# Isotope modeling with CESM

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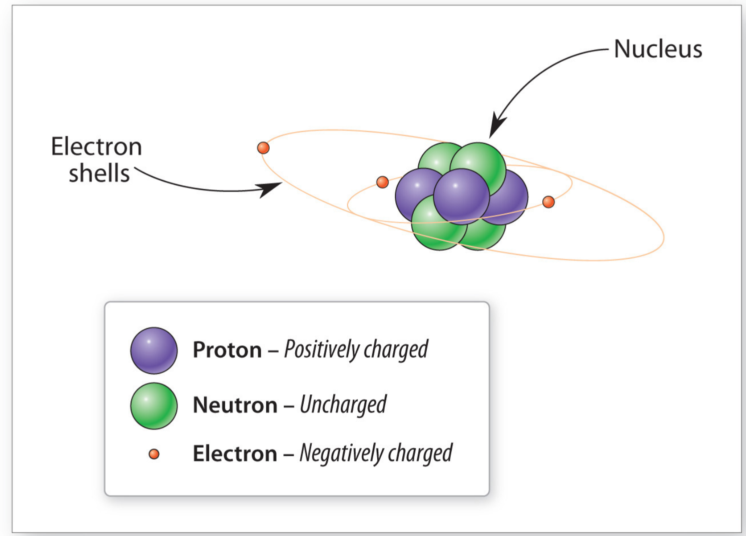
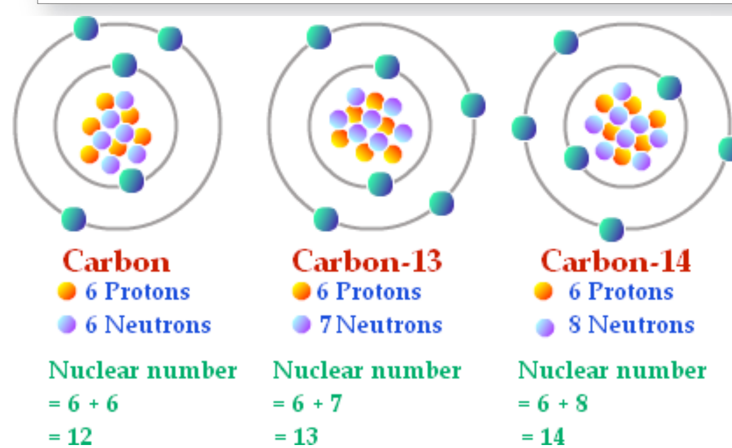
# What are isotopes?

- Isotopes are variants of an element with additional neutrones → these lead to small differences in the physical properties of the element
- Radioactive or unstable isotopes break down by radioactive decay at a constant rate to produce a “daughter” element
- The half life of a radioactive isotope is the time it takes for 50% of the original nuclei in a sample to decay to the daughter element

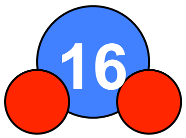


# Fractionation

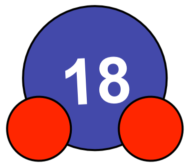
- The small differences in the physical properties of each isotope affect how isotopes are partioned between different parts of the climate system → this is called “fractionation”
- Due to fractionation, isotopes can be used to measure environmental changes
  - Oxygen and hydrogen Isotopes help us measure temperature and ice volume
  - Carbon isotopes help us infer changes in the ocean circulation and in the biological productivity, as well as use radiocarbon as “clock”

# Isotope Delta Notation




$H_2{}^{16}O$

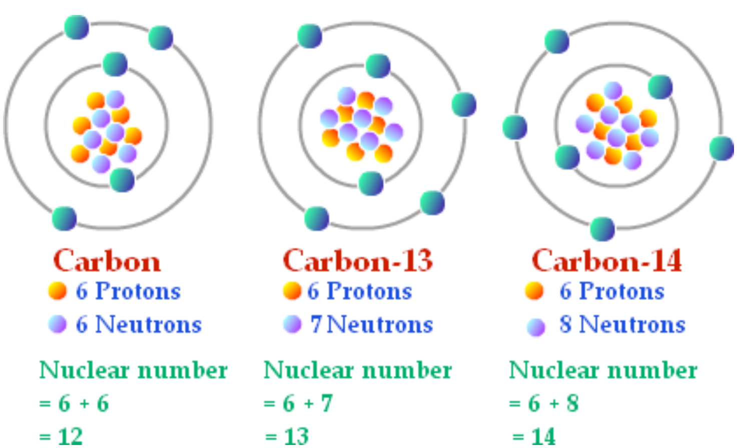
**Light Oxygen**




$H_2{}^{18}O$

**Heavy Oxygen (0.2% of all oxygen, 11% heavier than light oxygen)**

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




98.89% 1.11% <0.01%

$$\delta^{13}C = \left( \frac{\left(\frac{^{13}C}{^{12}C}\right)_{sample}}{\left(\frac{^{13}C}{^{12}C}\right)_{standard}} - 1 \right) * 1000\ \text{‰}$$

