Development of an isotope-enabled CESM for studying abrupt change

*Bette Otto-Bliesner, Zhengyu Liu, and iCESM Team****




U.S. DEPARTMENT OF ENERGY
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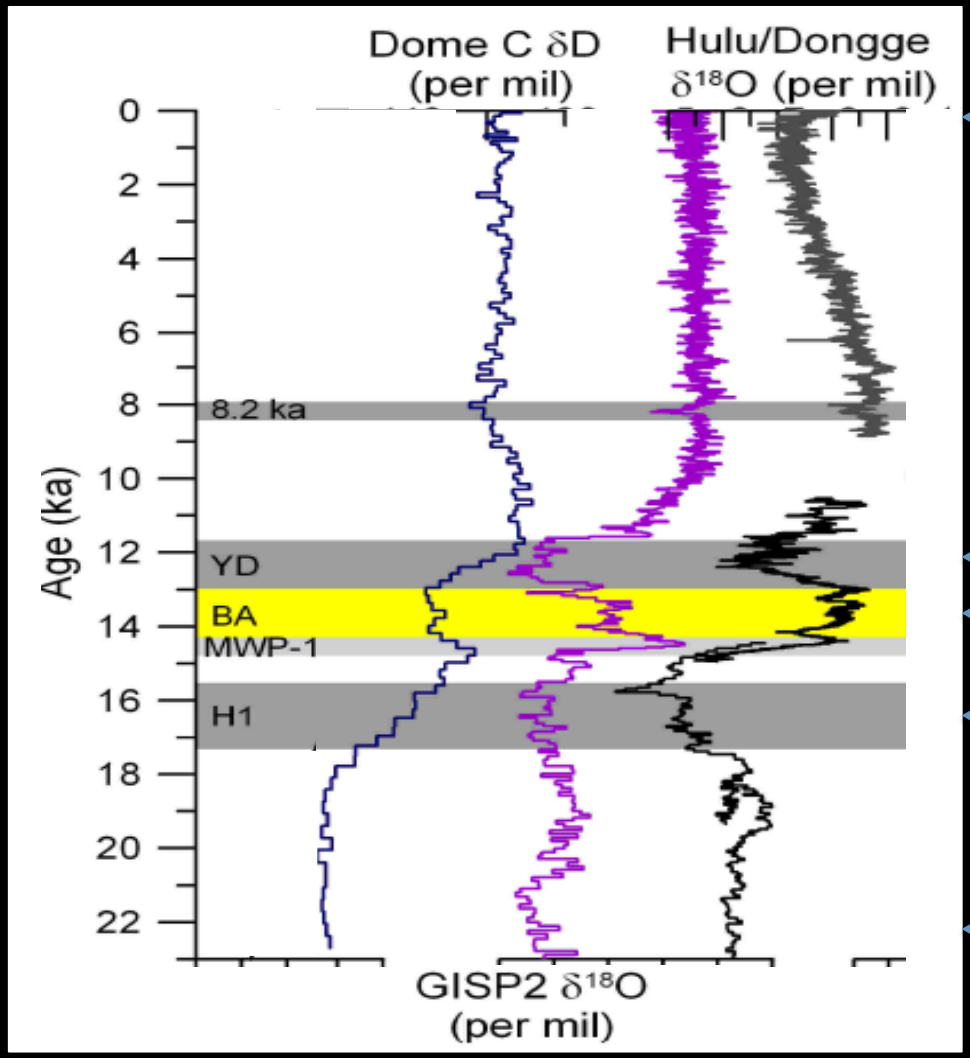
Abrupt changes of last 21,000 years



Present

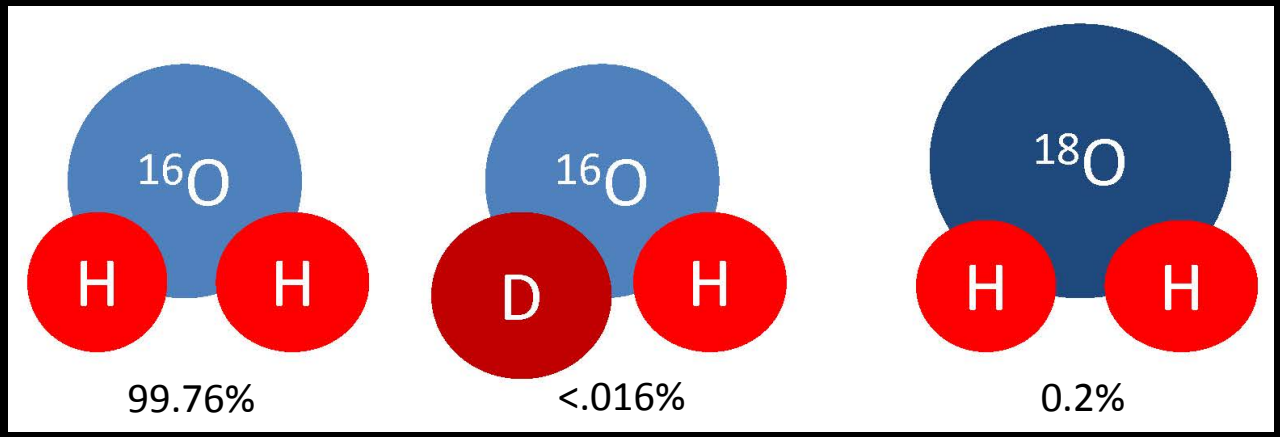
Younger Dryas

Bolling-Allerod

Heinrich 1

Last Glacial Maximum

Background



(Similarly for carbon isotopes: ^{12}C 98.89%, ^{13}C 1.11%, ^{14}C <0.01)

Temperature effect: (mostly high latitudes)

Greenland ice cores: $\Delta Temp/\Delta\delta^{18}O$= 3°C / ‰ calibrating Borehole Temps

