UNIVERSITY OF LEEDS

Exploring the complex uncertainties in coupled climate-ice simulations of the Last Glacial Maximum

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UK Research and Innovation

The Challenge: Biases of simulating co-evolution of Climate and ice sheets

Observations

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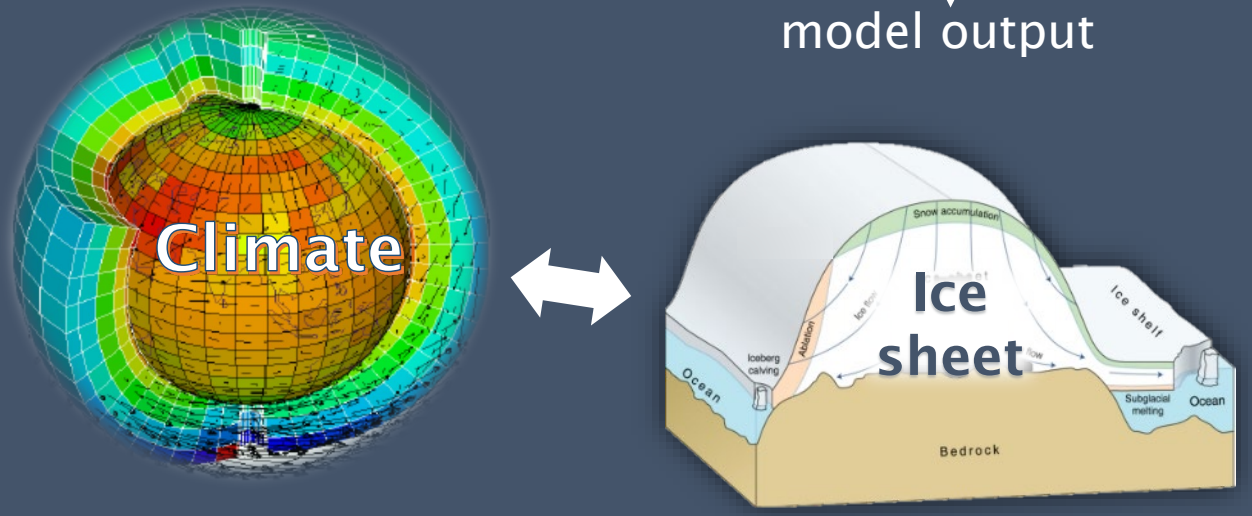
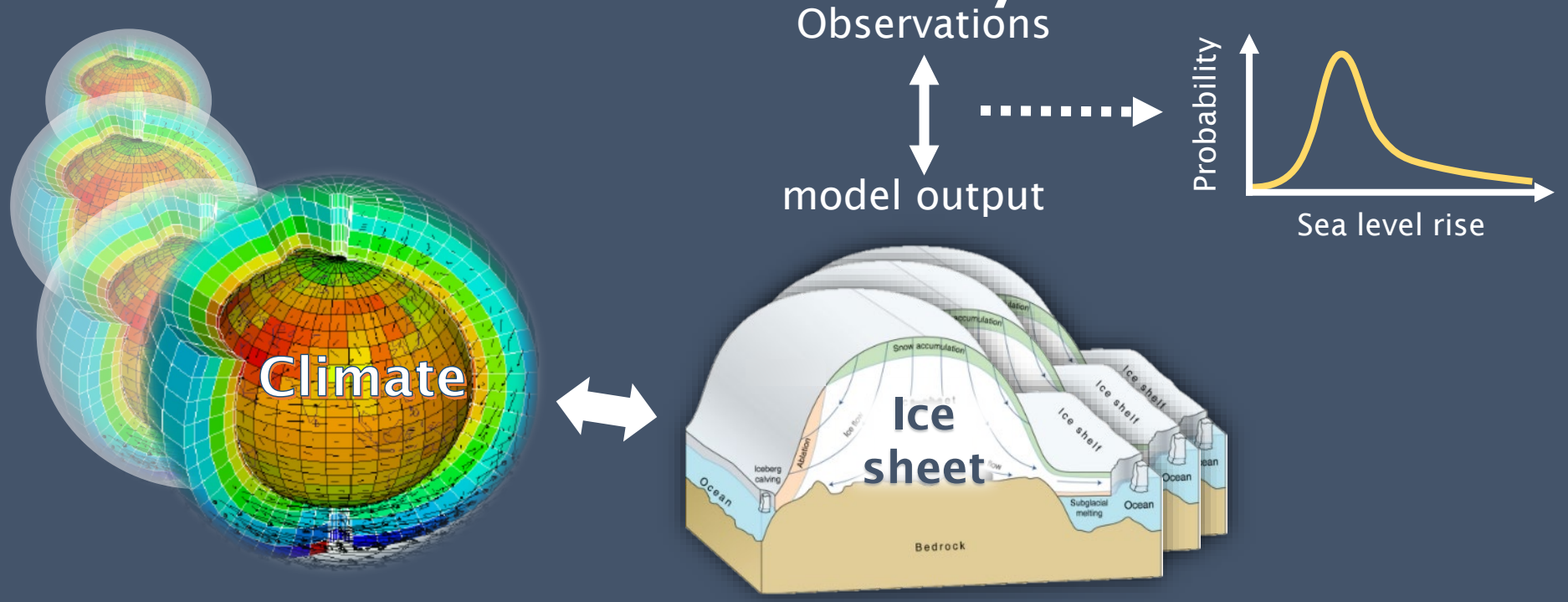
model output



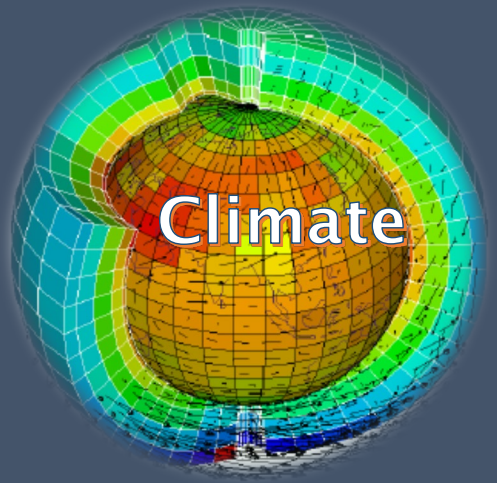
- Small biases amplified by strong ice-climate feedbacks

