Final Report

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" Does Iron Fertilization Lead to Enhanced Carbon Sequestration?" A Synthesis of Polar Star Results.

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Publications to date:

- daily cruise reports on web at:

<http://www.mbari.org/education/cruises/SOFEX2002/index.htm>

- other manuscripts:

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Coale, K.H., K.S. Johnson, F.P. Chavez, K.O. Buesseler, R.T. Barber, M.A. Brzezinski, W.P. Cochlan, F.J. Millero, P.G. Falkowski, J.E. Bauer, R.H. Wanninkhof, R.M. Kudela, M.A. Altabet, B.E. Hales, T. Takahashi, M.R. Landry, R.R. Bidigare, X. Wang, Z. Chase, P.G. Strutton, G.E. Friederich, M.Y. Gorbunov, V.P. Lance, A.K. Hilting, M.R. Hiscock, M. Demarest, W.T. Hiscock, K.F. Sullivan, S.J. Tanner, R. M. Gordon, C.L. Hunter, V.A. Elrod, S.E. Fitwater, J.L. Jones, S. Tozzi, M. Koblizek, A.E. Roberts, J. Herndon, J. Brewster, N. Ladizinsky, G. Smith, D. Cooper, D. Timothy, S.L. Brown, K.E. Selph, C.C. Sheridan, B.S. Twining and Z.I. Johnson (2004). Southern Ocean Iron Enrichment Experiment (SOFEX): Carbon cycling in high- and low-Si waters. *Science*, 304: 408-414.

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- none

Final Project Report

This research synthesized activities related to work conducted as part of the Southern Ocean Iron Experiment (SOFEX) which investigated the effects of iron fertilization on enhanced carbon sequestration. The primary interest was in the fate of sinking particles which carry carbon to the deep ocean, where it can be sequestered from the atmosphere for >100-1000 year time scales. This was accomplished through direct measurements of thorium-234, a naturally occurring particle reactive radionuclide that traces shallow

particle export; SF₆ measurements to track the position of the Fe fertilized region; and the collection of ancillary data and samples to augment the study of major C, nutrient and elemental budgets as well as appropriate samples for biological study.

Results of this work show a small, but progressively increasing flux of particulate organic C to depth as a consequence of Fe fertilization (Figure 1). This is the first data set to show any effect of Fe fertilization on C sequestration in the Southern Ocean. The changes in particle export during SOFeX are significant (Figure 2), but only possible to detect given what is arguably the largest ²³⁴Th data set ever collected as part of an oceanographic experiment.

Samples for SOFeX were collected between Feb. 12 to 20th on a research cruise that left McMurdo Station, Antarctica on Feb. 10th and ended March 6, 2002 in Valparaiso, Chile. Work was conducted at the Southern SOFeX experimental site (S-patch) over an 8 day period, relying primarily on sampling from an underway seawater system, a CTD/Rosette, using single 10L Niskin bottles on a Kevlar line, and sampling from a trace metal clean towed "fish". At-sea measurements of SF₆ allowed us to positively confirm patch location and Fv/Fm, or photosynthetic efficiency was high in association with the Fe enriched waters. While there was particle export during the experiment, surface ²³⁴Th activities in and out of the patch did not vary significantly, indicating that the "crash", or a major Fe induced export event had not taken place.

More detailed analyses of the vertical profiles however indicate a decrease in ²³⁴Th activities, hence enhanced export in response to iron. Determination of this decrease was the result of a newly developed method which allowed direct sampling for ²³⁴Th using 4 liter samples collected using a CTD/Rosette (Buesseler et al., 2001a; Benitez-Nelson et al., 2001). This allowed detailed time-series and high vertical resolution data during occupation both "in" and "out" of the Southern Patch. The 4L method is based upon the coprecipitation of ²³⁴Th by formation of Mn oxides, which are filtered on to a 25mm diameter filter and beta counted at sea. Using this method, counting errors of 2% were obtained, but overall accuracy is closer to 5% determined by the standard deviation between replicate samples of deep waters.

A yield monitor recovery procedure for ²³⁴Th funded, designed and tested under the DOE proposal found an average yield for the at sea Mn precipitation of $92.0 \pm 1.6\%$ (mean $\pm$ st. dev.) on the Polar Star, and $90.4\% \pm 3.2\%$ on the RV Melville. Of primary concern were some low ²³⁴Th activity anomalies, but by use of this yield monitor the chance for any false positive fluxes (low ²³⁴Th activities) have effectively been eliminated (Figure 3).

Most prior ²³⁴Th studies, simply use a steady-state approximation and ignore advective and diffusive fluxes in the calculation of ²³⁴Th fluxes. High resolution time-series of average 0-50m ²³⁴Th activities in and out of the Southern patch find a clear steady decrease in ²³⁴Th flux that is slightly larger in vs. out of the Fe fertilized patch. This decrease must be included in the full ²³⁴Th flux calculation and the deliberate tagging of this water mass with SF₆ combined with time-series sampling allowed for a careful

evaluation of this non-steady state (NSS) term. Likewise, the addition of SF₆ allows for the evaluation of vertical exchange (via the gradient of SF₆ below the patch) and dilution effects (after correction for atmospheric losses). In most settings these physical terms are small, but must be considered before the data can be finalized. The SF₆ results considered in context of the ²³⁴Th mass balance has improved the current NSS model by the addition of physical transport.

Participation in conferences and public presentation of SOFeX results has been important to bring these results to the attention of the widest audience of scientists, policy makers and general audiences. Findings have been presented through scientific lectures, participation in National Academy workshops on C sequestration, student and public lectures on ocean iron fertilization and maintenance of a web site.

Figure 1. Depth profiles of ^{234}Th activity (units: disintegrations per minute per liter = dpm l^{-1}) are shown for SOFeX “IN” (a) and “OUT” (c) stations. ^{238}U activity (dpm l^{-1} ; dashed line) as determined by salinity. Also shown are the start and end particulate ^{234}Th flux profiles ($\text{dpm m}^{-2} \text{ d}^{-1}$) for “IN” (b) and “OUT” (d) stations.

Figure 2. POC flux data ($\text{mM C m}^{-2} \text{ day}^{-1}$) from SOFeX determined at 50 meters (**a**) and 100 meters (**b**). Fluxes are shown for “IN” and “OUT” stations as indicated for the start and end of the experiment.

Figure 3. Profiles of ^{234}Th and ^{238}U activities from the Southern Ocean. Open triangles indicate sample activity prior to recovery corrections. Activities are given in mBq and dpm per liter. Note: error bars are $\leq$ symbol size.