

# Water Isotope Modeling with CESM

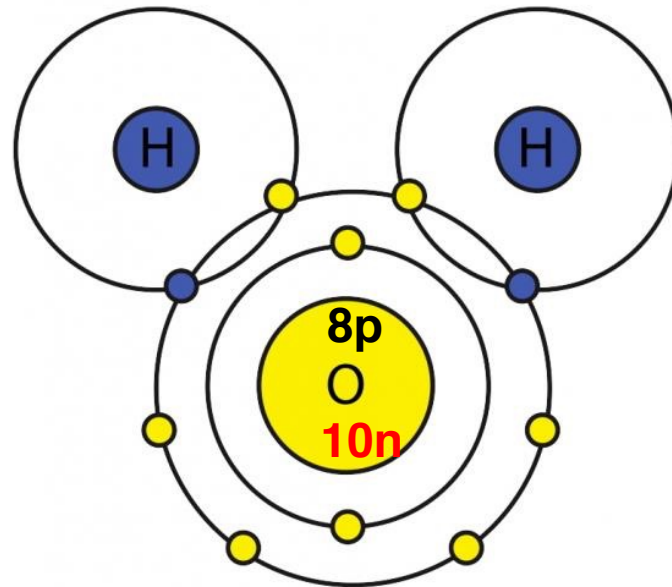
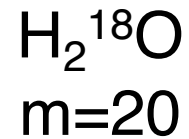
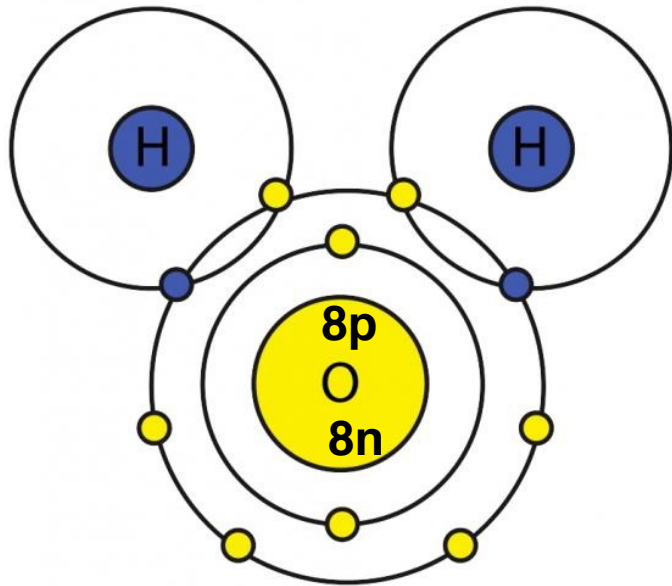
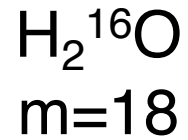
**Jiang Zhu**

***Paleo & Polar Climate, NCAR***

B. Otto-Bliesner, E. Brady, & The iCESM TEAM



# What are water isotopes (isotopologues)?



Heavier water has slightly

- **higher**  $\rho$ ,  $T_{\text{melting}}$ ,  $T_{\text{boiling}}$ ,  $v$ , ...
- **lower chemical reaction rates**