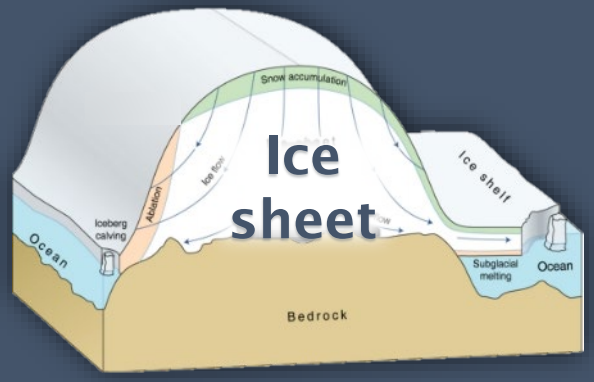
The Challenge: Tackling climate uncertainty



- Climate is the largest source of uncertainty
- Complex spatio-temporal problem
- Requires new Artificial Intelligence techniques

Model: FAMOUS-Ice





FAMOUS:

Low resolution
Ocean-Atmosphere
Dynamic vegetation
General circulation model
~500 model years per day

- Atmosphere only
- Slab ocean

Ice sheets

Glimmer: fast (Shallow ice approx.)
BISICLES: efficient intermediate complexity marine ice sheet model.

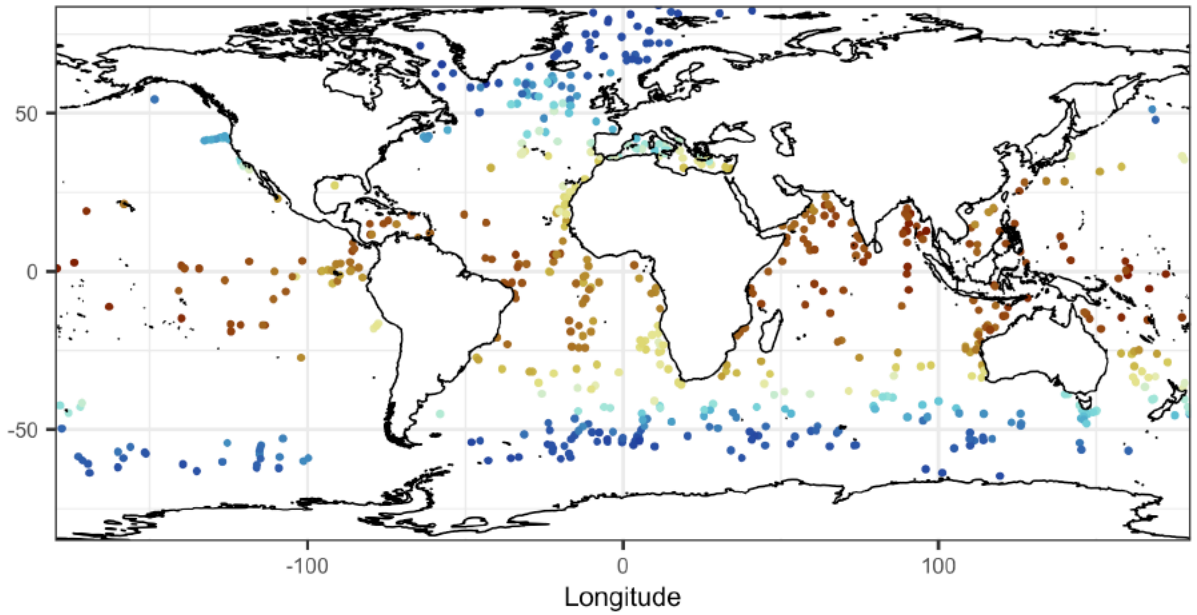
- Energy Mass balance calculation within each grid cell with land ice at 10 different elevations
- SMB downscaled onto ice sheet model surface by linear interpolation.
- Snow/firn layers ; albedo as function of grain size.