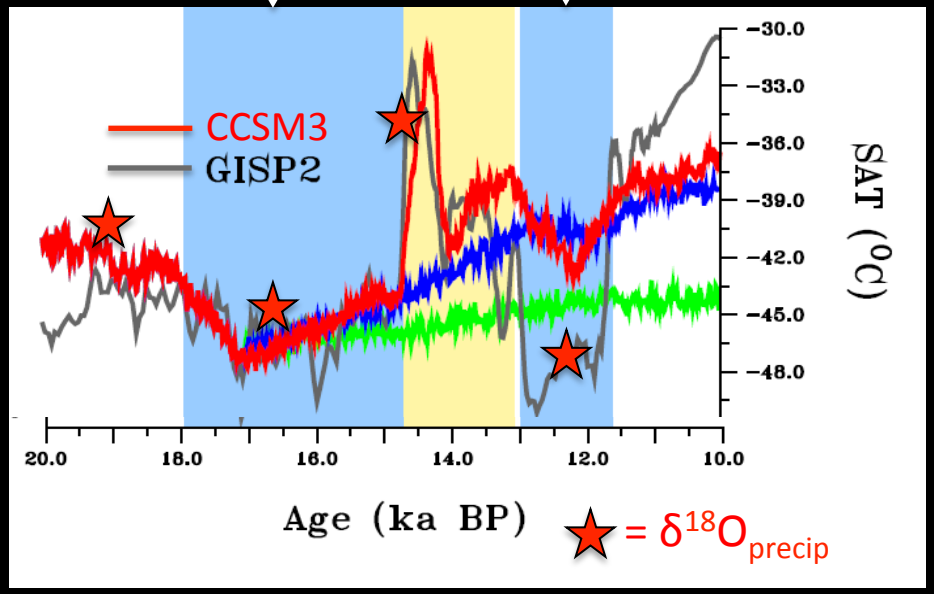
Precipitation amount effect: (mostly low latitudes)

Chinese cave speleothems: $\Delta\delta^{18}O$ ~ ΔRegional Precip (negative correlation)

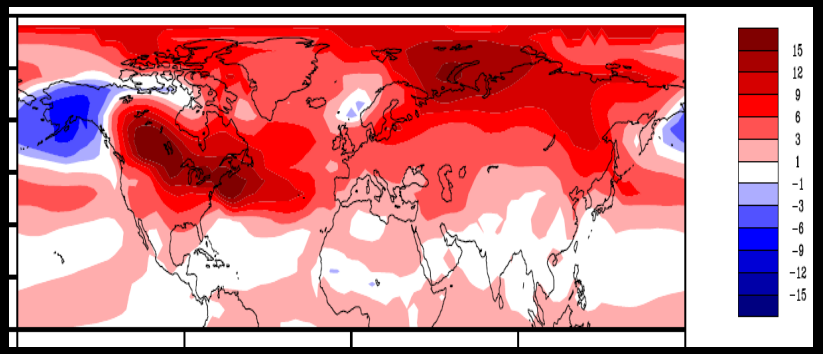
Ice core $\delta^{18}O$ versus Greenland temperature

