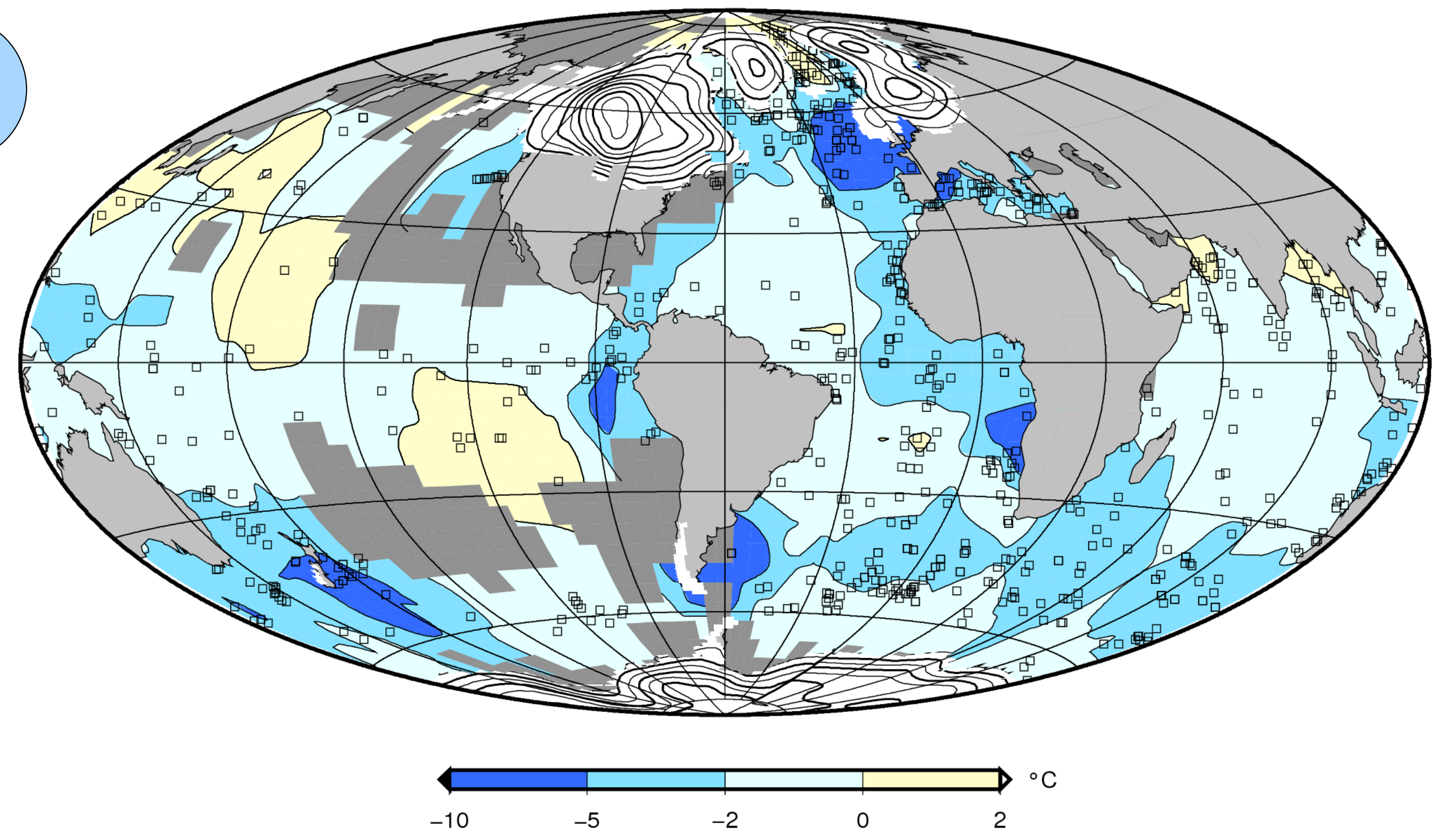
# Perspectives of data assimilation for the climate of the Last Glacial Maximum

André Paul[1] and Martin Losch[2]
(1) MARUM - Center for Marine Environmental Sciences and Department of Geosciences, University of Bremen, PO Box 33 04 40, D-28334 Bremen, Germany (apaul@marum.de),
(2) Alfred Wegener Institute for Polar and Marine Research, Bussestrasse 24, D-27570 Bremerhaven, Germany

