Revisiting Miocene Climatic Optimum

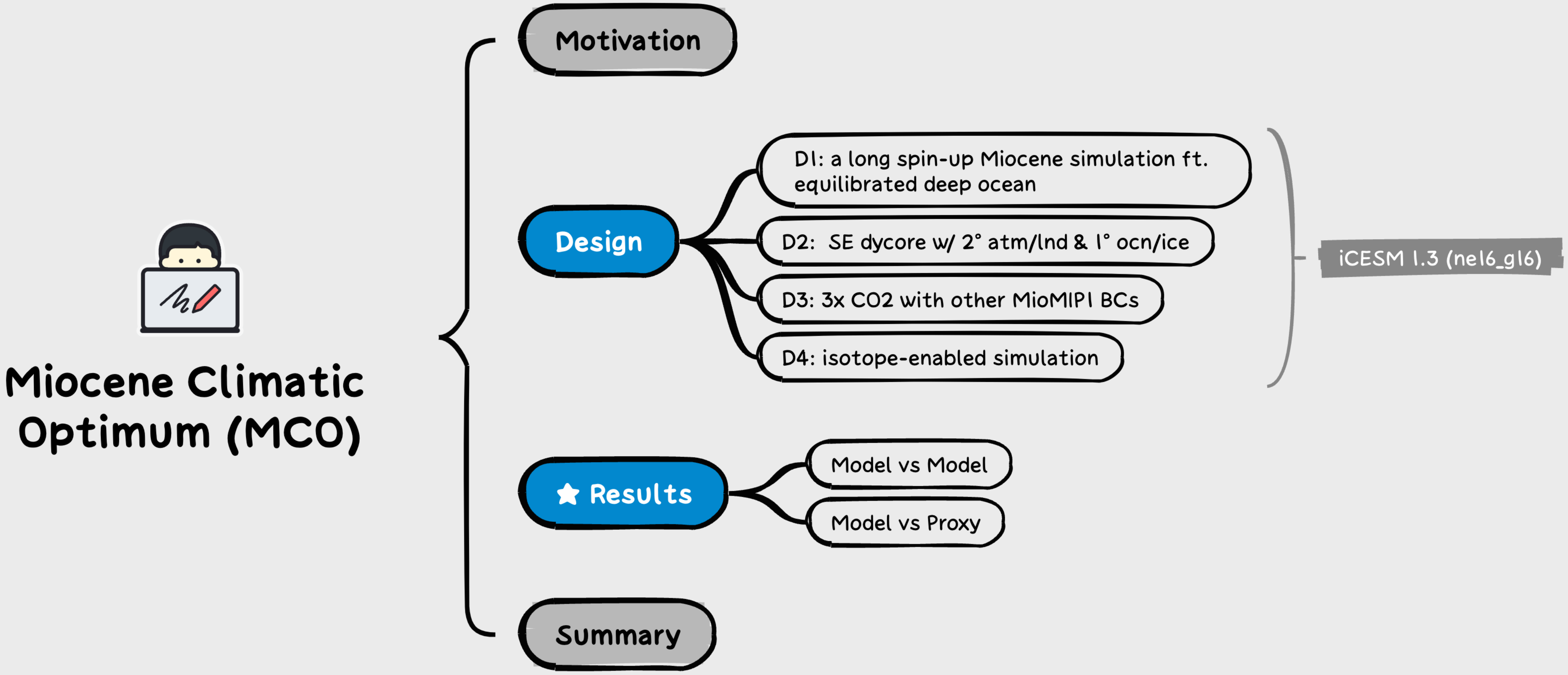
with a unique equilibrated iCESM simulation

***Feng Zhu*[1]**, *Jiang Zhu[1], Weimin Si[2], Timothy Herbert[2]*
1. NSF NCAR 2. Brown University

Jun 12, 2024
CESM Workshop 2024

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

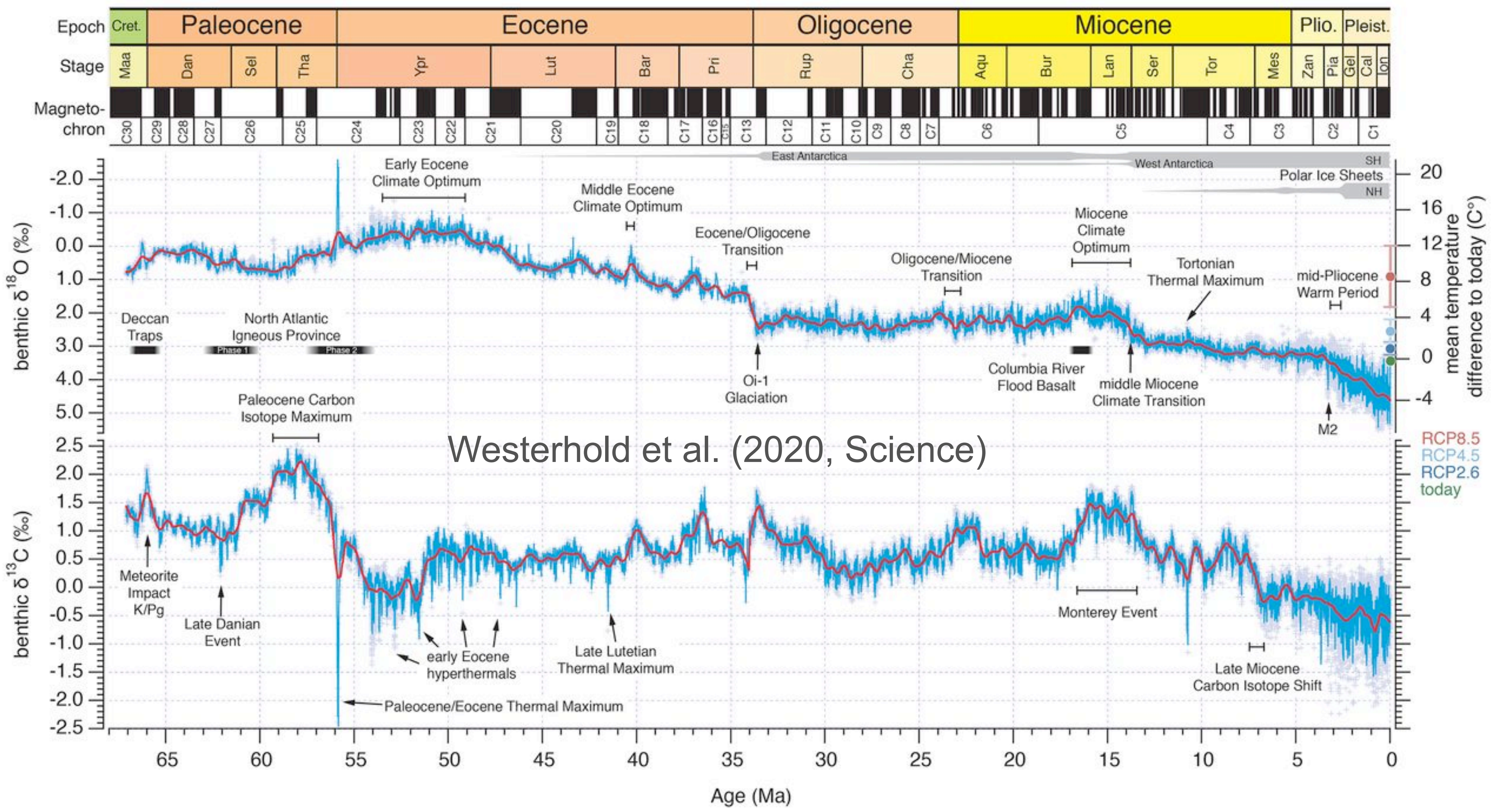
Outline



Miocene Climatic Optimum (MCO)

- Motivation
- Design
  - D1: a long spin-up Miocene simulation ft. equilibrated deep ocean
  - D2: SE dycore w/ 2° atm/lnd & 1° ocn/ice
  - D3: 3x CO2 with other MioMIP1 BCs
  - D4: isotope-enabled simulation
  - iCESM 1.3 (ne16_g16)
- ★ Results
  - Model vs Model
  - Model vs Proxy
- Summary

Miocene Climatic Optimum (~15 Ma)



Westerhold et al. (2020, Science)

Motivation

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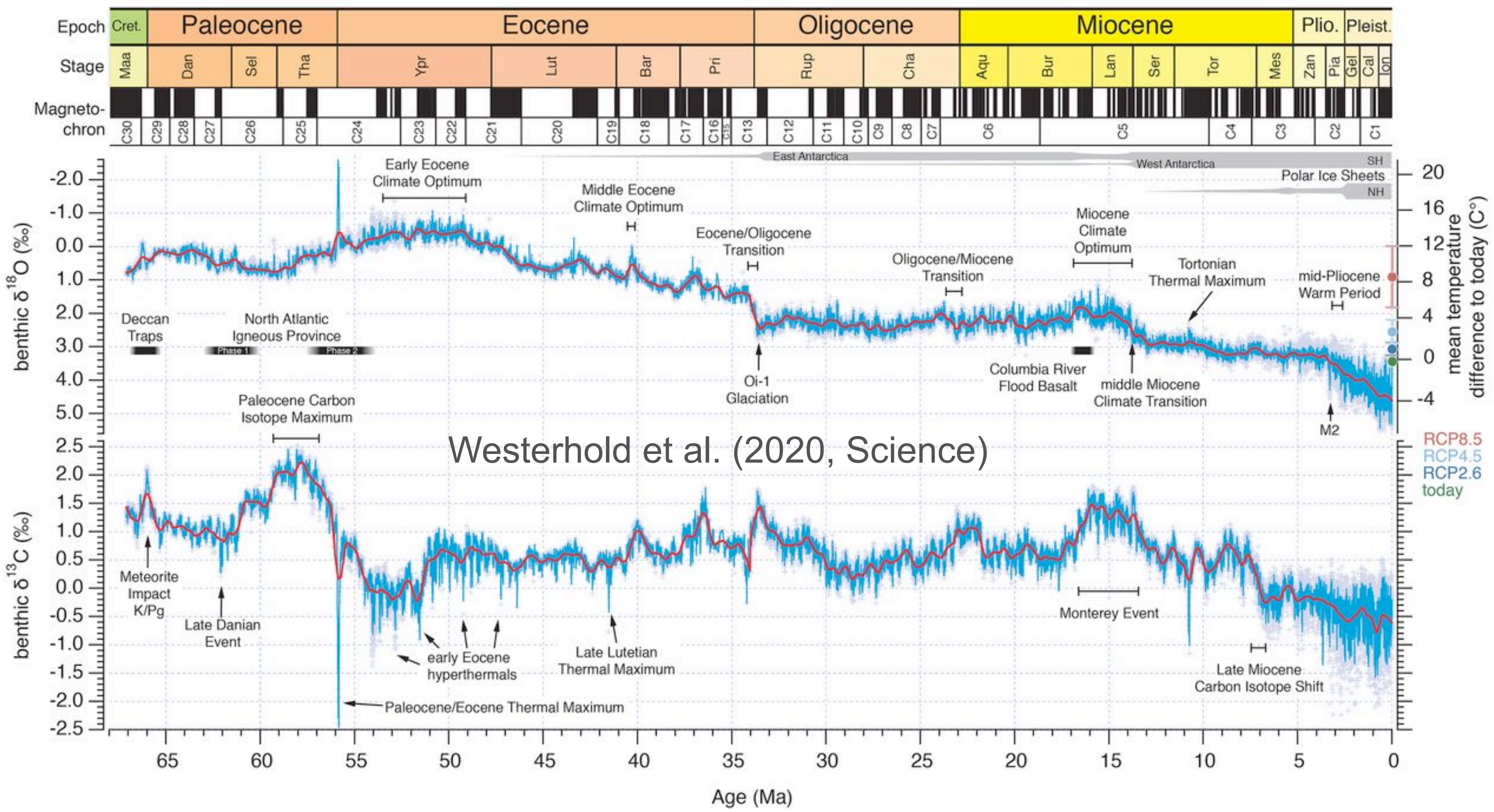

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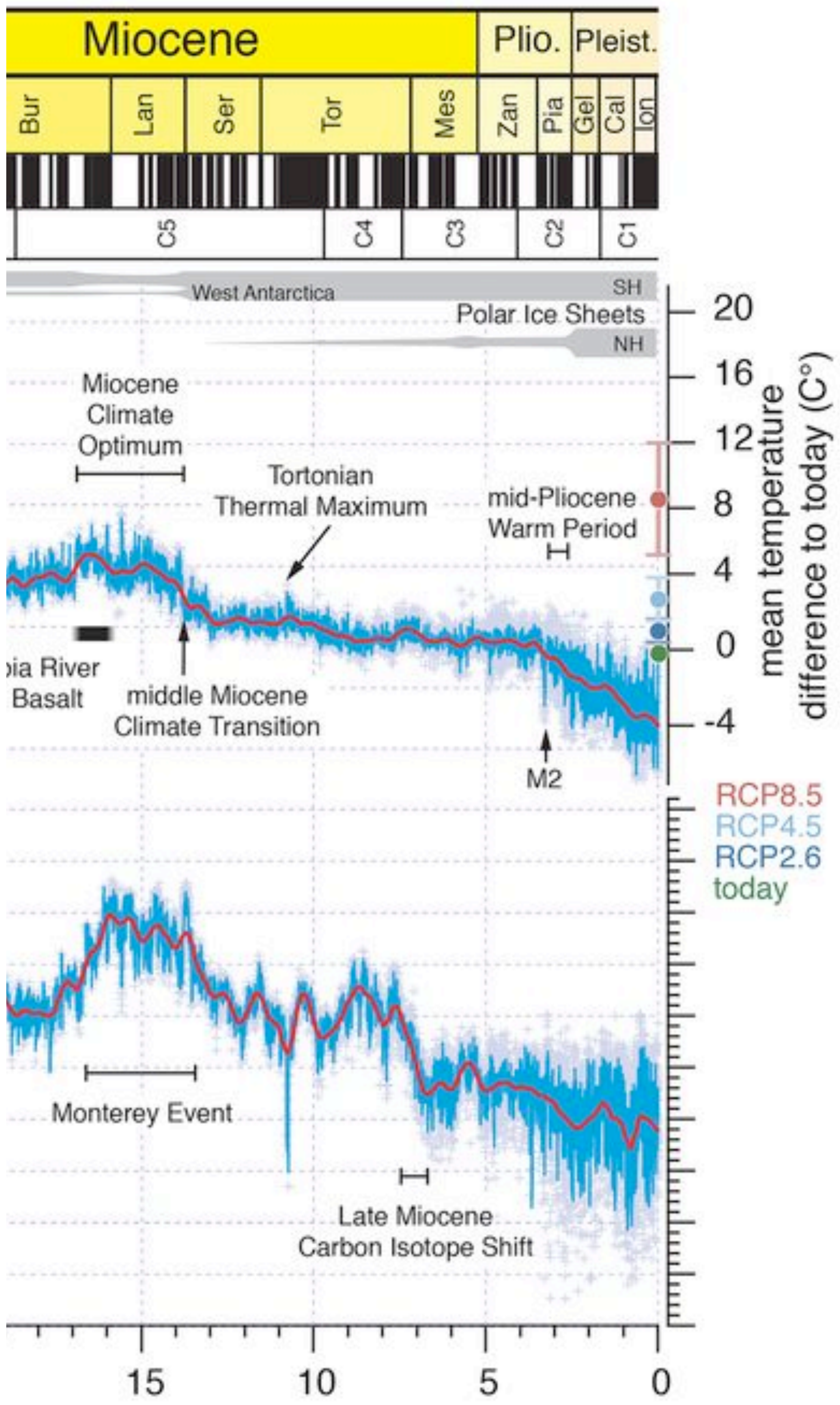

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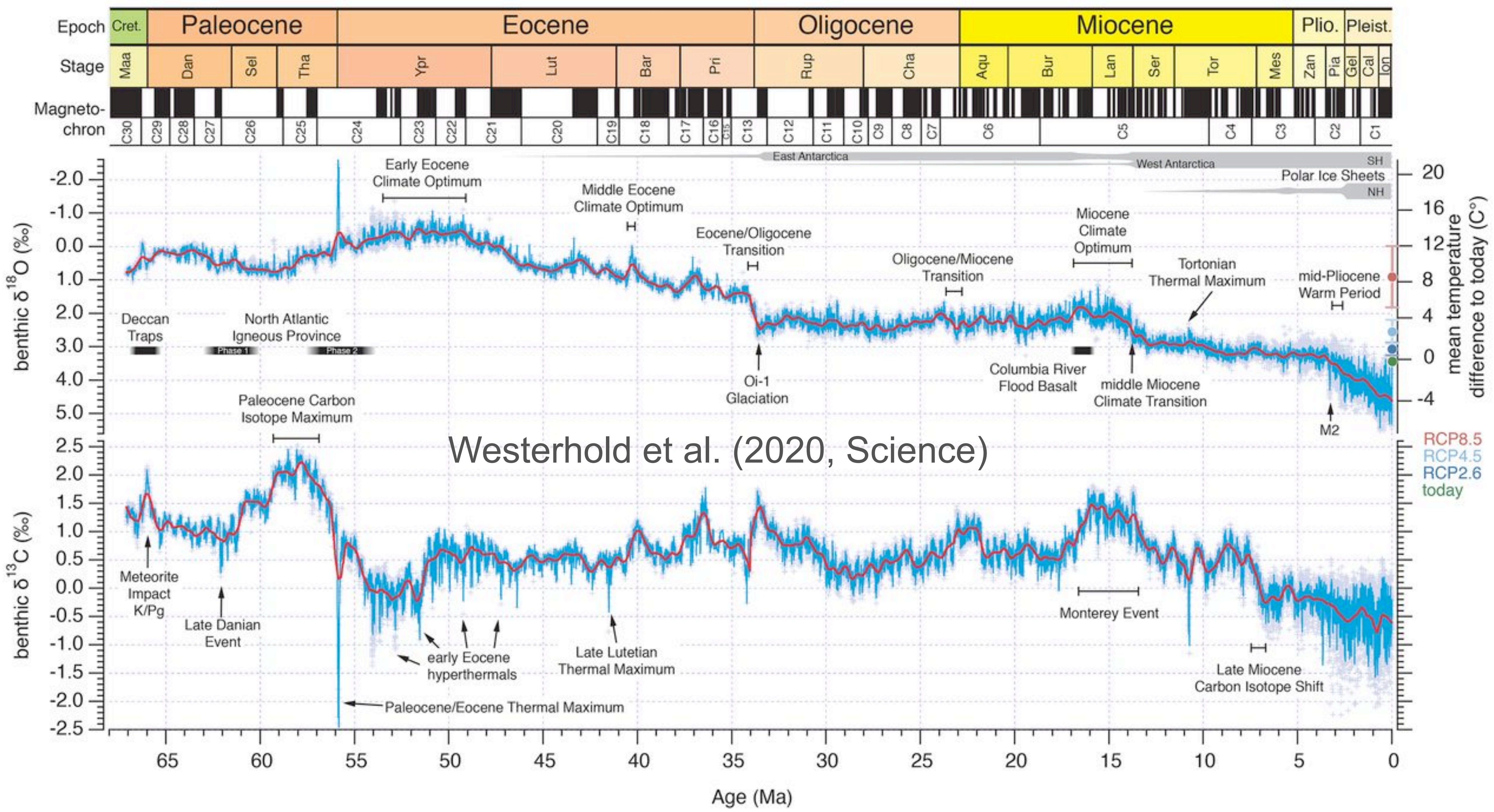

