Modeling of the glacial ocean carbon cycle with an ocean general circulation model

*Hidetaka Kobayashi[1], Akira Oka[1]

1. Atmosphere and Ocean Research Institute, The University of Tokyo

Ice core data indicates that atmospheric carbon dioxide concentration ($pCO2^{atm}$) changed associated with glacial-interglacial cycle in last 100,000 years. In the glacial periods, $pCO2^{atm}$ was reduced by about 100 ppm compared to the interglacial periods. Variation in ocean carbon cycle is recognized as the main cause of the decline in $pCO2^{atm}$ because the storage of carbon in the land area was considered to be decreased in the cold and dry climate during the glacial period. Many previous studies using ocean general circulation models (OGCMs) tried to resolve the mechanisms of glacial $pCO2^{atm}$ but failed to reproduce the glacial CO2 reduction, quantitatively; therefore, the detailed mechanisms about glacial CO2 changes are not fully understood. In these days, paleo proxy data showed that the deep Southern Ocean in the Last Glacial Maximum (LGM) was occupied by high salinity and old water mass. This suggests that the enhanced stratification by salinity may have increased the residence time of carbon in the glacial Southern Ocean. For this reason, the Southern Ocean has been recognized as a key region for carbon uptake during glacial periods. We conducted numerical experiments using an OGCM to investigate the role of the Southern Ocean in the glacial variation of $pCO2^{atm}$; we evaluated the glacial response of ocean carbon cycles under the high salinity and long water mass age in the glacial Southern Ocean, which is suggested by previous findings from paleoclimate proxy data.

The difference in $pCO2^{atm}$ between the preindustrial control simulation and the LGM control simulation was 44.1 ppm. Changes in solubility depending on sea surface temperature and salinity, ocean circulation, and biological production in the ocean surface layers due to iron fertilization resulted in the reduction of $pCO2^{atm}$, but all of the variation of glacial $pCO2^{atm}$ could not be explained in our control experiment as in previous studies. LGM control simulation underestimated the salinity and water mass age suggested by proxy data in the Southern Ocean. We thus curried out a sensitivity experiment (LGM stratification experiment) to reproduce the salinity and water mass age in the glacial deep Southern Ocean suggested by LGM proxy data. In the LGM stratification experiment, sea bottom salinity around the Antarctica was restored to the high salinity to mimic the deep water formation process. In addition, we decreased vertical diffusivity considering the enhanced salinity stratification in the glacial Southern Ocean.

High salinity in the deep Southern Ocean resulted in increased $pCO2^{atm}$ because Antarctic Bottom Water flow increased and residence time of carbon decreased in the deep Pacific. On the other hand, weakening of vertical mixing contributed to the increase of the vertical gradient of dissolved inorganic carbon and decrease of $pCO2^{atm}$. However, it is unable to explain the full magnitude of recorded reduction of glacial $pCO2^{atm}$ in our simulations which include the above-mentioned contribution of the Southern Ocean process in addition to gas-exchange, ocean circulation, and iron fertilization changes [Kobayashi et al., 2015].

Carbonate compensation process has been reported to amplify the variation of glacial–interglacial ocean carbon cycle but it is not explicitly included in our above-mentioned simulations. We now try to evaluate the role of carbonate compensation process by coupling a newly developed simple sediment model with our OGCM.

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

