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Paleoclimate Modeling with CESM

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Scientist

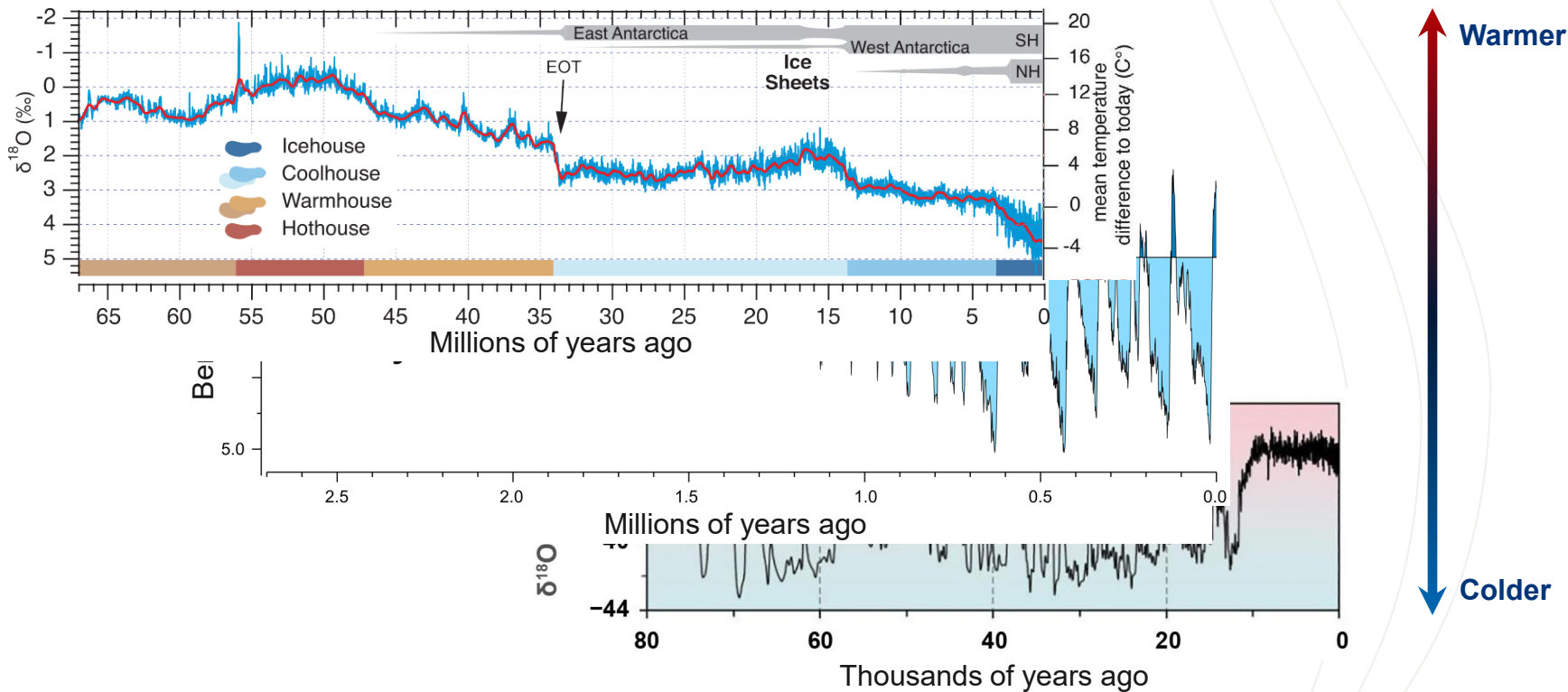
Co-chair of CESM Paleoclimate Working Group

NSF NCAR



- **Why paleoclimate?**
- **How to perform paleo simulations with CESM?**
- **Paleo contribution to CESM development: water isotopes**
- **Resources from the Paleoclimate Working Group**

