REDUKLIM:

Reduction of scenario uncertainties through climate models

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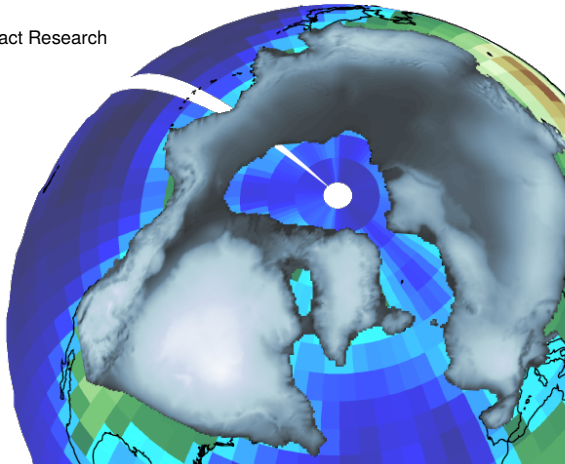
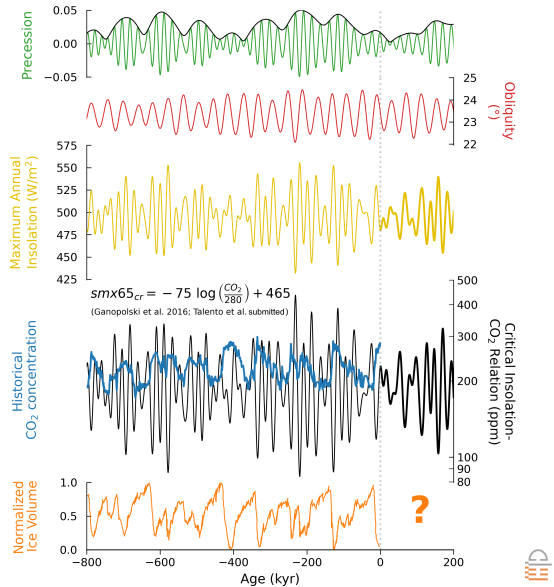


Brief summary on our climate...

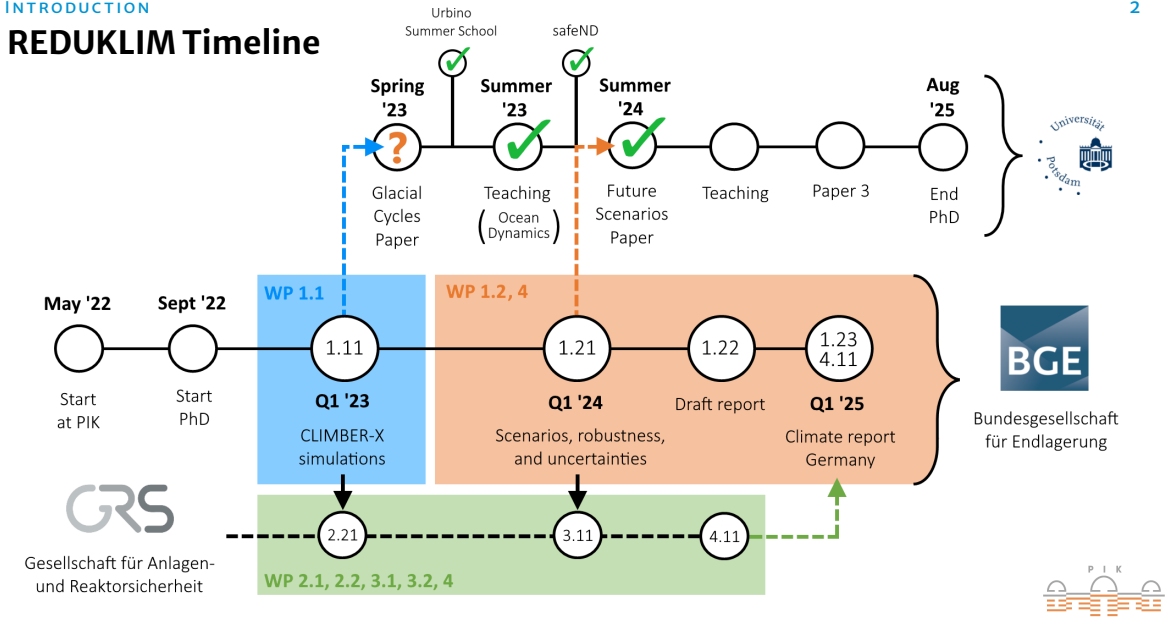
- Solar insolation (i.e., orbital parameters) and atmospheric (i.e., CO_2) concentration have a first order control on the climate

