How well would modern-day oceanic property distributions be known with paleoceanographic-like observations?

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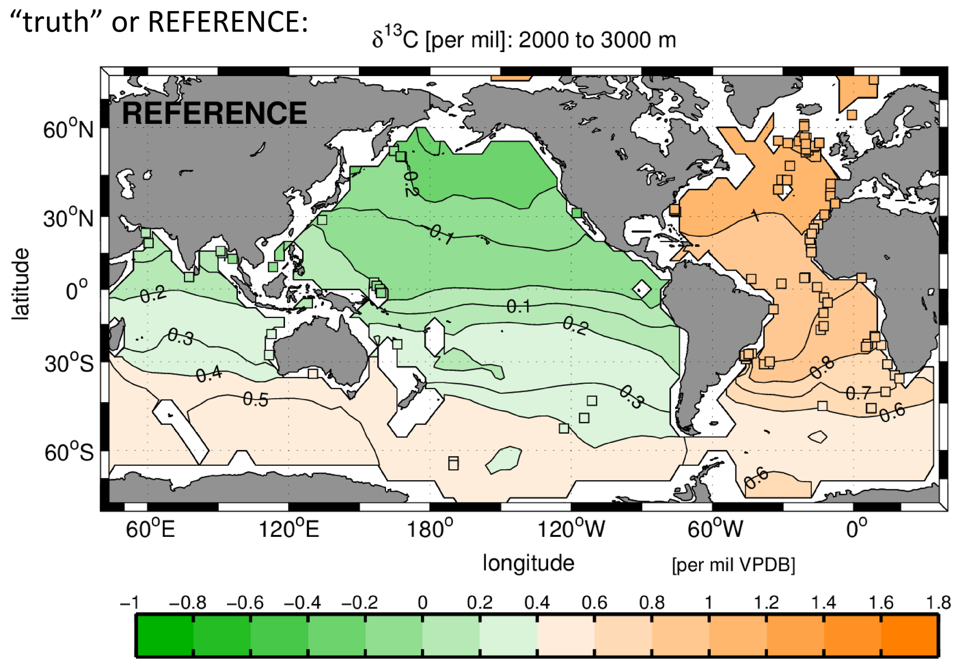
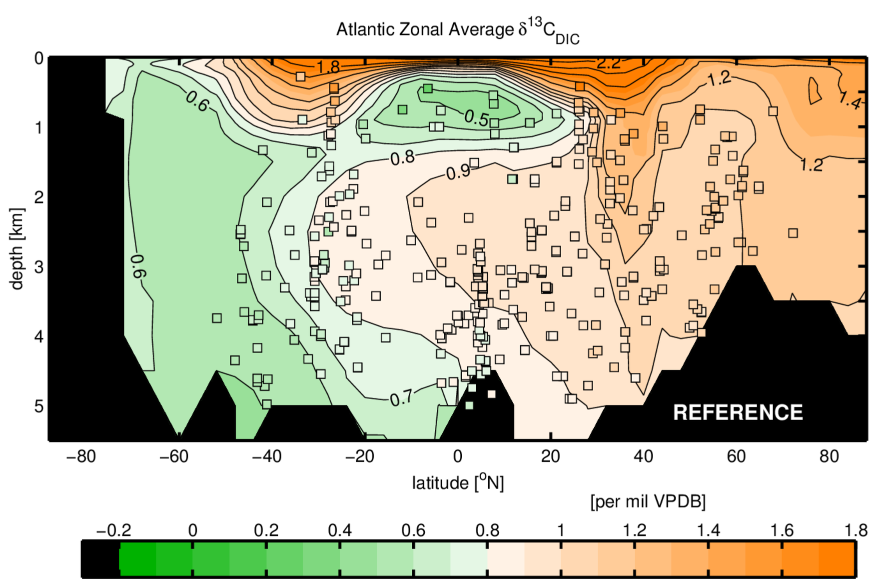
1.Introduction

Do paleo-data have the power to constrain the past ocean circulation and property distributions? Here we design an idealized experiment to test our predictive ability to reconstruct 3D ocean properties by considering paleoceanographic-like data. We attempt to reconstruct the known, modern-day global distributions by using a state estimation method that combines a kinematic tracer transport model with observations that have paleoceanographic characteristics.
This test is a prerequisite to being able to reconstruct the past ocean circulation.

