Constraining LGM Ocean Carbonate Chemistry and Circulation using Data Assimilation

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2024 Paleoclimate Working Group Meeting

This work was supported by the Heising-Simons Foundation

Overview

Goal:

explore the role of the ocean carbon cycle and circulation changes in deglaciation using data assimilation and an intermediate complexity earth-system model cGENIE

1. Background
2. Tools
   - cGENIE
   - data assimilation
3. Reconstruction
4. Key Finding
5. Takeaways

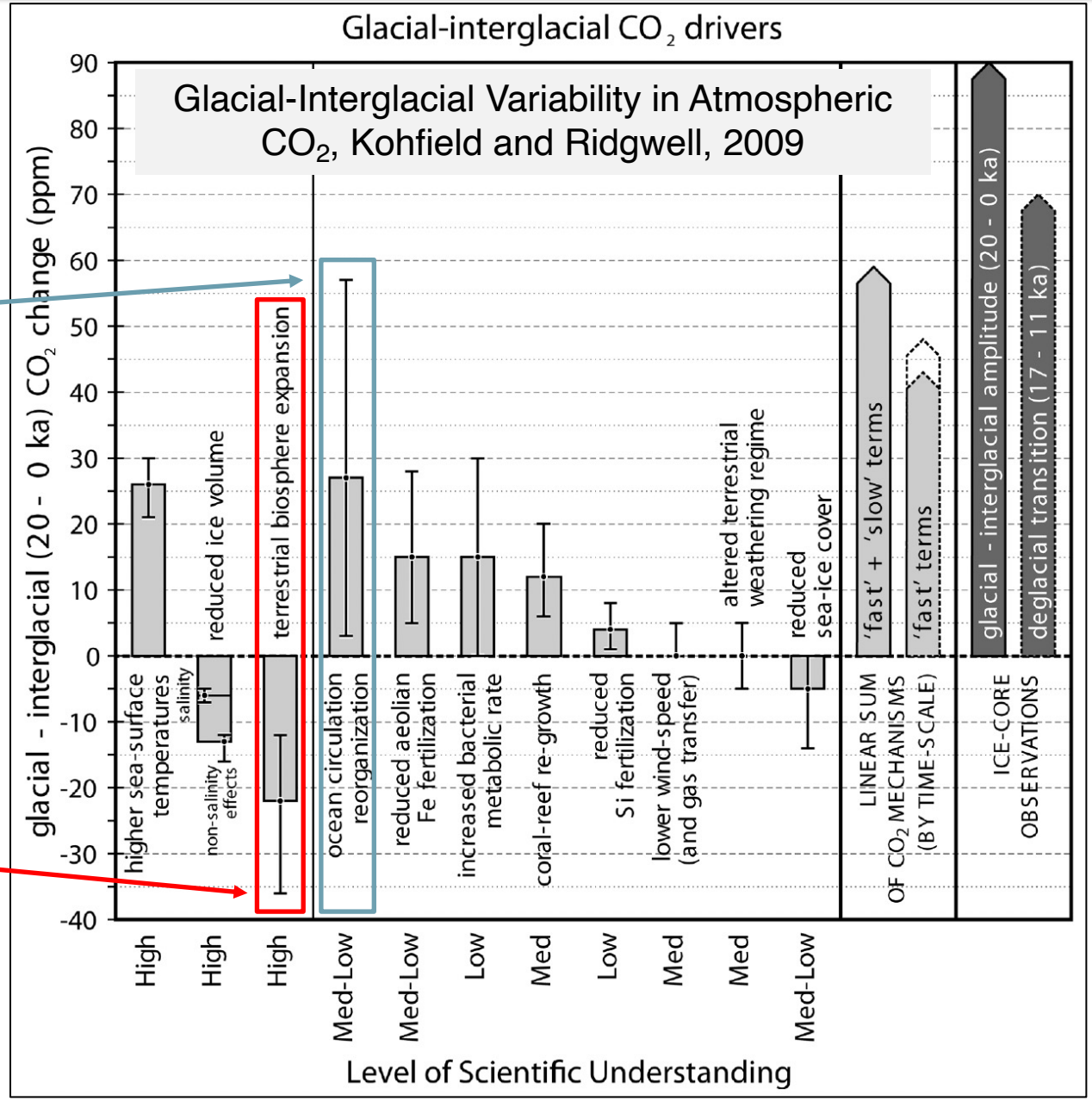
Background

Why increase in CO_2 from the Last Glacial Maximum (LGM) to the late Holocene (HOL)?

