Water Isotope Modeling with CESM

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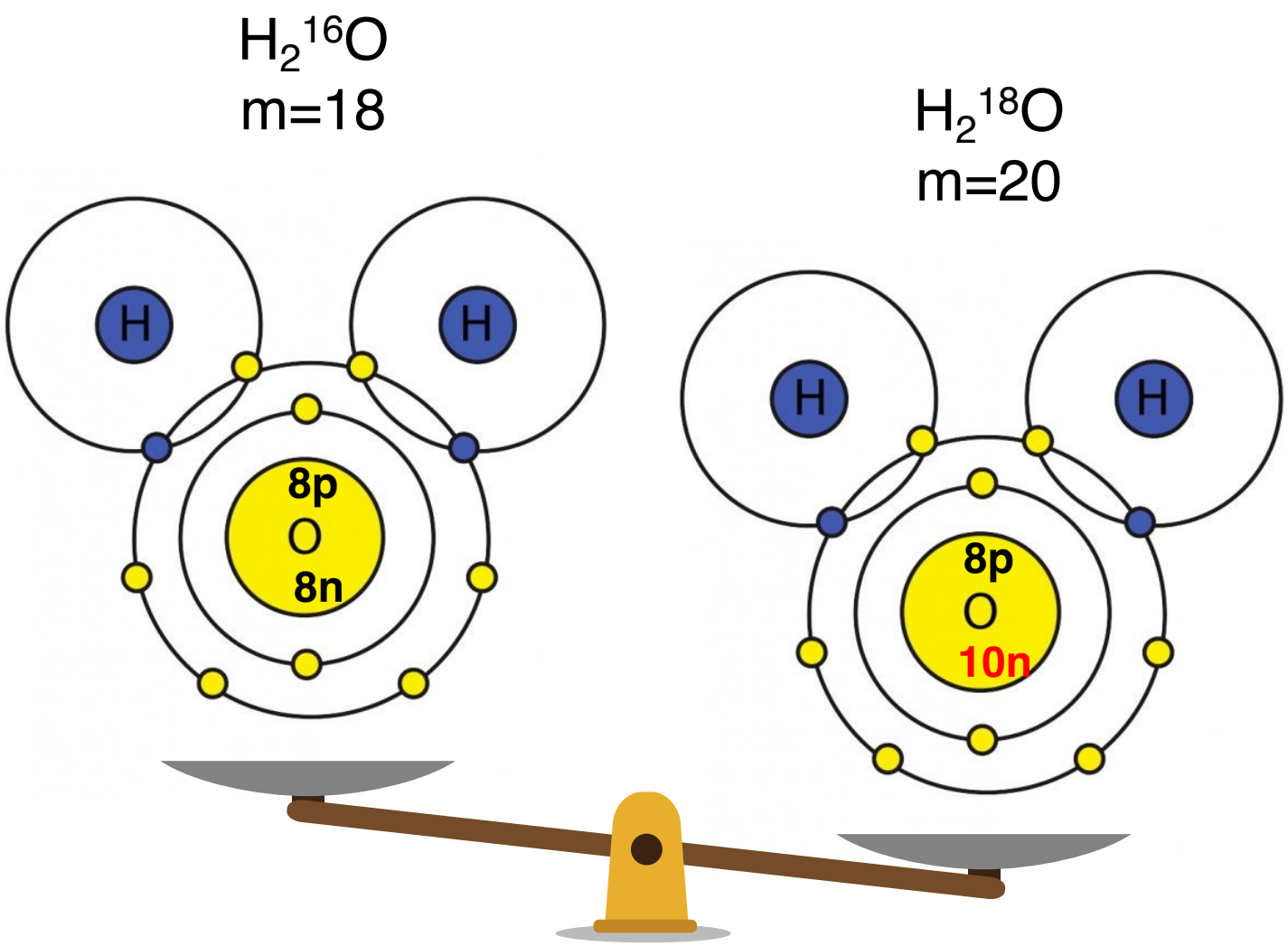
What are water isotopes (isotopologues)?



Heavier water has slightly

- ***higher ρ, $T_{melting}$, $T_{boiling}$, ν, …***
- ***lower chemical reaction rates***

