Isotope modeling with CESM

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What are isotopes?

- Isotopes are variants of an element with additional neutrons → 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 partitioned 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

$\delta^{18}O = \left( \frac{^{18}O_{sample}}{^{16}O_{standard}} - 1 \right) \times 1000 \text{ }^\circ/o$

$\delta^{13}C = \left( \frac{^{13}C_{sample}}{^{12}C_{standard}} - 1 \right) \times 1000 \text{ }^\circ/o$

Light Oxygen

$^{16}O$ (0.2% of all oxygen, 11% heavier than light oxygen)

Heavy Oxygen

$^{18}O$

98.89% 1.11% <0.01%
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 $\delta^{18}$O in Precipitation

$\Delta(\delta^{18}$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

- δ¹⁸Op* over Greenland From IsoCAM3 ‘slices’
- Greenland SAT CCSM3-Full
- CO2+IS, Orbital+IS
- δ¹⁸O GISP2 Record

CCSM3 suggests weaker YD cooling
But, Iso-CAM3 agrees better with Δδ¹⁸Op

*δ¹⁸Op ~ w/offset for bias

Liu Z et al. PNAS 2012;109:11101-11104
Carbon isotopes as ocean tracers

- 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

Curry and Oppo (2005)
Isotope-enabled CESM for studying abrupt change

Bette Otto-Bliesner, Zhengyu Liu, and iCESM Team


iCESM: Water Isotopic and Carbon isotope tracers development

**Water Isotopes**

- **iCAM**
  - C. Bardeen
  - D. Noone
  - J. Nusbaumer

- **iCLM**
  - D. Noone
  - T. Wong

- **iCPL**
  - M. Vertenstein
  - E. Kluzek
  - E. Brady
  - J. Zhu

- **iPOP**
  - J. Zhang
  - E. Brady
  - J. Zhu

- **iRTM**
  - J. Zhu

- **iCICE**
  - D. Bailey
  - A. Jahn
  - J. Zhu

**Carbon Isotopes**

- Atmosphere (iCAM5)
  - Fortunat Joos, A. Jahn, Chengfei He

- Ocean (iPOP2)
  - A. Jahn, K. Lindsay

- River Model (iRTM)
  - TBD

- Sea ice (CICE)
  - TBD

- Land (iCLM4.5)
  - A. Bozbiyik
  - Fortunat Joos

**Additional Institutions**

- UCAR
- University of Wisconsin-Madison
- University of Colorado Boulder
Coupled iCESM water isotopes

Legrande and Schmidt, 2006
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
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).

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Thank You!

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