Efficient selection of parameter vectors for fully coupled ice-climate modelling of glacial cycles

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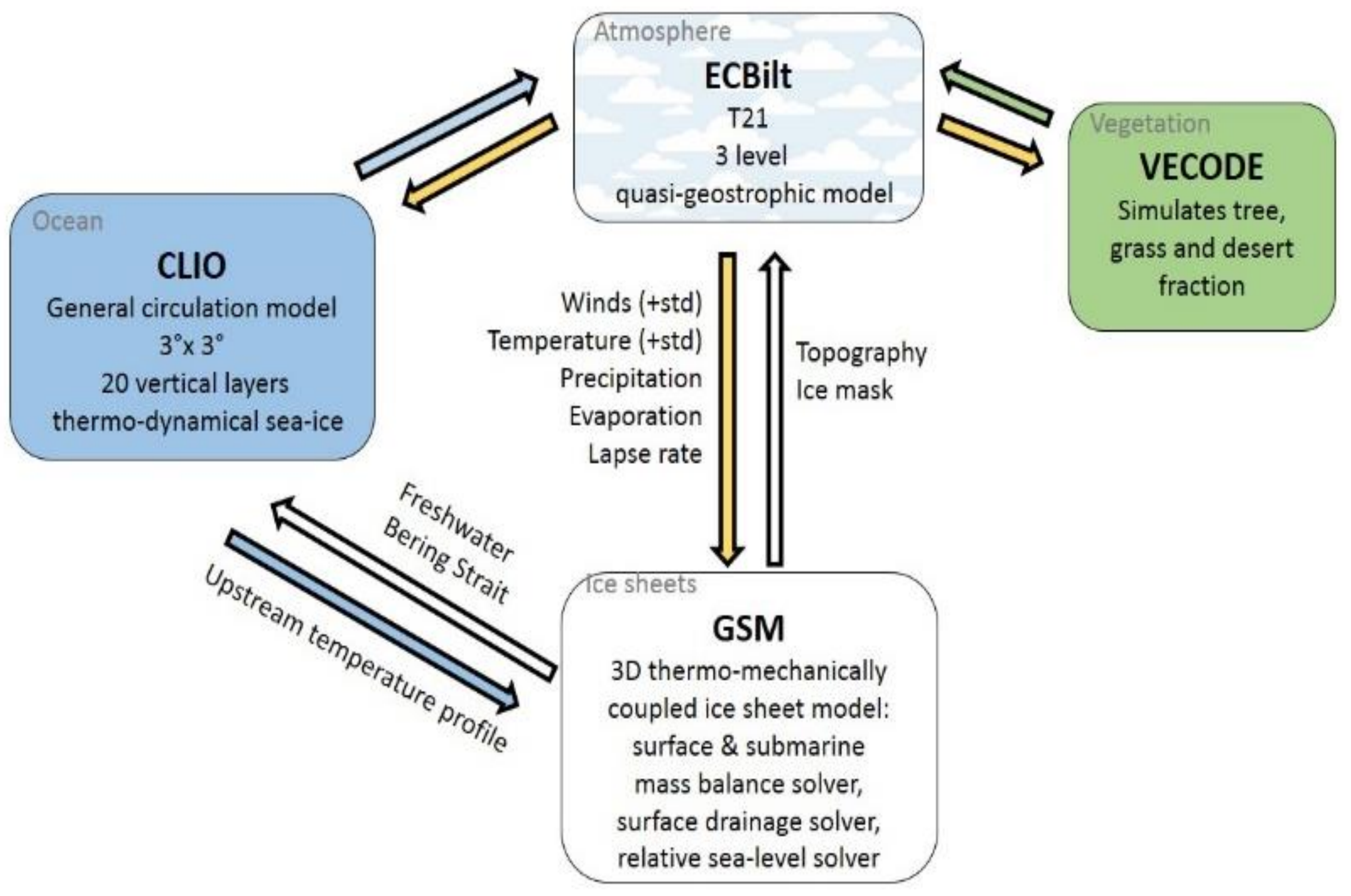
Introduction & Objective

While the Last Glacial Maximum (LGM) configuration of ice sheets and climate has had much attention, much less is known about glacial cycles further in the past. Geological evidence suggests that the Eurasian ice sheet was overall larger and reached further east during LGM than it did during the Penultimate Glacial Maximum (PGM, e.g. Svendsen et al, 2004).

