Modeling the Antarctic ice sheet and its contribution to Pliocene sea level

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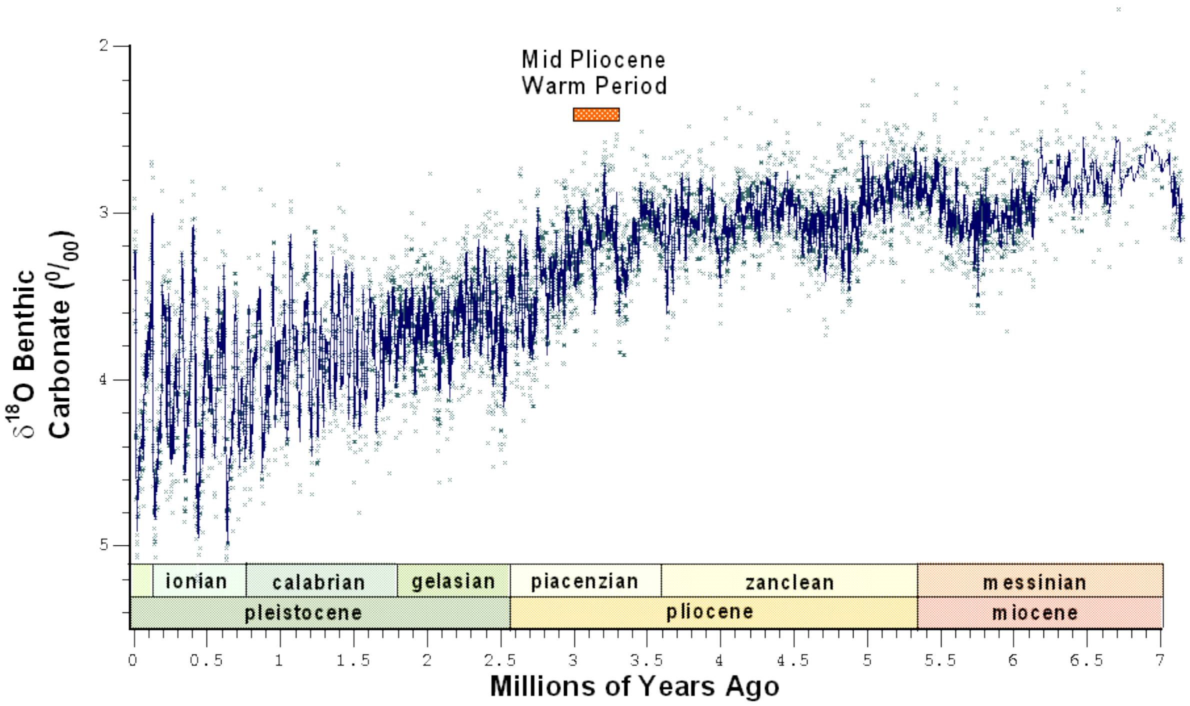
Introduction

- Background:
  - Pliocene Epoch (5.3-2.6 Ma) serves as a potential analogue for future climate
  - Focus on mid-Pliocene Warm Period (mPWP; 3.264–3.025 Ma)
  - High uncertainties in sea-level estimates
- Motivation:
  - How do uncertain ice sheet parameters affect sea level estimates during the Pliocene and how might our models account for this?
- Methodology:
  - Fully-coupled water isotope tracer enabled model emulated outputs used to force a three-dimensional ice sheet model
  - Ice sheet model simulations also forced with bias-corrected iCESM output fields



