Carbon Isotopes in the iCESM

Alexandra Jahn

Collaborators: Keith Lindsay, Mike Levy, Esther Brady, Synte Peacock, Bette Otto-Bliesner

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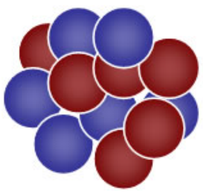
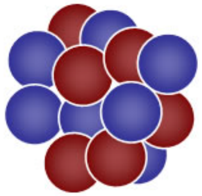
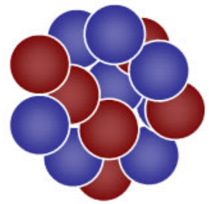
Carbon Isotopes and their usefulness



^{12}C
6 protons
6 neutrons
(stable)



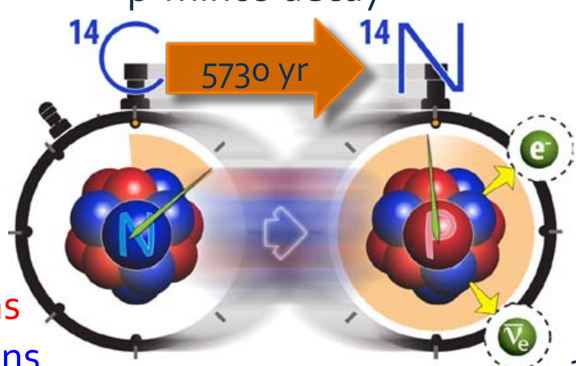
^{13}C
6 protons
7 neutrons
(stable)



^{14}C
6 protons
8 neutrons
(radioactive)

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

β-minus decay

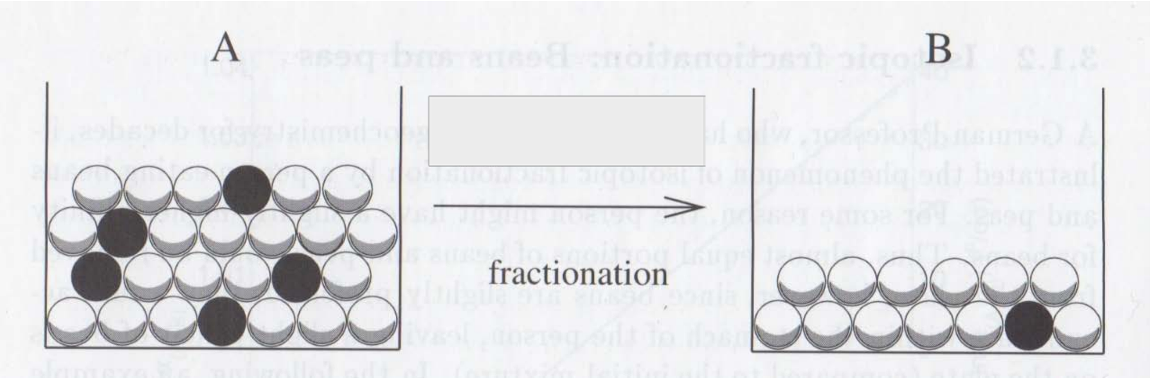


electron
7 protons
7 neutrons
antineutrino
6 protons
8 neutrons

^{14}C acts as clock

Fractionation

- **Equilibrium Fractionation:** The heavier isotope generally preferentially accumulates in the element in which it is bound most strongly
- **Kinetic Fractionation:** The lighter isotopes react more readily and become concentrated in the products, and the residual reactants become enriched in the heavy isotopes. Biological proceeesses (e.g., photosynthesis) are kinetic reactions



