Investigating the Physical State of the Modeled Eocene Ocean After Full Equilibration

- **Adam Aleksinski**
- CESM Paleoclimate WG, 11 June 2025

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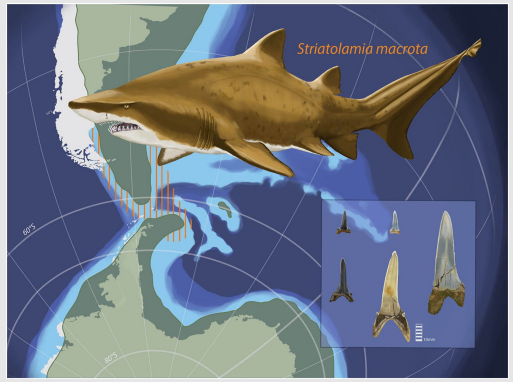
NCAR



NSF

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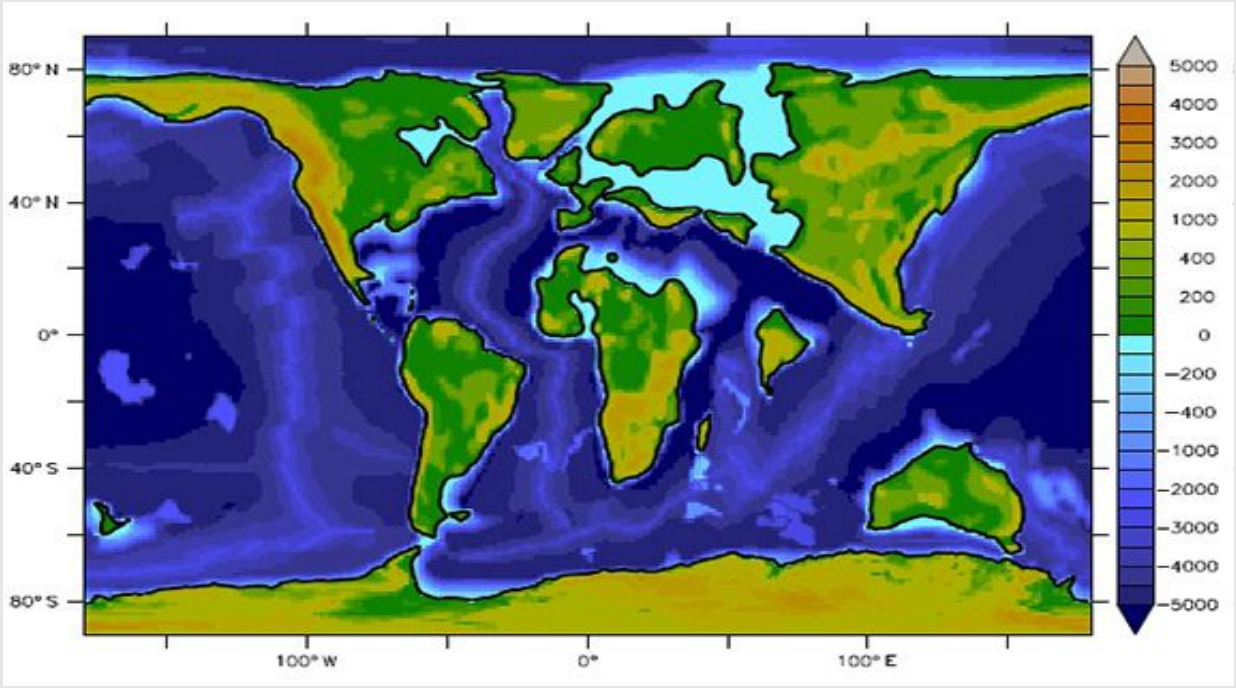
DeepMIP

- The Deeptime Model Intercomparison Project: Seeks to compare simulation performance across many GCMs used by the paleoclimate community (Lunt et al., 2017)
- DeepMIP simulations need to be run for at least 1,000 years and have reasonably stable surface energy balance to be considered equilibrated



From: Lunt et al. (2017)

DeepMIP

- Required runtime is adequate for a stable surface climate, but not for deep ocean equilibration
- This could be a problem if DeepMIP-compliant modeling research is used in long-term ocean circulation studies

What changes if a DeepMIP simulation continued out until the ocean is fully ventilated?

The iCESM Model

Based on ver. 1.2 of the Community Earth Systems Model (Hurrell et al., 2013)

- Isotope tracing added to POP2 and CICE functionality (Brady et al., 2019)

Component Function	Component Used
Atmosphere	Community Atmosphere Model 5 (CAM5)
Sea Ice	Community Ice CodE (CICE)
Land	Community Land Model 2 (CLM2)
Ocean	Parallel Ocean Program 2 (POP2)
Runoff	River Transport Model (RTM)

Parameter	Boundary Condition
Resolution	1.9° × 2.5° atmosphere, nominal 1° ocean/sea ice
Geography/Bathymetry	From Zhu et al. (2020) simulation, originally from Herold et al. (2014)
pCO_2	3x preindustrial levels, from Zhu et al. (2020) simulation
Nd composition of runoff and continental margins	Adapted from Jeandel et al. (2007)
Nd composition of dust	Adapted from Tachikawa et al. (2003)
Dust flux in POP2	Adapted from dust burden output of Zhu et al. (2020) simulation