2. Experimental Design

Define a suite of modern-day gridded tracer distributions [1,2,3] as the "truth" or REFERENCE:



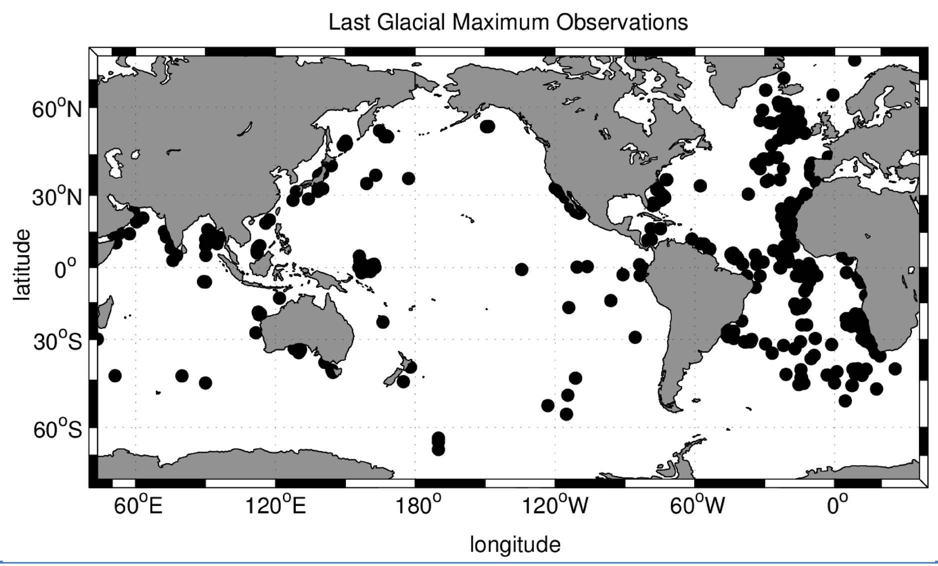


Use a steady-state estimation method [3] to reconstruct global property fields in the following scenarios:

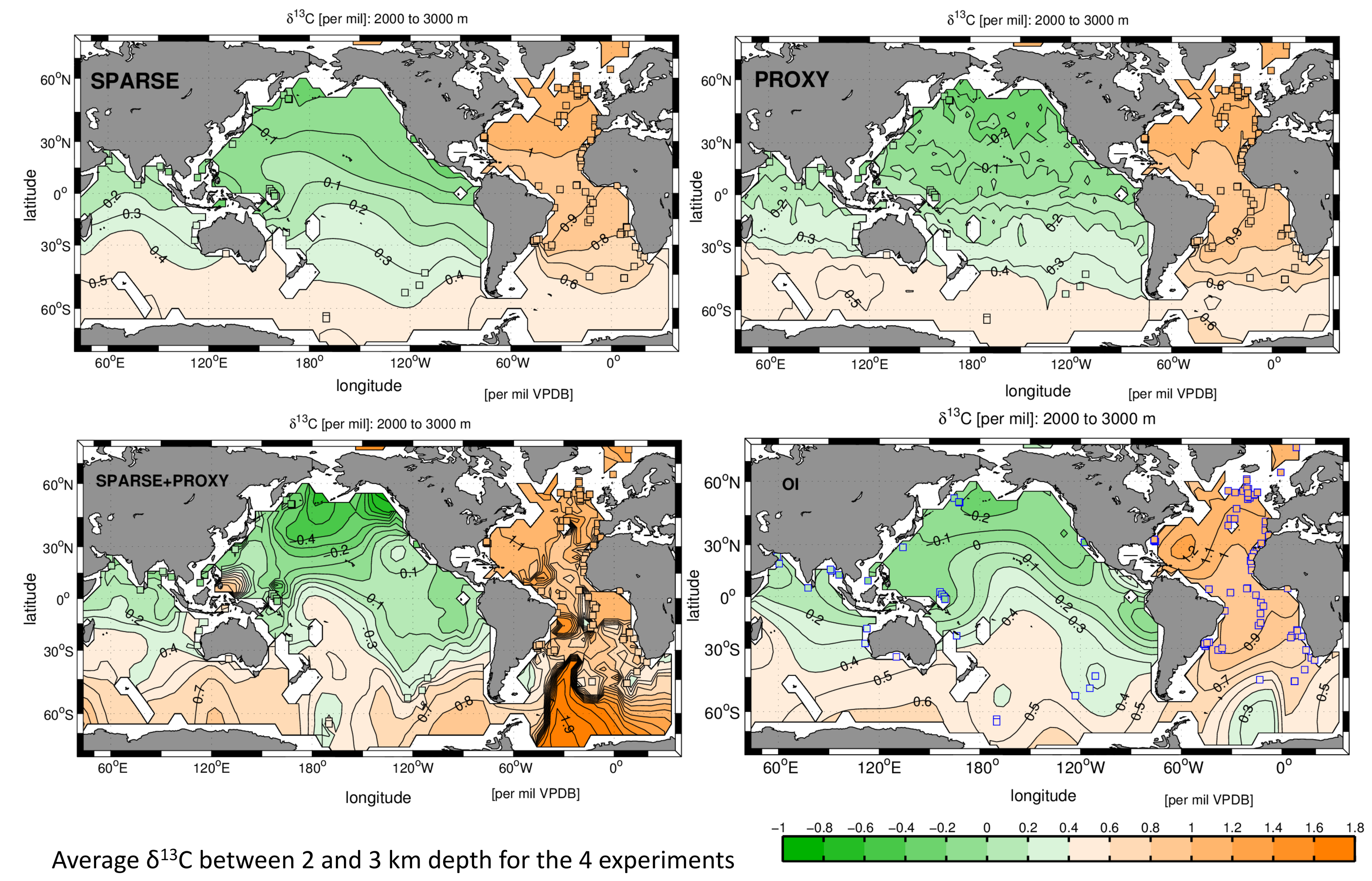
- SPARSE experiment: "Observe" T, S, PO_4, NO_3, O_2, $\delta^{13}C$, $\delta^{18}O$ at the 492 sites of benthic foraminiferal LGM data (see figure below)
- PROXY experiment: "Observe" $\delta^{13}C$, $\delta^{18}O$, Cd/Ca at all (74,064) gridded locations
- SPARSE+PROXY experiment: "Observe" $\delta^{13}C$, $\delta^{18}O$, Cd/Ca at the 492 sites

To assess the performance of the reconstruction method, add one additional case:

- OI: "Observe" $\delta^{13}C$ at the 492 sites and reconstruct with an optimal interpolation/objective mapping method