Delta Values

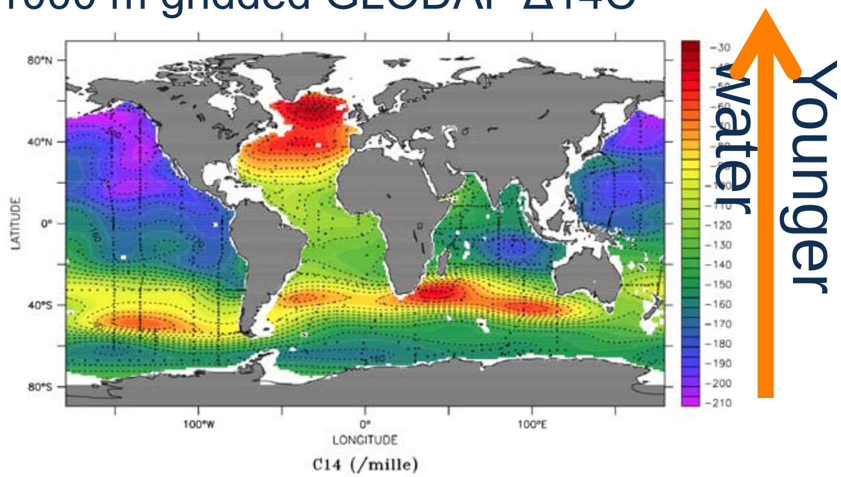
- Measured isotope ratios are expressed as delta (δ) values, calculated relative to a known standard.

  $\delta(‰) = (R_{sample} – R_{standard})/R_{standard} \times 1000$

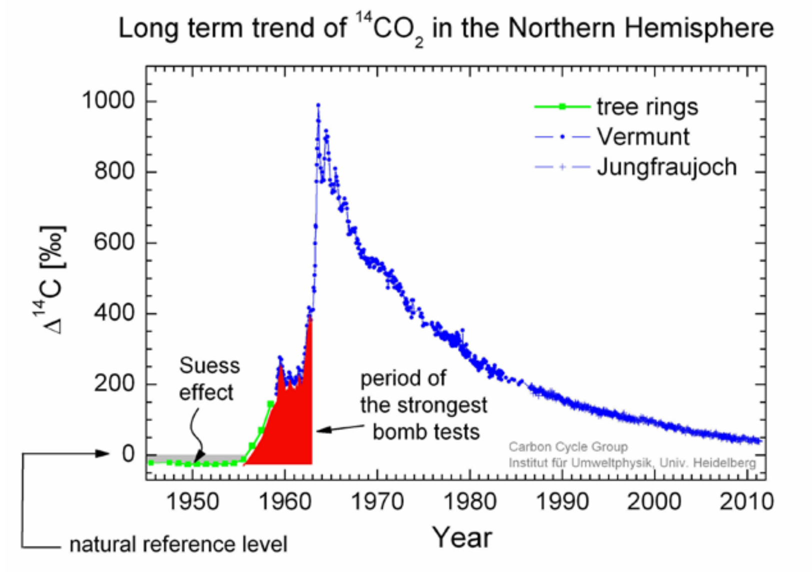
  where R is the measured isotopic ratio (e.g., $^{13}C/^{12}C$).