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

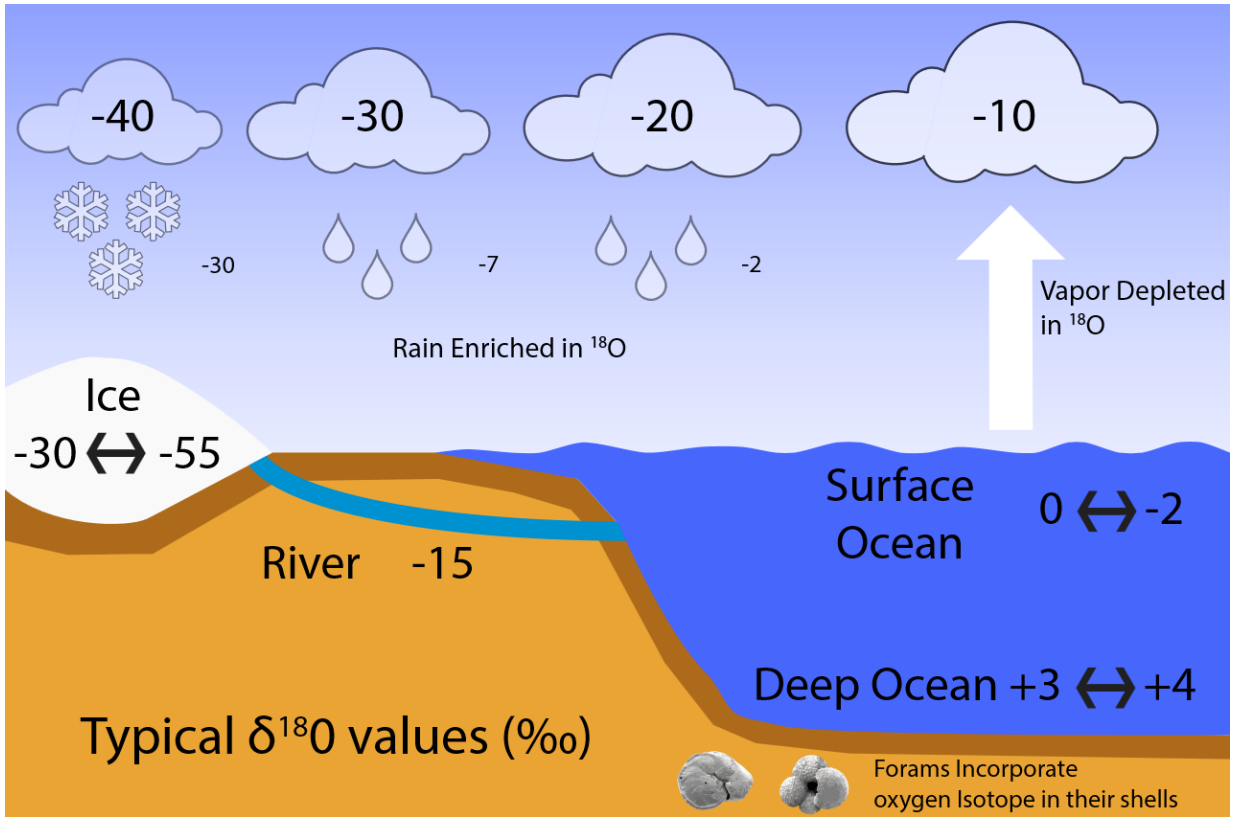
Other water isotopologues include $H_2{}^{17}O$, $HD^{17}O$, $D_2{}^{17}O$, …

The delta notation

- Natural abundance $\frac{H_2{}^{18}O}{H_2{}^{16}O} \approx \frac{1}{500}$
- Challenge to measure absolute value

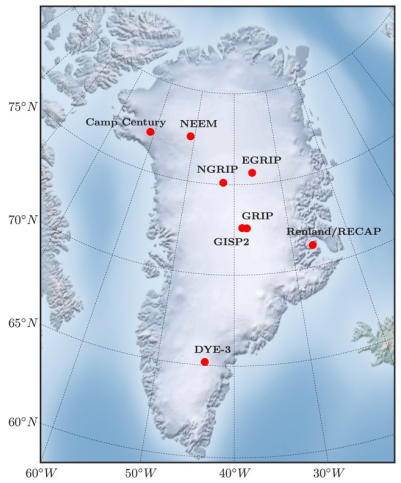
$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{sample}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1 \right) \times 1000‰$$

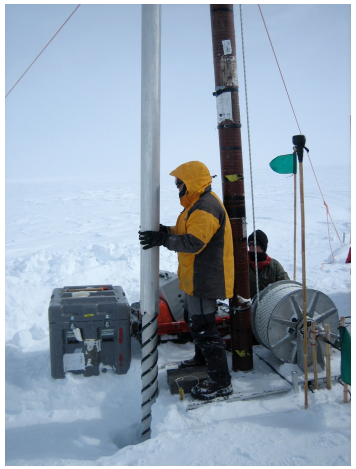
- Standards
  - Water: VSMOW (Vienna Standard Mean Ocean Water)
  - Carbonate: VPDP (Vienna Pee Dee Belemnite)



https://open.oregonstate.education

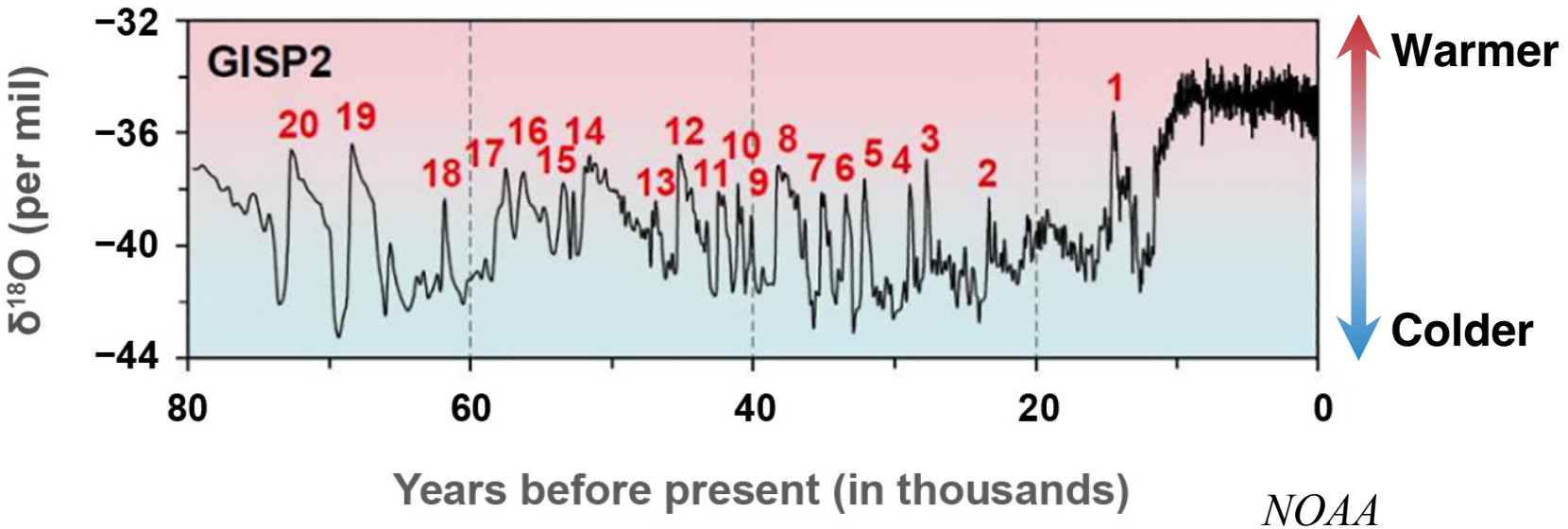
Why water isotopes? – "Ice-core thermometer"