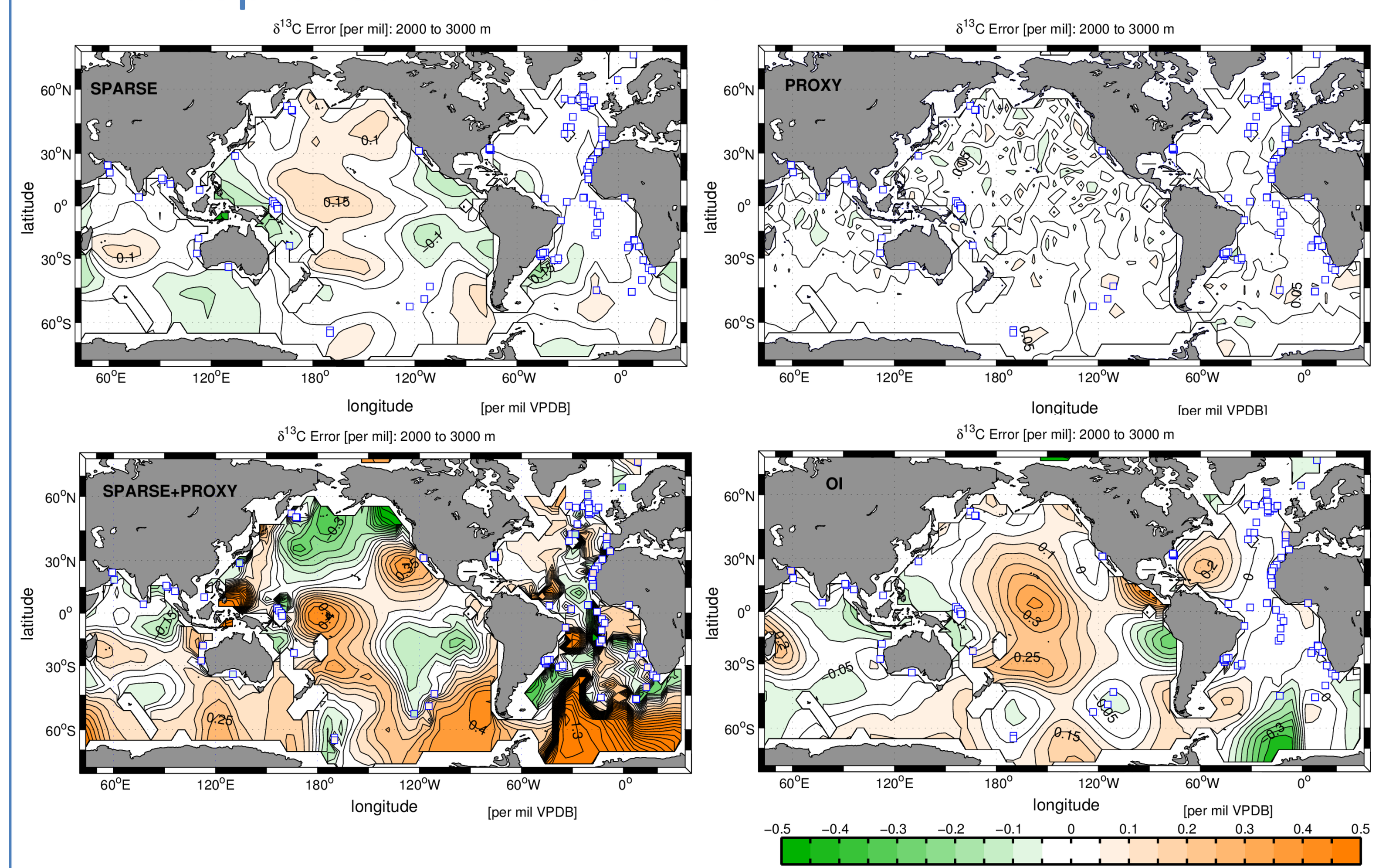


3. Reconstructed deep ocean $\delta^{13}C$ structure



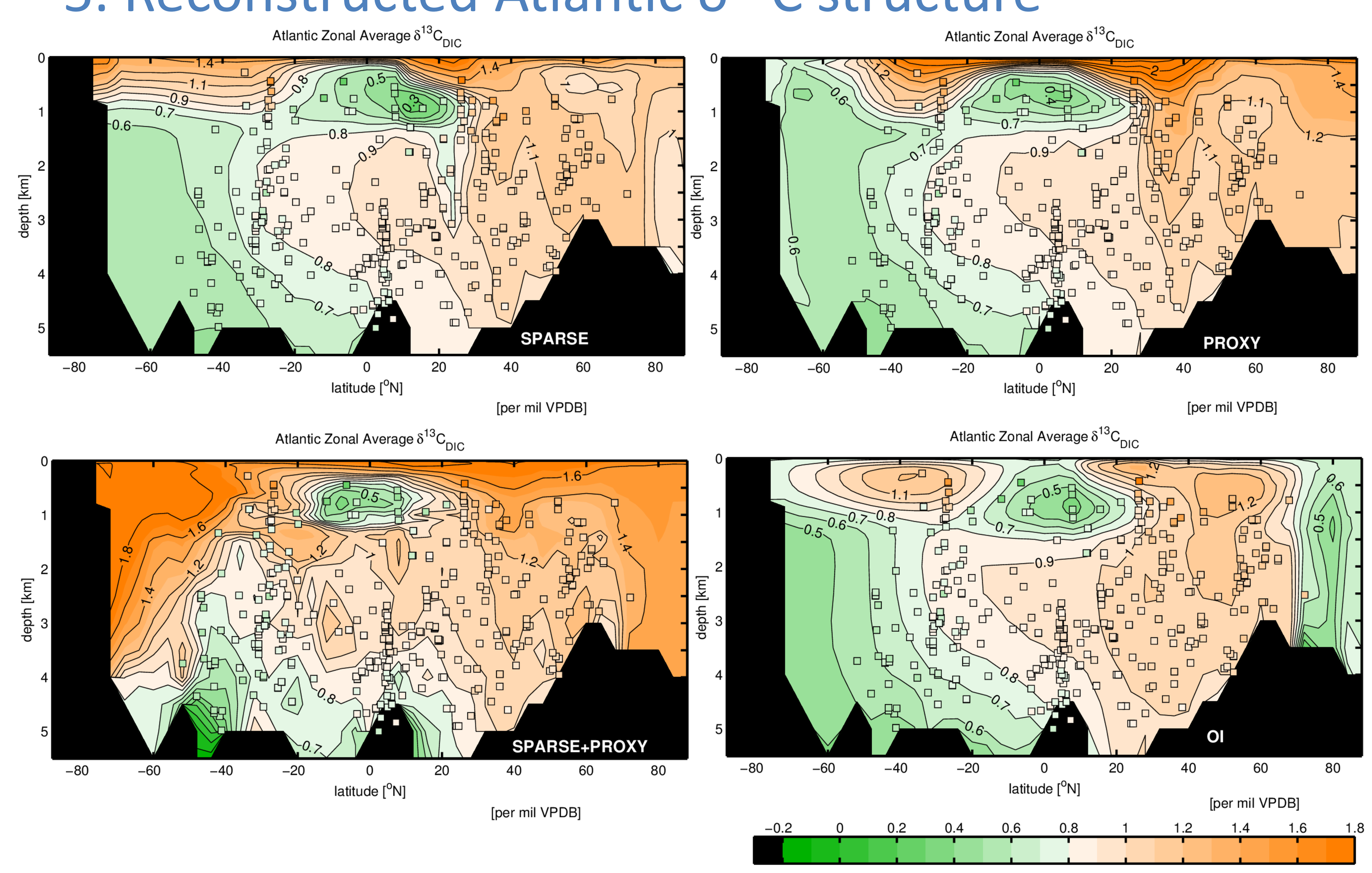
Average $\delta^{13}C$ between 2 and 3 km depth for the 4 experiments (background colors) and the observations in this depth range (colored squares). Compare to the true distribution in the left hand column of the poster. Paleo-data that are either sparse or proxy data types provide information to reconstruct the large-scale structure, but data that have both characteristics (i.e., sparse proxies) cannot.