Source: http://eps.ucsc.edu/

Climate Emulator

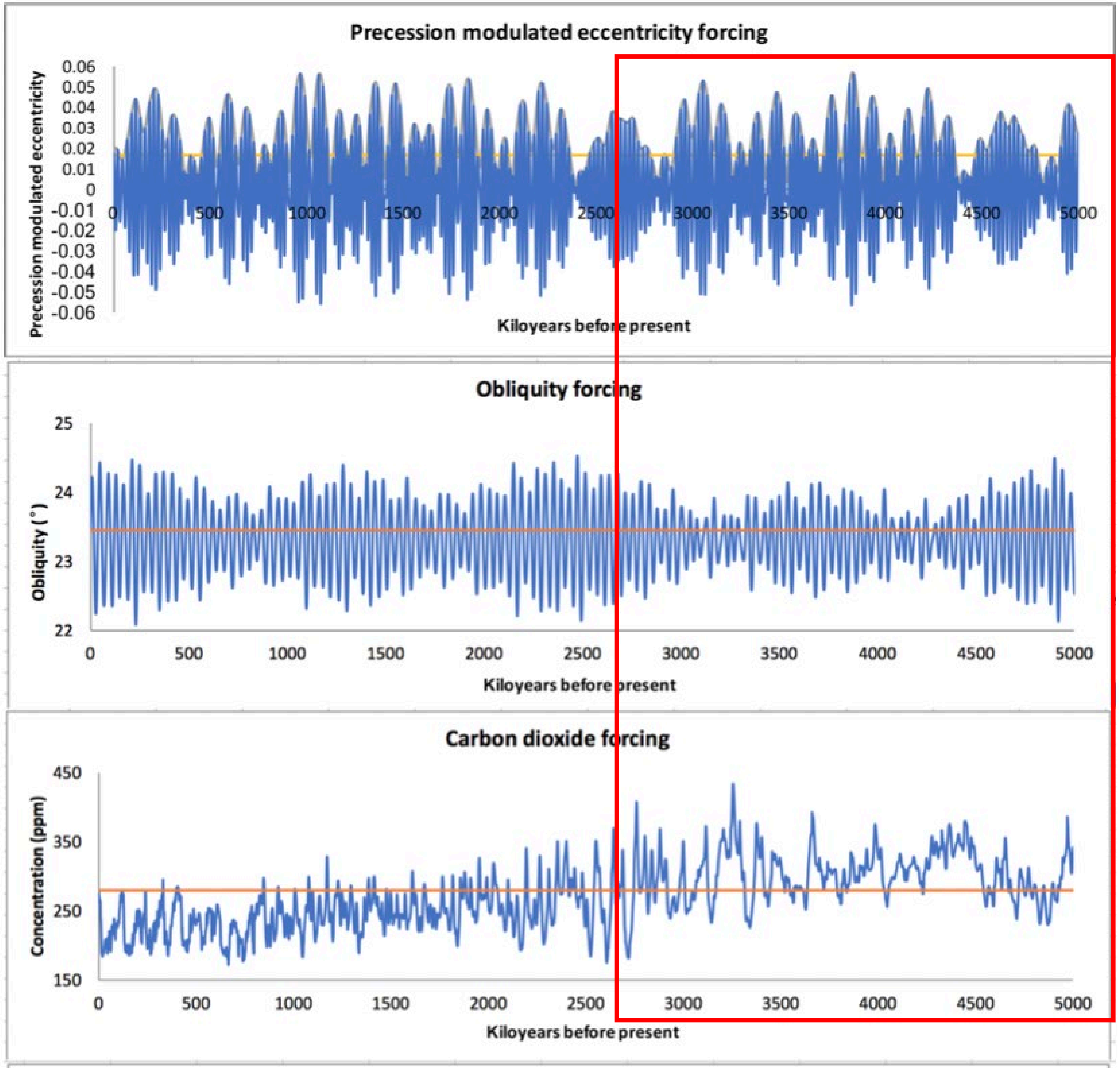
- Computationally fast statistical representations of simulators
  - Construct long-term continuous predictions of climate trends
  - Calibrated with temperature and precipitation model outputs
- Ensemble input file design:
  - Varying orbital parameters and CO_2 concentration
- Singular value decomposition (Holden et al., 2019):

$$\mathbf{Y} = \mathbf{L}\mathbf{D}\mathbf{R}^T$$

  - **Y** is the matrix, **L** is the matrix of left singular vectors, **D** is the $N \times N$ *(ensemble members)* diagonal matrix of the square roots of eigenvalues, and **R** is the $N \times N$ (*ensemble members*) matrix of right singular vectors
- Principal component (PC) Gaussian process (GP) emulator used

