Transient simulation of climate variability during the Last Glacial Maximum and the Holocene with an energy balance climate model

Elisa Ziegler[1] and Kira Rehfeld[1]

[1]Heidelberg University

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Abstract

Projected changes in climate are likely to affect not only its mean state but also its variability. As such, improving our understanding of the spectrum of climate variability and how different feedbacks in the climate system influence it is of vital importance. We perform a process-based examination of variability with respect to changing orbital insulation, ice coverage, and land/sea distribution during the Last Glacial Maximum and the Holocene. To this end, we adapt a two-dimensional energy balance model [Zhuang, North & Stevens, 2017] to run transient simulations. The model is forced by carbon dioxide and solar insolation changes for the last Glacial cycle. We evaluate the model's ability to reproduce changes in local to global, seasonal to millennial temperature distributions during the Last Glacial Maximum and the Holocene. We compare the simulated states and the transient evolution to those obtained by comprehensive coupled climate models. Finally, we test the mean-state dependence of temperature variability over a large range of model configurations and discuss implications for future climate.

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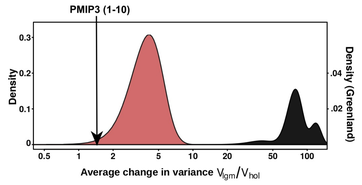
Elisa Ziegler, Kira Rehfeld
Institute of Environmental Physics, Heidelberg, Germany

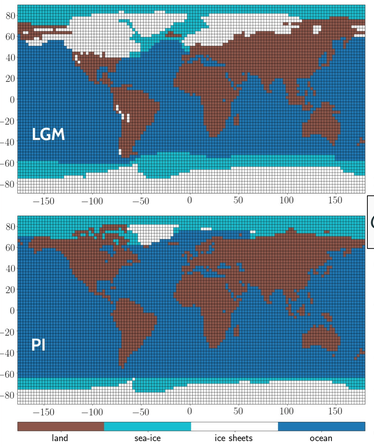
1 Motivation

Climate variability governs the probability of extreme events[1] and thus living conditions on Earth. How projected changes in mean climate will affect climate variability remains uncertain[2-5]. To this end, comparing the last glacial to the present interglacial can provide new insights. However, models simulate a lower change in variability during that period than reconstructions from proxies suggest[3,5]. Long transient simulations with low-dimensional models can contribute to the picture and allow a process-based examination of climate variability.



(A) Variability change in proxy data from LGM to Holocene[3]

2 Energy Balance Model



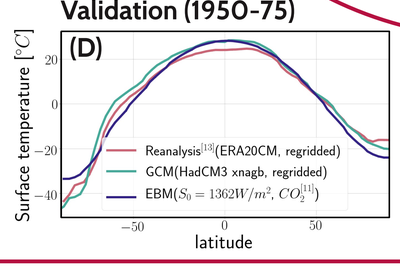
basis: EBM by Zhuang, North & Stevens[6,7]
resolution: 128 x 64 boxes (2.8° x 2.8°), 48 time steps per year
input: CO_2, S_0, orbital configuration, land-sea mask, ice distribution
solves:

$$C(\hat{\mathbf{r}})\frac{\partial T}{\partial t} + A + B \cdot T = \nabla \cdot (D(\hat{\mathbf{r}})\nabla T) + S_0 \cdot S(\hat{\mathbf{r}}, t)a(\hat{\mathbf{r}})$$

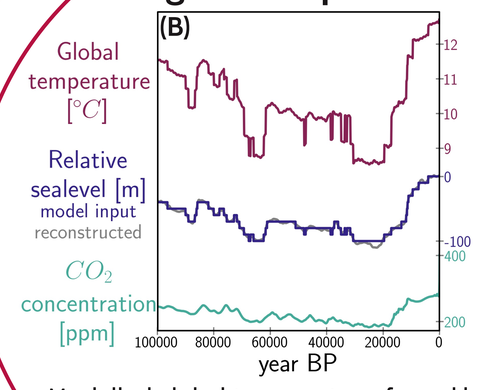
C: effective heat capacity
A,B: coefficients from satellite data[6,8]
D: diffusion coefficient
S_0: solar constant
S: insolation, depends on orbital parameters
a: albedo

	original[6,7]	**revised model**
runs	equilibrium	transient & equilibrium
restarts	no	yes
forcing	constant only	non-constant
map	all in one file	land-sea mask & ice separate
configuration	in model code	outside model
output	T	T, C, S, a, map

Validation (1950-75)



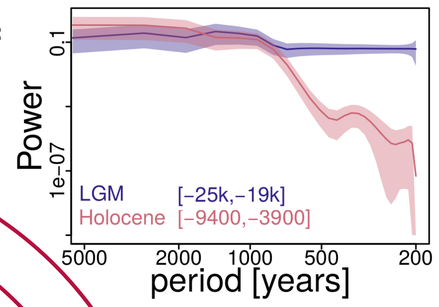
100kyr glacial to present



Modelled global temperature, forced by map changing with sea level[9,10], CO_2[11], 11-year solar cycle[12] and orbital configuration.

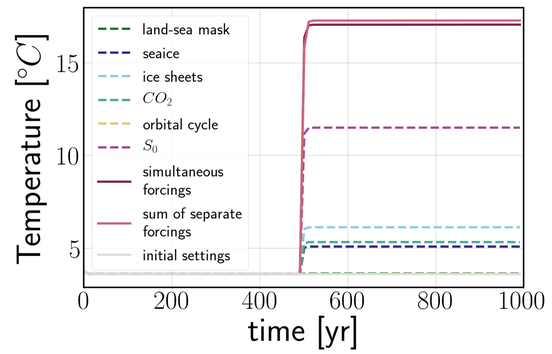
3 Results

(C) Spectrum:



Consistent with expectations, variability is lower during the Holocene than the LGM. However, more experiments need to compare the role of sealevel and CO_2 vs. solar variability.

(E) Testing feedbacks & non-linearity:
effect of separate vs. simultaneous forcings



step forcing	**0-500yr**	**500-1000yr**
orbital cycle	off	on
solar constant S_0	1300W/m²	1400W/m²
CO_2	200ppm	400ppm
ice sheets	LGM	PI
sea ice	LGM	PI
land-sea mask	LGM	PI

4 Conclusions

- EBM reproduces temperature distributions similarly to GCM (D)
- non-linearity: sum of forcings ≠ all together

Next Steps:
- expand validation of transient EBM
- comparison to transient GCM runs
- test volcanic forcing
- parallelise

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eziegler@iup.uni-heidelberg.de
uni-heidelberg.de/palaeoclimate-dynamics