To improve understanding of the penultimate glacial cycle, we are carrying out an order 400 member ensemble of fully coupled ice/climate transient simulations. The simulations are with the LCice coupled model (Bahadory and Tarasov, 2018) that incorporates the Glacial Systems Model and Loveclim. Previous experience with modelling last glacial inception (Bahadory et al, Cryosphere discussion), indicates that random parameter selection will tend to give model simulations that fail to be within uncertainty bounds for inferred sea-level. To improve the density of acceptable simulations as well as coverage of the potential glacial phase space, we have added more ensemble parameters (to a total of 19 LOVECLIM parameters) and redesigned the parameter selection algorithm.

The model LCice: coupling LOVECLIM components to the glacial system model GSM



Research Questions: How do glacial cycles I and II compare?

- why was the Eurasian ice sheet apparently larger during PGM than LGM?
- are there different sheet-climate interactions at play during the two recent glacial cycles (e.g. Taiga-Tundra feedbacks, standing atmospheric wave due to different ice sheet configuration)?

Setting up a large ensemble

Sensitivity analysis

- To identify the influential physical model parameters a sensitivity analysis is performed using min./max. of a range of plausible values of a variety of model parameters for an equilibrium climate simulation (present day)

Evaluate influence of the change in parameter value – Choosing metrics according to research questions:

- summer & winter temperature over North America and Eurasia
- Annual and winter precipitation over North America and Eurasia