- There exists a fundamental relationship between these two which can diagnose glacial inception
  - **New equation for CLIMBER-X!**

- Orbital parameters are known for the next 20 Myr, but large uncertainties for the long term climate with anthropogenic emissions

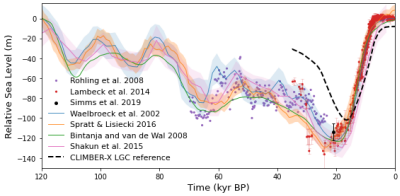


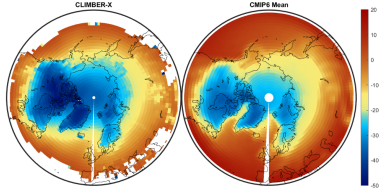
REDUKLIM Timeline



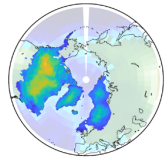
Recall: glacial cycles paper

→ on hold!

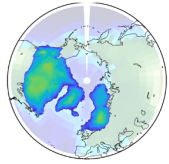




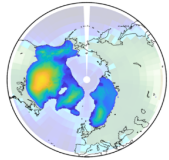
ICE-6G_C

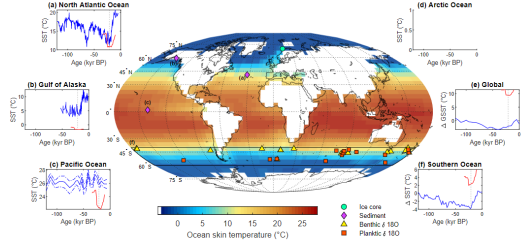


GLAC-1D



CLIMBER-X





Transient simulation and model-data comparison of the last glacial cycle using a coupled climate-ice sheet model

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1 Introduction

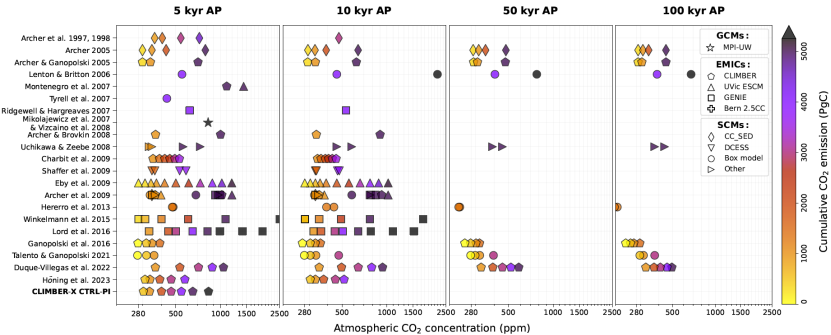
The last few million years in Earth's history saw generated a large variability in our climate (Lisiecki and Raymo, 2005). As a result, there are still many unknowns as global proxy data on seasonal to millennial timescales from sources ranging from ice cores to marine sediments has provided poor constraints on paleoclimatic conditions. Yet one such exception is the last glacial maximum (LGM) of the Pleistocene epoch, which is generally suggested to have occurred sometime between 24.5 to 17 kyr BP (Clark et al., 2009). Ice sheets at this time are generally well constrained by present-day observations in addition to terrestrial (tree rings, sediments), ice (e.g., stacked δ^{18}O data in cores) and marine indicators (e.g., lake sediments, ice-rafted debris). LGM can be distinctly recognized in paleoclimate records by a large volume of Northern Hemisphere (NH) ice sheets and correspondingly low global eustatic sea level (Fairbanks, 1989; Yokoyama et al., 2000; Waelbroeck et al., 2002; Peltier and Fairbanks, 2006; Lambeck et al., 2014).

