Ocean deoxygenation from the Last Glacial Maximum to the future global warming: inshight from model simulations

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Global warming is expected to decrease ocean oxygen concentration by less solubility of surface ocean, reduced ventilation and enhanced stratification. The associated expansion of the oxygen minimum zone would have adverse impact on marine organisms and ocean biogeochemical cycles. Earth system models show a consistent deoxygenation trend over the twenty-first century; however, longer-term changes in ocean oxygen are still unclear due to the uncertain response of deep ocean circulation.

During the Last glacial maximum, recent proxy data show that, despite greater oxygen solubility due to sea surface cooling, the oxygen concentrations throughout the deep ocean were generally lower. These records provide the response of oxygen content to climate forcing that are comparable in magnitude to the expected future changes. Therefore, the understanding of glacial deoxygenation will help us to better understand and predict future oxygen changes. In addition, glacial deep-water deoxygenation is crucial to understand glacial-interglacial CO_2 change, since glacial deoxygenation reflects increased accumulation of respired carbon in the glacial deep ocean. However, the mechanisms of deep-water deoxygenation and contribution form the biological pump to glacial CO_2 drawdown are poorly understood due to the difficulties in reproducing glacial deoxygenation.

In this study, we report the importance of glaciogenic dust for the glacial deep-water deoxygenation from our numerical simulation which successfully reproduces the magnitude and large-scale pattern of the observed oxygen changes from the present to Last Glacial Maximum. Sensitivity experiments reveal that physical changes (e.g., more sluggish ocean circulation) contribute to only half of all glacial deep deoxygenation, whereas the other half is driven by enhanced efficiency of the biological pump. We found that iron input from the glaciogenic dust with higher iron solubility is the most significant factor for enhancement of the biological pump and global deep-water deoxygenation. The model-proxy agreement of oxygen change supports the simulated contribution of the enhanced biological pump to the decrease of more than 30 ppm of glacial CO_2.

On the other hand, our model underestimates deoxygenation in the deep Southern Ocean due to enhanced ventilation in the Southern Ocean. Our results suggest that the stratified Southern Ocean is required for reproducing glacial deoxygenation in the Southern Ocean. However, present climate models cannot reproduce the stratified Southern Ocean. A possible reason is that climate models are too coarse to capture the process of dense water formation on the Antarctic shelf and tend to underestimate the strength of stratified Southern Ocean. Similar to glacial oxygen changes, our global warming simulation show that changes in ocean circulation in the Southern Ocean are crucial for long-term projecting future oxygen changes associated with global warming. Therefore, the understanding of glacial oxygen changes will help us to better understand and predict future oxygen changes.

Keywords: Dissolved oxygen, Glacial-interglacial cycle, Global warming, Ocean carbon cycle, Ocean biogeochemical model