Carbon Isotopes in the iCESM
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Motivation: Better model-data comparisons

- $\delta^{13}C$ is used to infer paleo ocean water masses (e.g., NADW)
- $\delta^{13}C$ can be used as tracers of carbon cycle processes → e.g., used to diagnose the oceanic uptake of anthropogenic $\text{CO}_2$
- $\Delta^{14}C$ is used as ocean reservoir age tracer

Curry and Oppo (2005)
Implementation Status
Carbon Isotopes

- POP2 development + testing completed
- CLM4 development + testing completed
- RTM (needs development, river bulk Carbon transport to ocean BGC is now from data input)
- CAM5.3 (tracer development initiated)
- CICE: TBD
Implementation of Carbon isotopes in POP2 (as additional passive tracers)

- **Two different implementations:**
  - **Abiotic Radiocarbon (2 additional tracers):** can be run independently of the ecosystem model, ocean-model cost increase is a factor of 1.2 compared to the normal ocean model.
  - **Biotic $^{13}$C and $^{14}$C (14 additional tracers):** Carbon isotopes in all seven carbon pools currently in the ecosystem. Cost increase is by a factor of 4 compared to ocean only model and 1.4 compared to the normal ocean-ecosystem model.
All simulations were ocean-active-only simulations

Spin-up simulations are forced with constant pre-industrial CO₂ (278 ppm), Δ¹⁴C (0 permil), δ¹³C (-6.379 permil)

Simulations from 1765 to 2010 were forced with prescribed changing CO₂, Δ¹⁴C, δ¹³C

Using CESM1.0.5
Fast spin-up of abiotic radiocarbon with Newton-Krylov (K. Lindsay)

After 3 Newton-Krylov iterations
(1 degree model, took < 24 h)

After 6000 model years (took ~2.5 months)

Plots courtesy of Keith Lindsay, NCAR
Results from abiotic Radiocarbon: $^{14}$C age

Atlantic section along 30.5° W, $^{14}$C age from GLODAP and POP2

Pacific section along 179.5° W, $^{14}$C age from GLODAP and POP2
Impact of fully spinning up the radiocarbon

Atlantic section along 30.5 W

Pacific section along 179.5 W
Adding the biological pump and $^{13}$C

Currently there are 7 carbon pools in the ecosystem model (DIC, DOC, small phytoplankton, diatoms, diazotrophs, zooplankton, CaCO$_3$)

Accounts for fractionation effects during gas exchange, photosynthesis, etc

“Biotic C isotopes” = Includes both biological effects and solubility effects
First results from the biotic $\delta^{13}C$ isotope simulation (1990s)

Model compared to the present-day $\delta^{13}C$ dataset compiled by Schmittner et al (2013)
Atlantic $\delta^{13}C$ (1990s)

Curry and Oppo (2005)
Carbon isotopes in the atmosphere

- $^{14}$CO$_2$ and $^{13}$CO$_2$ will be carried in the atmosphere as tracers in addition to the current CO$_2$ tracer, and will be exchanged with the ocean and land through the calculated surface fluxes.

- For $^{14}$C we need an atmospheric production term:
  - We will include a 2-D 14C production field (height and latitude), supplied by Fortunat Joos, Ulla Heikkilae, and Jürg Beer
Next steps

- Investigate relationship between δ13C and physical model variables under different MOC strengths
- Include abiotic radiocarbon in at least one ensemble member for the Last Millennium large ensemble, using the Newton-Krylov fast spin-up technique to obtain initial conditions
- Add Pa/Th to the ocean model as additional tracer (hopefully also Neodymium)
Thanks!

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