Using Models to Improve our Ability to Monitor Ocean Uptake of Anthropogenic Carbon

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1. Abstract

Monitoring global ocean uptake of CO_2 using repeat hydrographic measurements consists largely of two tasks. First, one must identify the anthropogenic component of the signal from the patchy changes in total carbon identified through repeat measurements. Second, one must extrapolate the anthropogenic signal from transects to the basin scale. In both cases, monitoring is complicated by variability in ocean circulation, and this manifests itself in two ways. Watermass anomalies involve changes in the mix of watermasses at individual points. Pycnocline anomalies involve the convergence or divergence of light waters at one point associated with the passage of planetary (Rossby and Kelvin) waves that are evident in remotely-sensed altimetry data. The first stage of our work has consisted of identifying the dynamical controls on natural carbon variability, both for observations and for ocean models. More recent work focuses on applying this understanding to large scales. Additional work has focused on Observing System Simulation Experiments (OSSEs) using state-of-the-art coupled climate models to identify the role of the seasonal cycle in modulating the rate of uptake of carbon by the ocean for IPCC-type scenario runs over the period 1861-2100.

2. Project Summary

Work continued towards development of a new method that would reduce uncertainty in estimates of the oceanic carbon uptake rate between the WOCE and CLIVAR decades. As part of this project, I attended the symposium in Switzerland between July 13-17 2009 entitled "Decadal Variations of the Ocean's Interior Carbon Cycle: Synthesis and Vulnerabilities"

(organized by Niki Gruber) at the Centro Stefano Franscini in Monte Verita. In addition to a large number of participants from Europe and Japan, several NOAA scientists (Richard Feely, Christopher Sabine, and Rik Wanninkhof) as well as Robert Key from Princeton were in attendance.

It was decided at the meeting that the assembled international group would initiate an effort to quantify the changing ocean carbon inventories on a timeframe so as to be included in the next IPCC report (AR5). This would be done through a first effort to establish changing carbon inventories for each of the major basins between WOCE and CLIVAR, and then through a coordinated synthesis effort for the global estimate. During the meeting, I agreed that in collaboration with Robert Key (Princeton) we would lead an effort for the important task of extrapolating anthropogenic carbon estimates from the individual transects to the basin scale. This work will be a natural extension of the work I am currently performing through the support of NOAA.

Thus the intended user community for the new method we are developing would be not only NOAA researchers from the US (Richard Feely, Christopher Sabine, and Rik Wanninkhof), but also participating scientists from Europe, Japan, and Australia.

3. Scientific Accomplishments

During the past year, our publication on the relationship between altimetry and natural carbon variability in the ocean was revised and accepted [Rodgers et al., 2009].

A new Observing System Simulation Experiment (OSSE) was initiated to test the idea that detection of the uptake of anthropogenic carbon by the ocean over the 21st century will require resolving the seasonal cycle with measurements. To this end, we have evaluated the response of two coupled ocean/atmosphere climate models that include the ocean carbon cycle under IPCC-type perturbations. The results have been compared to the signal found for model runs where there is only an 1860-control climate (natural variability for stationary 1860 conditions). The main result is that the anthropogenic transient signal in air-sea CO_2 fluxes projects differently onto summer and winter conditions in the extra-tropics. This difference manifests itself as a large increase in the seasonal cycle for both $DpCO_2$ and air-sea CO_2 fluxes. The changes in winter tend to be significantly larger than the changes in summer. The large increase in seasonality is common to the two models examined thus far (the GFDL and IPSL coupled models). However, the two coupled models exhibit significant differences in both their background pre-anthropogenic activity and their response to the anthropogenic climate perturbation.

The sign of the response is such that summer-biased observationally-based estimates of ocean uptake of carbon will tend to underestimate the rate of uptake. Having established the importance of the seasonal cycle for detection, current work is focused on developing a mechanistic understanding of the controls on changes in seasonality. A manuscript describing this work is currently under development, and the plan is to submit this for publication by the end of the second year of funding (by June 2010).