Earth's past spans climates far beyond the instrumental record



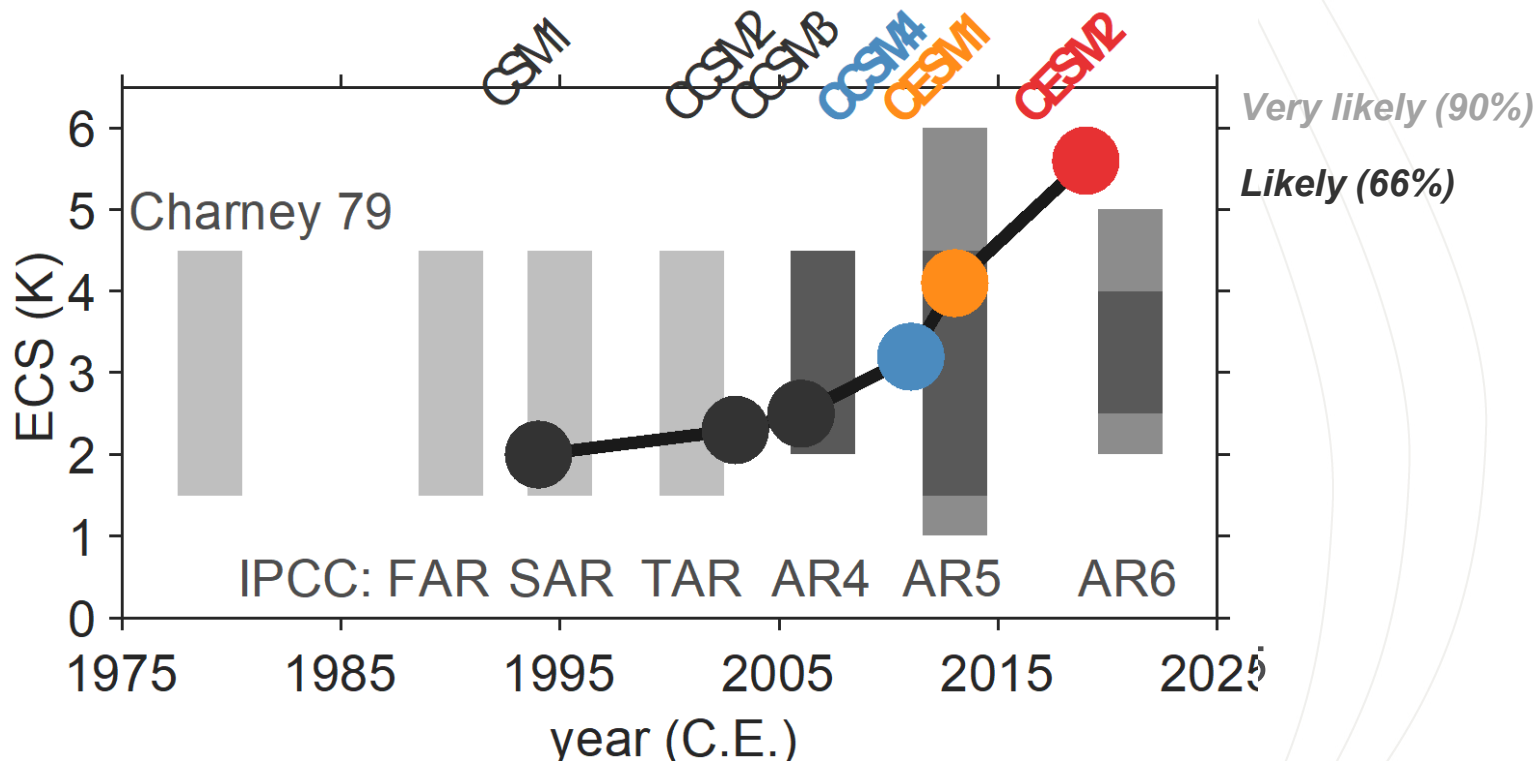
Paleo holds unresolved mysteries — and a test bed for CESM



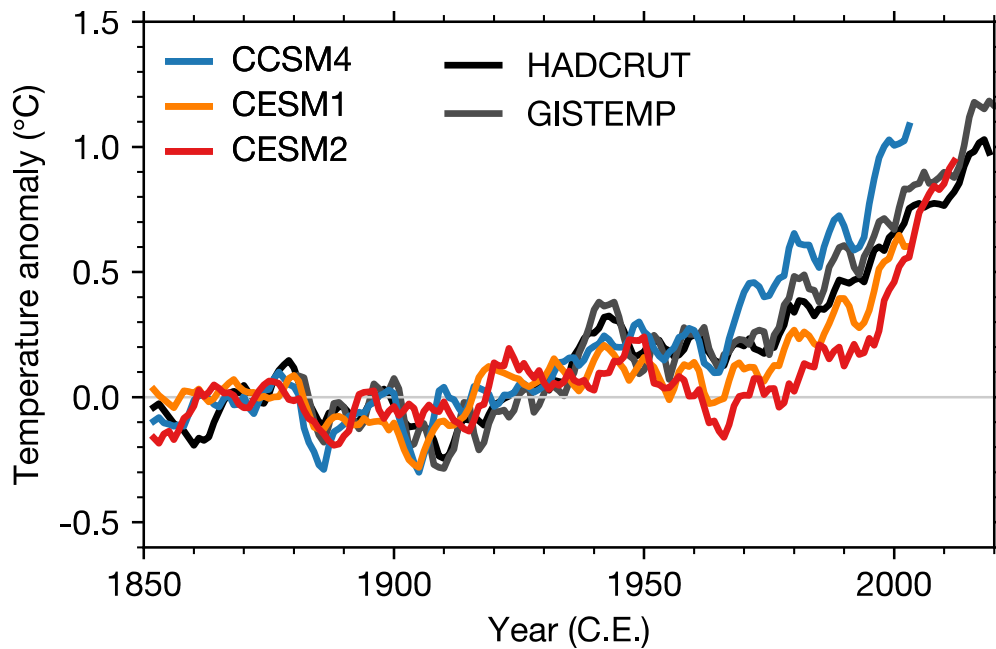
- Unresolved mysteries
 - Abrupt climate change & tipping behavior
 - Glacial cycles and ice sheet-carbon cycle feedbacks
 - Greenhouse climates: the Equable Climate Problem
 - Greenhouse-icehouse transitions
 - Past hydrologic cycle change and monsoon dynamics