Large amts of meltwater into N. Atl
Data and CCSM3: AMOC shutdown

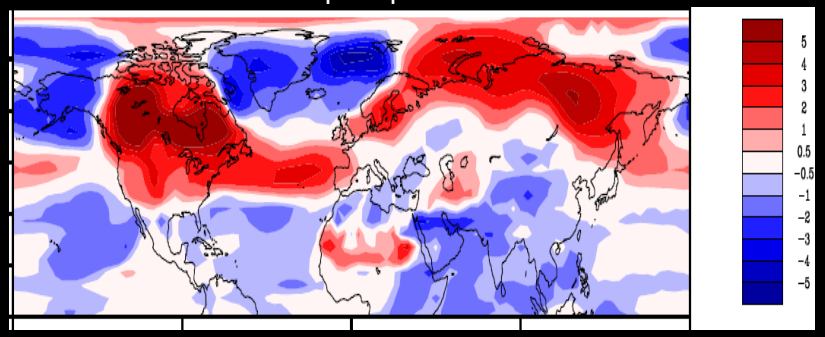
Heinrich 1 Younger Dryas



Δ Surface temperature : YD – H1

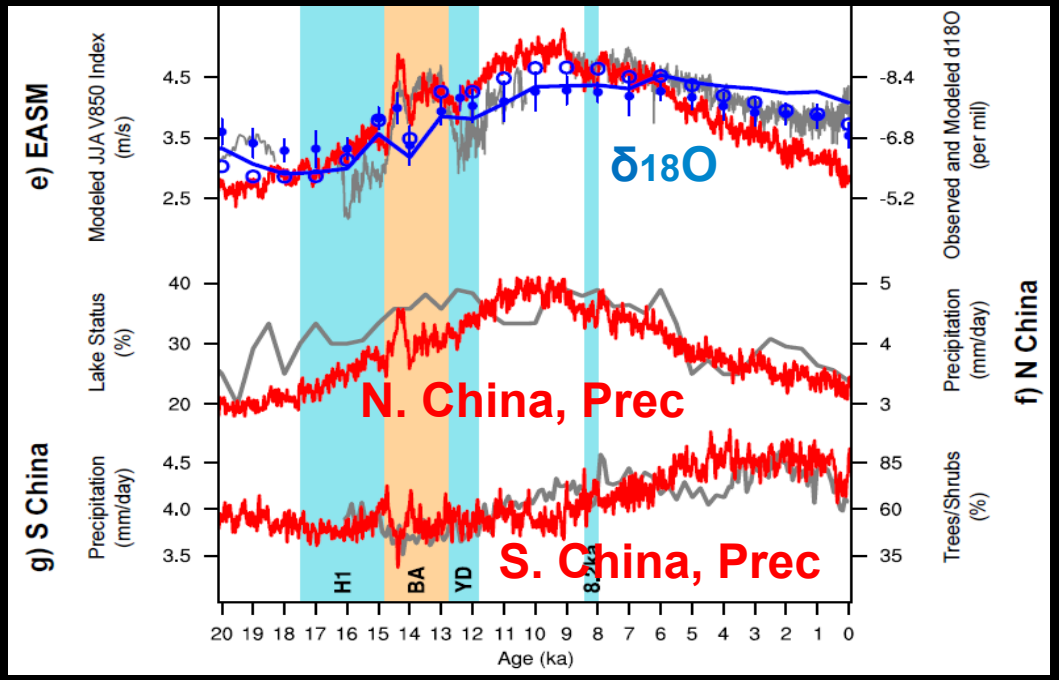


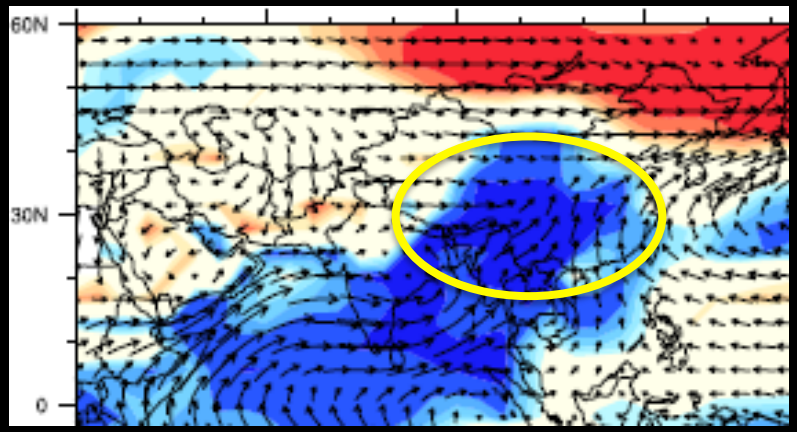
Δ $\delta^{18}O_{precip}$: YD – H1



Liu et al., 2012, PNAS

Chinese cave $\delta^{18}O$ versus local precipitation





- Spatial coherence larger in $\delta^{18}O$ than Precipitation
- Remote source of $\delta^{18}O$
- Intensified East Asian monsoon reflected in enhanced transport

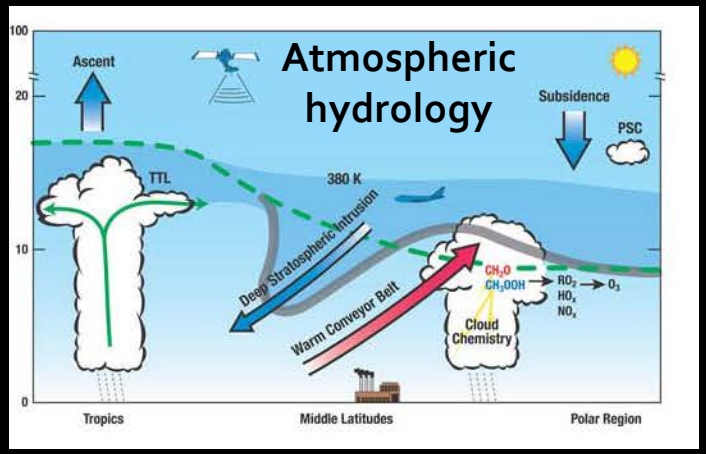
Liu et al., QSR, 2014

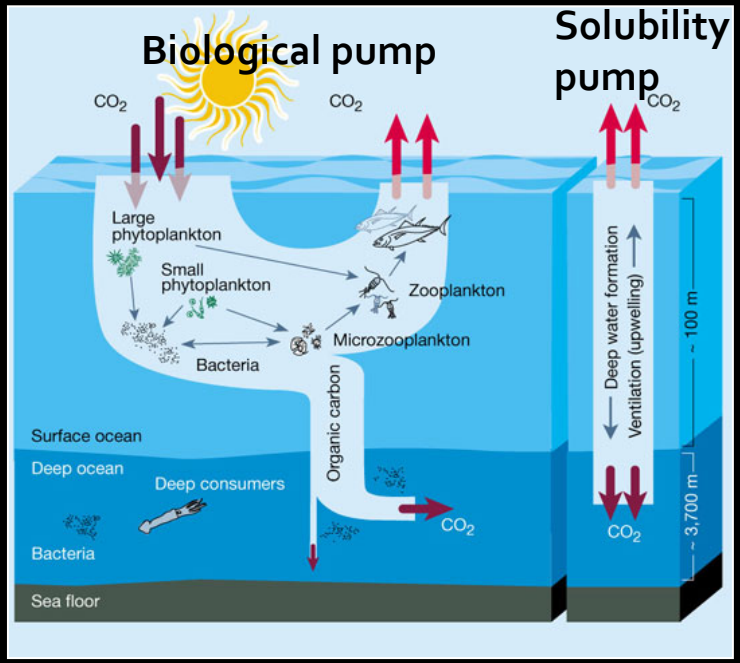
Project iCESM

COMPLEXITY:

Advection of isotopes but also fractionation during a chemical or physical process