Examples of $\Delta^{14}C$ as ocean tracer

1000 m gridded GLODAP Δ14C

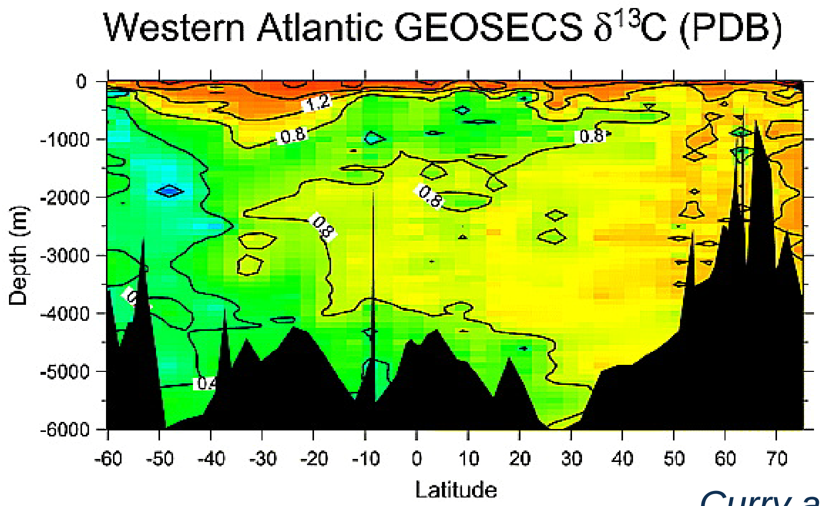


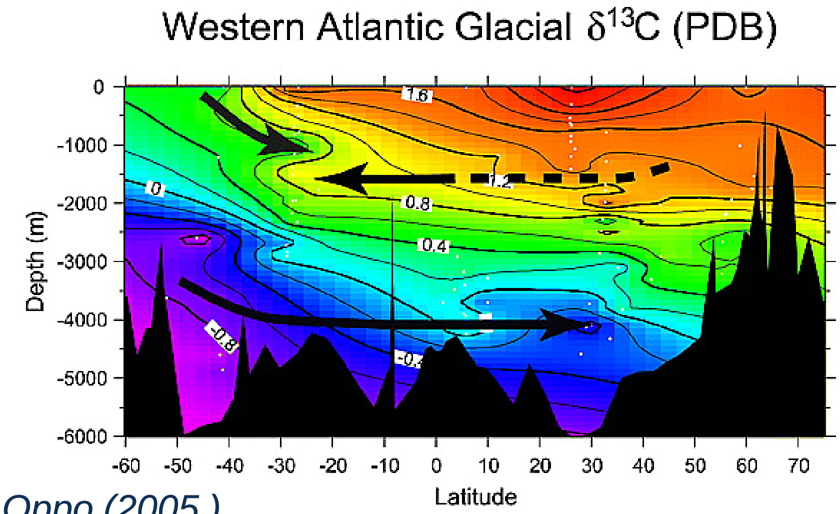
$\Delta^{14}C$ = Activity ratio relative to a standard



- $\Delta^{14}C$ is used as proxy for the age of water masses, circulation timescales, and to infer past and present ocean water ages
- Bomb $\Delta^{14}C$ is used to infer recent ocean ventilation (like CFCs) and oceanic carbon uptake

