A CTDO/Hydrography/CO2/Tracer/LADCP Transect from Australia to Chile R/V *Melville*, 21 November 2009 - 11 February 2010

An oceanographic transect from Australia to Chile - a repeat of WOCE Hydrographic Program section P6 - is scheduled on R/V *Melville* in late 2009. The current dates are:

- Load Brisbane, Australia 17 November - 21 November, 2010
- Depart Brisbane 21 November and begin leg 1 of the P6 transect (Chief Scientist: Alison Macdonald (WHOI))
- 44 UNOLS days at sea
- Arrive Papeete, Tahiti French Polynesia 2 January, 2010
- Unload those groups participating only on leg 1 and change personnel for most other science parties 2 – 5 January, 2010
- Depart Papeete, Tahiti French Polynesia 5 January, 2010 and begin leg 2 of P6 transect (Chief Scientist: Ruth Curry (WHOI))
- 38 UNOLS days at sea
- Arrive Bahia de Valparaiso, Chile February 11, 2010
- Unload Bahia de Valparaiso, 11 - 13 February, 2010

The dates may change somewhat during final ship scheduling.

Maps of the two legs of the planned 2009/2010 occupation of the P6 section are shown below. The science portion of the 2009/2010 P6 cruise plan from Australia to Chile will follow the P6 1992 track (R/V Knorr) and the 2003 Japanese occupation (R/V Mirai) along 32.5°S (30.1°S in the eastern portion), but during 2009/2010 stations will typically be somewhat closer together (no more than 30 nm) than they were in either of the previous occupations.

Dr. James Swift, an oceanographer at the Scripps Institution of Oceanography of the University of California, San Diego, is the coordinator for a program of global ocean measurements (carbon parameters, temperature, salinity 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/> and <http://www.ioccp.org/>. The science team also maintain a web site oriented toward the United States' contributions at <http://ushydro.ucsd.edu/>.

During March-May 2009 the R/V *Roger Revelle* performed a "repeat hydrography transect" of the I5 expedition at 32°S in the Indian Ocean from South Africa to Australia. As shown in the figures, our science team plans to perform the repeat hydrography transect from Australia to Chile allowing us to obtain near synoptic Indo-Pacific data set which can be compared to the 1992 (Wijffels et al., 2001) and 2003 observations (Johnson et al., 2007). The ends of this transect will carry to the 200 meter isobaths in Australian and Chilean waters, and therefore we seek research clearances for that part of our work. We will also pass through New Zealand waters during the first leg and seek clearance for this portion of the work. Approximately halfway across the basin we will make an excursion north to Papeete, French Polynesia for fuel and provisions, and to exchange scientific personnel and possibly some crew. To and from Papeete, our underway measurement systems (see description below) will be running. We therefore also seek clearance for French Polynesian waters.

For our work, at every 55 kilometers (approximately; closer over submarine ridges and near coasts), we stop the ship (we call this stop a "station") and we lower a device called a CTD/rosette, which measures the temperature, salinity, oxygen, and currents from just below the sea surface to approximately 10 meters above the ocean bottom. During each of these stations we also collect up to 36 water samples for measurement of various water properties, such as CO_2-related parameters, dissolved CFCs, oxygen, salinity, nutrients, and so forth (a complete list of science programs is included, below). We measure so-called trace metals (chiefly iron and aluminum) in the upper 1000 meters at some of our stations on Leg 1. While the ship is both underway and stopped we also continuously pump surface seawater through sensors for temperature, salinity, and partial pressure of CO_2; we operate standard meteorological sensors; we operate an Acoustic Doppler Current Profiler; and we normally operate a multibeam bathymetric sonar. If the ship is equipped with a working gravimeter, that is usually in operation also.