- *Paleo provides powerful test bed for CESM evaluation/development*
 - 3 examples

Example 1: How to constrain climate sensitivity?



The instrumental record cannot discriminate: all models match it



Nature has ran the experiment for us: the Last Glacial Maximum



A Comparison of Climate Model Sensitivity with Data from the Last Glacial Maximum

S. MANABE AND A. J. BROCCOLI

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, NJ 08542

(Manuscript received 1 April 1985, in final form 28 June 1985)

Last Glacial Maximum

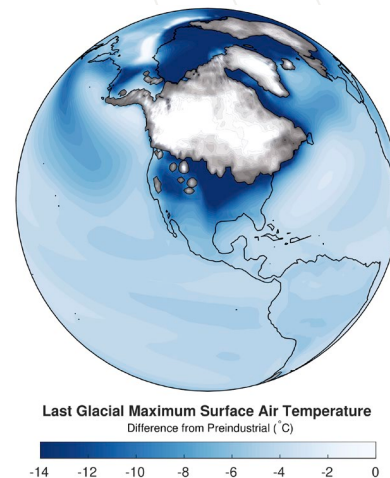
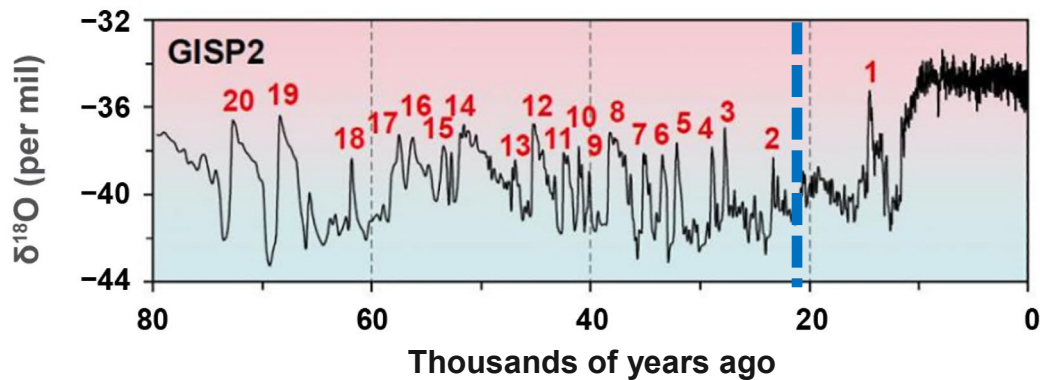
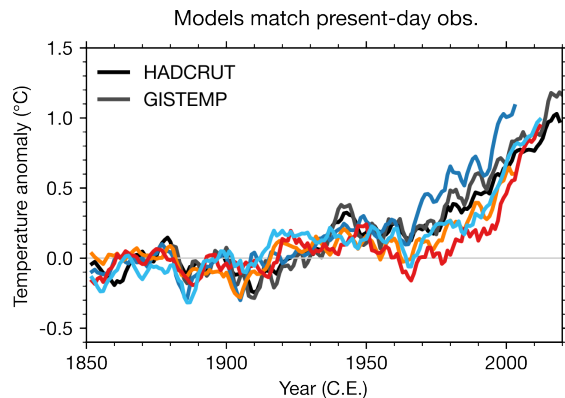
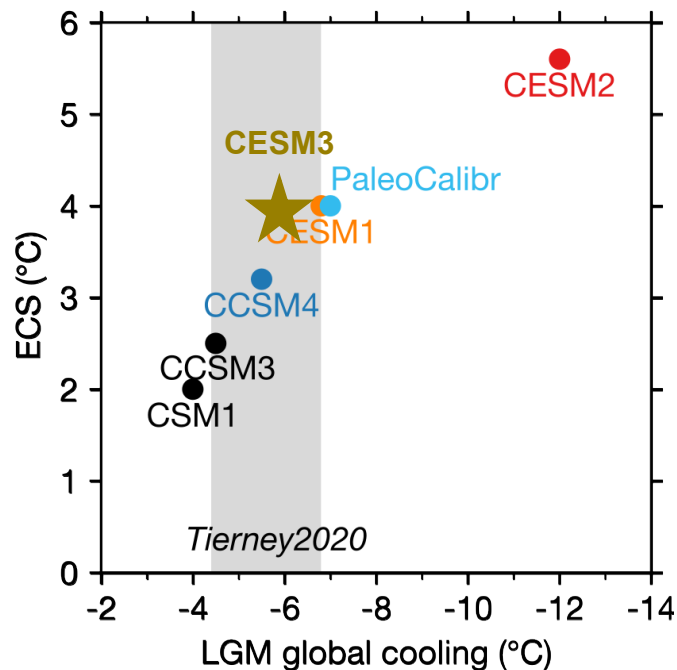