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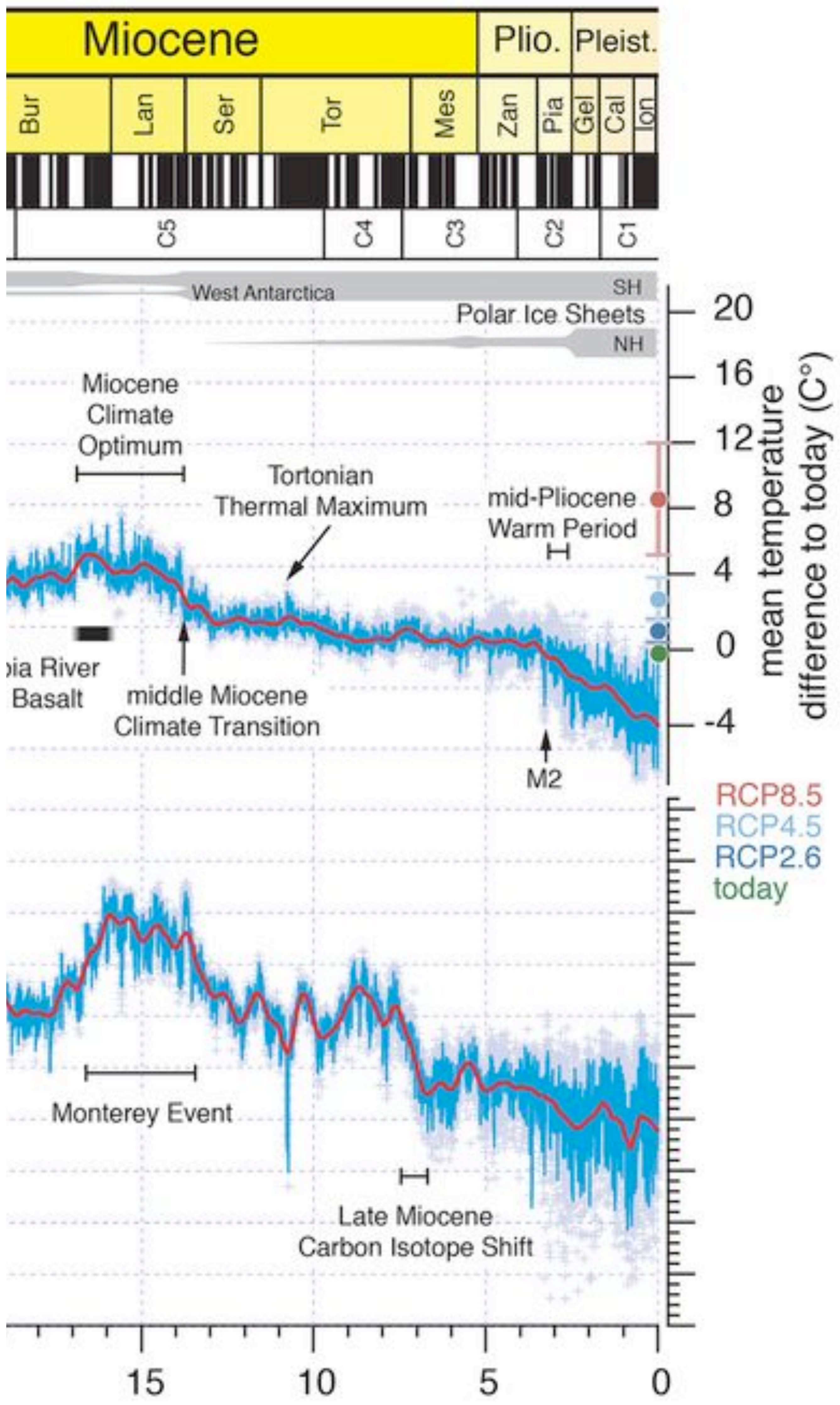

Of great scientific interests:

- ► Warm climate insights
- ► Global climate and carbon cycle
- ► Ocean circulation and ice sheets
- ► Climate models validation

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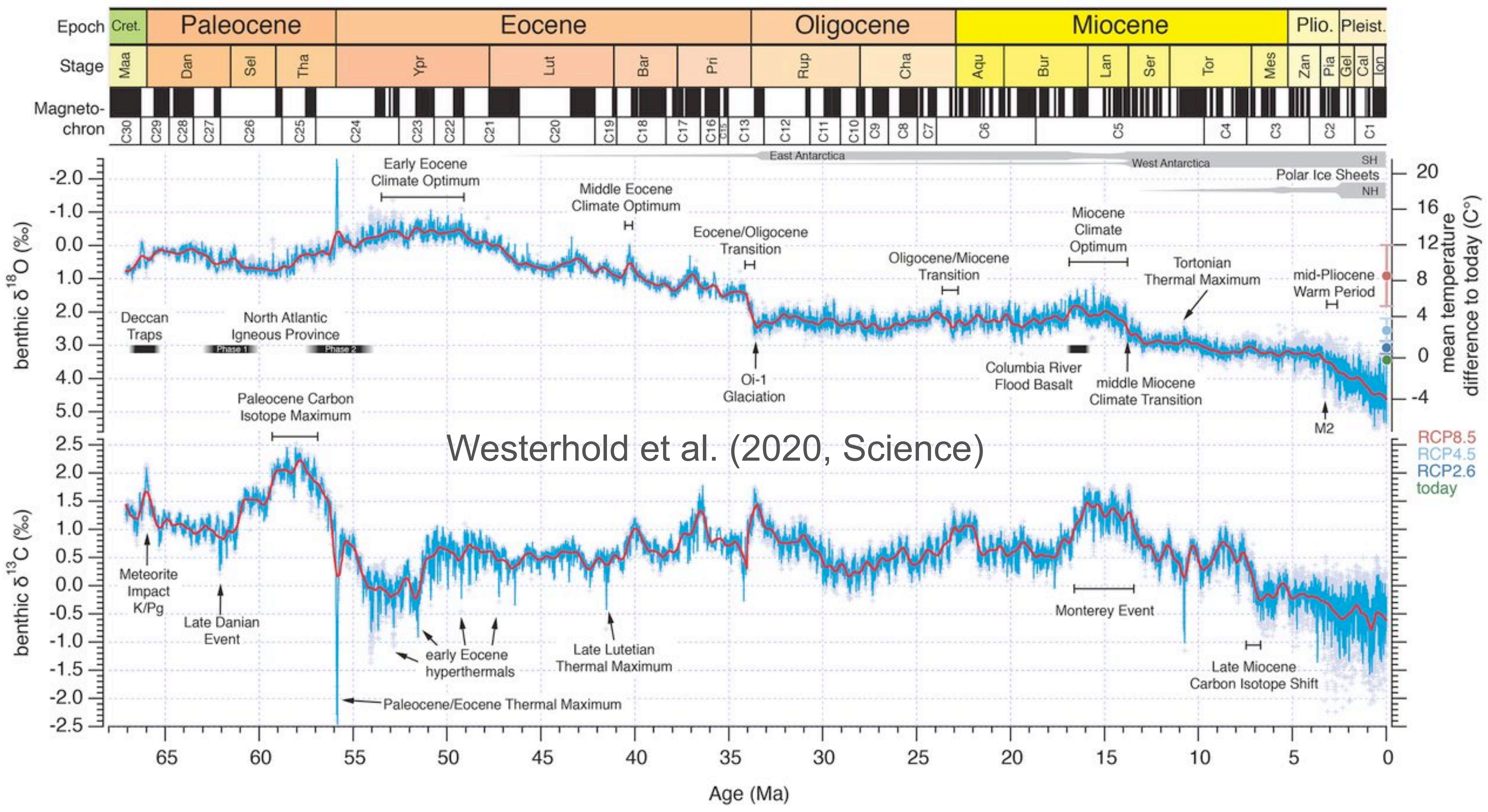

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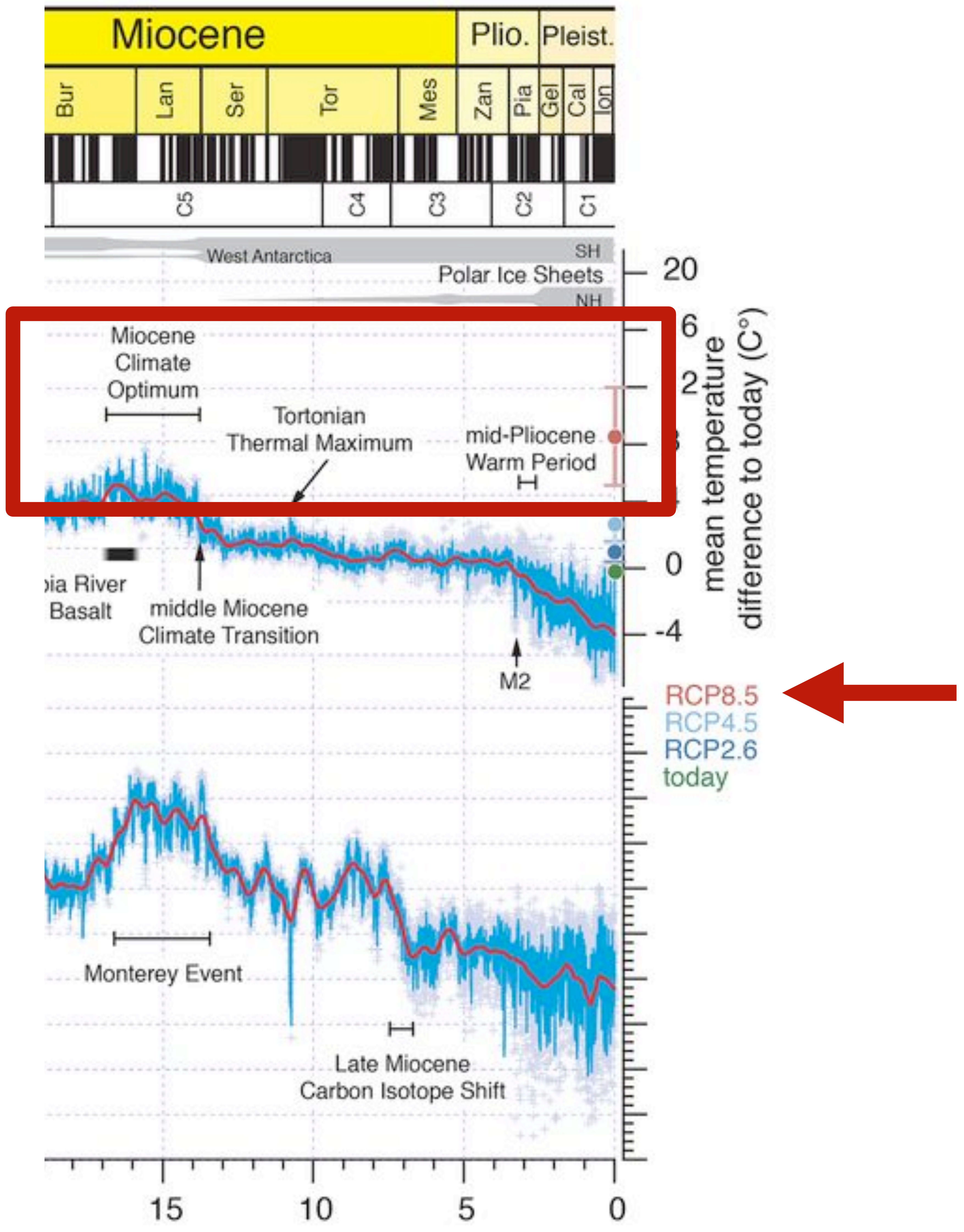

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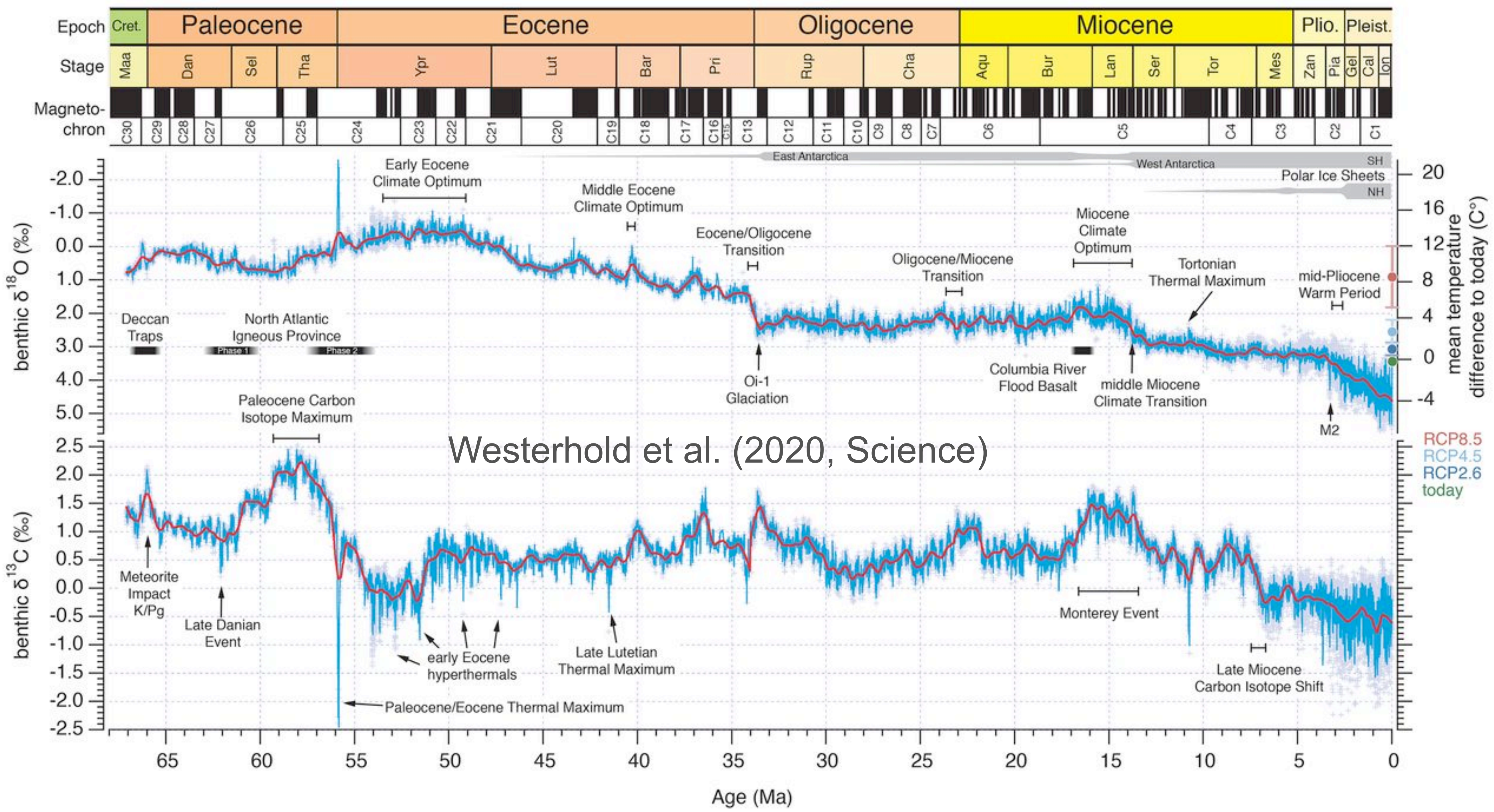

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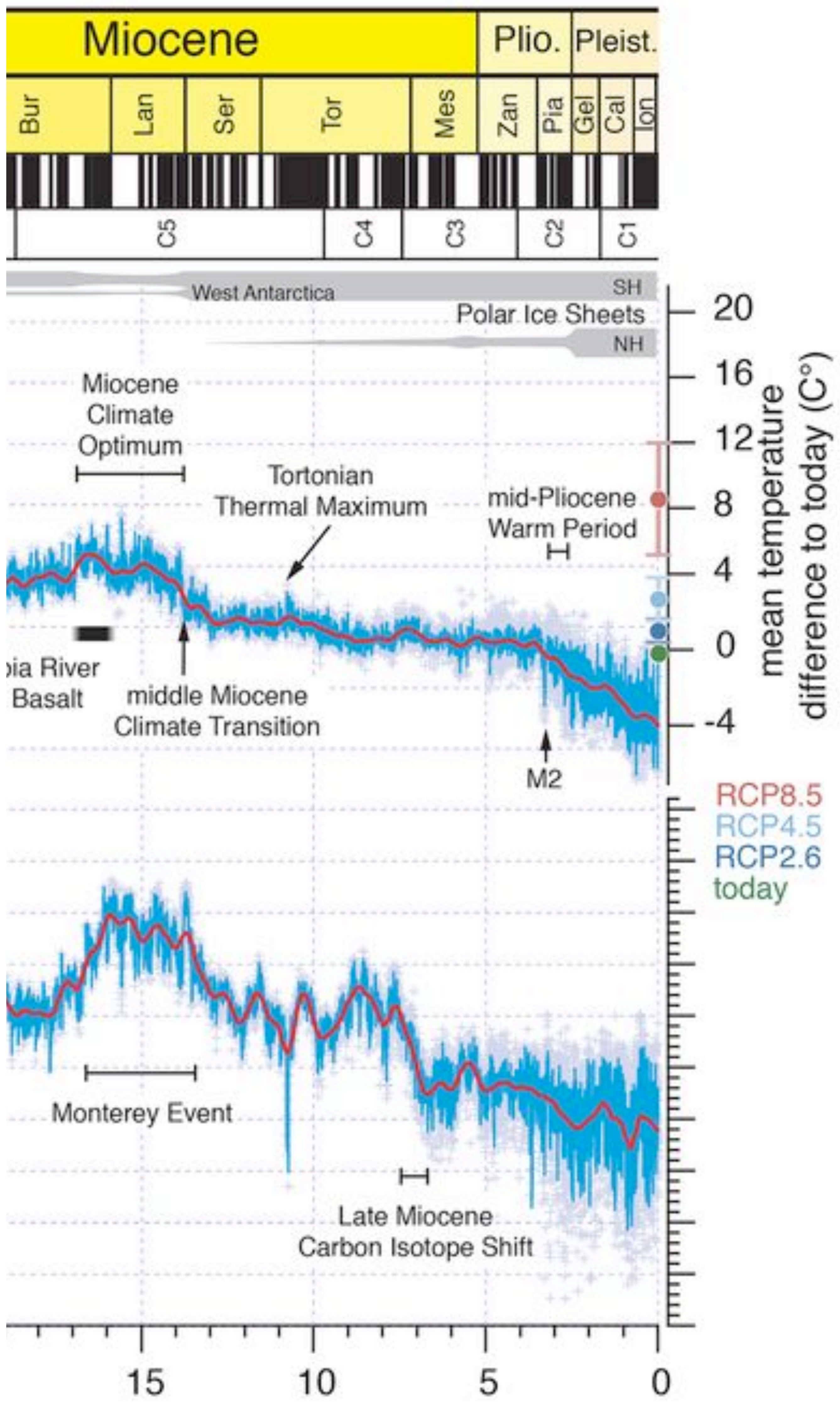
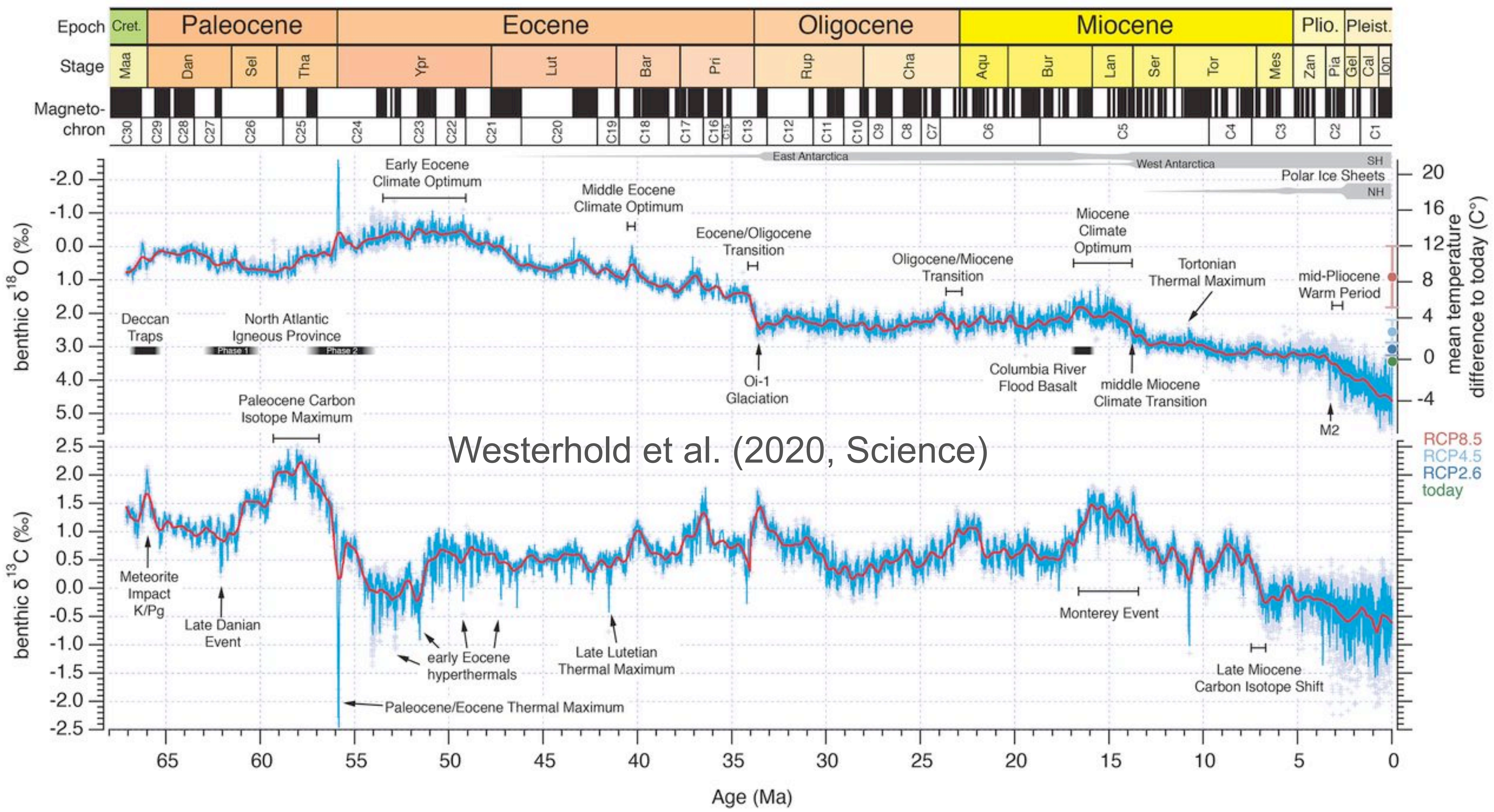


Scientific questions to address:

- ► How warm was MCO (e.g., GMST)?
- ► What was the equator-to-pole temperature gradient?
- ► How surface and deep ocean temperature are connected?

