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Three-dimensional budget analysis of global carbon cycle estimated from a coarse-resolution global OGCM

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Recent observational and model studies have begun to clarify natural and anthropogenic carbon cycle in the global ocean. In the observational studies, Sabine et al. (2004) estimate the inventory of anthropogenic carbon. Mikalloff-Fletcher et al. (2006, 2007) and Gruber et al. (2009) evaluate the basin-scale barotropic carbon transport using the inverse method. Combining these estimations and the imformations from the physical oceanography, Three-dimensional structure of carbon cycle has been discussed. It is, however, very hard to estimate how the carbon is transported through particular density bins from the limited observational data. On the other hand, model outputs can basically offer precise budget analysis even though these outputs have large uncertainty especially for the biochemical part as well as the physical part.

In this study, we estimate the three-dimensional structures of carbon cycle using OGCM output data obtained by Nakano et al. (2011, JO). The model incorporate a NPZD model. The resolution of the OGCM is 1 degree in latitude and 0.5 degree in longitude. There are 51 levels. The OGCM is forced by the COREv2 reanalysis data. Two experiments are conducted for evaluating the carbon cycle. One experiment is forced under the constant, preindustrial atmospheric pCO2 and the other is forced under the historically increasing one. The difference between these two experiment is defined as the anthropogenic carbon. The obtained results such as CO2 budget and pCO2 flux are largely the same as those of the previous model studies and consistent with the observational estimation.

We conduct three-dimensional budget analysis for each region and each month in the densities ranges with 0.1 sigma bins. We calculate the inventory (A), surface flux (B, surf in the figure), and divergence by the transport across the regional boundaries (C). The inner transport is calculated by dA/dt - B -C (Inn in the figure). We follow the regional division of Mikalloff-Fletcher et al. (2006, 2007) and Gruber et al.(2009) which is used for Regional Carbon Cycle Assessment and Processes (RECCAP). We use the monthly output because using the 5 days output gives nearly the same results in this coarse-resolution model. To the best of my knowledge, this is the first attempt to evaluate the three-dimensional budget analysis of global carbon cycle.

From the budget analysis, we can see the following three dimensional structures. In the Pacific, carbon is transfered in the shallow layer from the equatorial region to the midlatitues regions. In the midlatitude regions, the cooling of the ocean leads to the absorption of carbon from the atmosphere especially in the density range of Mode Waters. In addition to the direct absorption from the atmosphere, the cooling induce the movement of the carbon from the shallow layer to the Mode Waters. The carbon in the Mode Waters moves to the equatorial region through the subtropical cells. In the equatorial region, the carbon moves to the lighter densities through the eastward equatorial current. At the surface in the equatorial region, the carbon is released but the anthropogenic carbon is still absorbed due to the increase of the atmospheric carbon. In the Atlantic ocean, the barotropic movement of the anthropongeic carbon is know to be northward even though the movement of North Atlantic Deep Water (NADW), where the anthropogenic carbon is most accumulated. Here, we can explicitly show that this somewhat counterintuitive estimation is due to the larger northward shallow transport than the southward small transport of NADW. Even though the analysis is not so much new interpretation as our common understanding of the global carbon cycle, we think that explicit estimation of the budget analysis help understand the three-structure of the carbon cycle.

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