

**CTDO/Hydrography/CO2/Tracer/LADCP Transect I5  
Cape Town, South Africa, to Fremantle, Australia  
R/V Roger Revelle, 20 March - 15 May 2009**

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An oceanographic transect from South Africa to Australia - a repeat occupation of WOCE Hydrographic Program section I5 - will be carried out on R/V Roger Revelle during 20 March to 15 May 2009. The planned schedule is:

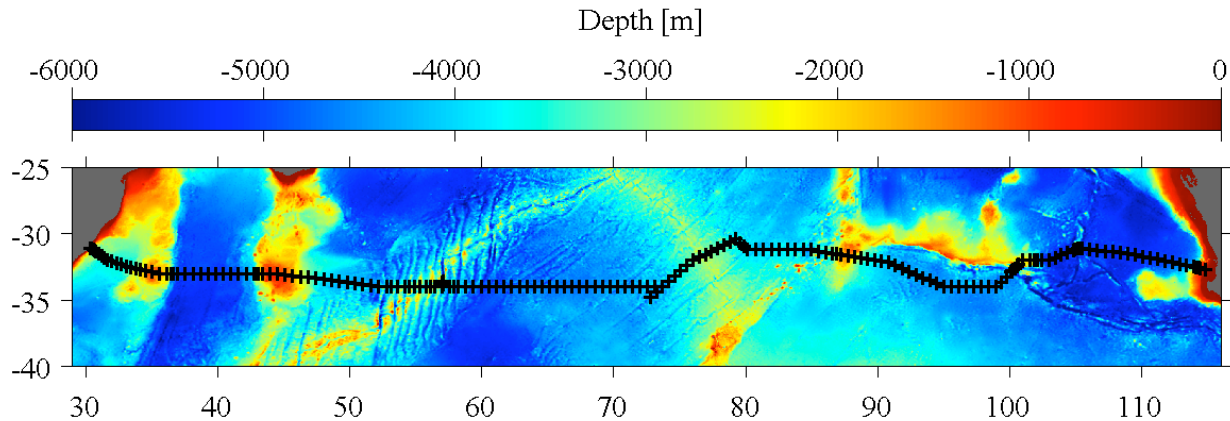
- load Cape Town, South Africa, 16-19 March
- depart South Africa 20 March and begin the I5 transect
- 57 UNOLS days at sea (no intermediate port stops are planned)
- arrive Fremantle, Australia, 15 May
- unload Fremantle, 16-17 May

Dr. James Swift, Scripps Institution of Oceanography of the University of California, San Diego, and Dr. Gregory C. Johnson, NOAA Pacific Marine Environmental Laboratory, will lead a program of ocean measurements (carbon parameters, temperature, salinity, oxygen, nutrients, CFCs, and other water properties) for the United States' contribution to the World Climate Research Program CLIVAR (Climate Variability) Repeat Hydrography Program and the UNESCO International Ocean Carbon Coordination Project.

One may learn more about the international programs at [http://www.clivar.org/carbon\\_hydro/](http://www.clivar.org/carbon_hydro/) and <http://www.ioccp.org/>. The US science team also maintain a web site oriented toward the United States' contributions at <http://ushydro.ucsd.edu/>.

The "repeat hydrography transect" from South Africa to Australia ("I5") will extend across the southern Indian Ocean along ca. 32°S between the 200 meter isobaths off South Africa and Australia. The science team has applied for research clearances for those parts of the work in South African and Australian waters. Roughly every 55 kilometers (closer over submarine ridges and near coasts), the science team will stop the ship to carry out a full-depth CTD/rosette/LADCP cast. The CTD will measure temperature, salinity, and oxygen from just below the sea surface to approximately 10 meters above the ocean bottom, and the LADCP will measure currents during the CTD cast. During each of these stations the science team will also collect up to 36 water samples for measurement of various water properties, such as CO<sub>2</sub>-related parameters (total carbon, total alkalinity, and pH), dissolved CFCs and SF<sub>6</sub>, oxygen, salinity, nutrients, and so forth (a complete list of science programs is included, below). A companion team will measure so-called trace metals (e.g., iron and aluminum) in the upper 1000 meters at some of the stations. While the ship is both underway and stopped surface seawater is also continuously pumped through sensors for temperature, salinity, and partial pressure of CO<sub>2</sub>. The science team operates standard meteorological sensors,

a shipboard Acoustic Doppler Current Profiler, a multibeam bathymetric sonar, and a gravimeter.



A map with the planned "I5" station locations (black plusses) over bathymetry (colors) is shown above.

Many of the data will be available at the end of the cruise, including the CTD and shipboard-analyzed data from the bottle samples. The USHYDRO web site <<http://ushydro.ucsd.edu>> will show the locations from which the data can be download when available. These will be preliminary data: CTD and water sample data are likely to be updated during the first 12-24 months after the cruise. A few types of water samples are analyzed in shore laboratories and so are available only several years later.

Dr. Swift will be the principal scientific point of contact. The operator of the R/V Roger Revelle is the UCSD Scripps Institution of Oceanography. The point of contact for the ship is the email address [shipsked@ucsd.edu](mailto:shipsked@ucsd.edu).

