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Quantifying Last Glacial Maximum ocean circulation by state estimation

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Motivation

The Last Glacial Maximum (LGM, ~19,000-23,000 years before present) allows us to study the response of the climate system to large perturbations, and is characterised by a good proxy-data coverage, so that forcing, boundary conditions and climate response are fairly well known. Using state estimation techniques, we plan to address the following questions.

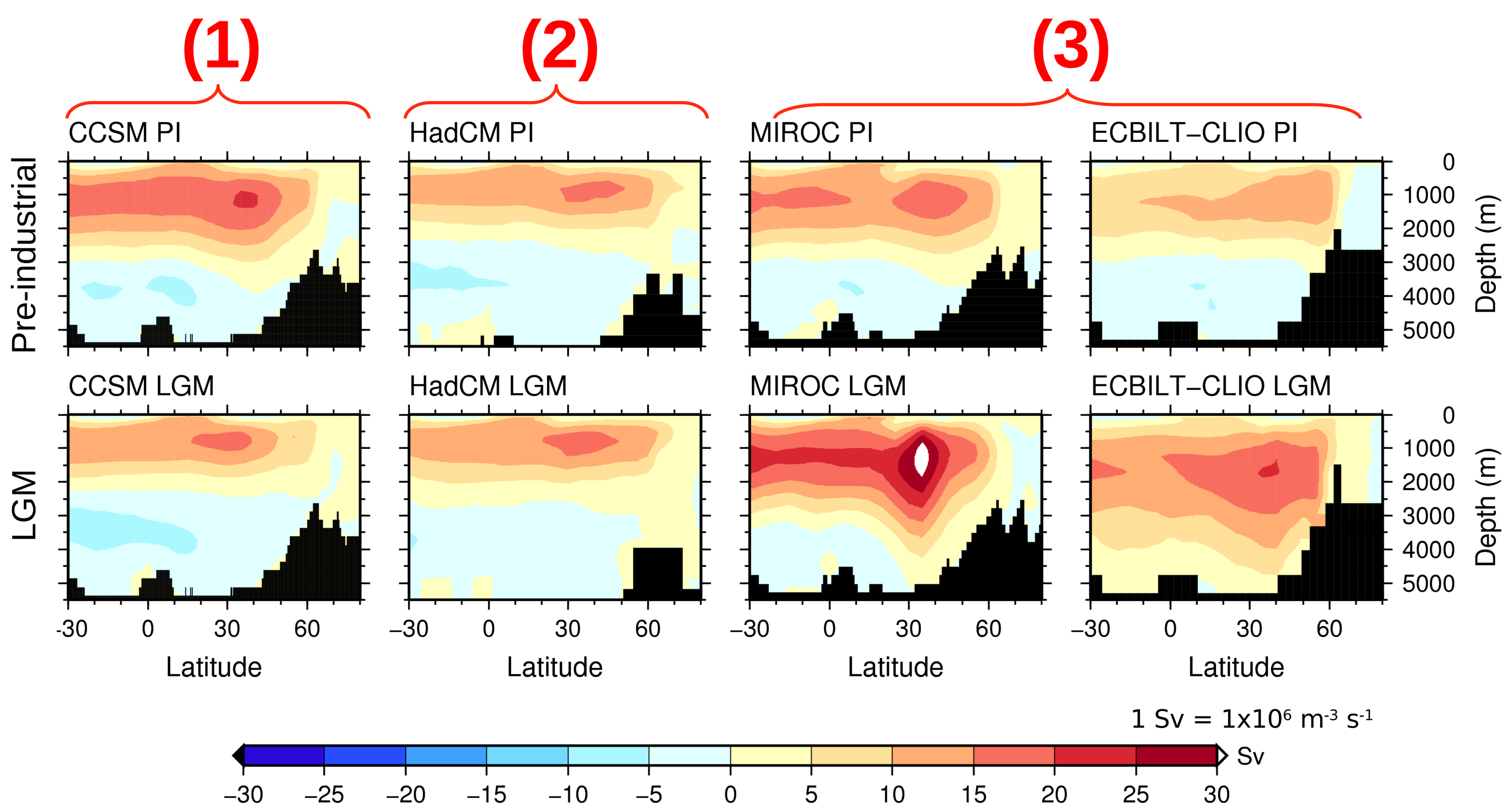


Figure 1: Atlantic Ocean meridional overturning circulations (after Otto-Bliesner et al., 2007) simulated by the PMIP2 (Paleo-climate Modelling Intercomparison Project Phase II) coupled atmosphere-ocean models.

- Was the ocean circulation during the LGM **(1)** weaker than today, **(2)** as strong as today, or **(3)** stronger than today?
- Are numerical ocean models and paleo-proxy data conclusive, at least in combination?
- Can we identify geographical locations where new observations (paleo-proxy data from new sediment cores) are most effective in constraining a numerical model?

State estimation

Integrate model

The model result ($\boldsymbol{V}$) is controled by the following control variables ($\boldsymbol{u}$).