Figure credit: J. Tierney

Only some models match the last ice age



Models simulate different LGM

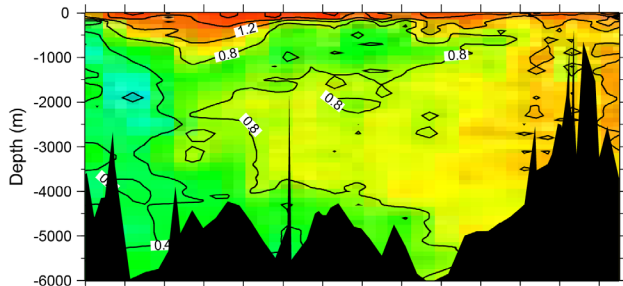


Shin et al., 2003
Otto-Bliesner et al., 2006
Brady et al., 2013, JC
Zhu et al., 2017, GRL
Zhu et al., 2021, GRL
Zhu et al., 2022, JAMES

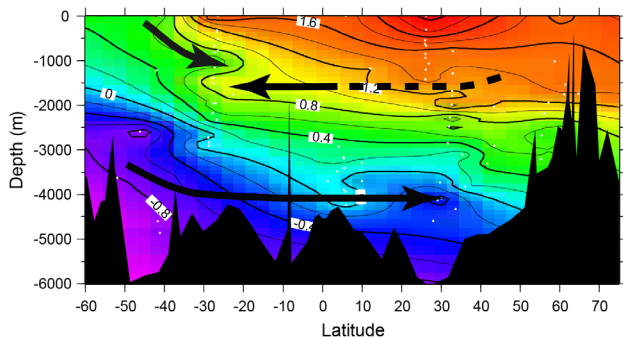
Example 2: Paleoclimate constrains ocean circulation



Western Atlantic GEOSECS $\delta^{13}\text{C}$ (PDB)



Western Atlantic Glacial $\delta^{13}\text{C}$ (PDB)



