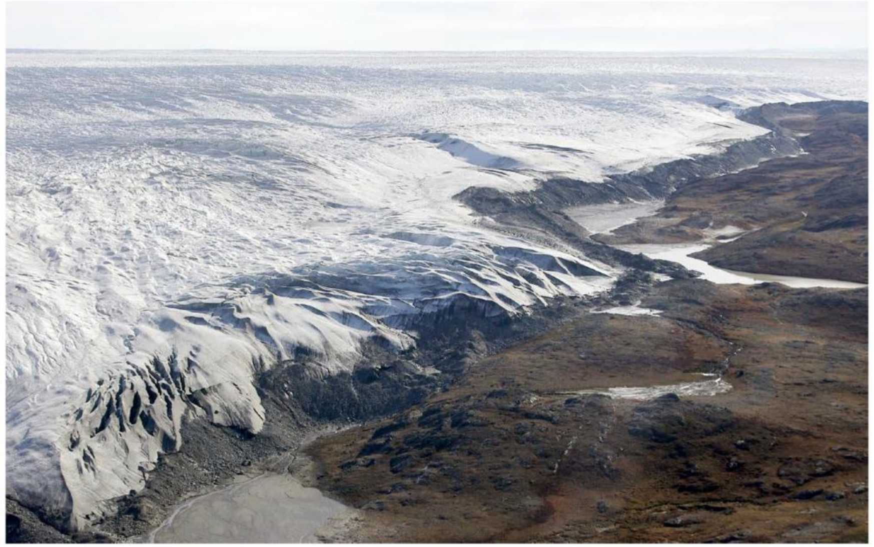


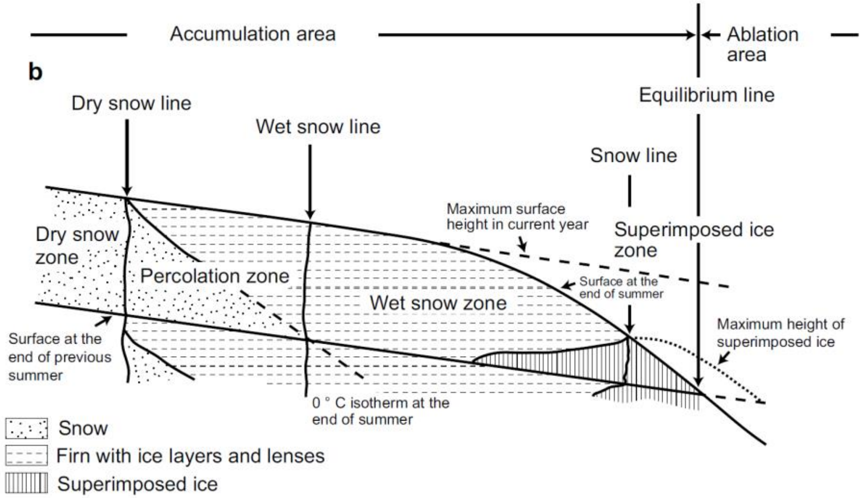
Näslund et al. 2020

Glaciers / ice sheets

- Mechanical load for the underlying rock and possible reduction in pore space
- Ice load can cause fractures in the underlying rock
- Increased temperature due to higher pressure at the rock surface – no Permafrost
- Formation of meltwaters at rock surface
- Increased surface runoff and groundwater recharge rate in melting areas
- Glaciation is accompanied by strong morphological changes in the area of the glacier front

- Glaciations in N- and S-Germany possible
  - Ice thicknesses of some 100 meters up to 1.500 m





Näslund et al. 2020

Permafrost

- Subsoil whose temperature is continuously below 0°C for at least two years
- Surface temperature presupposes the development of permafrost depth
- Water in the pore space is frozen except taliks
- ➢ Reduction of permeability and porosity
- ➢ No groundwater recharge in permafrost areas

- Permafrost thickness max. 450 m in Forsmark region under unrealistic model assumptions
  - 250 m under more realistic assumptions
- Permafrost thickness around 120 to 200 m assumable in Germany

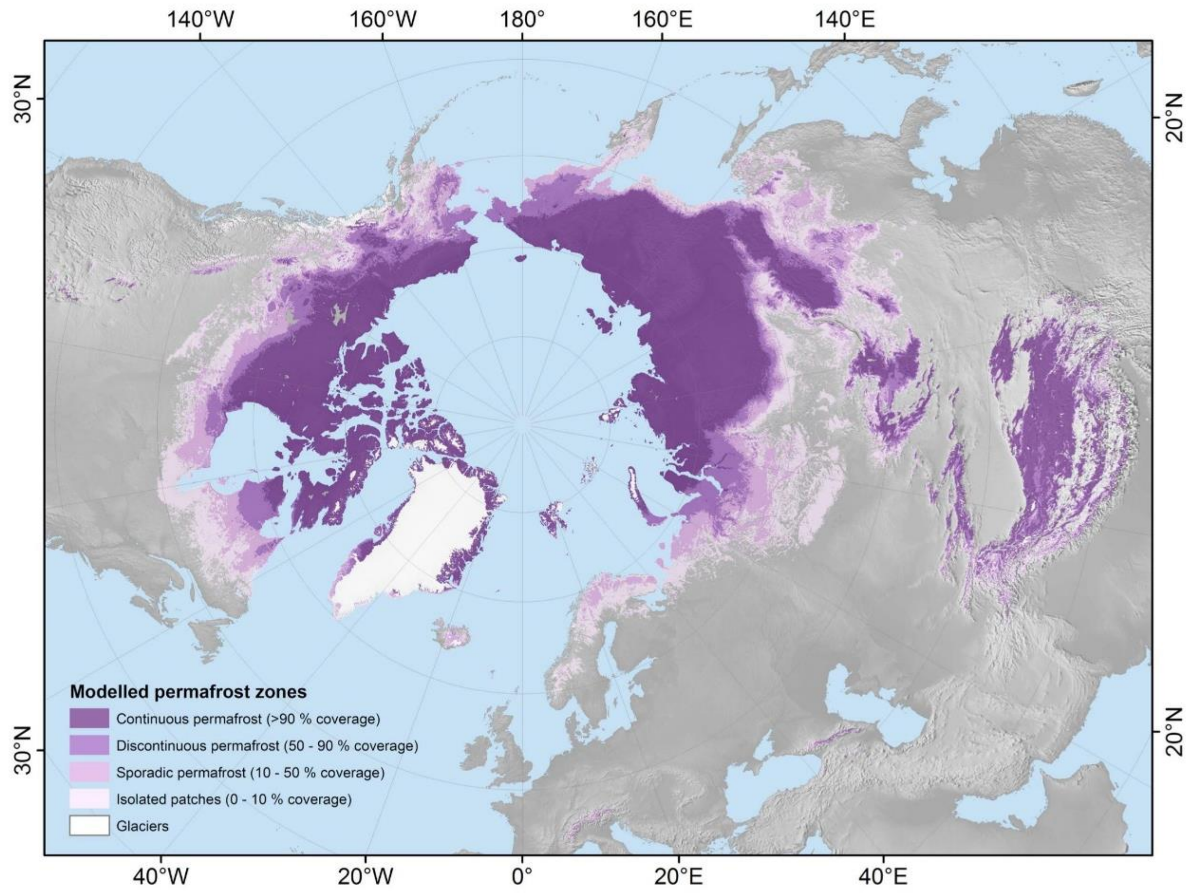
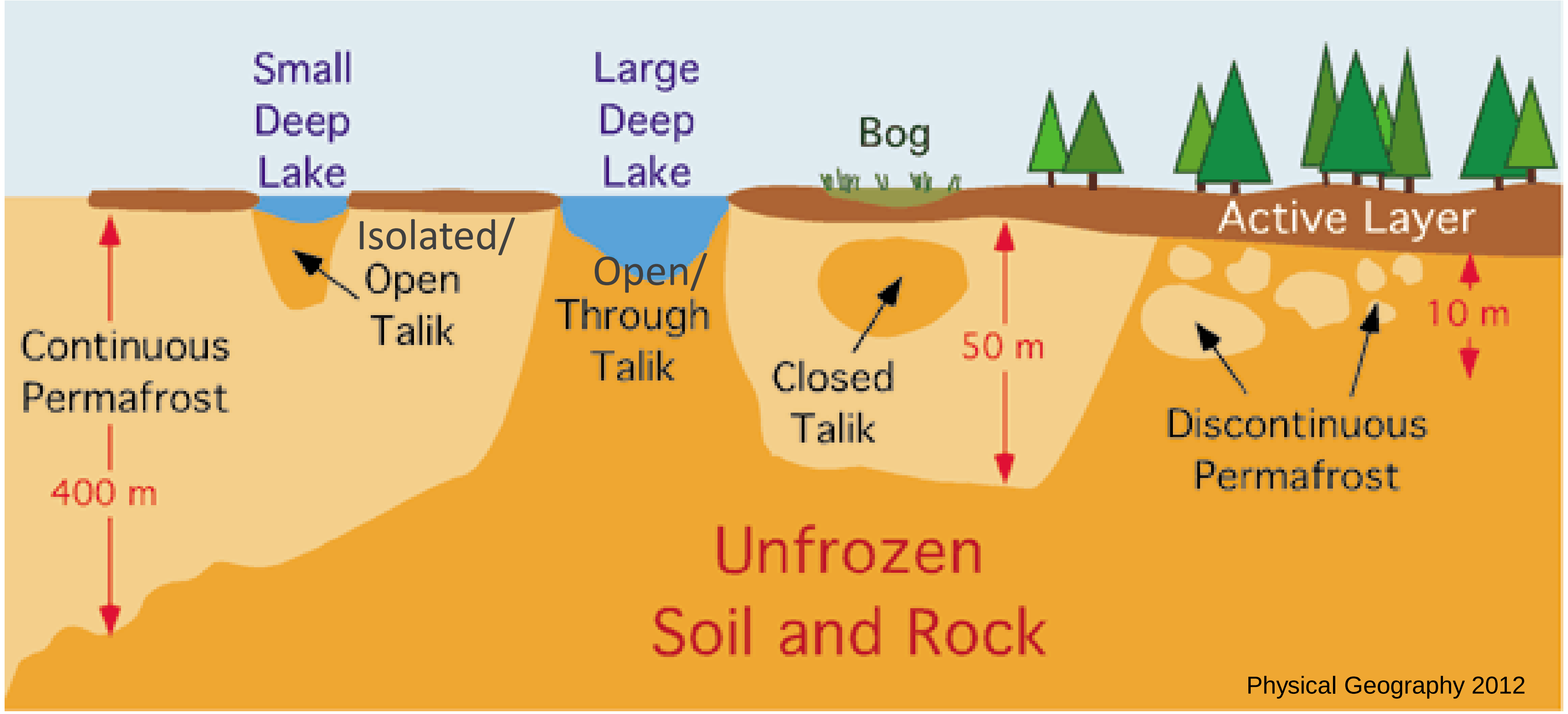


Fig. 5. Permafrost zonation based on classified modelled permafrost probabilities (Fig. 4) which correspond with the fraction of each 1 km^2 pixel underlain by permafrost.