Smith et al. GMD discuss

Gregory et al. The Cryosphere 2020

Generating a range of plausible Sea surface conditions for atmosphere only runs

Data



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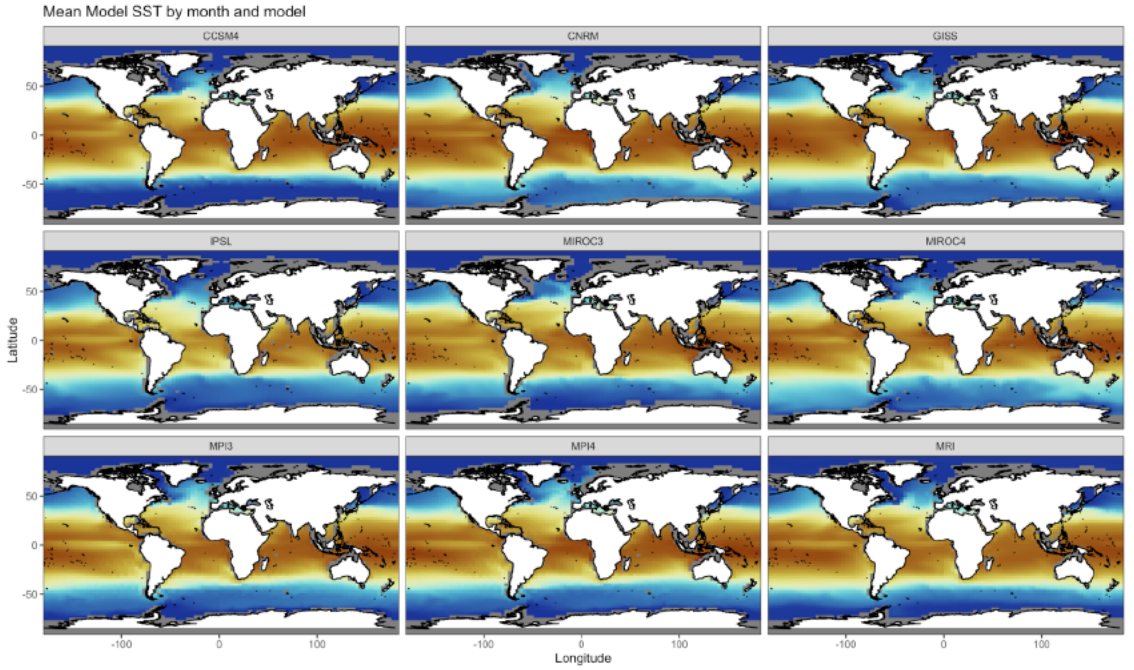
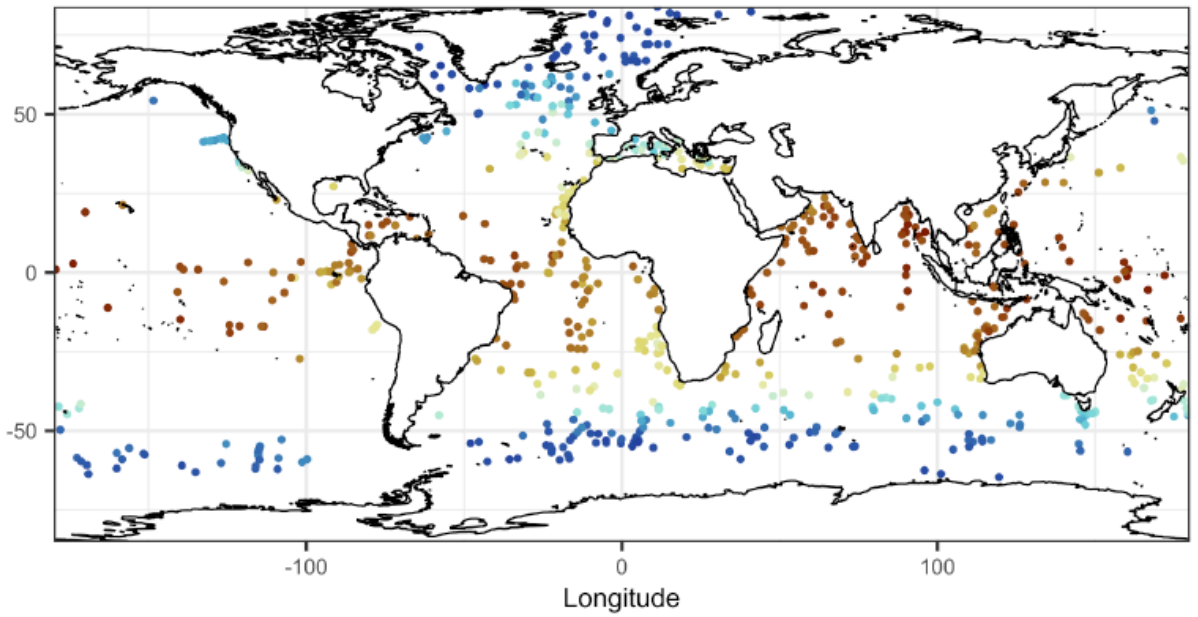
Model Runs



Margo Sea surface Temperatures + Southern Ocean

PMIP3 and PMIP 4 LGM simulations


50
0
-50
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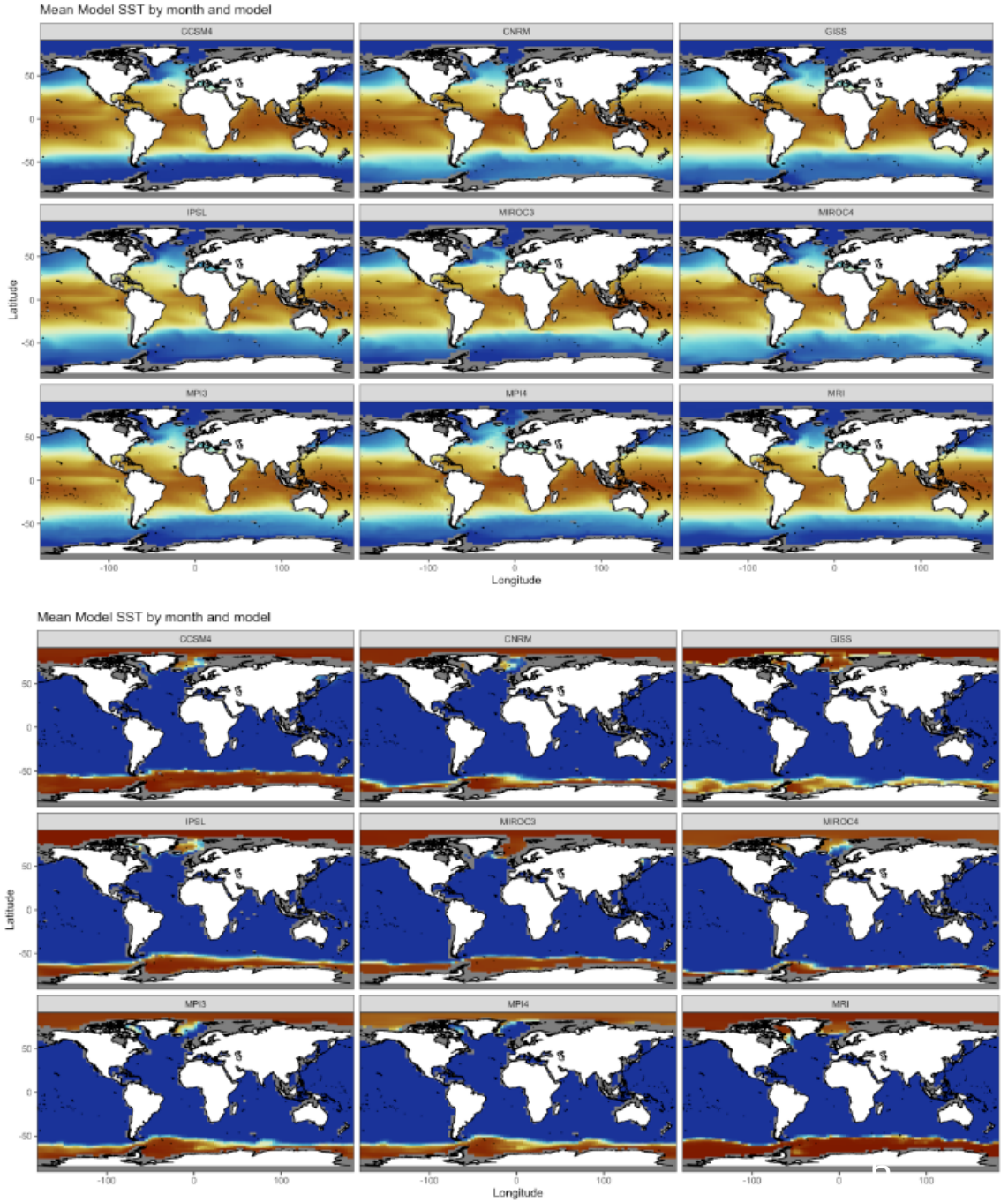
100
Longitude

+


Mean Model SST by month and model
CCSM4
CNRM
GISS
IPSL
MIROC3
MIROC4
MPI3
MPI4
MRI
Latitude
Longitude
Mean Model SST by month and model
CCSM4
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GISS
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MIROC4
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MPI4
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Latitude
Longitude

We want a method to update BOTH sea-surface temperature and sea-ice concentration.