Examples of δ^{13}C as ocean tracer

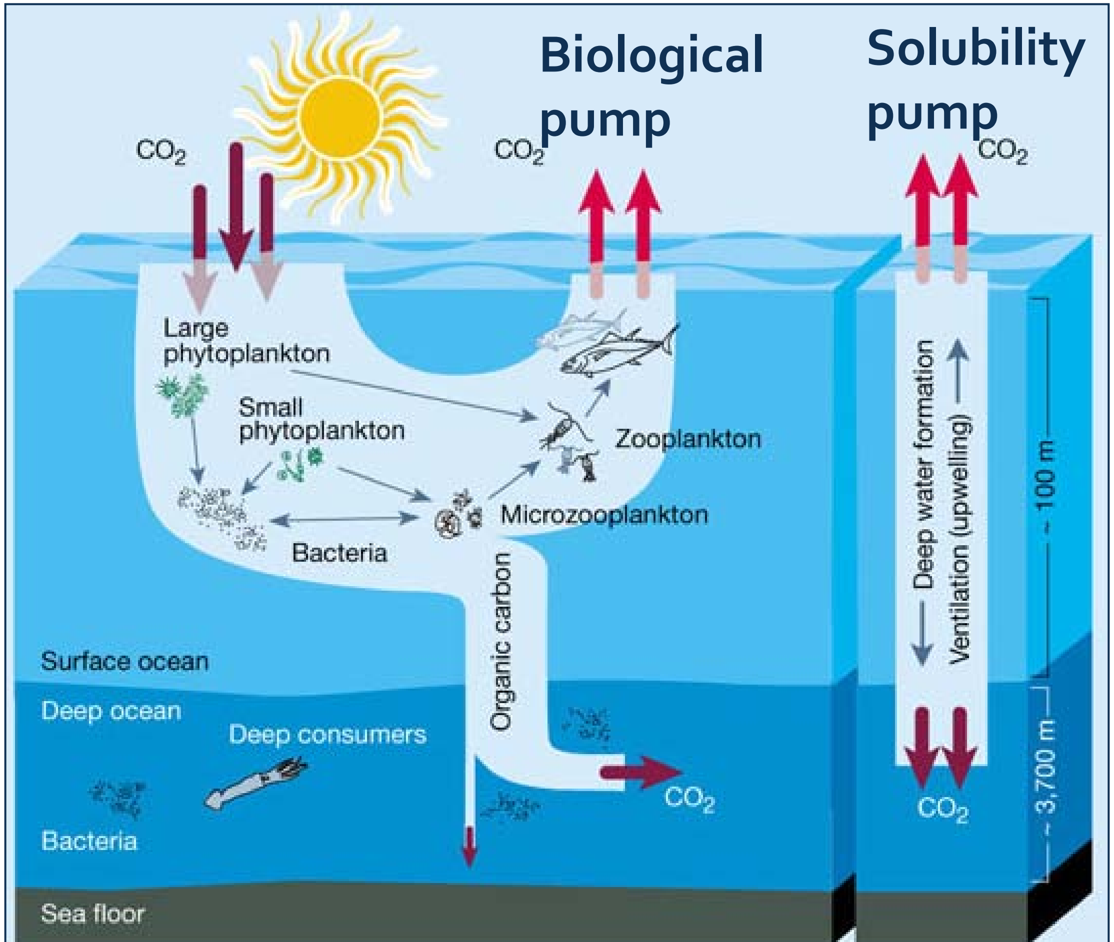




Curry and Oppo (2005)

- δ^{13}C is used to infer paleo ocean water masses (e.g., NADW)
- δ^{13}C can be used as tracers of carbon cycle processes → e.g., used to diagnose the oceanic uptake of anthropogenic CO_2