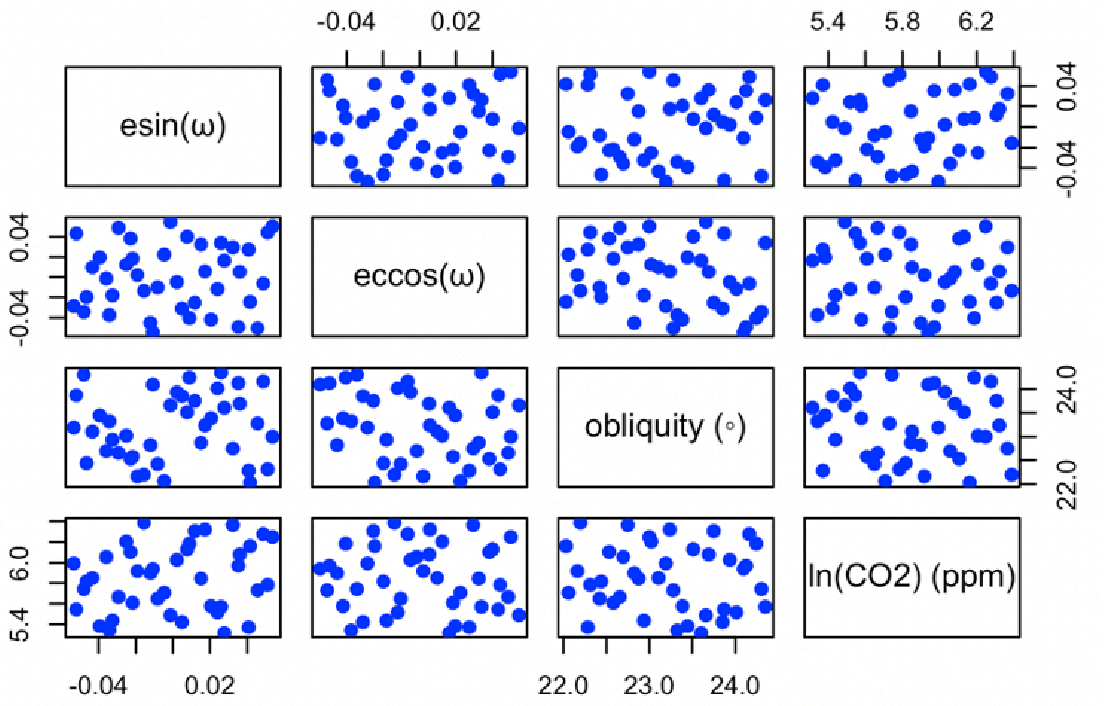
Emulator Time Series Forcing

- Emulator time-series forcing from Holden et al. (2019).
- Orbital forcings are taken from Berger and Loutre (1991, 1999).
- Carbon dioxide forcing uses the Stap et al. (2017).