The iCESM Model

Continuation of iCESM run performed in Zhu et al. (2020)

- Case already at surface equilibrium
- Prescribed neodymium distribution based on Jeandel et al. (2007) and Tachikawa et al al. (2003)

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- Using ideal age as main indicator of ocean mixing

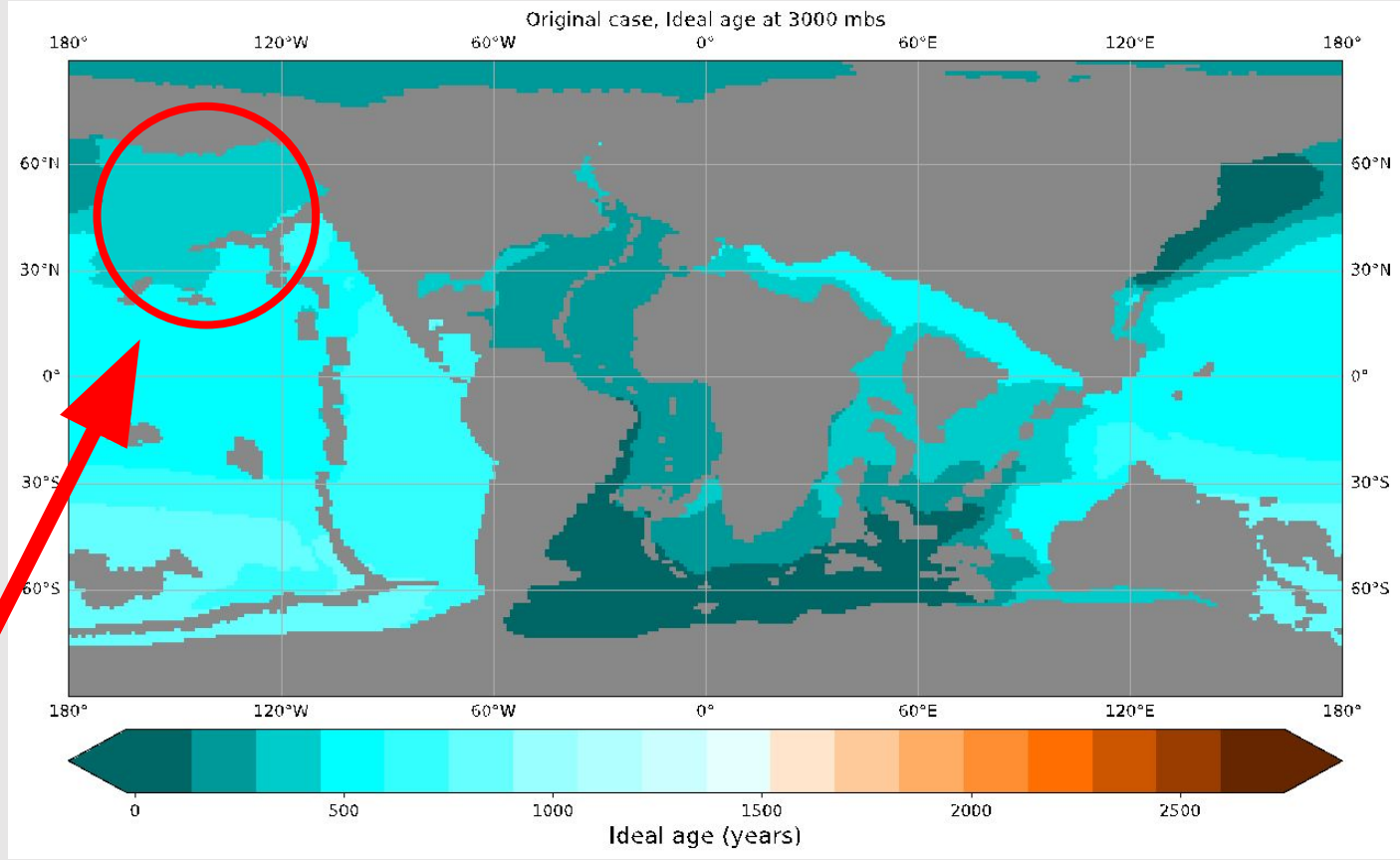
Original simulation:

2,200 year runtime

Continued simulation:

7,000 year runtime

(+4,800 years added)



Take note of this part of the North Pacific basin

- Using ideal age as main indicator of ocean mixing

Original simulation:

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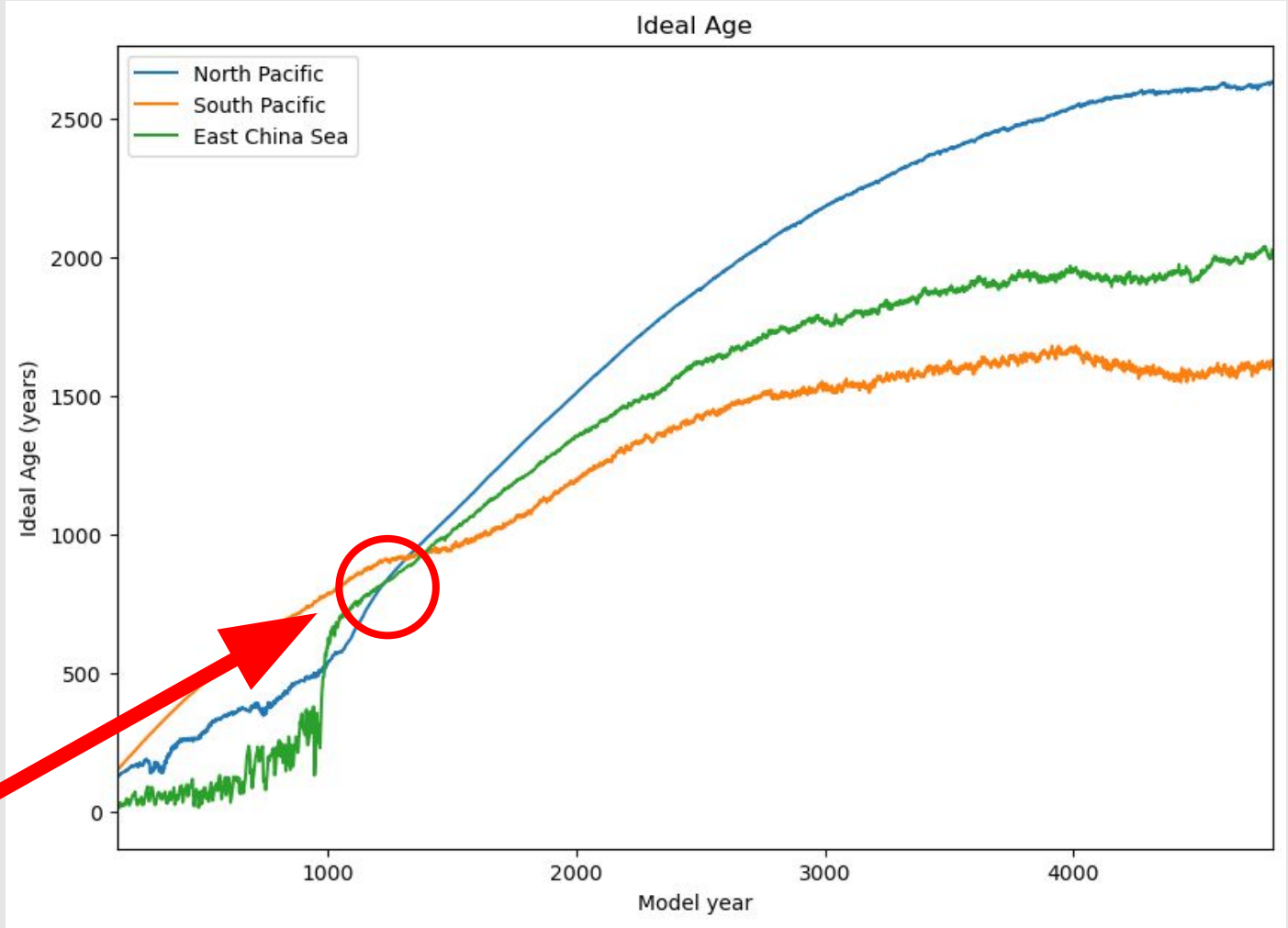
At this point, the basin is completely cut off from younger water