- initial conditions (e.g. temperature)
- boundary conditions (e.g. surface winds, heat flux)
- internal parameters (e.g. vertical diffusivity)

$$\boxed{\boldsymbol{V} = \mathrm{F}(\boldsymbol{u})}$$

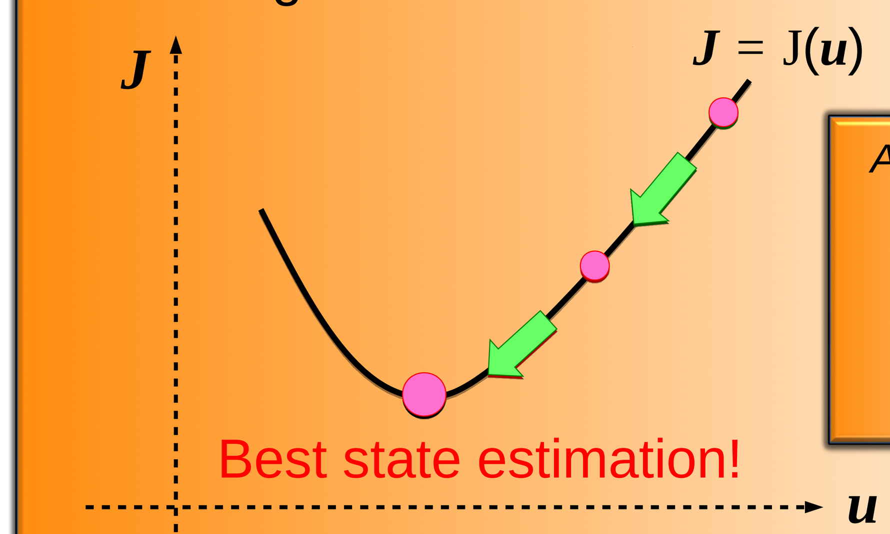
Compare model to data

Misfit between model and data ($\boldsymbol{J}$) is quantified by objective function (J).

$$\boxed{\begin{aligned}\boldsymbol{J} &= \mathrm{J}(\boldsymbol{V}) = \mathrm{J}[\boldsymbol{V}(\boldsymbol{u})] \\ &(= \Sigma_i(\mathrm{model}_i - \mathrm{data}_i)^2\,)\end{aligned}}$$

Iterative optimization of the objective function

Adjust control variables to minimize $\boldsymbol{J}$ via the gradient descent method.



Adjoint (linear) sensitivity:

$$\frac{\partial \boldsymbol{J}}{\partial \boldsymbol{u}}$$

Figure 2: Schematic illustration of data assimilation with state estimation techniques.

Methods

Model

We configured the *MITgcm* as the 'baseline' global model ocean for data assimilation. We adopted a cubed-sphere grid system thereby avoiding converging grid lines and pole singularities. Ocean biogeochemistry processes are included in the model. The ocean model is also coupled to an atmospheric energy-moisture balance model (EMBM) on the same grid.

