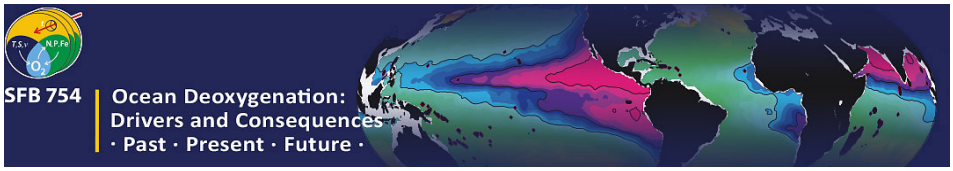

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Large changes in ocean oxygenation during the last ice age: observations, mechanisms and ecosystem responses to change

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The controls on dissolved oxygen are complex, involving oxygen saturation concentrations, ocean circulation, air-sea gas exchange and the rate of organic matter respiration. Marine sediment records of oxygenation during the last ice age provide a means to gauge the relative importances of these mechanisms, as well as the response of the marine ecosystem, under climate forcings that are comparable in magnitude to the expected future changes. During the peak of the last ice age - the last glacial maximum - observations show that, despite greater oxygen solubility caused by lower ocean temperatures, the oxygen concentrations throughout the deep ocean were generally lower. This implies that greater oxygen utilization overwhelmed the solubility changes, which could have been due to more sluggish ocean circulation, more restricted air-sea exchange, and/or a more rapid sinking flux of organic matter to depth. Radiocarbon measurements from the last glacial maximum have previously been interpreted as showing more sluggish circulation, but model simulations show that the measured radiocarbon values can instead be explained by a change in ocean circulation patterns, which would not necessarily change oxygen concentrations. On the other hand, model simulations show that a significant decrease in the preformed oxygen content of Antarctic bottom waters could have occurred under glacial conditions, due to blocking of air-sea exchange by very extensive sea ice cover. In addition, a greater flux of organic matter to the deep sea may have contributed to the low deep ocean oxygen concentrations, due to an increased supply of iron and nitrogen to the surface, and/or ecosystem changes that increased the export fraction, transfer efficiency, or both. Relatively abrupt changes in the Atlantic Meridional Overturning Circulation that punctuated the glacial period and deglaciation were accompanied by dramatic changes in oxygen concentrations, particularly at intermediate-depths of the northern Indian and Pacific oceans. Qualitatively, these abrupt changes are well captured by models, but it is not clear if the models correctly simulate the magnitude of changes, owing to a paucity of quantitative observational constraints. Microscopic fossil assemblages, including fish debris, show large responses to changes in dissolved oxygen concentrations, pointing to an unrealized potential for sediment records to inform the sensitivity of marine ecosystems to changes in oxygenation.

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