Importantly need to incorporate into physical and biological components

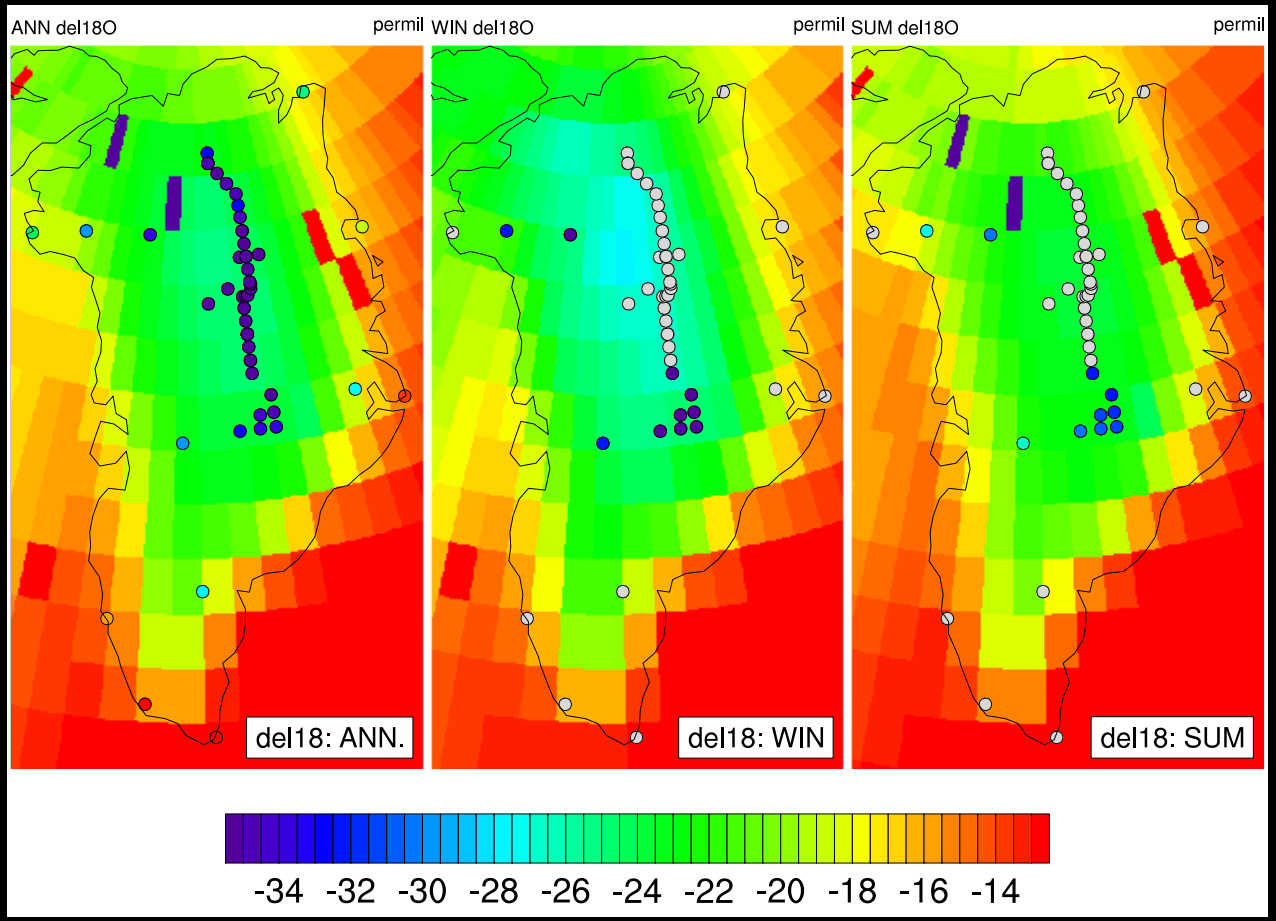




Some of our successes so far …..

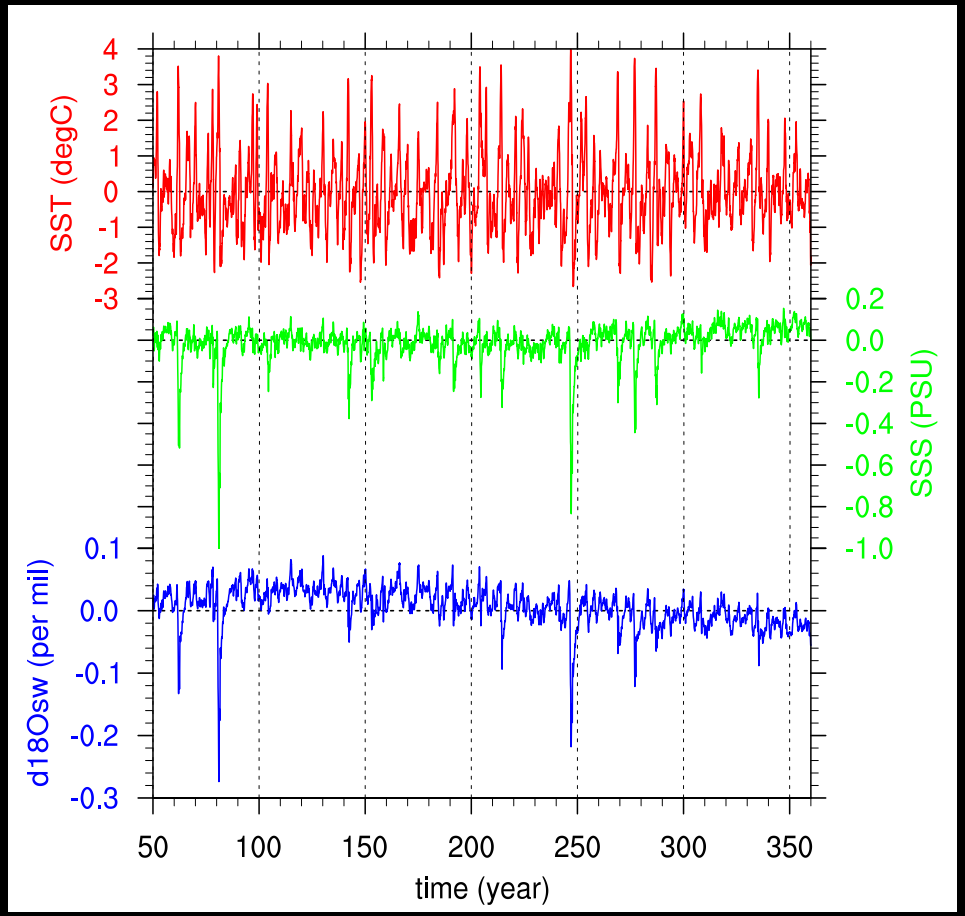
$\delta^{18}O$ simulation with iCAM5 (FV2)