Work has also begun on an analysis of the CORE-forced ocean model runs performed at GFDL by John Dunne using the MOM4-TOPAZ model. As CORE is derived from the NCEP reanalysis product, the real world variations are represented in the CORE atmospheric boundary conditions. In order to represent anthropogenic carbon in the ocean, two separate ocean simulations were performed, each with identically evolving physical state variables. One run used the anthropogenic transient in atmospheric CO_2 over the historical period (until 2005), while the other maintained constant pre-anthropogenic CO_2 concentrations in the atmosphere. The anthropogenic carbon tracer is then defined as the difference in the carbon concentrations and fluxes between the two model runs.

The initial focus of this work is the evaluation of the commonly used empirical eMLR method for detection of anthropogenic carbon in the ocean [Friis et al., 2005]. A previous modeling study [Levine et al., JGR Oceans, 2007] previously applied eMLR to a coupled model simulation to evaluate the uptake of anthropogenic carbon by the ocean. However, that study did not include a perfect anthropogenic DIC tracer, so that they were limited in their skill assessment of the eMLR method. Additionally, their study focused on quantifying carbon changes along particular sections over decadal timescales. They did not explore the more general question of the skill of eMLR in identifying three-dimensional changes in anthropogenic carbon, nor did they consider timescales other than decadal. Thus the CORE-forced runs with MOM4-TOPAZ at GFDL provide an opportunity to address these questions quantitatively.

Currently we are focusing on the North Atlantic inventory of anthropogenic carbon, with an analysis of changes along the A16 section between 1993 (WOCE) and 2003 (CLIVAR). The second stage will test the ability of eMLR to estimate the basin-scale changes in anthropogenic DIC by including the full three-dimensional model fields for temperature, salinity, alkalinity, and nutrients. An important component of this work will be testing the extent to which dynamical information (sea surface height and vorticity) improves the skill of the method.

The final stage of this work will test the skill of the eMLR method in extrapolating inferred anthropogenic carbon changes to basin-scale inventory changes. This will be done with the specific goal of applying this to the international synthesis effort in estimating global anthropogenic carbon inventory changes between the WOCE and CLIVAR decades, within the context of the IPCC AR5 assessment.

Additionally, we are extending the work considered in our recently published JGR Oceans paper [Rodgers et al., 2009] where we considered changes in carbon along the OVIDE section in the North Atlantic between June 2002 and June 2004. In the published study, we considered changes in the column inventory of carbon. In the extension of the earlier work, we are considering the full vertical structure in the distribution of hydrographic properties and nutrients. Again, the objective is to demonstrate whether the inclusion of dynamical information (vorticity and sea surface height) can improve the skill of the empirical eMLR method.

The work conducted over the last year contributes to the observing system program in two ways. First, the methods being developed will be applied to a community-wide effort to estimate the

changes in the oceanic carbon inventory between the 1990s and the 2000s (between WOCE and CLIVAR). Second, the focus on the seasonal cycle with the OSSE will be important for the future extension of the existing detection network for carbon fluxes, as it demonstrates that a bias towards summertime measurements of sea surface $DpCO_2$ will inevitably lead to an underestimate of the rate of uptake of CO_2 by the ocean over the 21st century. For this reason, this work will be continued in collaboration with the observational community.

4. Education and Outreach

Although the work conducted to date has not involved outreach, it is the intention of the Principal Investigator to initiate communication with students on the role of the oceans in climate change.

5. Publications and Reports

5.1. Publications by Principal Investigator

Rodgers, K.B., R.M. Key, A. Gnanadesikan, et al., 2009: Using altimetry to help explain patchy changes in hydrographic measurements, J. Geophys. Res., 14, C09013, doi:10.1029/2008JC005183.

Gorgues, T., O. Aumont, and K.B. Rodgers, 2010: A mechanistic account of increasing seasonal variations in the rate of ocean uptake of anthropogenic carbon, submitted to Biogeosciences.

Sarmiento, J.L., M.L. Gloor, N. Gruber, C. Beaulieu, A.R. Jacobson, S.M. Fletcher, S. Pacala, and K.B. Rodgers, 2009: Trends and regional distributions of land and ocean carbon sinks, Biogeosciences Discuss., 6, 10583-10624.

5.2. Other Relevant Publications

As the first publication from the project is so recent (September 2009) there are not yet any relevant publications that cite this work.