### **RATIONALE FOR REPEAT HYDROGRAPHY SURVEYS IN SUPPORT OF CLIVAR AND CARBON CYCLE OBJECTIVES (written in 2001)**

This summarizes the scientific rationale and scope of an integrated approach to a global observational program for carbon, hydrographic and tracer measurements. The program is driven by the need to monitor the changing patterns of carbon dioxide (CO<sub>2</sub>) in the ocean and provide the necessary data to support continuing model development that will lead to improved forecasting skill for oceans and global climate. The WOCE/JGOFS survey during the 1990s has provided a full depth, baseline data set against which to measure future changes. By integrating the scientific needs in the following five areas, major synergies and cost savings will be achieved. These areas are of importance both for upcoming research programs, such as CLIVAR and the U.S. GCRP Carbon Cycle Science Program (CCSP), and for operational activities such as GOOS and GCOS. In this regard, consensus was reached at the First International Conference on Global Observations for Climate, held in St. Raphael, France in October 1999, that one component of a global observing system for the physical climate/CO<sub>2</sub> system should include periodic observations of hydrographic variables, CO<sub>2</sub> system parameters and

other tracers (Smith and Koblinsky, 2000). The large scale observation component of the CCSP has also clearly defined a need for systematic observations of the invasion of anthropogenic carbon in the ocean superimposed on a variable natural background.

### **A. Carbon system studies**

There is broad consensus based on a variety of atmospheric, oceanic and modeling constraints that the ocean took up  $2.0 \pm 0.6$  Gt carbon annually during the last decade (Battle 2000, Takahashi, 1999; Orr et al, 2001). The data from the recent WOCE/JGOFS global carbon survey are providing the first comprehensive inventory of anthropogenic CO<sub>2</sub> in the ocean. This survey provided a large data set on the total dissolved inorganic carbon (DIC) content of the ocean, at an unprecedented accuracy of 2  $\mu\text{mol/kg}$  (or 0.1 % of the total concentration). This is equivalent to 1-2 year's uptake of anthropogenic carbon in surface waters. The total anthropogenic inventory of DIC into the ocean can be determined using concurrent, hydrographic, alkalinity, oxygen nutrient and tracer measurements (Gruber et al., 1996). Utilizing transport estimates, the fluxes of carbon within and between oceans and ocean basins can be better constrained, particularly interhemispheric exchange of carbon through the ocean. Atmospheric interhemispheric exchange is an important diagnostic for models and pre-industrial oceanic carbon transport is a key parameter to estimate interhemispheric differences of carbon sources and sinks. The WOCE/JGOFS sections provide a valuable baseline to determine the possible large scale effects of global warming on the ocean's biogeochemistry, whether due to changes in stratification, circulation, or perturbations such as a change in the dust deposition on the ocean's surface.

It is clearly important in terms of predicting long-term climate change and man's effect on the rate of change that we continue to sample the ocean for dissolved carbon components. Further justification on the need for continued oceanic observations of the carbon system are given in the U.S. GCRP publication "A U.S. Carbon Cycle Science Plan" (Sarmiento and Wofsy, 1999) and detailed in the implementation plan (Bender et al., 2001). The repeat observational plan should provide sufficient coverage to determine basin wide changes in DIC and related biogeochemical parameters over a period of approximately a decade. It would serve as a backbone to assess changes in the ocean's biogeochemical cycle in response to natural and/or man induced activity. The proposed cruises can also be a venue for other relevant measurements such as the determination of the partial pressure of CO<sub>2</sub> in the surface water which is a critical component to assess the air-sea CO<sub>2</sub> flux, and which is a sensitive indicator of changes in the functioning of the biological pump in surface waters.

### **B. Heat and freshwater storage and flux studies**

While we have a reasonably good understanding of the pathways of large-scale transport of heat and freshwater in the ocean, we have no real idea of how these pathways change over decadal time scales. One hypothesis is that systematic changes in temperature-salinity relations in the subtropical and subpolar regions are related to changes in the hydrological cycle (Wong et al., 1999). Both modeling and paleo-oceanographic studies

suggest the ocean's response to, for instance, changes in the forcing to be expected if atmospheric greenhouse gas concentrations continue to increase, can be rapid. Such changes might shut down the thermohaline circulation in the North Atlantic, for example, by capping the subpolar region with a layer of warmer, fresher water. Global warming-induced changes in the ocean's transport of heat and salt that could affect the circulation in this way can only be followed through long-term measurements at particular sites. (The necessary heating is forecast to be of the order of  $2-4 \text{ W/m}^2$  for a doubling of carbon dioxide; this is too small to measure with any confidence in the ocean.) This component is vital for CLIVAR and for the CCSP as changes in circulation can dramatically change carbon transport and sequestration estimates (Sarmiento et al., 1998)

