Simulated carbon isotope distributions in the ocean model of the CESM

Alexandra Jahn

Collaborators: Keith Lindsay, Esther Brady, Bette Otto-Bliesner, Zhengyu Liu, Nicolas Gruber, Xavier Giraud

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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 x1.2 compared to normal ocean model.

**Biotic $^{13}$C and $^{14}$C (14 additional tracers):** Carbon isotopes in all 7 carbon pools in the ecosystem (DIC, DOC, small phytoplankton, diatoms, diazotrophs, zooplankton, CaCO$_3$). Cost increase by x4 compared to ocean only model and x1.4 compared to the normal ocean-ecosystem model.
All simulations were ocean-active-only simulations at 3° resolution.

Spin-up simulations are forced with constant “pre-industrial” CO₂ (278 ppm), Δ¹⁴C (0 permil), δ¹³C (-6.379 permil), but present-day CORE-II Normal year winds and temperatures.

Simulations from 1765 to 2010 were forced with prescribed changing CO₂, Δ¹⁴C, δ¹³C and CORE-II.
Spin up of abiotic $^{14}$C

Carbon isotopes (especially $^{14}$C) need long spin-ups. Approximately 10,000 years or more. Need a fast-spin up technique to make them useable for frequent science applications.

OCMIP2 definition of equilibrium:
- For DIC, the globally integrated air-sea flux should be less than 0.01 Pg C/yr: After 6000 years, it is - 0.0414 Pg C/yr ✗
- For $^{14}$C, 98% of the ocean volume should have a drift of less than 0.001 permil/year: After 6000 years, it is only around 18.5% ✗
Fast spin-up of abiotic radiocarbon with Newton-Krylov technique

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

After 6000 model years
(3° model, took ~2.5 months)

Plots courtesy of Keith Lindsay, NCAR
Simulated 1990s “zonal” averages of $\Delta^{14}C$
Simulated 1990s zonal “mean” $\delta^{13}$C
Freshwater hosing experiments

- Baseline exp., extended from spin-up simulation at year 2000

- Freshwater hosing of 0.25 Sv per year in North Atlantic, for 200 year
Freshwater hosing experiments

Oppo and Curry, 2012

Shallow

Deeper

FW hosing

No hosing

Western Atlantic Glacial $\delta^{13}C$ (PDB)

Western Atlantic H1 Average $\delta^{13}C$ (PDB)

Western Atlantic GEOSECS $\delta^{13}C$ (‰ PDB)

Oppo and Curry, 2012
Summary

- Abiotic $^{14}$C and biotic $^{13}$C and $^{14}$C have been added to the ocean model of the CESM
- Initial results for present day look good in comparison with observations
- First sensitivity experiments with freshwater hosing to shut down AMOC show a $\delta^{13}$C signature generally consistent with reconstructions in the North Atlantic for glacial times
- A fast spin up technique is key in order to use the carbon isotopes in the ocean (and the marine ecosystem model in general) for paleo applications and to further test the model sensitivities
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
- Release of carbon isotope code planned for the 2015 CESM1.3 release
Future work

- Investigate relationship between $\delta^{13}C$ and physical model variables
- Add Pa/Th to the model
- Apply the fully-coupled iCESM to the LGM
- Perform isotope enabled iTRACE (21 ka to present)
Thanks!

Contact: ajahn@ucar.edu
Simulated 1990s surface $\Delta^{14}C$
Simulated 1990s surface $\delta^{13}C$

Schmittner et al., 2013 data compilation

Gruber et al., 1998

Biotic
Model Corals

Present-day “global” depth profiles

DIC

$\delta^{13}C$

$\Delta^{14}C$
Present-day global depth profiles

**DIC**

- Abiotic
- Biotic
- GLODAP
- Schmittner et al.

**δ^{13}C**

**Δ^{14}C**