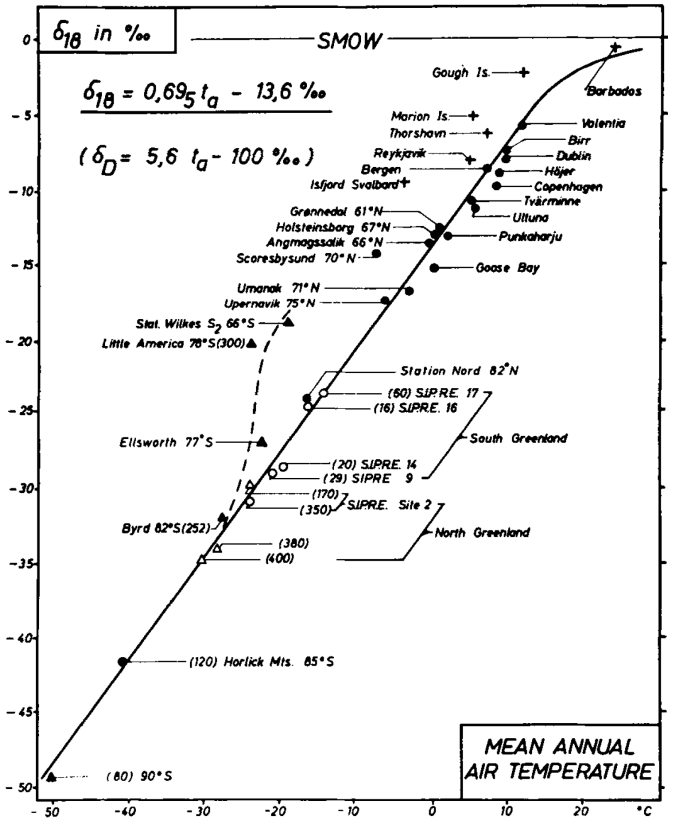
$$\delta^{18}O = \alpha T + \beta$$

Rayleigh fractionation:
heavy water condenses more easily



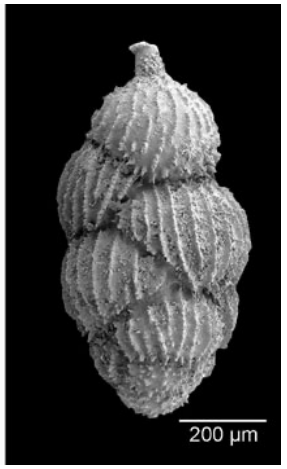
NOAA

Calibration



Dansgaard, 1964
10,000+ citations so far

Why water isotopes? – "Carbonate-water thermometer"

