Role of ocean carbon cycle in glacial reduction of atmospheric carbon dioxide concentration

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From climate reconstructions using ice core records, it is shown that atmospheric carbon dioxide concentration (pCO_2) at the Last Glacial Maximum (LGM) is about 100 ppm lower than that at the pre-industrial period. Since carbon isotope data from ocean sediment records indicates that carbon storage in the terrestrial biosphere was reduced at the LGM, this atmospheric pCO_2 reduction must have arose from changes in the ocean carbon cycle. Paleo-ocean reconstructions recently show that high salinity and old water mass occupied the deep Southern Ocean at the LGM. These reconstructions suggest a hypothesis that carbon storage in the deep Southern Ocean increased at the LGM as a result of enhanced salinity stratification and caused a decline in atmospheric pCO_2 (" Southern Ocean hypothesis"). However, previous studies using an ocean general circulation model (OGCM) underestimate the pCO_2 change between the LGM and pre-industrial. One of the causes of this underestimation in OGCM studies is that the enhanced stratification in the glacial Southern Ocean suggested by the Southern Ocean hypothesis may not be appropriately represented by OGCMs. In this study, I focus on the Southern Ocean hypothesis and attempt to explain the mechanism of ocean carbon cycle change which contributes to the 100-ppm decline of atmospheric pCO_2 at the LGM.
I first try to improve the insufficient reproducibility of the high salinity and old water mass in the glacial deep Southern Ocean, and then investigate its influence on the ocean carbon cycle and atmospheric pCO_2. For this purpose, a LGM simulation is conducted, in which salinity in the ocean deepest layer in the Southern Ocean is restored toward high salinity reported from paleo-ocean proxy data and small vertical diffusion coefficient is prescribed to reproduce the enhanced stratification in the Southern Ocean. In the simulated glacial Southern Ocean, salinity stratification is strengthened, and the residence time of deep water gets longer. As a consequence, the concentration of dissolved inorganic carbon (DIC) increases in the Southern Ocean and decreases in the surface ocean glacial decline in atmospheric pCO_2 is only about 47 ppm.
Next, the role of carbonate compensation process in the glacial reduction of atmospheric pCO_2 is investigated with a newly created ocean sediment model. As a result of carbonate compensation, atmospheric pCO_2 decreases due to an increase in whole ocean alkalinity as previous studies suggested. It is newly found that this carbonate compensation process works more effectively by the enhanced stratification in the Southern Ocean. Owing to this contribution, the glacial reduction of atmospheric pCO_2 reaches about 73 ppm, which is much larger response than that obtained in previous OGCM studies.

Keywords: ocean carbon cycle, glacial-interglacial cycle, global ocean meridional overturning circulation, carbonate compensation process