Latin Hypercube Sampling

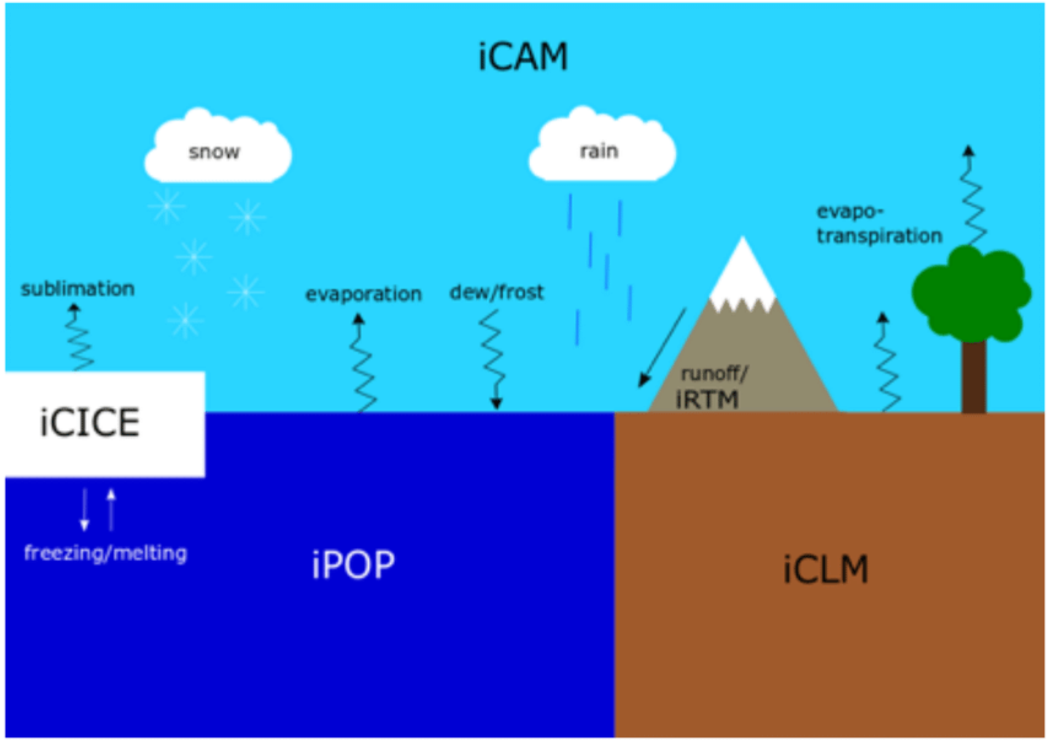
- Generate orbital and CO_2 configurations from a multidimensional distribution
- 10 principal components per input parameter (i.e., climate variables)
- Branched off an experiment with the default Pliocene Model Intercomparison Project (PlioMIP2) configuration (Haywood et al., 2016)



Distribution of 40 Pliocene iCESM1 experiments derived from LHS utilizing the programming language R. The variables are $e \sin \varpi$, $e \cos \varpi$, obliquity (ε, ◦), and atmospheric $\ln(CO_2)$ concentration (ppm).

iCESM1.2

- Isotope-enabled Community Earth System Model version 1.2
  - Fully coupled-water isotope tracer enabled Earth system model
  - Simulates water isotopes in the atmosphere-ocean-land-runoff-sea ice system
  - 1.9° x 2.5° resolution (atmosphere/land)
  - ~1° resolution (sea-ice/ocean)
  - 40 Pliocene experiments each run for 500 years



Schematic of iCESM1 showing the five major model components (iCAM, iCLM, iRTM, iPOP, and iCICE) and all the major intercomponent fluxes that impact water isotopes (Brady et al., 2019).

