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Tracking Glacial Ocean Waters from Surface Source to the Seafloor: An Inverse Method Applied to the Last 25,000 years

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Sediment core records show that seawater tracers varied widely between the Last Glacial Maximum (19,000 to 23,000 years ago) and the modern day, but it is difficult to interpret whether it was due to changes in ocean circulation or changes in surface boundary conditions. For example, the paleoceanographic tracer delta-18-O shows that the arrival of deep-water changes was 4,000 years earlier in the Atlantic Ocean than the Pacific Ocean, hypothesized to occur due to changes in ocean circulation because the lag is longer than typical oceanic timescales. Another scenario is that the ocean circulation has remained fairly stable and that the paleo-tracer evolution is due to a passive response to atmospheric changes and oceanic transit delays. To explore the plausibility of this second scenario, we use a newly-developed extension to the TMI method, an ocean circulation inverse method that explicitly solves for the volume fraction of water that has originated from thousands of surface sites. Here we apply TMI to the global ocean at 2 by 2 degree horizontal resolution and 33 vertical levels, and confirm that the method is successful with the modern-day datasets from WOCE and GLODAP. Applying the method to glacial times, the inverse solution quantifies how the response to oceanic surface conditions depends upon the location of the surface forcing, whether it be a regional (i.e. North Atlantic) phenomenon or a global one. The TMI method yields a three-dimensional reconstruction of paleo-tracers, giving evidence about the relative times of melting of the Northern Hemisphere versus Antarctic ice sheets, and quantifying the proportion of glacial Atlantic waters originating from the north versus the south and the depth of the interface between the two.