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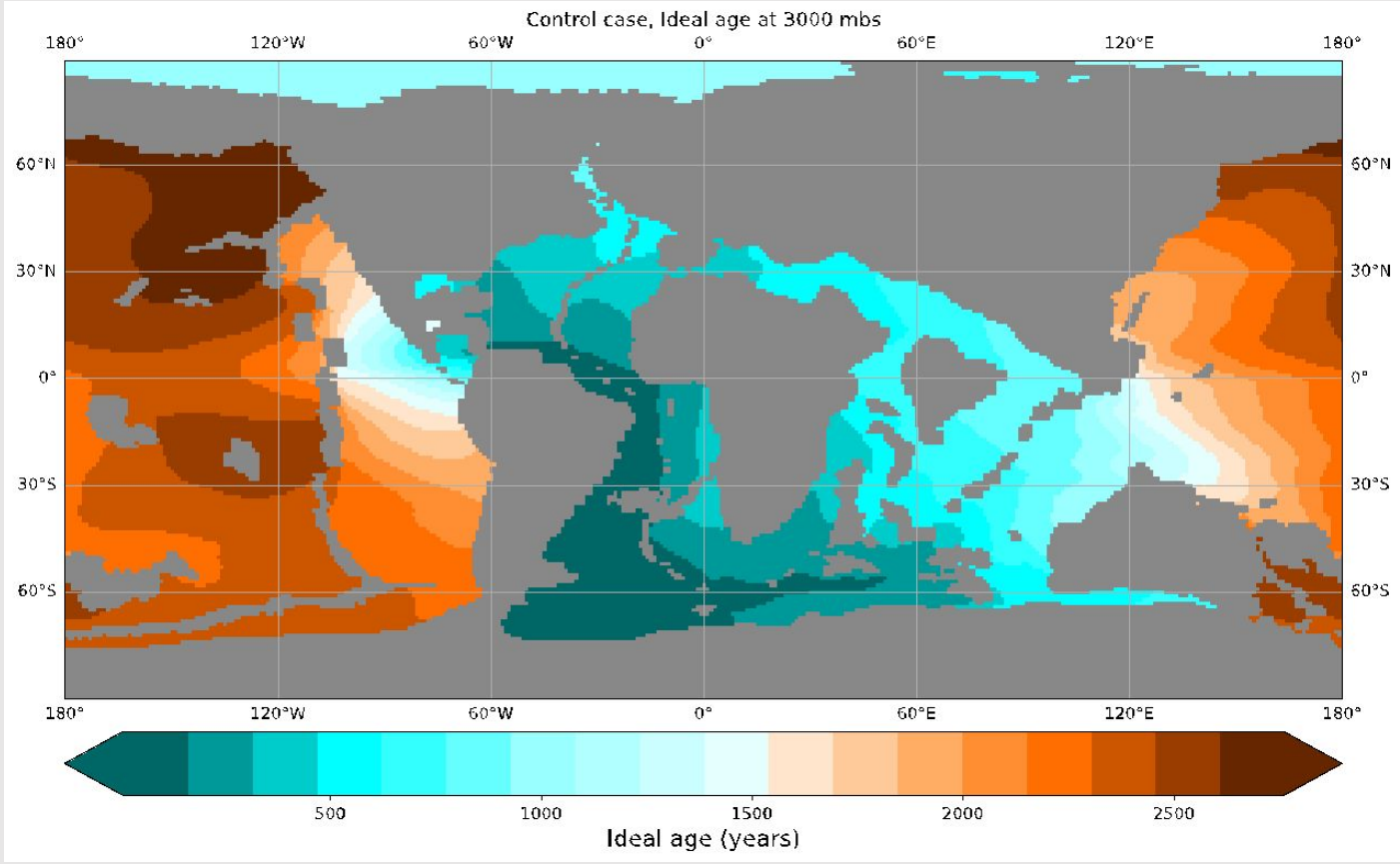