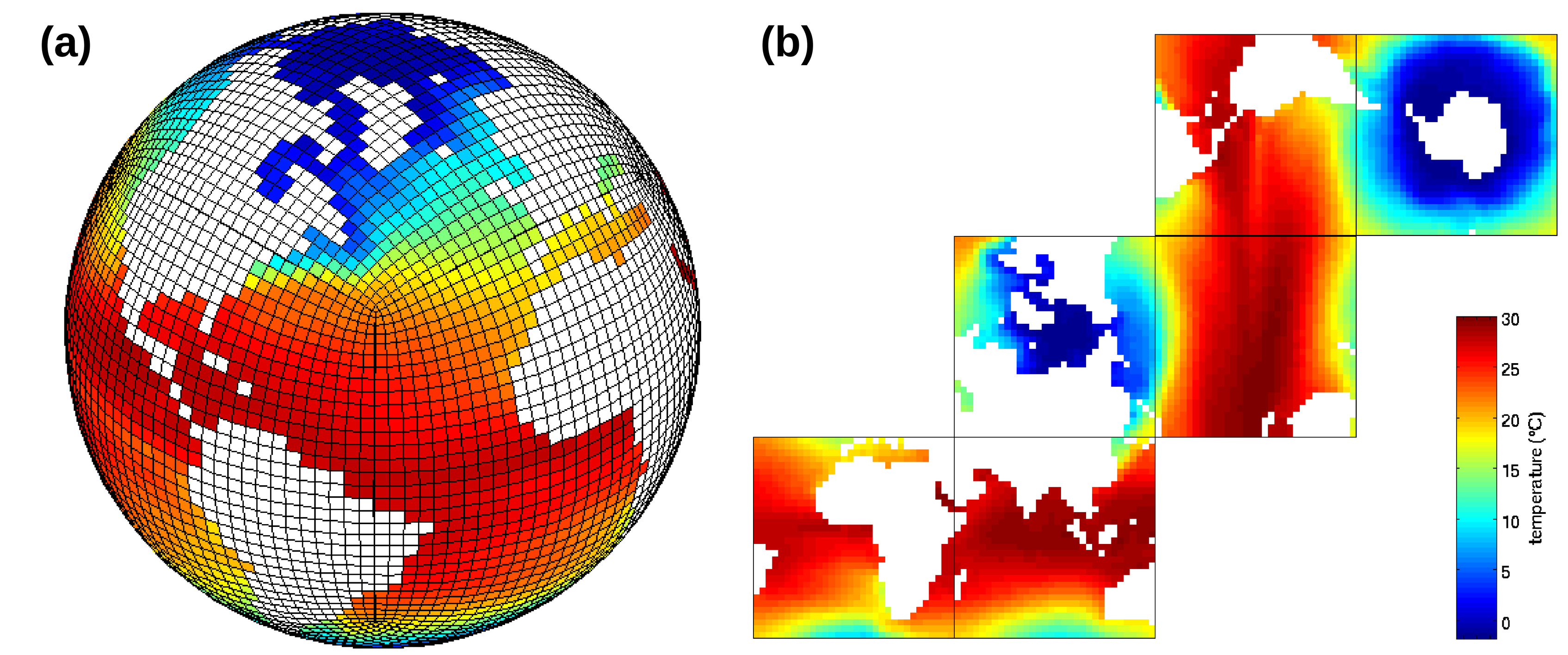


Figure 3: Configuration of the cubed-sphere grids. This example shows the projection of annual mean sea surface temperature climatology on (a) a spherical shell, and (b) its development view.

Data

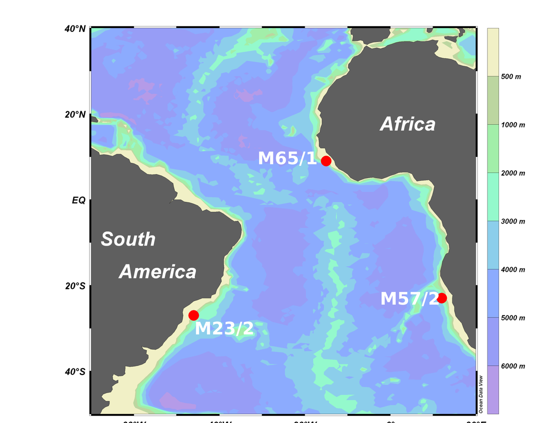


Figure 4: Sediment core locations that will add new paleo data to the database.

The "Glacial Ocean Atlas" (www.glacialoceanatlas.org) will provide us with a great amount of paleo-proxy data for the LGM. Paleo-nutrient proxies ($\delta^{13}C$, *Cd/Ca*) and $\Delta^{14}C$ as a kinematic proxy will be used. Initially, data from this database will be converted to nutrient concentrations to compare them to model output. Eventually, the proxy-data will be simulated directly.

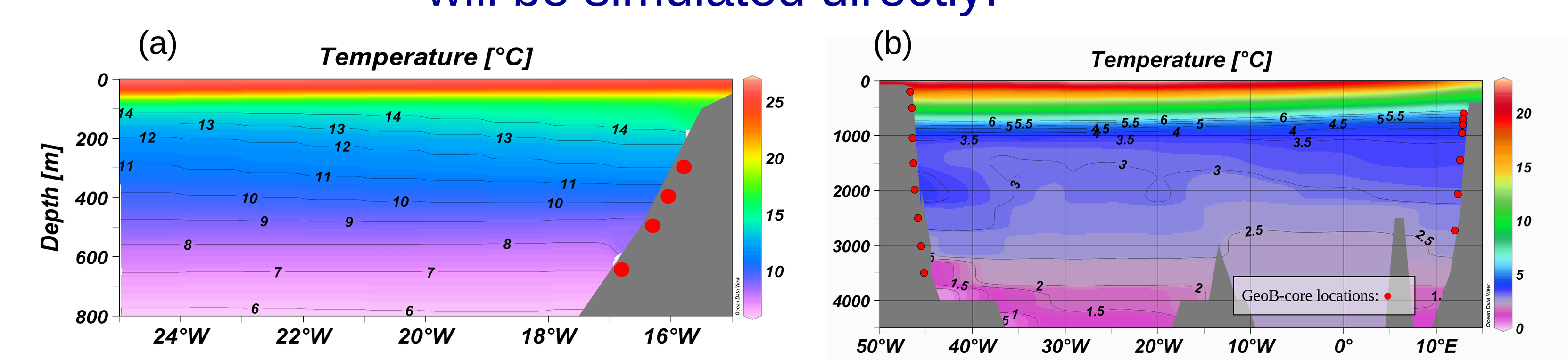


Figure 5: Cross-sectional view of the sediment core locations in the Atlantic Ocean: (a) at 8°N (b) at 25°S. (Color shading: the modern temperature profiles)

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