LGM proxies: a shallower, likely weaker AMOC

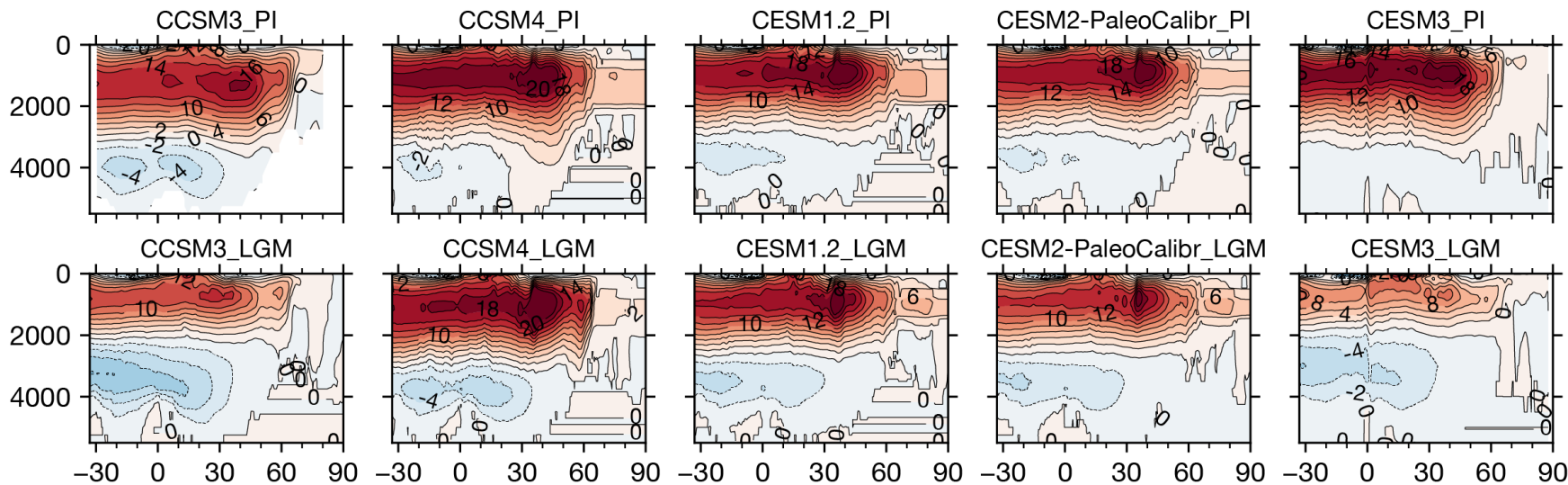
Curry & Oppo, 2005, Paleoceanography

Oppo et al., 2018, Paleoceanogr Paleoclimatol.

Muglia & Schmittner, 2021, Paleoceanogr Paleoclimatol.

Poppelmeier et al., 2023, Nat. Geosci.

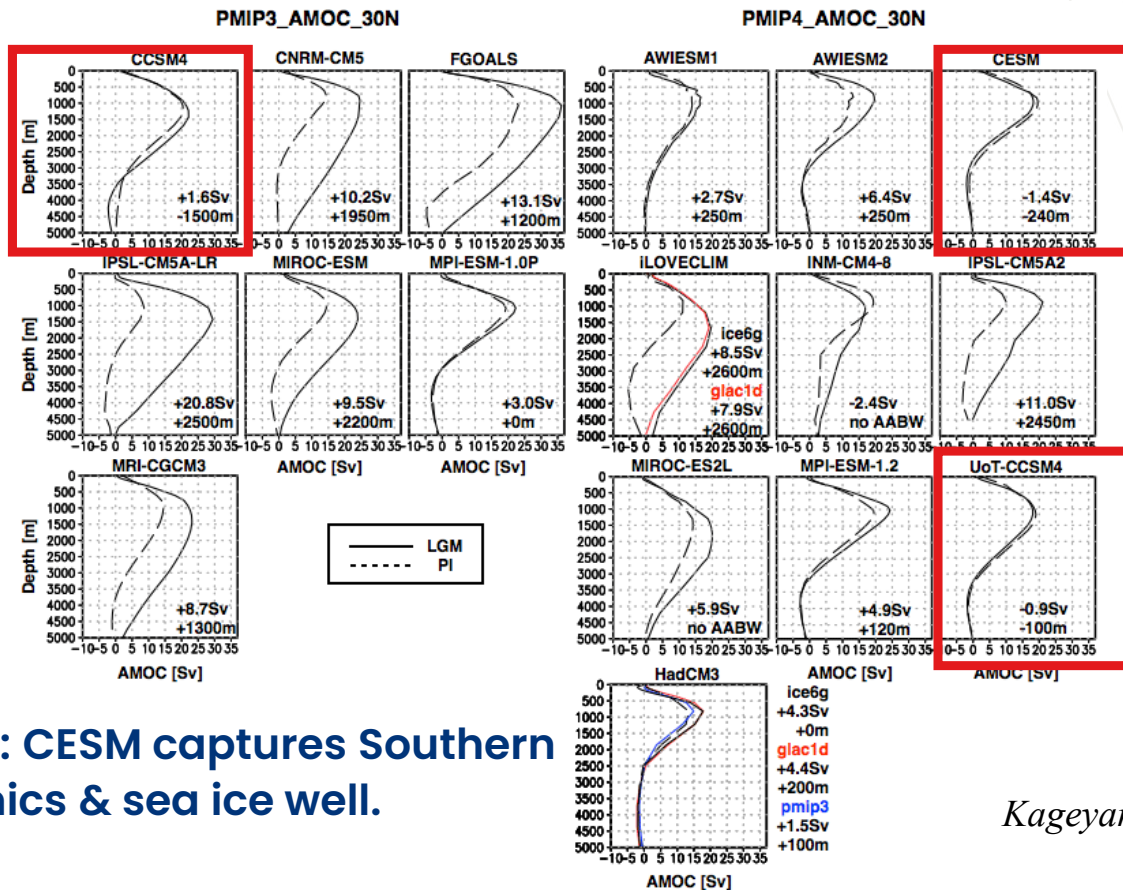
CESM gets the shallower glacial AMOC



Otto-Bliesner et al., 2006, JC
Brady et al., 2013, JC

Zhu et al., 2020, CP
Zhu et al., 2022, JAMES

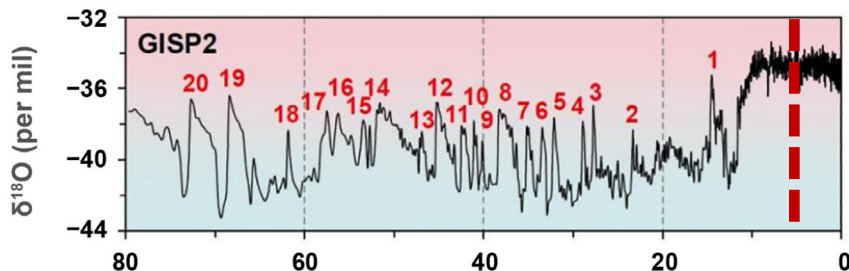
Only CESM-family models get the LGM AMOC shoaling