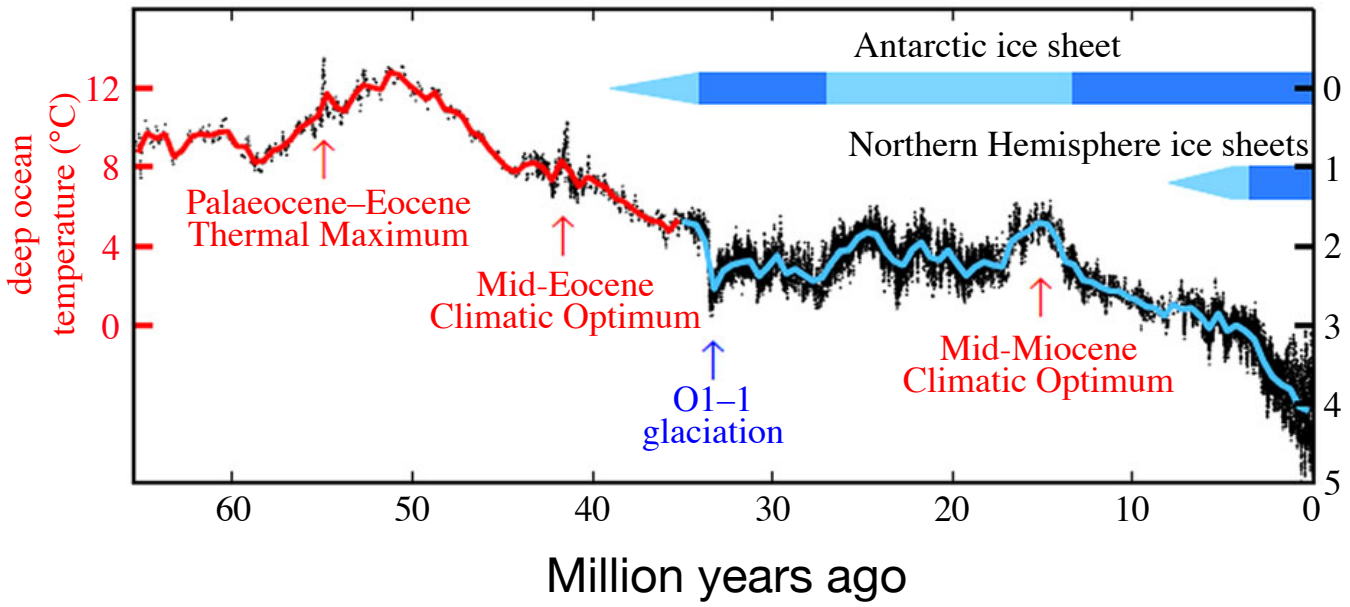


$$T = -4.8\,(\delta^{18}\mathrm{O}_{\mathrm{carbonate}} - \boldsymbol{\delta^{18}\mathrm{O}_{\mathrm{water}}}) + 16.5$$

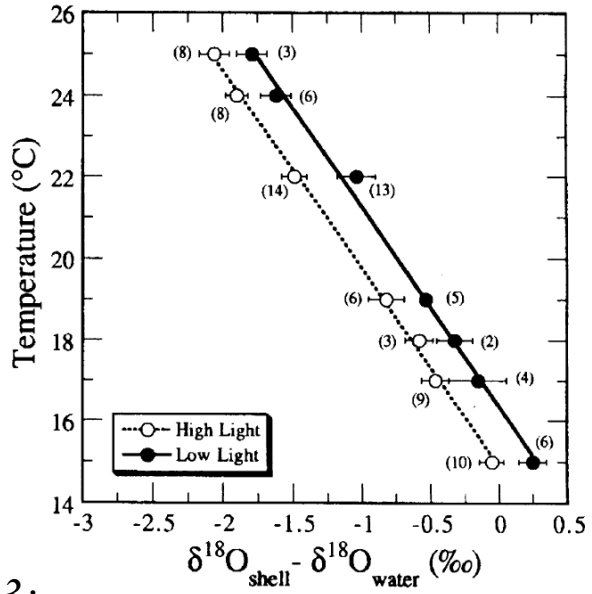
T-dependent reaction rates

$$\mathrm{CaC^{16}O} + 3\mathrm{H_2^{18}O} \rightleftharpoons \mathrm{CaC^{18}O} + 3\mathrm{H_2^{16}O}$$