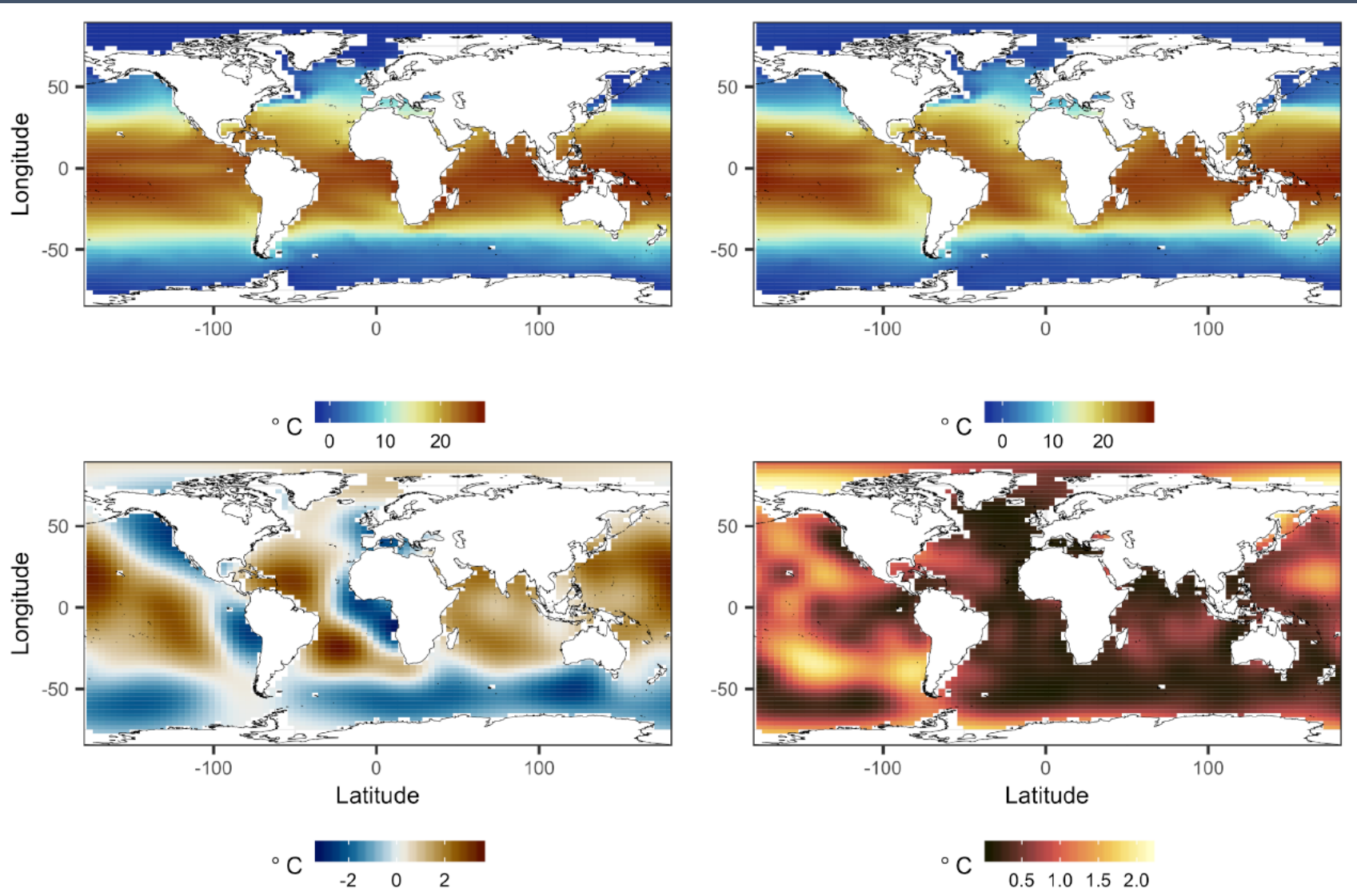
Exchangeable regressions

Multi-model mean

Mean Correction

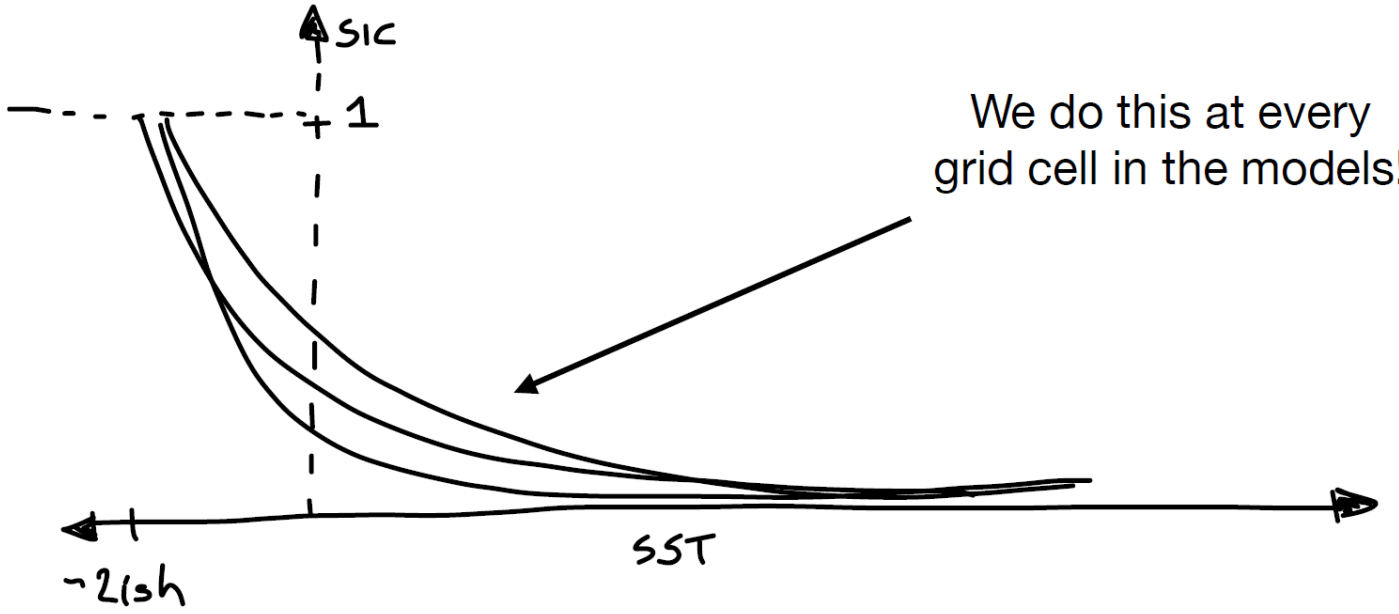
Reconstructed Mean

Reconstructed Variance



Learning plausible sea ice – SST relationship

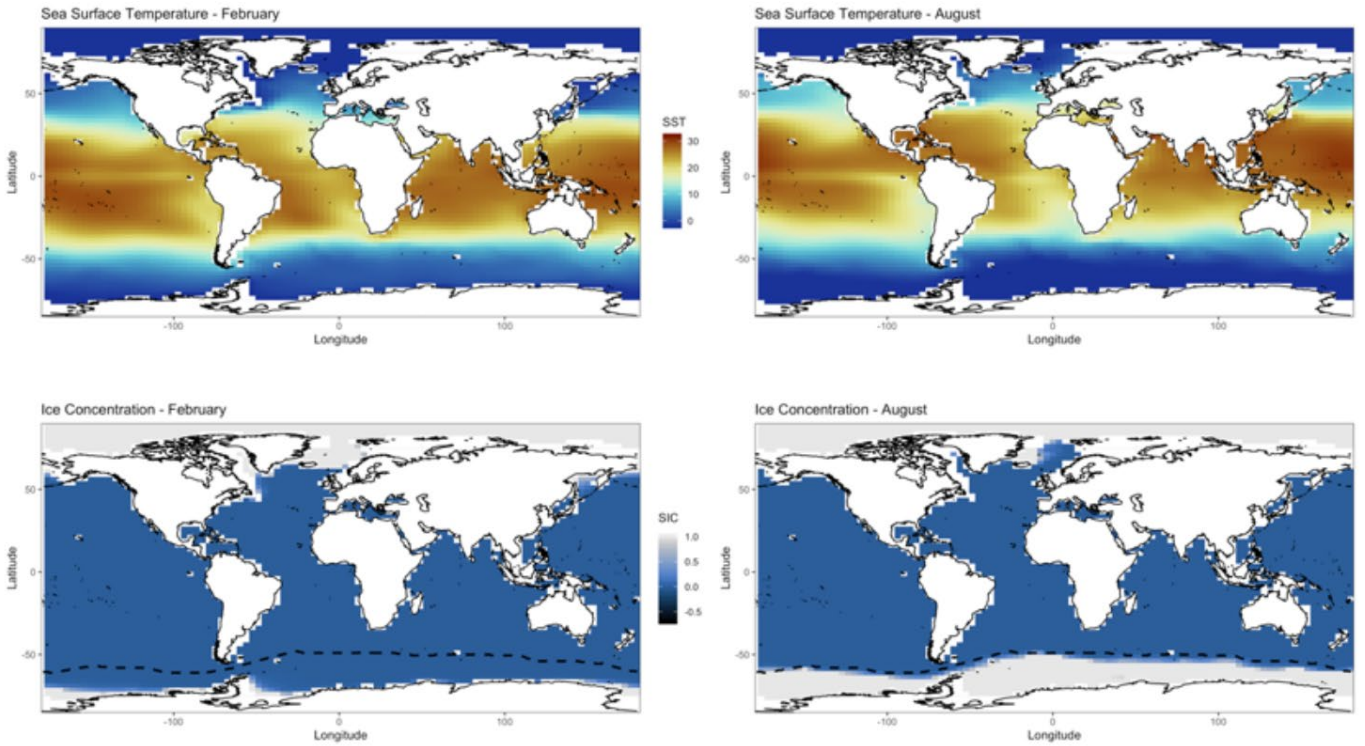
But what about sea-ice??



We do this at every grid cell in the models!

Co-reconstruction of sea surface temperature and Sea ice cover

We use the empirical relationship between SST and SIC to also update SIC in a physically coherent manner



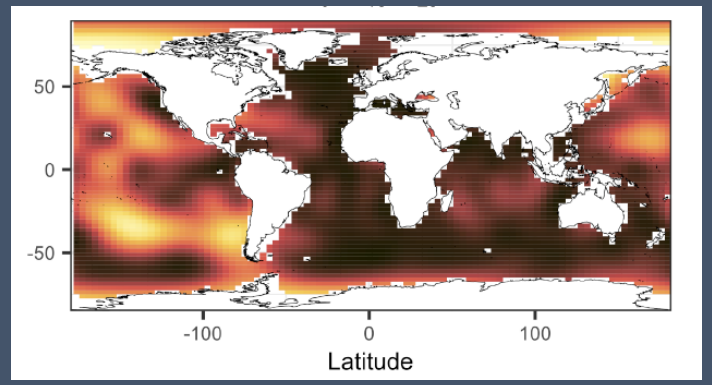
Sampling from an uncertain reconstruction