**Fractionations** occur during **physical, chemical, & biological** processes

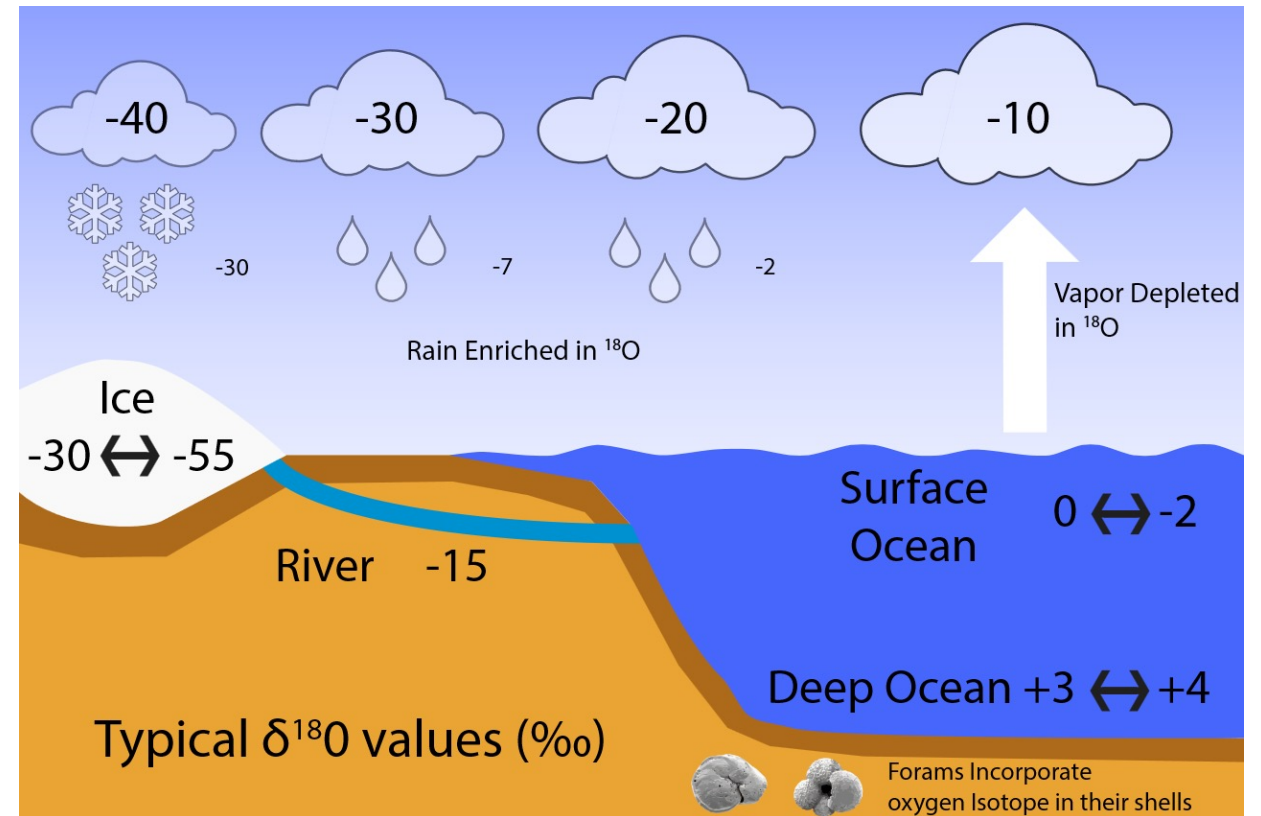
# The delta notation

- Natural abundance  $\frac{\text{H}_2^{18}\text{O}}{\text{H}_2^{16}\text{O}} \approx \frac{1}{500}$
- Challenge to measure absolute value

$$\delta^{18}\text{O} = \left( \frac{\left( \frac{^{18}\text{O}}{^{16}\text{O}} \right)_{\text{sample}}}{\left( \frac{^{18}\text{O}}{^{16}\text{O}} \right)_{\text{standard}}} - 1 \right) \times 1000\text{‰}$$

- Standards

- Water: VSMOW (Vienna Standard Mean Ocean Water)
- Carbonate: VPDP (Vienna Pee Dee Belemnite)

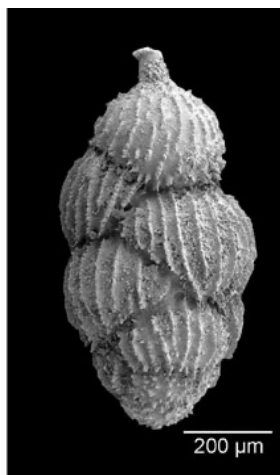
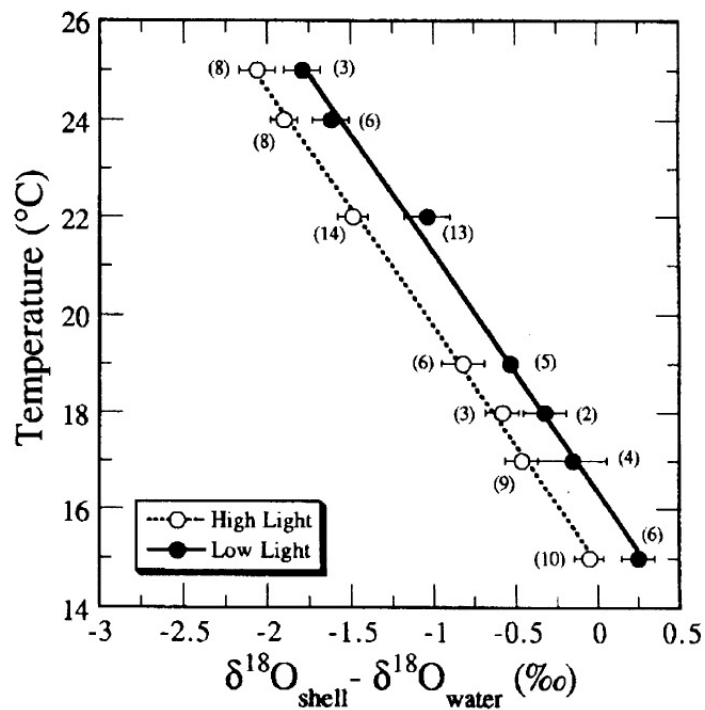
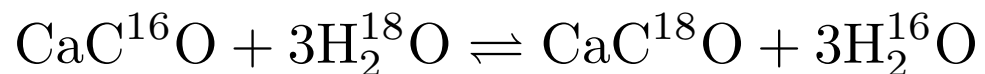


