

Modelling of long-term future climate change with application to the problem of permanent nuclear waste storage in Germany

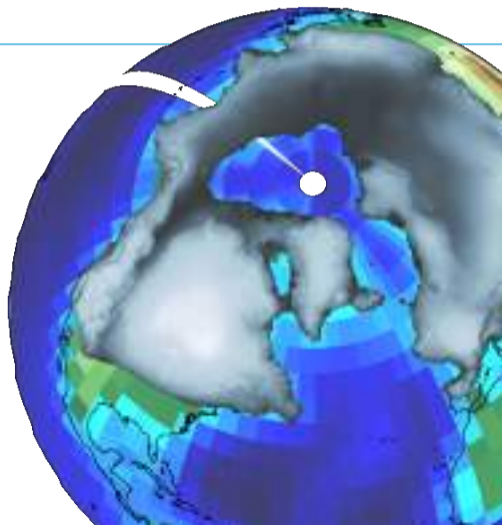
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Potsdam Institute for Climate Impact Research
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URS 2023 **KLAUSURTAGUNG**



POTSDAM INSTITUTE FOR
CLIMATE IMPACT RESEARCH



Our past climate...

- Climate has been changing for last Myr via Milankovitch cycles
- Connection between maximum summer insolation at 65°N and CO₂ for glacial inception

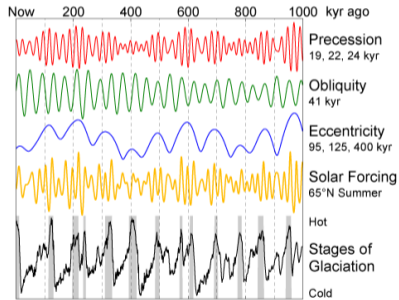


Figure 1: Data from Quinn et al. 1991/Liseki & Raymo 2005. Generated by Rohde 2006.

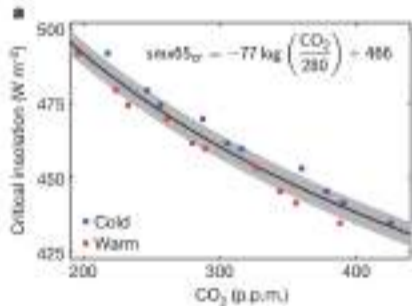


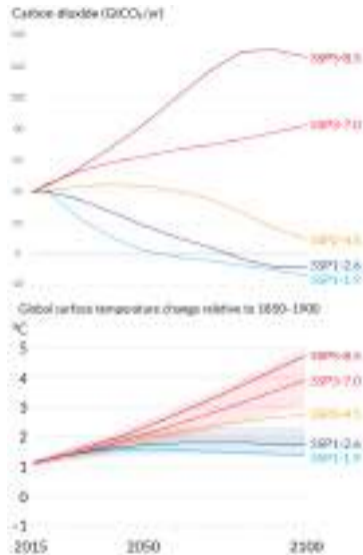
Figure 2: Critical CO₂-insolation relation for glacial inception. From Ganopolski 2016, *Nature*.



Our future climate...

- Available fossil fuel carbon reserves have the capacity to impact the climate hundreds of thousands of years into the future
- Large uncertainties exist in long-term future climate evolution since we cannot accurately predict anthropogenic CO₂ emissions even during this century
 - RCP-SSP scenarios with extensions
- Anthropogenic CO₂ emissions can change future glacial cycles

Figure 3: Taken from IPCC's AR6.



How does this affect the management of nuclear waste?