Obu et al. 2019

Permafrost - Taliks

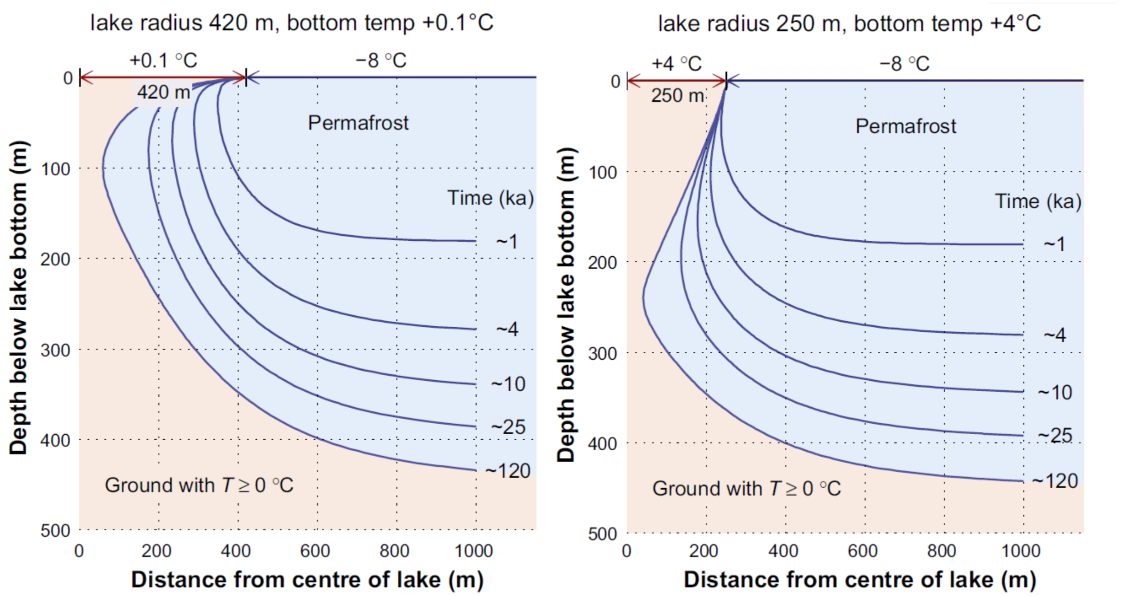
- Unfrozen body or layer in permafrost areas due to thermal, hydrological, hydrogeological, or hydrochemical anomaly
- Temperatures above 0°C (non-cryotic) or below 0°C (cryotic)
  - Isolated (open) talik
  - Closed talik
  - Open (through) talik



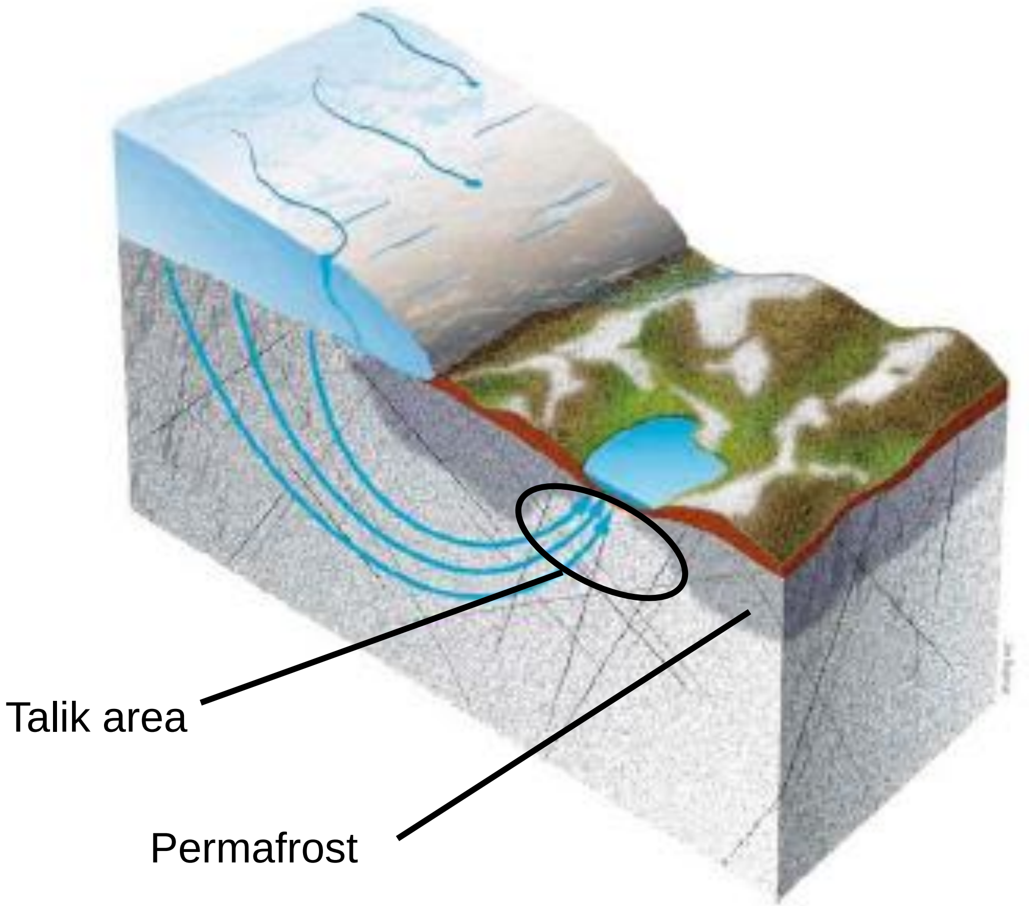
Physical Geography 2012

Permafrost - Taliks

- Lakes in front of glaciers as basis for taliks
- Possible hydraulic interaction with glacier and melt water



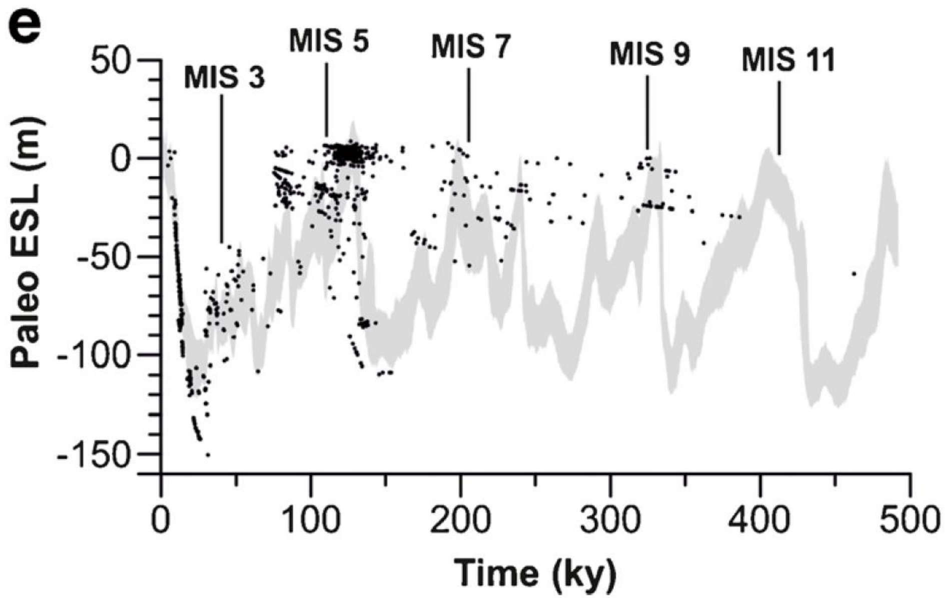
Näslund et al. 2020



Jaquet et al. 2019 (SKB R-19-17)

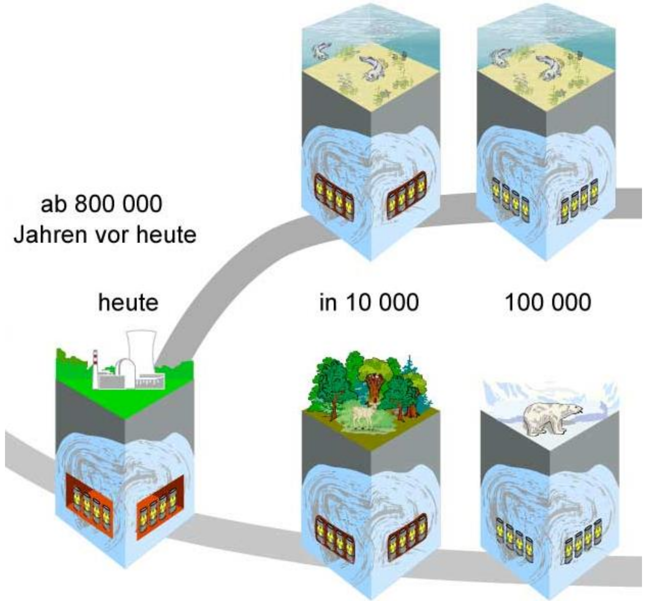
Sea level changes

- Global ice volume and growing or melting ice masses change the sea level
- ➢ Possible "global warming" scenario: long term flooding of a final repository
- Salt water intrusion into the subsurface
- Changing of the hydrogeological conditions and watersheds

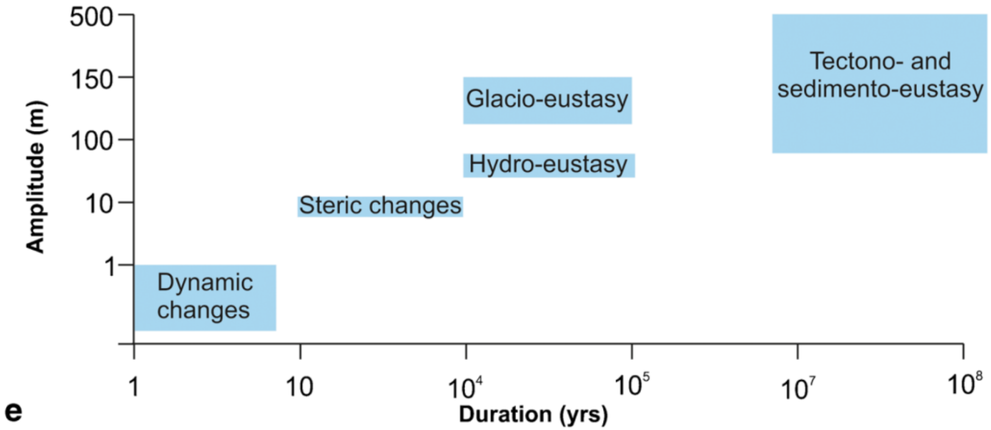


Melting of the Antarctica and Greenland ice sheet leads to sea level rise of about 65 m