<https://open.oregonstate.edu>

# Why water isotopes? – “Paleo-Thermometer”

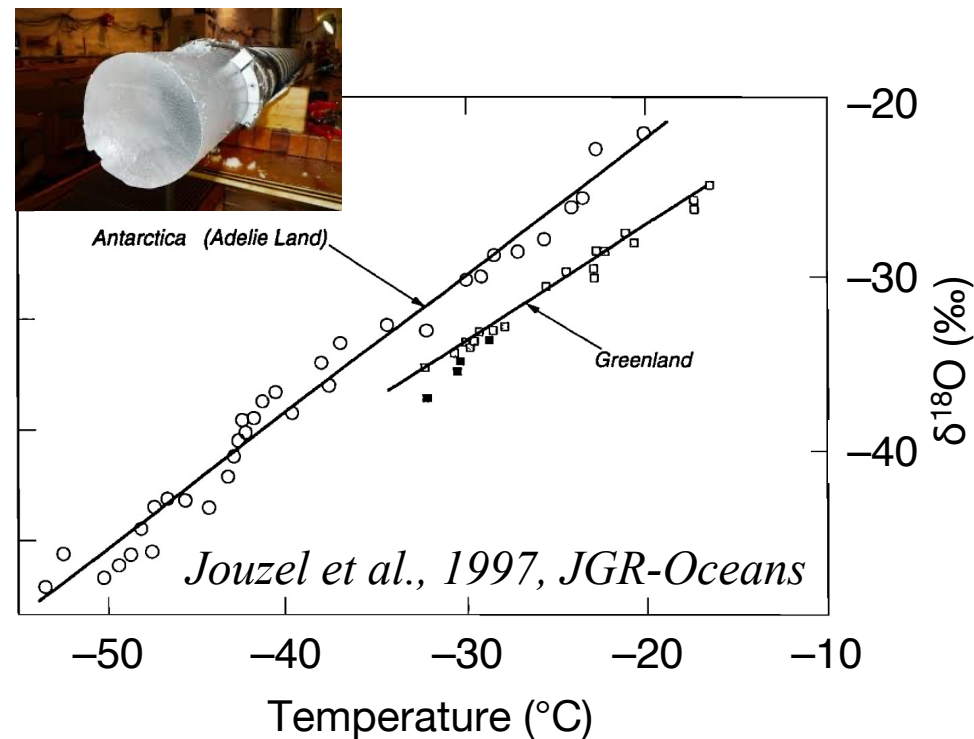
## Carbonate-water thermometer

- $T = -4.8 (\delta^{18}\text{O}_{\text{carbonate}} - \delta^{18}\text{O}_{\text{water}}) + 16.5$
- T-dependent reaction rates