Carbon isotopes in POP2

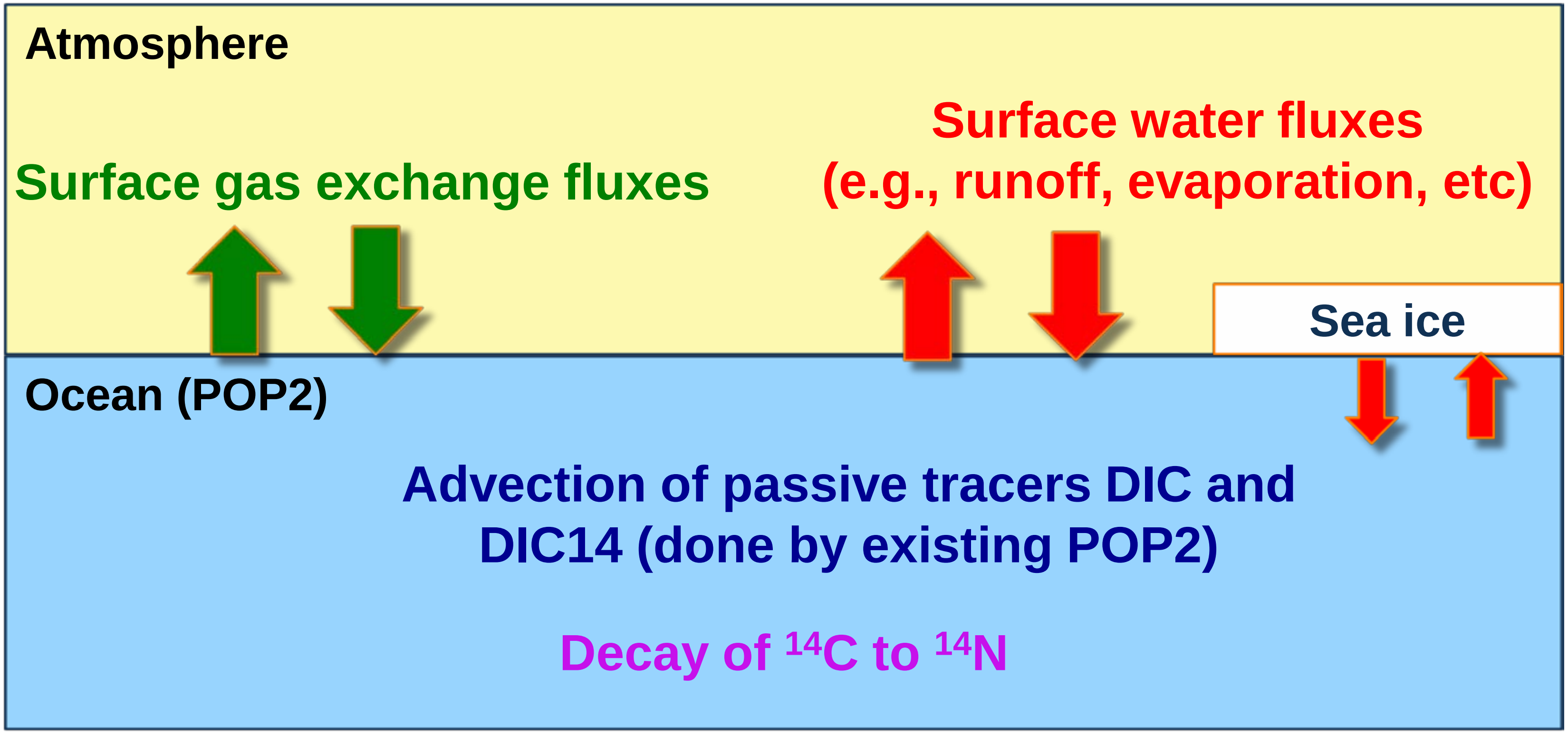


Source: S. Chisholm, Nature, 2000

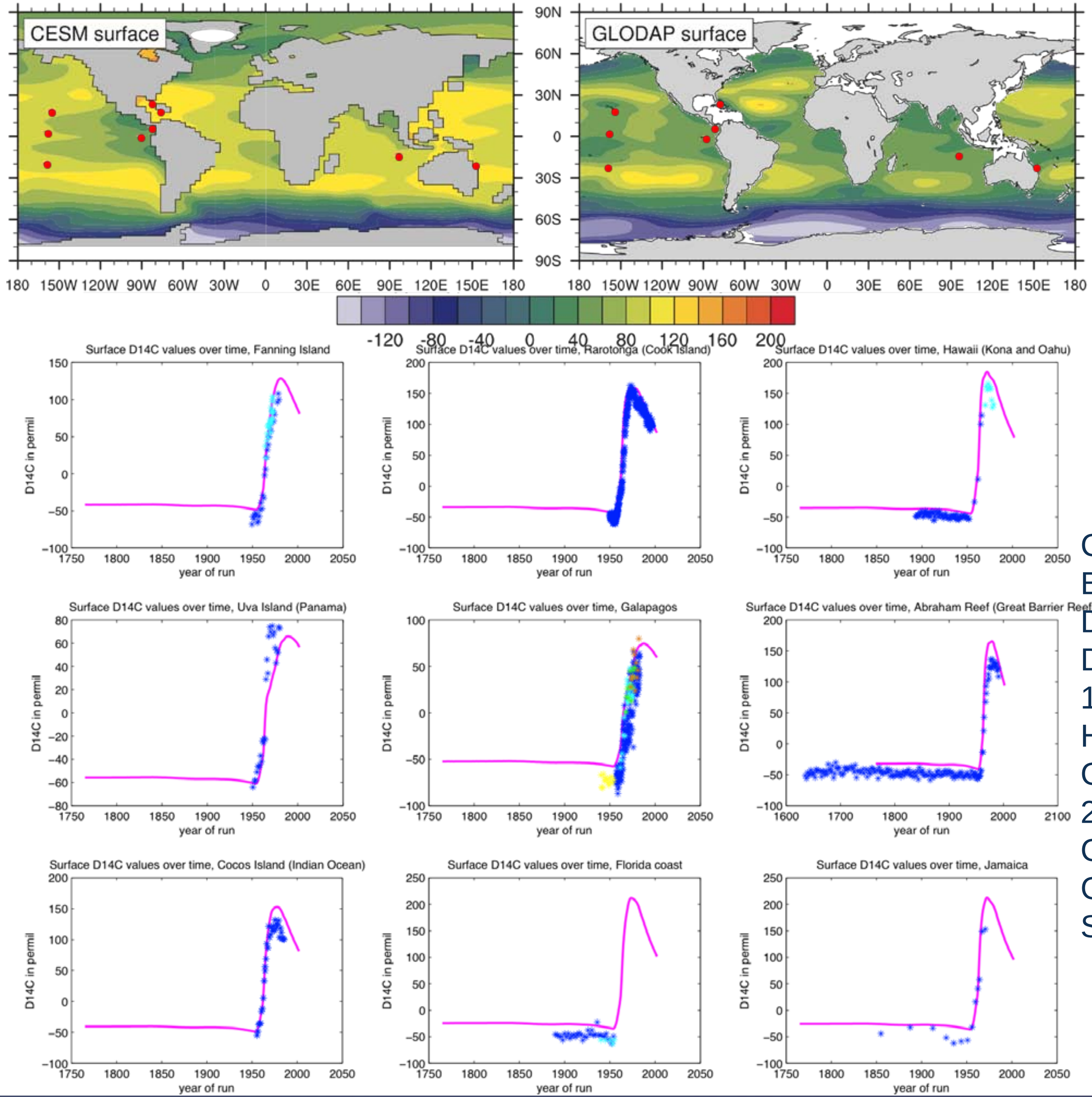
1. **Abiotic ^{14}C in DIC in POP2** (solubility pump only)
   → follow OCMIP2 protocol