Allison et al. 2009



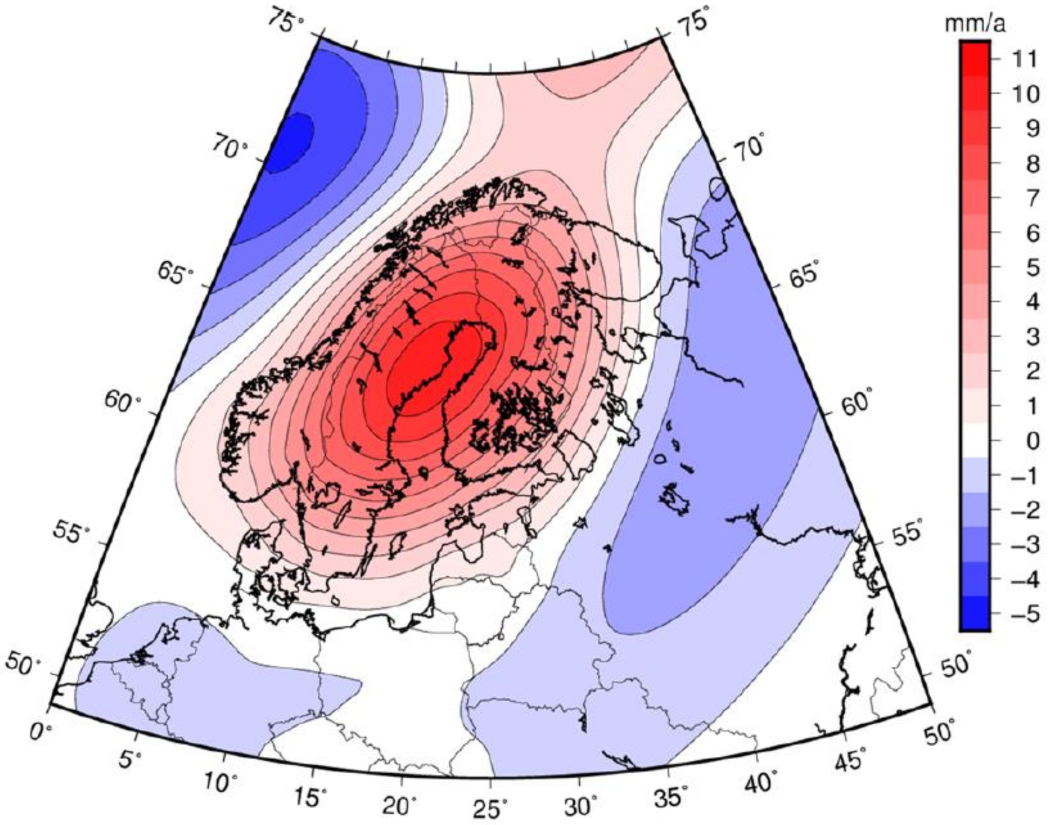
Weitkamp 2010



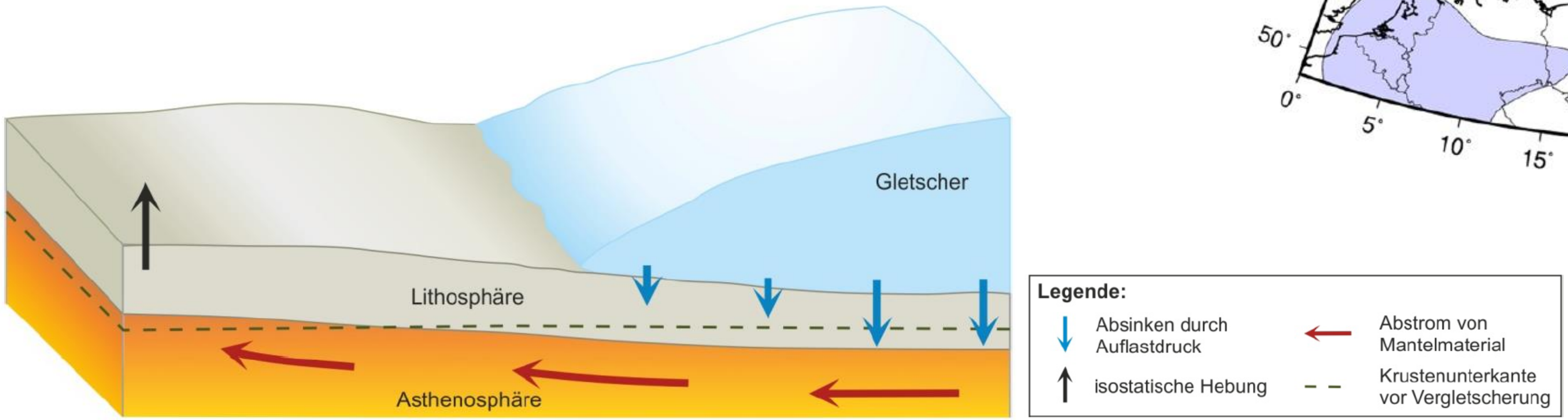
Rovere et al. 2016

Glacial Isostatic adjustment (GIA)

- Increased or decreased loading of glaciers and ice sheets causes crustal deformation related to isostatic adjustments movements
- Uncertainties of climate development outweigh the minor isostatic adjustment movements that could be expected in Germany
- Influence of climate-induced sea level changes is higher



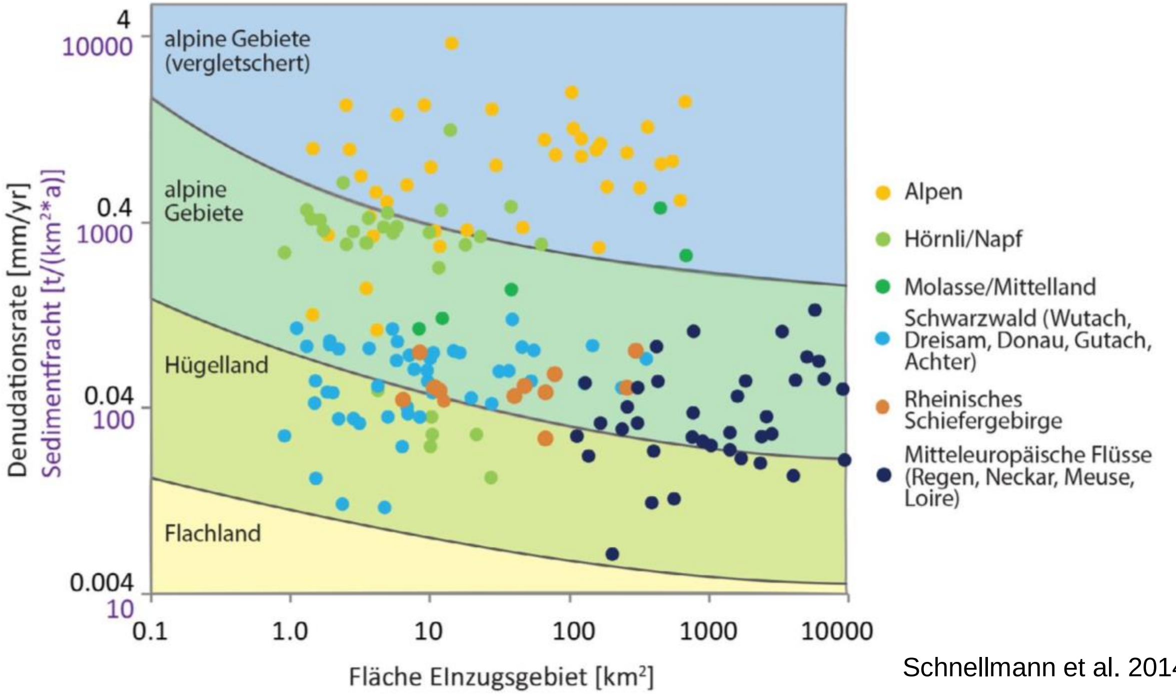
Vestøl et al. 2019



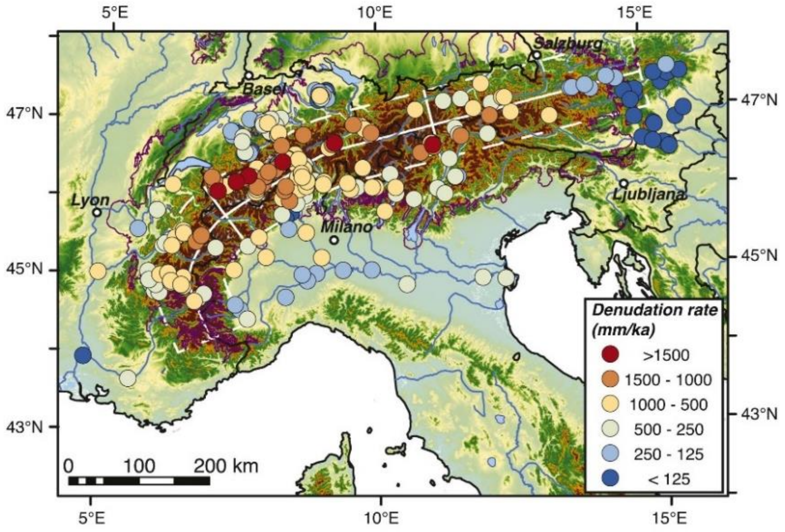
Mrugalla 2011 (GRS-275)

Surface Denudation

- Denudation is a combination of weathering, erosion and transport
- Broad range of erosion rates (higher with glacial cycles or tropical conditions)
- Glaciers and rivers can erode big volumes over short time
- Soil and quaternary sediments can have higher erosion rates but has lover slope in Northern Germany
- Bedrock erosion rates are lower but the slope can be higher (e.g. alps)
- Erosion with more than 400 m deep valleys are possible