The Zachos Curve



Calibration

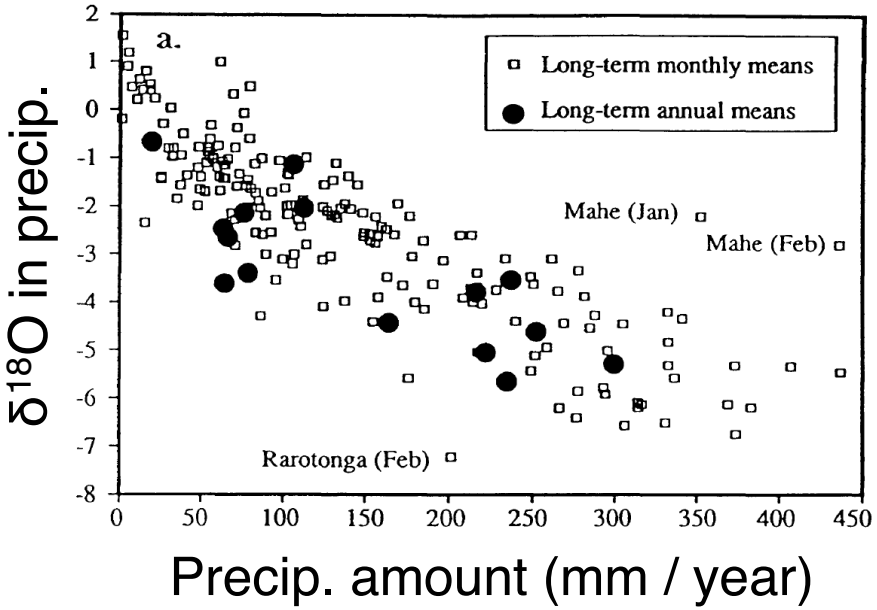


Hansen et al., 2013;
Zachos et al., 2001
10,000+ citations so far

Pearson, 2012

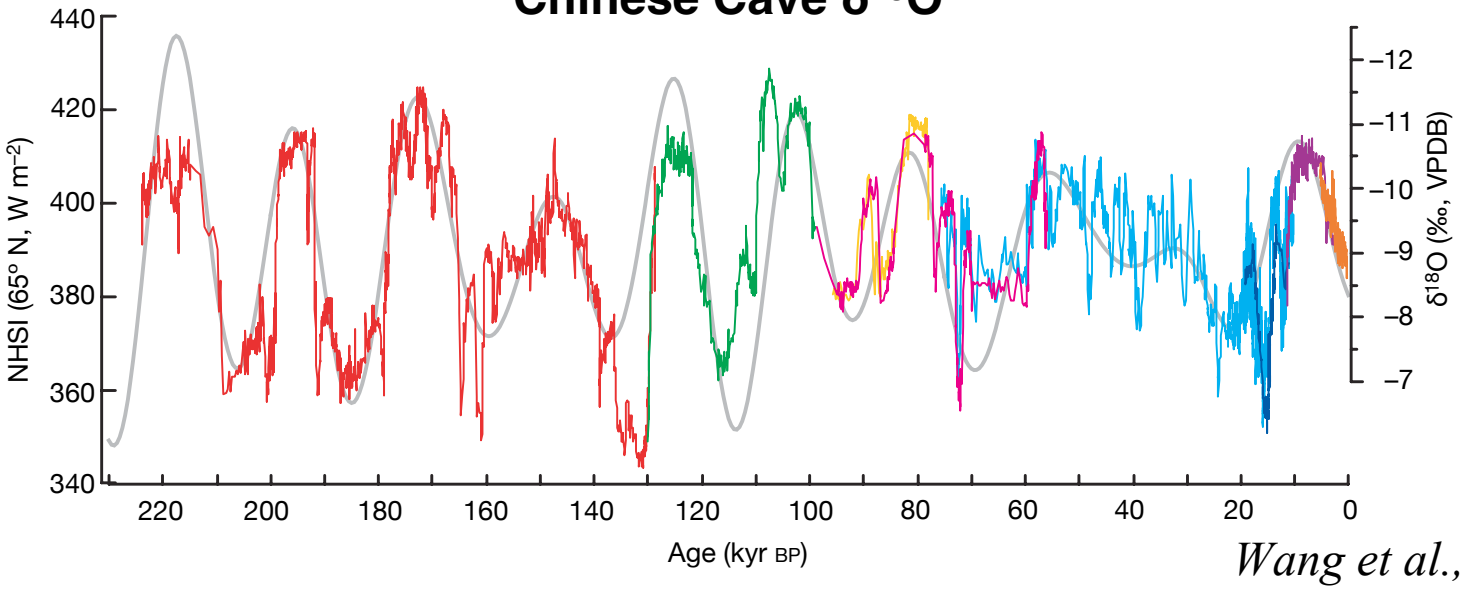
Why water isotopes? – "Paleo-Rain gauge"

"The amount effect"



Rozanski et al., 1993

Chinese Cave $\delta^{18}O$



Wetter

Drier

Wang et al., 2008, Nature

An isotope-enabled Community Earth System Model (iCESM)

- Physically consistent simulation of water isotopes in the Earth system
  - Better interpretation of the isotope records
  - Direct synthesis of model-data information
- https://github.com/NCAR/iCESM1.2

JAMES | Journal of Advances in Modeling Earth Systems

RESEARCH ARTICLE
10.1029/2019MS001663

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

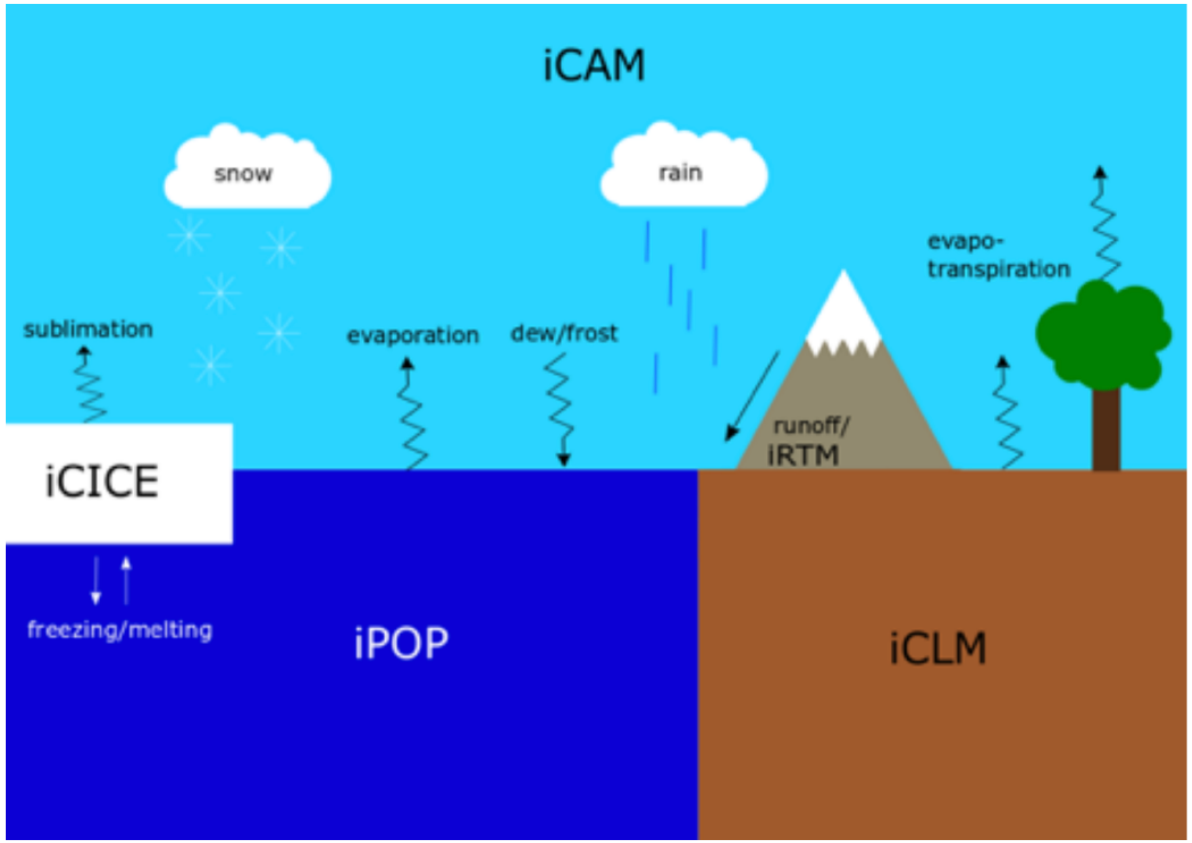
The Connected Isotopic Water Cycle in the Community Earth System Model Version 1