1.1 Early LGC

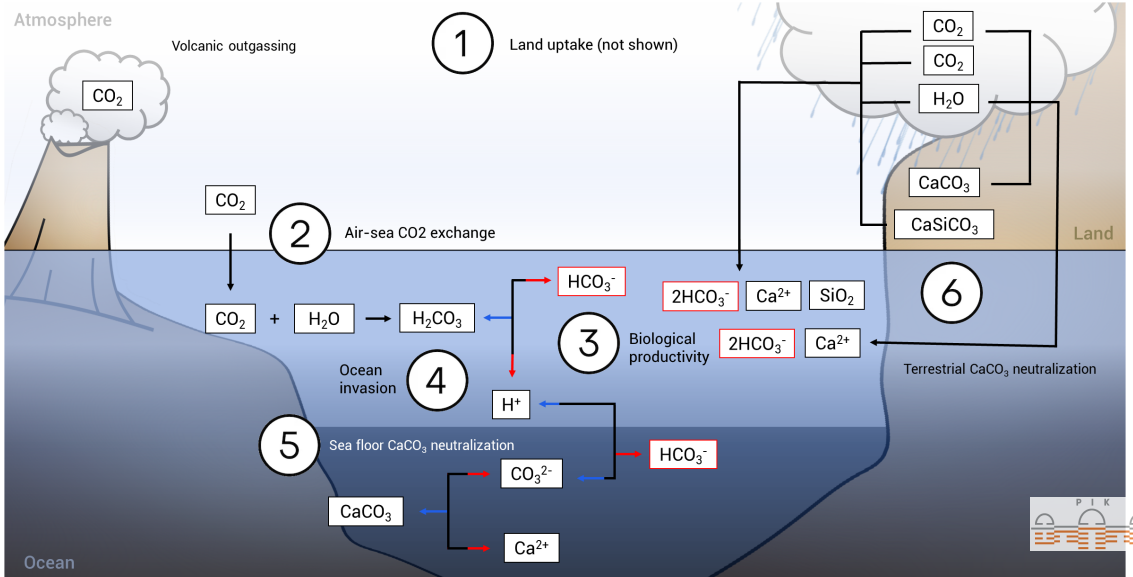
The last glacial cycle (LGC, ca. 115-10 kyr BP; Dalton et al., 2022) was an incredibly dynamic time starting from the last interglacial (LIG, ca. 127 kyr BP) period and persisting until the Holocene. The LIG is sometimes referred to as the Eemian

Future scenarios paper… part 1?

- Glacial inception is ***directly*** related to the atmospheric concentration of CO_2
  - **Problem: long-term (> 10 kyr) carbon cycle poorly constrained!**
- This necessitates a thorough investigation on how the long-term carbon cycle deals with emissions
- We therefore split the results in two parts, (1) the carbon cycle, and (2) glacial cycles/climatology