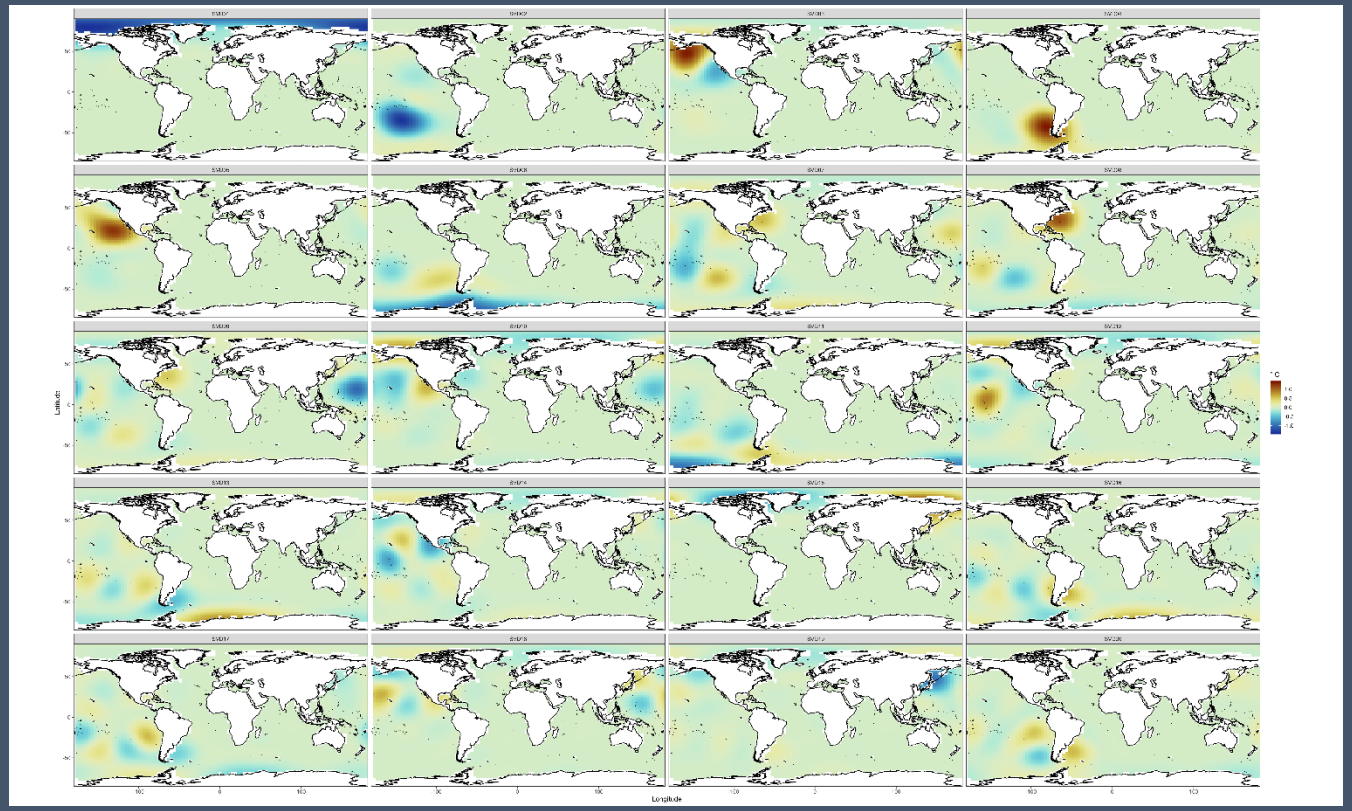
1. Decomposition of Covariance matrix to select direction of maximum variance and remove small scale patterns.

