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Atmospheric pCO_2 variations: the effect of ocean circulation changes

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Ancient air trapped in Antarctic ice cores shows that atmospheric CO_2 concentration, pCO_2, was lower during glacial periods in the last ~400 ky than during interglacial periods such as the present Holocene. At the Last Glacial Maximum (LGM) ~20,000 years ago, pCO_2 was 180-200 ppm which is 80-100 lower than the preanthropogenic value. The pCO_2 variations in the glacial-interglacial cycles have synchronized with the temperature variations in Antarctica and the variations in ice-sheet volume. This observation suggests that variations in pCO_2 has played an important role of some kind 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.

The carbon cycles in the ocean have great influence on pCO_2, because the deep ocean is a much larger reservoir of CO_2 compared to the atmosphere-surface ocean system. CO_2 in the surface ocean is transported by physical and biological ways to the deep ocean to make a contrast in carbon concentration between the surface ocean and the deep ocean, resulting in lowering pCO_2. The global thermohaline circulation (THC) of ocean would have influence both on the physical and biological transport of CO_2. It is very important to assess adequately the effect of changes of the global THC on pCO_2. We tackle this issue using an ocean general circulation model (OGCM) coupled with a biogeochemical model. This study is important for the better understanding of natural variability of pCO_2 as well as the glacial-interglacial cycles.

Concerning this problem, we have investigated the effect of various changes in physical conditions of ocean including the circulation field on pCO_2 by 17 numerical experiments. We assumed five model-ocean physical fields which are based on reproduction by an atmosphere-ocean coupled general circulation model (MIROC3.2). We found that the effect of the difference in the circulation field on pCO_2 was very small in every case. For example, if a last-glacial-maximum physical ocean field reproduced by MIROC3.2 was assumed, pCO_2 was lowered by ~30 ppm compared to the interglacial value. Most of the 30 ppm reduction can be explained by higher solubility of CO_2 into the ocean due to the glacial lower sea-surface temperature. On the other hand, the effect of change in the circulation was less than several ppm. Weaker global THC would affect the ocean carbon cycle in two ways as follows. (1) It means less physical CO_2 transport to the deep ocean. (2) It means more effective storage of biologically transported CO_2, that is more effective soft tissue pump, because the slower THC corresponds to longer duration of the deep water. Interestingly, those two effects offset each other in all cases of this study, resulting in the small changes of pCO_2. Additional abiotic experiments is supporting this idea.