2. **Biotic ^{14}C and ^{13}C in POP2** (solubility and biological pump)
   → base code on ^{13}C code from ETH (Gruber et al) for POP1
   → Add biotic ^{14}C

Oceanic abiotic ^{14}C tracer module



Total surface ocean 1990-98 $D^{14}C$



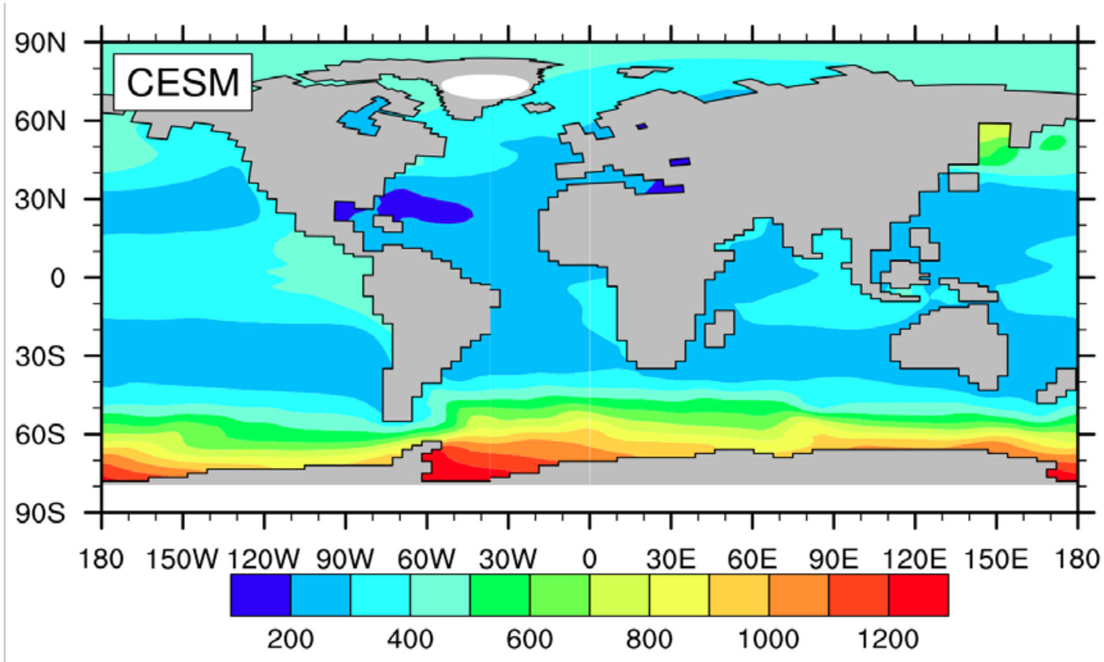
Model

Corals

Corel data from: Benavides, and Druffel. 1986,, Druffel 1980/81/82/87/97, Hua, et al 2005, Guilderson et al. 2000, Druffel and Griffin 1999, Guilderson, and Schrag 1998