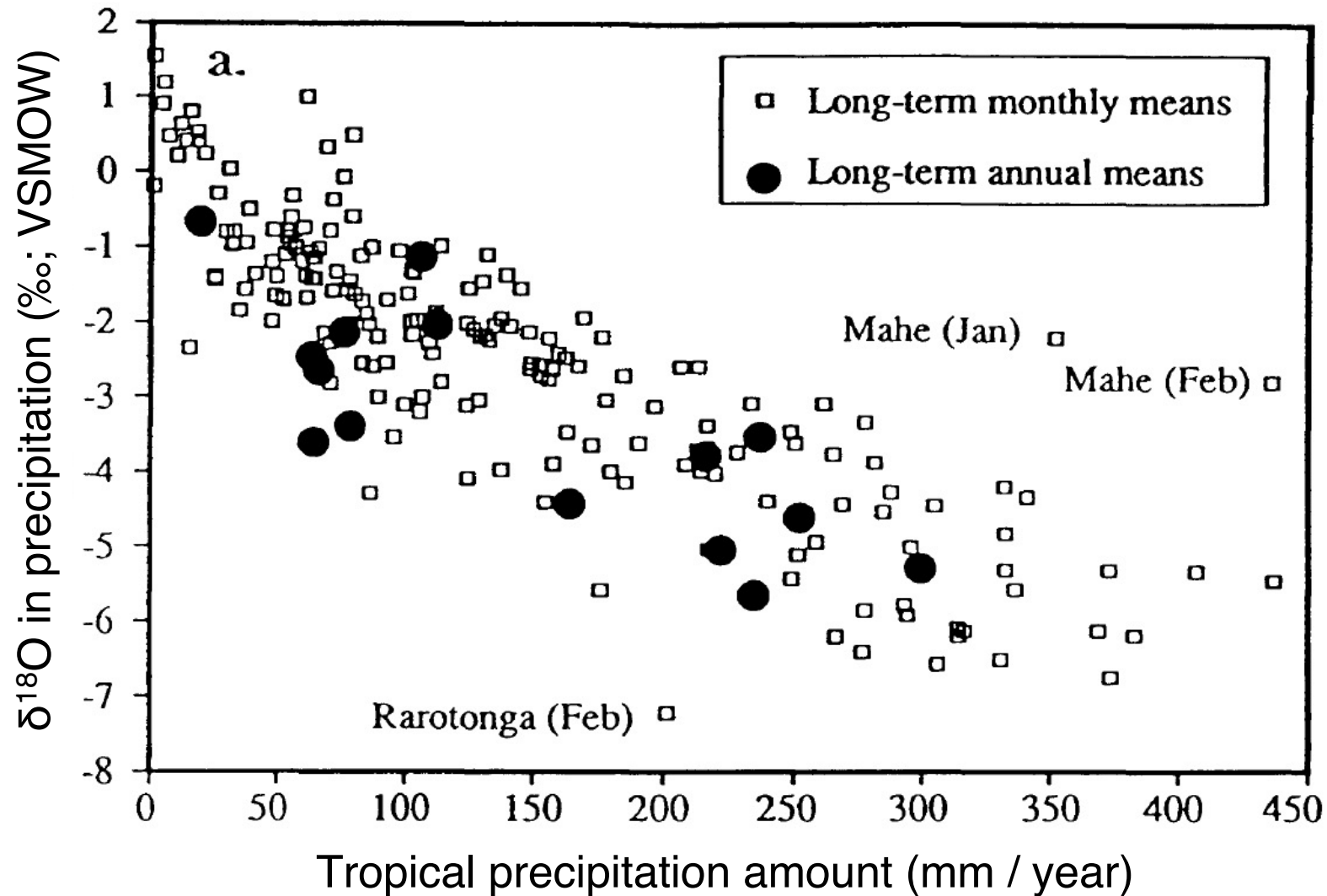


## Ice-core thermometer

- $\delta^{18}\text{O} = \alpha T + \beta$
- Rayleigh fractionation (heavy water condenses more easily)