Miocene Climatic Optimum (~15 Ma)

Benthic foram d18O



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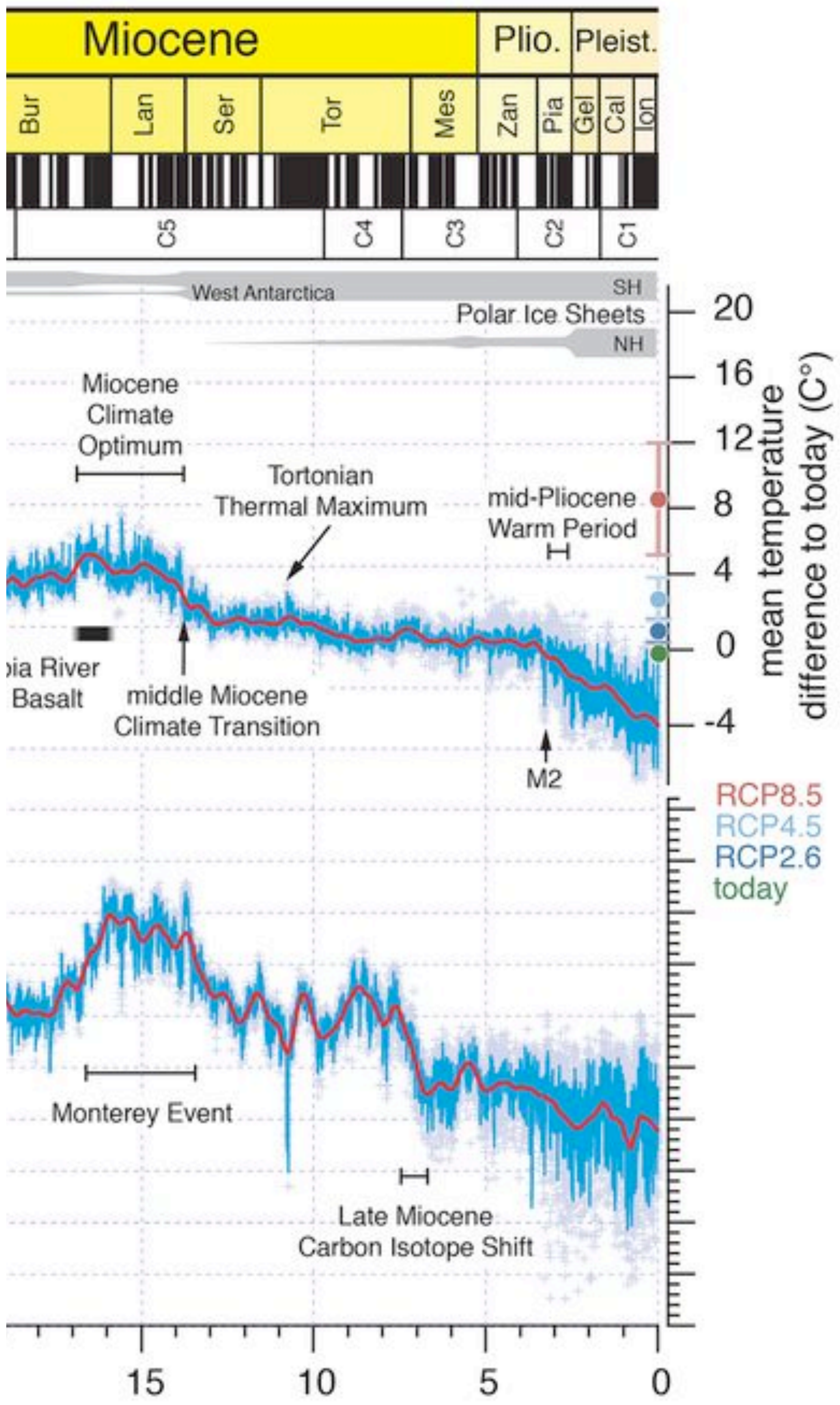

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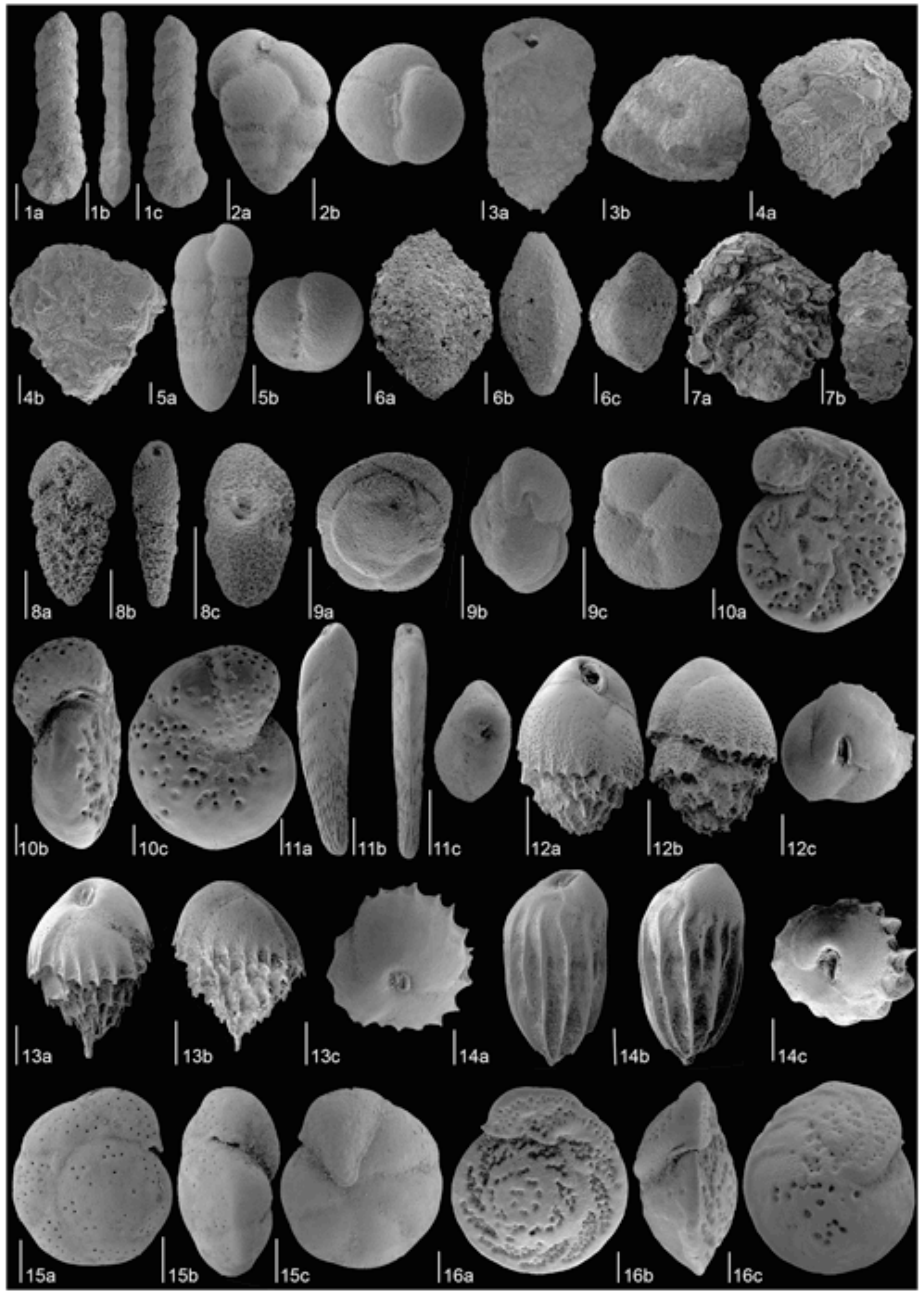
Motivation Benthic Foraminifera



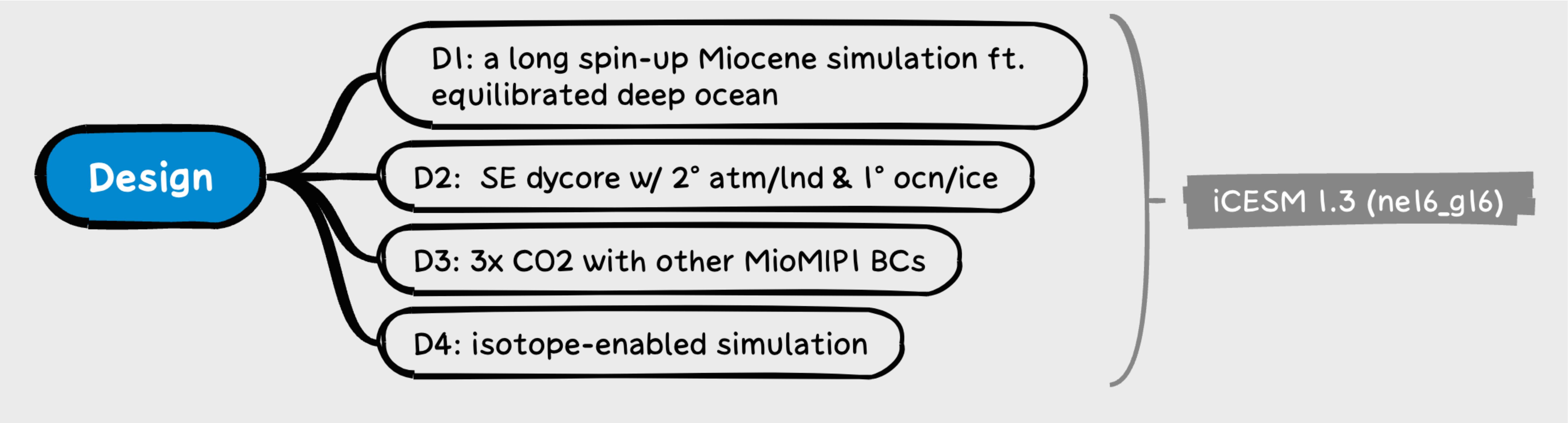
Gastaldello, M. E., Agnini, C., and Alegret, L.: Late Miocene to Early Pliocene benthic foraminifera from the Tasman Sea (International Ocean Discovery Program Site U1506), J. Micropalaeontol., 43, 1–35, https://doi.org/10.5194/jm-43-1-2024, 2024.

Benthic foraminifera is one of the most reliable proxies of the deep time climates, and can be **a good validation target for paleoclimate model simulations**.

However, **most of the existing simulations cannot be compared to benthic foram d18O records directly**, which requires:

(i) **isotope-enabled simulation**
(ii) **equilibrated deep ocean**

Design



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D4: isotope-enabled simulation

iCESM 1.3 (ne16_g16)

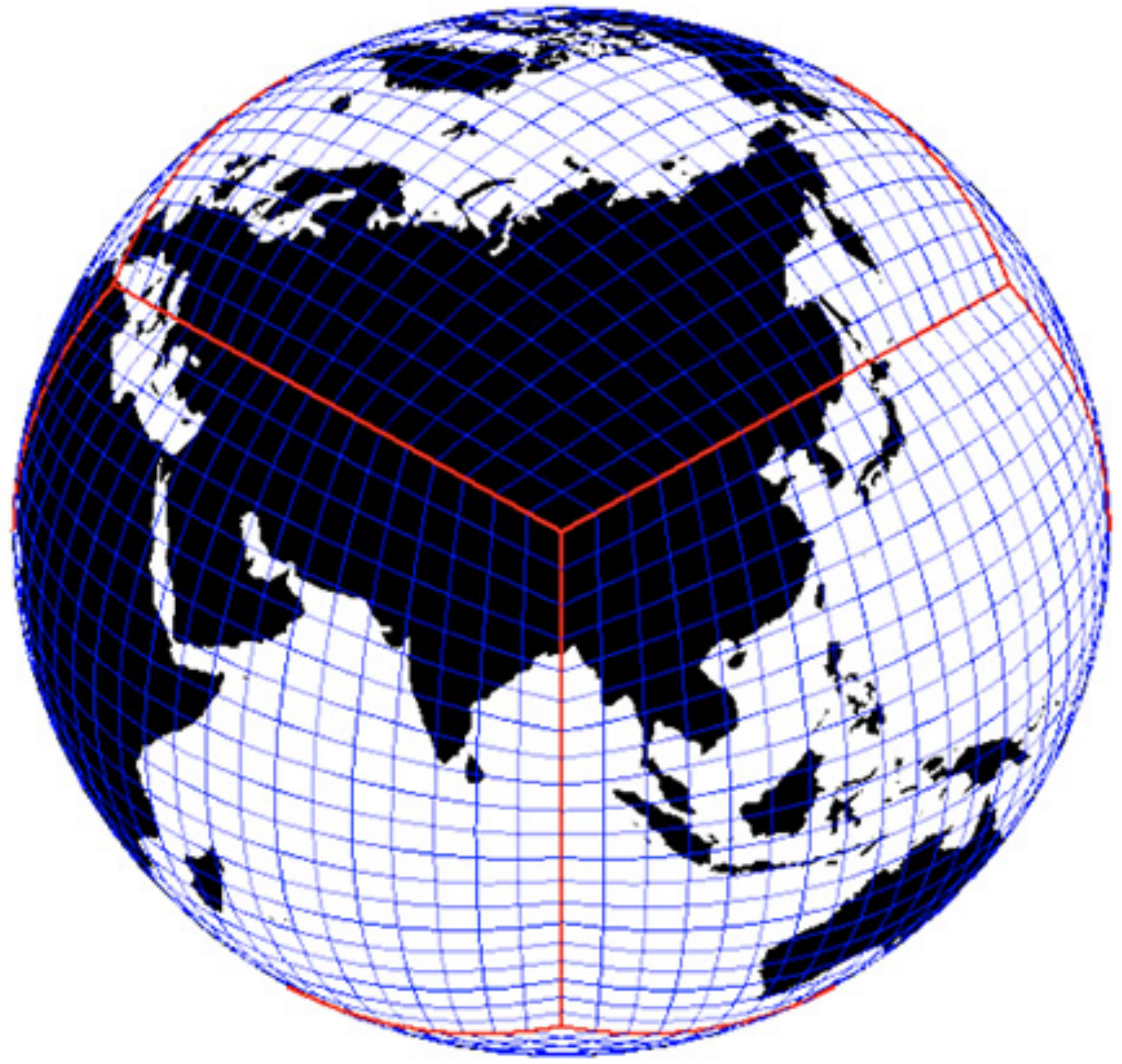
Model

isotope-enabled CESM (iCESM) 1.3

- **Brady et al., 2019**
- **Otto-Bliesner et al., *in prep***

Dynamical Core

Spectral Element (ne16)