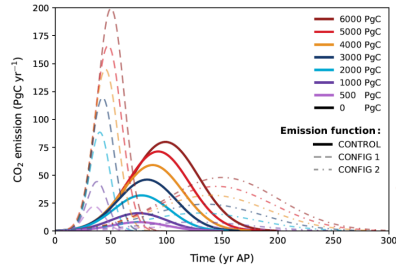


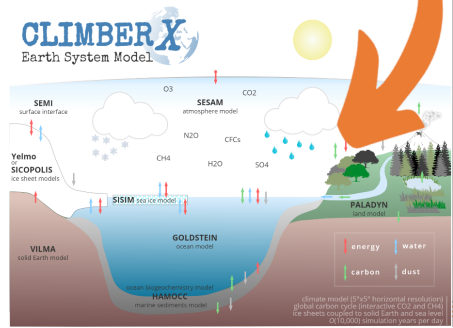
Long-term carbon cycle



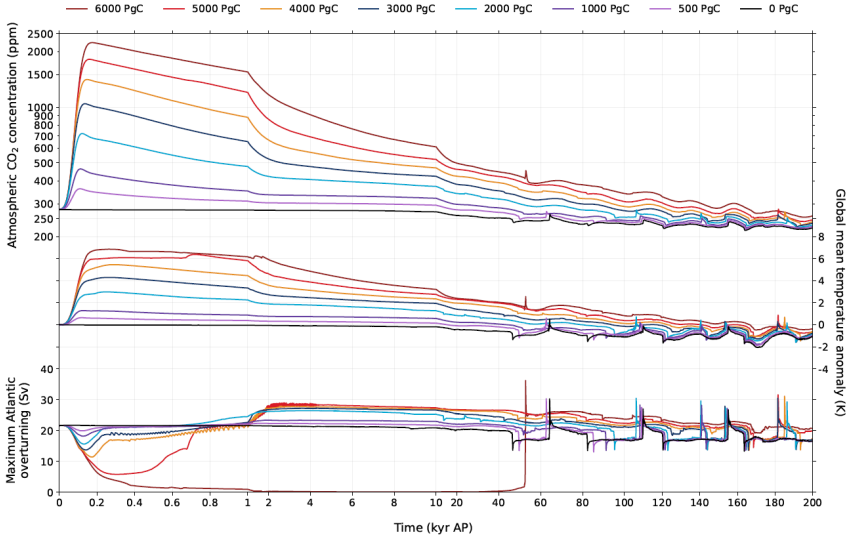
Experimental set-up

- Interactive carbon cycle enabled (i.e., carbon flux through all reservoirs)
- Experiments started at present day and forced by orbital parameters and emission functions and run for 100,000-200,000 years
- **CTRL-LGC:** control function, constant methane, volcanic outgassing set by the average value over the LGC
- **CTRL-PI:** volcanic outgassing set to PI, no orbital parameters



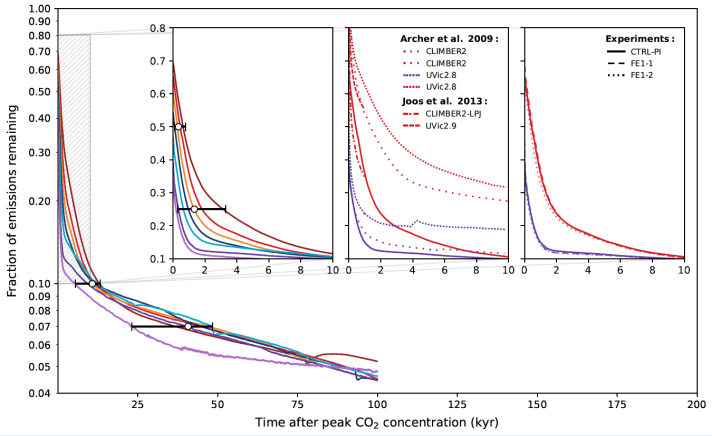


CTRL–LGC response



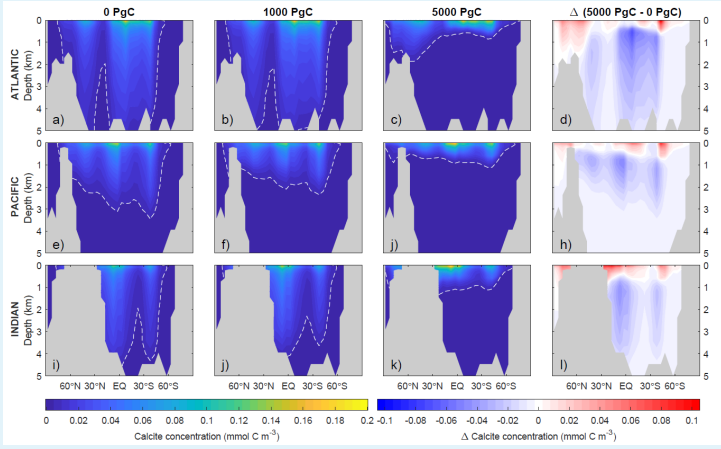
Atmospheric lifetime

- Long term carbon can be estimated as a superposition of exponentials
- Using a least squares fit, we determine an average equilibrium lifetime of 1,300 years
- 10% of emissions persist for longer than 10 kyr, while 5% longer than 100 kyr
- All these results agree with previous studies ✓



Carbonate compensation depth (CCD)

- Lysocline/CCD decreases with increasing emissions ✓
- Pacific is shallower than Atlantic or Indian oceans in natural conditions ✓
- Depth of the CCD doesn't recover in Atlantic/Indian oceans in high emission scenarios !
- We observe an eventual overdeepening of the CCD in the Pacific ocean !