E. Brady[1], S. Stevenson[2], D. Bailey[1], Z. Liu[3], D. Noone[4], J. Nusbaumer[5], B. L. Otto-Bliesner[1], C. Tabor[6], R. Tomas[1], T. Wong[7], J. Zhang[8], and J. Zhu[9]

How does iCESM work?

$$H_2{}^{18}O \text{ water cycle} = \underbrace{H_2{}^{16}O \text{ water cycle}}_{\textbf{CESM}} + \text{fractionations}$$

iCESM



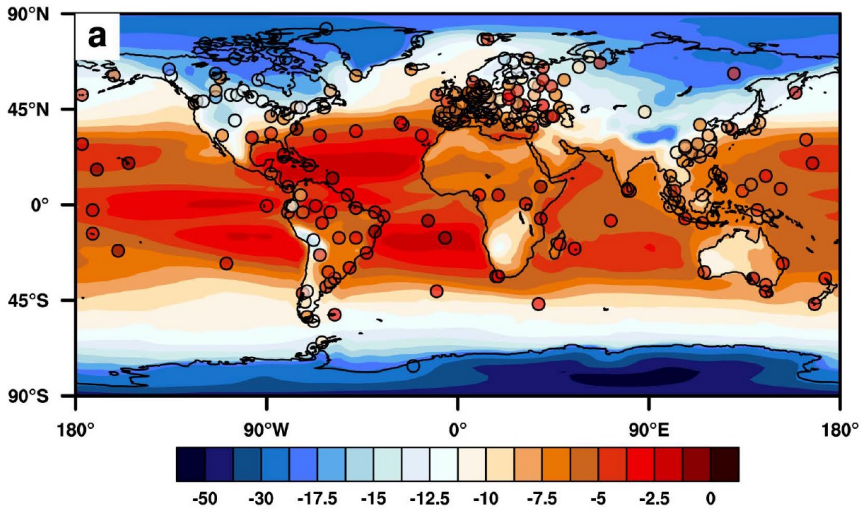
Brady et al., 2019, JAMES

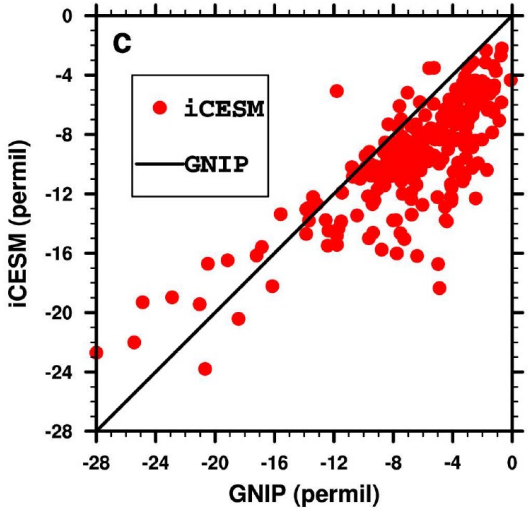
A complete suite of physical processes

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

iCESM reproduces the large-scale features in observed isotopes

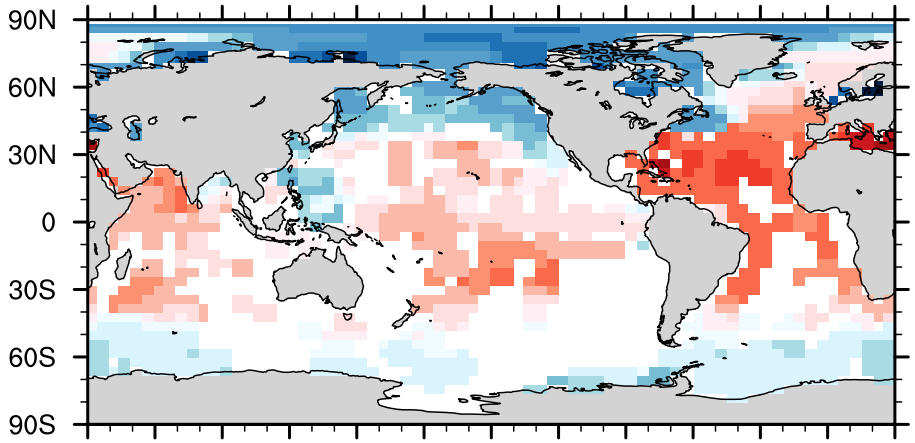
$\delta 18O_{preicp}$: Model vs. Observation