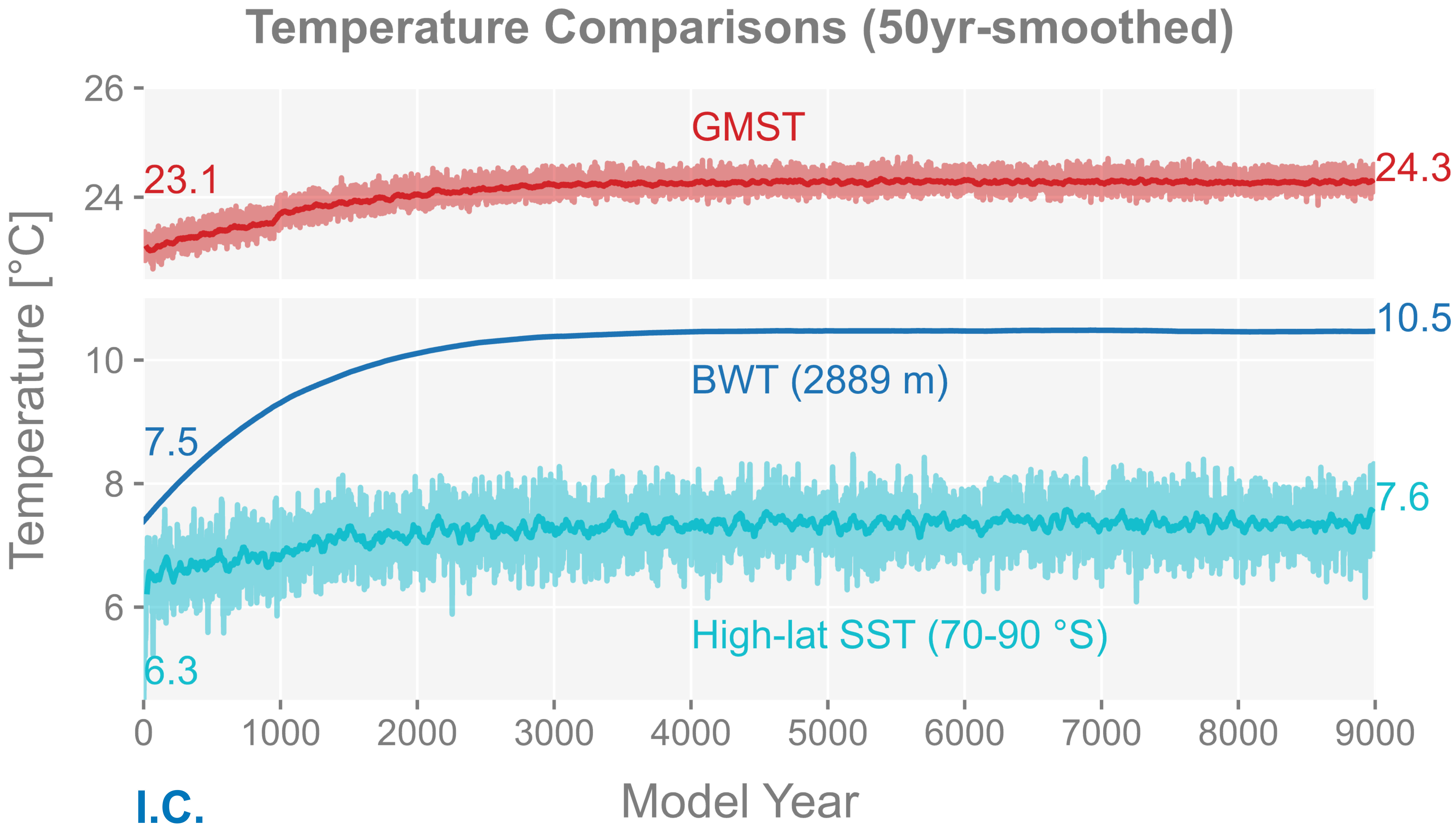
Initial Conditions

Acosta et al. (2022)
w/ a 2-kyr spin-up

Boundary Conditions

The MioMIP1 setup

▣ Results Deep ocean equilibrium achieved after 5 kyrs



I.C.
Acosta et al. (2022)
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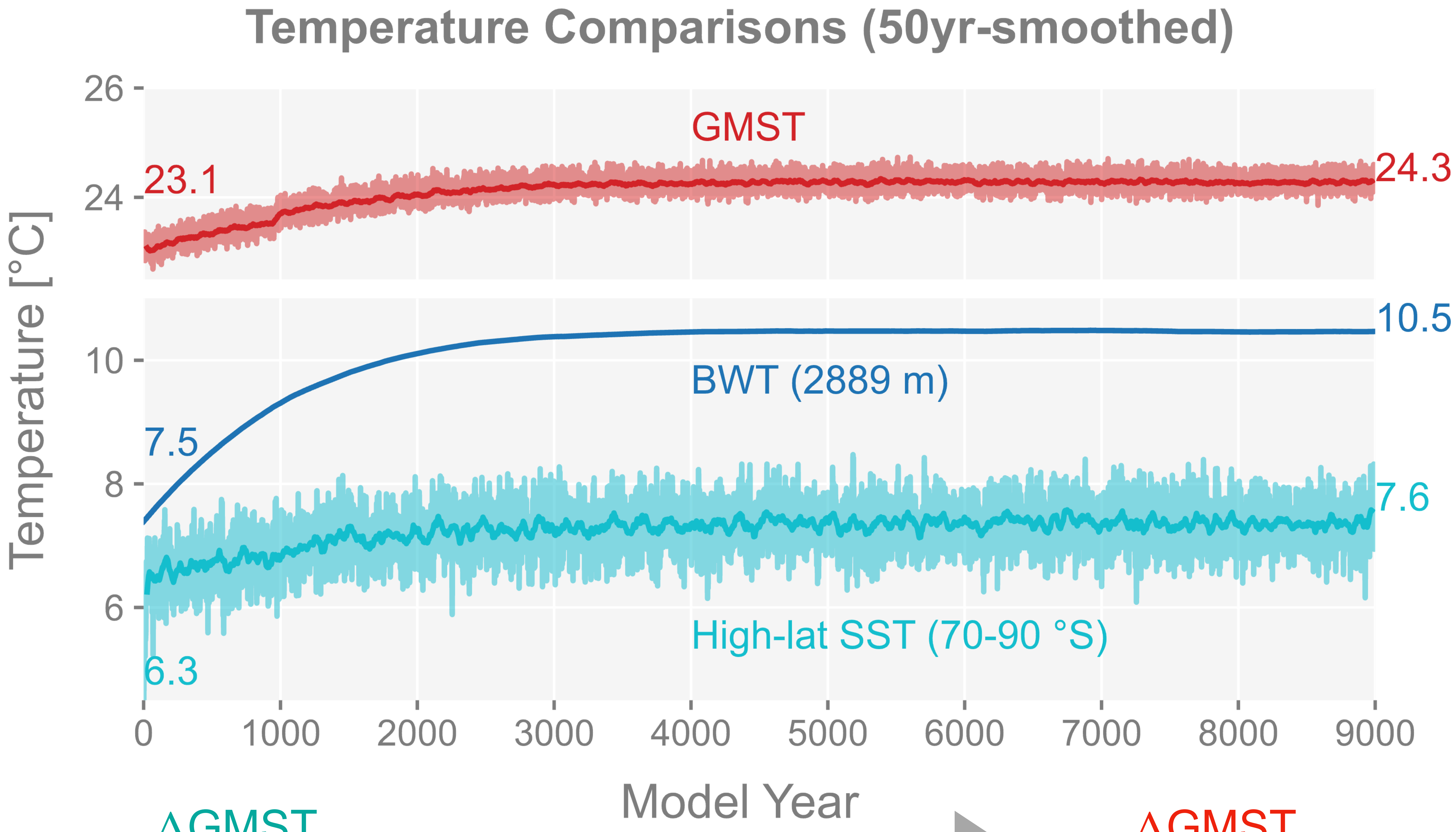
▣ Results The connection between GMST and BWT



Δ : MCO – PI

$$\frac{\Delta \text{GMST}}{\Delta \text{BWT}} \approx 1.65 \quad \longrightarrow \quad \frac{\Delta \text{GMST}}{\Delta \text{BWT}} \approx 1.17$$

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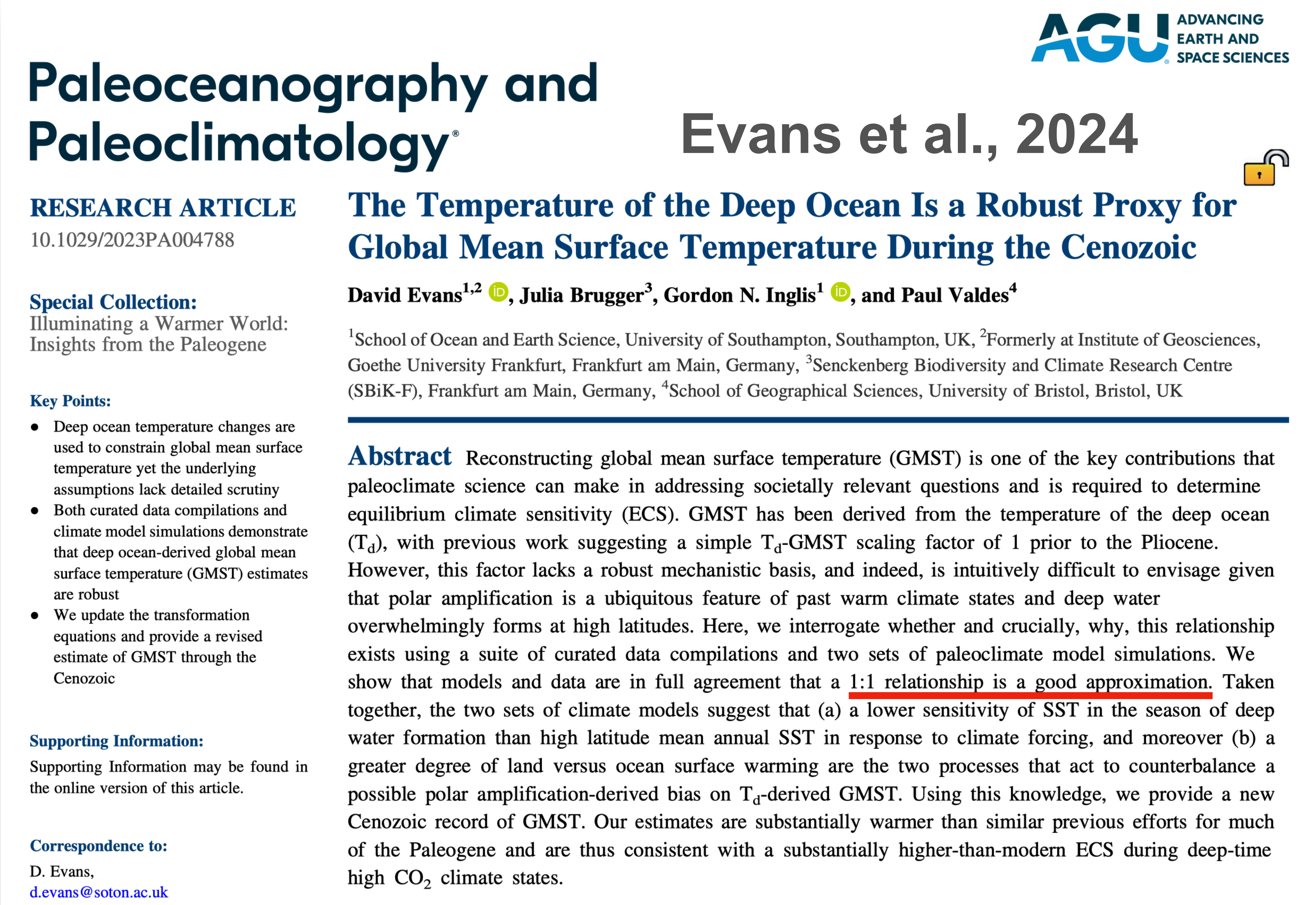

Paleoceanography and Paleoclimatology®

Evans et al., 2024

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RESEARCH ARTICLE

10.1029/2023PA004788

Special Collection:
Illuminating a Warmer World: Insights from the Paleogene

Key Points:

- Deep ocean temperature changes are used to constrain global mean surface temperature yet the underlying assumptions lack detailed scrutiny
- Both curated data compilations and climate model simulations demonstrate that deep ocean-derived global mean surface temperature (GMST) estimates are robust
- We update the transformation equations and provide a revised estimate of GMST through the Cenozoic

Supporting Information:

Supporting Information may be found in the online version of this article.

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The Temperature of the Deep Ocean Is a Robust Proxy for Global Mean Surface Temperature During the Cenozoic

David Evans[1,2], Julia Brugger[3], Gordon N. Inglis[1], and Paul Valdes[4]

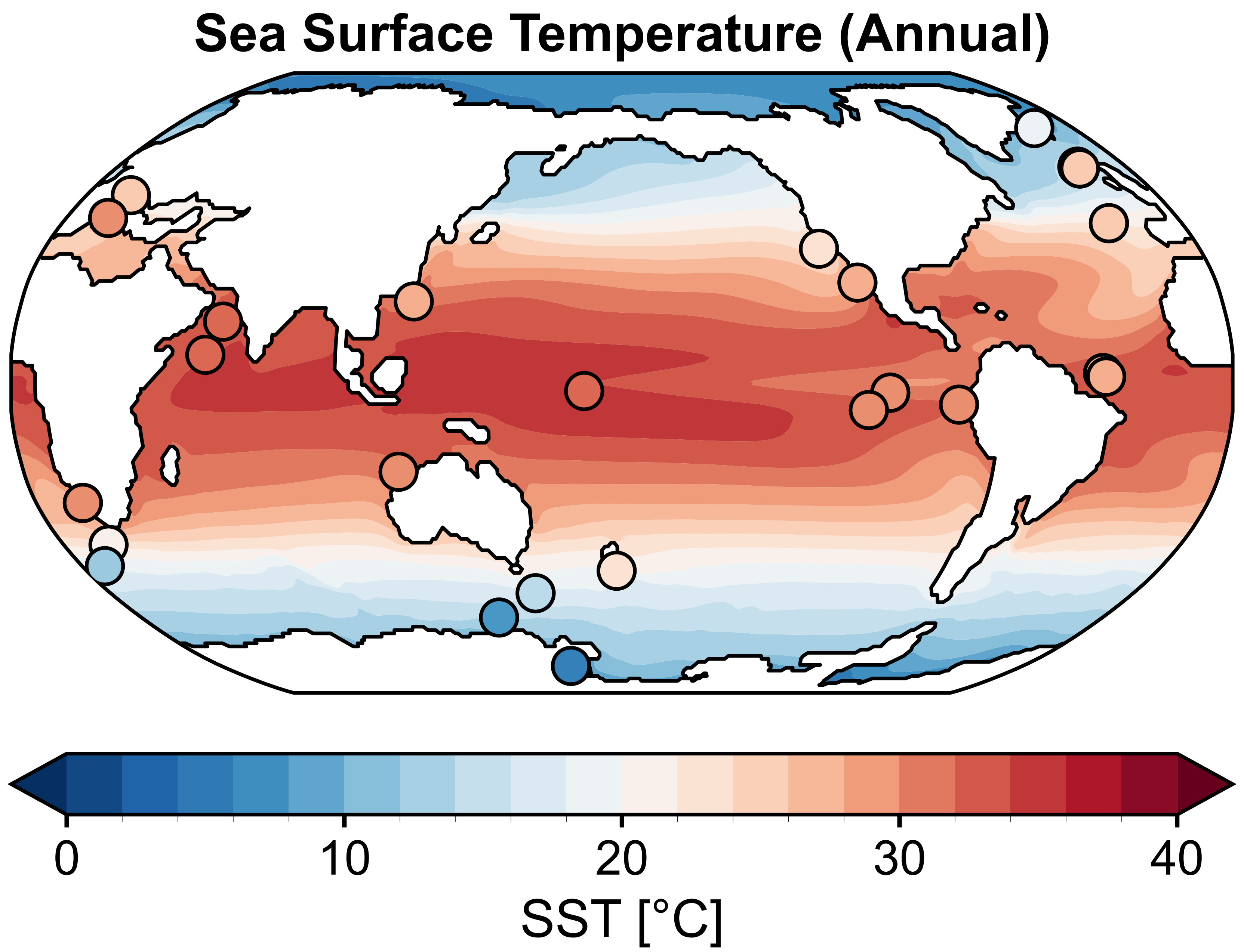
[1]School of Ocean and Earth Science, University of Southampton, Southampton, UK, [2]Formerly at Institute of Geosciences, Goethe University Frankfurt, Frankfurt am Main, Germany, [3]Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Frankfurt am Main, Germany, [4]School of Geographical Sciences, University of Bristol, Bristol, UK

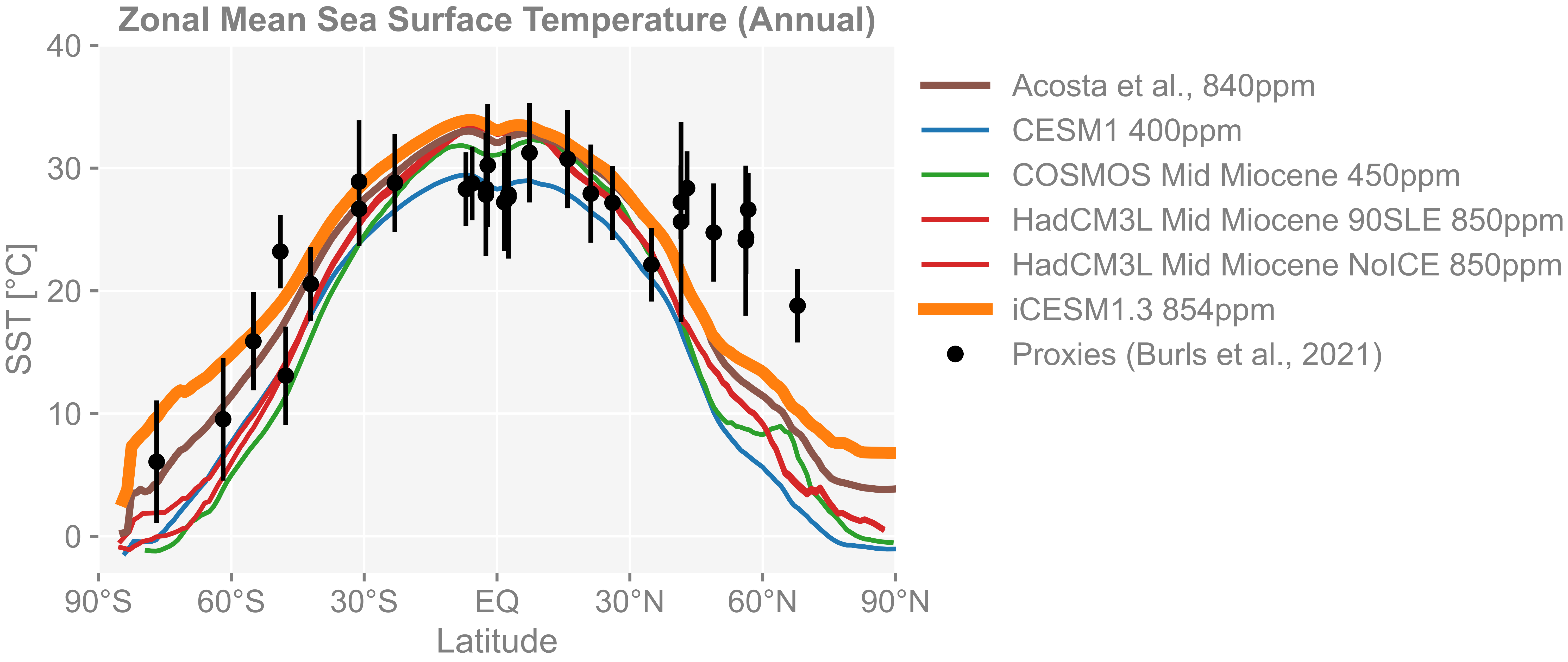
Abstract Reconstructing global mean surface temperature (GMST) is one of the key contributions that paleoclimate science can make in addressing societally relevant questions and is required to determine equilibrium climate sensitivity (ECS). GMST has been derived from the temperature of the deep ocean (T_d), with previous work suggesting a simple T_d-GMST scaling factor of 1 prior to the Pliocene. However, this factor lacks a robust mechanistic basis, and indeed, is intuitively difficult to envisage given that polar amplification is a ubiquitous feature of past warm climate states and deep water overwhelmingly forms at high latitudes. Here, we interrogate whether and crucially, why, this relationship exists using a suite of curated data compilations and two sets of paleoclimate model simulations. We show that models and data are in full agreement that a 1:1 relationship is a good approximation. Taken together, the two sets of climate models suggest that (a) a lower sensitivity of SST in the season of deep water formation than high latitude mean annual SST in response to climate forcing, and moreover (b) a greater degree of land versus ocean surface warming are the two processes that act to counterbalance a possible polar amplification-derived bias on T_d-derived GMST. Using this knowledge, we provide a new Cenozoic record of GMST. Our estimates are substantially warmer than similar previous efforts for much of the Paleogene and are thus consistent with a substantially higher-than-modern ECS during deep-time high CO_2 climate states.