# Many climate proxies are inferences of past climate change from isotopic records in archives like sediment and ice cores

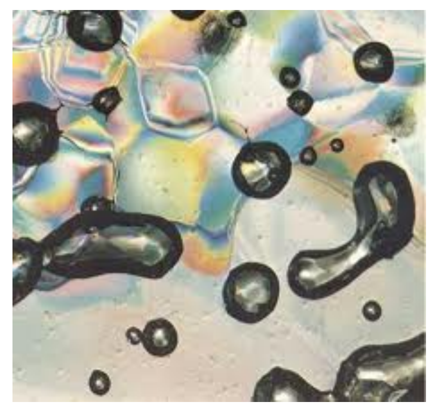
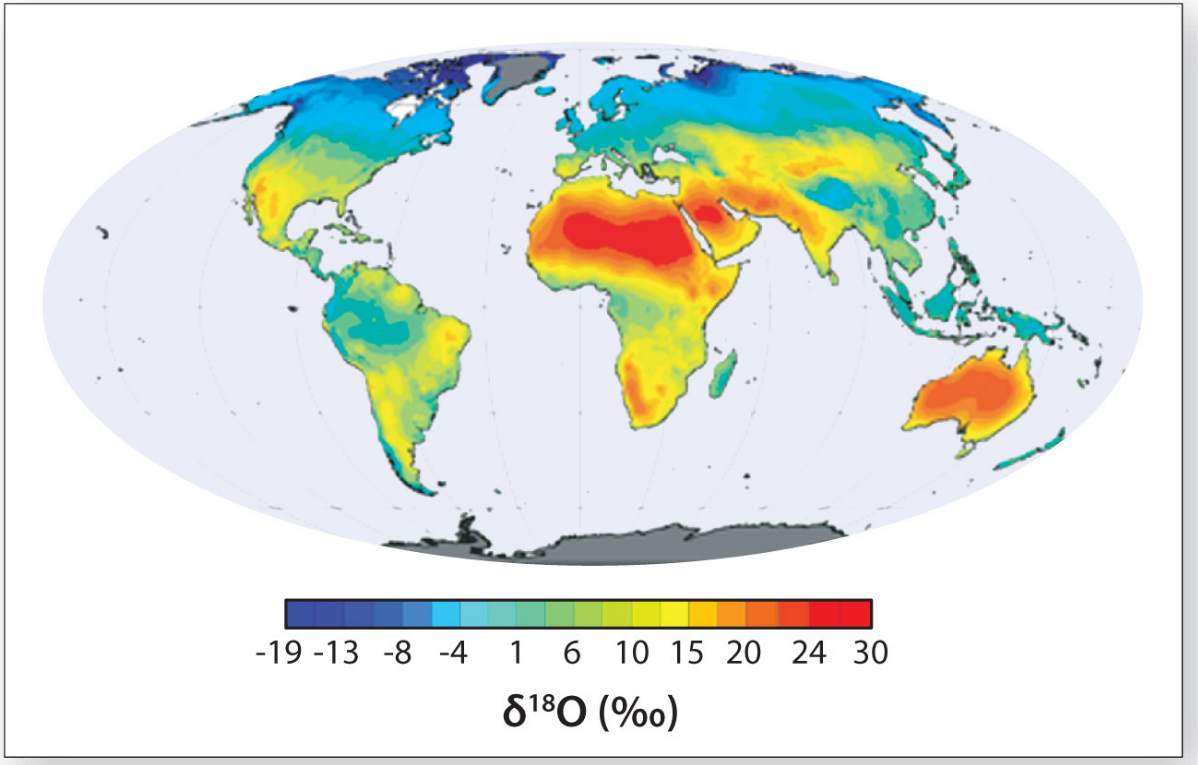


*Fig. courtesy of N. Rosenbloom, Deep Time Liaison*

# Observed Oxygen isotope distribution of precipitation over land

- Lowest values of $\delta^{18}O$ towards the poles, meaning more $^{16}O$ reaches these latitudes than $^{18}O$
- Ice sheets are located at high latitudes, so depleted in $^{18}O$