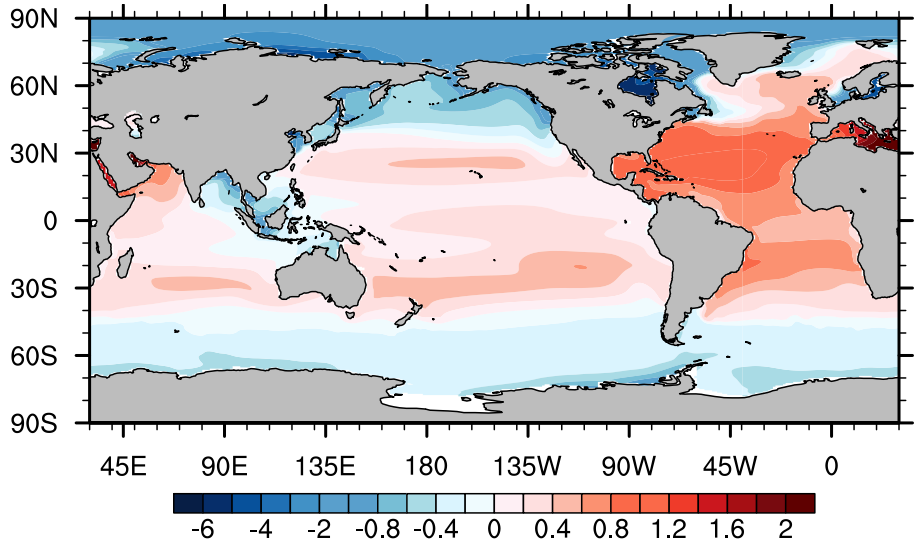


Brady et al., 2019, JAMES

Observational estimates of $\delta 18O_{sw}$



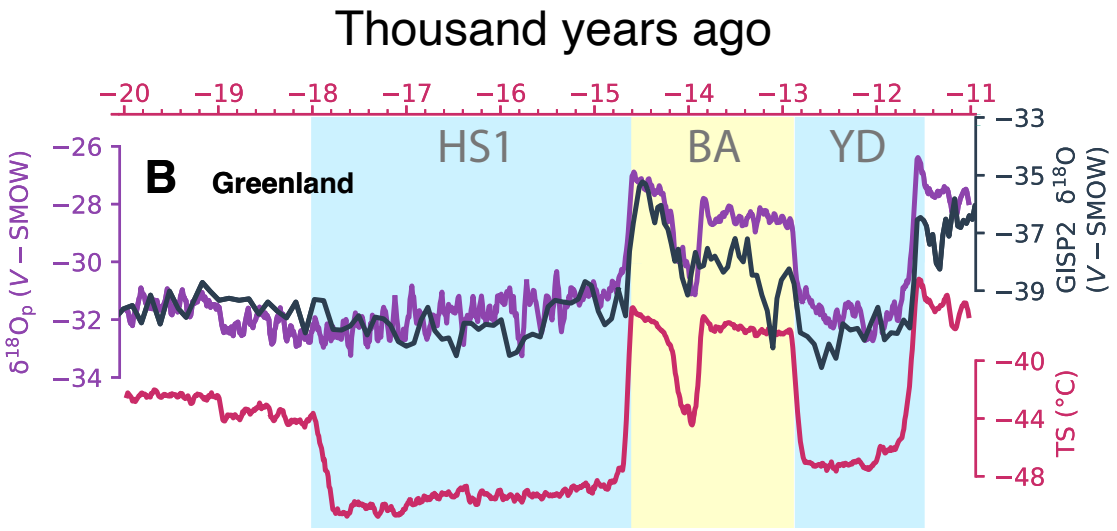
iCESM



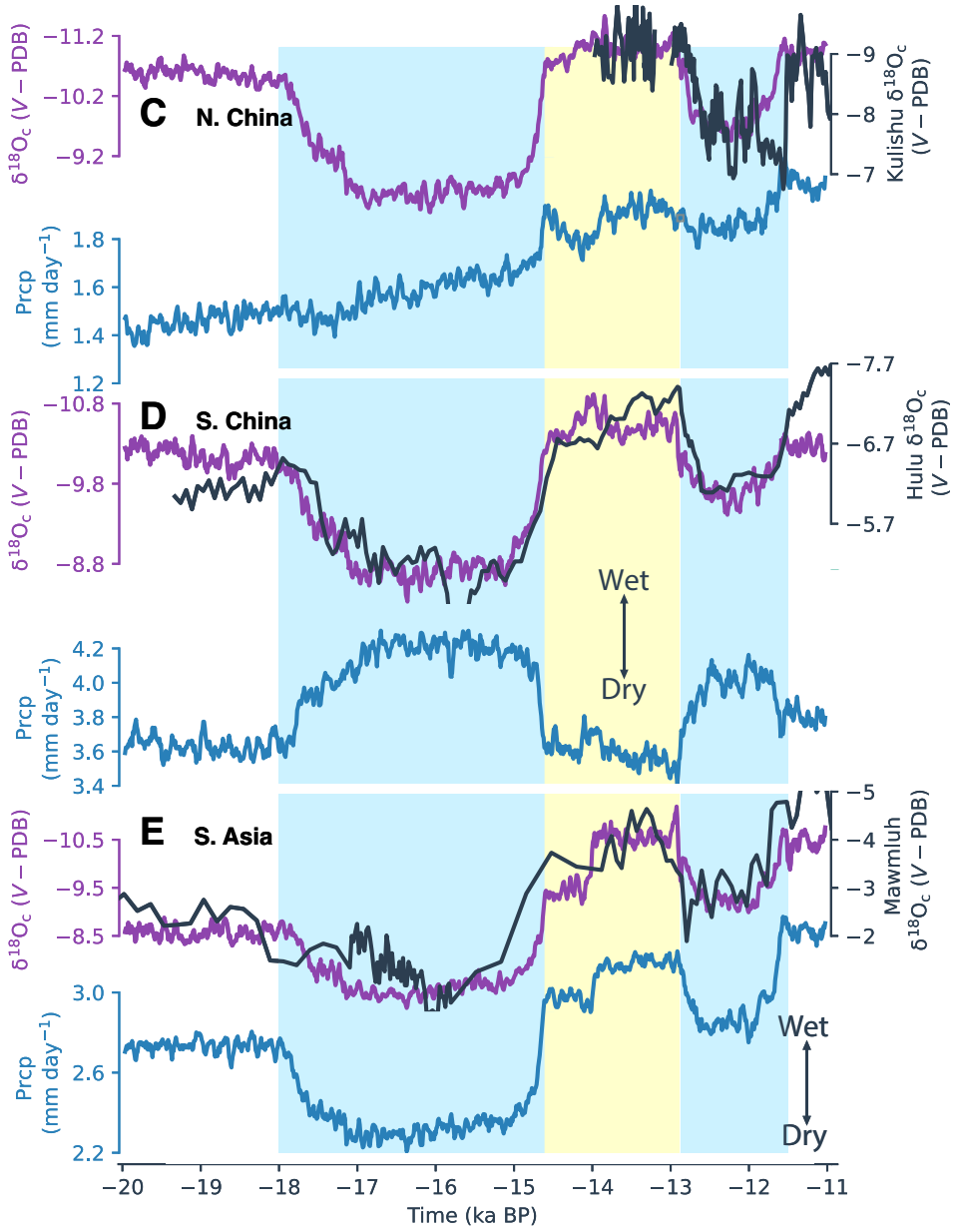
Application: transient deglaciation simulation using iCESM

