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

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Project Summary

How is the ocean carbon cycle changing in response to anthropogenic perturbations? What are the processes controlling these changes, and how can process understanding inform how we measure and interpret carbon in the ocean? This project focuses on addressing these questions with four parallel approaches. The common thread linking this work is the application of models to the interpretation of carbon measurements, and to the general theme of "Ocean Carbon Uptake and Content".

The first project involves the development of an empirical method for estimating changes in the ocean inventory of anthropogenic carbon. The approach is general, but the specific focus being developed is on estimating the changes between the WOCE (1990s) and CLIVAR (2000s) decades. Work to date has focused on testing the "skill" of a new implementation of an empirical (multiple linear regression) detection method on an ocean carbon cycle model. Results with the model indicate that the method is robust, with uncertainty of 5% lying well below the threshold of "acceptable" uncertainty of 10%. This demonstrates that the method is appropriate to apply to real-world ocean observations. New work has begun on an analysis of decadal carbon accumulation over the North Pacific.

The second phase of this work focuses on the mechanisms controlling carbon uptake by the ocean. This is being addressed through two different model analyses. One of the main findings of the work to date is that uptake of anthropogenic carbon is strongly impacted by water mass transformations. In particular, uptake over the subtropical gyres and tropics constitutes approximately 2/3 of the global total, but approximately ½ of this quantity is transferred through winter release of heat during winter in western boundary currents (as well as other related processes) to deeper densities. This understanding will have important implications for efforts of the observational community to synthesize surface pCO_2 measurements and ocean interior DIC measurements.

The third phase of this project focuses on how the seasonal cycle in the ocean carbon cycle may change over the 21st century. Given that the current observing system for pCO_2 is biased heavily towards summer measurements, it is important to know the degree to which a summer bias may introduce errors in pCO_2-based ocean uptake estimates in the future. Analyses with Earth System Models suggest that underestimates of order ~1 PgC/year may result by the 2040s from (a) using summer-only measurements, and (b) assuming that the seasonal cycle is stationary. By the 2090s, this bias may result in a ~3 PgC/year underestimate of ocean carbon uptake. This work underscores the potentially critical importance of full resolution of the seasonal cycle for future carbon monitoring.

The fourth phase of this work involves development of a new method for estimating pre-anthropogenic variability in the strength of the winds, and potentially the carbon cycle, over the Southern Ocean. Recent work by a number of international researchers has focused on the question of whether Southern Ocean uptake of carbon is slowing in response to a trend towards increasing winds over the Southern Ocean. This research has taken at face value that the recent multi-decadal trend in reanalysis products (NCEP) towards stronger winds is a secular trend, and focuses largely on whether ocean mesoscale eddies act to diminish an ocean carbon cycle response. We have instead set out to test the hypothesis that the secular trend in Southern Ocean winds is indistinguishable from the natural decadal variability in Southern Ocean winds. Through the use of models, we have interpreted variations in tree ring $\Delta^{14}C$ variations over the last millennium (850 – 1850AD) to indicate that natural decadal variations are in fact as large as the recent secular trend revealed in reanalysis products. This work points to the way in which elevated natural variability potentially complicates the task of detection of climate feedbacks ove the Southern Ocean, and the need for significantly longer time series measurements.