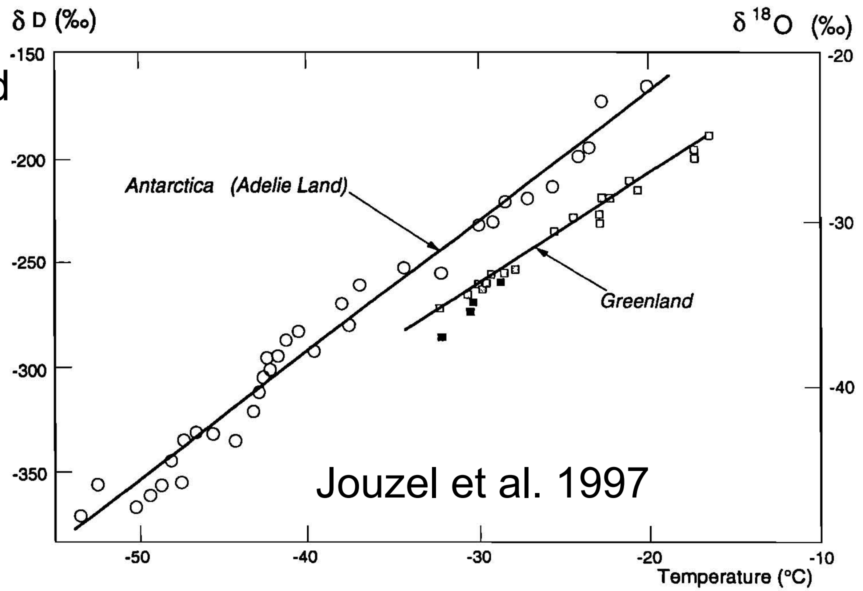


# Temperature Effect for δ$^{18}$O in Precipitation

δ$^{18}$O in Snow vs. Temp.

Less depleted

More depleted




Colder

Warmer

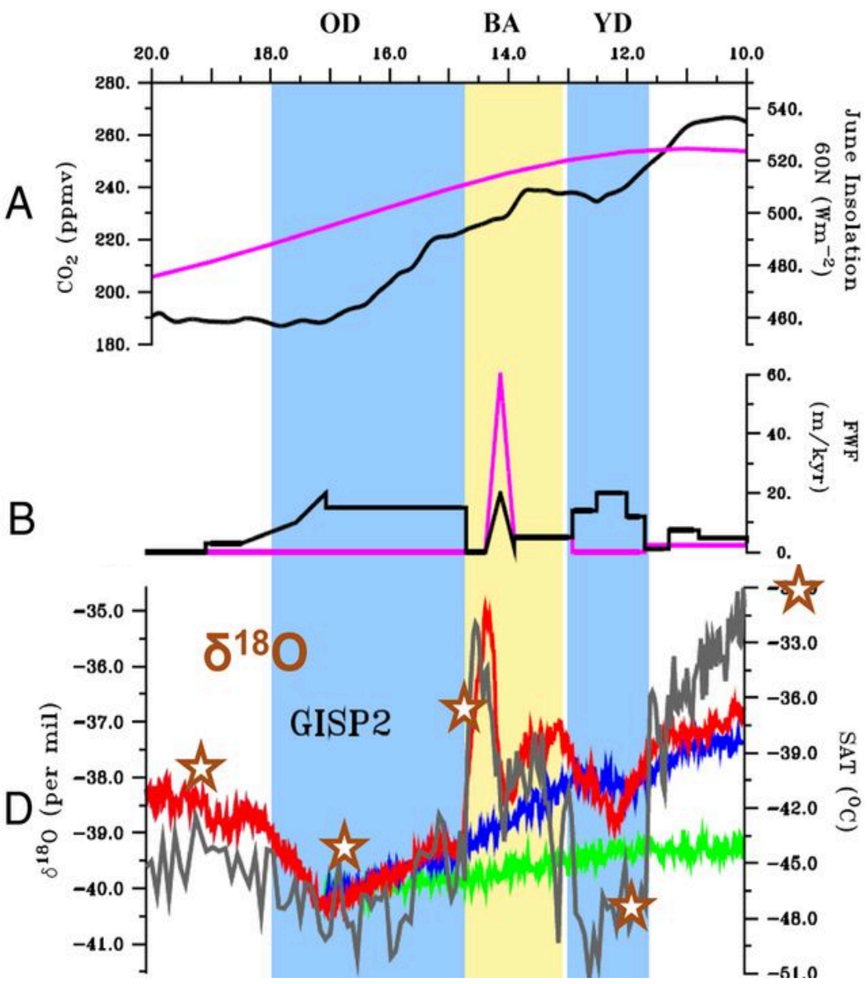
"Paleo-Thermometer"

$\Delta(\delta^{18}O) \sim 0.7[^o/_{oo}/K]\ \Delta T$

Spatial relationship – Observed to hold temporally over seasons and interannually in ice cores.

But can the modern relationship be used to reconstruct high-latitude temperature change over the long time periods of Glacial-Interglacial change?