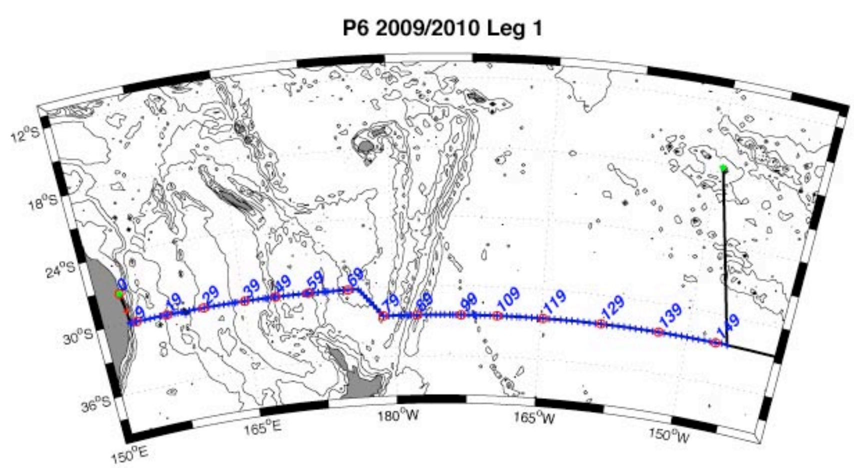

Figure 1: Proposed CLIVAR P6 leg 1 stations between Brisbane, Australia and Papeete, French Polynesia.

According to the draft ship schedule at the time of writing this document, our work from R/V Melville will begin off Australia November 21, 2009. We will work eastward to a longitude of 145.4°E at which point we will steam north to Papeete arriving on or around January 2, 2010. We will leave Papeete three days later returning to 32.5°S, 145.4°E and work eastward arriving in Bahia de Valparaiso on or around February 11, 2010. The number of our planned stations that will be inside Australian and Chilean coastal waters will be on the order of 48 and 12, respectively. The former number is higher because we pass Lord Howe Island and Norfolk Island.

We are prepared to offer immediate, unlimited access to all of our scientific data from the cruise as soon as they are ready to be used. Most of the data will be available at the end of the cruise. This includes data from every system noted in this document, i.e. water sample data, CTD data, meteorological data, underway T/S/pCO2, multibeam data, and so forth. A few types of samples are analyzed in shore laboratories and so are available ca. 1 to 3 years later. We are also prepared to offer berths for one or two scientists from each nation to join us in Australia (for leg 1) or Papeete (for leg 2), work with us or observe us at sea, and disembark at Papeete (for leg 1) or Bahia de Valparaiso (for leg 2).

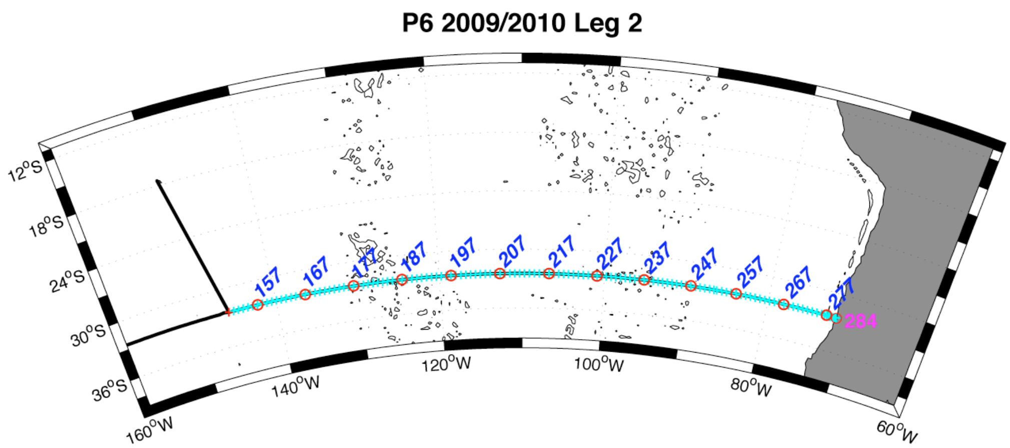

Figure 2: Proposed stations for leg 2 of the 2009 P6 hydrographic cruise from Papeete to Bahia de Valparaiso.