Greenland



Noone, Nusbaumer, and Faber: Univ Colorado

$\delta^{18}O_{sea\ water}$ simulation with iCAM5 + iPOP2
Nino 3.4 region

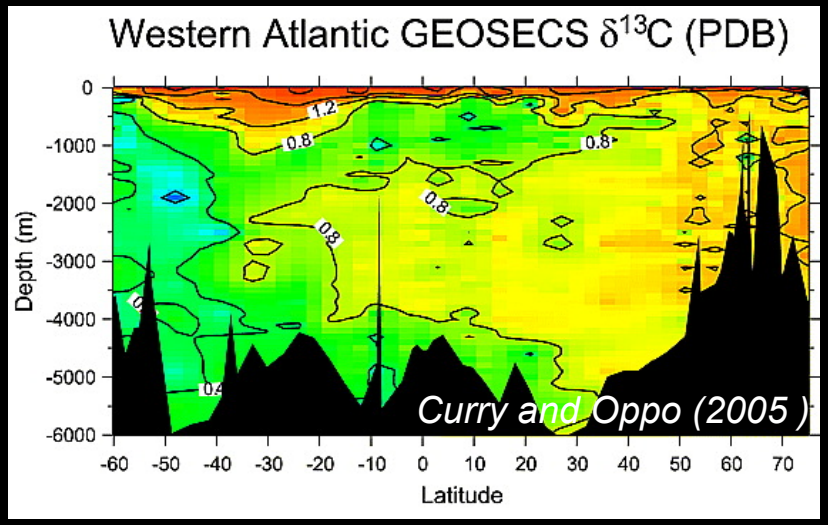


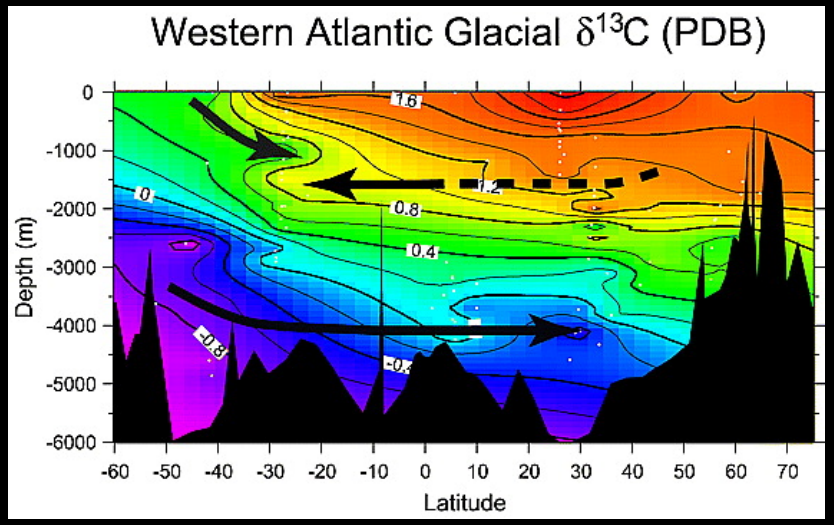
- Very large warm events are associated with large negative excursions of SSS and $\delta^{18}Osw$
- Non-linearity occurs with large ENSO-related precipitation events with implications in reconstructing magnitudes of SST anomalies from corals
- Simulated $\delta^{18}Osw$ plus forward proxy modeling will allow direct comparison to coral reconstructions

Brady and Zhu: NCAR

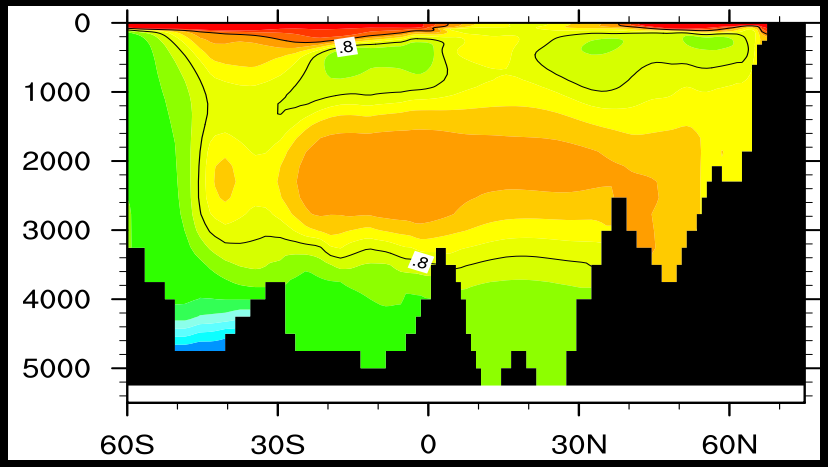
$\delta^{13}C$ simulation with iPOP2-BGC
Western Atlantic

Observations





iPOP2-BGC



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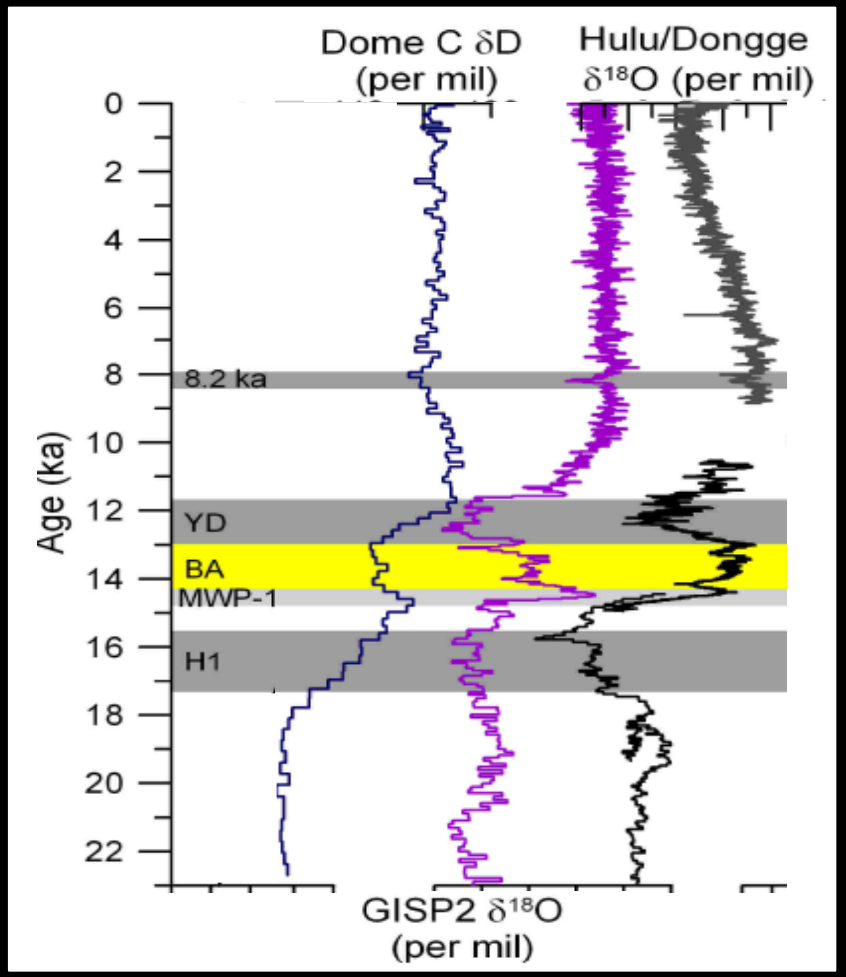
Jahn: NCAR

Status of isotopes and geotracers iCESM

	Atm	Lnd	Runoff	OCN	OCN-Eco	Sea Ice	Land Ice	CPL
Water isotopes	✔	Soon	Soon	✔	–	Soon	planned	✔
Carbon ^{14}C	planned	✔	*prescribed*	✔	✔	–	–	planned
^{13}C	planned	✔	*prescribed*	–	✔	–	–	planned
Pa/Th	–	–	–	In progress	In progress	–	–	–
Nd	–	–	–	In progress	In progress	–	–	–

