Yager – Final report to DOE for DE-FG02-02ER63472

The impact of enhanced nitrogen fixation on carbon sequestration: a reassessment of the inorganic carbon system in LNLC regions.

This project examined the inorganic carbon system associated with nitrogen fixation in the "low nutrient low chlorophyll" (LNLC) regions of the Western Tropical North Atlantic (WTNA) and Subtropical Pacific. Total dissolved inorganic carbon (DIC) and alkalinity (ALK) data from all seven expeditions have been finalized, checked for quality assurance, and uploaded to the Carbon Dioxide Information Analysis Center website (http://cdiac.ornl.gov/). Sample precision (based on measurements of duplicate samples; DOE 1997) was 0.95 umol/kg for DIC and 2.1 umol/kg for ALK. Underway pCO2 data are also available (precision is 1 uatm) for two cruises to the Subtropical Pacific and the final cruise to the WTNA.

Two manuscripts using this data are published or in press so far and we are current working on two others. The first (**Cooley and Yager, 2006, JGR**) uses a mixing model to remove the dilution effects of the Amazon River from the WTNA inorganic carbon data set. Once the physical effect is removed, the paper then estimates net community production (NCP) for each station. Enhanced rates of production (over respiration) are seen in the river plume, establishing a large biogenic atmospheric carbon sink in this region that is otherwise a source of carbon to the atmosphere. We note that this sink occurs in the absence of a measurable nitrate flux, and correlates well with the abundance of diatoms containing endosymbiotic diazotrophs, so it must be supported by nitrogen fixation. The second manuscript (**Cooley et al., in press, GBC**) compares our WTNA data (from Winter 2001, Spring 2001, and Summer 2003) to previously collected datasets (Ternon et al. 2000, Kortzinger et al. 2003) for the purposes of identifying seasonal and interannual variability in Amazon River-associated carbon sequestration. For the mid-salinity regions of the plume only, we estimate a carbon sink of 15±6 TgC per year. This is a globally significant flux that also agrees well with estimates of carbon fixation supported by nitrogen fixation and also with estimates of carbon flux to depth.

In a third manuscript in review (**Subramaniam et al., in review, Nature**) the elevated NCP is compared to sources of nutrients to the region, rates of carbon and nitrogen fixation, and phytoplankton community structure. The greatest NCP is seen in association with diatoms (*Hemiaulus* sp.) containing endosymbiotic cyanobacteria (*Richelia*) that fix nitrogen. These phytoplankton are stimulated by enhanced levels of iron, phosphorous, and silicate in the river plume and they appear to be efficient vectors for carbon export. *Trichodesmium* (a colonial diazotrophic cyanobacterium) is similarly productive, especially in response to atmospheric dust deposition, but a greater fraction of its production appears to be leaked to dissolved organic carbon and respired since the NCP is

lower at those stations. Overall, we estimate that the diatom/diazotroph assemblages associated with the Amazon River plume contribute to an atmospheric carbon sink of about 15-20 Tg per year (Subramaniam et al., in review). If the riverine flux of iron, phosphorous, and silicate to the WTNA is further increased by human activities in the Amazon watershed, we can expect this number to increase. But if the Amazon experiences increased drought in response to anthropogenic warming of the tropical Atlantic sea surface temperature (Zeng et al., in press, Nature), there may be a reduction in river-mediated carbon sequestration in this region. This system therefore provides a good example of climate-sensitive carbon sequestration.

Carbon isotope sample analyses (del13C-DIC) are also completed and checked for quality assurance. Sample precision was 0.15 per mil (0.08 per mil for standards). We are currently working on a manuscript that examines the isotope data from the WTNA in order to corroborate the above estimates of export. The application of data analyses techniques used previously (Zhang and Quay, 1998) must be modified due to the presence of the river plume (and therefore multiple mixed layers). Nevertheless, preliminary results so far corroborate the large carbon sink discussed in the above publications.

Human resource contributions from this grant include the training of one female doctoral candidate (Sarah Cooley, degree completed August 2006), six undergraduate students (two males, five females; including two honors thesis), and two part-time Master's level research technicians (both female). This grant was also instrumental in Dr. Yager's promotion and tenure, which was finalized in May 2007.

REFERENCES CITED (* indicate products from this project):

*Cooley, S.R. (2006). Dissolved inorganic carbon cycling in the offshore Amazon River plume and the western tropical North Atlantic Ocean. Dissertation. University of Georgia, School of Marine Programs. August 2006.