Schnellmann et al. 2014

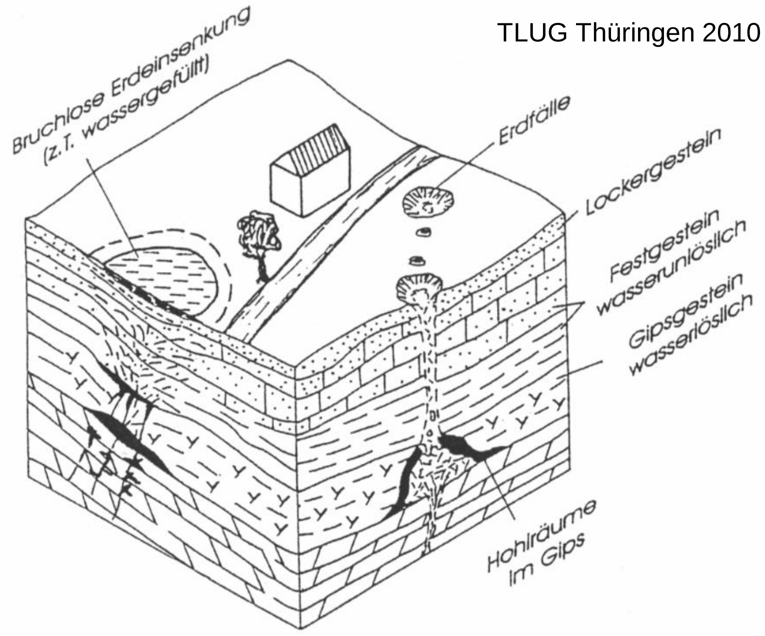


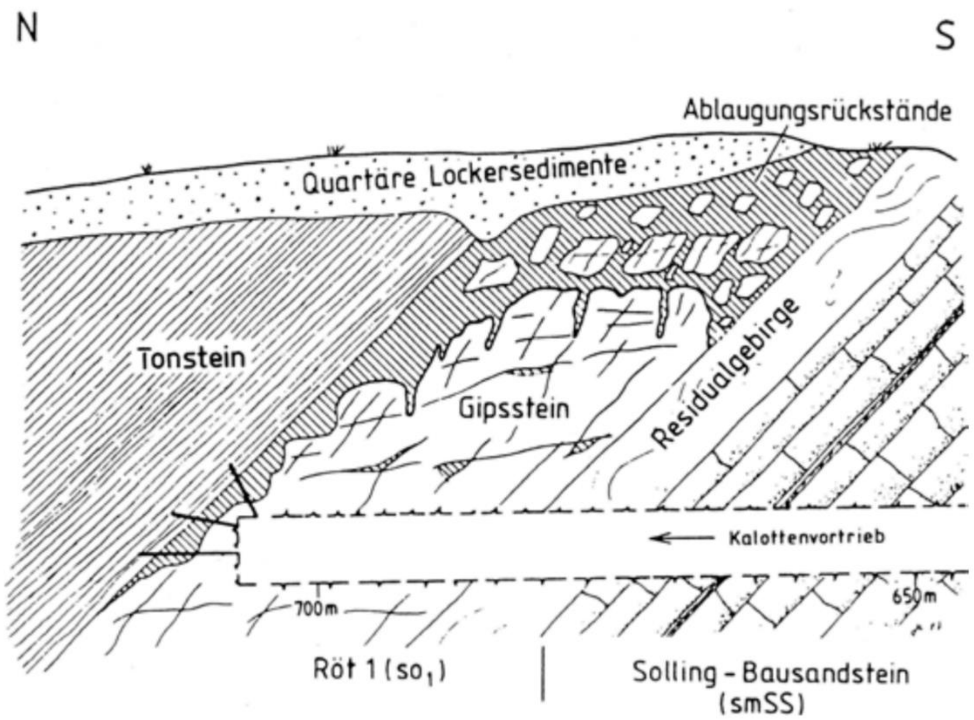
Delunel et al. 2020

Subrosion

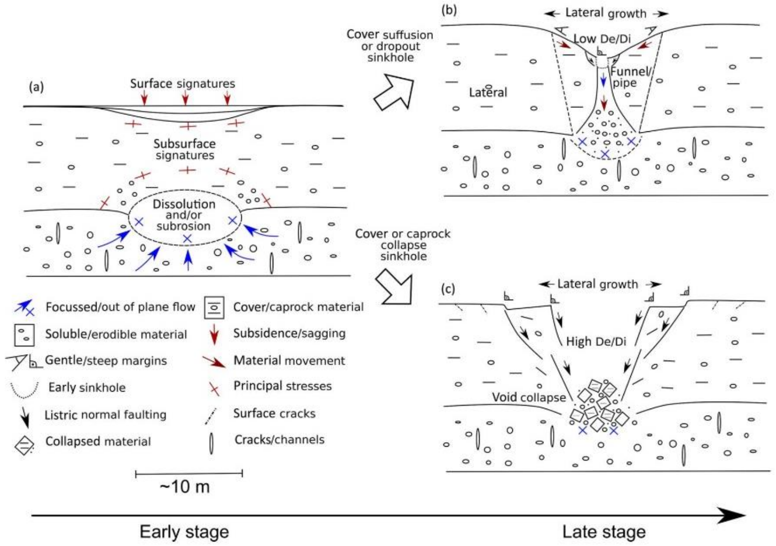
TLUG Thüringen 2010

- Dissolution of salt from host rock or contaminant-providing rock zone
- Chlorides or carbonates are affected
- Collapse of dissoluted areas can cause sinkholes





Prinz & Strauß 2018



Al-Halbouni et al. 2019

Implementation of climate factors – d³f++

- Conditions are represented by changed boundary conditions in the groundwater model
- No change of model geometry possible
- Change of parameters stepwise or with time functions

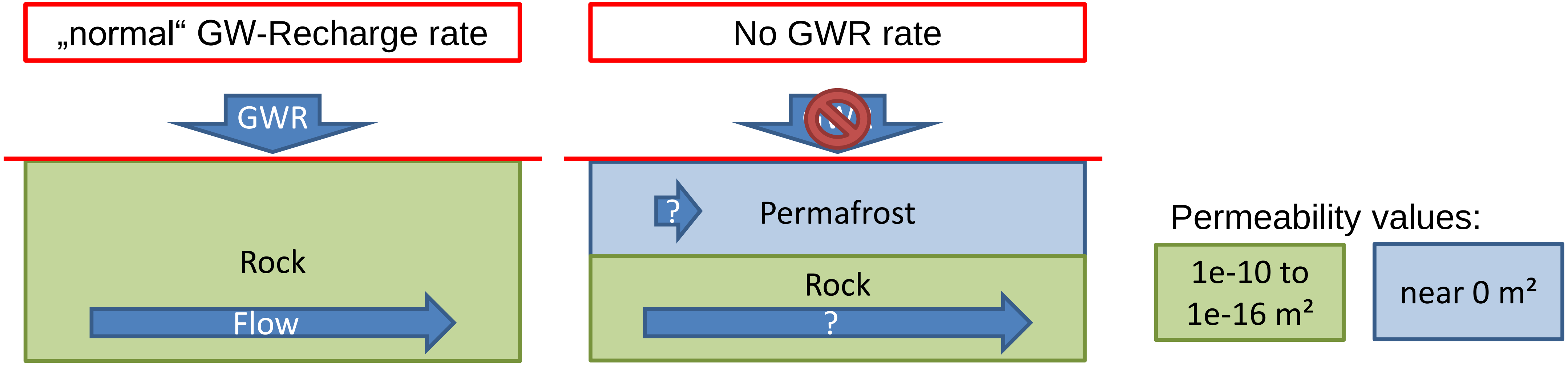
d³f++

- Flow and salt transport equations
- Finite Volume Discretisation
- Fully parallelized
- Structured and unstructured grids
- Advection, dispersion, diffusion
- Porous medium and fractures
- Sources and sinks
- Free groundwater surface
- Heat transport
- Permafrost conditions (icing and melting)
- Dirichlet, Neumann and Cauchy boundary conditions
- Fluid density and viscosity in depending on salt concentration and temperature

- Transport equations
- Advection, dispersion, diffusion
- Element dependent porosity
- Dirichlet, Neumann and In/Out boundary conditions
- Sources and sinks
- Radioactive decay
- Sorption
- Precipitation / Solution

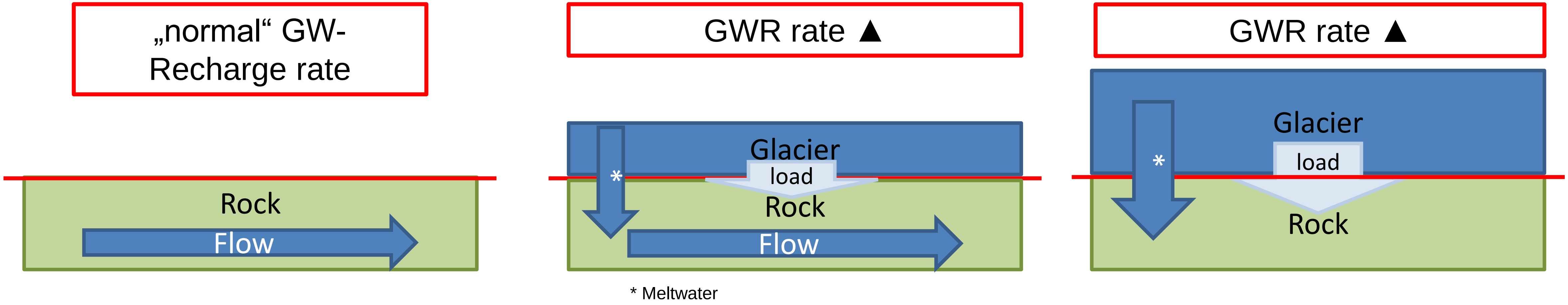
Implementation of climate factors - Permafrost

- Water in the pore space is frozen and thus reduces permeability
  - ➢ Reduction of permeability in the affected model area
  - ➢ No groundwater recharge in permafrost areas



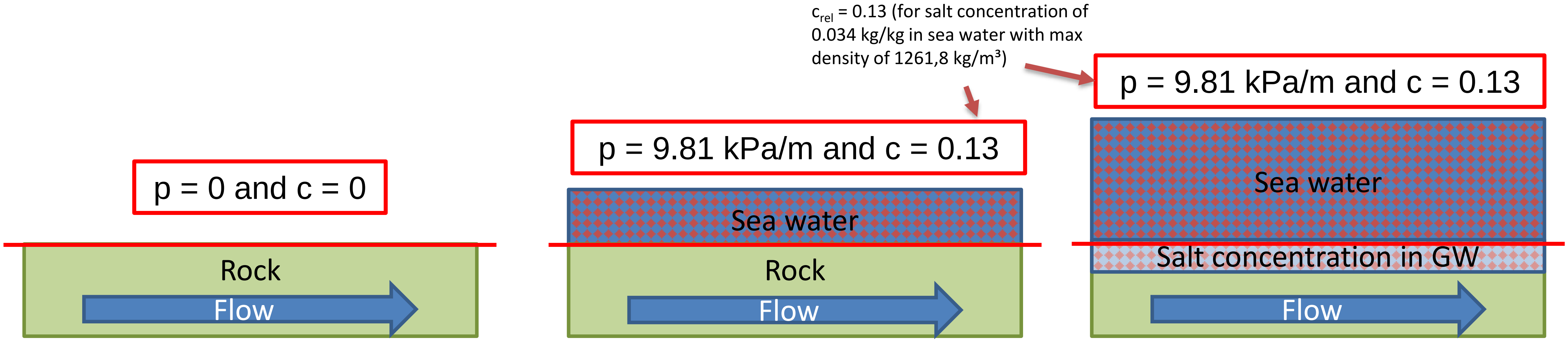
Implementation of climate factors - Glaciers and ice sheets