- Previous glaciation events reached Germany
 - many short-term and long-term consequences
 - precipitation, temperature, subterranean stress, surface denudation, and permafrost/taliks
- High emissions scenarios present sea level rise
- Why does this matter for repository health?
 - some radioisotopes have long half lives
 - waste must be stored for a period of 1 million years (EndSiAnfV § 3)
 - **we must consider future climate for deep geological repositories**



The REDUKLIM project

Research Field 4:

Preliminary safety investigation

Research Cluster:

Uncertainties and Robustness with regard to the Safety of a repository for high-level radioactive waste (URS)

Topic 4:

Physics-based scenario modelling and impact models

Project:

Reduction of scenario uncertainties through Climate models (REDUKLIM)



Figure 4: Structure of the URS cluster from BGE

The goals of REDUKLIM

The task:

- assess future climate for next 100 kyr and 1 Myr
- link climate development to groundwater processes (GRS)
- identify and quantify uncertainties via our projections
- **provide additional confidence in site selection**

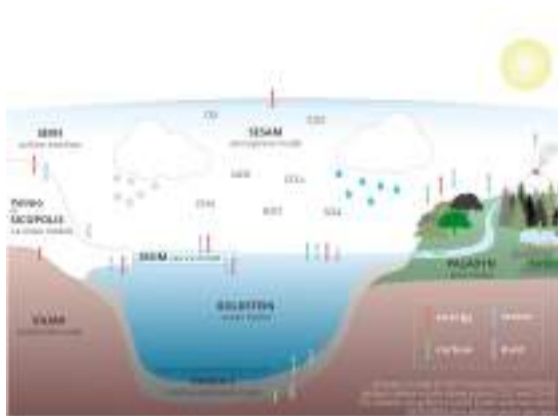
Our tools at hand:

1. distributed density-driven flow model d^3f++ (GRS)
2. Earth system model of intermediate complexity CLIMBER-X
3. reduced complexity model by Talento & Ganopolski 2021





- Fully coupled EMIC
- Climate components have comparable complexity and grid ($5^\circ \times 5^\circ$)
- More options for the ice sheet model
 - e.g., variable domain
- Best suited for long timescales
 - does not resolve weather, inter-annual variability, diurnal cycle, etc.
 - we will use until ~ 100 kyr AP
- Model validation in Willeit et al. 2022



A reduced complexity model

3 coupled, nonlinear equations concerning mechanisms relevant for the climate–icesheet–carbon cycle system on very long timescales (> 10 kyr)

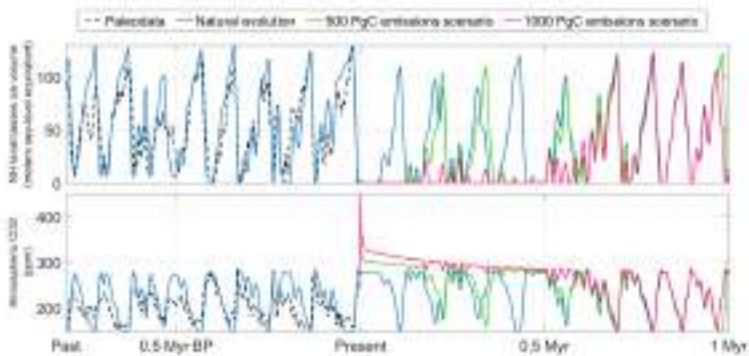


Figure 5: Talento & Ganopolski 2021

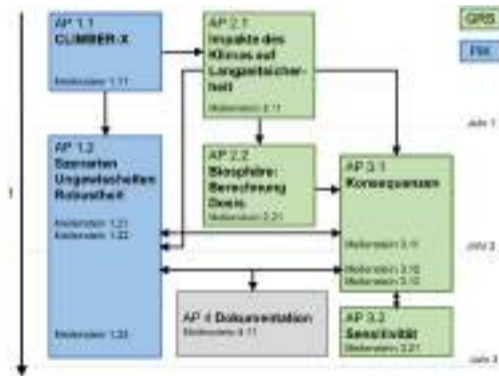


Package milestone #1

Working Package 1.1:

Construction and evaluation of climate models

1. simulate the last glacial cycle
2. simulate the next 100,000 yrs for different scenarios
3. for 100,000 yrs and beyond, the reduced complexity model is used
4. scenarios developed for the next million years in northern Germany/Alpine region