Variance-Covariance Matrix

	1	2	3	4	5
1	σ^2	COV	COV	COV	COV
2	COV	σ^2	COV	COV	COV
3	COV	COV	σ^2	COV	COV
4	COV	COV	COV	σ^2	COV
5	COV	COV	COV	COV	σ^2

Variance



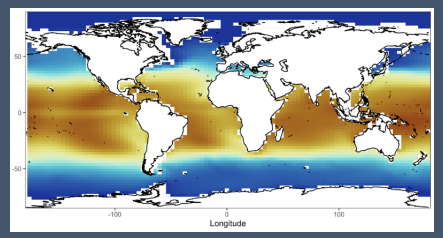


Sampling plausible SST and sea ice

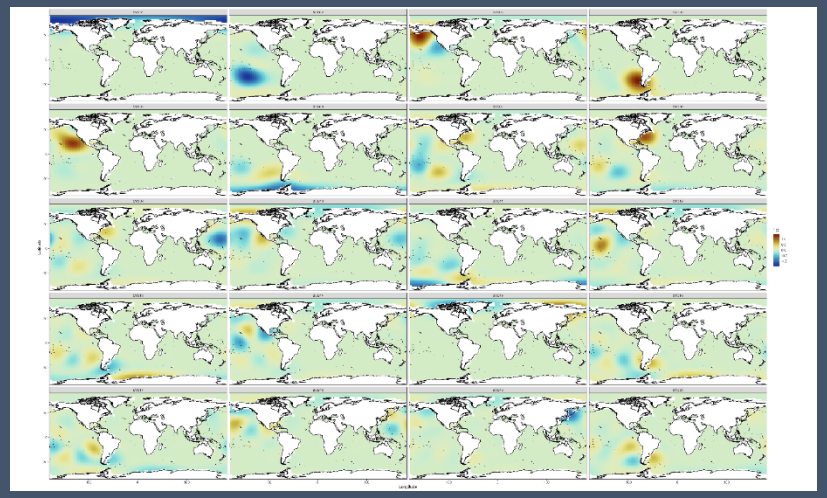
Reconstructed Mean

Linear combination of principle components

Ensemble of plausible SSTs and Sea ice



+ a_i



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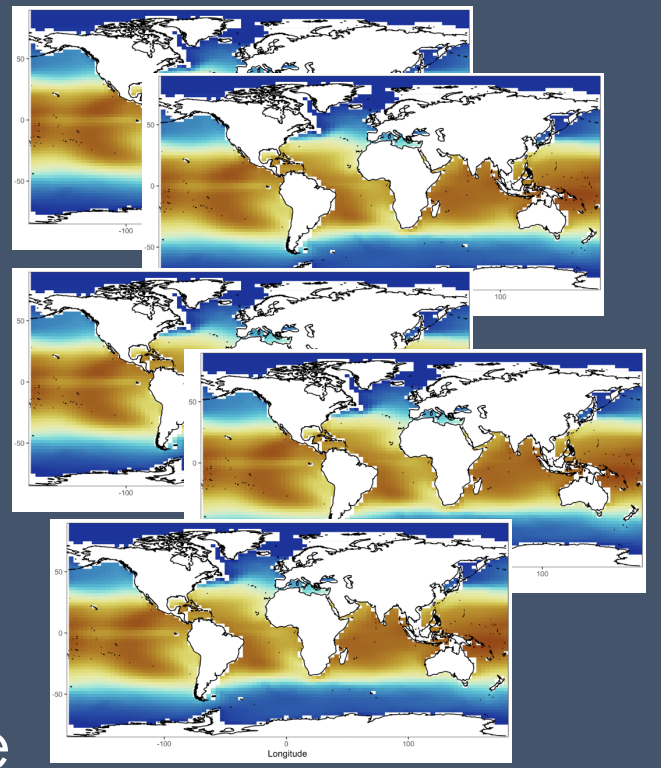
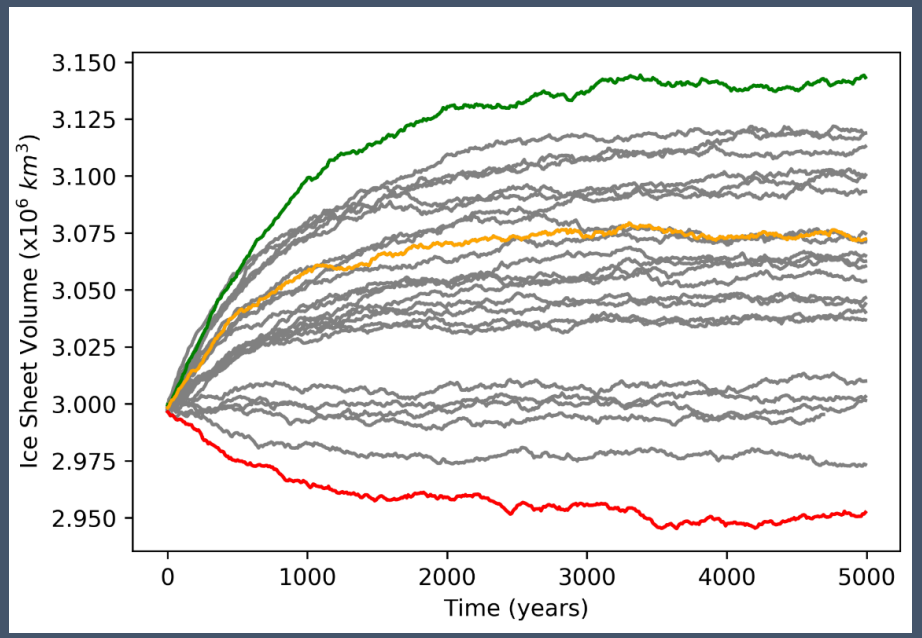
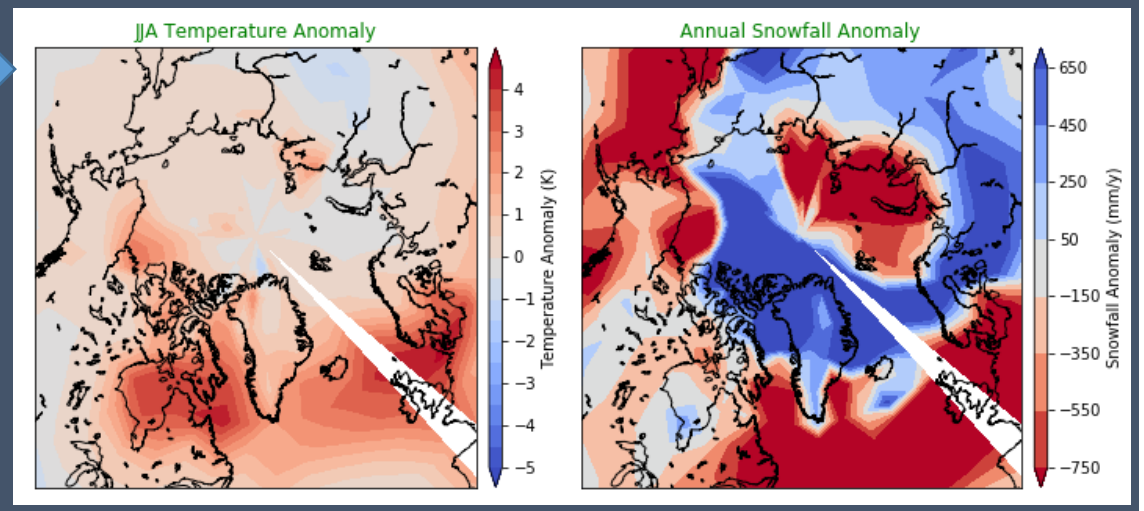


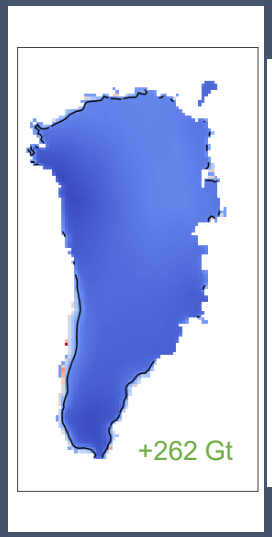
We randomly sample parameters a_i to generate ensembles of plausible boundary conditions for FAMOUS

Initial results: Greenland Ice Sheet

- Test ensemble; Greenland Ice Volumes varying due to SST+ sea ice concentration fields