- Mechanical loading for the underlying rock
  - Increased temperature due to higher pressure at the rock surface (→ No Permafrost)
  - Formation of meltwater at rock surface or during short-term events
- ➢ Increased groundwater recharge rate in the model area



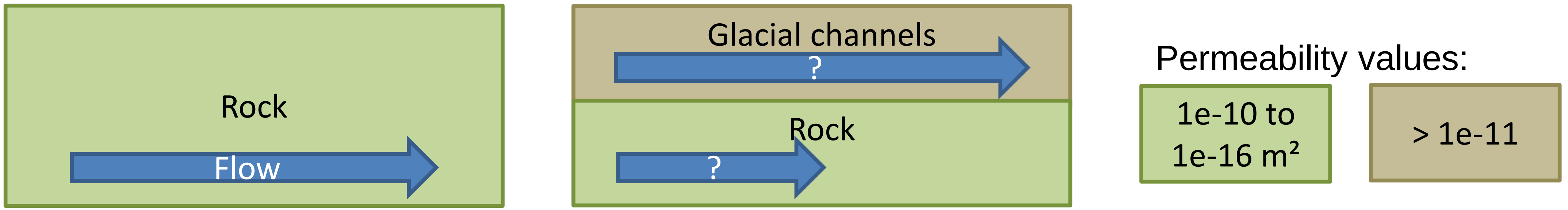
Implementation of climate factors – Sea level changes

- Change in sea level due to global melting of ice masses
  - Possible long-term flooding of land areas
- Saltwater intrusions
  - Change in salinity boundary condition
- Higher hydraulic pressure during transgression

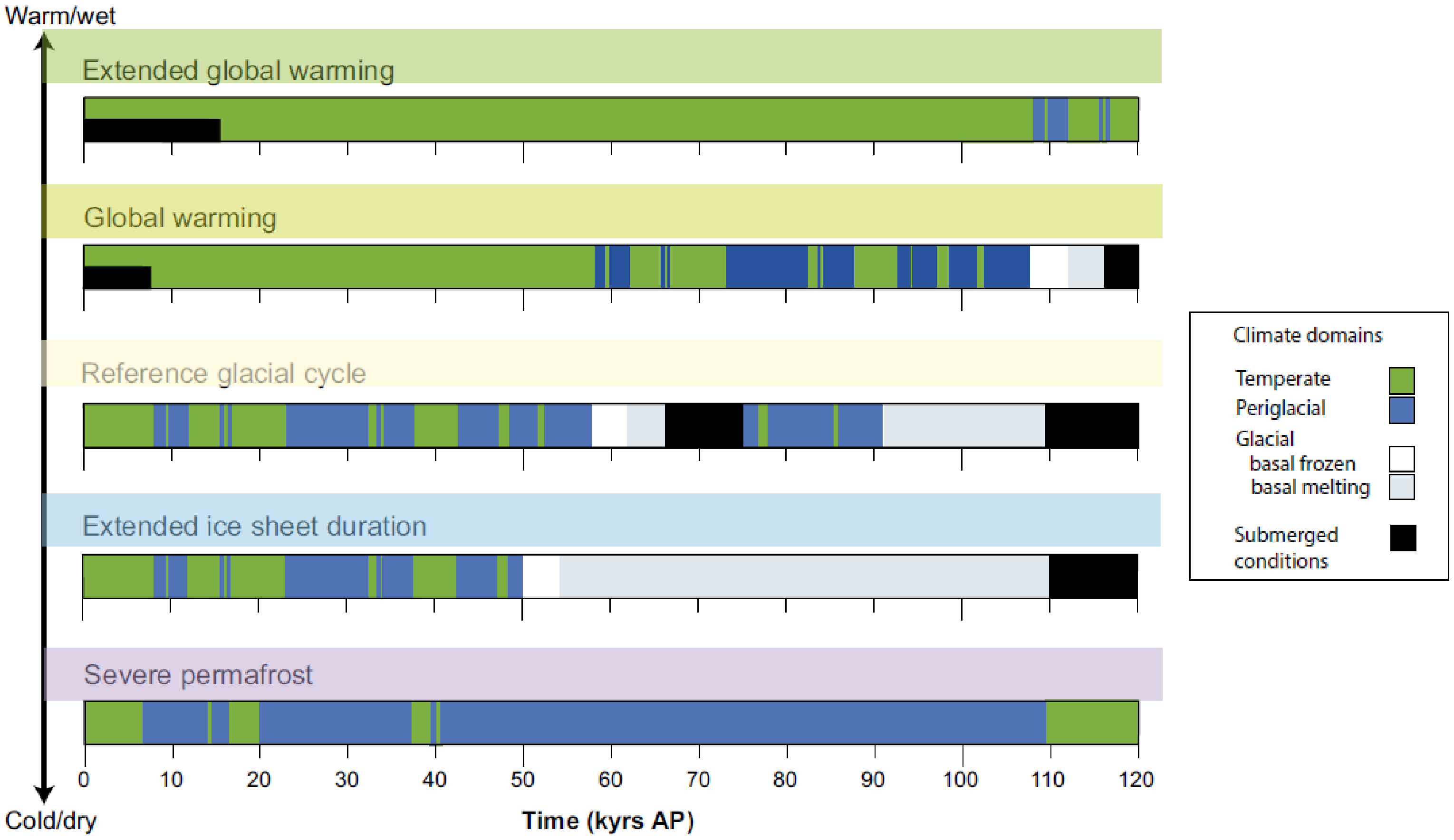


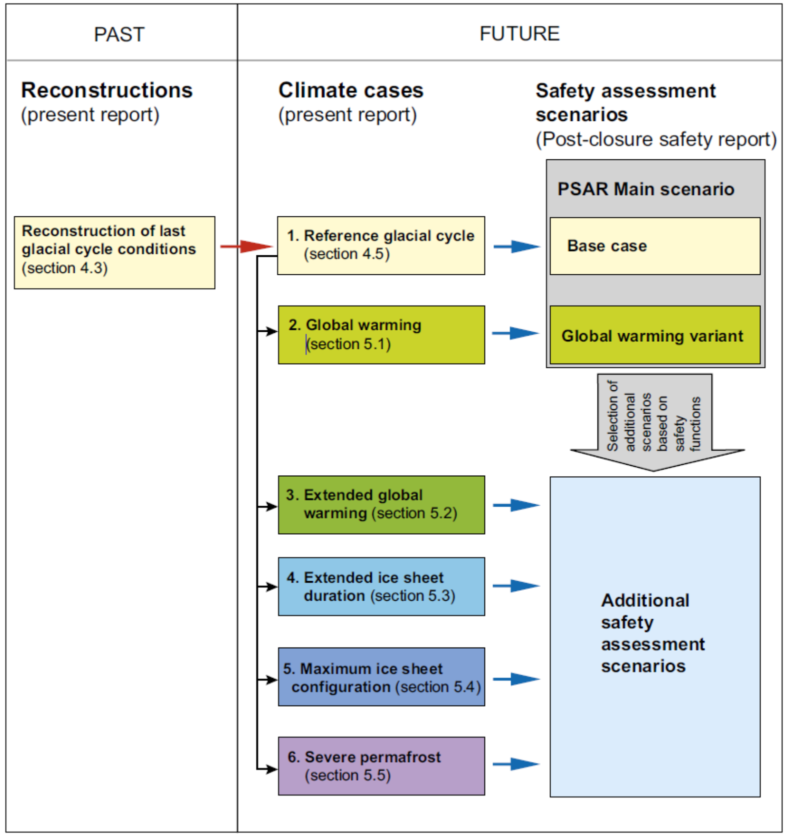
Implementation of climate factors – Erosion

- Glacial ice and resulting meltwater can cause glacial channels/ overdeepened valleys
  - Filling of channels with sediments
- ➢ Permeability increase in channels



Climate scenarios – SKB





Näslund et al. 2020 (SKB 2011 TR-11-01) / (2020 TR-20-12)

Summary and Outlook

- Most relevant processes are identified
- Several climatic processes have influence on an final repository
- Climate scenario depends on several inputs and depends on the specific region of disposal site
- Variability for parameters, processes, models, and scenarios

- Grid generation
- Modelling climate processes for better understanding of groundwater development
- Parameter variation for uncertainty study

Save the Date!
26.-29.09.2023

- 4 Days of Networking (Tuesday to Friday)
- Visit of the Morsleben final repository (ERAM)
- Tour through the GRS Lab in Braunschweig
- Keynote Speakers

Decay Days: Promovierende aus der Endlagerforschung aufgepasst! | GRS gGmbH
Decay Days | GRS gGmbH

Thank you for your attention!

Contact: marc.johnen@grs.de

Research order number:
STAFuE-21-4-Klei

Literature

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OECD/NEA – FEP catalogue

- 268 Features, Events and Processes (including groups and subgroups) mentioned in the International FEP List of the OECD/NEA
- Starting point for important factors/impacts of climate developments
- Filtering for climate relevant FEP
- Comparing to safety assessment/climate development literature