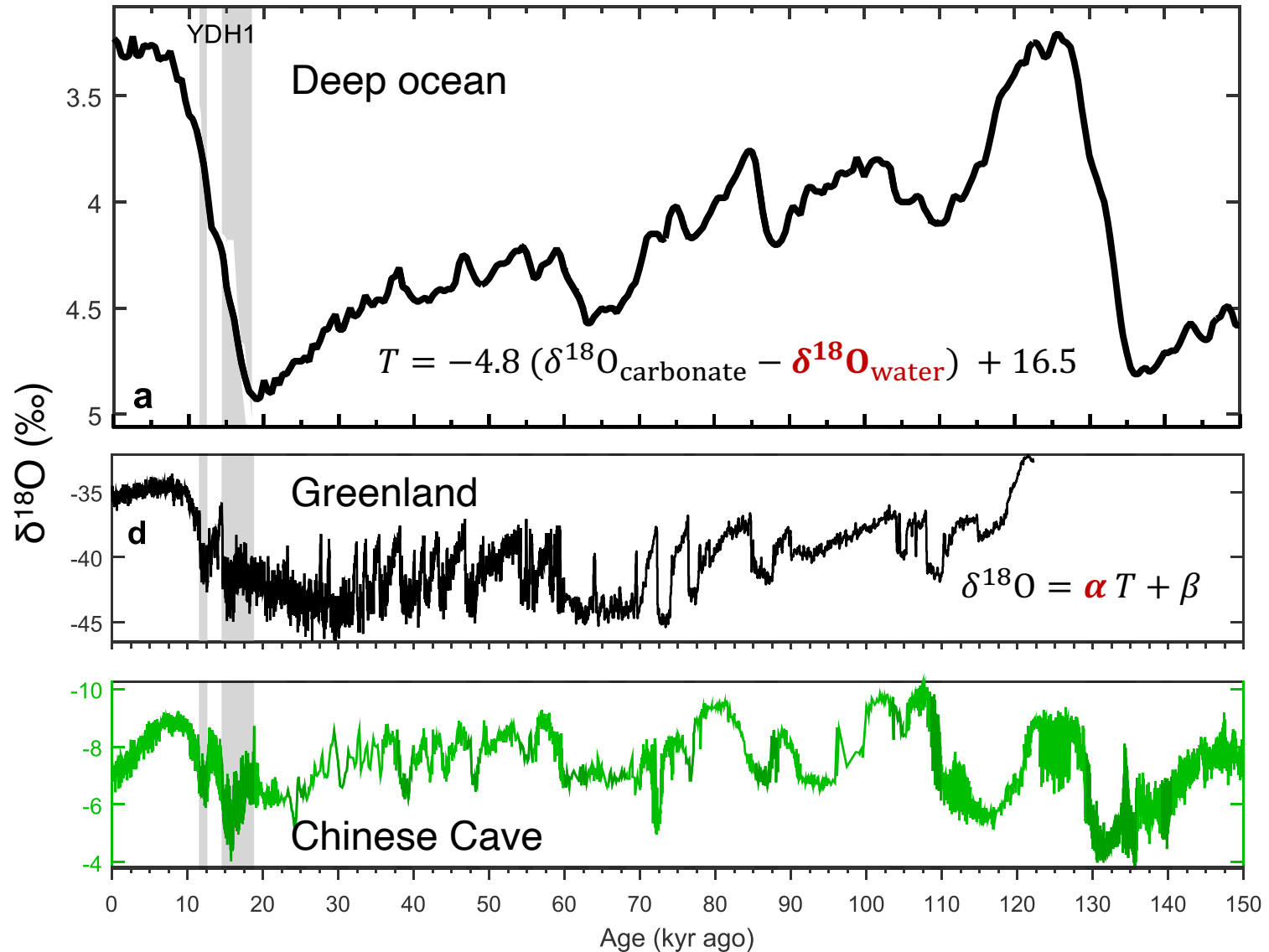
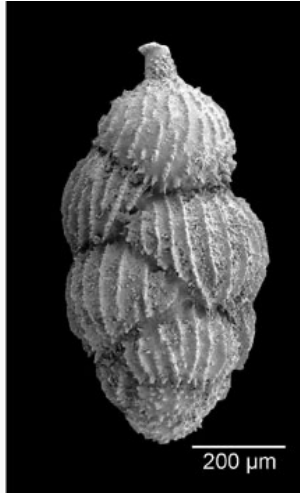
# Why water isotopes? – “Paleo-Rain gauge” (the amount effect)