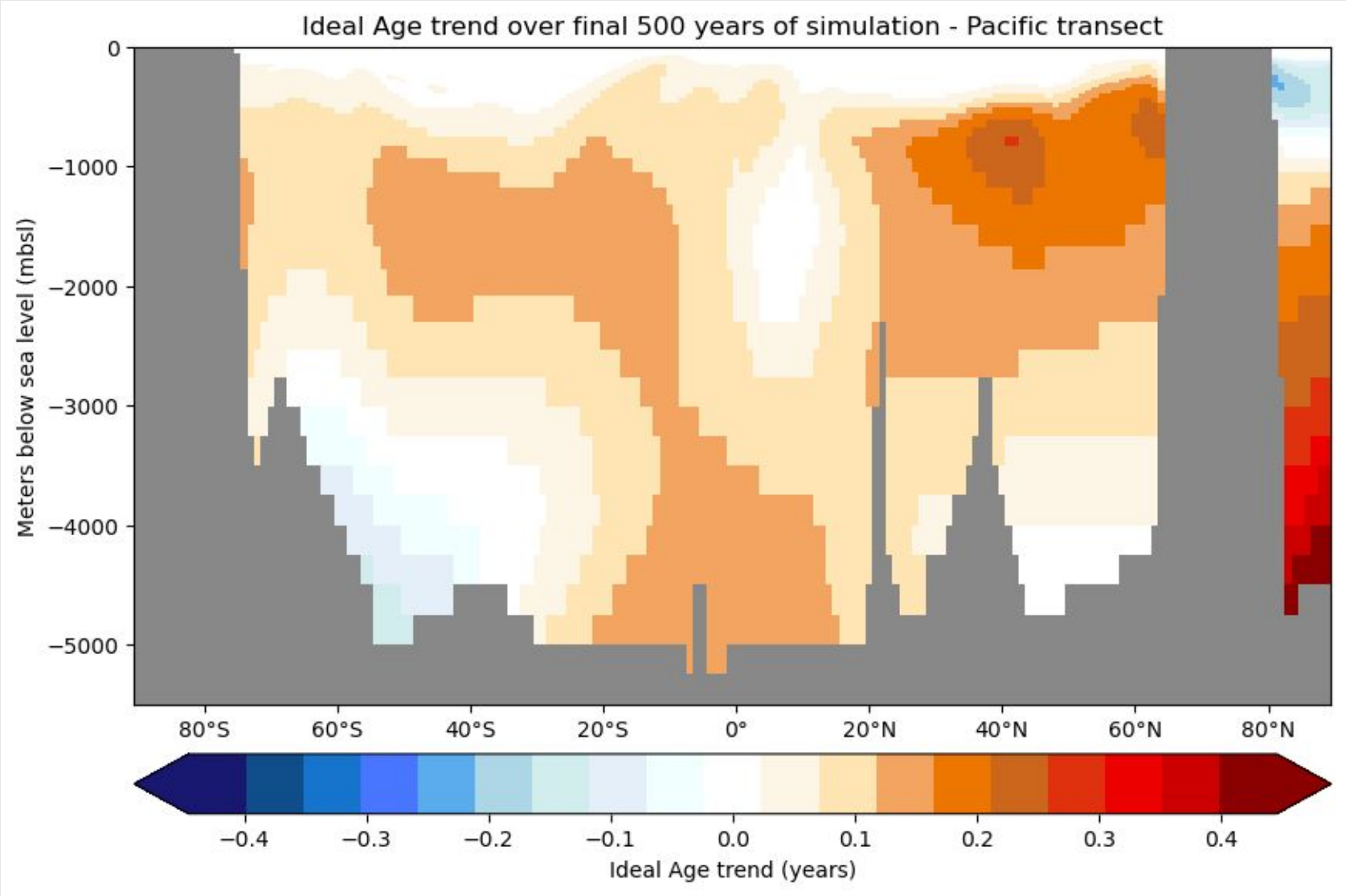
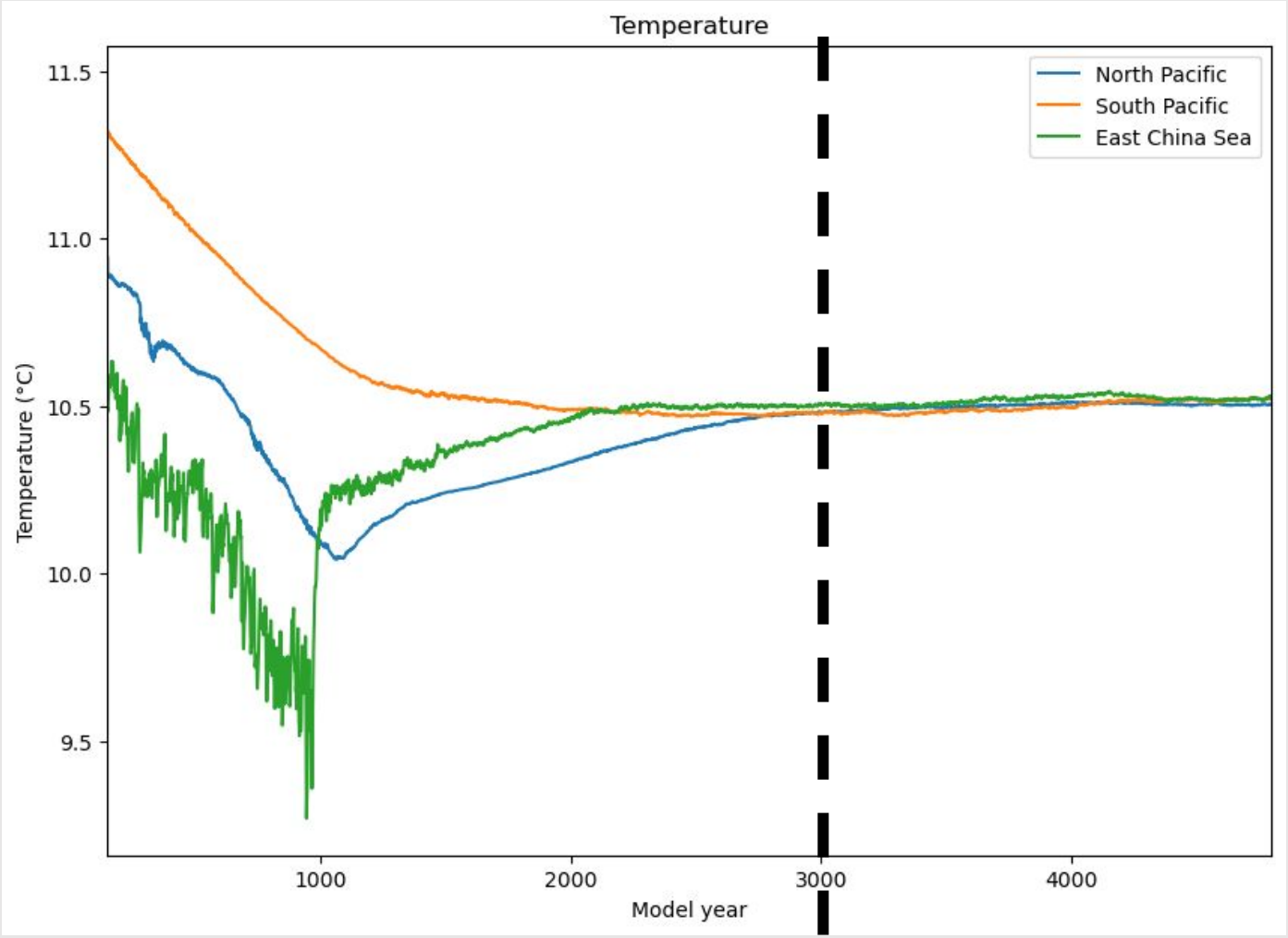