PSU-ISM

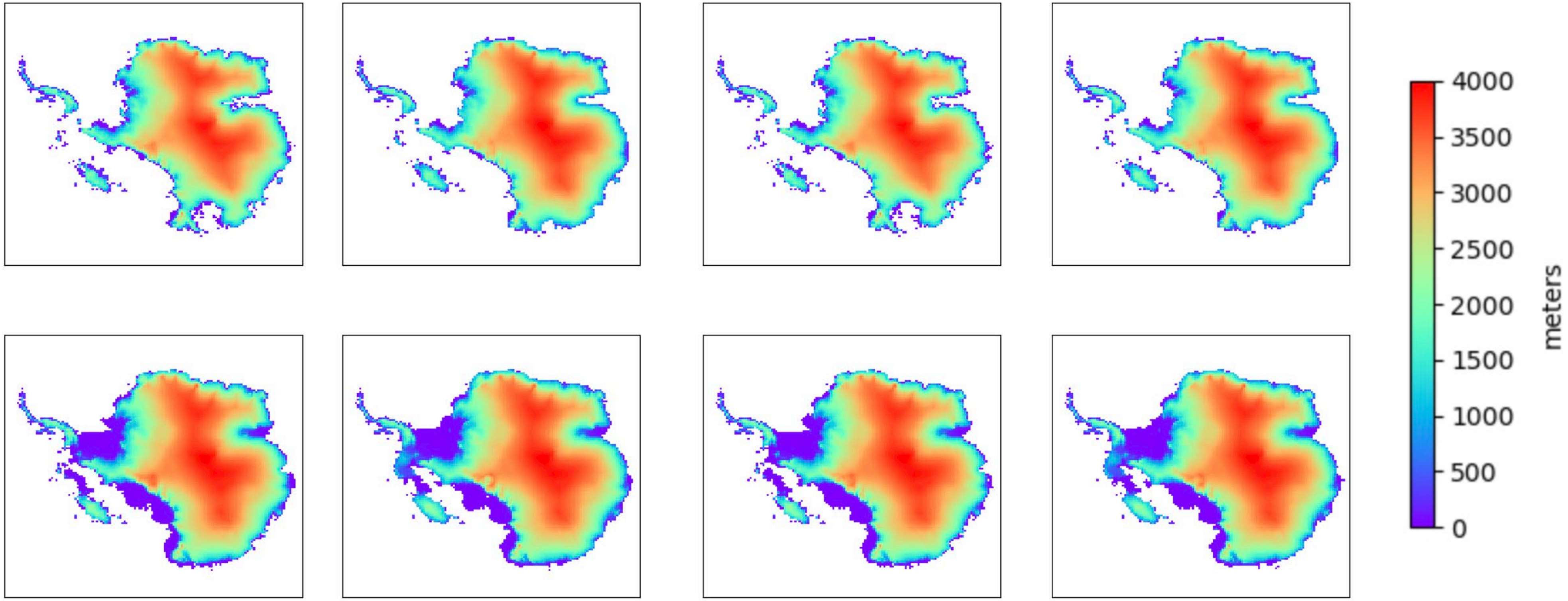
- PSU-ISM is a 3-D thermomechanical ice sheet model
  - Vertically averaged ice dynamics (Pollard and DeConto, 2012)
  - Includes marine ice sheet instability (MISI) and marine ice-cliff instability (MICI) processes (Pollard et al., 2015)
- Surface geopotential, total precipitation, surface and ocean temperatures from model outputs used to force PSU-ISM
  - Ice sheet topography initialized from modern observed BedMap2
  - Climate model fields are interpolated onto the ice sheet model grid with bilinear spatial interpolation
  - Differences between interpolated surface elevations in models are accounted for with surface temperature and precipitation lapse-rate corrections (Tsai et al., 2020)
- Bias-corrections calculated using differences between present-day iCESM1.3 simulation, and interpolated WOA18 and ERA5 data

Surface elevation of mid-Pliocene

	CALVLIQ = 107 m^{-1} yr^{2} CLIFFVMAX = 7.7 km yr^{-1}	CALVLIQ = 107 m^{-1} yr^{2} CLIFFVMAX = 3.3 km yr^{-1}	CALVLIQ = 100 m^{-1} yr^{2} CLIFFVMAX = 7.7 km yr^{-1}	CALVLIQ = 100 m^{-1} yr^{2} CLIFFVMAX = 3.3 km yr^{-1}

Bias-corrected Climate

Raw Climate

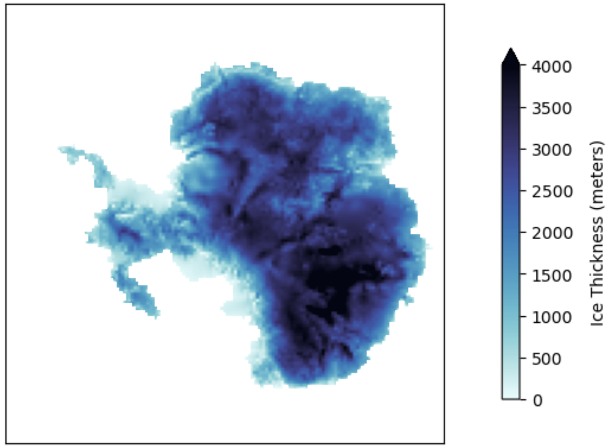


- CLIFFVMAX- maximum erosion retreat rate for ice cliffs exceeding 100 meters in subaerial height (Pollard et al., 2015)
- CALVLIQ- scaling depth for the deepening of surface crevasses by hydrofracturing attributed to surface melt and rainfall (Pollard and DeConto, 2012)