Interpretation: CESM captures Southern Ocean dynamics & sea ice well.

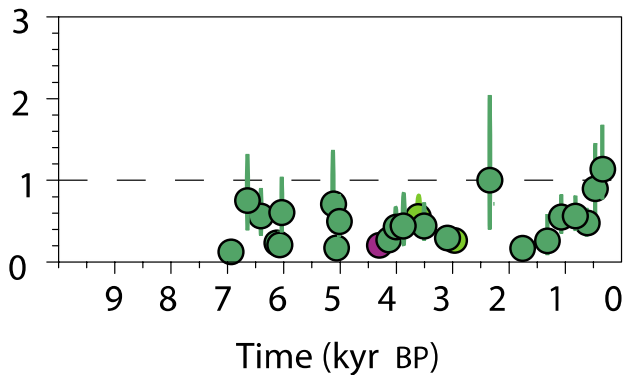
Kageyama et al., 2021, CP

Example 3: Paleoclimate constrains ENSO

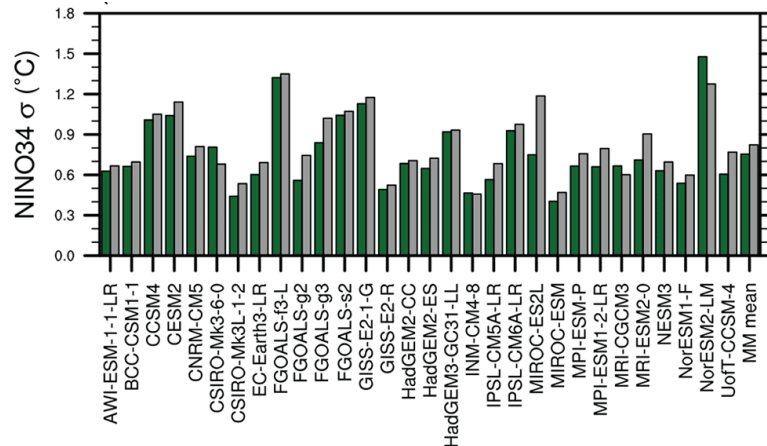


Mid-Holocene (6ka)