Next step: iTraCE-21 simulation

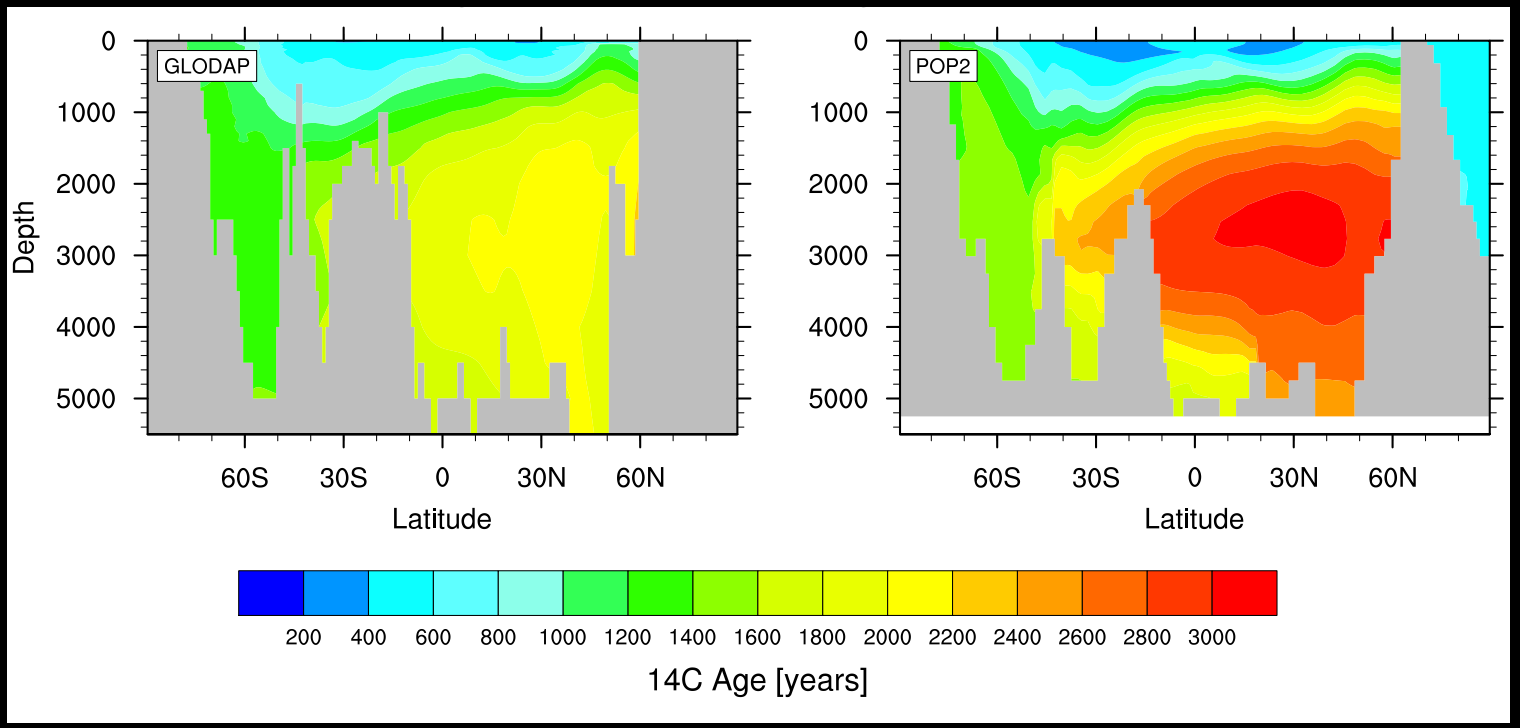
- iCESM should be ready in next few months to let us evaluate the skill of CESM, the interpretations of the proxies, and the mechanisms associated with abrupt changes of the last 21,000 years
- Also even more detailed assessment of climate variability of the Holocene and Last Millennium



Isotopes also very useful for model development and understanding the present…..

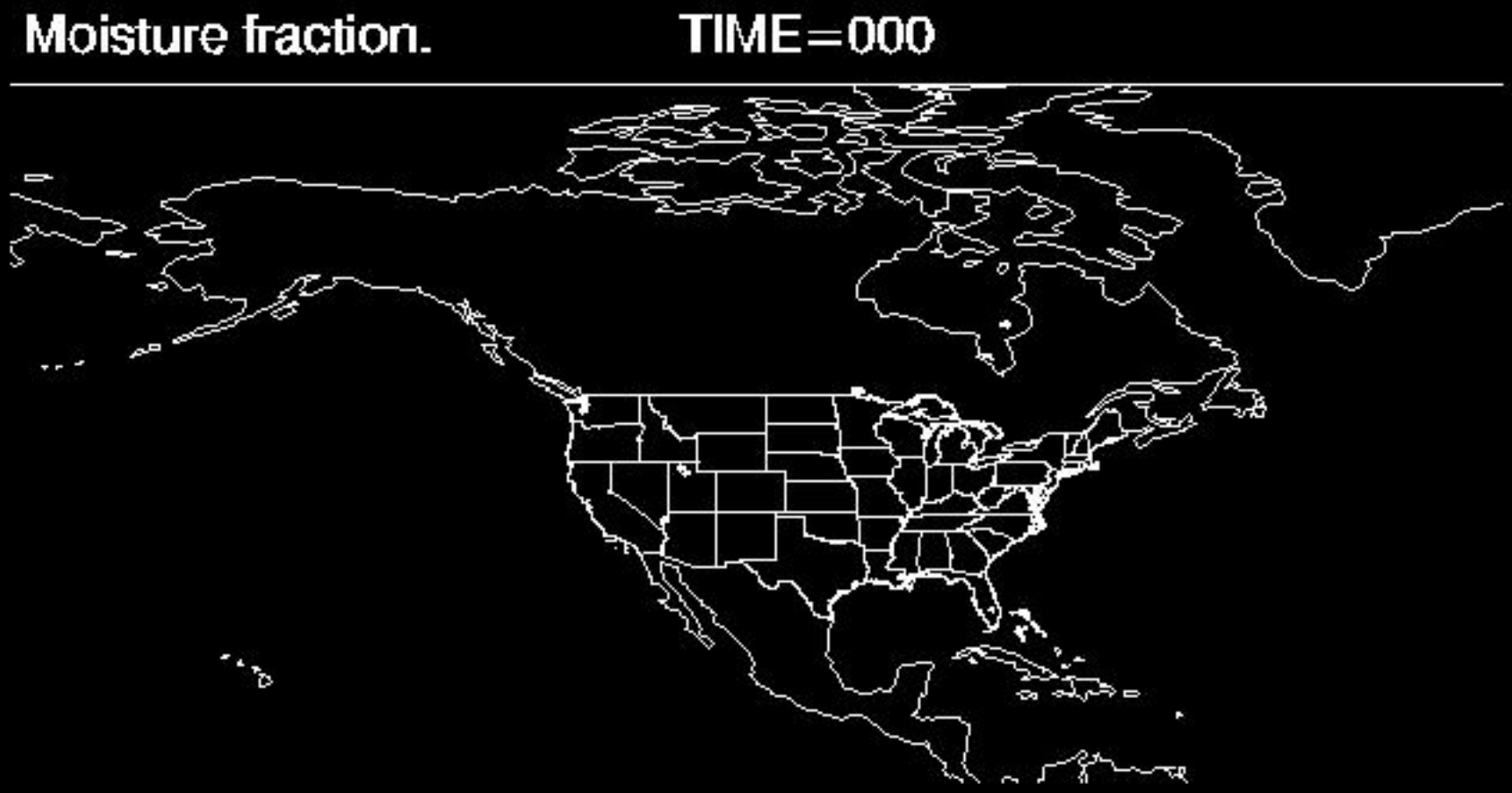
Radiocarbon ^{14}C as diagnostic tool for the physical ocean model