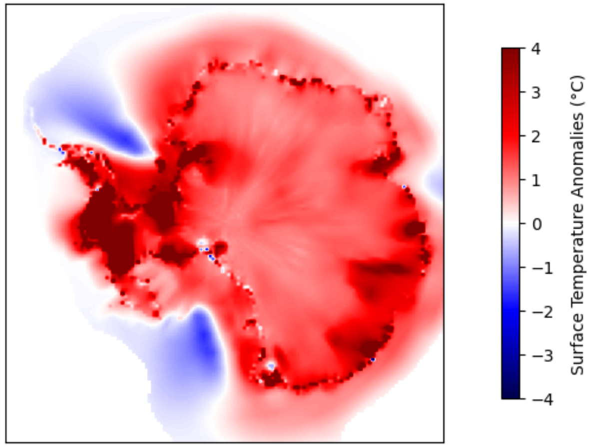
Transient simulations

eccentricity	0.0431
precession	1.75°
obliquity	23.689°
CO_2	303.81 ppm

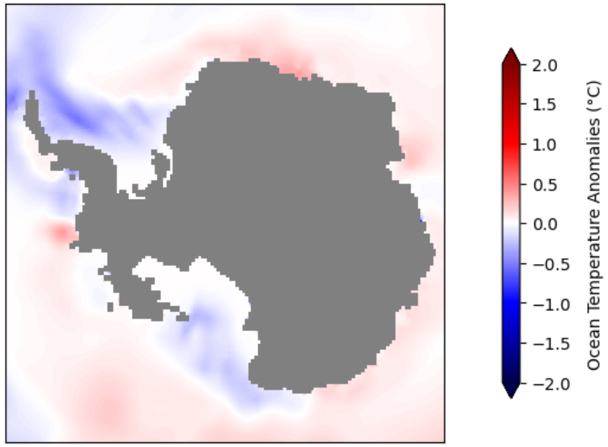
4.237 Ma
Ice thickness



4.237 Ma-4.016 Ma
Surface Temperature

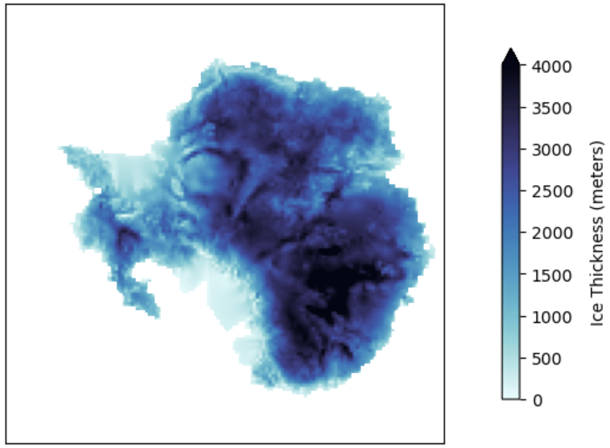


4.237 Ma-4.016 Ma
400 m Ocean Temperature

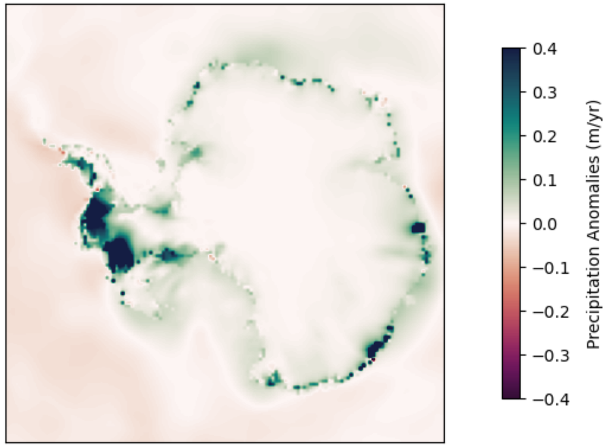


eccentricity	0.0257
precession	4.46°
obliquity	22.795°
CO_2	330.67 ppm

4.016 Ma
Ice Thickness



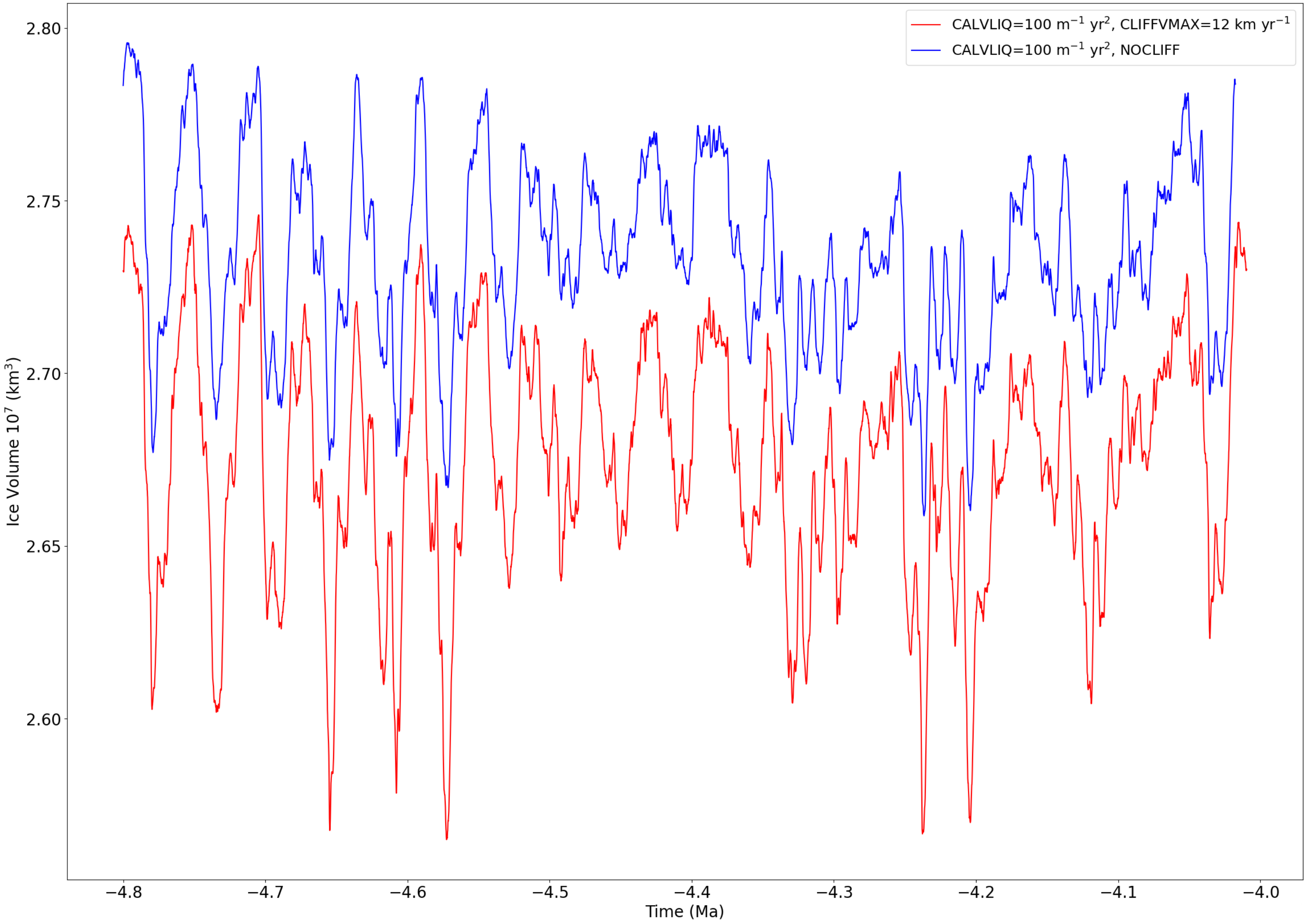
4.237 Ma-4.016 Ma
