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Sequential dissipation of a poorly-ventilated water mass upon the last glacial termination - implications for the marine and atmospheric carbon cycles.

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It is believed that no single mechanism can account for the full amplitude of past CO_2 variability. But although multiple synergistic processes may be involved, intensified isolation of deep-water masses from the atmosphere has emerged as a central mechanism for low glacial CO_2. This could have resulted from increased oceanic density stratification, increased sea ice cover, or a decrease wind-driven vertical mixing. Recent evidence is consistent with the existence of a poorly ventilated, carbon-rich water mass in a large portion of the glacial Pacific and Southern Oceans. However, the mechanisms by which this water mass dissipated upon glacial terminations remains a subject of debate.

Here we present sedimentary redox-sensitive trace metal records from subarctic Pacific sites ODP Site 882 & 887 and South Atlantic sites TN057-13/14 to reconstruct changes in deep ocean oxygenation – and, by inference, respired carbon storage - across the last glacial termination. These observations are complemented by ^{230}Th-normalized opal measurements, which we apply as proxies for past organic carbon sedimentation in these diatom-dominated regions. In combination, these allow us to separate the time-varying influences of deep-water oxygen concentration and sedimentary organic carbon respiration on the redox state of the sediment.

Our results suggest that the abyssal Pacific and Southern oceans were depleted in oxygen during the last glacial maximum, though they were not anoxic. The large and abrupt increase in sedimentary opal accumulation observed in the Southern Ocean at approx. 18 kyr is accompanied by a decrease in authigenic uranium concentrations suggesting better oxygenation at the depth of the core site. Enhanced mixing within the Southern Ocean, driven by stronger winds and/or changes in the density profile of the water column, would have invigorated circulation at depth., The increase in the rate of nutrient supply to the surface would have enhanced the strength of the Southern Ocean High Nutrient Low Chlorophyll (HNLC) region, and increased the leakage of nutrients into intermediate and mode waters of the southern hemisphere. Simultaneously, the decrease in nutrient-poor NADW to the deep sea, caused by the freshwater forcing associated with Heinrich Event 1, allowed nutrient-rich AABW to dominate the deep ocean. Both of these mechanisms would have increased global preformed nutrient concentrations, previously shown to contribute to higher atmospheric $p\mathrm{CO}_2$, and could have explained the large-scale transfer of carbon from the deep ocean to the atmosphere between 18 and 15 ka. In the subarctic Pacific, the arrival of well-oxygenated abyssal waters appears to have taken place at the onset of the Bolling/Allerod, 14.7 ka, accompanying the reinvigoration of North Atlantic Deep Water, which increased the overall rate of deep ocean ventilation, even as it contributed to an overall decrease in the preformed nutrient load of the global ocean. The fact that atmospheric $p\mathrm{CO}_2$ stopped increasing at this time is consistent with this interpretation. Our results suggest that this stepwise reinvigoration of deep water circulation, resulting from the buffeting of ocean density structure by large inputs of freshwater, was responsible for driving carbon out of the abyssal ocean during the melting of the large continental ice sheets.