# CCSM3 TraCE, Transient Simulation of the Last Deglaciation




***Forcing:***

60°N June Insolation(Orbital)

Atm CO2 concentration

(+Ice Sheet orography)

***Meltwater input***

NH

SH

***Proxy Comparison***

★ $\delta^{18}$Op* over Greenland From IsoCAM3 'slices'

Greenland SAT CCSM3-Full

CO2+IS, Orbital+IS

$\delta^{18}$O GISP2 Record

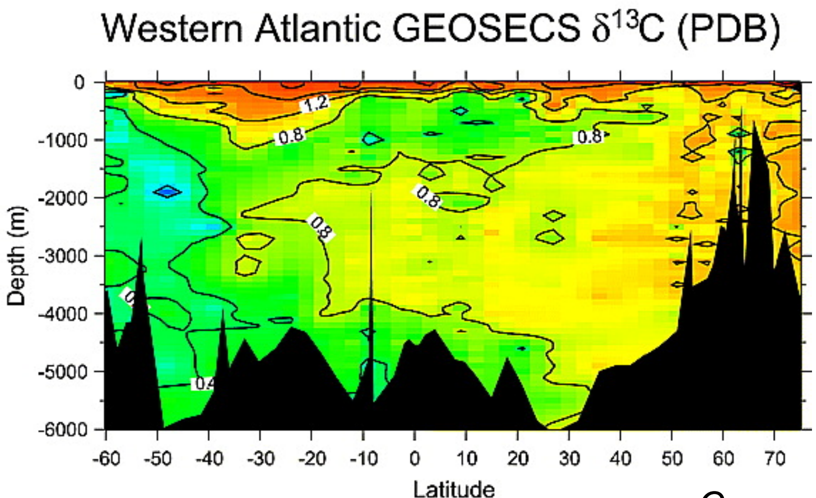
*$\delta^{18}$Op ~ w/offset for bias

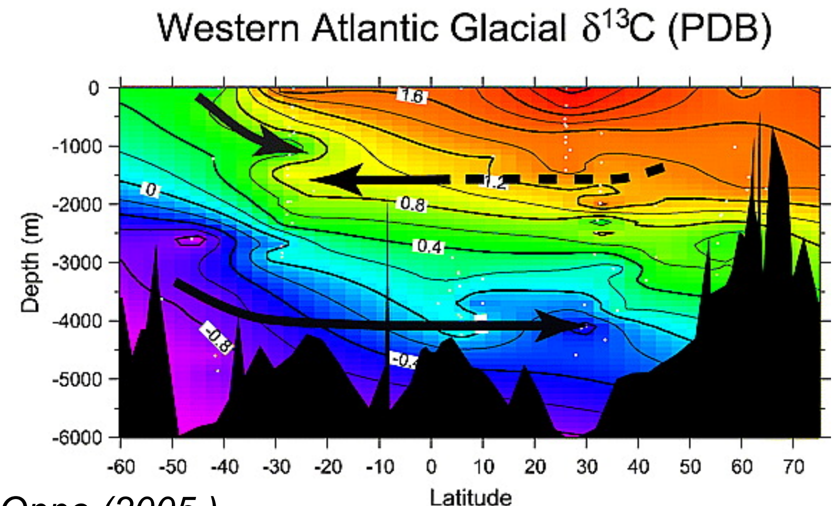
**Liu Z et al. PNAS 2012;109:11101-11104**

*CCSM3 suggests weaker YD cooling*

*But, Iso-CAM3 agrees better with Δδ18Op*

# Carbon isotopes as ocean tracers




*Curry and Oppo (2005 )*

- The $\delta^{13}C$ ratio of shells is a measure of how much photosynthesis is taking place in the oceans and/or how much organic material is removed from the surface to the deep ocean via circulation, as both processes enrich the water in $^{13}C$

→paleo proxies mainly use $\delta^{13}C$ as a water mass tracer, neglecting biological productivity changes

- $\delta^{13}C$ can be used as tracers of carbon cycle processes → e.g., used to diagnose the oceanic uptake of anthropogenic $CO_2$
- $\Delta^{14}C$ is used as ocean reservoir age tracer

# Isotope-enabled CESM for studying abrupt change

*Bette Otto-Bliesner, Zhengyu Liu[2], and iCESM Team****

****E. Brady, A. Jahn[7], D. Noone[4], K. Lindsay[1], M. Vertenstein[1], D. Bailey[1], F. Joos[3], A. Bozbiyik[3], A. Gettelman[1], S. Gu[2], C. Koven[5], E. Kluzek[1], J. Nusbaumer[4], B. Riley[5], J. Tang[5], P. Thornton[6], X. Wen[2], T. Wong[4], J. Zhang[2], J. Zhu[2]*

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# iCESM: Water Isotopic and Carbon isotope tracers development