Rozanski et al., 1993, *Geophysical Monograph Series*



# Why water isotopes? – infer past changes (largely qualitatively)



# An isotope-enabled Community Earth System Model (iCESM)

- Physically consistent simulation of water isotopes in the Earth system
  - Better interpret the isotope records
  - Direct synthesis of model-data information
- <https://github.com/NCAR/iCESM1.2> (Not yet available for CESM2)

**JAMES**

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RESEARCH ARTICLE

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**Key Points:**

- An isotope-enabled version of the Community Earth System Model (iCESM1) is now publicly available

## The Connected Isotopic Water Cycle in the Community Earth System Model Version 1

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B. L. Otto-Bliesner<sup>1</sup> , C. Tabor<sup>6</sup> , R. Tomas<sup>1</sup>, T. Wong<sup>7</sup> , J. Zhang<sup>8</sup> , and J. Zhu<sup>9</sup> 

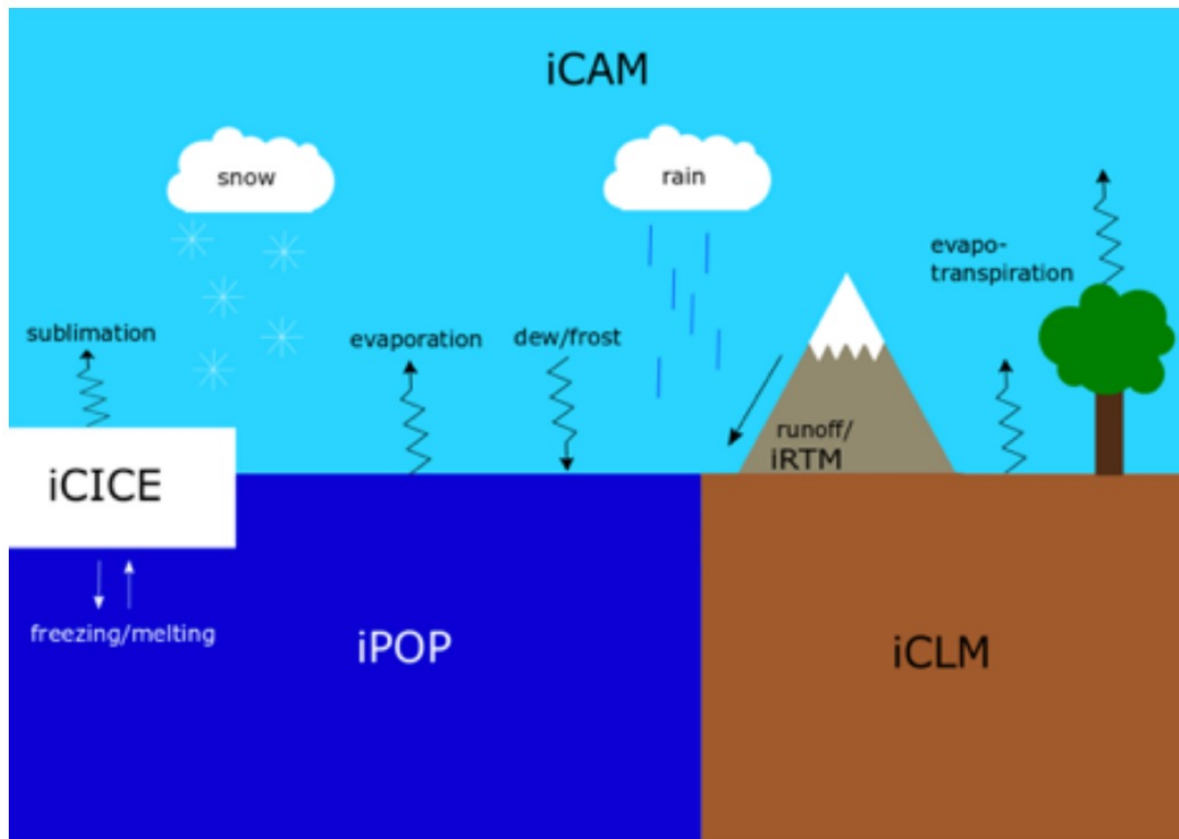


# How does iCESM work?

$H_2^{18}O$  water cycle =  $H_2^{16}O$  water cycle + fractionations

CESM

**iCESM**



A complete suite of physical processes

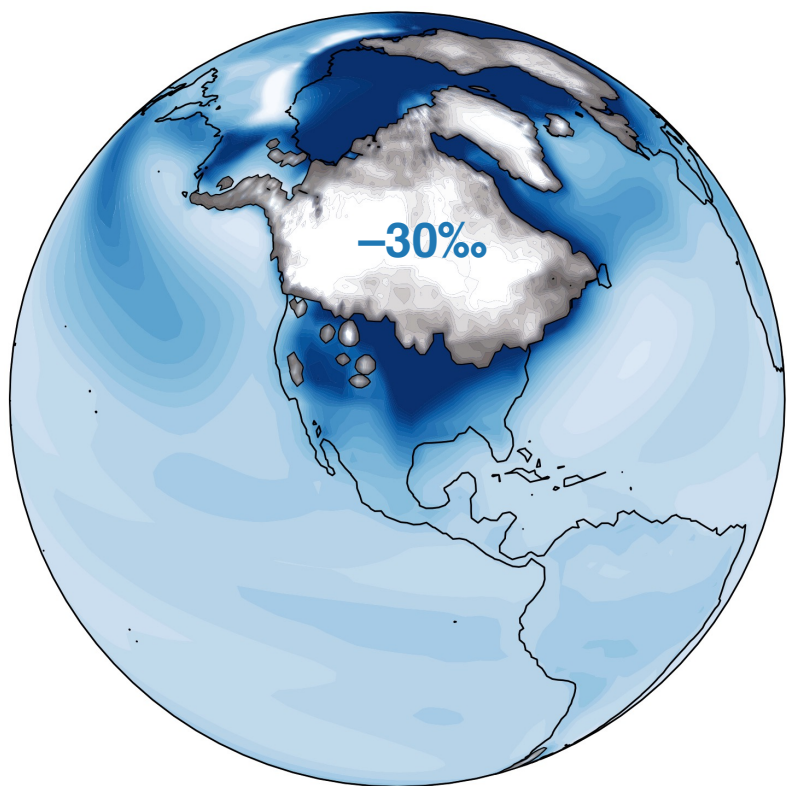
- Ocean & atmosphere circulation
- Clouds & convection
- Turbulence & mixing
- Soil & vegetation
- Snow & ice
- River
- Flux exchanges
- ...