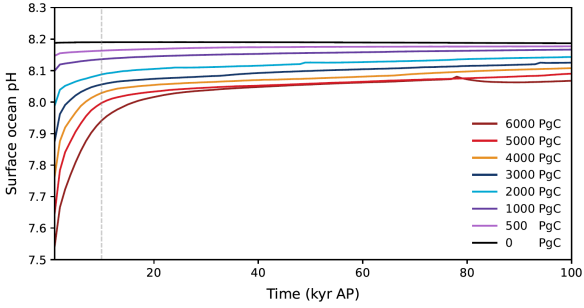


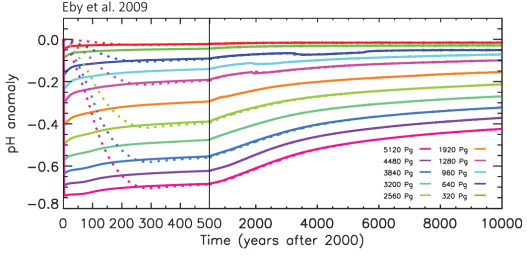
An abyssal carbonate compensation depth overshoot in the aftermath of the Palaeocene–Eocene Thermal Maximum

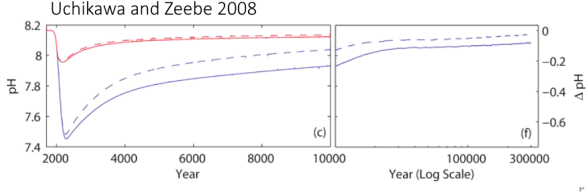
nature geoscience Penman et al. 2016

Surface ocean pH

- Similar pH anomaly observed as in several publications ✓
- Surface ocean pH doesn't recover after 100,000 years !

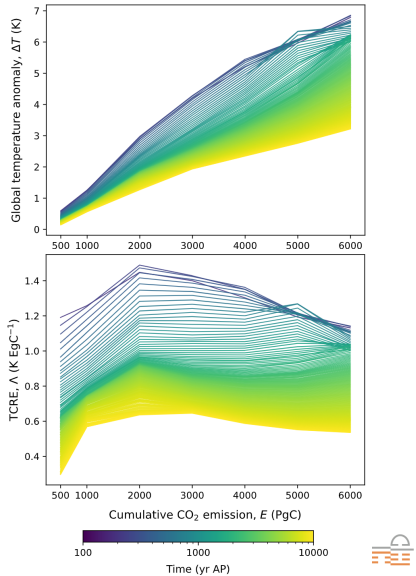






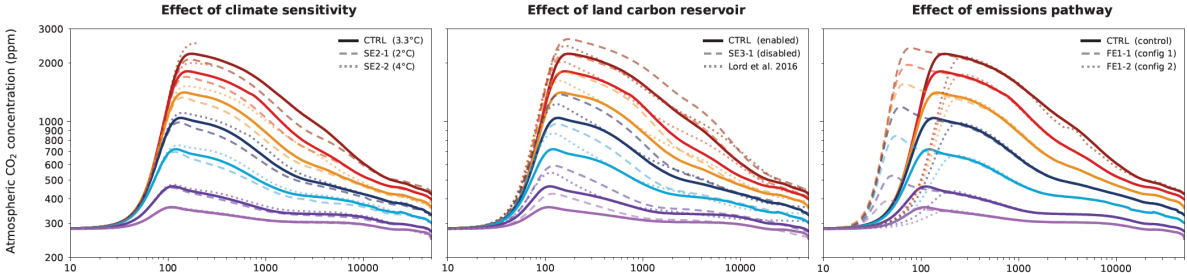
Model evaluation

- We have described the journey of CO_2 emissions into the different carbon reservoirs. **But how can we evaluate our results?**
- Four main ways: (1) previous modelling studies, (2) robust processes, (3) emission metrics, (4) climate metrics
- These metrics provide a systematic and objective way of reporting our model results and can include:
  - impulse response (Green's) function
  - transient climate response to cumulative emissions (TCRE)
  - airborne fraction of CO_2
  - turnover/residence time
  - relaxation timescales

