

A set of long-term future climate change scenarios for Germany

Evaluating climate-safe repository sites via the REDUKLIM project

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September 8, 2022



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1. Motivation for including climate science
2. Our model toolbox
3. Planned considerations and summary

The evolution of future climates...

- Climate has been changing for last Mya via Milankovitch cycles
 - Earth's orbital parameters known for many Myr
- Uncertainty regarding the inclusion of anthropogenic CO₂
 - available fossil fuel carbon reserves have the capacity to impact the climate hundreds of thousands of years into the future [Archer and Ganopolski, 2005]
 - cannot predict future CO₂ emissions
 - but we can assume scenarios from fuel reserves

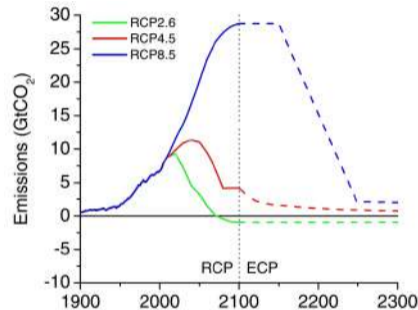


Figure 1: Modified from [van Vuuren et al., 2011]

How does climate affect the management of nuclear waste?

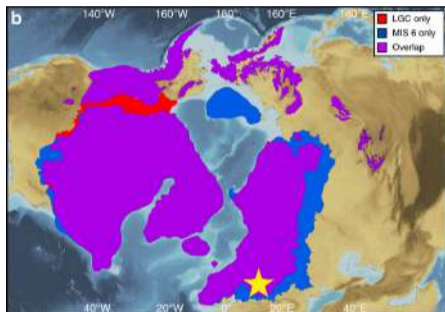


Figure 2: From [Batchelor et al., 2019]

- Anthropogenic CO₂ emissions can change future glacial cycles [Ganopolski et al., 2016]
- Why does this matter for repository safety?
 - some radioisotopes have long half lives
 - must consider repository health for next Myr
- Previous glaciation events reached Germany
 - can remove regolith and create permafrost
 - affects subsurface temperature, groundwater dynamics and precipitation

We must consider future climate scenarios for subterranean waste management

The goals of REDUKLIM

The task:

- assess future climate for 100 kyr to the next 1 Myr
- link climate development to groundwater processes
- identify and quantify uncertainties
- provide additional confidence in site selection

The tools at hand:

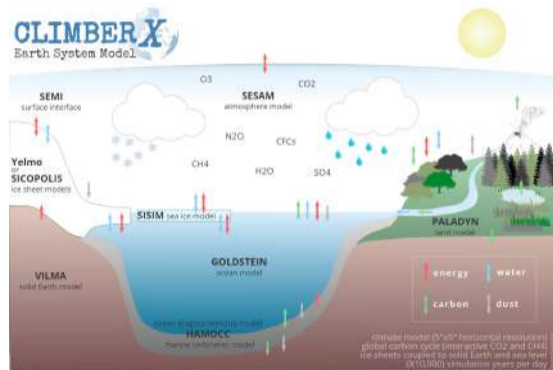
1. Earth system model of intermediate complexity (EMIC) CLIMBER-X
2. reduced complexity model for glacial cycle dynamics



1. Earth system model CLIMBER-X

- Atmos./ocean/land of comparable complexity and same horizontal grid ($5^\circ \times 5^\circ$)
- Suited for long timescales
 - seasonal time scales do NOT resolve weather, interannual variability, diurnal cycle
- Land responds to changing sea level
- Several ice sheet model options
- Fully interactive carbon cycle

Figure 3: From [Willeit et al., 2022]



CLIMBER-X compared to historical data

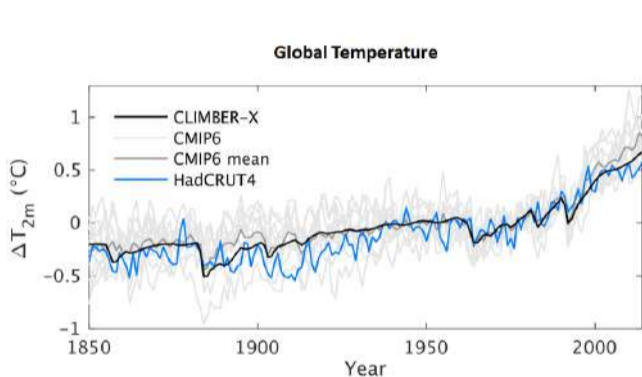
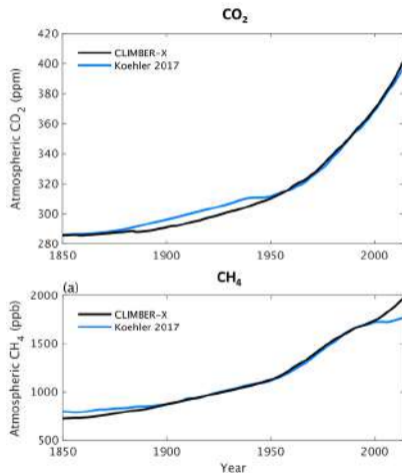