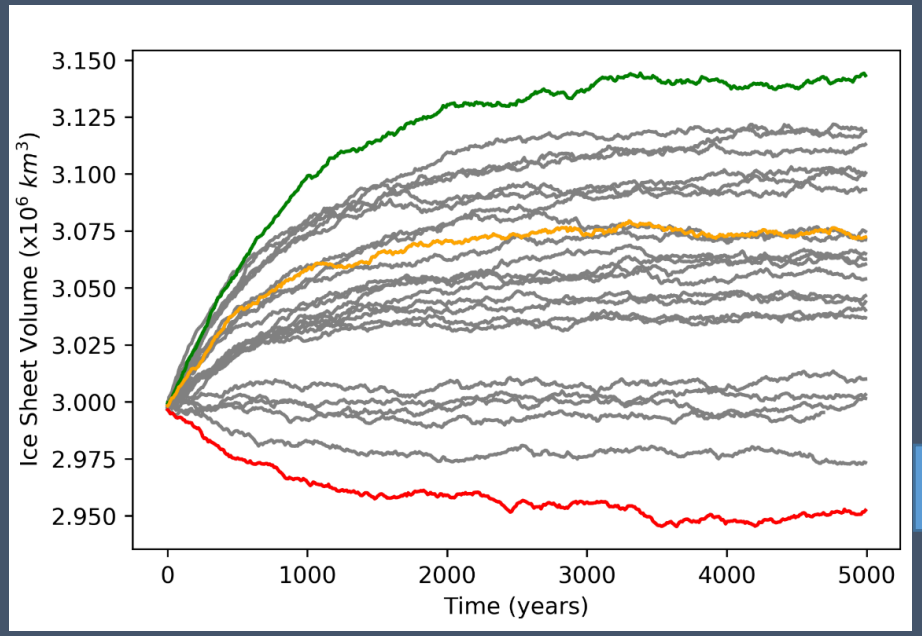


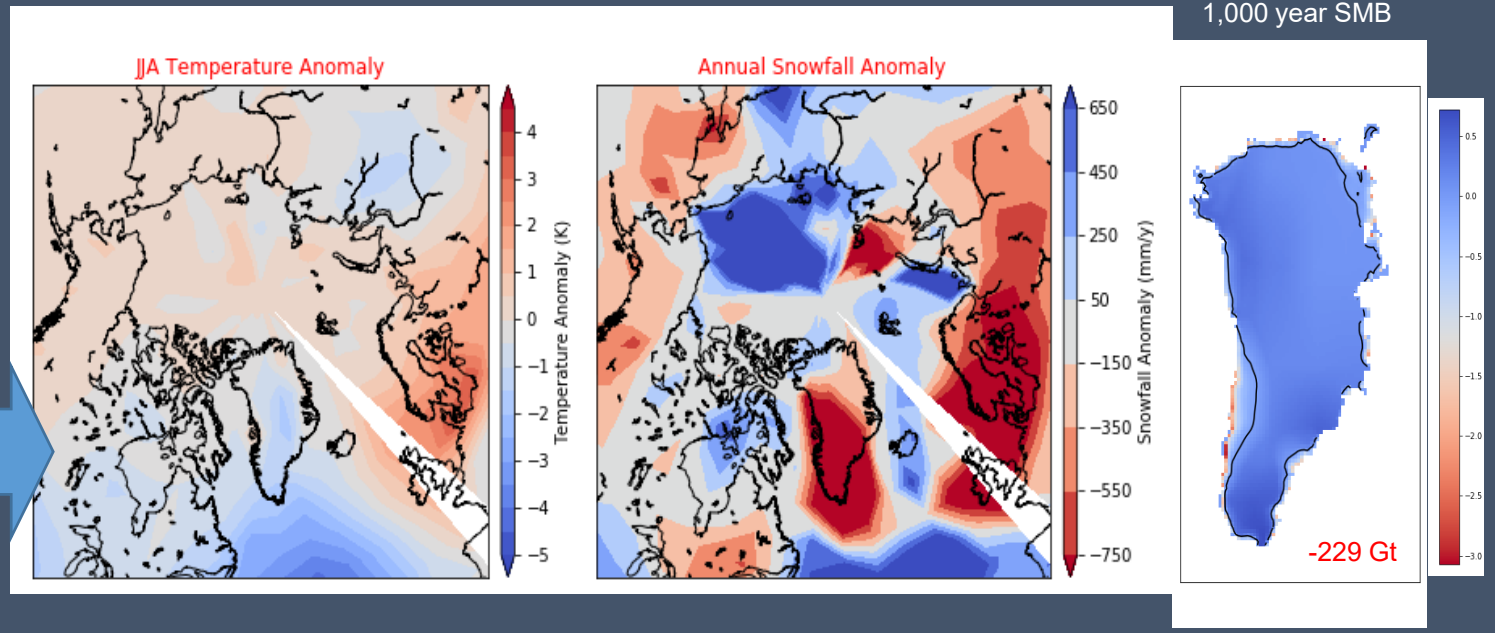


- High ice sheet volume due to higher snowfall

Initial results: Greenland Ice Sheet

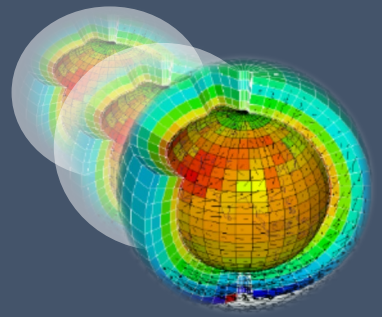
- Test ensemble; Greenland Ice Volumes varying due to SST+ sea ice concentration fields





- Low ice sheet volume due to low snowfall

Developing a Surface mass balance generator (SMB-Gen)



Observations

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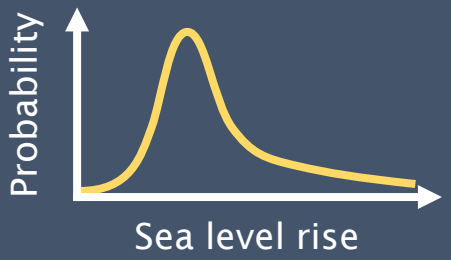
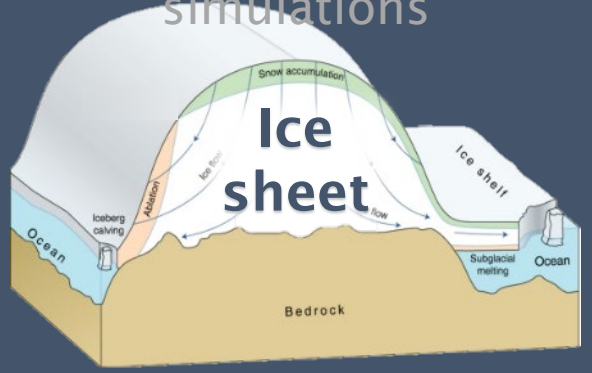
AI statistical tool (SMB-Gen)

Observations

Outputs of 1000s of simulations





- Novel Artificial intelligence tool
- Use ensembles of simulations to train statistical emulator of surface mass balance

Summary and perspective

- Bias reduction by assimilating data on sea surface temperature (SST) and sea ice concentrations (SIC)
- Bayes Linear method to jointly reconstruct SST and SIC and sample ensemble of plausible states.
- Next steps:
  - Ensemble of FAMOUS-Ice simulations with Northern Hemisphere ice sheets
  - Simulations of the deglaciation and 8.2 kyr event with fixed and slab ocean
  - Gaussian Process emulation of ice sheet volume and 3D SMB.
- **Quantitatively relate past and future ice sheet evolution.**