4. Deep ocean $\delta^{13}C$ errors



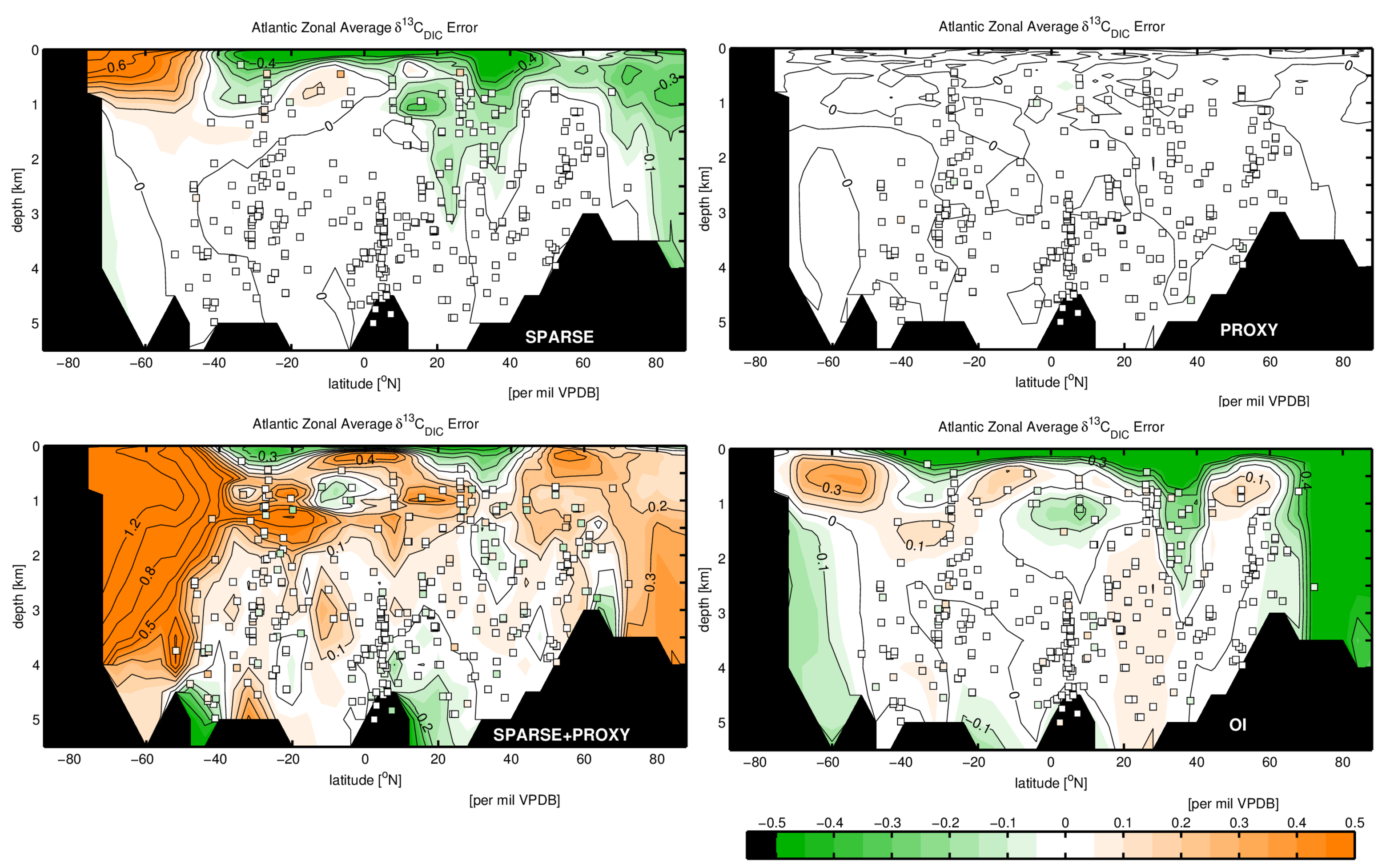
Errors in reconstructed $\delta^{13}C$ defined as the difference between the distributions in panel (3) and the truth in panel (2). Errors are generally lowest near the observations (blue squares) where the color of the square represents the pointwise error.