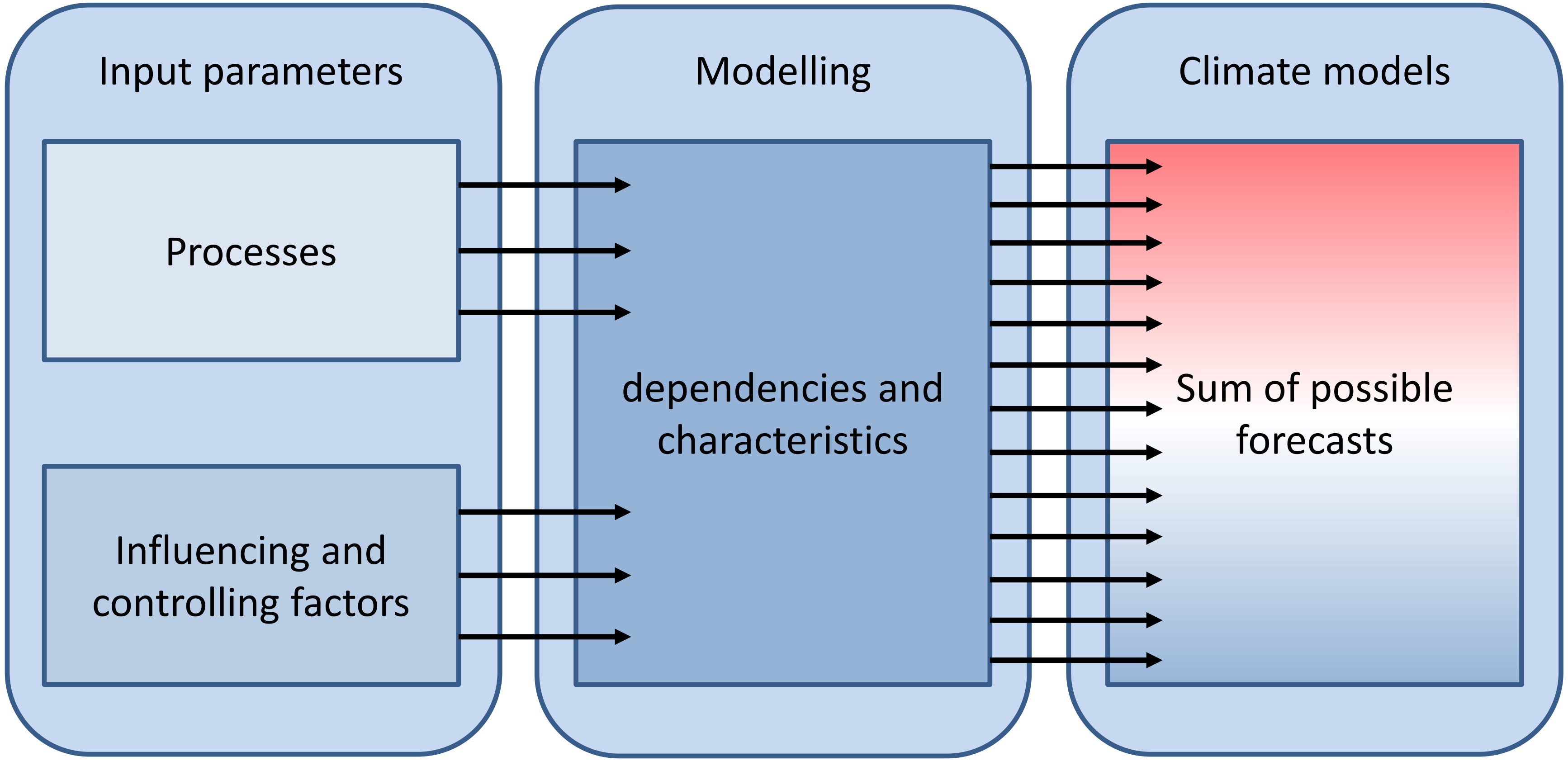
OECD/NEA 2019

Climate factors

- Different factors have different impacts on the geosphere and a potential repository
- The data basis and models has to fit to the repository site
- Development of climate scenarios for Germany

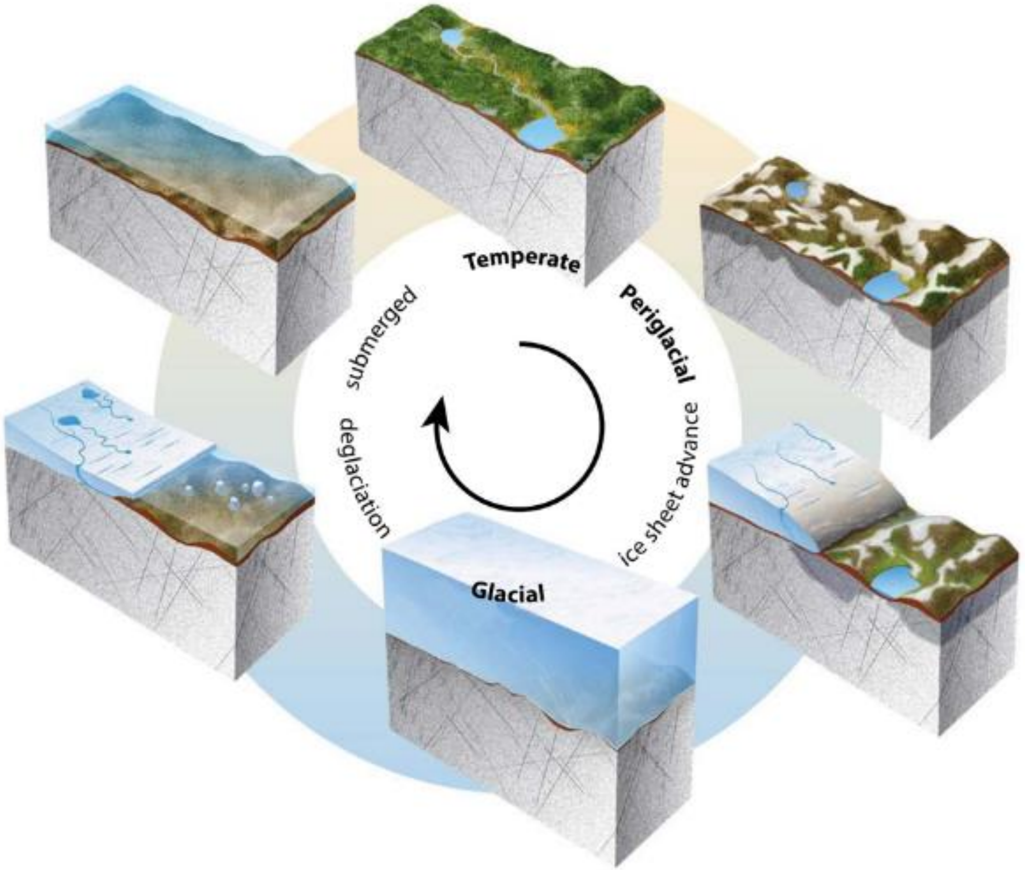
Scenario development

- Scenarios are no predictions
- Scenarios or “What if” cases can offer a bandwidth of possible (model) outcomes
  - Support for safety assessment decisions and important further research areas to focus on

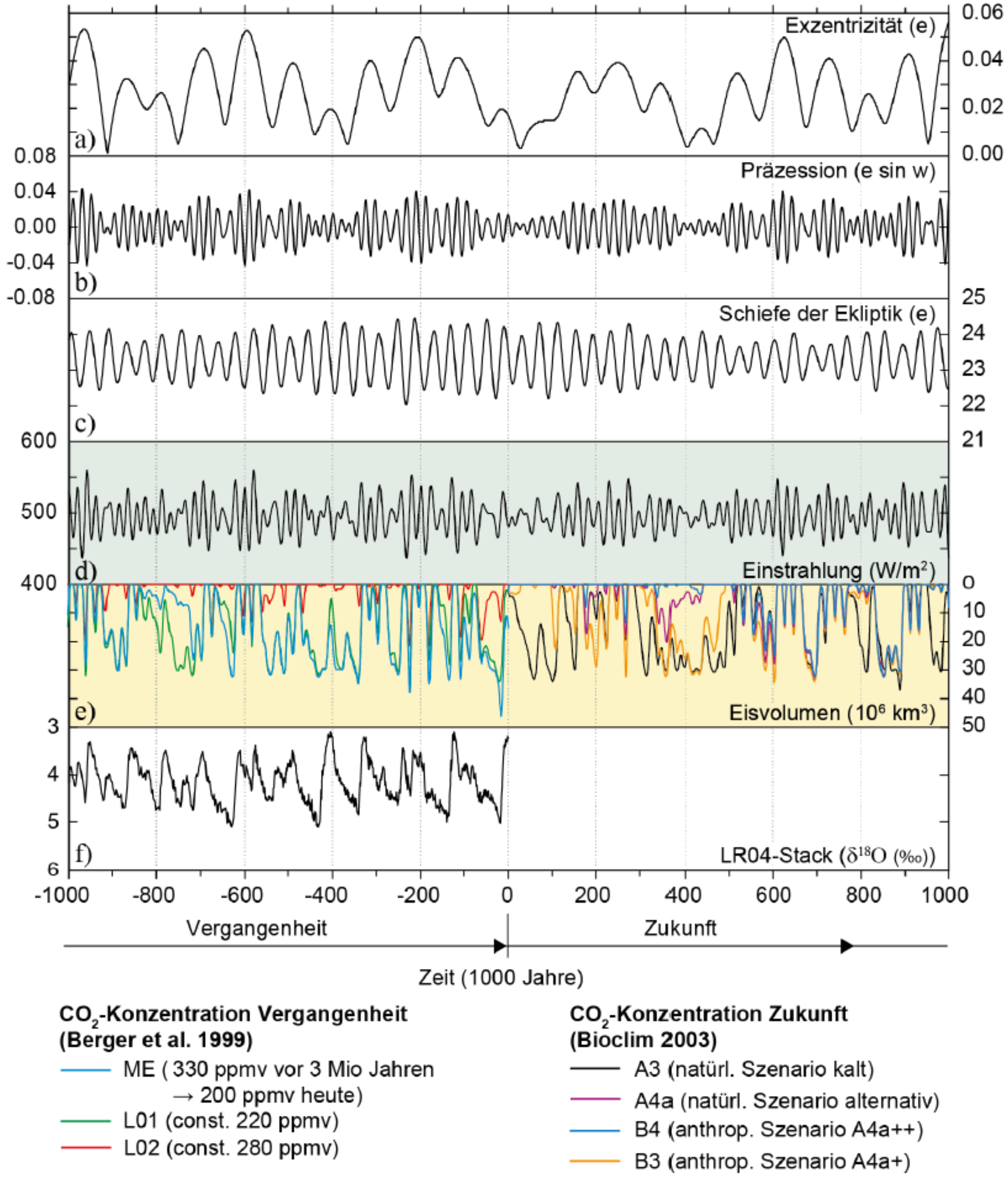


Edited after Mrugalla 2011 (GRS-275)