*Cooley, S. R. and P. L. Yager (2006). Physical and biological contributions to the western tropical North Atlantic Ocean carbon sink formed by the Amazon River plume. Journal of Geophysical Research – Oceans 111: C08018, doi:10.1029/2005JC002954.

*Cooley, S.R., V.J. Coles, A. Subramaniam, and P.L. Yager (in press). Seasonal variation in the Amazon plume-related atmospheric carbon sink. Global Biogeochemical Cycles.

DOE (1997). Handbook of methods for the analysis of the various parameters of the carbon dioxide system in sea water. A. G. Dickson and C. Goyet, eds., ORNL/CDIAC-74.

Körtzinger, A. (2003). A significant CO2 sink in the tropical Atlantic Ocean associated with the Amazon River plume. Geophysical Research Letters 30(24): 2287-2290.

*Subramaniam, A., P.L. Yager, E. J. Carpenter, C. Mahaffey, K. Björkman, S. Cooley, A.B. Kustka, J.P. Montoya, S. A. Sañudo-Wilhelmy, R. Shipe, and D.G. Capone (in review, June 2007). Amazon River enhances diazotrophy and carbon sequestration in the tropical North Atlantic Ocean. Nature.

Ternon, J. F., C. Oudot, A. Dessier and D. Diverres (2000). A seasonal tropical sink for atmospheric CO2 in the Atlantic Ocean: the role of the Amazon River discharge. Marine Chemistry 68: 180-201.

Zeng, N., J.-H. Yoon, J. A. Marengo, A. Subramaniam, C. A. Nobre, A. Mariotti, J. D. Neelin (in press). Causes and impacts of the 2005 Amazon drought. Nature.

Zhang, J., and P. D. Quay (1997). The total organic carbon export rate based on DIC and DI^{13}C budgets in the equatorial ocean. Deep-Sea Res. II 44: 2163-2190.

ABSTRACTS AND PRESENTATIONS RESULTING FROM THIS PROJECT

*Yager, P., S. Cooley, A. Subramaniam, R. Shipe, C. Mahaffey, K. Bjorkman, S. Sanudo-Wilhelmy, A. Tovar-Sanchez, E. Carpenter, and D. Capone (2006). Diatom-Diazotroph Associations in the Amazon River Plume are Linked with Carbon Sequestration in the Western Tropical North Atlantic. *AGU Ocean Sciences Meeting*, Honolulu, Hawaii, February 2006.

*Cooley, S. R. and P. L. Yager (2006). Biologically induced seasonality in the Amazon Plume carbon sink. *AGU Ocean Sciences Meeting*, Honolulu, Hawaii, February 2006.

*Subramaniam, A., E.J. Carpenter, R. Shipe, P. Yager, D. G. Capone (2005). The diatom express. American Society of Limnology and Oceanography, Santiago, Spain June 2005.

*Yager, P.L. (2005). The impact of nitrogen fixation on carbon sequestration: a reassessment of the inorganic carbon system in LNLC regions. Meeting of principal investigators of DOE's Carbon Sequestration Research Program. Belmont, Maryland (May 2005).

*Cooley, S. R., and P. L. Yager (2005). Intra- and interannual variation in the Western Tropical Atlantic inorganic carbon system. *American Society of Limnology and Oceanography Aquatic Sciences Meeting*, Salt Lake City, UT. February 2005.

*Carpenter, E. J., A. Subramaniam, J. Burns, S. Cooley, J. Finzi, T. Gunderson, R. Shipe, P Yager, D. Capone, C. Mahaffey (2005). Carbon and nitrogen fixation in the Western Tropical North Atlantic (WTNA) Ocean. *American Society of Limnology and Oceanography Aquatic Sciences Meeting*, Salt Lake City, UT. February 2005.

*Cooley, S. R., and P. L. Yager (2003). Distinguishing summertime biological inorganic carbon drawdown from physical effects in the western tropical Atlantic Ocean. *American Society of Limnology and Oceanography Aquatic Sciences Meeting*, Salt Lake City, UT. February 2003.

*Cooley, S. R. and P. L. Yager (2002). The dissolved inorganic carbon system during the 2001 MANTRA/PIRANA Expeditions in the Western Tropical Atlantic. Eos. Trans. AGU, 83 (4), Ocean Sciences Meet. Suppl., Abstract OS32E-166, 2002.