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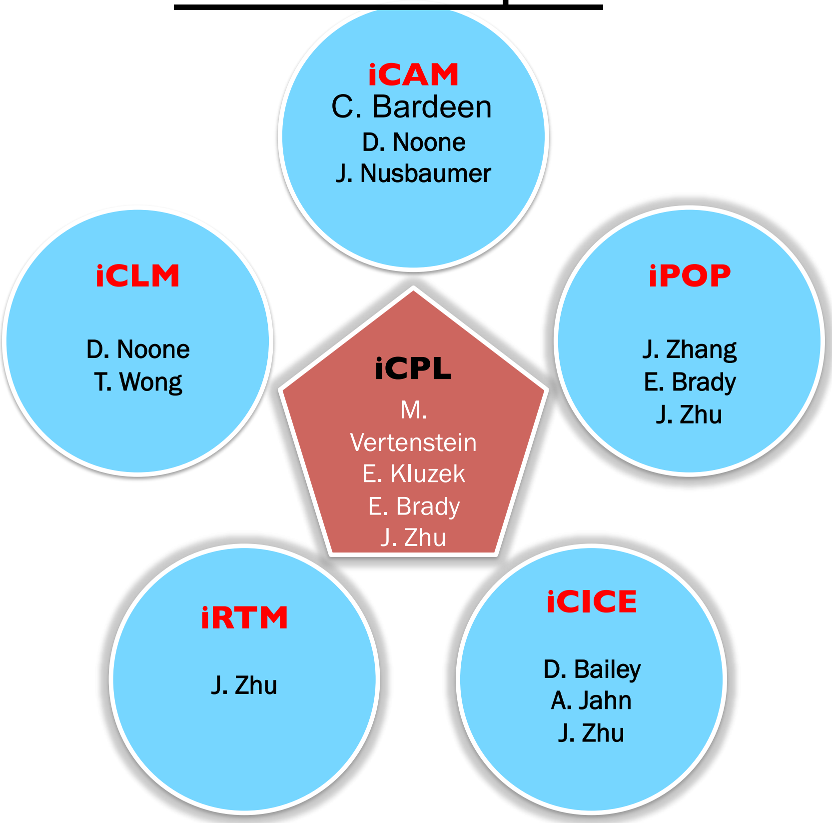
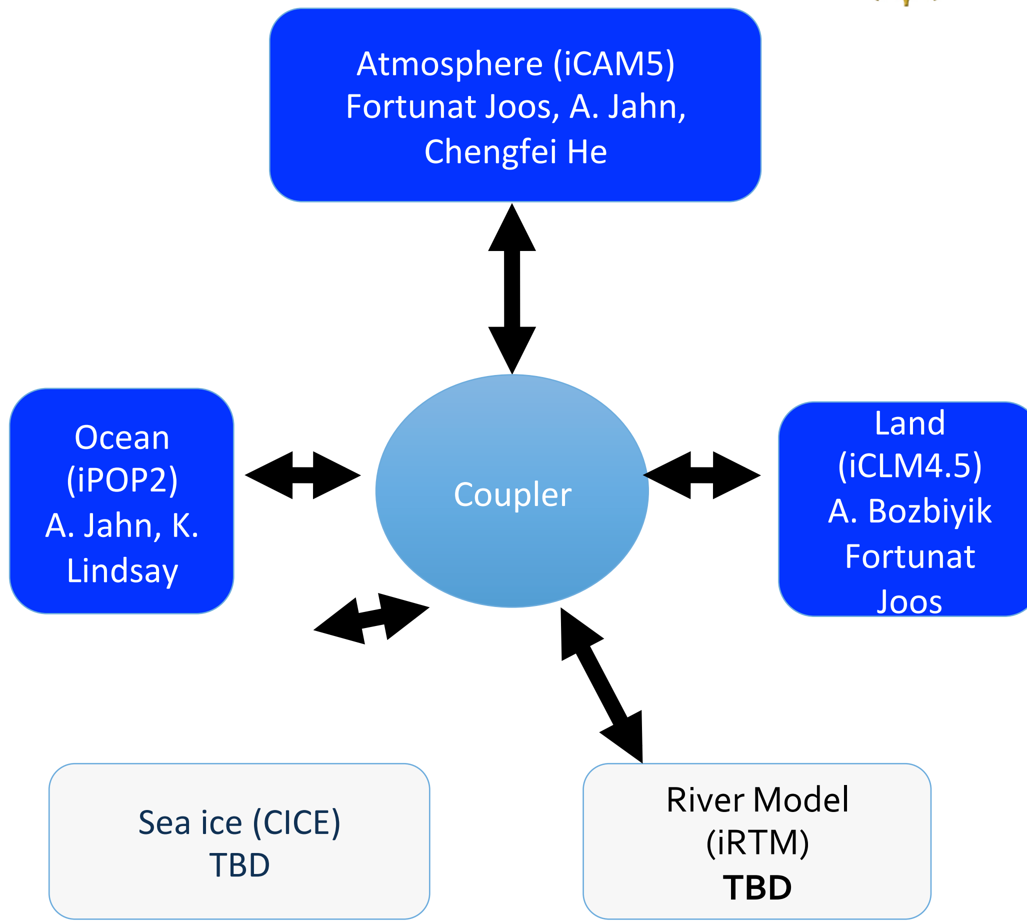
## Water Isotopes




