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Role of Southern Ocean stratification in glacial atmospheric CO2 reduction

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The global temperatures and atmospheric carbon dioxide (pCO_2) concentrations varied during the last 800 thousand years. During the glacial times, such as Last Glacial Maximum (LGM), the atmospheric partial pressure of carbon dioxide (pCO_2) was about 80-100ppmv lower than interglacial times, such as Holocene. Compared to interglacial conditions, terrestrial carbon stocks were reduced during glacial conditions. Marine carbon cycles must have been the main driver for lowering atmospheric pCO_2 during ice ages. A number of candidate mechanisms to explain the reduction in glacial atmospheric pCO_2 have been proposed. However, they failed to explain full amplitude of 80-100ppmv reduction. Based on paleo-proxy reconstructions, $\delta^{13}C$ gradient between surface and deep ocean was larger than today, suggesting that the glacial ocean circulation state was different from today. In the deep glacial Southern Ocean, very saline water was identified from paleo proxy data. Moreover, radiocarbon record showed the existence of radiocarbon-depleted old waters in glacial ages. One hypothesis that has been proposed to explain the glacial atmospheric pCO_2 is the isolated reservoir hypothesis: a carbon-rich, radiocarbon-depleted water mass was isolated from the atmosphere during the glacial periods. The stratification of the Southern Ocean water column may have contributed to a reduction of atmospheric pCO_2.

In this study preindustrial and LGM marine carbon cycle sensitivity experiments are conducted to estimate a role of stratification in glacial Southern Ocean quantitatively, by using an ocean general circulation model (OGCM). In the control case, atmospheric pCO_2 between Modern case and LGM case is about 44ppmv, which was comparable to previous AOGCM study. However, LGM case cannot explain the saline glacial Southern Ocean.

Previous study using intermediate complexity models suggested that glacial atmospheric pCO_2 and $\delta^{13}C$ distribution can be reproduced by considering brine induced stratification.

Therefore, we also consider the effect of brine induced stratification. We partly succeeded in reproducing the saline glacial South Atlantic Ocean by imposing body forcing near the bottom in the Weddell Sea, Ross Sea and Eastern Antarctica, whereas saline glacial Southern Ocean resulted in increased northward flow of AABW and increased atmospheric pCO_2. Additionally, we used stratification-dependent vertical eddy diffusivity parameterization suggested by Gargett (1984) to discuss changes in vertical eddy diffusivity in Southern Ocean. Contrary to our expectation, vertical eddy diffusivity in high latitude becomes very higher under glacial conditions, and sequestered carbon in deep ocean was released into the atmosphere and resulted in higher atmospheric pCO_2.

Finally, very stratified Southern Ocean achieved by extremely small vertical eddy diffusivity also cannot reduce glacial atmospheric pCO_2. Other processes, which are not taken into account in our study may be important to reproduce the glacial condition.

Keywords: ocean carbon cycle, Last Glacial Maximum, Southern Ocean, Ocean general circulation model