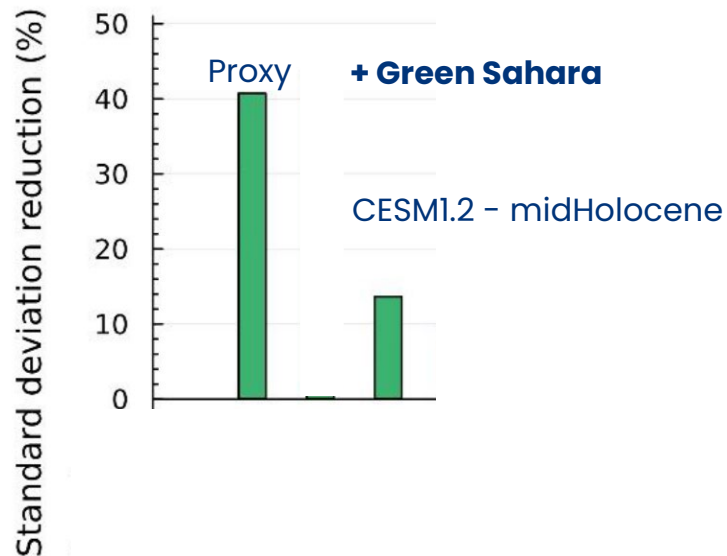
Proxy: 40% weaker ENSO



Models: ~10% weaker ENSO



A missing forcing: the Green Sahara



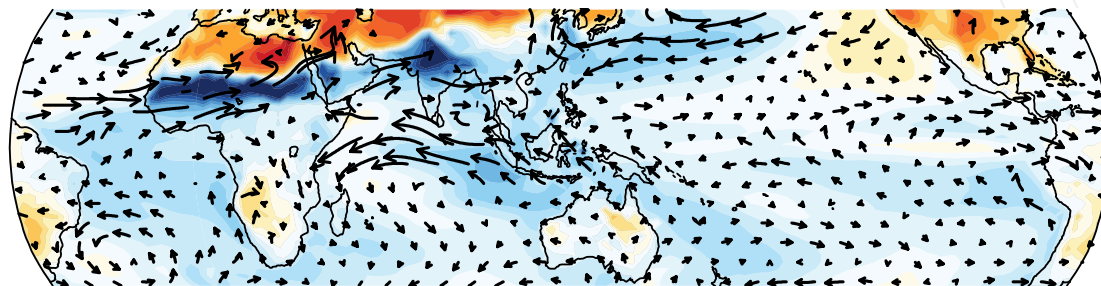
Sato et al., GRL, submitted

Green Sahara strengthens Walker circulation and damps ENSO

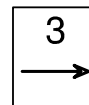
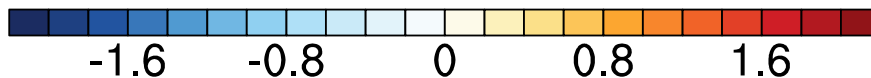
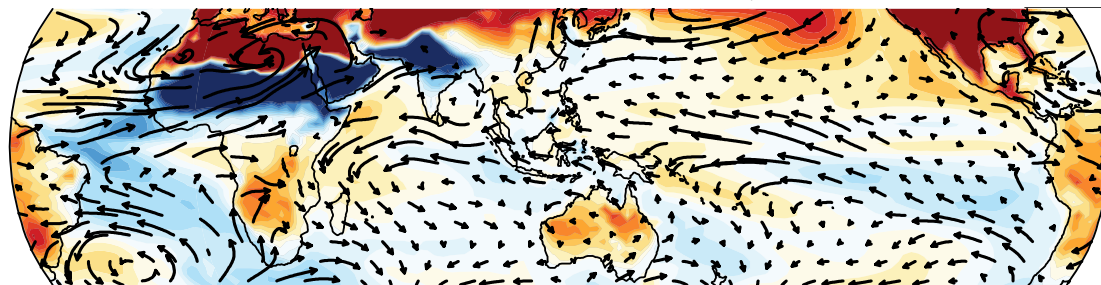


850 winds & surface ΔT

MidHolocene
– piControl



MidHolocene
GreenSahara
– piControl



- Climate sensitivity: paleo helps evaluate models & improve parameterizations (*e.g., Zhu et al., JAMES, 2022*)
- Ocean circulation: Southern Ocean dynamics & sea ice are critical
- ENSO variability: remote land forcing can be as important as local dynamics, with implications for African greening & Amazon deforestation
- *(Many other lessons are not listed here)*
- *CESM family models are the best-performing CMIP models in paleoclimate, building confidence in their future projections.*

How to run paleoclimate simulations with CESM

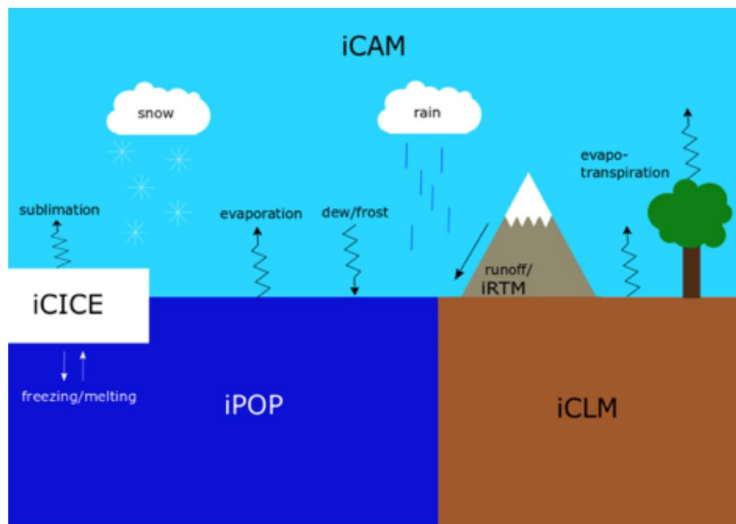


- For CESM3 midHolocene, go to the Lab Exercise on Friday
- For CESM3 LGM, change many boundary/initial condition files
 - *CAM7: topography & greenhouse gas*
 - *MOM6: bathymetry, tidal mixing, vertical coordinate, & background harmonic viscosity*
 - *CICE6: grid & land-sea mask*
 - *CLM6: land surface data*
 - *CISM3: grid & data files*
 - *WW3: new mesh file*
 - *Coupler: land-sea mesh & river to ocean mapping files*
- Recipes for CESM3 LGM: <https://github.com/jiang-zhu/paleowg-recipes>
 - Talk: <https://www.cesm.ucar.edu/sites/default/files/2026-02/2026-cesm-paleo-jzhu.pdf>
- For older versions, use paleoToolkit but it is no longer supported: <https://github.com/CESM-Development/paleoToolkit>