## Carbon Isotopes

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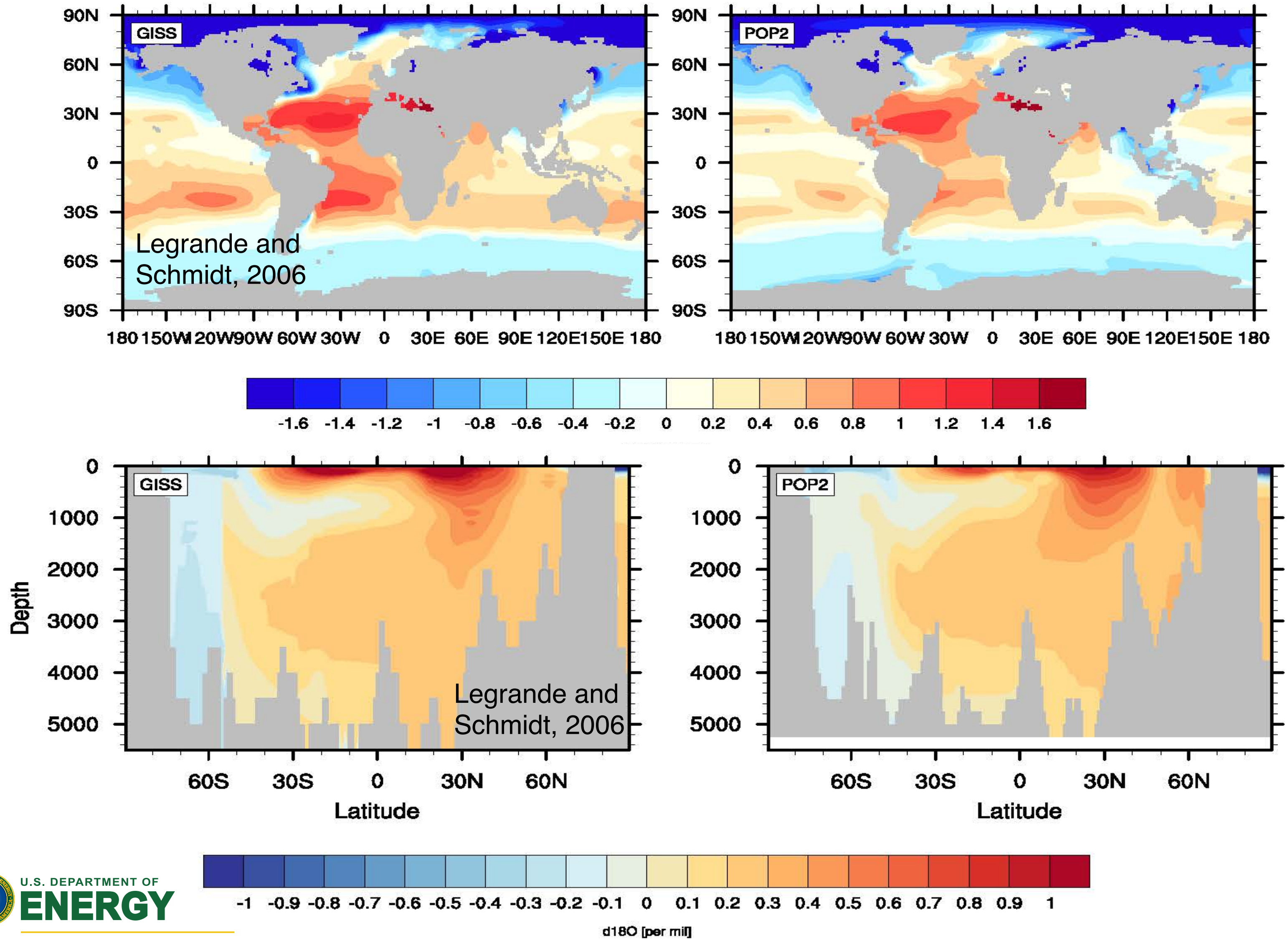
# Coupled iCESM water isotopes