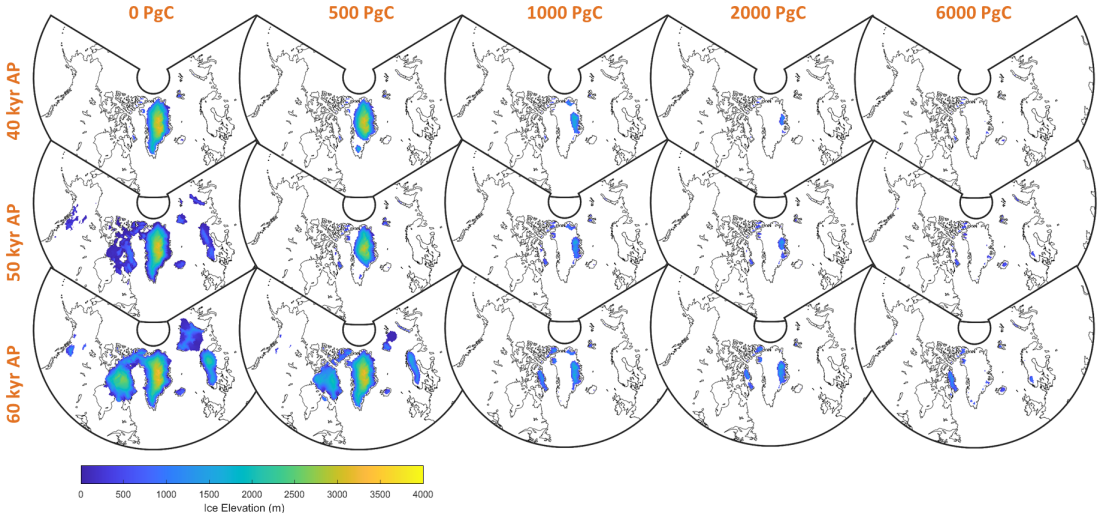


Sensitivity studies

- Still considerable disagreement with the atmospheric lifetime of anthropogenic CO_2
- Due to large uncertainties with the long term carbon cycle, and different considerations of the models
- We perform an extensive sensitivity test on pertinent model parameters (some highlighted here)

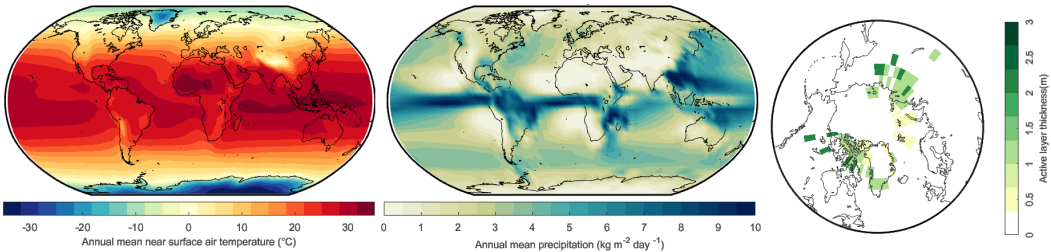


Part 2: Glacial cycles (preliminary work)



Summary & outlook

- This data is to be shared! CLIMBER-X has a large catalogue of variables that can be used as initial and boundary conditions for other simulations
- **Variables of interest for nuclear repository safety:** runoff, soil porosity, active layer thickness, etc.



- Clear aim in terms of what must be done, and good progress on general timeline
- **We hope to submit this paper this year!**
- **Contact:** kaufhold@pik-potsdam.de