Carbon Isotopes in the iCESM

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Carbon Isotopes and their usefulness

Stable isotopes become preferentially concentrated because of differences in their mass: this is called fractionation → It allows the tracing of pathways/origins of carbon

\[ ^{12}\text{C} \quad ^{13}\text{C} \quad ^{14}\text{C} \]

- 6 protons, 6 neutrons (stable)
- 6 protons, 7 neutrons (stable)
- 6 protons, 8 neutrons (radioactive)

\(^{14}\text{C}\) acts as clock
Uses of Carbon isotopes

- $\Delta^{14}C$ is used as proxy for the age of water masses, circulation timescales, and to infer past and present ocean water ages
- $\delta^{13}C$ is used to infer paleo ocean water masses (e.g., NADW)
- Simulating carbon isotopes in the model allows a more direct comparison with observations (paleo proxies and present day isotopic measurements)

Curry and Oppo (2005)
Implementation of Carbon isotopes in POP2 (as additional passive tracers)

Two different implementations:

- **Abiotic Radiocarbon** (1 additional tracer): 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. $^{13}$C code was based on code from ETH (Gruber et al) developed for POP1.

Status update:

- Abiotic Radiocarbon is implemented, spun-up in the 3° model, and tested.
- Biotic $^{13}$C & $^{14}$C are implemented and spin-up in the 3° model is under way.
Model set-up

+ Simulations are forced by prescribed atmospheric CO₂, Δ14C, δ13C data

+ Spin-up simulations are forced with constant pre-industrial CO₂ (278 ppm or 284 ppm), Δ14C (0 permil), δ13C (-6.379 permil)

+ Simulations are performed in the ocean-active-only 3° POP2 model, forced by CORE normal year atmospheric forcing (C-Compset)
Results from abiotic Radiocarbon: $^{14}$C age

C14 age from GLDAP, POP2, and GLDAP-POP2
Results from abiotic Radiocarbon: $^{14}$C age
Adding the biological pump

- Currently there are 7 carbon pools in the ecosystem model (DIC, DOC, small phytoplankton, diatoms, diazotrophs, zooplankton, CaCO₃).
- Each Carbon isotope adds 7 tracers.
  - Currently the ecosystem model has 24 tracers.
  - The 14 additional carbon isotopes increase the ocean-model computation cost by:
    - a factor of 1.4 compared to just running the ecosystem model,
    - a factor of 4 compared to just running the ocean-only model without the ecosystem.

“Complete”
= Include both biological effects and solubility effects.
Adding an ecosystem driver

passive_tracers

CFC_mod  IAGE_mod  ecosys_driver  abio_14C_mod  wiso_mod

ecosys_mod  ecosys_Ciso_mod  ecosys_Th_Pa_mod  Ecosys_Xiso_mod

ecosys_fields_mod (sharing of data)

(possible future extensions)
First, very preliminary results from the spin-up of biotic $^{13}$C isotope simulation (year 1500)

Model compared to the d$^{13}$C dataset compiled by Schmittner et al (2013)
First, very preliminary results from the spin-up of biotic $^{14}$C isotope simulation (year 1500)
Update: Carbon isotopes in the land model (CLM4.5)

- $^{13}\text{C}$ and $^{14}\text{C}$ tracers have been added to the CLM4.5 land model as fully-prognostic variables.
- The CLM4.5 has been spun-up in stand-alone mode for over 7000 years to equilibrium and more testing is under way.
- Developers: A. Bozbiyik, J. Fortunat (University of Bern), W. Riley, C. Koven (LBNL), D. Lawrence (NCAR)

Global $\delta^{13}\text{C}$ of the Total Vegetation

A. Bozbiyik
Next steps for the Carbon isotope development in CESM

+ Add $^{13}$C and $^{14}$C isotope tracers to the atmosphere
+ Couple the carbon isotope enabled iCAM5, iCLM4.5, and iPOP2 for a coupled carbon isotope simulation
+ Consider adding carbon isotopes in CICE?
Future work

- Complete and analyze the biotic POP2 Carbon isotope spin-up simulation
- Spin-up carbon tracers for use in the the 1° coupled CESM (need fast spin-up technique for this)
- Include tracers in paleo simulations
  - Use the coupled carbon isotopes to investigate the Mystery Interval and the LGM
  - Compare simulations to observations, using the new tracers for more direct (but still not “apple to apple”) comparisons
  - Investigate how the physical climate parameters from the model (temperature, density, etc) relate to the simulated geochemical tracers
- Add tracers for Protactinium (Pa) and Thorium (Th) to the ecosystem model of the CESM as additional tracer for the strength of the overturning circulation
Thanks!

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