### **C. Deep and shallow water mass and ventilation studies**

While we know that water mass characteristics can change on short-term timescales (for example, the North Atlantic "great salinity anomaly" or the El Nino/La Nina system) and often in a non-linear fashion (Doney et al., 1998), we still do not understand how and on what time scales the full-depth water mass structure of the ocean responds to atmospheric variability. Chemical tracers such as chlorofluorocarbons CFCs,  $3\text{H}/3\text{He}$  or  $14\text{C}$  add a time dimension, which can vary between days or centuries. This time dimension can be used to: identify newly-ventilated water masses and their formation rates; determine pathways, time scales and rates of water mass spreading along with its anthropogenic  $\text{CO}_2$  imprint; determine rates of ventilation/subduction and mixing; monitor freshwater input into high latitudes; constrain rates of biogeochemical processes; and constrain model-based estimates of ocean mixing and circulation processes and parameterizations. There is, at present, no alternative to using shipboard sampling for these tracers, and it makes sense to combine such a sampling scheme with any planned sampling of the ocean carbon system. This is particularly true because estimates of anthropogenic  $\text{CO}_2$  inventories rely heavily on the tracer measurements. Thus this aspect is of importance to both CLIVAR and carbon research.

### **D. Calibration of autonomous sensors**

While the development of sensors for many parameters is ongoing, there is an immediate need for salinity calibration for the Argo program ([www.argo.ucsd.edu](http://www.argo.ucsd.edu)). The release of some 3,000 PALACE-type floats in Argo is a major component of both the CLIVAR ocean program and the initial Global Ocean Observing System (GOOS). It is hoped that both temperature and salinity sensors will remain accurate to within about  $0.01^\circ\text{C}$  and 0.01 in salinity for the lifetime of each float (4-5 years). Temperature sensors seem to be stable (within specifications) for this length of time, but salinity sensors are not, being affected mainly by biofouling near the surface. Independent data are therefore necessary to check the salinities provided by these instruments, especially in regions such as the subpolar North Atlantic where deep T/S relationships are known to vary on decadal time scales. Other autonomous sensors, such as  $\text{CO}_2$ , nutrient, and particle sensors, are presently being deployed. This new technology will need *in situ* validation and possibly calibration.

## **E. Data for Model Calibration**

Data on the carbon dioxide system, hydrography and transient tracers provide key observational fields to validate process models, and for the calibration of (climate) models. To predict future atmospheric CO<sub>2</sub> levels and global heat and freshwater balances, long-term model integrations must ensure water mass formation and transport occur at the correct rates. For example, large volumes of the ocean (e.g., the sub-thermocline Angola Basin or the deep North Pacific) are still free of either transient tracers. Thus, monitoring the penetration of tracers into these areas gives us a direct measure of the rate of uptake of greenhouse gases for comparison with model outputs. Similarly, regions of active ventilation, for instance, south of Iceland, or in the Labrador Sea, can be easily identified and provide a key diagnostic for ventilation rate estimates. Changes in carbon and heat inventory also provide strong constraints on models and their forcing functions.

### **An integrated sampling strategy**

The scientific and logistical interests of the ocean carbon, hydrographic, and tracer communities presently overlap, and considerable synergism (and cost reduction) will be achieved by occupying a series of full-depth hydrographic cruises at decadal intervals. A suggested minimum set of such lines is given in Table 1 (see strawman plan on sections). While this set has been selected for looking at long-term changes, not seasonal changes, some lines will be monitored more frequently in companion efforts. The choice and sequencing of lines takes into consideration the overall objectives of the program, dates of last occupation during WOCE/WHP, international plans, providing global coverage, and anticipated resources.

Beyond the repeat hydrography program, a limited number of time-series stations is recommended but not proposed here. These can help determine whether observed changes are local, regional, or basin-wide, monitor temporal changes between survey cruises, and possibly even alert us to unexpected rapid changes associated with air-sea forcing such as the PDO or NAO that may need to be reassessed with survey cruises sooner than planned. Potential sites for such monitoring include the sites of the Ocean Weather Ships (e.g., Mike in the Norwegian Sea and Bravo in the Labrador Sea), as well as off Hawaii and Bermuda where observations have been taken throughout WOCE and JGOFS. Additional sites might take advantage of ongoing activities such as the TAO and PIRATA moorings to monitor the air-sea CO<sub>2</sub> fluxes in the equatorial Pacific and Atlantic oceans. The necessary instrumentation to support such fixed stations either exists, or are in development, which will reduce the present heavy reliance on shipboard sampling. The large scale observational fields will also serve to put time series and process studies in proper spatial context.

The integrated approach and multi-year proposal mechanism provides many scientific benefits as outlined above and also significant logistic advantages. Ship time requirements can be planned well in advance and it provides continued support for groups of trained seagoing technicians for the analyses, together with the associated

quality control and data archiving. It also facilitates investments in upgrades in quality control, data management and instruments necessary for the US to remain on the forefront of this type of research. Mechanisms must be put in place to ensure that data is rapidly disseminated to the community at large, and that opportunities are available to interpret the data and use the data in a meaningful fashion in modeling exercises. Without a commitment for long-term funding of such efforts, the full long-term potential of these measurements will not be realized.

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