Ideal Age trend over final 500 years of simulation - Pacific transect
Meters below sea level (mbsl)
0
−1000
−2000
−3000
−4000
−5000
80°S
60°S
40°S
20°S
0°
20°N
40°N
60°N
80°N
−0.4
−0.3
−0.2
−0.1
0.0
0.1
0.2
0.3
0.4
Ideal Age trend (years)

Comparing to classic metrics of physical equilibration

- Temperature? Stable after ~3000 years runtime
- Salinity? Stable after ~3250 years runtime

Both significantly undershoot the actual equilibration age



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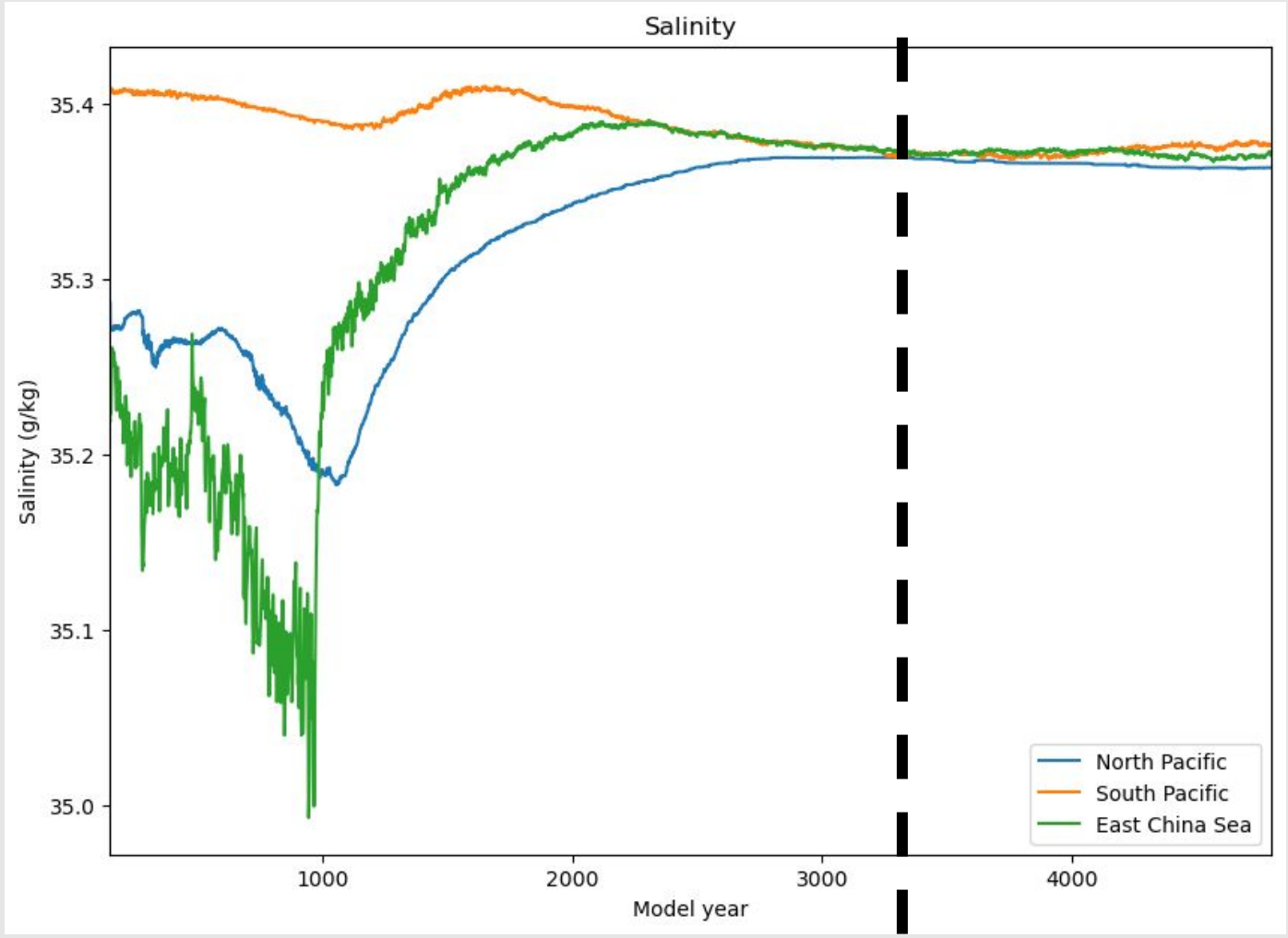
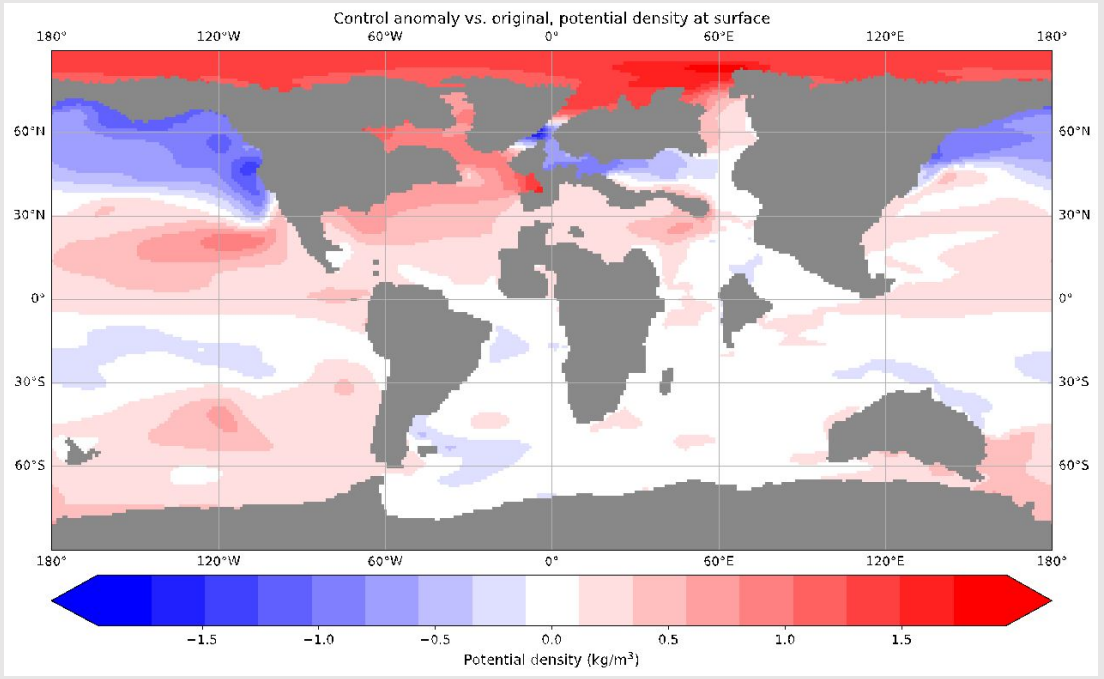
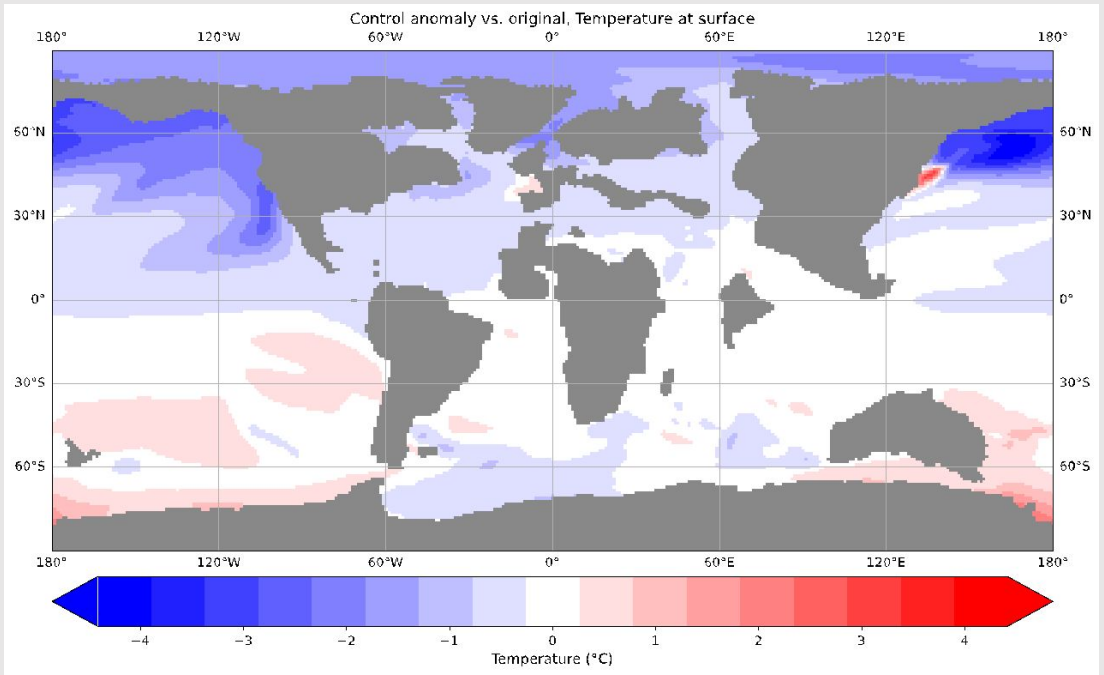