Δ : MCO – PI

$$\frac{\Delta \mathrm{GMST}}{\Delta \mathrm{BWT}} \approx 1.65 \quad\longrightarrow\quad \frac{\Delta \mathrm{GMST}}{\Delta \mathrm{BWT}} \approx 1.17$$

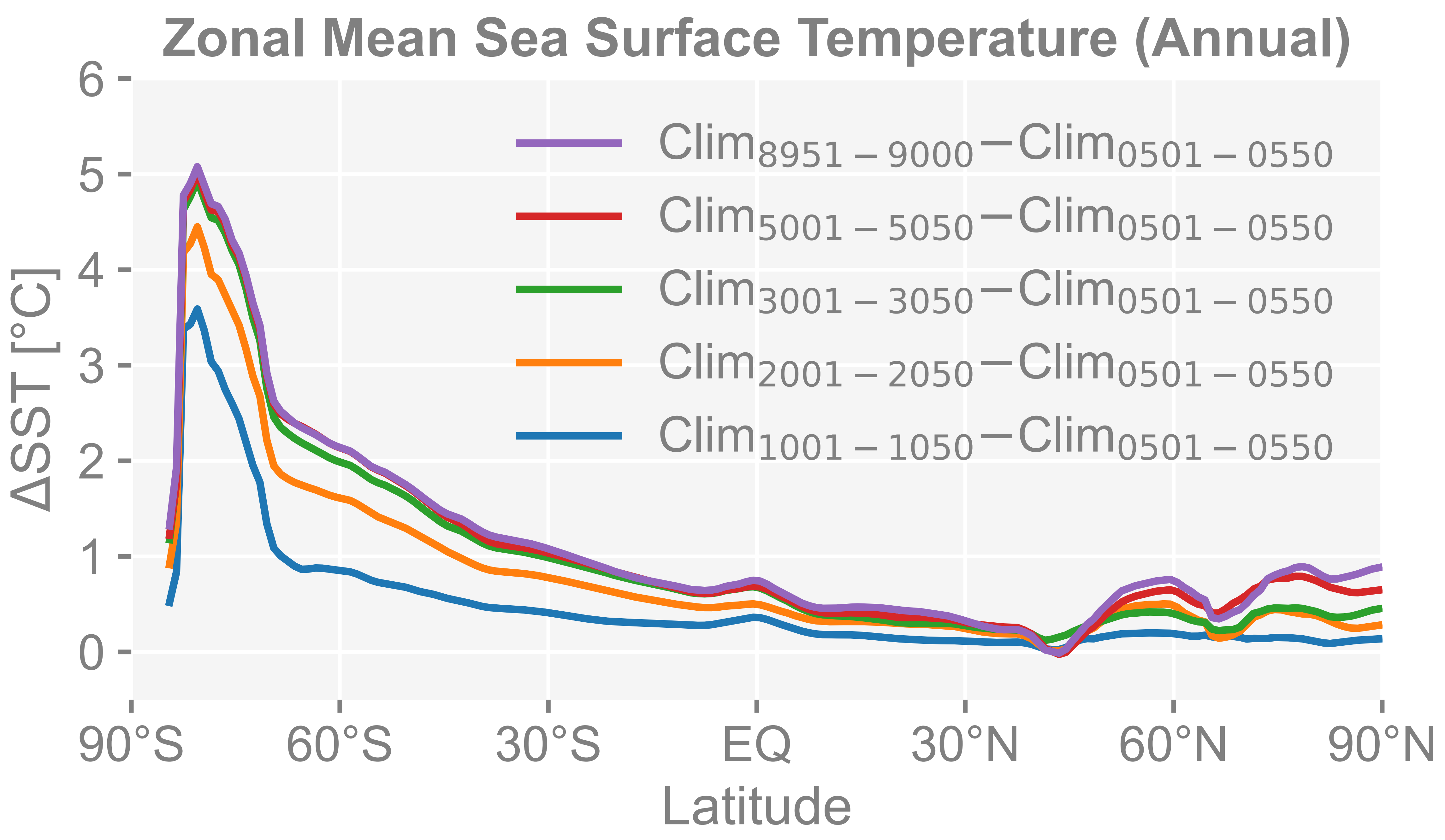
Results Comparison with MioMIP1 (Burls et al, 2021)





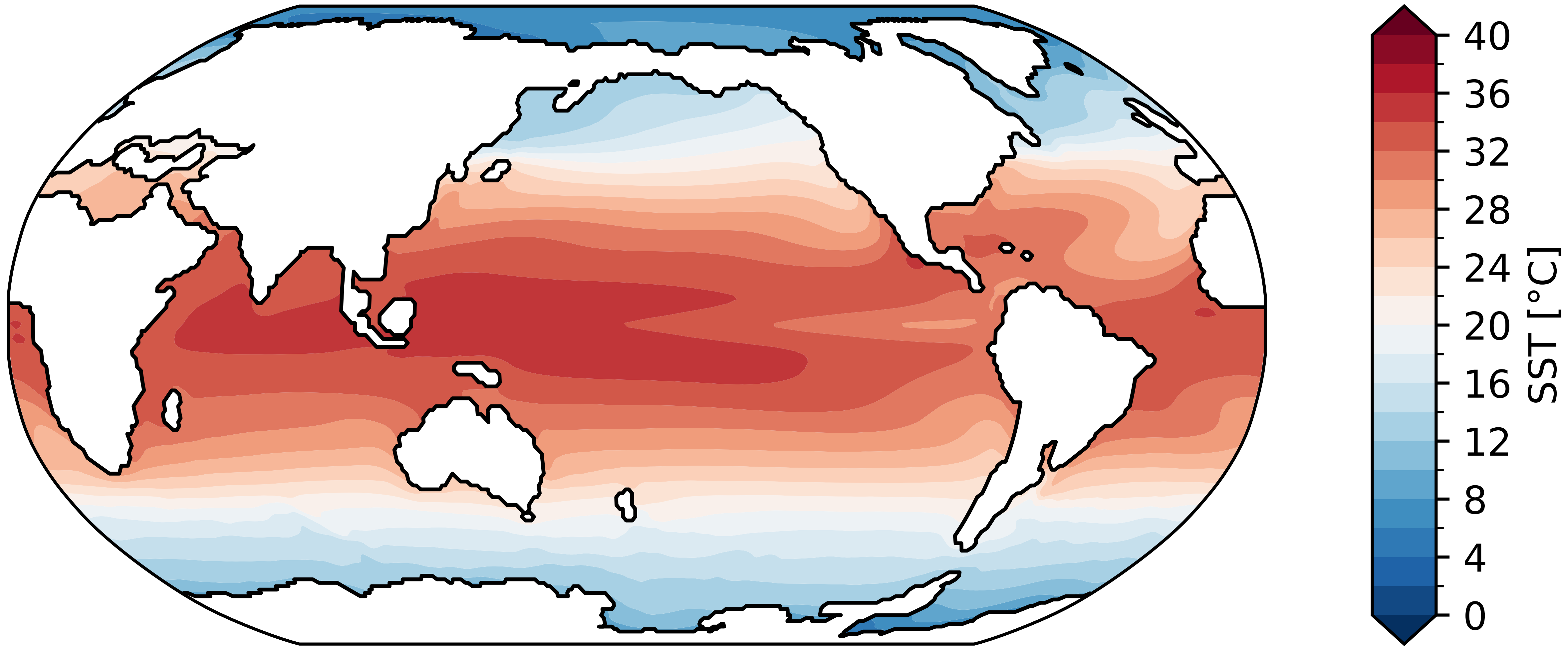
Results

Long spin-up alone → significant high-lat SST diff.



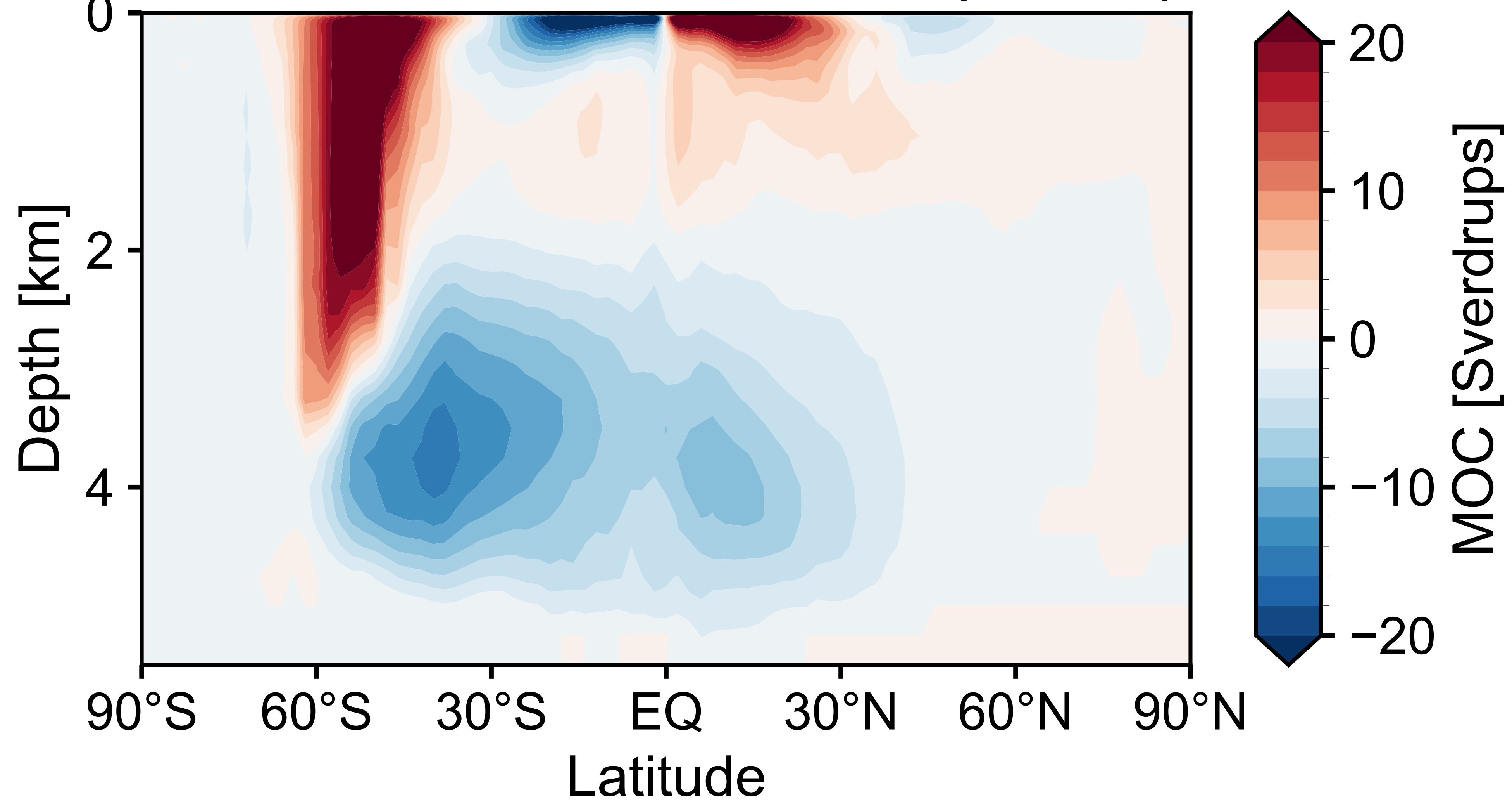
Deep ocean circulation

SST (Annual): $\mathrm{Clim}_{8951-9000}$

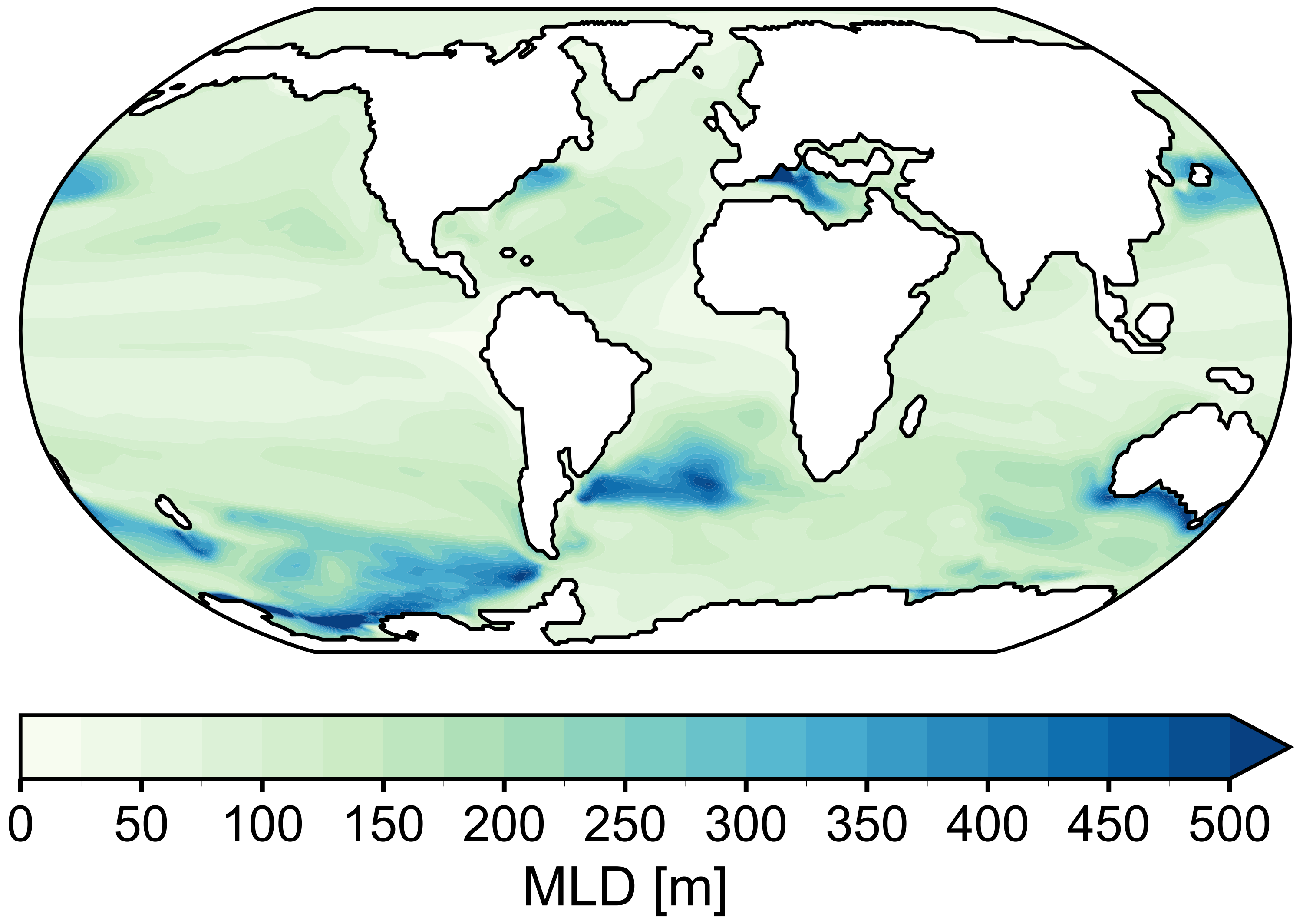


**No AMOC;
Deepwater formation over Pacific Sector of SO;
SO MOC of ~16 Sv.**

Meridional Ocean Circulation (Annual)



Mixed Layer Depth (NH: Mar; SH: Sept)



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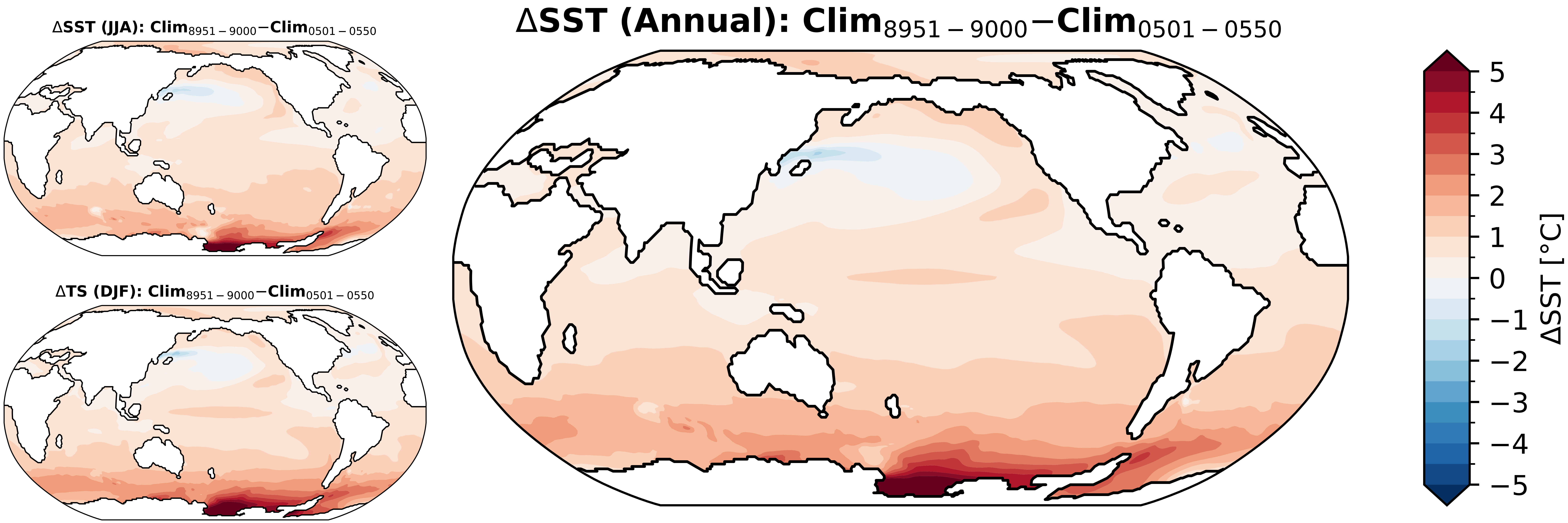
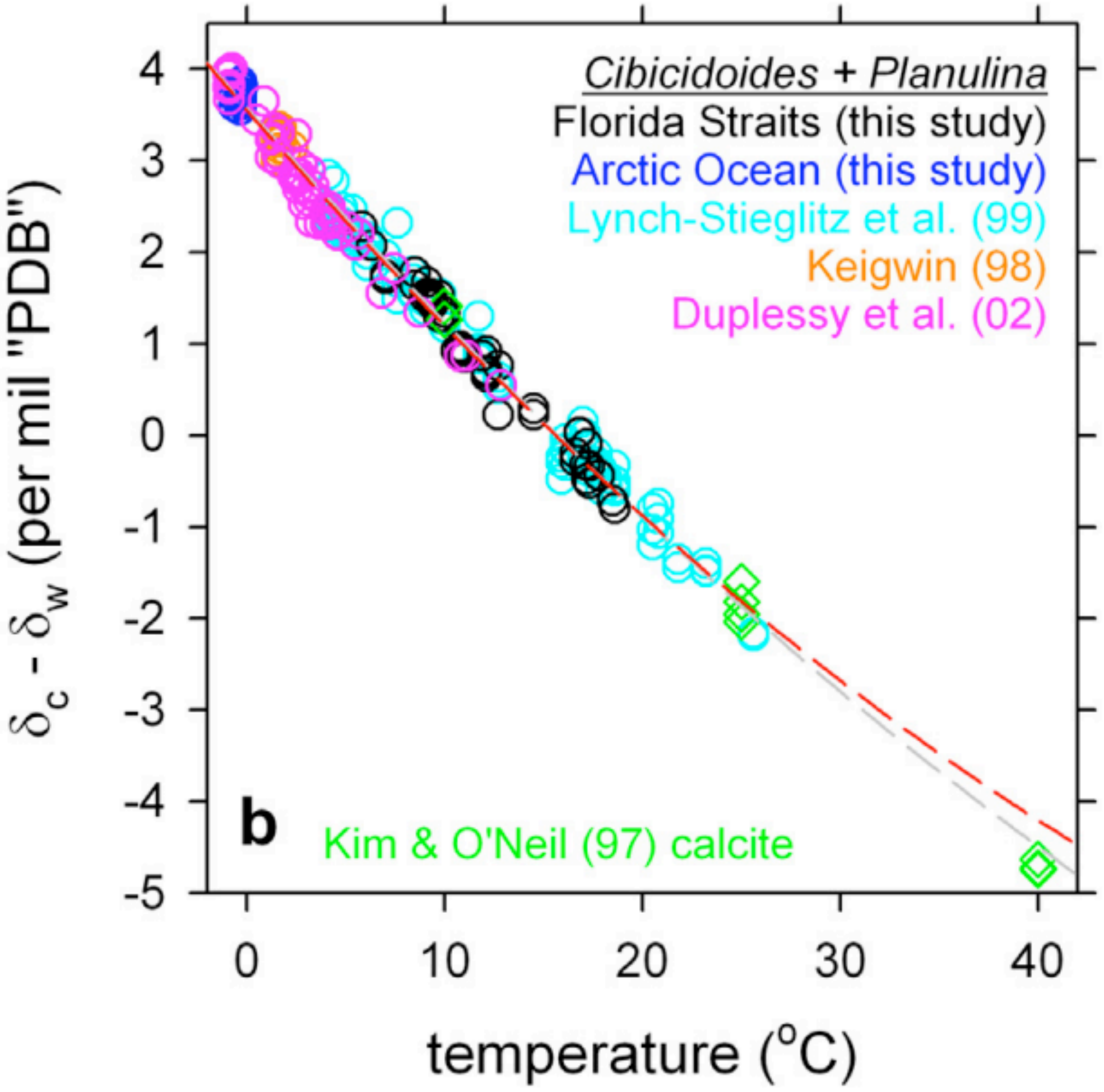