1

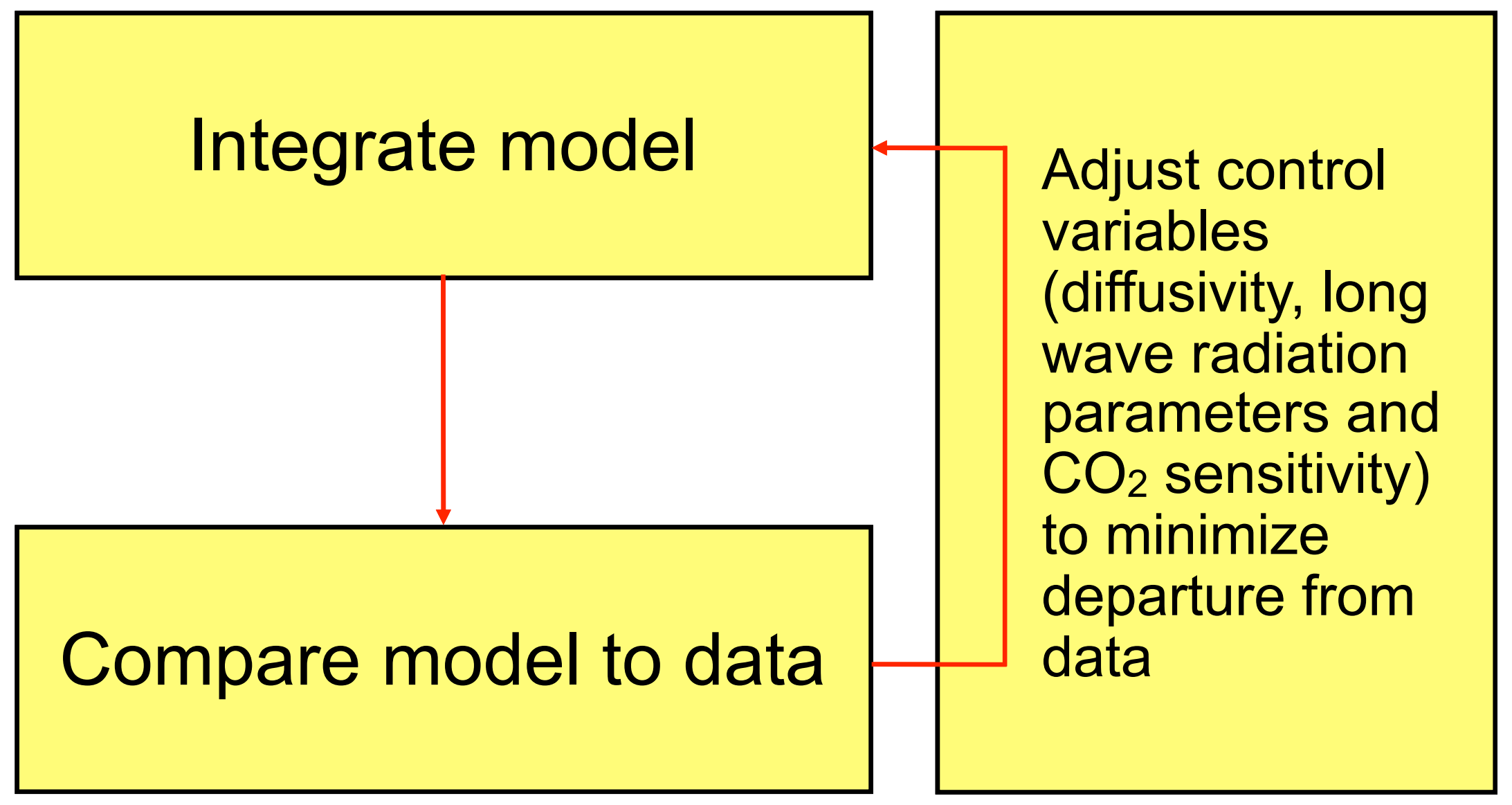


MARGO LGM annual-mean sea-surface temperature anomaly

## Methods

We applied the "adjoint method" (Fig. 2) to a classical one-dimensional energy balance climate model "`Ebm1D`", to minimize the misfit between this model and sea-surface temperature data from the LGM (Fig. 1), taken from the Multiproxy Approach for the Reconstruction of the Glacial Ocean surface (MARGO). The "adjoint model" (derivative code) was generated by the "adjoint compiler" TAMC (http://autodiff.com/tamc/).