5. Reconstructed Atlantic $\delta^{13}C$ structure



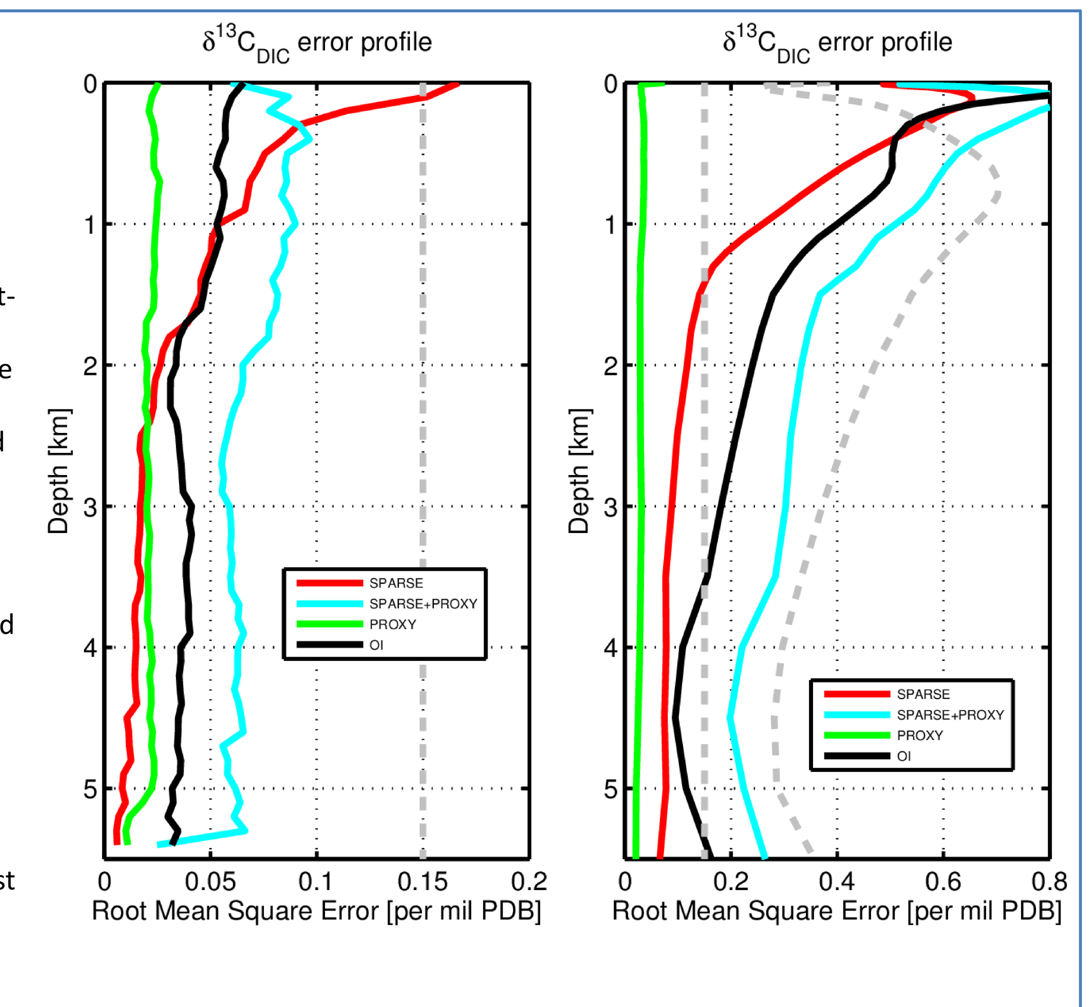
Atlantic Ocean zonally-averaged $\delta^{13}C$ (background colors) and the observations in this basin (colored squares). Compare to the true distribution in the left hand column of the poster. The SPARSE and PROXY experiments are generally successful, but the SPARSE+PROXY experiment is not.

6. Atlantic $\delta^{13}C$ errors



Atlantic Ocean zonally-averaged $\delta^{13}C$ errors (background colors) and the pointwise observational misfit in this basin (colored squares). In the more realistic SPARSE+PROXY experiment, errors are large in the Southern Ocean and the Arctic Ocean. Large errors in the surface ocean may be alleviated with the inclusion of planktonic foraminiferal data.