Lack of PMOC?

- Output from Zhu et al. (2020) simulation had PMOC, but it stagnated over the course of the continuation case
- Suggesting that modeled PMOC presence is physically unstable
- Analysis of water mass transformation needed to more closely examine density flux





Deep Ocean Circulation vs. Global Climate

- Compared to Zhu et al. (2020): Shut down PMOC, change in regional SSTs
  - North Pacific becomes colder, consistent with reduced heat transport capacity
- However — Global mean climate is relatively unchanged!
  - GMST decreases by 0.457° C

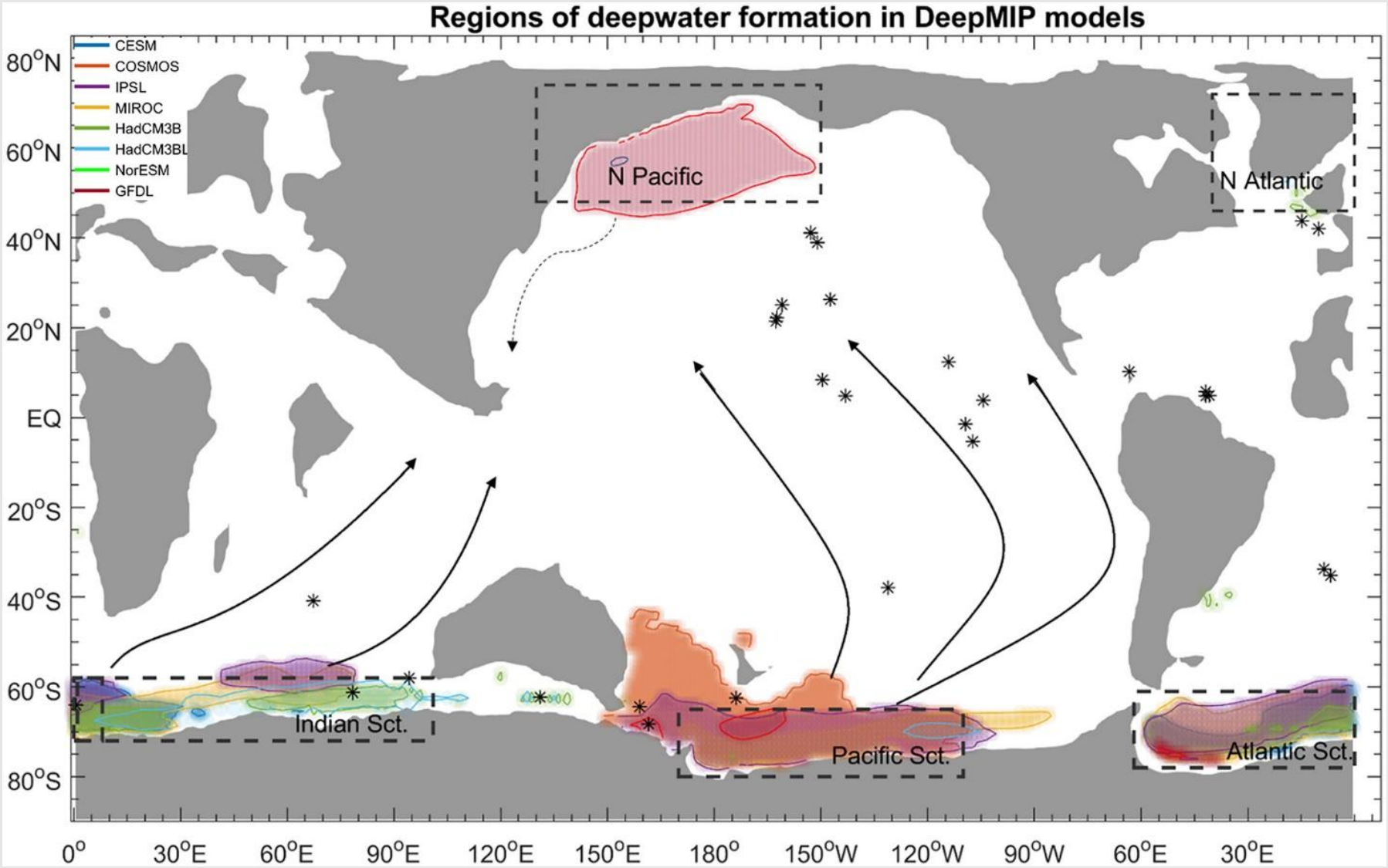
AMWG diagnostic variable	Original Run	Continuation	Difference
TS	298.935	298.478	-0.457 °C
TS_LAND	294.174	293.495	-0.679 °C
PRECT	3.857	3.830	-0.027 m/s
PRECT_LAND	3.154	3.153	-0.001 m/s
PRECT_OCEAN	4.114	4.080	-0.034 m/s

Comparison with circulation in other DeepMIP models

- Zhang et al. (2022) compared ocean circulation patterns among several DeepMIP-compliant GCM simulations, including CESM1.2
  - Simulation runtime varied between 2,000 years and 7,500 years
- Many displayed PMOC in both north and south sectors, which are both absent from my continuation case

Model	Simulations (Atm. pCO_2)	Duration (kyr)
CESM1.2	PI, 1x, 3x, 6x, 9x	2
COSMOS	PI, 1x, 3x, 4x	7
IPSL-CM5A2	PI, 1.5x, 3x	4
MIROC4m	PI,1x,2x,3x	5
HadCM3B	PI, 1x, 2x, 3x	7.4
HadCM3BL	PI, 1x, 2x, 3x	7.5
NorESM1-F	PI, 2x, 4x	2.1
GFDL-CM2.1	PI, 1x, 2x, 3x, 4x, 6x	6

Adapted from: Zhang et al. (2022)



From: Zhang et al. (2022)

Conclusions

- Simply continuing the Zhu et al. (2020) simulation unaltered caused the case's PMOC to shut down
- Despite a massive overhaul of deep ocean circulation, global climate did not experience much significant change
- More care should be taken when using DeepMIP simulations for ocean circulation studies — we can better understand past ocean dynamics if we know that our simulations are fully equilibrated!

Thank you for listening!