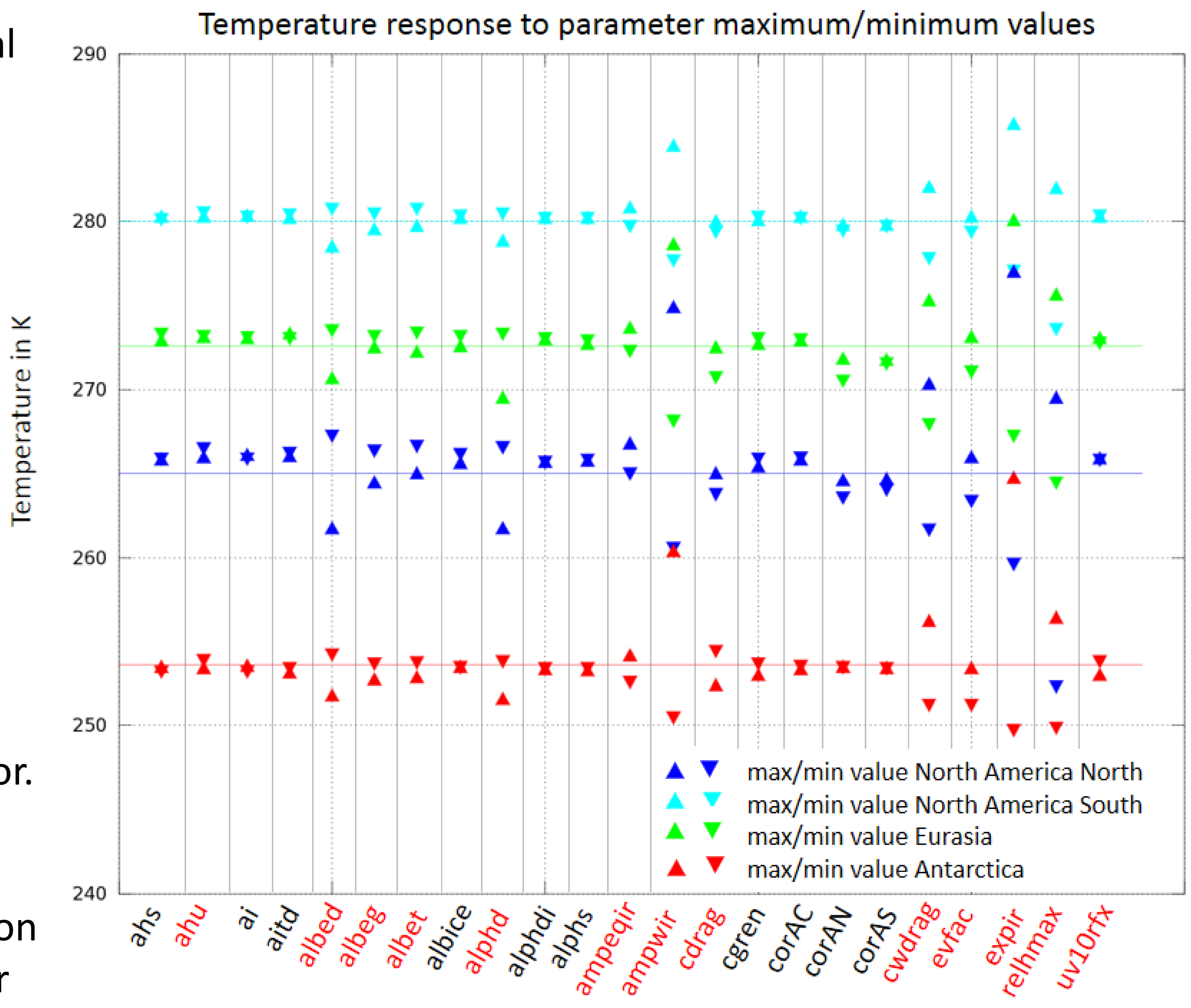
→ mass balance of ice sheet

- Maximum sea ice concentration in North Atlantic and Southern Ocean
- Summer SST in North Atlantic and Southern Ocean

→ moisture availability & heat advection onto land

- Vertical ocean temperature in Southern Ocean → sub-shelf melt
- Parameters evoking largest changes in metrics are identified as influential and included in the large ensemble (see figure right)
- Parameters are assigned a distribution over their value range (either uniform or with higher density around standard values)
- Using Latin Hypercube sampling on the influential parameter distributions, the first part of the parameter vectors is assembled
- We sampled 2000 parameter vectors for the large ensemble

Temperature response to parameter maximum/minimum values



Minimizing structural uncertainty

- Structural uncertainty can be minimized by parameterizing as many sources of uncertainty in model structure as possible
- The structure of upscaling from ice sheet to atmospheric grid resolution (simple average, envelope and silhouette) is parameterized
- This structure of the model becomes a parameter and is included in the Latin Hypercube sampling scheme and added to the parameter vector.

Including uncertainty in initial conditions

- Length of model spin-up as well as the start year of the coupled simulation are varied and included as parameters in the individual parameter vector for each ensemble member
- Loveclim spinup length varies from 1000 to 3000 years and coupled simulation for present day starts from years 1300 to 1600