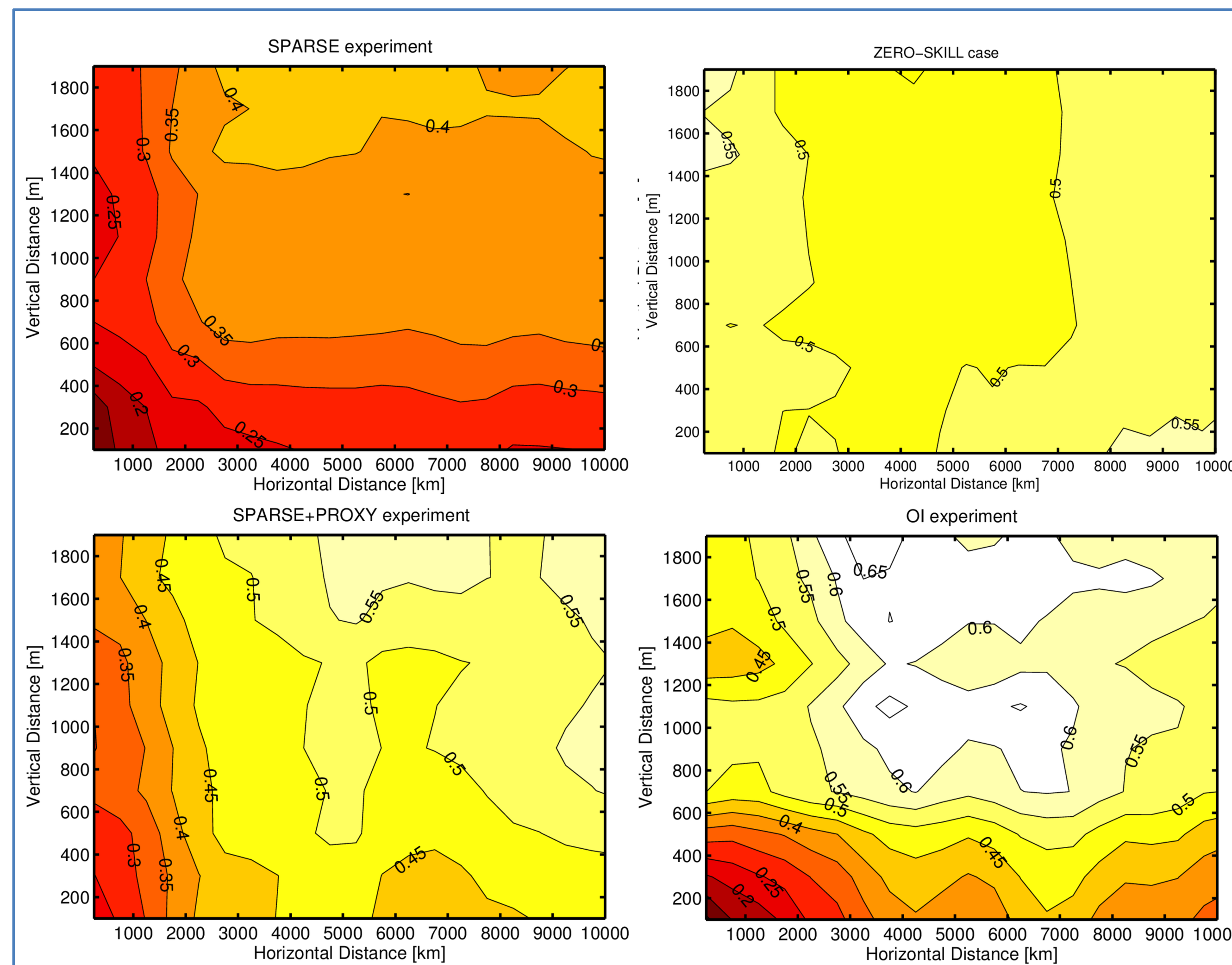
7. Vertical error stats



Vertical profile of the root-mean-square error of the reconstruction (left) at the observational sites and (right) at every global grid point. The metrics are diagnosed for the SPARSE (red), SPARSE+PROXY experiments (cyan), PROXY (green), and OI (black) experiments. The 0.15‰ error level (vertical dashed gray line, both panels) is the noise level in the observations. The "zero skill" error level (rightmost dashed gray line, right panel) is included for context.

The SPARSE and PROXY experiments reconstruct the withheld data everywhere below 1500 meters depth.

8. Influence function of an observation



$\delta^{13}C$ RMS error as a function of horizontal distance (x axis) and vertical distance (y axis) from a given observation for the following experiments: (top left) SPARSE, (top right) zero skill, (bottom left) SPARSE+PROXY, and (bottom right) OI. Hotter colors represent the reconstruction being closer to the truth. The contour interval is 0.05‰ VPDB. The SPARSE experiment, for example, shows the influence of observations over 10000 horizontal km and 2 vertical km.

9. Summary

- Global property distributions can be reconstructed from data as sparse as that from the LGM.
- Inference of past ocean properties is limited, however, with a sparse dataset of 3 LGM proxy data types ($\delta^{13}C$, $\delta^{18}O$, Cd/Ca).
- A state estimation method has skill at large spatial scales and outperforms objective mapping/optimal interpolation.
- Reconstruction of the past overturning circulation is likely more difficult than the 3D property distributions [4,5].

References

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This work:

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