- Multiple proposed components
- Example, changes in ocean circulation

Benthic foraminiferal proxy data:

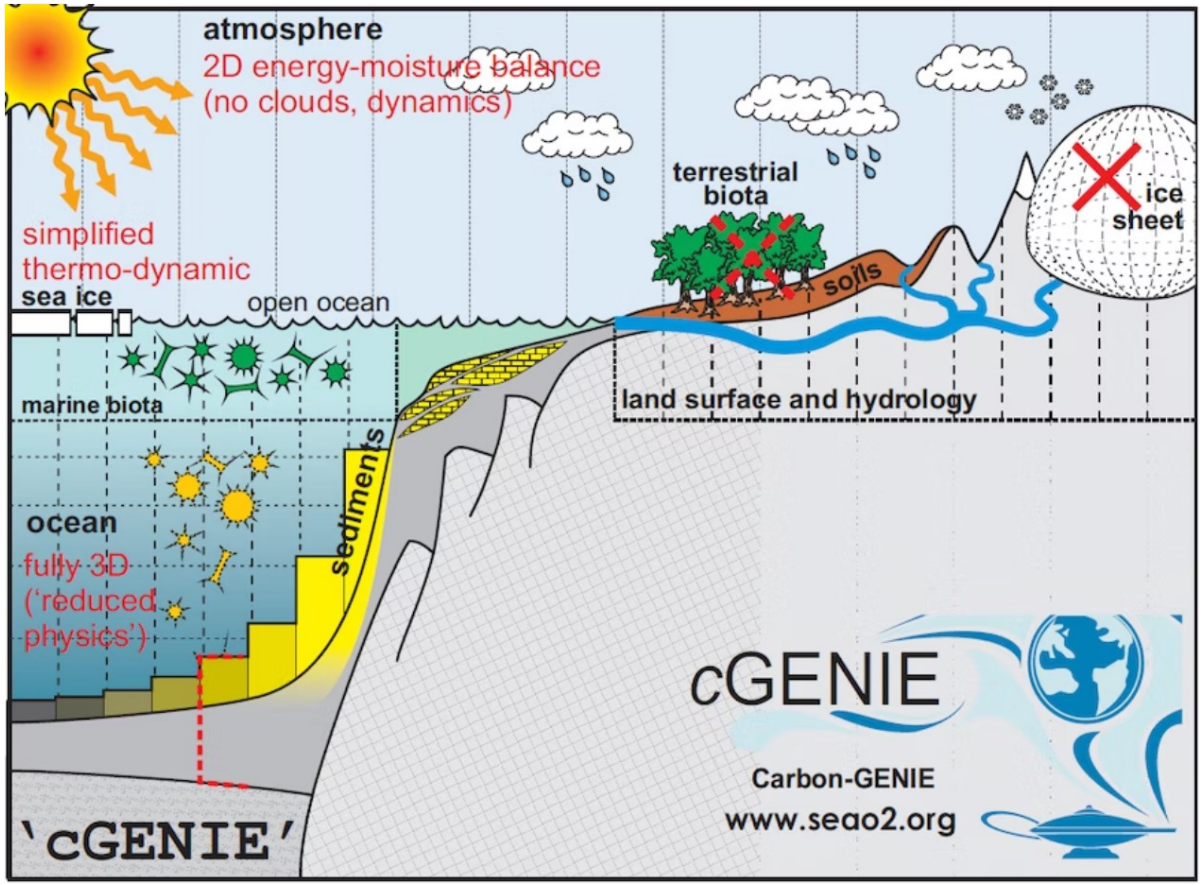
- An increase in $\delta^{13}C$ is inferred from benthic foraminiferal data
- Peterson et al, 2014:
  - whole-ocean $\delta^{13}C$ increase of 0.34 ± 0.19‰ estimated from 480 benthic foraminiferal records
  - implies an uptake in carbon by terrestrial biosphere consistent with recent vegetation model estimates of 330–694 Pg C



Tools: cGENIE

cGENIE: a chemistry enabled earth system model of intermediate complexity (EMIC)

- Components include:
  - biogeochemical cycling
  - ocean circulation
  - ocean–atmosphere exchange
  - ocean–sediment exchange
  - geological cycle of carbon
- Prior: 60-member, 20k-year ensemble
- LGM and HOL scenarios with volume correction
- Latin hypercube sampling of 3 tuning parameters:
  - wind stress scaling → general circulation
  - freshwater flux → NADW formation
  - brine water rejection → S Ocean source