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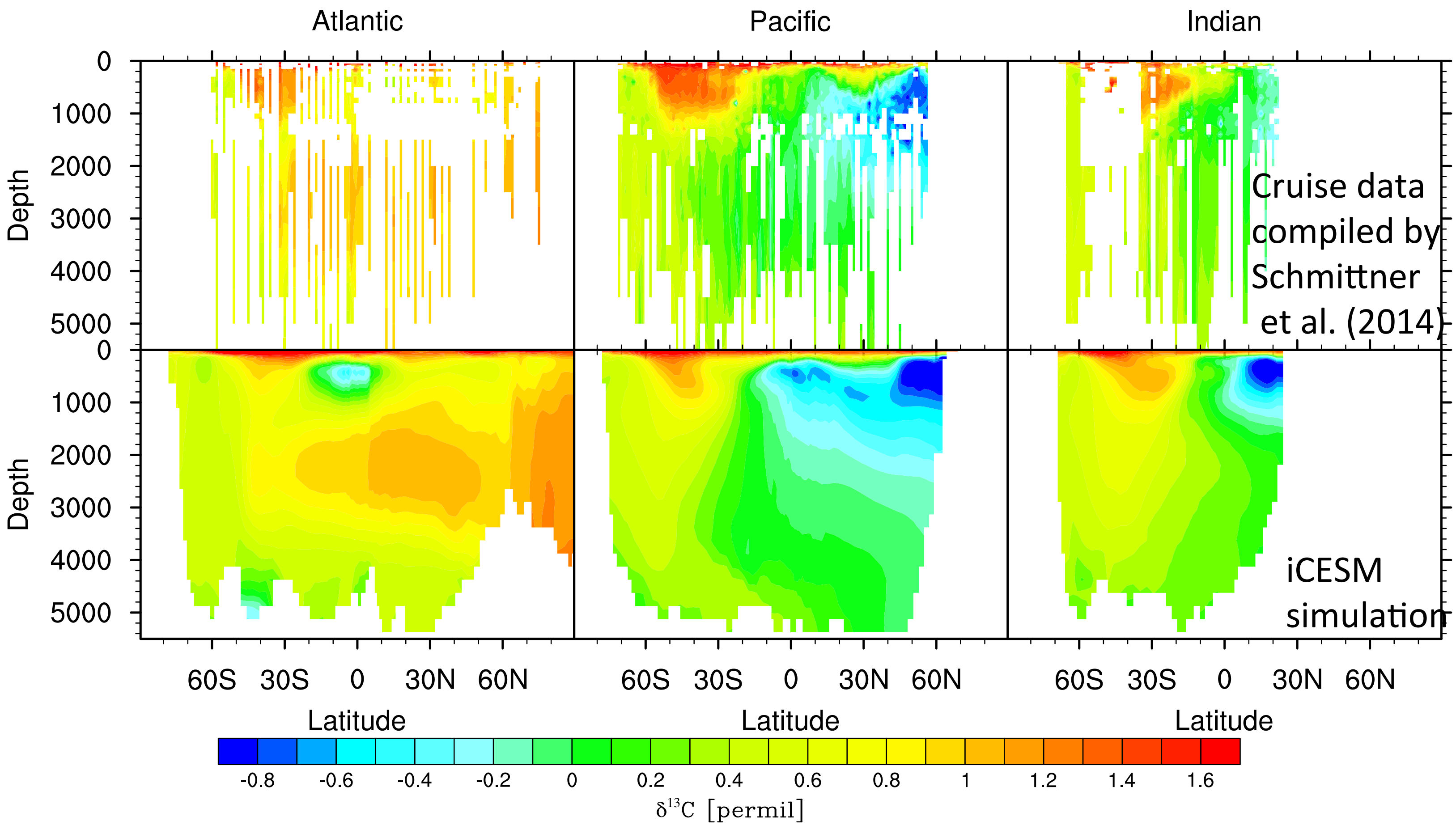
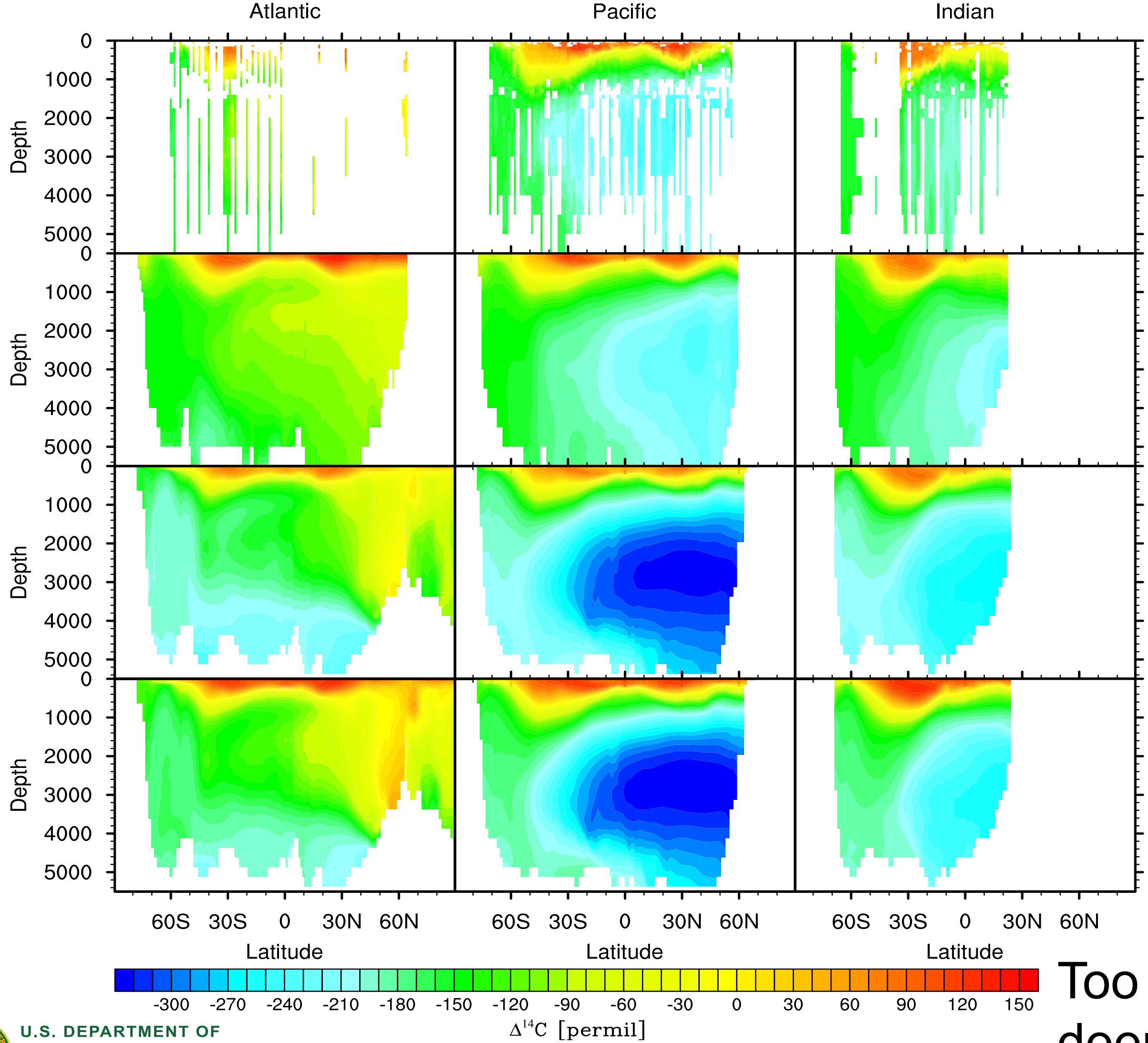
# Cross sections of oceanic $\delta^{13}C$ (1990s)