Figure 4: From [Willeit et al., 2022]



CLIMBER-X against present-day values

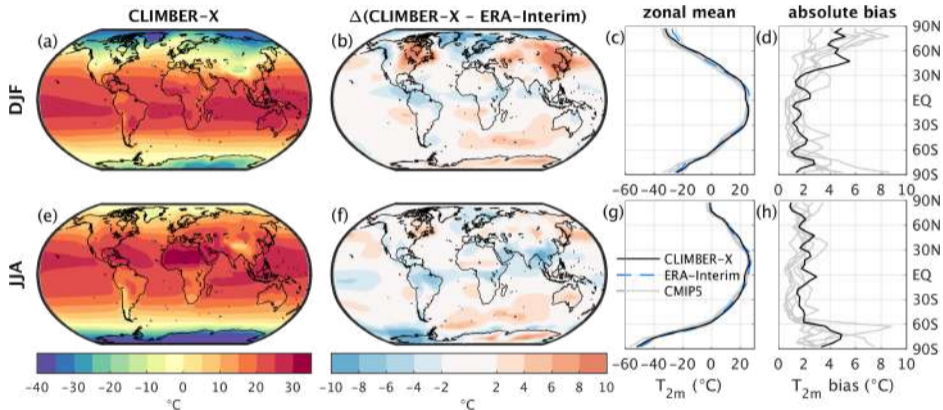


Figure 5: From [Willeit et al., 2022]

Reduced complexity model

3 coupled, nonlinear ODEs concerning mechanisms relevant for the climate–icesheet–carbon cycle system on very long timescales (> 1 kyr)

$$\frac{dv}{dt} = \frac{b_1 v - b_2 v^{3/2} - b_3 (f - \bar{f}) - b_4 \log \text{CO}_2}{1 - b_5 M_v} + b_6$$

$$\text{CO}_2 = c_1 T + c_2 v + c_3 \min\left(\frac{dv}{dt}, 0\right) + c_4 + \text{AnthCO}_2$$

$$T = d_1 v + d_2 \log\left(\frac{\text{CO}_2}{278}\right)$$

Variable:

v	NH landmasses ice volume
CO_2	Atmospheric CO_2 concentration
T	Global mean surf. temp. anomaly
t	Time

External forcings:

f	Summer insolation at 65°N
AnthCO_2	Anthropogenic CO_2 anomaly

2. Reduced complexity model performance

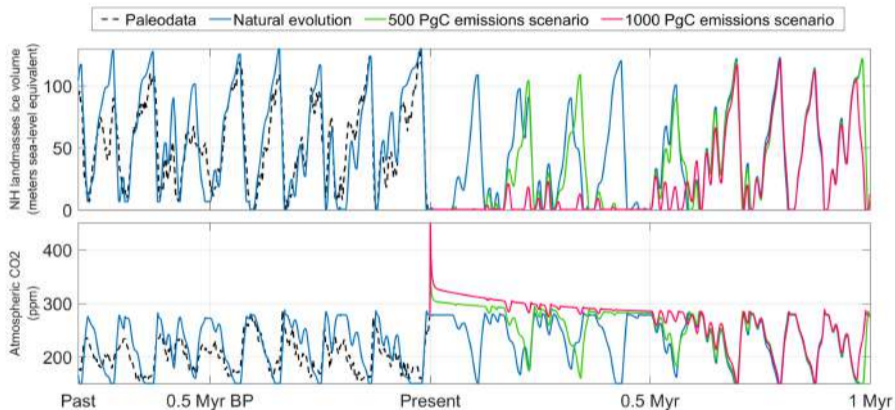


Figure 6: Adapted from [Talentó and Ganopolski, 2021]

Current plan

The following will be taken into account:

- Different CO₂ emission scenarios
- Extent and persistence of icesheets
- Regolith weathering
- Sea level change
- Volcanism

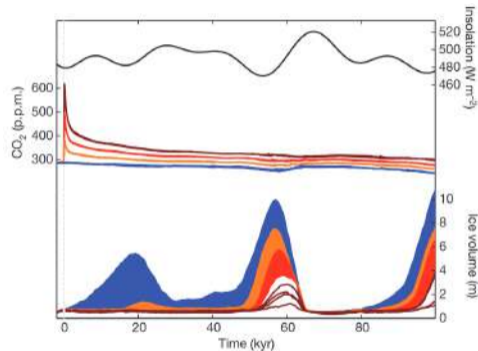
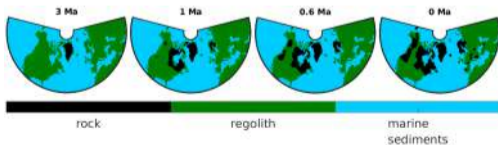


Figure 7: From [Ganopolski et al., 2016] and [Willeit et al., 2019]

Thank-you for your attention!

More information on the project:

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

Funded by:







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Besides the REDUKLIM research goals, we are open to other
long-term considerations, and collaborations by providing boundary conditions

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