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

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1. Project Summary

Given the importance of CO_2 as a greenhouse gas and driver of climate change, it is important to understand how much of the CO_2 produced through human activities is being absorbed by the ocean, and how that quantity is changing in time. A number of recent studies have suggested that ocean uptake of the anthropogenic perturbation to atmospheric CO_2 may be slowing, and if this were true it could imply that there has been a positive feedback in the climate system. This would implicate the ocean carbon cycle in an acceleration of the rate of warming.

I am currently working on four projects that address directly the way in which ocean uptake of anthropogenic carbon may be changing. The common thread with each state of this work is the use of ocean or climate models, which despite their numerous caveats and inherent uncertainties allow for fully consistent three-dimensional analyses of climate variables to be analyzed. Rather than attempting to validate the models, the objective is to evaluate how well different sampling strategies can allow one to characterize the globally integrated fields of interest.

There are two intended user communities that should benefit from the research described above. First, I am working directly in collaboration with an international group (including NOAA researcher Rik Wanninkhof) to provide a global estimate of ocean interior carbon inventories between the mid-1990s and the mid-2000s. The second intended beneficiary of this research should be the community of researchers measuring sea surface pCO_2 with the goal of quantifying whether the rate of uptake of carbon by the ocean is changing. My intention is that through the use of models, we can also provide a framework and methods for the synthesis between these user groups.

2. Scientific and Observing System Accomplishments

During the past year, the publication on the global eMLR method was revised and published (Plancherel et al., 2013). The work presented in that study will be incorporated in a global synthesis study to be presented at Ocean Sciences 2014 in Honolulu, through collaboration with Dominique Clement (first author) and Niki Gruber at the ETH in Zurich Switzerland. This work will subsequently be published in a peer-reviewed, presenting a synthesis of ocean interior changes over the WOCE-to-CLIVAR decades.

The second track of work has continued with the new Observing System Simulation Experiment (OSSE) initiated to test the idea that detection of the uptake of anthropogenic carbon by the ocean will require resolving the full seasonal cycle with carbon measurements. The main results were presented in a plenary talk at the Ninth International Carbon Dioxide Conference (ICDC9) in Bejing in June 2013. This work is currently nearing final preparations in manuscript form, and will be submitted in late 2013 as Rodgers et al. (2013). This work is being conducted in collaboration with Rik Wannikhof at NOAA AOML.

A third track of work has focused on testing the hypothesis that that winds have an important role in determining the rate of exchange of CO_2 between the atmosphere and ocean through wind stirring over the Southern Ocean. This was tested with sensitivity study using an ad hoc parameterization of wind stirring in an ocean carbon cycle model. The objective was to identify the way in which perturbations to the vertical density structure of the planetary boundary layer in the ocean impacts the carbon cycle and ocean biogeochemistry. Wind stirring in the model led to a reduced uptake of CO_2 by the Southern Ocean of 0.9 PgC/yr over the region south of 45°S. Wind stirring impacted not only the mean carbon uptake, but also the phasing of the seasonal cycle of carbon and other species associated with ocean biogeochemistry. Enhanced wind stirring delays the seasonal onset of stratification, and this has large impacts on both entrainment and the biological pump. It was also found that there is a strong sensitivity of nutrient concentrations exported in Subantarctic Mode Water (SAMW) to wind stirring. This finds expression not only locally over the Southern Ocean, but also over larger scales through the impact on advected nutrients. In summary, the large sensitivity identified with the ad hoc wind stirring parameterization offers support for the importance of wind stirring for global ocean biogeochemistry, through its impact over the Southern Ocean. This work, conducted in collaboration with Rik Wanninkhof at NOAA AOML, has been submitted and is available as an online Discussion paper at Biogeosciences Discussion (Rodgers et al., 2013).

Work to extend this third track are currently underway in collaboration with Matt Harrison at NOAA GFDL using the ESM2G climate model at GFDL. Preliminary results from this collaboration suggest that model biases in simulations of sea surface temperature (SST) over the Southern Ocean are significantly improved through the use of wind stirring, and that this also has significant impacts on ocean biogeochemistry. The intention is that this work will contribute to improving the model representation of the Earth System.

A fourth track of work is currently underway in collaboration with Joseph Majkut (Phd student) and Jorge Sarmiento at Princeton University to address observing system design. The work addresses the question: what sampling density of carbon-measuring surface floats is required in the Southern Ocean to constrain carbon uptake over the Southern Ocean in a way that satisfies the LSCOP criteria of Bender et al. (2004)? This work can be thought of as being the air-sea CO_2 flux analogue of our recently published study on ocean interior carbon inventory changes (Plancherel et al., 2013). The work, which focuses on the Southern Ocean, is in fact perfectly general, and it is intended that this analysis eventually be applied over global scales, and to benefit the extension of the current observing system. The work will be submitted with Joseph Majkut as first author to the Royal Society in late 2013.

3. Outreach and Education

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.

4. Publications and Reports

4.1. Publications by Principal Investigators

Published

Plancherel, Y., K.B. Rodgers, R.M. Key, A.R. Jacobson, and J.L. Sarmiento, 2013: Role of regression model selection and station distribution on the estimation of oceanic anthropogenic carbon change by eMLR, Biogeosciences, 10, 4801-4831.

Submitted or Under Review

Rodgers, K.B., O. Aumont, S.E. Mikaloff Fletcher, Y. Plancherel, L. Bopp, C. de Boyer Montégut, D. Iudicone, R.F. Keeling, G. Madec, and R. Wanninkhof, 2013: Strong sensitivity of Southern Ocean carbon uptake and nutrient cycling to wind stirring, Biogeosciences Discuss., 10, 15033-15076.

Ishii, M., R.A. Feely, K.B. Rodgers, G.-H. Park, R. Wanninkhof, D. Sasano, H. Sugimoto, C.E. Cosca, S. Nakaoka, M. Telszewski, Y. Nojiri, S.E. Mikaloff Fletcher, Y. Niwa, P.K. Patra, V. Valsala, H. Nakano, I. Lima, S.C. Doney, E.T. Buitenhuis, O. Aumont, J.P. Dunne, A. Lenton, and T. Takahashi, 2013: Air-sea CO_2 flux in the Pacific Ocean for the period 1990-2009, BIogeosciences Discuss., 10, 12155-12216.

Majkut, J.D., J.L. Sarmiento, and K.B. Rodgers, 2013: A Growing Oceanic Carbon Uptake: Results from an inversion study of surface pCO_2 data, under revisions, Global Biogeochemical Cycles.

4.2. Other Relevant Publications

The original publication from this grant (Rodgers et al., 2009) has now been cited nine times, with three citations over the last year. In addition to the citation in Plancherel et al. (2013), with that paper described immediately above, there have been two additional references to this paper in the last year listed below.

Kouketsu, S., T. Doi, and A. Murata, 2013: Decadal changes in dissolved inorganic carbon in the Pacific Ocean, Global Biogeochemical Cycles, 27, doi:10.1029/2012GB004413.

McGrath, T., C. Kivimae, T. Tanhua, R.R. Cave, and E. McGovern, 2012: Inorganic carbon and pH levels in the Rockall Trough 1991-2010, Deep-Sea Research I 68, 79-91.