2



Integrate model

Compare model to data

Adjust control variables (diffusivity, long wave radiation parameters and $CO_2$ sensitivity) to minimize departure from data

Schematic diagram for the assimilation of paleo-proxy data by data estimation techniques

## Motivation

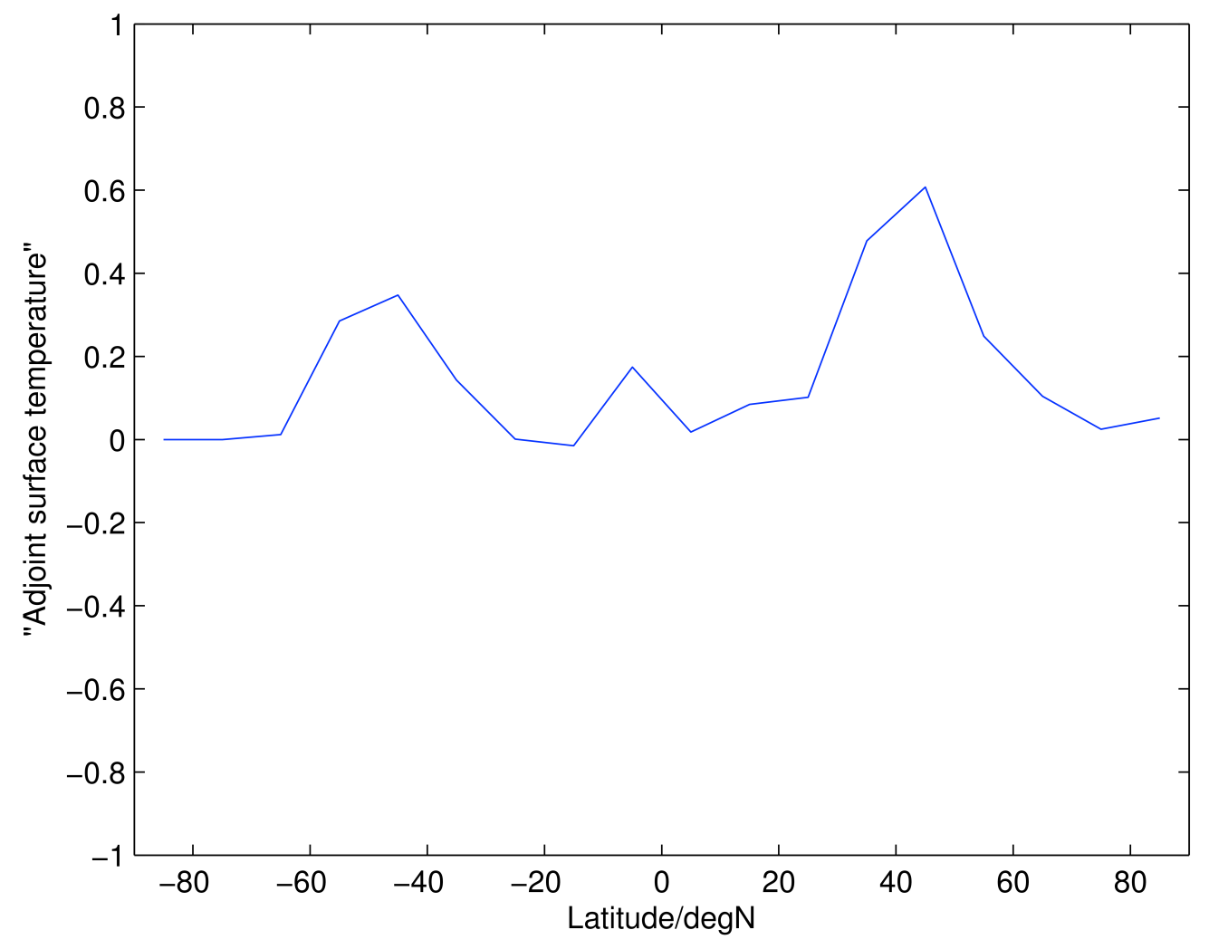
We propose to apply data assimilation techniques to constrain climate models rigorously by paleo data in order to further advance our understanding of, e.g. the climate of the Last Glacial Maximum (LGM, ~19,000- 23,000 years before present, Fig. 1). Such techniques combine paleo-data with a numerical model in a systematic way, by taking into account the uncertainties of both models and data.

