Role of ocean and sea ices in climate responses to the increase in carbon dioxide

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Climate responses to the atmospheric CO2 increase were simulated using a general circulation model (GCM) developed by the Center for Climate System Research, University of Tokyo (CCSR), National Institute for Environmental Studies (NIES) and Frontier Research Center for Global Change (FRCGC). We performed a climate feedback analysis, the scheme of which was developed recently [1], and found that the results of CO2 increase experiments are strongly dependent on feedback processes concerning ocean and sea ices. The present results suggest that knowledge about processes of ocean and sea ices would play an important roll to reduce uncertainties in climate prediction.

The surface air temperature (SAT) on earth has been observed to increase about 0.6 degree during the 20th century, and it can be attributed to the increase in anthropogenic greenhouse gases in the atmosphere [2]. Predictions by the various numerical climate models suggest that the SAT would increase much more if the atmospheric greenhouse gases would increase in the future. However, the predicted changes in the SAT varies considerably across climate models [2]: Since resolution or parameterization is different among climate models, the behavior of components in the climate system varies and thus feedback processes would show varieties among climate models.

It is important to clarify the reason why the predicted results differ among climate models, in order to reduce the uncertainty in climate prediction. In this study, we have performed CO2 increase experiments by using an atmosphere-ocean coupled GCM, MIROC 3.2, developed by CCSR/NIES/FRCGC and investigated the mechanisms that determine climate responses to CO2 increase. We have used the two versions of MIROC with different resolutions, higher (about 100 km, Hi-Res) and lower (about 500 km, Mid-Res) resolution versions. The numerical simulations consist of doubled CO2 equilibrium (2XCO2) and 1%/year CO2 increase (1%CO2) experiments. In the 2XCO2, we have used the atmospheric part of MIROC coupled with a slab ocean in order to save the numerical integration time to achieve the equilibrated states. In the 2XCO2, sea ice is described by a simple thermodynamic model in the atmosphere-slab ocean coupled model. On the other hand, in the 1%CO2, the dynamics of sea ice is considered in the atmosphere-ocean coupled model. The results obtained from the numerical experiments and climate feedback analysis are as follows:

1) The responses of SAT to the CO2 increase (Delta-T) of the Hi-Res version is larger than that of the Mid-Res version in the 1%CO2, while Delta-T are similar between the Hi-Res and Mid-Res versions in the 2XCO2. Delta-T in the time of the doubled CO2 concentration of Hi-Res and Mid-Res versions are 2.4 K and 1.9 K in the 1%CO2, while they are 4.3 K and 4.0 K in the 2XCO2.

2) One of the reasons for the larger Delta-T of the Hi-Res version in the 1%CO2 is that the ocean heat uptake (OHU) of the Hi-Res version is smaller than that of the Mid-Res version at the mid-to-high latitudes. Since the heat transport to the deeper ocean in the Hi-Res version is weaker, the ocean surface layer warms effectively and thus the Delta-T become larger. In the 2XCO2, on the other hand, the contributions of OHU to Delta-T can be negligible because the equilibrium state of the atmosphere-ocean system is achieved.

3) Other reason for the larger Delta-T of the Hi-Res version in the 1%CO2 is that the ice-albedo feedback (IAF) of the Hi-Res version is larger than that of the Mid-Res version at the southern high latitudes. Since the sea ice model adopted in the 1%CO2 and 2XCO2 are different, the behaviors of sea ices are different between those experiments, which cause the different response of IAF. The details will be discussed in the presentation.

[1] Yokohata et al. 2005. Geophys. Res. Lett., doi :10.1029/2005GL023673. [2] IPCC 2001. Edited by Houghton et al., Cambridge Univ. Press.