^{14}C ages and ideal ages in the model

Average surface ^{14}C age=366 years



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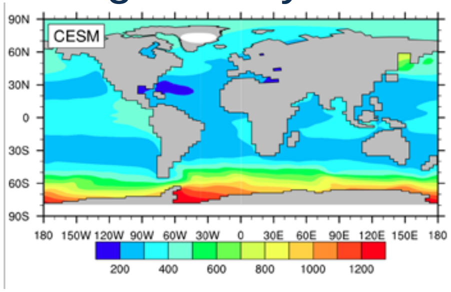
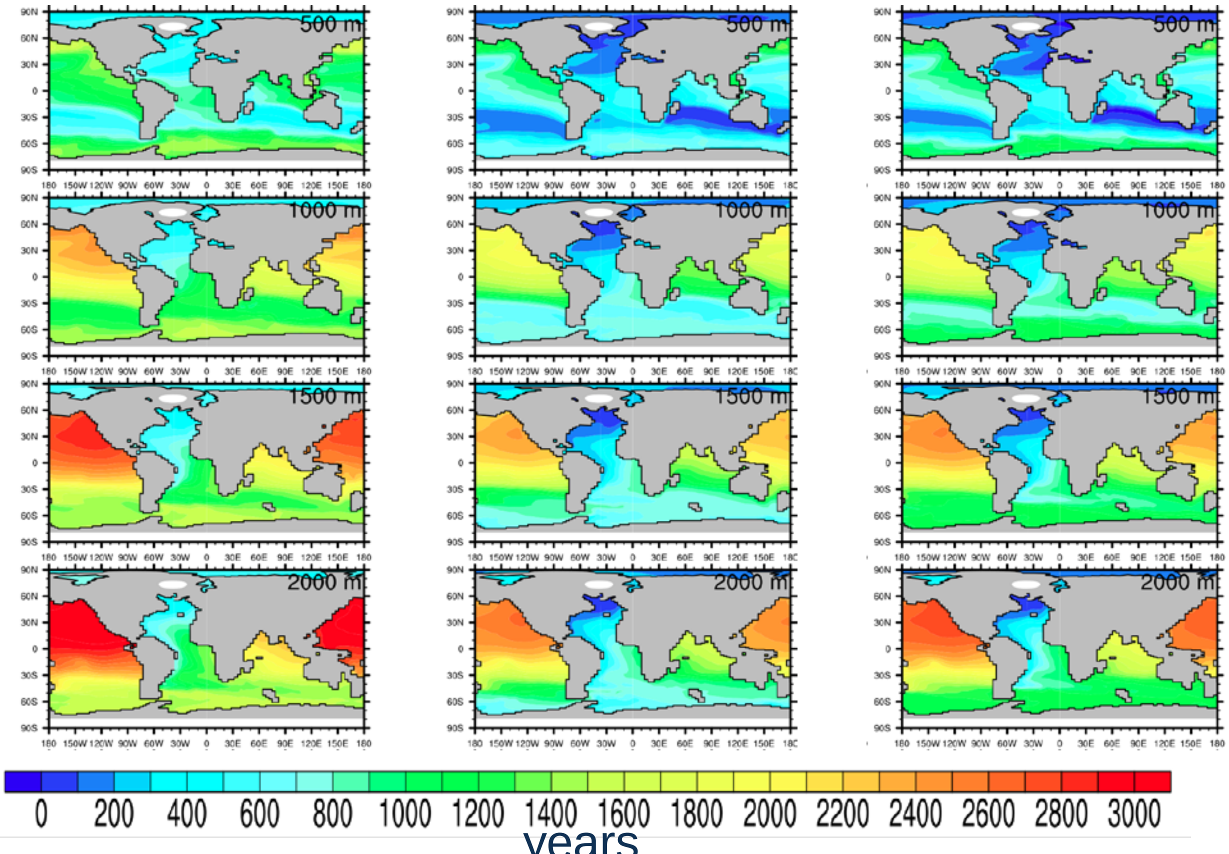