## Results

The "adjoint method" can be used to adjust model parameters to be consistent with first modern surface temperature observations and then the reconstructed LGM surface temperature anomaly (Fig. 3). The meridional structure of the MARGO data implies a change in the diffusive heat transport in the `Ebm1D`.

4

Sensitivity of cost function to surface temperature anomaly in `Ebm1D`: positive values imply that cooling reduces misfit to LGM anomaly.



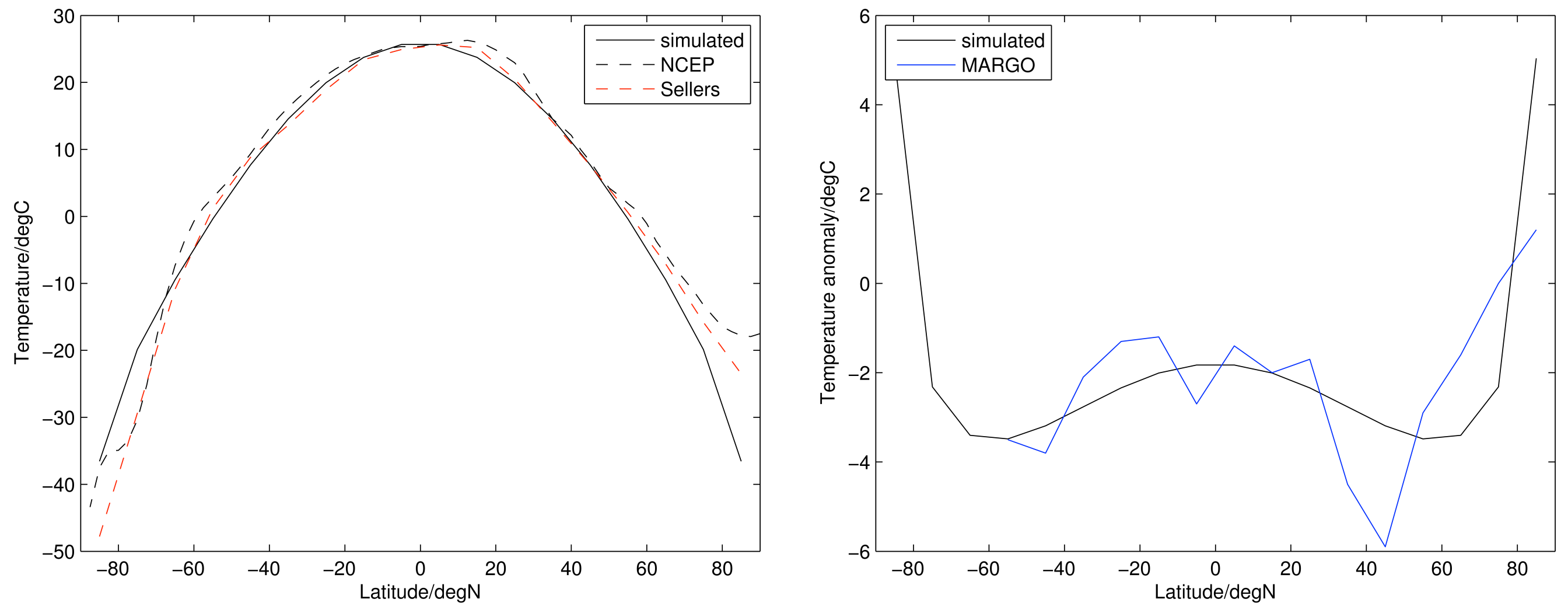
## Conclusions

Benefits and issues of adjoint method:

1.Model sensitivities are a useful by-product of the method and can guide observational efforts (Fig. 4 and Fig 5).

2.However, it is still questionable whether the available paleo-data for the LGM is accurate and abundant enough to be useful for our purpose.

