Modeling study on glacial-interglacial variations of atmospheric CO2 concentration: the effect of physical conditions of ocean

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Ancient air trapped in Antarctic ice cores shows that atmospheric CO_2 concentration, pCO_2, was lower during glacial periods than during interglacial periods. At the Last Glacial Maximum (LGM), pCO_2 was 180-200 ppm which is 80-100 lower than the preanthropogenic value. This observation suggests that variations in pCO_2 have played an important role in global climate change during the late Quaternary. Although many hypotheses have been proposed to explain the pCO_2 variations, the reason for the low glacial pCO_2 is still unclear.

In this study, we have investigated the effect of physical changes in ocean (the circulation field, temperature, salinity, and the sea-ice extent) on pCO_2 by numerical experiments. We consider two model ocean circulation fields which are based on reproduction by an atmosphere-ocean coupled general circulation model (MIROC3.2). One corresponds to the preindustrial state, and the other to the LGM state. In order to consider the carbon cycle in the ocean, we use an ocean general circulation model (COCO3.4), which is an ocean component of MIROC3.2, coupled with a simple biogeochemical model. First, we simulate distribution of chemical tracers, and obtain pCO_2 of 280 ppm when the preindustrial physical ocean field is assumed. On the other hand, when the LGM physical ocean field is assumed (any other conditions are the same) pCO_2 is lowered by ~30 ppm. Next, in order to evaluate the effect of solubility change by lower sea surface temperature (SST) on pCO_2, we calculate the solubility using SST at the LGM, although we assume that the circulation field is identical to the preindustrial state. As a result, pCO_2 also is lowered by ~30 ppm. This result suggests that the effect of solubility change (lower SST) would be responsible for most of the 30 ppm reduction. We obtained that the SST change in the high-latitude Northern Atlantic could explain 1/3-1/4 of the overall change in pCO_2. The effect of salinity change would be rather small (several ppms).

We also have examined model sensitivities to changes in sea ice extent in the Southern Ocean on pCO_2 and discussed the effect of the Southern Ocean on the low pCO_2. The effect of reduced ventilation caused by sea-ice cover was much weaker than that predicted by a box model in a previous study. We discussed the difference in model behaviors between box models and our GCM. Sea-ice cover may have had the additional effect of reducing biological activity; we propose that this effect was opposite and possibly stronger than the reduced-ventilation effect. These results suggest that sea-ice expansion was far from the principal mechanism for low CO_2 concentration during the LGM.