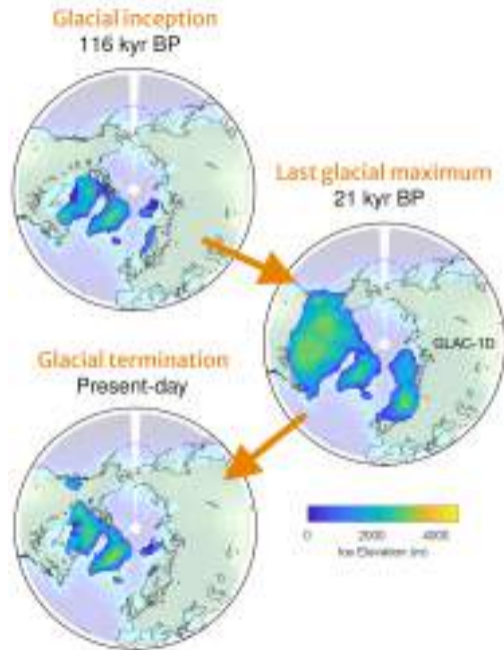


Milestone 1.11 (month 12):

Evaluation of future climate scenarios for Germany based on results of CLIMBER-X

Paper 1: Glacial cycles

- **To simulate future glacial cycles, we must be able to simulate the last one!**
 - glacial inception, LGM, and deglaciation
- Major objective as model performance can be tested against paleodata
 - sediment core, ice core, planktonic data
 - reconstructions (GLAC-1D, ICE-6G_C)
 - sea level reconstructions
 - PMIP4 model ensemble results
- Currently status:
 - model tuning
 - identifying model biases
 - drafting paper (e.g., introduction, methods)



Paper 1: Transient simulation

"a serious impediment... is that no modern model of the coupled climate system has ever been shown to naturally produce such oscillatory behavior under glacial climate conditions"

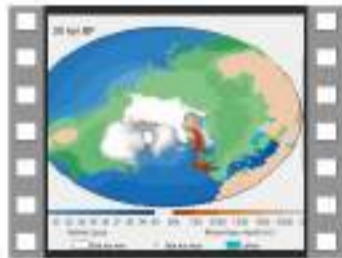
- **Peltier 2014, Geophysical Research Letters**

"this deficiency is related to both the computational expense which prevents models from being run for the longer time periods..."

- **Malmierca-Vallet 2022, EGU sphere**

"a full transient glacial cycle is currently computationally unfeasible as it requires a too-large amount of computation time"

- **Scherrenberg 2023, Climate of the Past**

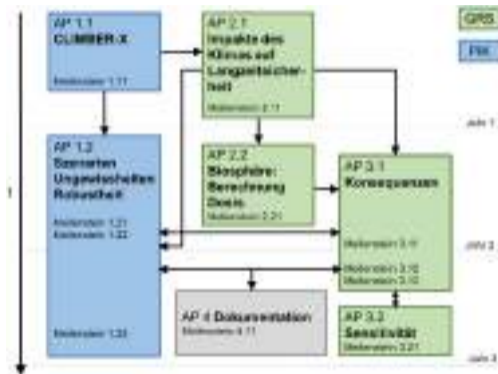


Package milestone #2

Working Package 1.2:

Scenarios, uncertainties, robustness

1. examine uncertainty/consequences of a wide range of cumulative CO₂ scenarios
2. examine how glacial inception depends on parameters of the carbon component
3. explore uncertainties in climate sensitivity and ice sheet parameterization

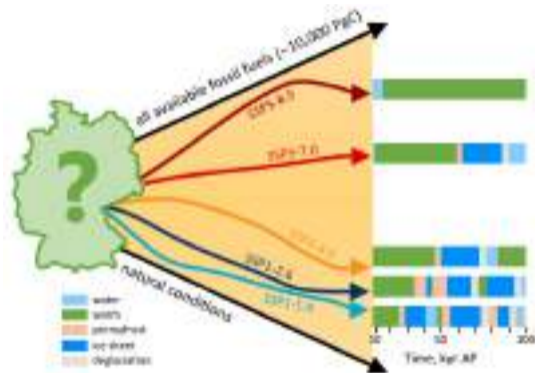


Milestone 1.21 (month 24):

