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Millennial global ocean oxygen reconstructions from thallium isotopes over glacial-interglacial cycles

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With the stoichiometric link between respired carbon accumulation and oxygen consumption, ocean dissolved oxygen can provide insights on whether marine carbon storage plays a major role in glacial-interglacial atmospheric CO_2 variations. However, currently available ocean oxygen proxy records (e.g., laminations, foraminiferal assemblages and trace metals, redox-sensitive metals, nitrogen isotopes, and carbon isotopic composition records) are influenced by local factors like ventilation and/or export of organic matter to the sediments, making it challenging to determine the average global state of ocean oxygen and the controlling mechanisms on millennial to glacial-interglacial timescales. Here we apply the thallium isotope system as a novel proxy to reconstruct globally integrated ocean oxygen content. With recently published data and new measurements, we corroborated that ocean oxygen content was lower during the Last Glacial Maximum and the Penultimate Glacial relative to the Holocene. During the two terminations, we reveal re-oxygenation in both Heinrich Stadials and the Younger Dryas, with deoxygenation during the Bølling–Allerød interstadial period. The ocean oxygen changes were decoupled from North Atlantic Deep Water formation rates and imply that Southern Ocean ventilation may have controlled ocean oxygen during the last two terminations. We additionally found coherence of global ocean oxygen content with mean ocean heat content [1, 2] and atmospheric CO_2 on millennial timescales, highlighting the Southern Ocean's role in CO_2 rise in the last two terminations.

[1] S. Shackleton, *et al.*, Global ocean heat content in the Last Interglacial. *Nat. Geosci.* **13**, 77–81 (2020).

[2] B. Bereiter, S. Shackleton, D. Baggenstos, K. Kawamura, J. Severinghaus, Mean global ocean temperatures during the last glacial transition. *Nature* **553**, 39–44 (2018).