Central Pacific (179.5°W)



Jahn: NCAR

Tagging source regions of water



Blue = North Pacific moisture Green = North Atlantic moisture Red = Land moisture

Noone and Nusbaumer: Univ Colorado

An Isotope-Enabled CESM

Bette Otto-Bliesner[1], Zhengyu Liu[2], Esther Brady[1], Alexandra Jahn[1], Fortunat Joos[3], Keith Lindsay[1], David Noone[4], Bill Riley[5], Mariana Vertenstein[1], David Bailey[1], Anil Bozbiyik[3], Andrew Gettelman[1], Charles Koven[5], Jesse Nusbaumer[4], Jinyun Tang[5], Xinyu Wen[2], Tony Wong[4], Jiaxu Zhang[2], Jiang Zhu[2]

1. National Center for Atmospheric Research, Boulder, 2. University of Wisconsin, Madison, 3. University of Bern, Switzerland, 4. University of Colorado, Boulder, 5. Lawrence Berkeley Laboratory

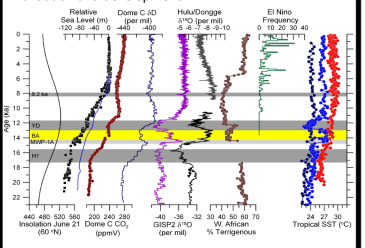
Room 20
#90

Project Overview

~ Past climates display numerous examples of thresholds and abrupt changes.

~ Validation against past proxy records requires geochemical tracers to be directly simulated.

~ An isotope-enabled CESM (iCESM) is a new tool for validation and development.



Project Goals:

~ To enhance the CESM with the capability of simulating key isotopes and geotracers, notably $\delta^{18}O$, δD, Pa/Th, $\delta^{14}C$, and $\delta^{13}C$.

~ To perform transient simulations to test the iCESM directly against proxy records of the last 21,000 years, especially on major abrupt events and onset/collapse of monsoon-ecosystem systems.

~ To understand the mechanisms for the abrupt changes in the CESM.

Motivation: Asian Monsoon

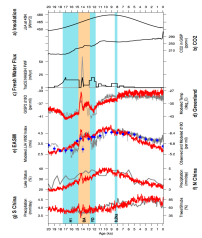


Figure shows the evolution of climate and $\delta^{18}O$.
(a) Summer insolation (b) CO_2, (c) Meltwater fluxes (d) Hulu $\delta^{18}O$ (grey), northerly wind (red) and snapshot model $\delta^{18}O$ (blue) in E. China, (e) lake status (grey) and model rainfall in northern China, (f) pollen records (grey) and model rainfall (red) in Southeast China. (Liu et al., 2014)

- A study using isotope-enabled CAM3 snapshot simulations driven by TraCE21 provides an interpretation of the Chinese cave speleothem $\delta^{18}O$ record that reconciles its representativeness of EASM and its driving mechanism of upstream depletion.
- The $\delta^{18}O$ records do represent the intensity of the EASM system.
- Enhanced southerly monsoon winds correlate strongly with negative $\delta^{18}O$ over China and enhanced monsoon rainfall in northern China, as well as continental scale Asian monsoon rainfall response in upstream regions.

Simulations

Experiment	Grid	# yrs	Status
Water Isotopes			
1850 iCAM5 (SST & ice)	FV45	30	*Complete*
1850 iCAM5 (SST & ice)	FV2	30	*Complete*
1990 iPOP2 (CORE2 & GNIP)	3° grid	500	*Complete*
1850 iCAM5+iPOP2 Coupled	FV2_gx1	360	*Complete*
1850 iCAM5+iPOP2 Coupled	FV45_gx3	397	*Complete*
1990 iCAM5+iCLM4	FV45	30	*In Progress*
1850 iCAM5+iCLM4+iRTM	FV2_gx1	30	*Planned*
AMIP iCAM5+iCLM4 resolution sensitivity studies	FV2, FV1, FV.5, FV.25	4x50	*Planned*
Carbon Isotopes			
1765 abiotic ^{14}C iPOP2 spin-up	3° grid	6000	*Complete*
1765-1950 abiotic ^{14}C iPOP2	3° grid	185	*Complete*
1950-2007 abiotic ^{14}C iPOP2 bomb-spike sensitiv.	3° grid	4x60	*Complete*
1765 Biotic ^{13}C and ^{14}C iPOP2 spin-up in cesm1.0.5	3° grid	2400	*Complete*
1765-2007 Biotic ^{13}C and ^{14}C iPOP2 in cesm1.0.5	3° grid	242	*Complete*
1765 Biotic ^{13}C and ^{14}C iPOP2 spin-up in cesm1.2.1	3° grid	2100	*In progress*
1765-2007 Biotic ^{13}C and ^{14}C iPOP2 in cesm1.2.1	3° grid	242	*Planned*
Hosing experiments with C-isotopes	3° grid	500	*In progress*
Last Millennium transient with abiotic ^{14}C	FV2_gx1	1000	*Planned*
LGM snapshot with biotic & abiotic C-isotopes	1° grid	1000	*Planned*
All isotopes			
LGM spin-up simulation with isotopes	FV2_gx1	1000	*Planned*
iTRACE simulation (24 ky to 11ky)	FV2_gx1	13000	*Planned*