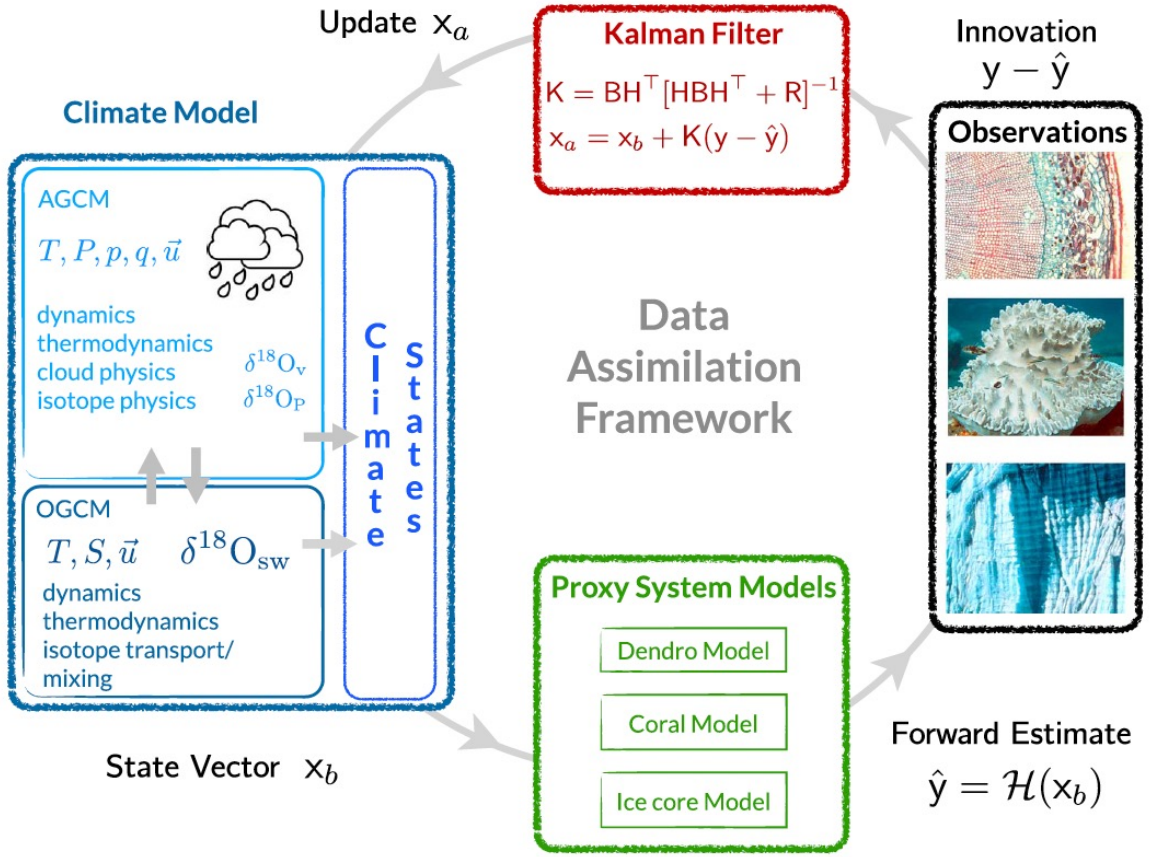


Tools: Data Assimilation

Data assimilation combines model and proxy data to create an ensemble reconstruction

$$\boldsymbol{X_a = X_b + K(Y - \hat{Y})}$$

- X_a: "analysis" posterior = update
- X_b: "background" prior = climate model output
- $Y - \hat{Y}$: innovation
  - Y: proxy records
  - $\hat{Y}$: estimate from proxy system models
- K: Kalman gain matrix for weighting