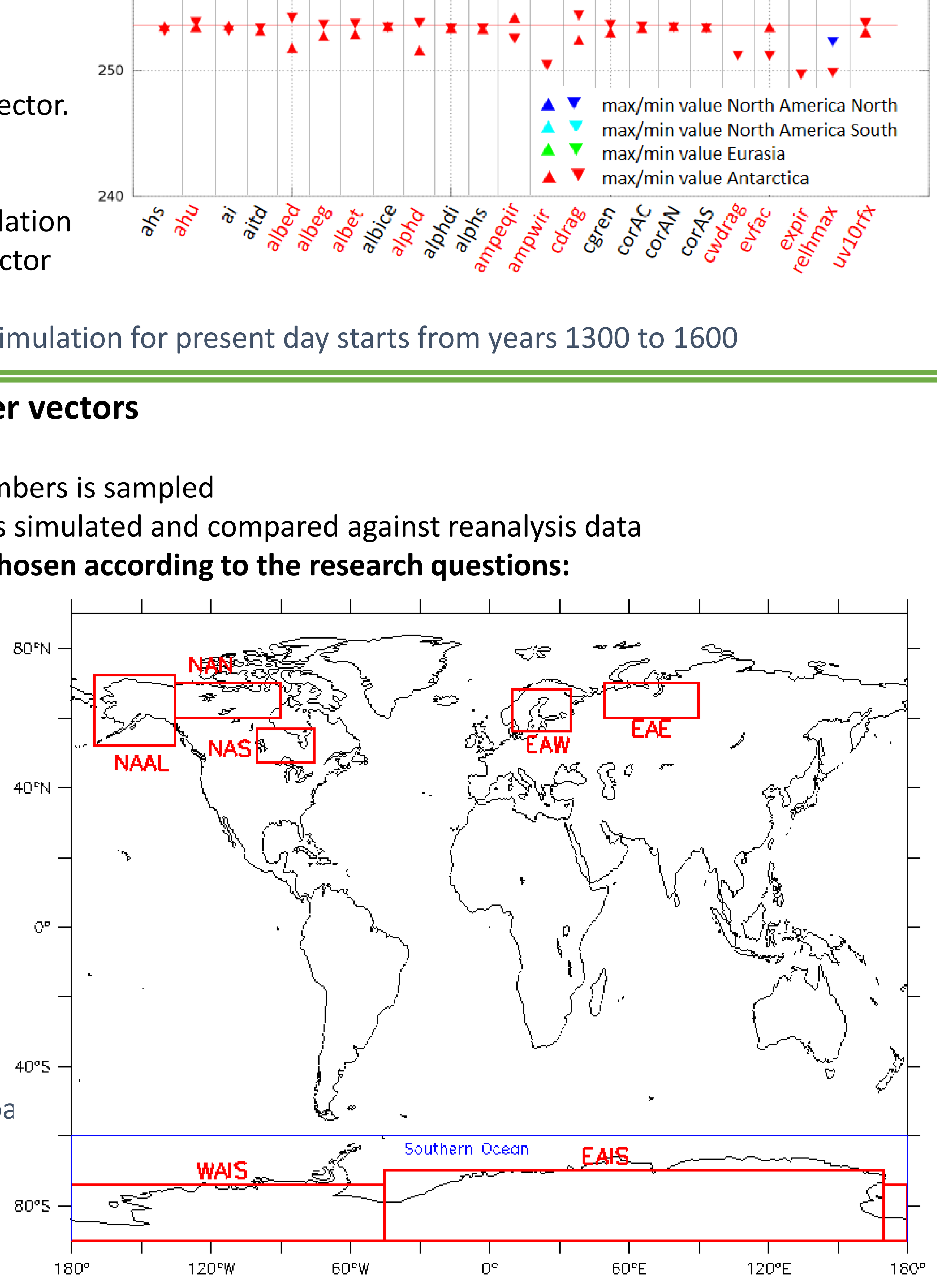
Filtering the large ensemble and selecting promising parameter vectors

Present Day (PD) climate filtering

- From the parameters identified above, a large ensemble of 2000 members is sampled
- To evaluate the performance of the ensemble members, PD climate is simulated and compared against reanalysis data

Metrics used to evaluate ensemble member performance need to be chosen according to the research questions:

- sections of interest for ice sheet build up are defined (see figure)
- air temperature seasonality (JJA-DJF) over land sectors
- annual precipitation over land sectors
- Well performing ensemble members are kept for the next stage of filtering



Glacial climate filtering

- LGM can be used as an example for glacial climate, together with PD climate this represents the two ends of the spectrum of climate states an ensemble member has to be able to simulate for a glacial cycle simulation
- We use GLAC1-D boundary conditions
- Due to fewer precise observational data to compare the simulations to, we test for near-stable mass balance at LGM conditions and compa simulated temperatures at ice core locations GRIP, EPICA DOME C, and WAIS to proxy derived temperatures
- Well performing ensemble members are kept for the next stage of filtering

Accelerated Glacial Inception Filtering

- We test ensemble members' sensitivity to orbital forcing and their ability to simulate stadial as well as interstadial conditions in transient simulations of Last Glacial inception
- The ensemble members performance is evaluated against sea level reconstructions

Main ensemble simulation

- Filtering for the two 'extreme' climate states in a glacial cycles as well as for a transient periods of stadial and interstadial conditions has reduced the size of the large ensemble we started with to a few hundred promising parameter vectors
- Filtering continues along the way once the main simulation starts:
- How can promising ensemble members be identified along the way? What are possible constrains?

Constrains for (penultimate) glacial cycle modelling

- Temperature from Antarctic ice cores
- Sea level records
- maximum Eurasian ice sheet extent during penultimate glacial
- minimum Greenland ice sheet extent during Last interglacial
- ...?