^{14}C age

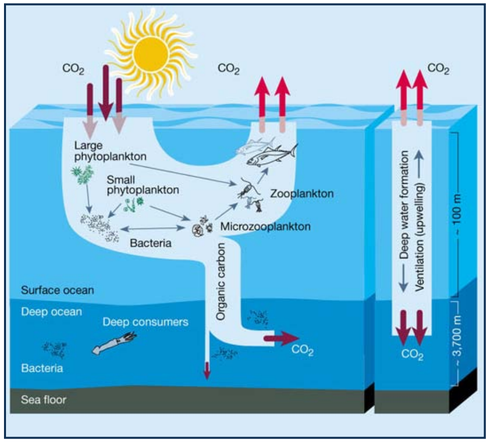
Ideal Age

Surface-corrected ^{14}C age



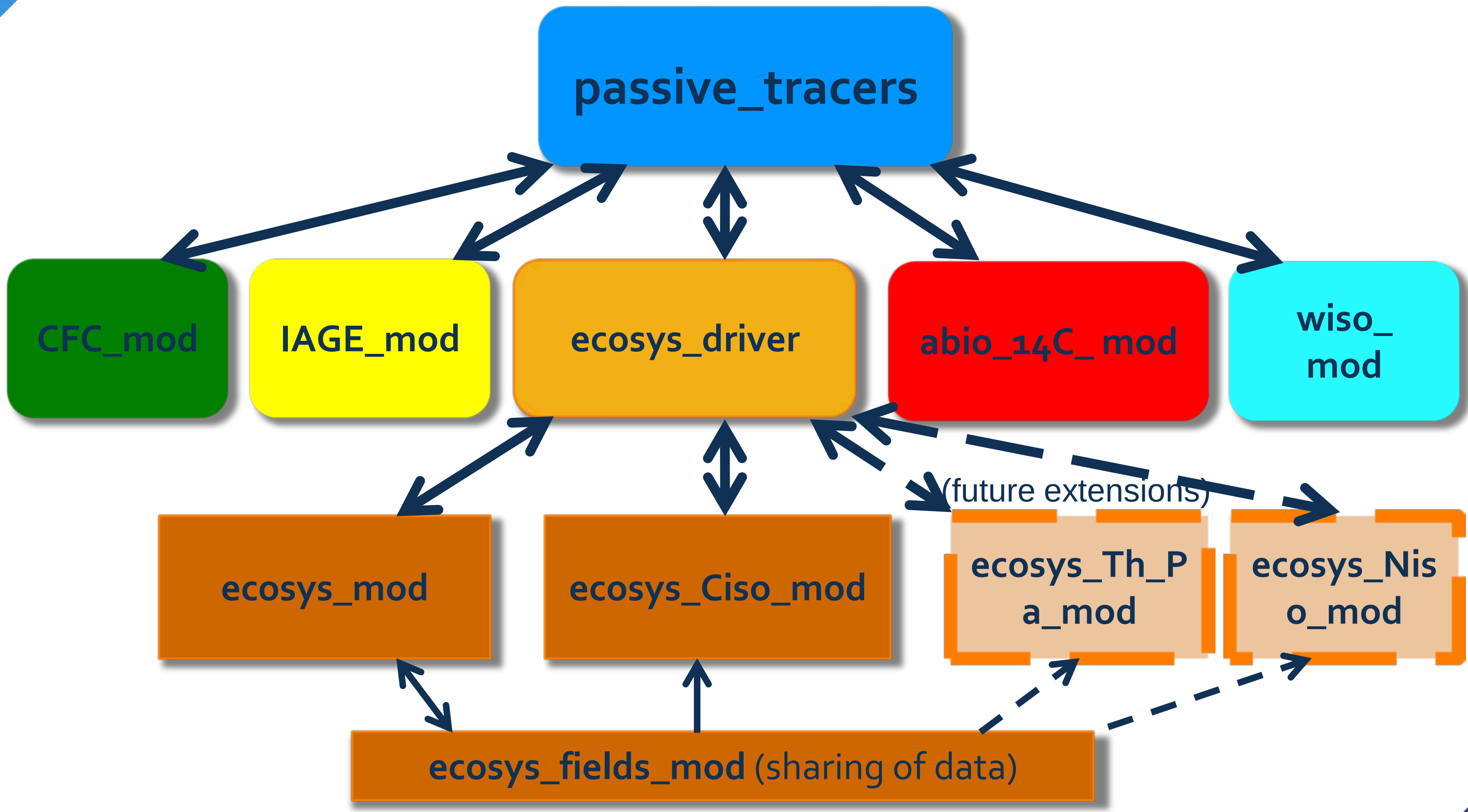
Adding the biological pump

- Currently there are 7 carbon pools in the ecosystem model (DIC, DOC, small phytoplancton, diatoms, diazotrophs, zooplankton, $CaCO_3$)
- Each Carbon isotope adds 7 tracers
  - Currently the ecosystem model has 24 tracers
  - 14 additional carbon isotopes add a considerable expense (>50% increase in number of tracers)
  - → Carbon isotopes need to be an optional feature



"Complete"
=
Include both biological effects and solubility effects

Addition of biotic ^{13}C and ^{14}C to POP2



Future work

- Finish addition of ^{13}C and ^{14}C and test implementation
  - How large is the difference for ^{14}C between the abiotic module and the "complete" ^{14}C module?
- 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
- Spin-up all tracers for use in the the 1 degree coupled CESM → need fast spin-up technique (Keith Lindsay, NCAR)
- Include tracers in iTraCE simulation for LGM to present
  - 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 tracer fields

Thanks!

Contact: ajahn@ucar.edu

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