Inferring the Uptake of Anthropogenic Carbon by the Ocean

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The ocean is a major sink for the increasing levels of atmospheric CO_2 caused by human activity. According to the Intergovernmental Panel on Climate Change, roughly one third of the anthropogenic carbon is sequestered by the ocean. While much progress has been made in estimating the distribution of anthropogenic carbon ("$\Delta\mathrm{DIC}$") in the ocean from observations, considerable uncertainty remains in the rate of uptake and the present inventory of anthropogenic carbon in the ocean. Improved quantification of the oceans role in the perturbed carbon cycle is one of the major challenges in climate research.

A number of techniques have been developed to estimate the inventory of anthropogenic carbon in the ocean from measurements of total dissolved inorganic carbon (DIC). The fundamental difficulty is that the anthropogenic signal represents a small perturbation (order 1%) on a large, and spatially variable background of naturally occurring (i.e., "preindustrial") DIC. The problem is compounded by the fact that DIC has numerous, poorly known, biogeochemical sources and sinks. To improve upon our knowledge of the ocean carbon sink we have, in recent years, developed a technique for inferring $\Delta\mathrm{DIC}$ from oceanic measurements of transient tracers. This technique is based on 3 key ideas: (1) $\Delta\mathrm{DIC}$ represents a sufficiently small perturbation to be treated as a passive tracer that is "transparent" to biogeochemical interactions, (2) transport of tracers in the ocean can be characterized by a Green's function or "transit-time distribution" (TTD), and (3) measurements of transient tracers such as CFCs can be used to parameterically constrain the TTD. Application of this method to ocean data has allowed us to estimate $\Delta\mathrm{DIC}$ uptake by the ocean. Interestingly, these estimates differ considerably from those obtained by previous workers, and in ways that can be related, at least qualitatively, to the assumptions underlying the prior research. However, further work is necessary to gain confidence in our results.

The proposed undergraduate research project aims to systematically evaluate and improve the TTD method through explicit computation in a 3-D ocean circulation model. In particular, we propose a "twin experiment" in which the penetration of anthropogenic carbon and transient tracers such as CFCs is directly simulated. The TTD technique is then applied to the synthetic tracer "data" to see how well we can reconstruct the simulated uptake of anthropogenic carbon. This approach will allow us to understand the biases and errors in our data-based $\Delta\mathrm{DIC}$-inference method. A second goal of this proposal will be to investigate several ideas for improving the basic approach, in particular, the use of tracers other than CFCs with different characteristics (e.g., ^{39}Ar) or surface time histories (e.g., SF_6) to constrain the TTD. Specifically, the student, working in close collaboration with the PI, will pursue the following goals:

- Implement a simple biogeochemistry model for simulating carbon in the ocean.
- Perform simulations of natural and anthropogenic carbon, CFCs, ^{39}Ar, SF_6, and Green's functions (TTDs) for different surface source regions.
- Apply the TTD-method to the synthetic model "data" to reconstruct anthropogenic carbon uptake.
- Asses the accuracy of the TTD method and the value of using additional tracers such as ^{39}Ar.

Tracer simulations will be performed using the "transport matrix" method developed by the PI, a numerical scheme for efficient and accurate simulation of oceanographic tracers. The student will make extensive use of MATLAB and PETSc, a widely used library for high-performance scientific computation. Some prior programming experience would certainly come in handy. We believe participation in this project provides a unique opportunity for students to gain research experience and skills in an outstanding problem in climate science.