Geophysical Research Abstracts
Vol. 12, EGU2010-3775, 2010
EGU General Assembly 2010

Interaction between ocean circulation and sea-ice coverage controlling marine carbon cycle

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During the late Pleistocene, the global temperature and atmospheric carbon dioxide partial pressure (pCO_2) has varied with 100 kyr glacial-interglacial cycles. Despite of the prominent relationship between climate and the carbon cycle, the mechanisms controlling the glacial-interglacial pCO_2 variations are still under debated. Factorial experiments are conducted with an offline biogeochemical model and an Atmosphere-Ocean General Circulation Model (AOGCM) to investigate the atmospheric pCO_2 sensitivity to glacial climate dynamics. The prescribed climate field is obtained from runs of an AOGCM, Model for Interdisciplinary Research on Climate (MIROC), following the Paleoclimate Modeling Intercomparison Project 2 protocol. This is a new approach to evaluate glacial climate effect on marine carbon cycle using a fully coupled AOGCM. Moreover, the factorial experiments switching on and off each climate factor enable us to recognize the characteristics of ocean circulation and sea-ice coverage that control marine carbon cycle and consequently atmospheric pCO_2. In our simulation, atmospheric pCO_2 is lowered when Atlantic meridional overturning circulation is weakened in conjunction with increased Southern Ocean sea-ice coverage. However, neither process alone decreases atmospheric CO_2. This is because the redistribution of oceanic dissolved inorganic carbon (DIC) is obviously influenced by the background states of Antarctic Intermediate Water (AAIW) and sea ice extent in the Southern Ocean. The factorial experiment switching only on the glacial condition of sea ice in the southern hemisphere shows that the upwelled carbon rich AAIW is transported northward. This response increases surface DIC over the North Atlantic and consequently contributes to the atmospheric pCO_2 buildup. On the other hand, the factorial experiment switching on the glacial conditions of sea-ice in the Southern Ocean and ocean circulation shows that the deep-water carbon increase induced by ocean stratification is furthermore enhanced by the sea-ice expansion in the Southern Ocean. The sea-ice extent in the two hemispheres plays a different role in modulating atmospheric pCO_2. The sea-ice coverage in the Southern Ocean decreases atmospheric pCO_2 by inhibiting the degassing of DIC-rich deep water. However, the coverage in the northern hemisphere increases the pCO2 through less soluble CO_2 in cold water. It is the interaction between ocean circulation and sea-ice coverage that is a key factor accounting for the observed glacial pCO_2 drawdown. We have also found that atmospheric pCO_2 is relatively insensitive to glacial ocean circulation. Since ocean circulation drives surface DIC and alkalinity simultaneously, these responses allow the relative small reduction in surface CO_2 concentration as an influenced by seawater chemistry. The climate-induced biogeochemical process would amplify further atmospheric pCO_2.