Hakim et al, 2016

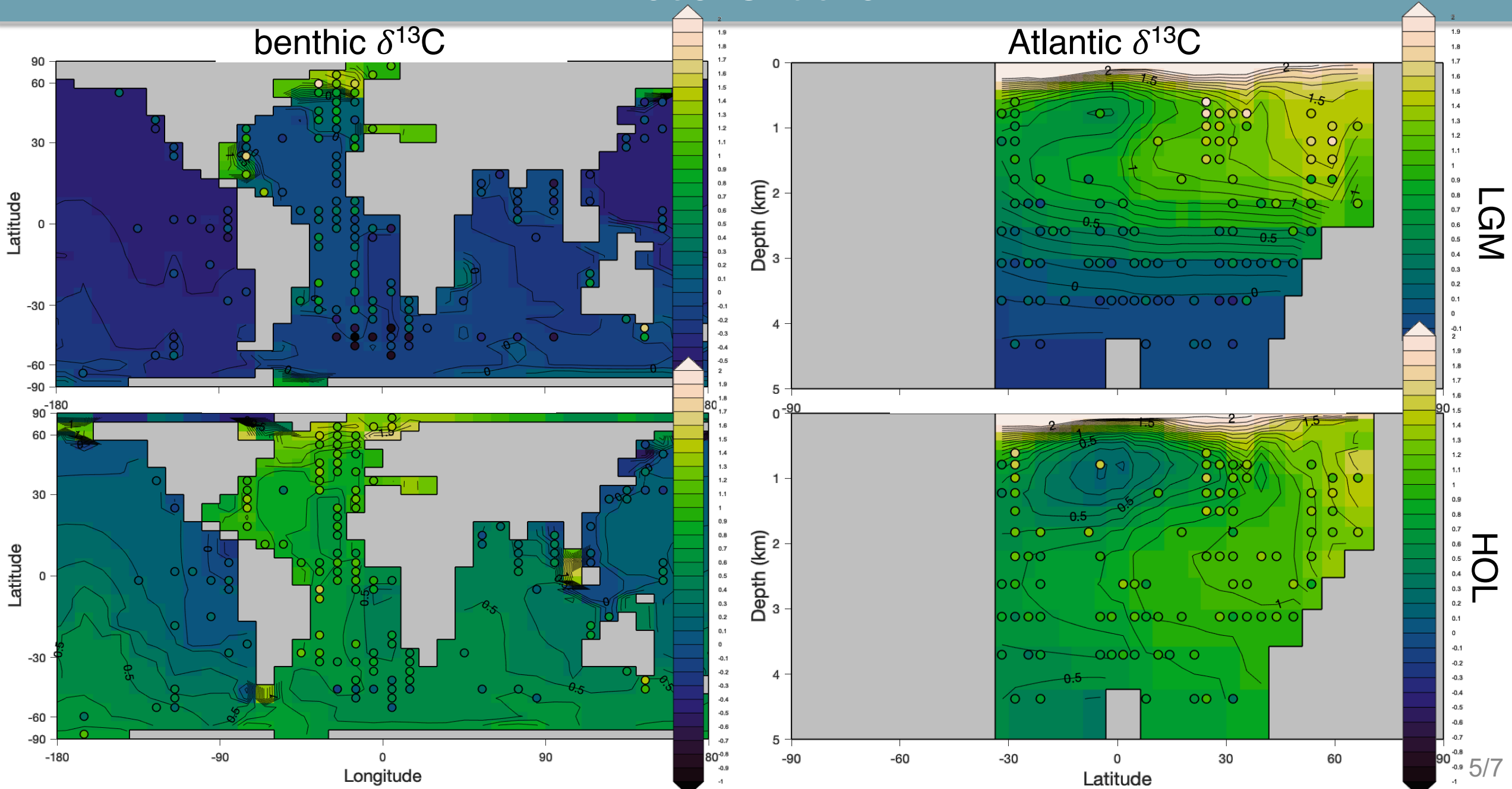
Innovation:

- $\delta^{13}C$ from *Peterson et al, 2014*, >200 sites
- cGENIE outputs $\delta^{13}C$

Posterior:

- mean and 60-member ensemble
- varied uncertainty/error, localization, re-gridding
- using DASH (Jonathan King, available on GitHub)

Reconstruction



Key Finding

Carbon inventories:

- Whole-ocean $\delta^{13}C$ increase of 0.22 ± 0.1‰
- DIC increase of -33 ± 50 Pg (aka, a *decrease*)

	LGM_DA		HOL_DA	
	C (Pg)	δ13C (‰)	C (Pg)	$\delta^{13}C$ (‰)
Atmos CO_2	410	-6.46	584	-6.35
Ocean DIC	36462	0.23	36429	0.45
Total	36872	0.15	37014	0.34
	(sum)	(weighted)	(sum)	(weighted)

Theory:

- Expected change in $\delta^{13}C$ accompanied by insignificant DIC change: what does that mean?
- From LGM → HOL, we see an increase in isotopically heavy carbon
- One way is to accumulate isotopically neutral carbon and bury organic matter
- Another possibility is terrestrial carbon growth pulling out light carbon, but also a large increase in neutral carbon
- If $\delta^{13}C$ change was only by terrestrial carbon change, would be significantly less DIC in HOL

Conclusion: unable with these results to interpret the ocean δ13C change in terms of terrestrial biosphere growth

Takeaways

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Ongoing Work:

- $CaCO_3$ co-assimilation with sediments module: add ALK as parameter → can we recover modern ALK? Same carbon storage results?
- Where are the $\delta^{13}C$ changes coming from (if not from terrestrial carbon storage)? → add tracers to explore carbon cycle

With a range of data assimilation solutions, our results are contrary to the conventional interpretation of an increase in $\delta^{13}C$ in the Holocene corresponding to uptake by terrestrial biosphere.

We also demonstrate the power of combining models with proxy data through rigorous data assimilation methods.

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