Milankovic-cycles



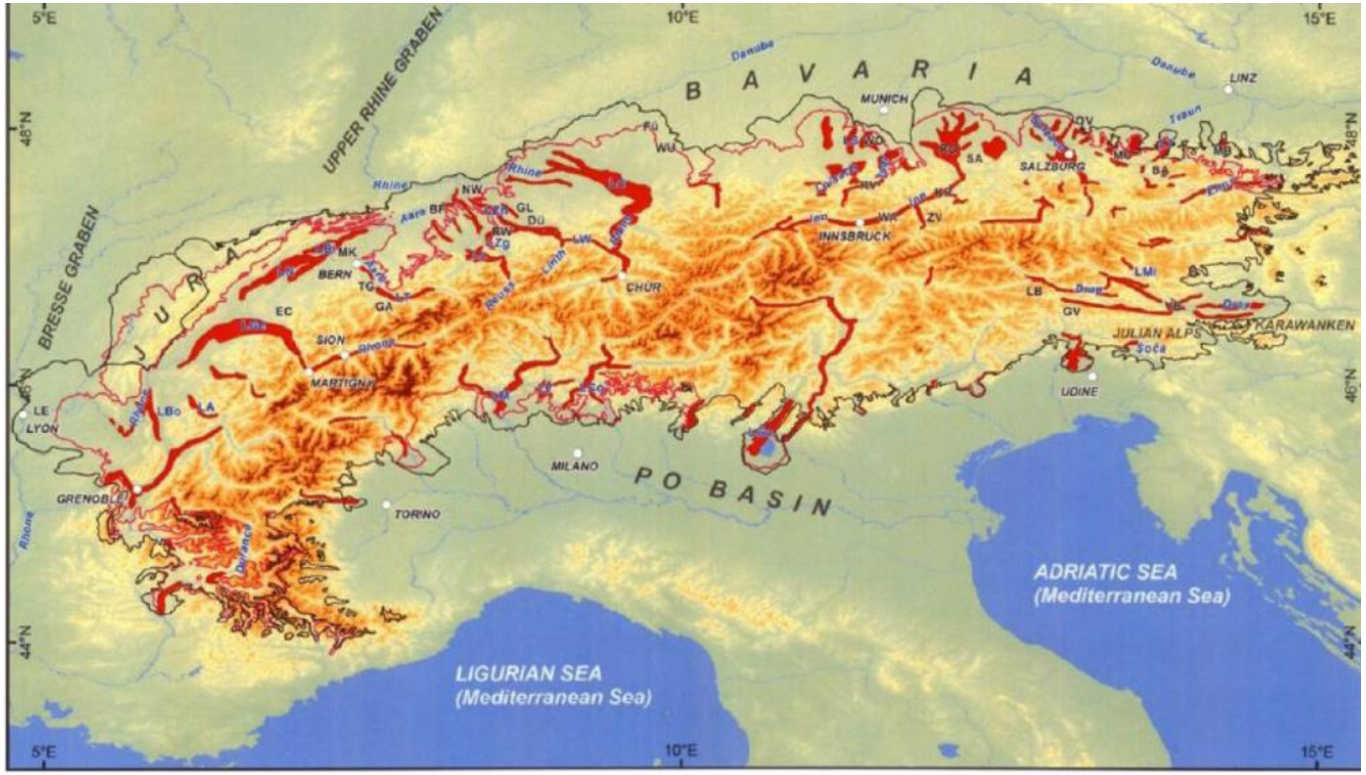
Brandefelt et al. 2019 / SKB (2019) (TR-19-04)



Schnellmann et al. 2014
(NAGRA NAB 14-25)

Past climate development in Germany

Ice advances in the alps area
- overdeepened valleys
- last ice advance
- max. ice advance in Pleistocene



Stark 2014 (BGR - AnSichT Süd)

Classification of most important ice advances in northern Germany and the alps area

Stufe/Alter	Norddeutschland	Nordwestliches Alpenvorland	Nordöstliches Alpenvorland
Oberpleistozän	Weichsel-Kaltzeit	Würm-Komplex	Würm-Kaltzeit
Mittelpleistozän	Saale-Komplex	Riss-Komplex	Riss-Komplex
	Elster-Kaltzeit	Hoßkirch-Komplex	Haslach-Mindel-Komplex

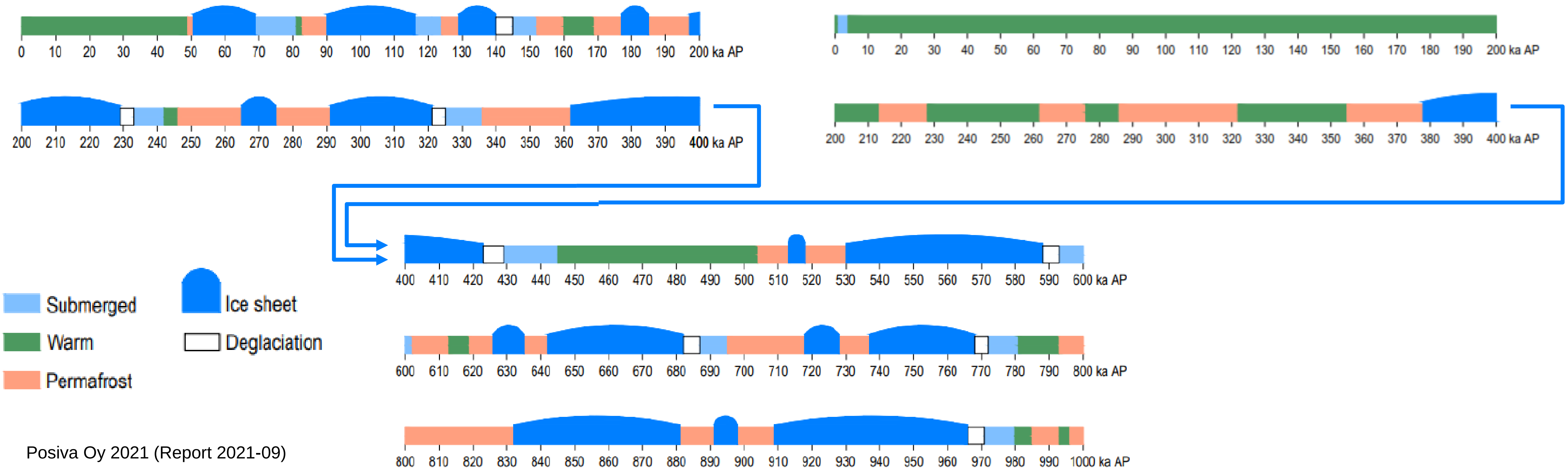
Stark 2014 (BGR - AnSichT Süd)

Ice margins after Wagenbreth & Steiner 1990, Walther 2007, WWU-M 2007

Climate scenarios – Posiva Oy

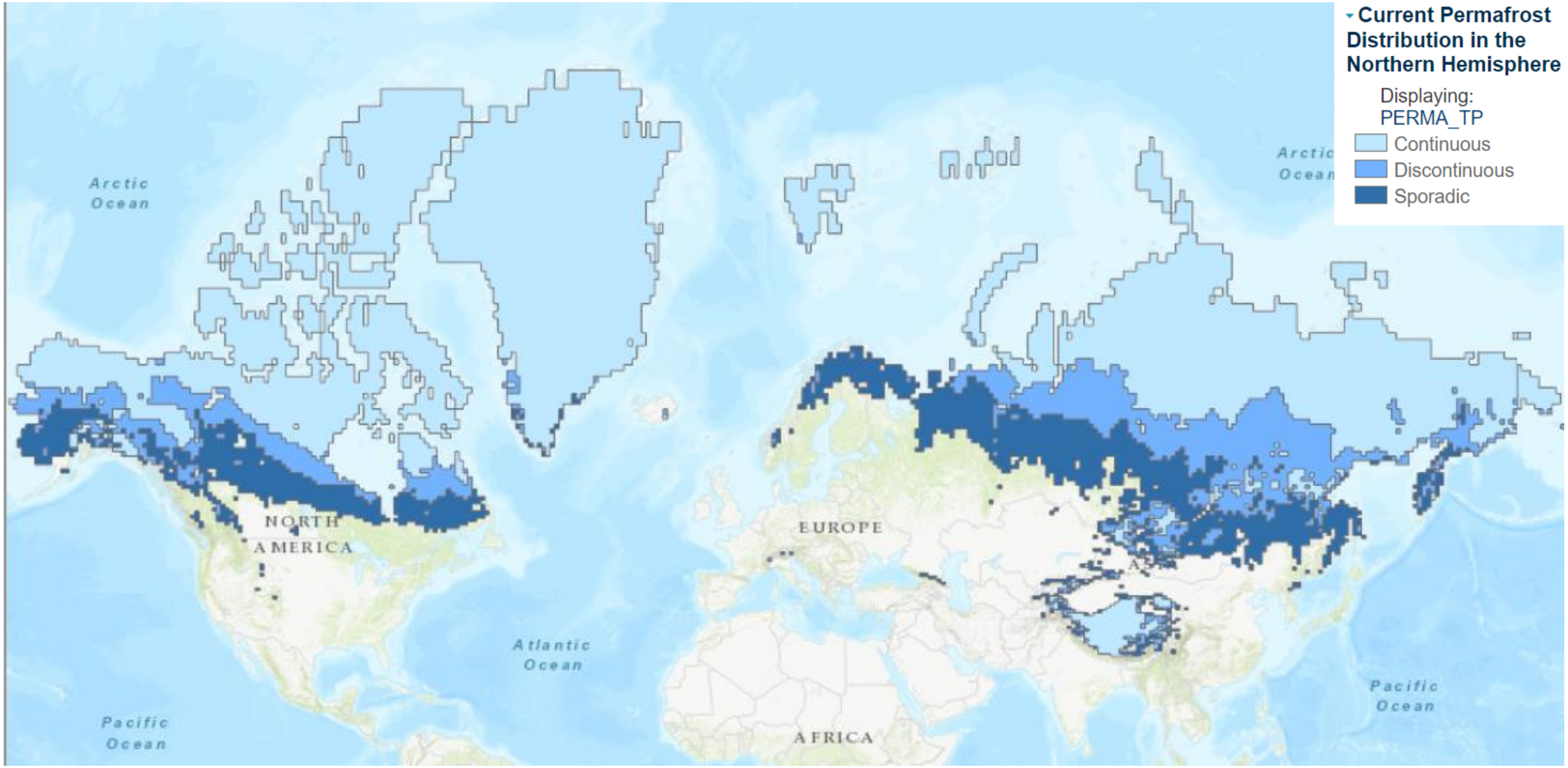
Scenario „global warming“

Scenario „extended global warming“



Posiva Oy 2021 (Report 2021-09)

Permafrost



Nelson et al. 2000 / National Science Foundation Arctic Systems Science Program (University of Delaware)

Climate scenarios in international literature

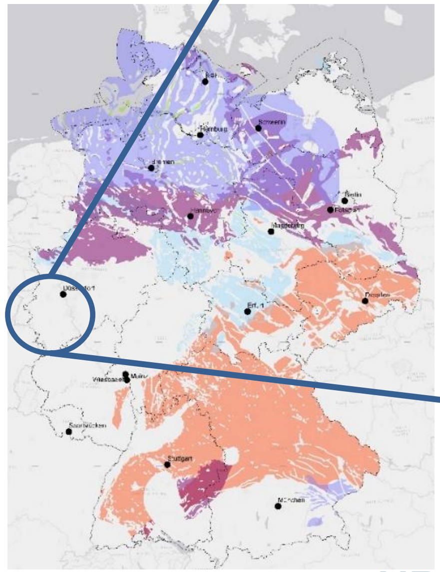
Different focus of works about future climate