▣ Results Direct comparison to benthic foram calcite d18O

Marchitto et al. (2014)



e.g., Kim & ONeil (1997); Bemis et al. (1998);
Pearson (2012); Marchitto et al. (2014); Hollis et al. (2019)

d18Osw to d18Oc conversion:

$$T_{sw} = a(\delta^{18}O_c - \delta^{18}O_{sw})^2 + b(\delta^{18}O_c - \delta^{18}O_{sw}) + c$$

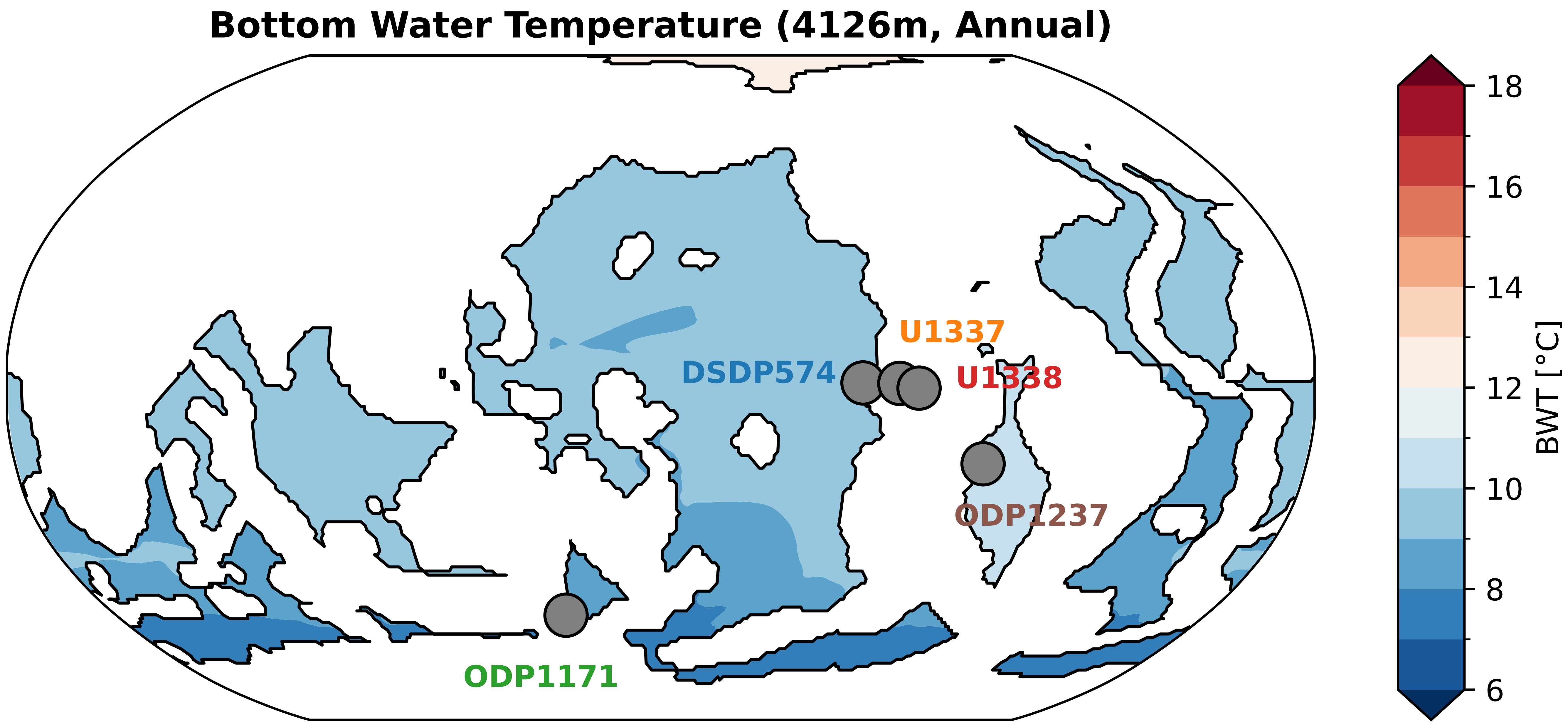
$$\delta^{18}O_c = \delta^{18}O_{sw} + f(T_{sw}; a, b, c)$$

Results   Direct comparison to benthic foram calcite d18O

5 benthic foram sites,

each site has >= 200 samples during MCO (14-17 Ma)

	pid	paleo_lat	paleo_lon	depth
0	DSDP574	1.144312	-124.468053	4561.0
1	ODP1171	-55.594620	148.692904	2150.0
2	ODP1237	-18.458773	-90.138832	3212.0
3	U1337	1.031639	-114.364687	4476.0
4	U1338	-0.114414	-109.091734	4210.0



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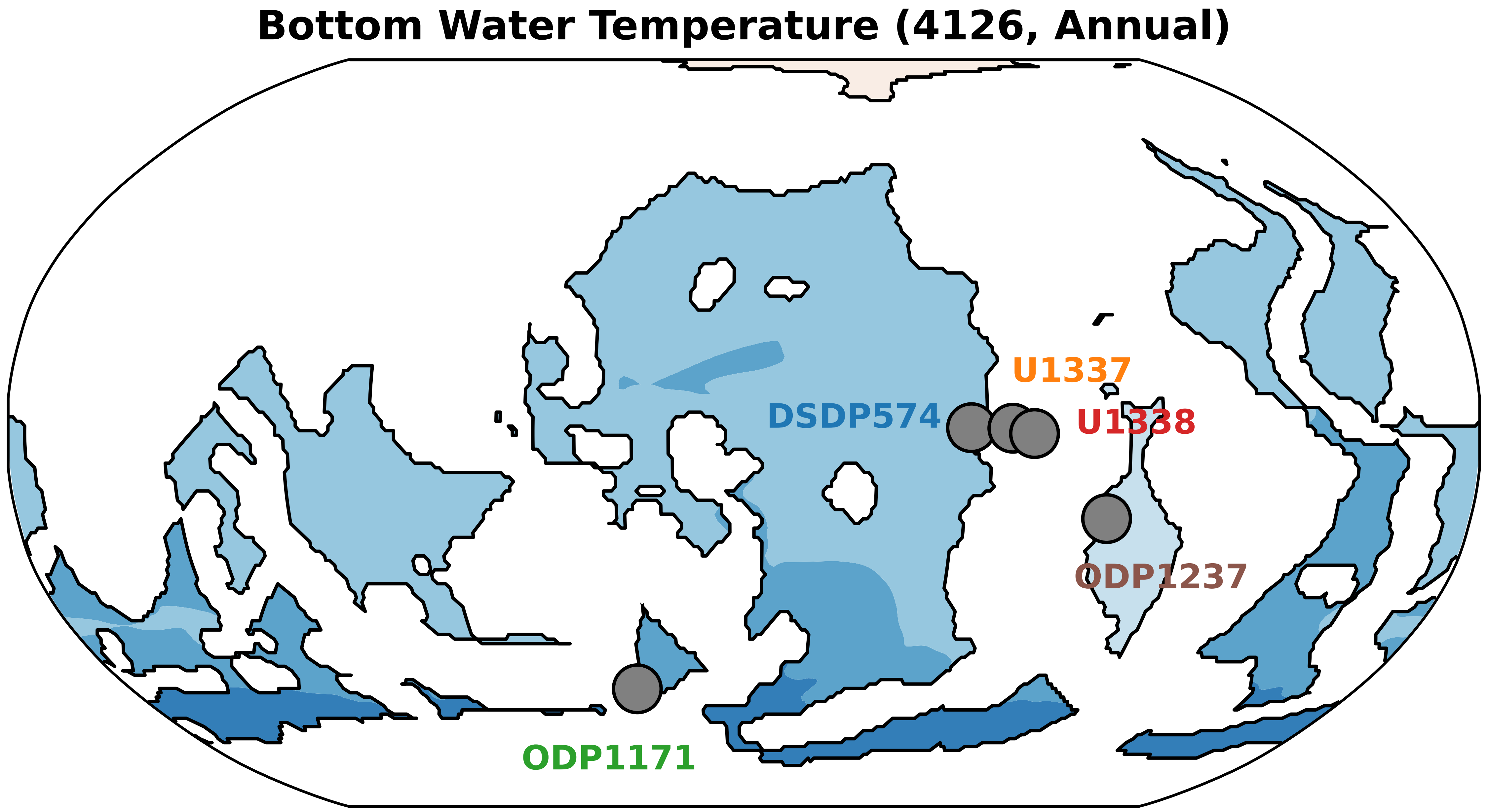
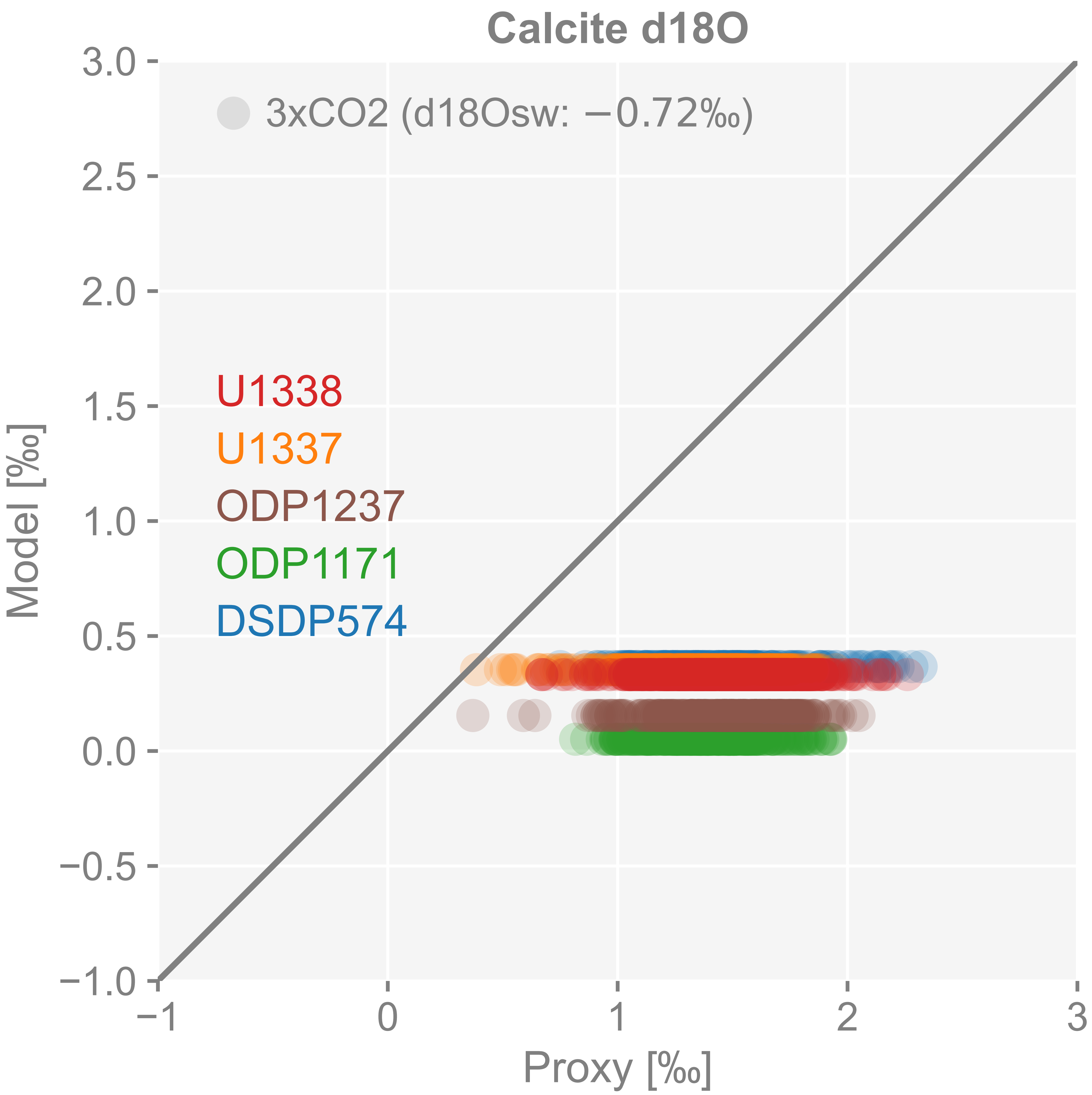
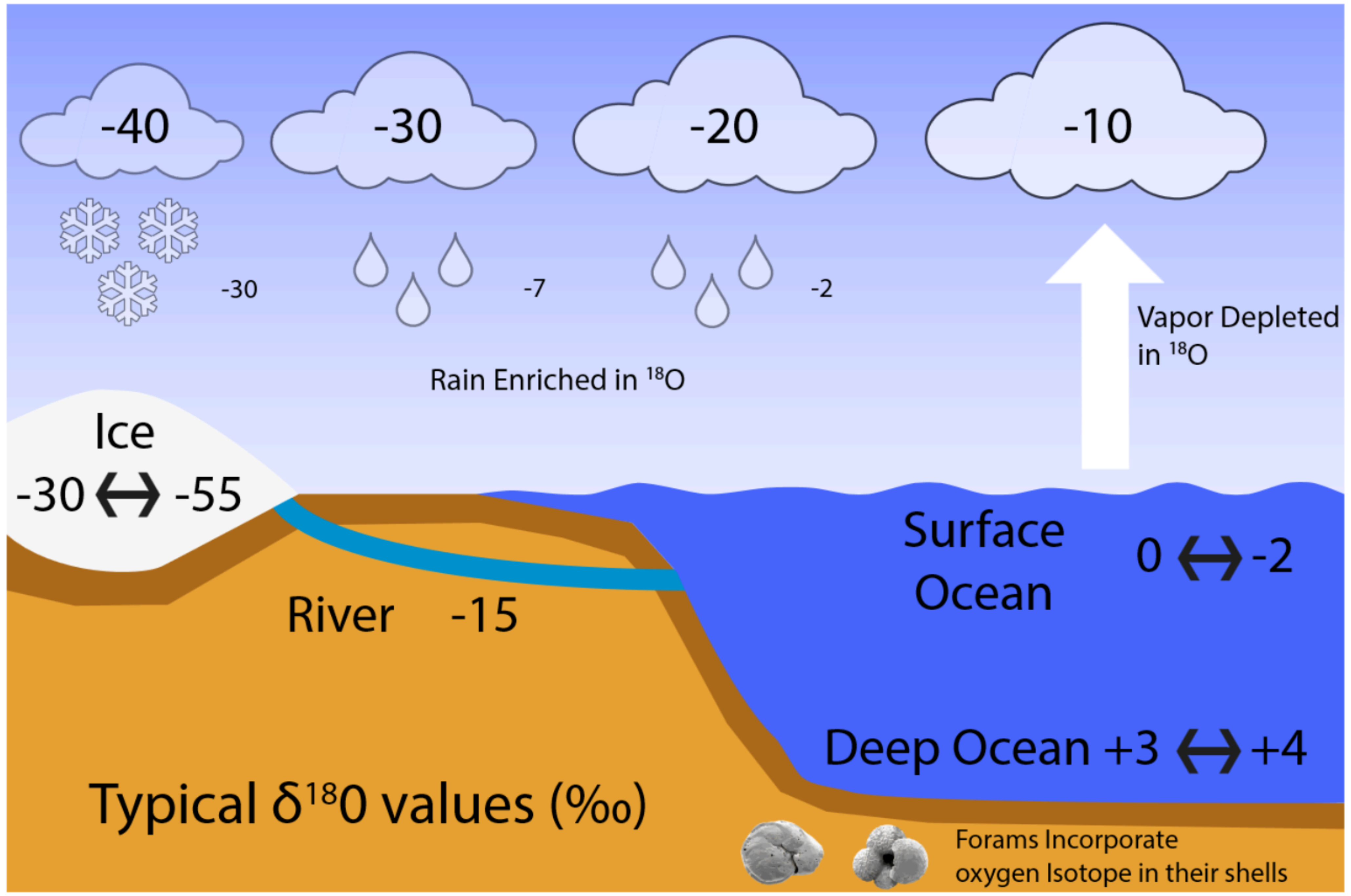
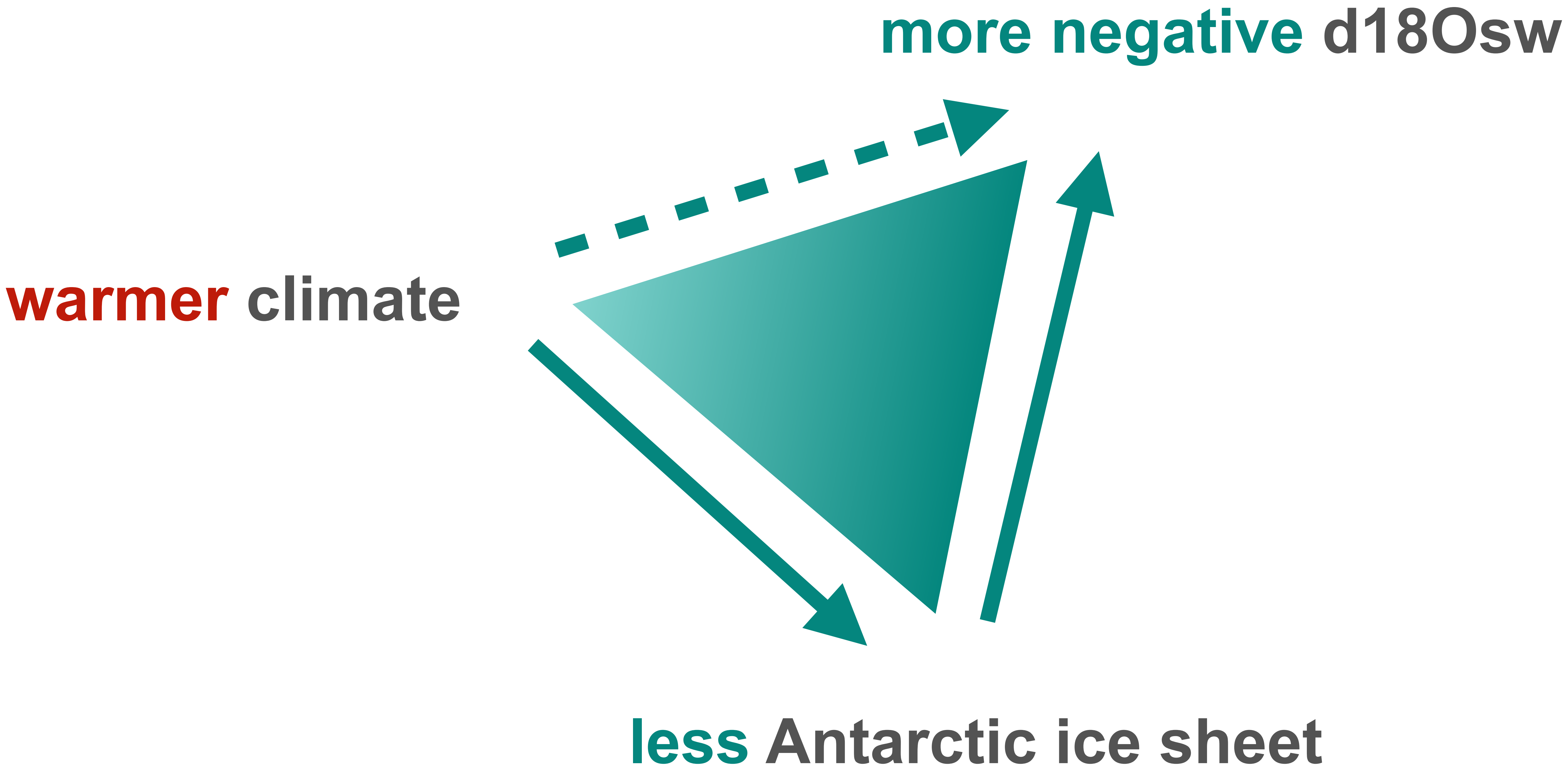