The iCESM

Water isotopes implemented (in progress/planned) in: POP2, CAM5, CLM4, (CICE4), (RTM), CPL7

Carbon isotopes implemented (in progress/planned) in: POP2, CLM4.5, (CAM5)

Pa/Th and Neodymium geotracers in POP2

The CESM* model

**CESM is a fully-coupled, community, global climate model that provides state-of-the-art computer simulations of the Earth's past, present, and future climate states.*

Isotope Definitions

Notation:

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

$\delta(‰) = (R_{sample}/R_{standard} - 1) \times 1000$

where R is he measured isotopic ratio relative to the most abundant isotope (e.g., $R=^{13}C/^{12}C$ or $R=^{18}O/^{16}O$).

- Negative δ → depleted relative to the standard
- Postive δ → enriched relative to the standard

Fractionation:

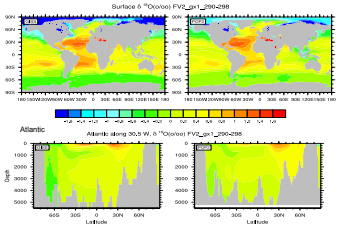
- Fractionation refers to the small differences in isotopic ratio that arise as a result of different behavior during a chemical or physical (thermodynamic) process.
- Examples of processes that lead to fractionation include photosynthesis, evaporation/condensation, melting/crystallization, adsorption/desorption.

Water Isotopes

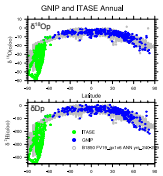
Development of Water isotope Tracers in CESM

Water isotope tracers for $H_2{}^{18}O$ and $^1H^2HO$ (HDO) have been added to the CAM5 (Nusbaumer et al. 2013), POP2, CLM4, and the coupler, CPL7. Testing is underway in the CICE model, and isotopic river transport in RTM is in development. Initial results are shown for the iCAM5 coupled to iPOP2 in a preindustrial climate simulation at the FV2_gx1 resolution.

Preliminary Coupled iCESM Results



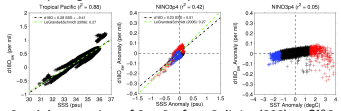
Simulated annual mean $\delta^{18}O$ distribution in the surface ocean (top panels) and the Atlantic Ocean at 30W (bottom panels) is in good agreement with LeGrande and Schmidt (2006) data shown in left panels.



The latitudinal distribution of the isotopic composition of iCAM5 precipitation in the coupled simulation compares well to the GNIP and ITASE observations in tropics and mid-latitudes. The high latitude regions show a positive bias.

Application of Water Isotopes in the iCESM

Investigating isotope-climate relationships assumed in proxy reconstructions may help improve the interpretation of isotopic signals measured in paleoclimate records.



- Spatial regression of Sea Surface Salinity (SSS) to $\delta^{18}O_{sw}$ (left) compares well to data in the tropical Pacific. [This relationship is often used to estimate $\delta^{18}O_{sw}$ in forward coral proxy models if salinity is known.]
- Temporal regression of SSS to $\delta^{18}O_{sw}$ in the Nino3.4 region is close to the observed spatial slope (center).
- Large Warm events can show large negative $\delta^{18}O_{sw}$ anomalies.

Carbon Isotopes

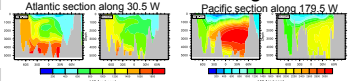
Development of Carbon isotopes in the ocean model

Two kinds of carbon isotopes have been added to the ocean model (POP2) of the CESM (Jahn et al., 2014):

- **Abiotic radiocarbon (^{14}C)**
- **Biotic ^{13}C and ^{14}C**

The biotic implementation calculates the fractionation during gas exchange and photosynthesis, using the ocean ecosystem model. The abiotic implementation does not require the ocean ecosystem model, making it much cheaper to run.

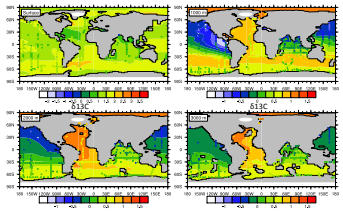
Simulated abiotic ^{14}C ages



Shown are radiocarbon ages (see below for the equation) from the model and from the GLODAP data set (Key et al., 2004).

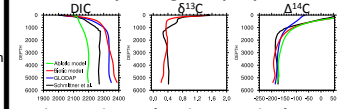
^{14}C age =(-1) * 8033 years * log(1 + $\Delta^{14}C$ /1000)

Simulated $\delta^{13}C$



Shown are $\delta^{13}C$ model results for the 1990s (shaded), compared to observational $\delta^{13}C$ data for the 1990s (dots; Schmittner et al., 2013)

Globally averaged depth profiles



Projects using carbon isotopes in the ocean

- Using abiotic $\Delta^{14}C$ to separate the influence of wind and atmospheric $\Delta^{14}C$ on southern ocean carbon uptake during recent decades
- Improvements of physical parameterizations, using abiotic $\Delta^{14}C$ as diagnostic tool
- Freshwater hosing experiments to evaluate the relationship between $\delta^{13}C$ and the physical circulation

Carbon isotopes in the land model

Carbon isotopes have been added to the land model of the CESM (CLM4.5) by A. Bozbiyik and F. Joos and are ready for coupling to the ocean model.

Next steps

- Add carbon isotopes to the atmospheric model (CAM5) and couple to the ocean and land carbon models
- Finish the implementation of water isotopes in the river transport model and the sea ice model and couple these modules to the others for a fully-coupled water isotope simulation
- Complete development of Pa/Th and Neodymium tracers in the ocean model as additional paleo ocean circulation tracers
- Incorporate the isotope modules into the trunk of the CESM, to ensure that these developments are maintained as CESM evolves
- Release model output and isotope modules to the community of CESM users

Acknowledgements and References

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Computing resources were provided by the Climate Simulation Laboratory at NCAR's Computational and Information Systems Laboratory (CISL), sponsored by the NSF and other agencies.

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