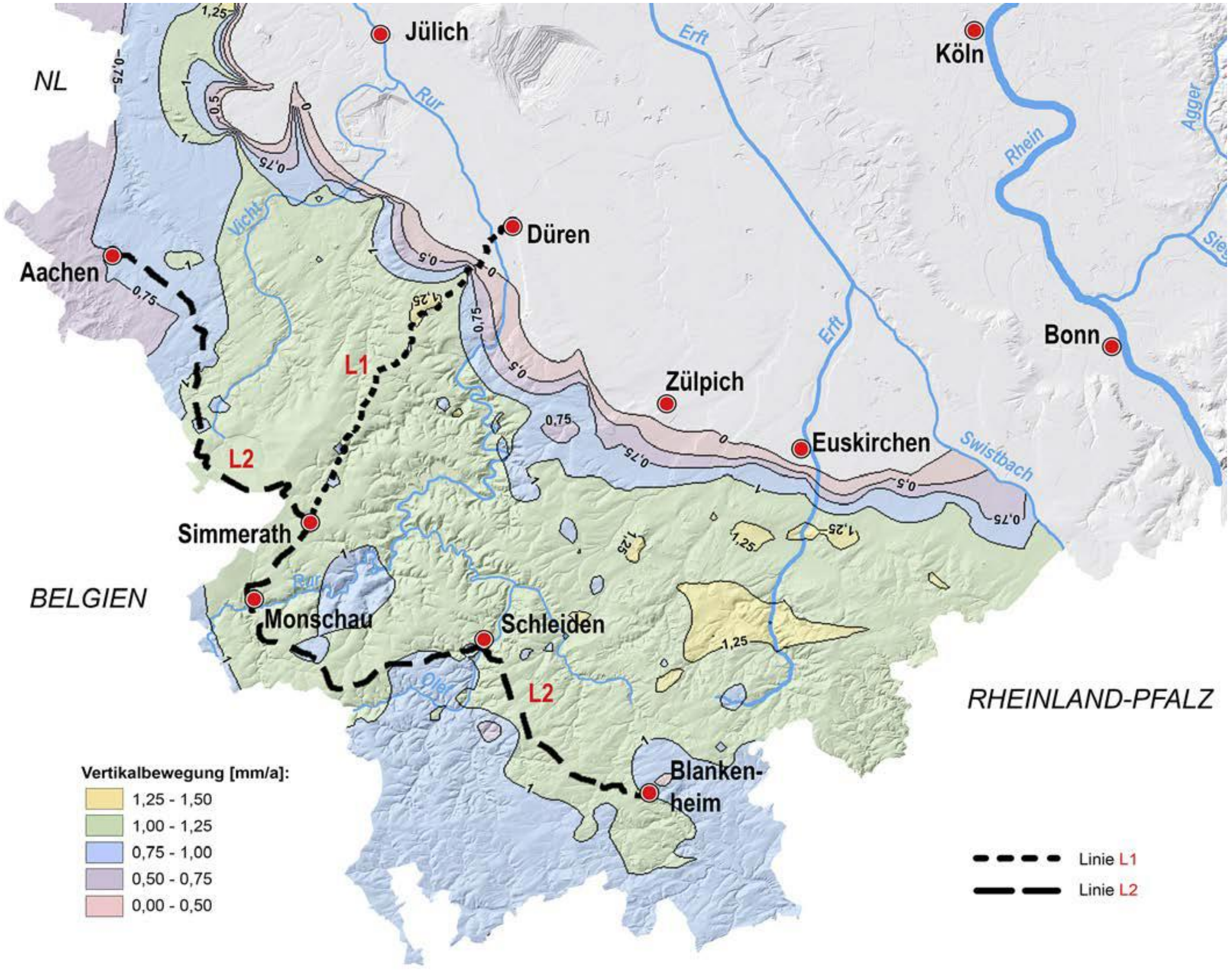
- Canada (NWMO): primary climate developments until 2100, permafrost development over next 100,000 a
- United States (NRC U.S.): just groundwater recharge rates as primary climate factor in Yucca Mountain site
- France (Andra): climate scenarios for “natural” and “anthropogenic” climate and BIOCLIM scenarios
- Switzerland (Nagra): glacial valleys and overdeepenings (erosion)
- Sweden (SKB): considering different climate relevant processes like permafrost, glacier dynamics, sea level changes, denudation (erosion, subrosion)
- Finnland (Posiva Oy): climate scenarios “global warming“ and “extended global warming” for possible processes which can affect the repository safety
- Belgium (Onraf/Niras): considering climate cycles and see no glaciation of Belgium but a higher likelihood of sea level fluctuations that could flood the repository
- Climate institutions/ ICRP models: CO_2 Emissions for future climate developments as temperature rise and sea level changes (Vulnerability of humanity)

Isostatic adjustment

Exclusion criterion according to Section 22 (2) No. 1 StandAG: large-scale vertical movements

- Not suitable as a repository site if "large-scale geogenic uplift of more than 1 mm per year on average over the assessment period of one million years is to be expected“
- No region is excluded by this criterion in the sub-areas report

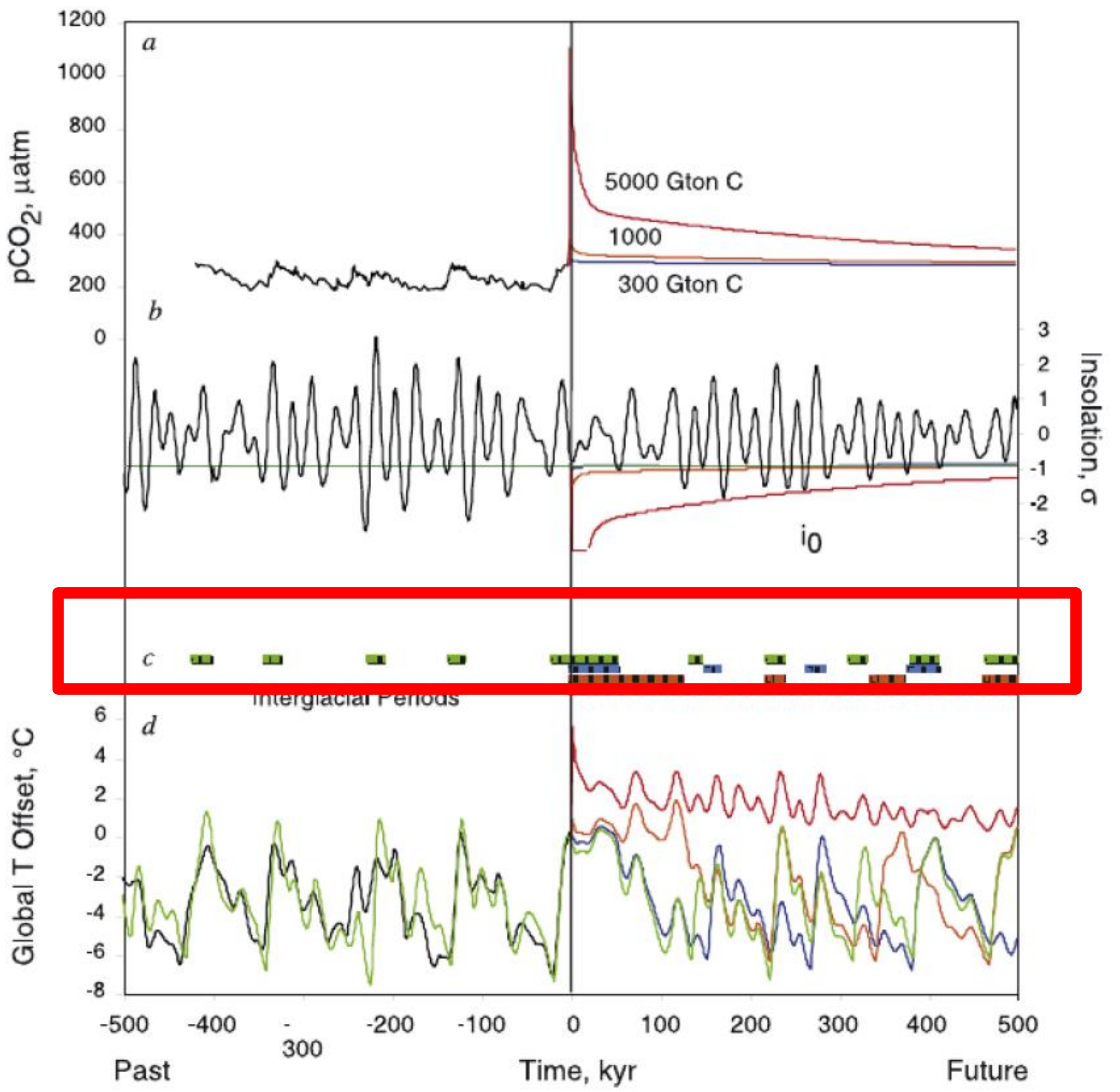




Klein et al. 2016

Climate scenarios – PIK

Earth systems model of intermediate complexity (EMIC) in relation to the ICRP models related to the anthropogenic CO_2 emissions



Archer & Ganopolski 2005

Definition of uncertainties

- Uncertainty: “lack of certainty in describing and modelling a system” (Nummi 2019)
- Three sorts of uncertainty (Funtowicz & Ravetz 1990):
  - inexactness,
  - unreliability,
  - border with ignorance
- Possible grouping of uncertainties (after OECD 2012):
  a. input data to the project (waste inventory)
  b. the inherent characteristics of the components
  c. processes affecting evolution (including the applicability of models)
  d. technological uncertainties
  e. external events

Uncertainties in the preliminary safety analyses

Endlagersicherheitsuntersuchungsverordnung (EndlSiUntV) § 11

- Systematic identification and characterisation of uncertainties
- Documentation of the handling of uncertainties and their effects
- Possibilities for reducing uncertainties by additional actions

Types of uncertainties

Epistemic uncertainty

- Lack of knowledge
- Avoidable uncertainty
- Additional data to reduce uncertainties

Aleatoric uncertainty

- Random variability
- Unavoidable uncertainty
- Description e.g. by distribution functions

- Clear boundary between uncertainty categories usually not possible
- Not usually considered separately in modelling

Uncertainties

- “lack of certainty in describing and modelling a system” (Nummi 2019)
- Two types of uncertainties
  - Epistemic (lack of knowledge)
  - Aleatoric (random variability)

Endlagersicherheitsuntersuchungsverordnung (EndlSiUntV) § 11

- Systematic identification and characterisation of uncertainties
- Documentation of the handling of uncertainties and their effects
- Possibilities for reducing uncertainties by additional actions

- Three categories of uncertainties for describing repository systems:

Parameter uncertainties	Model uncertainties	Scenario uncertainties