3



Fit to (a) modern climate and (b) the LGM anomaly in `Ebm1D`. `Ebm1D` can be fit to the MARGO tropical cooling, but only at the cost of large positve anomalies in high latitudes.

## 5 Outlook: Global Ocean Model

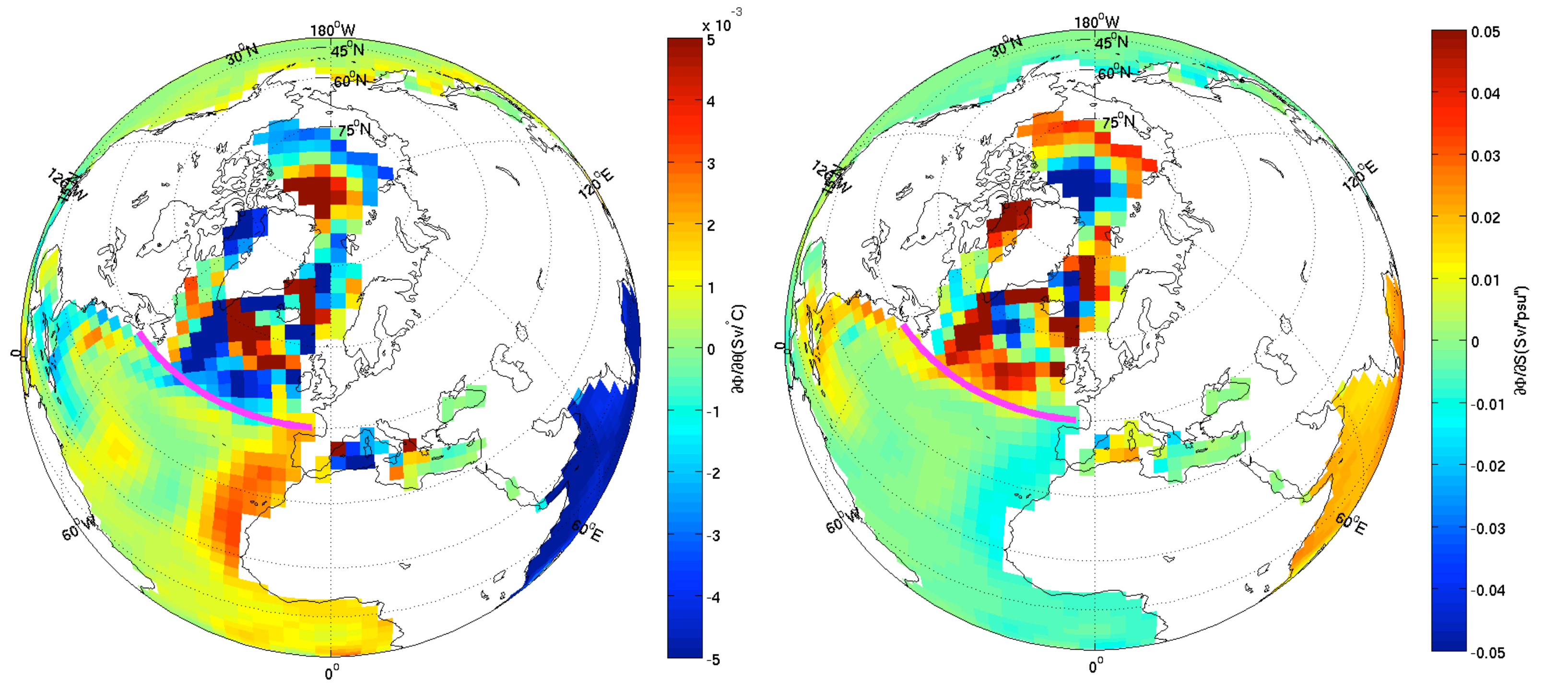


Fig 5: Adjoint sensitivity (MITgcm) of meridional overturning circulation strength (MOC, along 45˚N, magenta line) to initial conditions (temperature and salinity at 450 m depth). Negative values mean a decrease of MOC with increasing temperature (left) or salinity (right).

**Observed sensitivities have a straightforward dynamical interpretation:** lower temperature (higher salinity) north of 45˚N lead to less stability and more convection. The sensitivity pattern along the coast of North America implies that a stronger density gradient increases the surface branch (gulf stream) of the MOC.