Paleo-contributed development: iCESM1

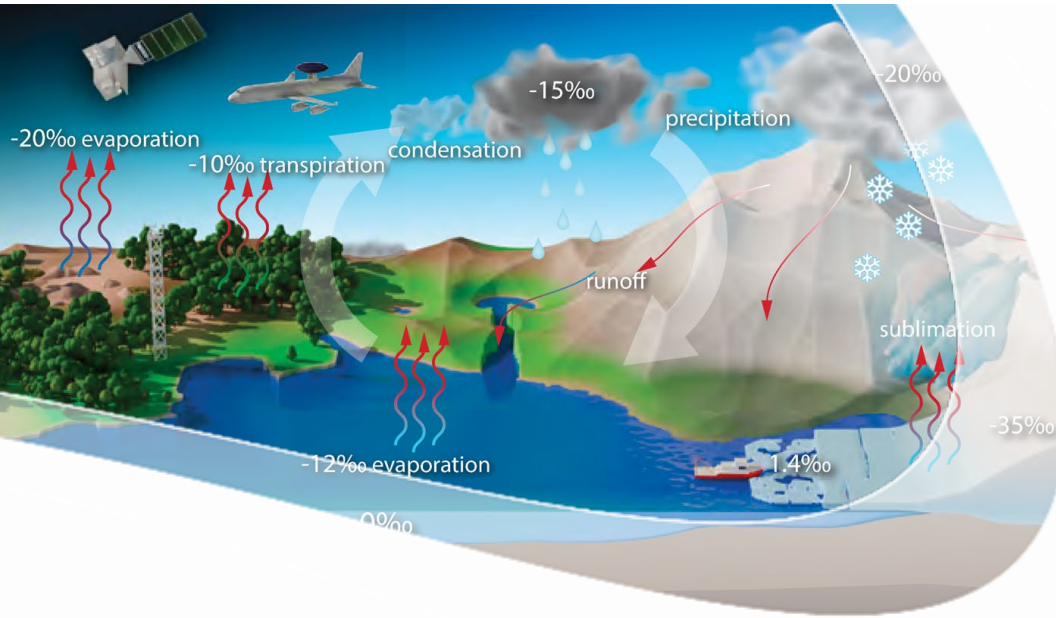


$$\underbrace{\text{H}_2^{18}\text{O water cycle}}_{\text{iCESM}} = \underbrace{\text{H}_2^{16}\text{O water cycle}}_{\text{CESM}} + \text{fractionations}$$



- A complete set of physical processes
 - Ocean & atmosphere circulation
 - Clouds & convection
 - Turbulence & mixing
 - Soil & vegetation
 - Snow & ice
 - River
 - Flux exchanges
- Moisture tracking capability (thanks to Jesse Nusbaumer)
- https://github.com/NCAR/iCESM1.3_iHESP_hires
- Lab Exercise on Friday!

iCESM3: next-generation water isotopes and tracking



SCI-SWIM delivers a modernized, next-generation **isotope-enabled CESM** version 3 (iCESM3) to the scientific community

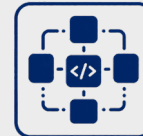
Includes comprehensive **modeling of the isotopic water cycle** (H_2^{18}O , HDO , H_2^{17}O , and more) across the Earth system, along with **powerful water-tracking functionality** in multiple components.



Advancing Community Research on Water Cycle and Extremes



Supporting Decision-Making on Water-related Impacts



Enhancing CESM Code Infrastructure and Extensibility

CESM Paleoclimate Working Group Resources



- Website: <https://www.cesm.ucar.edu/working-groups/paleo>

- Simulation and data access
- Recipes
- Version navigation
- Diagnostic plots



**Bette Otto-
Bliesner**



**Sophia
Macarewich**



Feng Zhu



Esther Brady

- Email list: cesm-paleoclimate@ucar.edu
- DiscussCESM Forum
- Join our winter meeting and summer workshop



**Jung-Eun Lee
(Brown U.)**



Jiang Zhu

Summary



- Paleoclimate provides unique constraints on CESM, as well as opportunities to improve CESM.
- Overall, CESM is among the best-performing models in CMIP for paleo tests, increasing confidence in the model.
- Paleo Working Group also contributes to CESM development through water isotope capability.
- Please stay connected with us
 - <https://www.cesm.ucar.edu/working-groups/paleo>
 - Email list: cesm-paleoclimate@ucar.edu
 - Join our winter meeting and summer workshop

Thank you!
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