*Brady et al., 2019, JAMES*

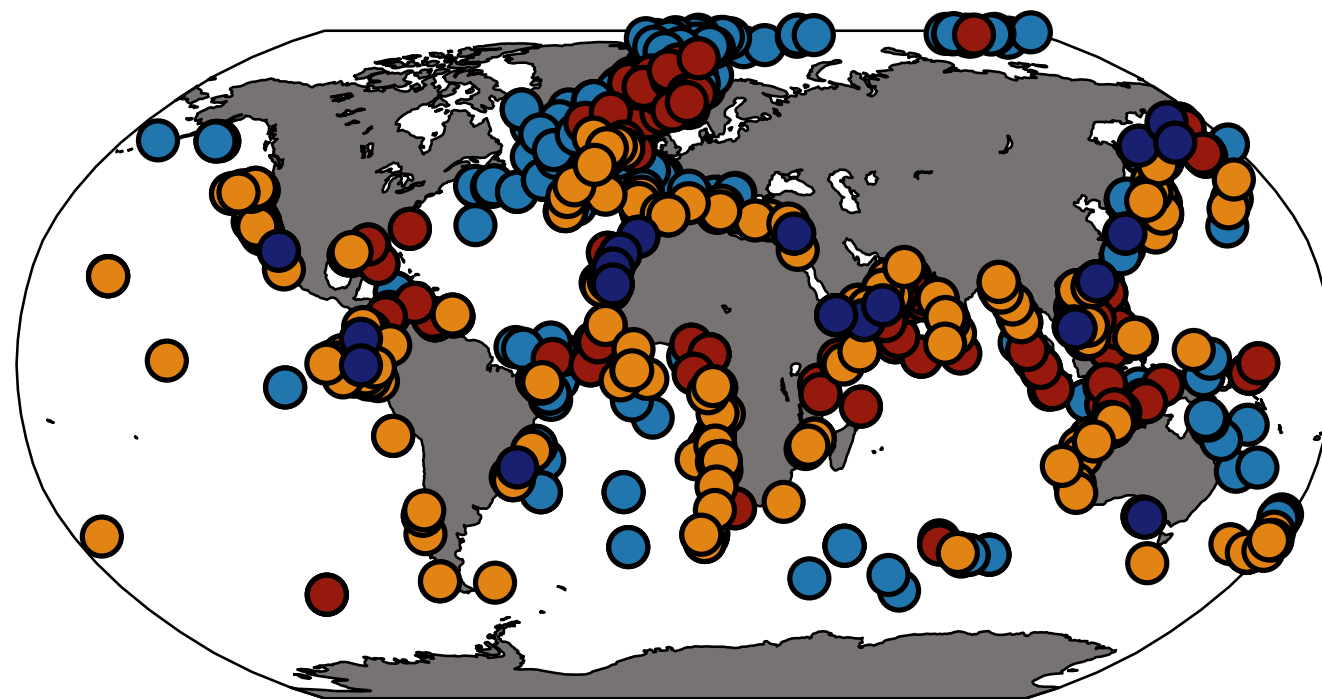


# An application: how cold was the Last Glacial Maximum (LGM)?

LGM (20,000 years ago)



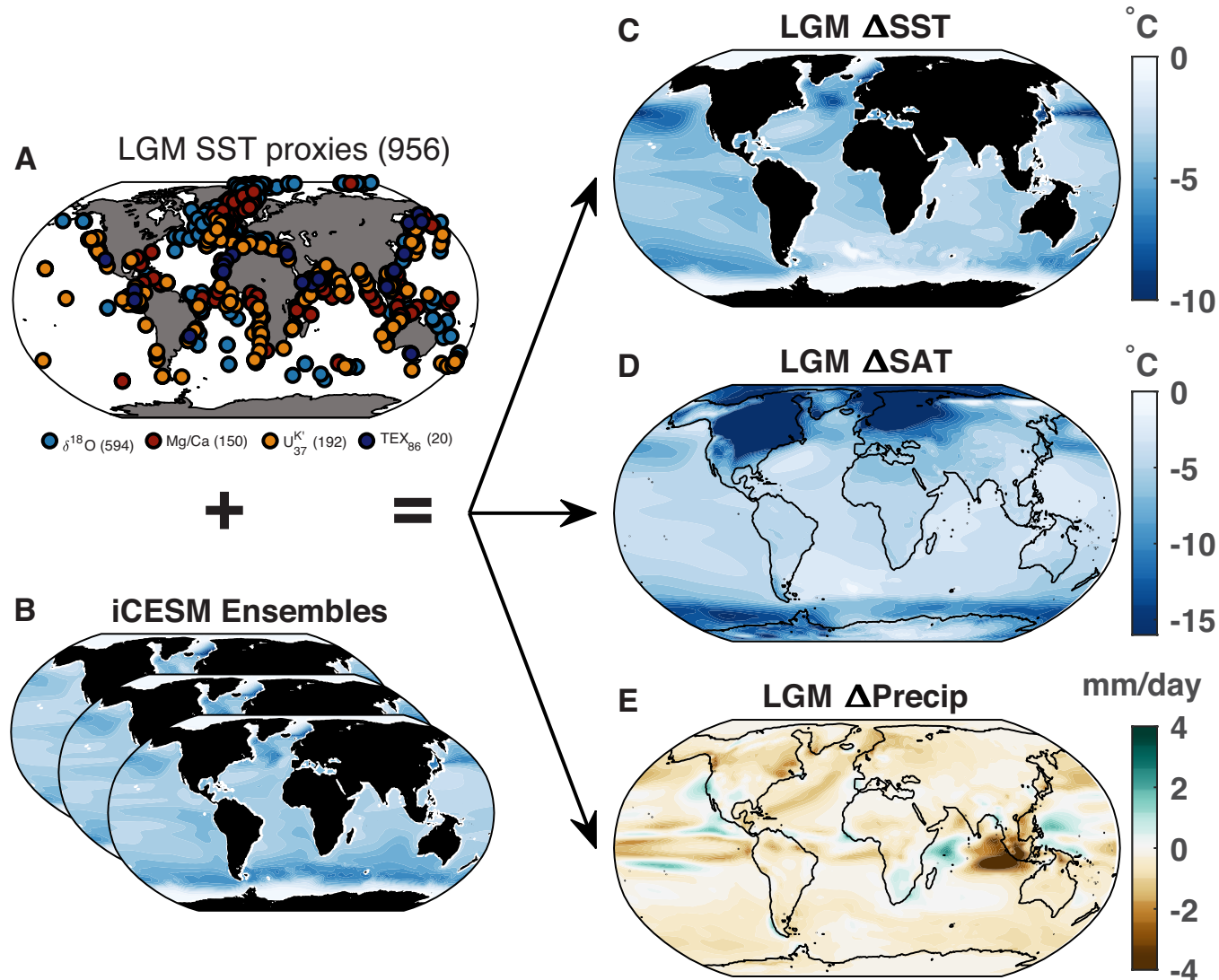
LGM SST proxies (956)