Dr. Macdonald will be the principal scientific point of contact for leg 1. Her email address is amacdonald@whoi.edu, telephone 508-289-3507, fax 508-457-2181. Dr. Swift will be the acting scientific point of contact for leg 2, and is an overall reference and coordinator for both legs. His email address is jswift@ucsd.edu, telephone 858-534-3387, fax 858-534-7383). The operator of the R/V *Melville* is the UCSD Scripps Institution of Oceanography. The point of contact for the ship is the email address shipsked@ucsd.edu.

LIST OF P6 SCIENTIFIC PROGRAMS (subject to pending funding)

CTDO/rosette/S/O2/nutrients/data processing
Jim Swift, Scripps (jswift@ucsd.edu; ph 858-534-3387; fx 858-534-7383)

Transmissometer
Wilf Gardner, Texas A&M U (wgardner@ocean.tamu.edu; ph 979-845-3928)

Research Technician Group
Carl Mattson, Scripps (cmattson@ucsd.edu or restech@ucsd.edu; ph 858-543-1632)

Shipboard Computer Group
Frank Delahoyde, Scripps (fdelahoyde@ucsd.edu; ph 858-534-2751)

CO2 (alkalinity and pH)
Frank Millero, University of Miami (fmillero@rsmas.miami.edu: 305-361-4144)

CO2 (DIC and underway pCO2)
Rik Wannikhof, AOML/NOAA (Rik.Wanninkhof@noaa.gov; ph 305-361-4379)

DOC/TDN
Craig Carlson, U California Santa Barbara (carlson@lifesci.ucsb.edu, 805-893-2541)

CDOM
Dave Siegel, U California Santa Barbara (davey@icess.ucsb.edu, 805-893-4547)
Norm Nelson, U California Santa Barbara (norm@icess.ucsb.edu, 805-893-3202)

13C/14C
Ann McNichol, WHOI (amcnichol@whoi.edu; ph 508-289-3394; fx 508-457-2183)
Robert Key, Princeton (key@Princeton.EDU)

CFCs
Rana Fine, RSMAS/Miami (rfine@rsmas.miami.edu; ph: 305-361-4722) (Leg 1)
Mark Warner, U of Washington (mwarner@ocean.washington.edu; ph: 206-543-0765) (Leg 2)

He/Tr
William Jenkins, WHOI (wjenkins@whoi.edu; ph 508-289- 2554)

ADCP/LADCP
Eric Firing, U Hawaii (efiring@hawaii.edu; ph 808-956-7894)

Trace elements (Leg 1 only)
Chris Measures, U Hawaii (chrism@soest.hawaii.edu; ph 808-956-8693)
Bill Landing, U Florida (landing@ocean.fsu.edu; ph 850-644-6037)

ARGO floats
Ann Thresher CSIRO (Ann.Thresher@csiro.au, ph (61-3) 62-325-419)

Isotopic Composition of Nitrate
Mark Altabet, U of Massachusetts (maltabet@umassd.edu; ph 508-999-8000)

14C in DIC
Ellen Druffel, U of California (edruffel@uci.edu, (949) 824-2116, 3272)

RATIONALE FOR REPEAT HYDROGRAPHY SURVEYS IN SUPPORT OF CLIVAR AND CARBON CYCLE OBJECTIVES (written in 2001, updated May 2009)

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_2) 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/CO2 system should include periodic observations of hydrographic variables, CO2 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 that the ocean took up 2.0 +/- 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 CO2 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 µmol/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 inter-hemispheric 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 CO2 in the surface water which is a critical component to assess the air-sea CO2 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 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, 3H/3He or 14C 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 CO2 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 CO2 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). 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°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 CO2, 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 CO2 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. While these have been selected for looking at long-term changes, not seasonal changes, some lines will 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 have been recommended but are not discussed here. 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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