Jahn et al. (2015), GMD

# Cross sections of Radiocarbon




Cruise data compiled by Schmittner et al. (2014)

GLODAP (Kay et al. 2004)

Biotic Radiocarbon Simulation

Abiotic Radiocarbon Simulation

Too old radiocarbon ages in deep Pacific → shows model biases in that region

Jahn et al. (2015), GMD

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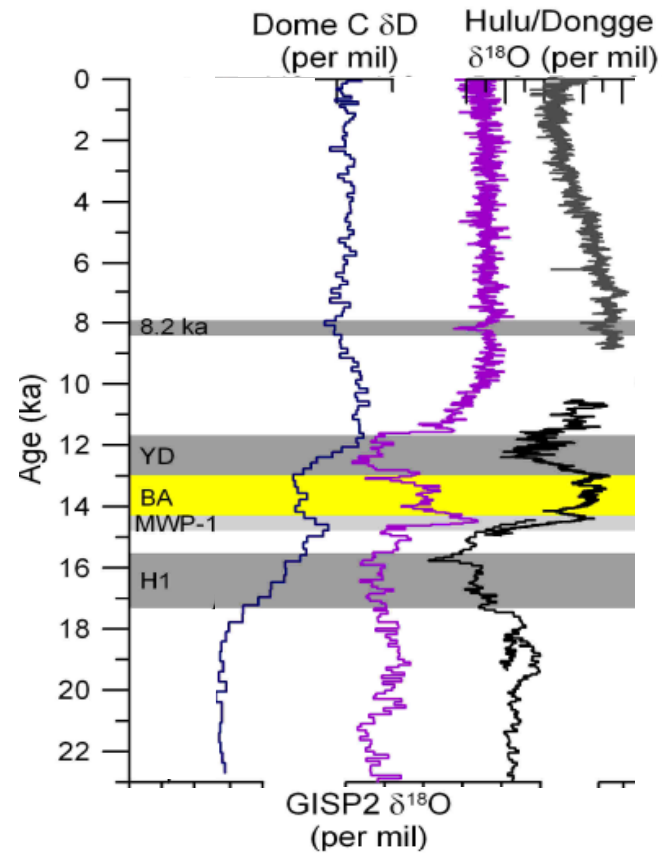
# Paleo Application: iTraCE simulations

- iTraCE will allow us to evaluate the skill of CESM, stability through time of the interpretations of the proxies, and the mechanisms associated with abrupt changes of the last 21,000 years

- Most of the isotope capabilities will be available to the community in CESM2 (to be released in Dec. 2016)




**Water isotope iTraCE:** Funded by NSF-P2C2: PIs: B. Otto-Bliesner (NCAR), Z. Liu (U. Wisc.), P. Clark (OSU)
**Carbon Isotope O-iTraCE:** Funded by NSF-P2C2: PIs: A. Jahn (CU) and Z. Liu (U. Wisc.)

# Thank You!

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