Bottom Water Temperature (4126, Annual)


Calcite d18O

Results Direct comparison to benthic foram calcite d18O



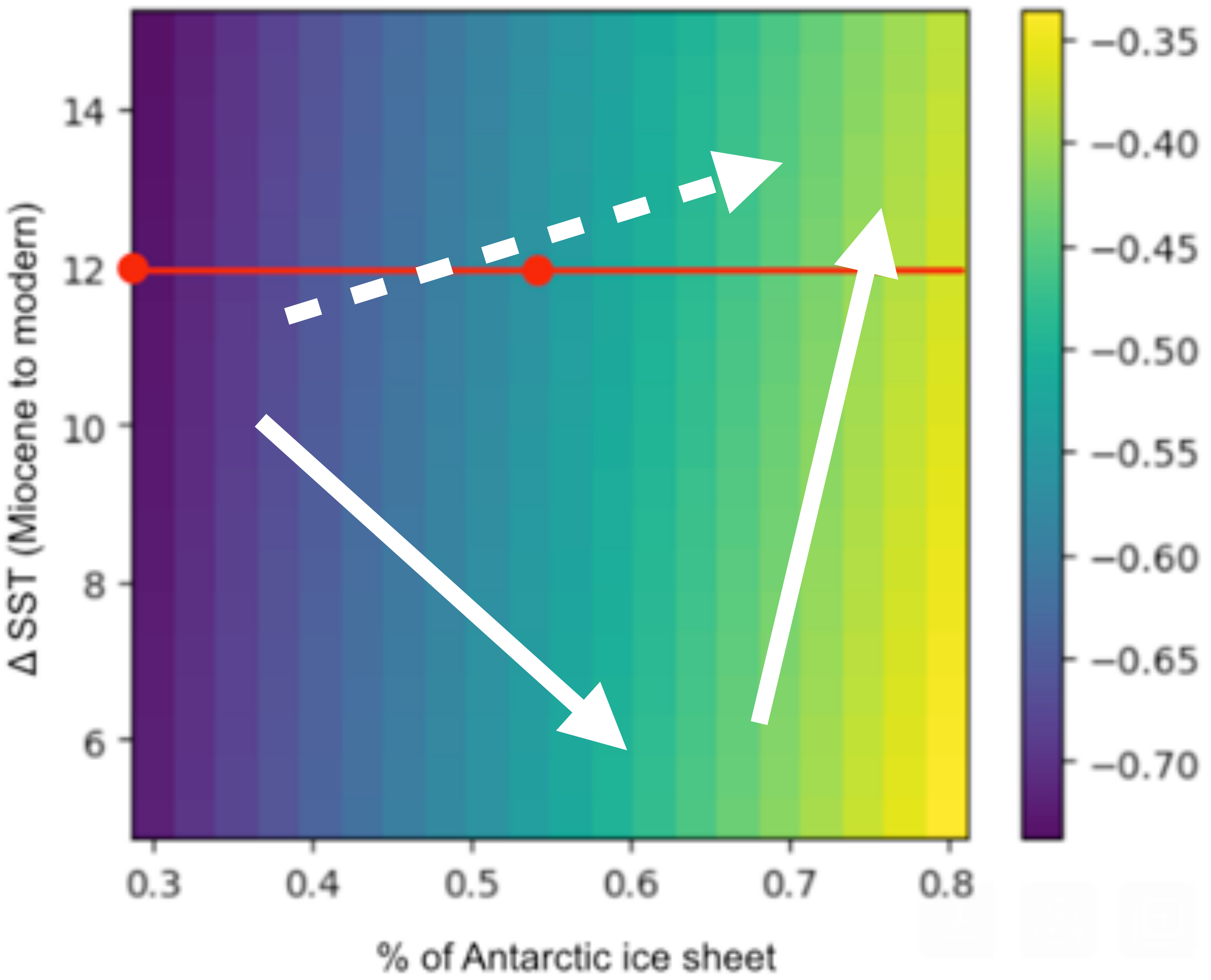
https://open.oregonstate.education


more negative d18Osw

warmer climate

less Antarctic ice sheet

▣ Results Direct comparison to benthic foram calcite d18O



less negative d18Osw

colder climate

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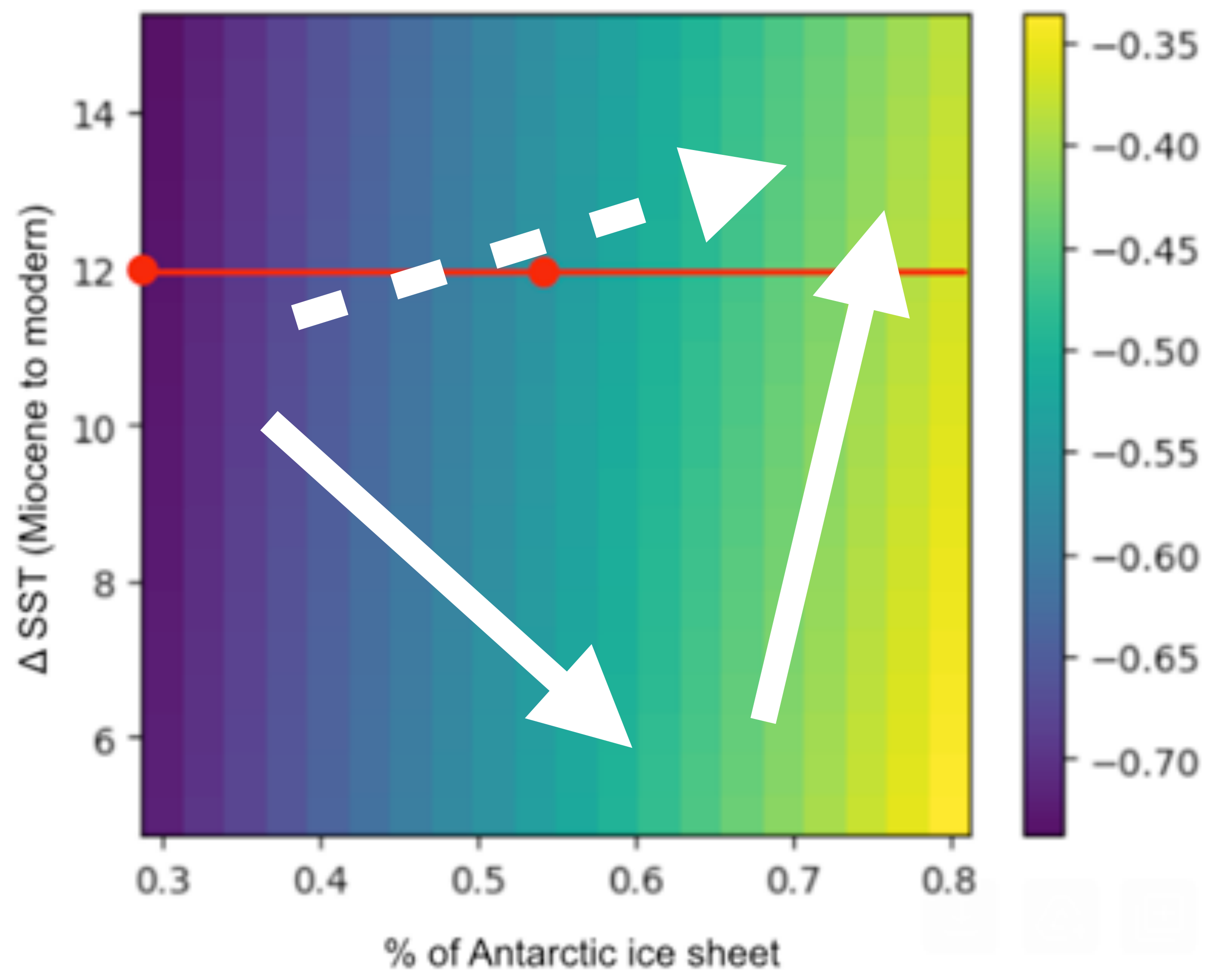
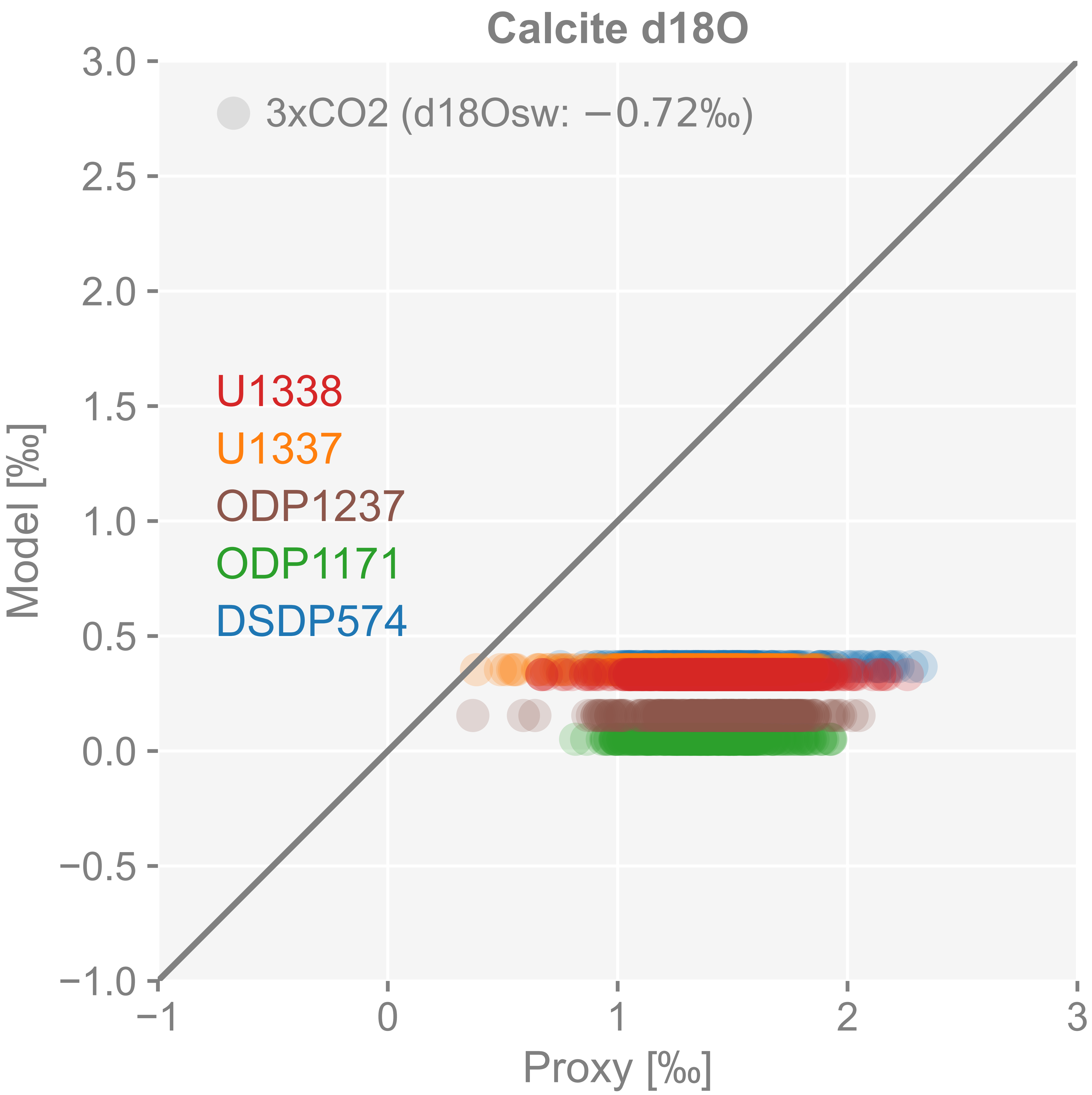


more Antarctic ice sheet

Three possible causes:

- The foram data is not really the counterpart of our simulation.
- The simulated ocean temperature is too warm.
- The specified d18Osw is too negative (the effective ice sheet is too small).



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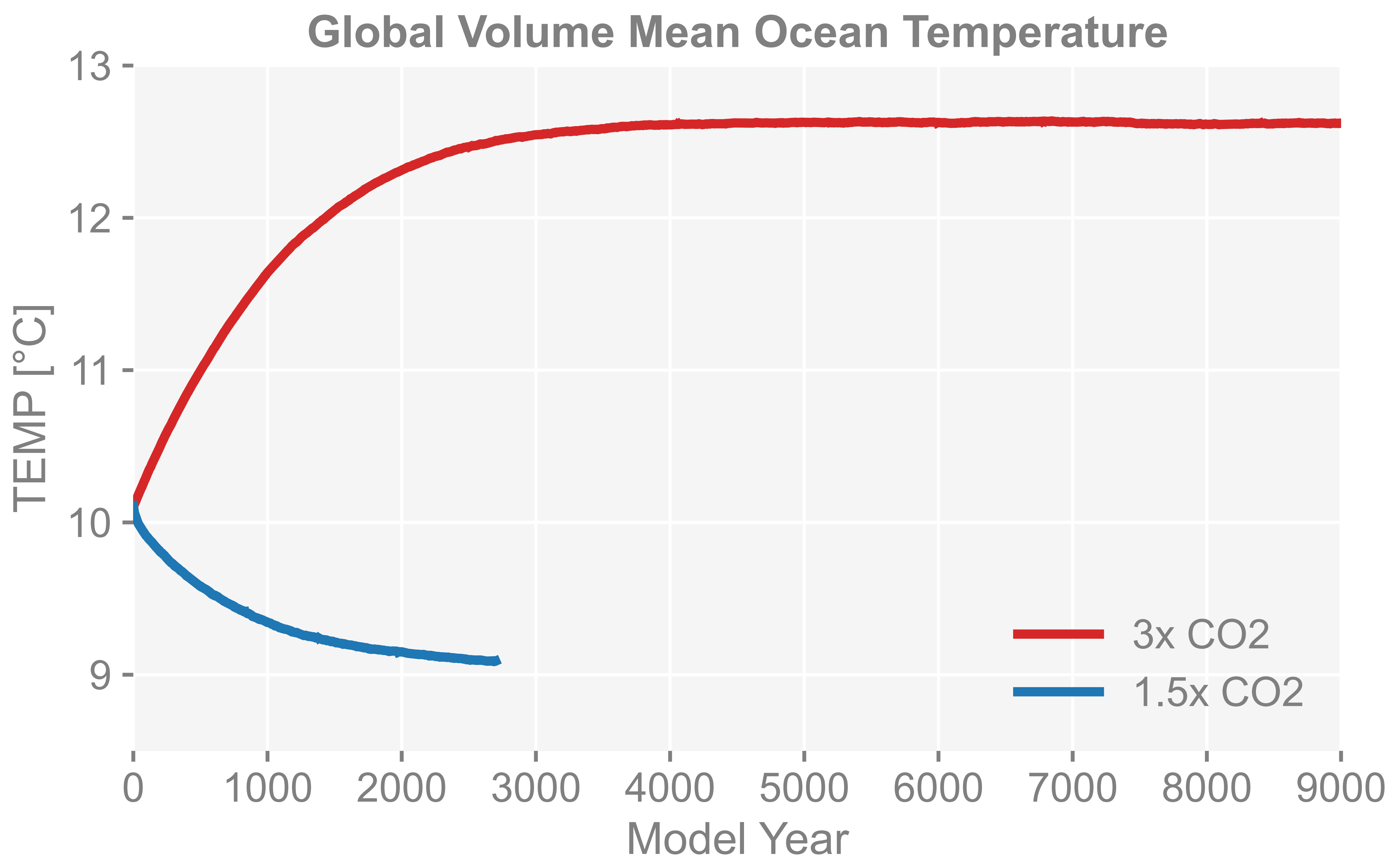
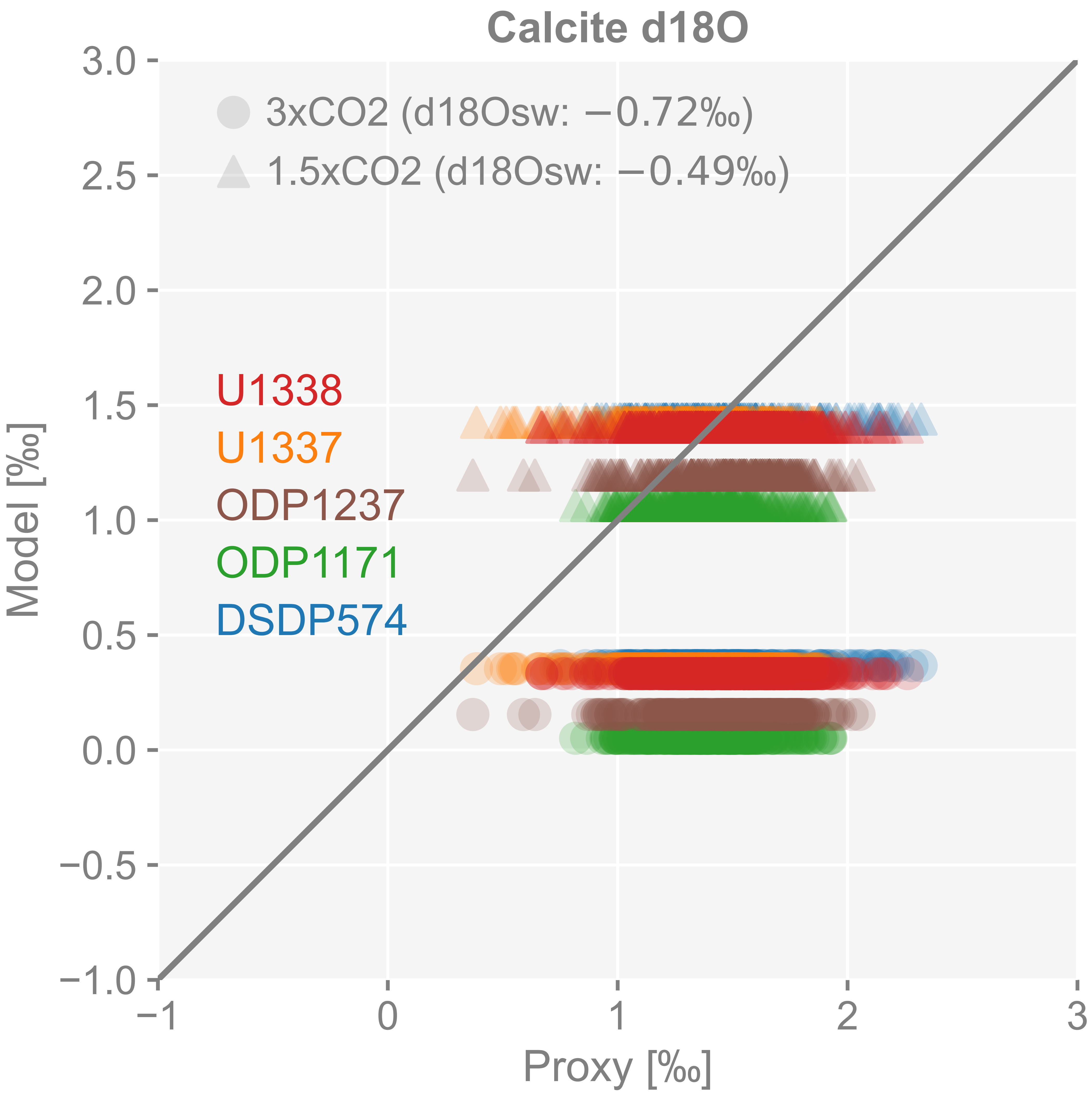
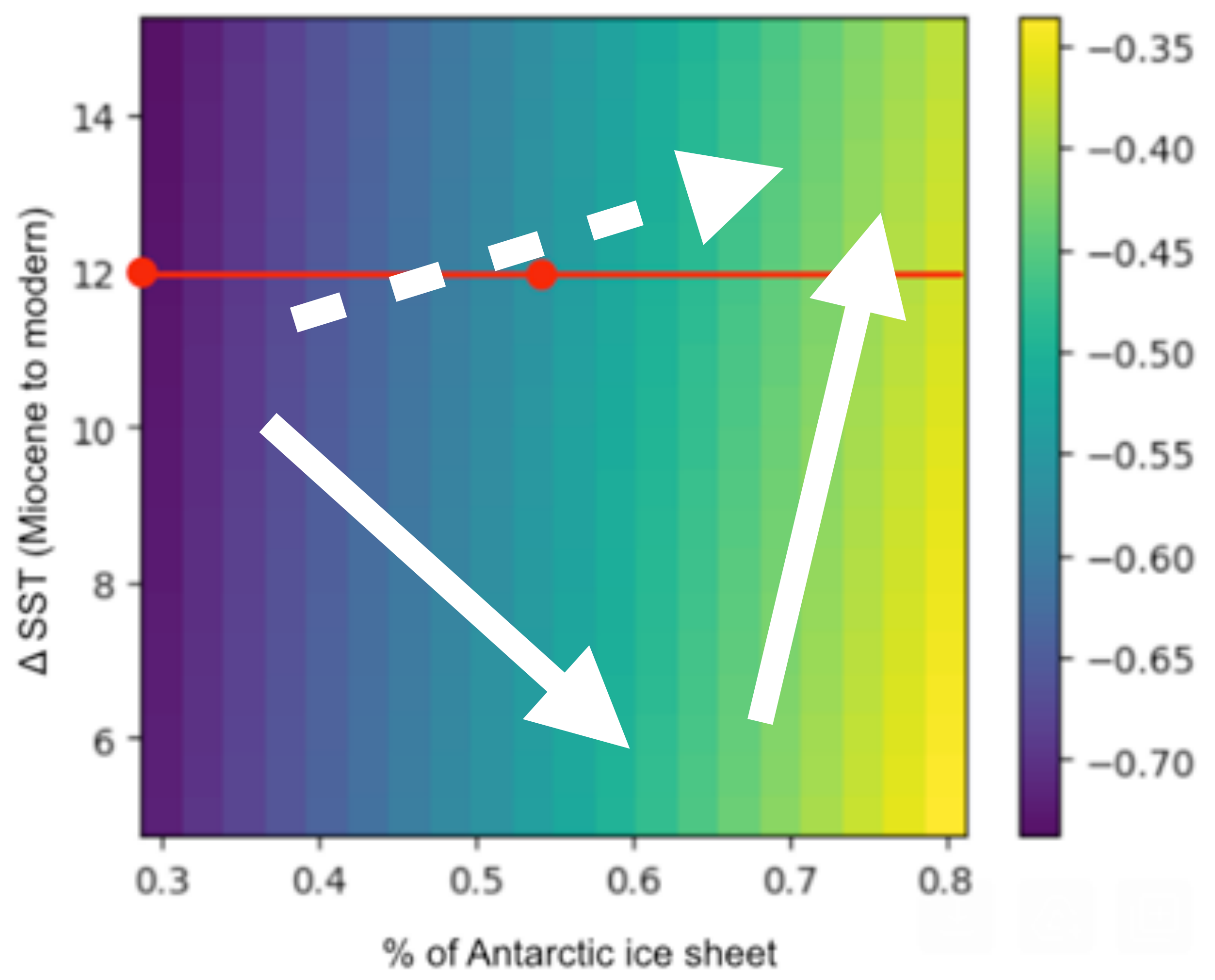