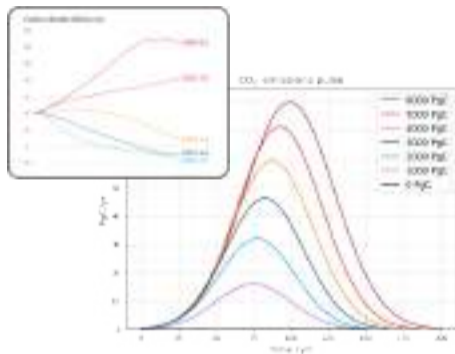
Assessment of the robustness and uncertainties of future climate scenarios for Germany

Paper 2: Future scenarios

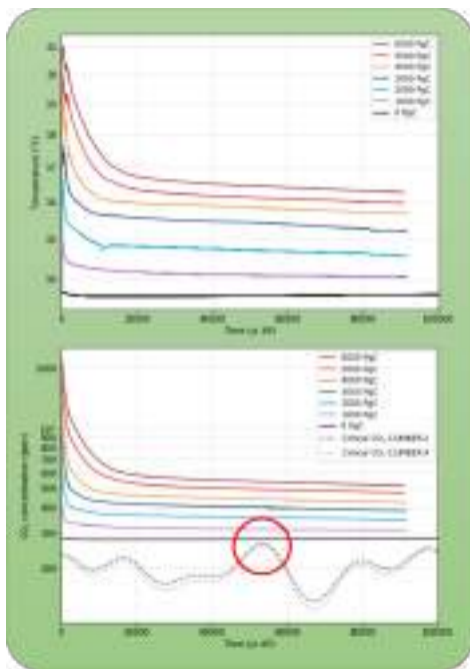
- Climate scenarios offer a spectrum of possible model outcomes
- Simulate long-term scenarios for a broad range of cumulative CO₂ emissions
- **How do cumulative CO₂ emissions affect timing of the onset of next glaciation?**
- Prescribe CO₂:
 - interactive open carbon cycle
 - reduced complexity model
 - Lord et al. 2016
- range of possible climates over Europe (temperature, precipitation, sea level, etc.)



Paper 2: Preliminary results



CLIMBER X
Earth System Modeling



Gawropolski 2016
Critical CO₂, CLIMBER-2:

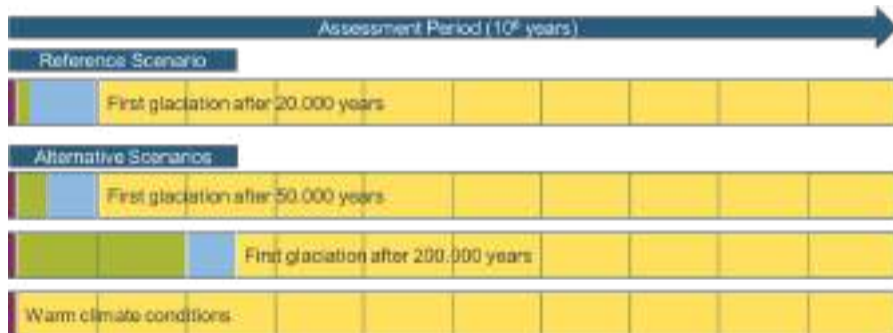
$$\text{time} \tau_{\text{CO}_2} = -77 \log \left(\frac{\text{CO}_2}{280} \right) = 446$$

1506 ppb
1330 ppb
976 ppb
8 ppb C

This block contains a yellow box with text and a small graph. The text defines a time constant for CO₂ concentration. The small graph shows CO₂ concentration over time with a red circle highlighting a peak.

Climate development benchmark

- Successful climate workshop held by BGE in February
- Common scenario benchmark was developed for our climate reports



Strategy & outlook

- Learnt CLIMBER-X over the course of the last months and made good progress
- Clear aim in terms of what must be done & the general timeline
- Few ideas to navigate bumps and prepare for success
- **We are open to collaborations and can provide climate variables to those interested**

Funded by:



Project Information:

Ungewissheiten und Robustheit mit Blick auf die Sicherheit eines Endlagers für hochradioaktive Abfälle (bge.de)

Contact:

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