Model vs. **Proxy:**

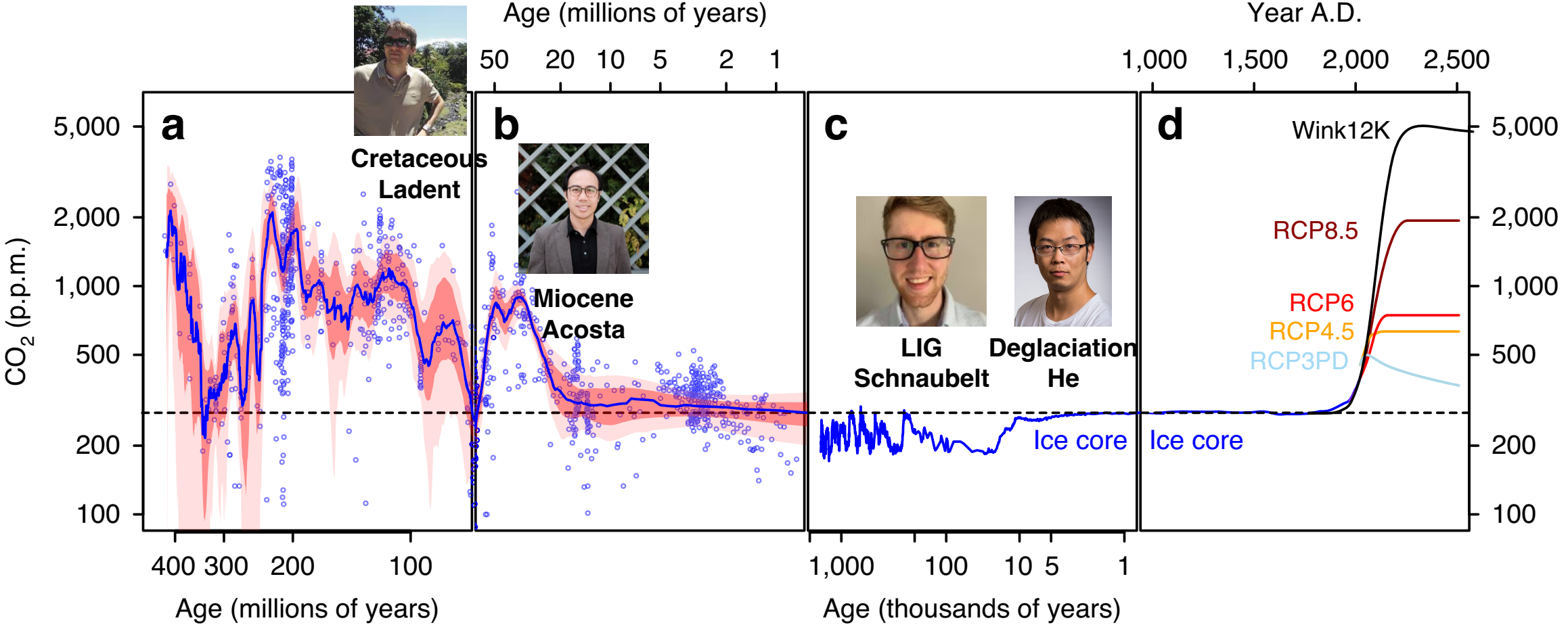
the need for systems view of isotopes



He et al., 2021a,b, Science Advances

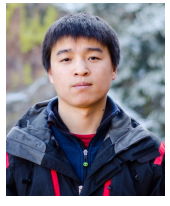


Available iCESM1 simulations & early career researchers



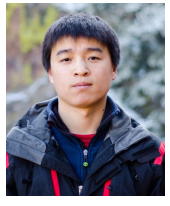
Carboniferous
Macarewich

Eocene
Zhu



Pliocene
Feng

LGM
Zhu



Holocene
Zhu, Tabor

Last Millennium
Stevenson

Summary

- 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
  - better understand how the Earth system works
- *iCESM2 not yet available due to limited resources*

Thank you!

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