Results Direct comparison to benthic foram calcite d18O

less negative **d18Osw**

colder **climate**



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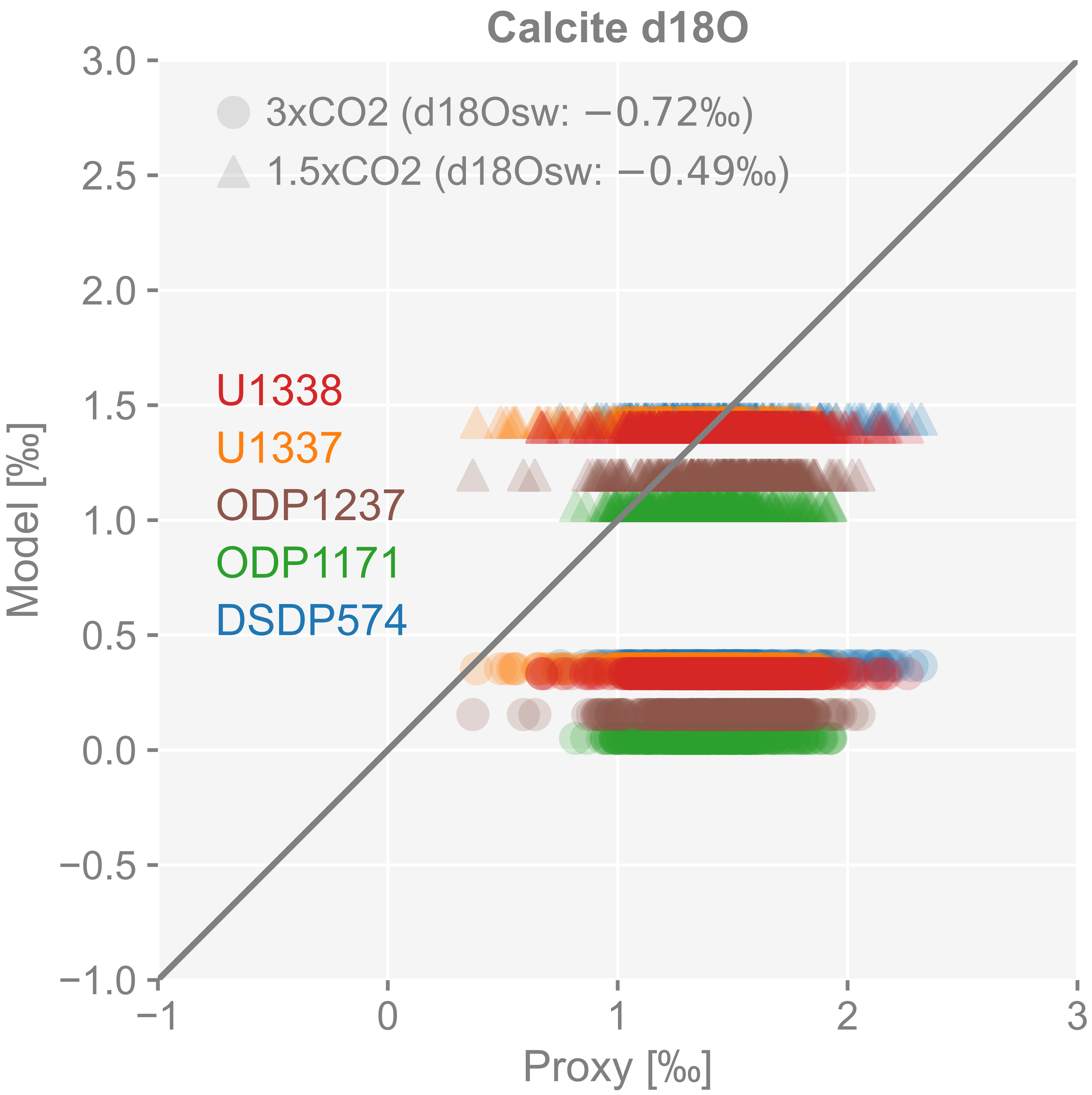

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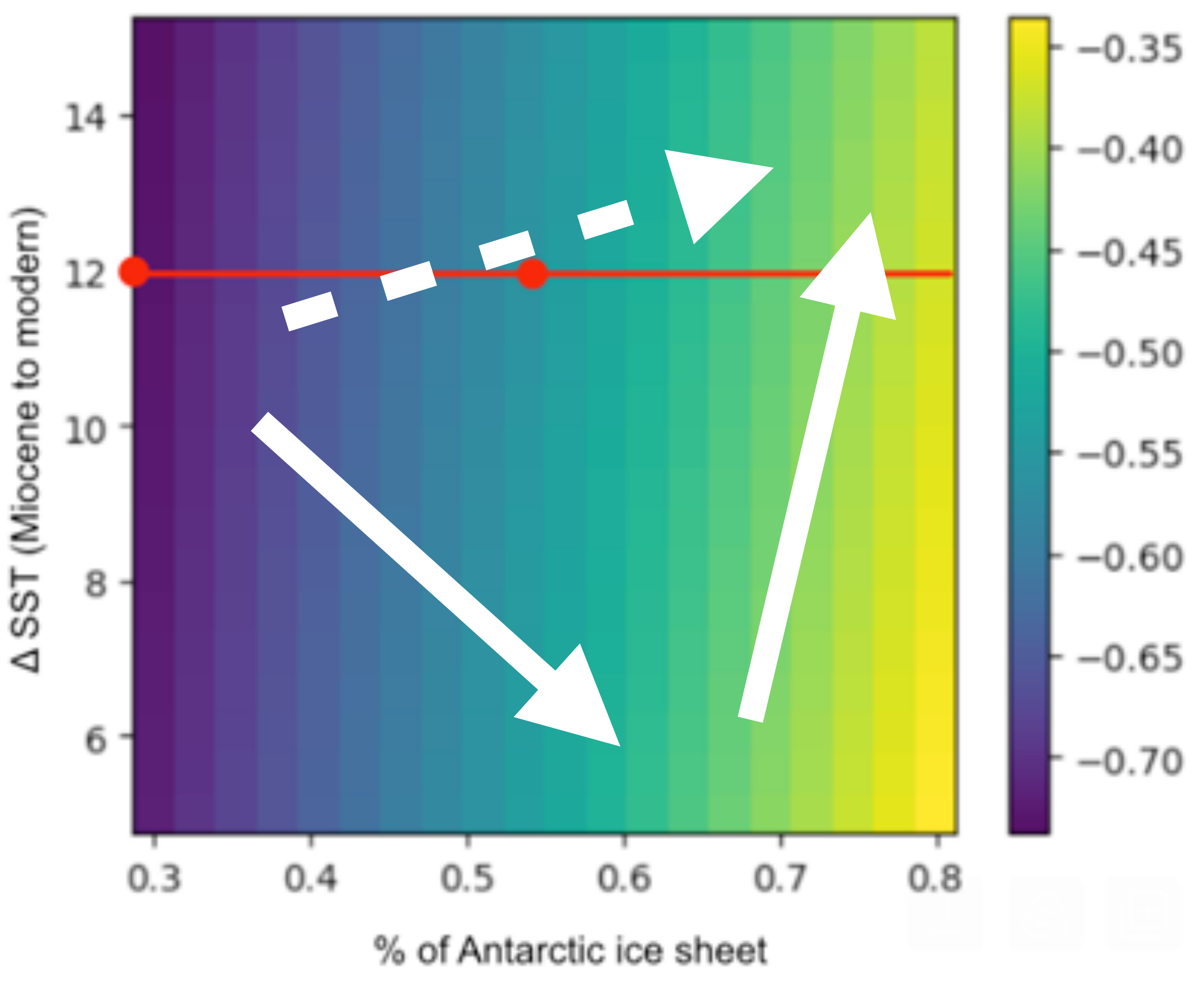
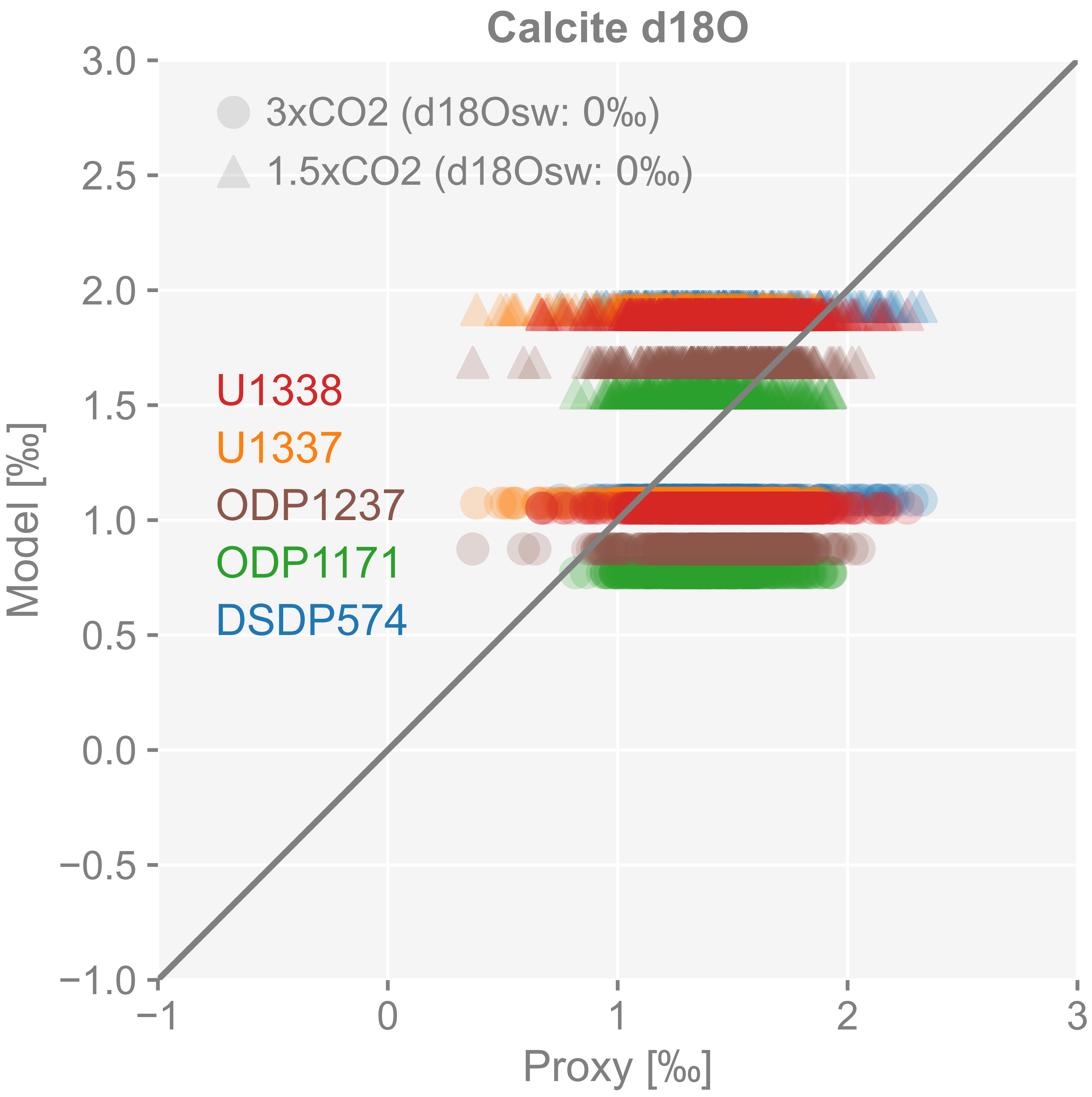


more Antarctic ice sheet



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- The specified d18Osw is too negative (the effective ice sheet is too small).
- **“deep heat but big ice”? (Modestou et al., 2020)**

Summary

- We revisited MCO leveraging **a unique state-of-the-art iCESM 1.3 simulation ft. equilibrated deep ocean**.
- (!!) **Long spin-up alone** can introduce **high-lat SST differences up-to 5°C**.
- (!) The equilibrated deep ocean **also affects the ΔGMST:ΔBWT (Δ: MCO-PI)**.
- (?) **3xCO2** might be too much for MCO, according to our benthic d18O evidence.

Analysis & visualization powered by

x4c

— Xarray for CESM —

fzhu2e.github.io/x4c

Thank you!

(fengzhu@ucar.edu)

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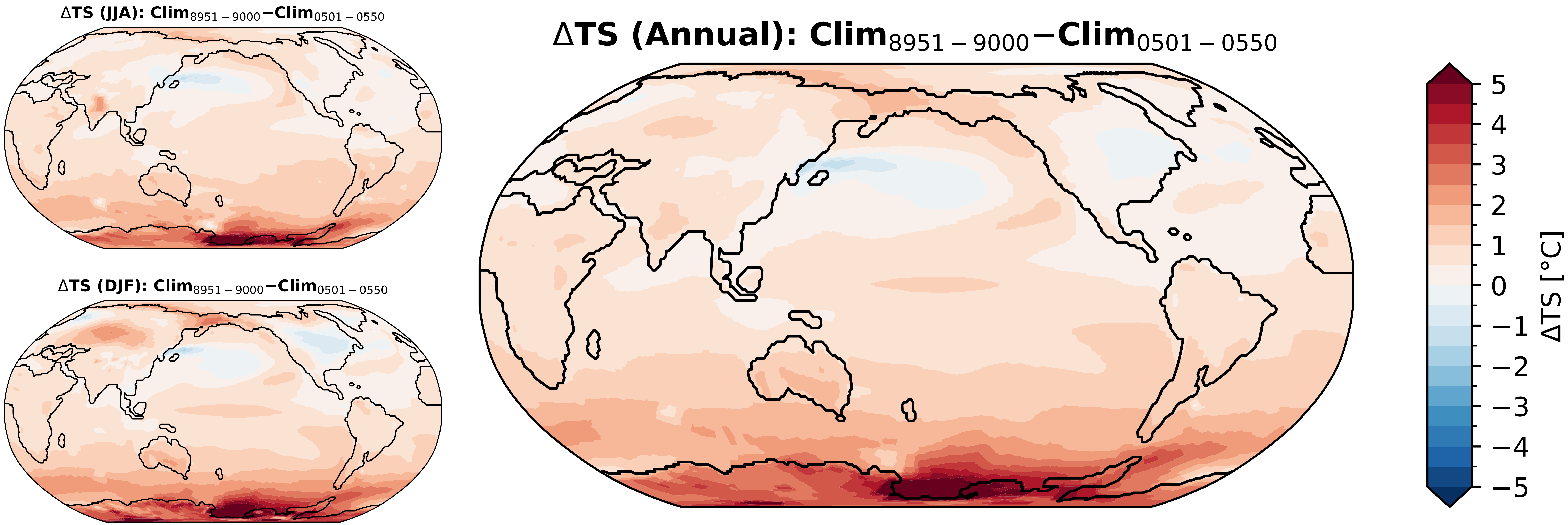
1. NSF NCAR 2. Brown University

Jun 12, 2024
CESM Workshop 2024

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

Results

Long spin-up alone → significant Antarctic SST differences up-to 5°C



ΔTS (JJA): $\mathrm{Clim}_{8951-9000} - \mathrm{Clim}_{0501-0550}$

ΔTS (DJF): $\mathrm{Clim}_{8951-9000} - \mathrm{Clim}_{0501-0550}$

ΔTS (Annual): $\mathrm{Clim}_{8951-9000} - \mathrm{Clim}_{0501-0550}$