●  $\delta^{18}\text{O}$  (594) 62% ● Mg/Ca (150) ●  $\text{U}_{37}^{\text{K}}$  (192) ●  $\text{TEX}_{86}$  (20)

$$T = -4.8 (\delta^{18}\text{O}_{\text{carbonate}} - \delta^{18}\text{O}_{\text{water}}) + 16.5$$

# iCESM enables direct assimilation of $\delta^{18}\text{O}$ records



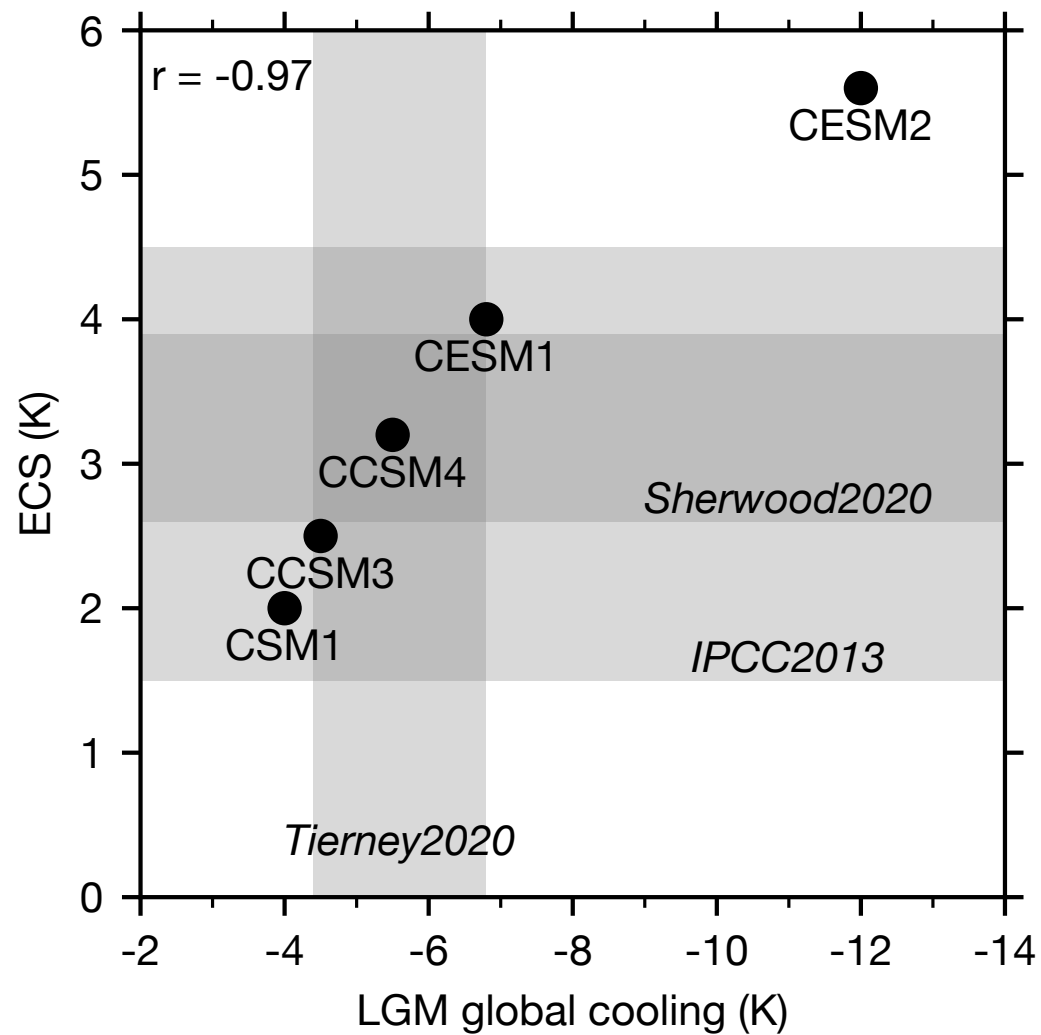
LGM is 5.7–6.5 $^{\circ}\text{C}$  colder  
cf. 3–8 $^{\circ}\text{C}$  in IPCC (2013)

*Tierney et al. 2020a,b, Nature; Science*

$$T = -4.8 (\delta^{18}\text{O}_{\text{carbonate}} - \delta^{18}\text{O}_{\text{water}}) + 16.5$$

# LGM informs equilibrium climate sensitivity (ECS)

- ECS = global warming due to  $2\times\text{CO}_2$
- One of the most important metrics in climate science



*Zhu et al., 2021a,b, GRL; JAMES (in preparation)*

- Water isotopes are paleo-thermometer & rain gauge but *imperfect*
- We need a dynamical model, iCESM, to
  - provide a physically consistent simulation of water isotopes in the Earth system
  - better interpret the isotope record
  - directly synthesize information from model & data for a mechanism understanding of past and future climate change
- iCESM can also be used to study present-day climate: *e.g. Bailey, A. (2020). A New Lens for Evaluating Dynamic Controls on Shallow Convection. Journal of Advances in Modeling Earth Systems*

**Thank you!**  
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