Precipitation



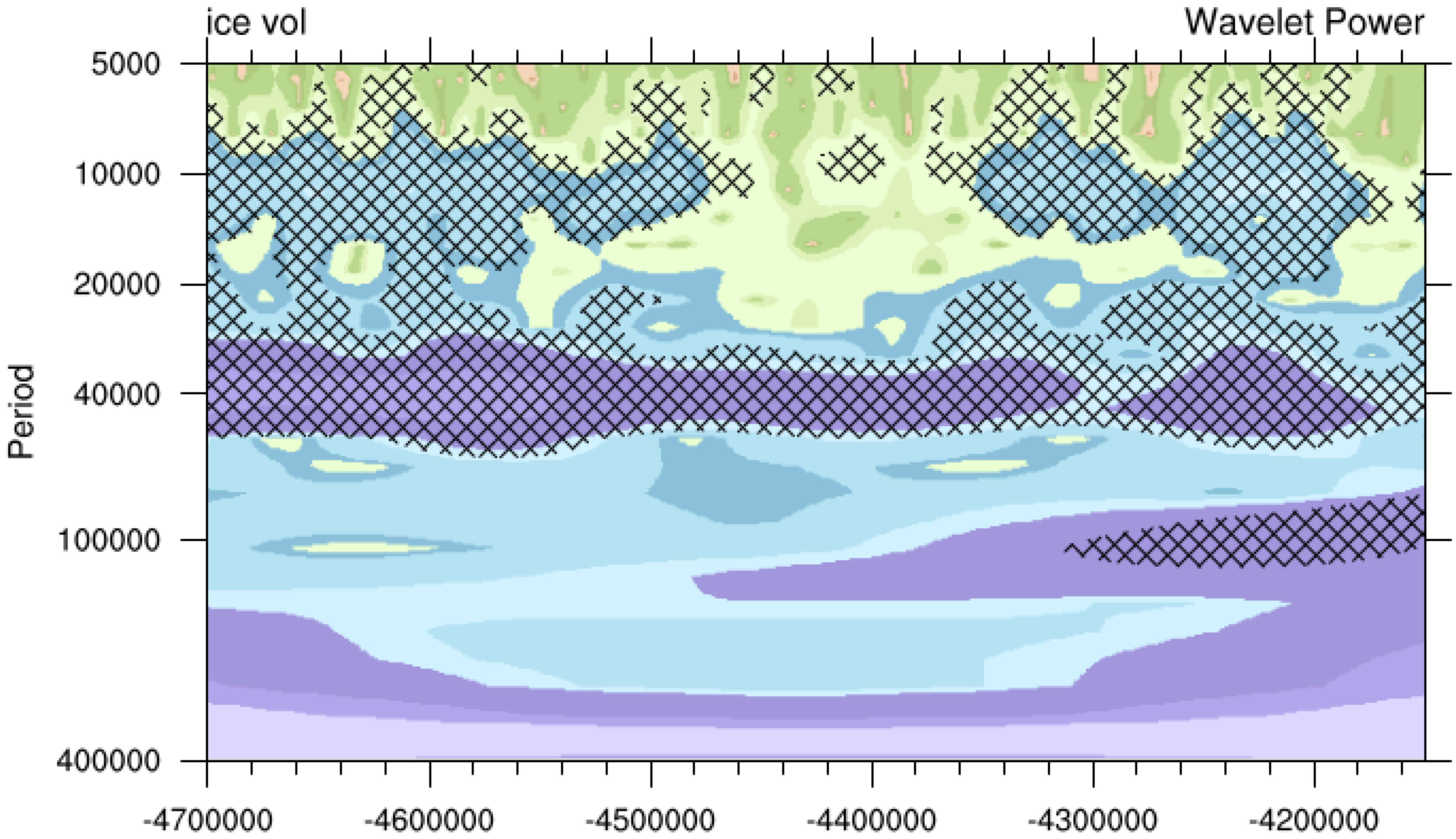
$$\Delta ESL = 2.1739\ m$$

Change in global mean equivalent sea level rise between 4.237 Ma and 4.016 Ma

Ice Volume of Transient Simulations



Wavelet Power of Transient Simulations



Conclusions

- Preliminary results of AIS response show a collapse of ice shelves across West Antarctica during the mPWP, with greater ice loss when forcings are bias-corrected
- Both ISM parameterization and representation of physical processes in climate models can influence the response of the AIS and alter the accuracy of sea-level rise estimates
- Future work:
  - Extend simulations with iCESM1.3
  - Bias-correct emulated ISM outputs
  - Force ISM with iCESM emulated $\delta^{18}O$ of precipitation outputs using Lagrangian tracking subroutine
  - Explore a range of melt factors of snow and ice, basal friction and melting, and glacial isostatic adjustment with statistical sampling methods

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Questions?

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