Weddell Sea Moorings

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1. Project Summary

The world's deep oceans are filled with water masses formed at the continental margins of Antarctica. The Weddell Sea is a major source of these so-called Antarctic Deep and Bottom Waters. Relatively warm, salty water originating in the North Atlantic enters the Weddell Gyre to the east of the Greenwich Meridian as Circumpolar Deep Water (CDW). As it traverses the gyre, the CDW cools and freshens, mixing with Antarctic waters, feeding bottom water-forming processes on the continental shelves, and interacting with floating ice shelves to produce Weddell Deep and Bottom water types. Because these formation processes include heat exchange with the atmosphere and ice shelves, the properties of the water masses formed carry an imprint of any recent changes in atmospheric and shelf ice characteristics, including temperature, distribution of shelf and sea ice, and shifts in large scale wind stress patterns such as those associated with the Southern Annular Mode (SAM) and El Nino/Southern Oscillation (ENSO).

The goal of this project is to observe the properties of the Weddell deep and bottom waters as they exit the Weddell system to contribute to the world's deep ocean basins. Observations of this type are essential to understanding the oceanic component of the climate system, especially the exchange of heat and fresh water between the poles and equator. The data obtained over the course of a decade and more can be used to better understand deep water formation and long term changes in ocean circulation and their relation to the climate system. To obtain the necessary measurements, this project maintains an array of oceanographic moorings south of the South Orkney Islands in the Northwest Weddell Sea to provide a time series of the combined outflow (currents and temperature/salinity) of Antarctic Deep and Bottom Water drawn from various sites within the Weddell Sea. The observation sites were selected to monitor the integrated properties of the outflowing deep and bottom waters after they have traversed the key formation sites in the western Weddell Sea.

The moorings sites are visited approximately every 2 years, with ship time made available under the auspices of an Agreement of Cooperation between Lamont-Doherty Earth Observatory of

Columbia University (LDEO) and the British Antarctic Survey (BAS). The agreement with BAS provides for sharing of equipment, personnel and data between LDEO and BAS, with BAS providing the ship time to do so. Under this agreement, by sharing material resources with BAS, we have been able to expand the mooring array to encompass the Orkney Passage to the east of the Orkney Plateau, a site of potential escape of Weddell Deep Water into the Southern Ocean. Our collaboration with BAS will continue, so this work is part of an international effort.

The data are made publicly available after retrieval from the moorings and suitable data processing has been completed. Real or near real time data reporting is not yet technically feasible for these sites as they are covered by pack ice for most of the year. The data are archived at the project web site [http://www.ldeo.columbia.edu/res/div/ocp/CORC-ARCHES/cm_data/] and at the OceanSITES data portal [http://www.oceansites.org]. To date, the data have been used by diverse groups of ocean and climate modelers, educators and observational oceanographers. Publications and data from this project have been cited in more than 10 publications by other researchers, including 5 in the past year.

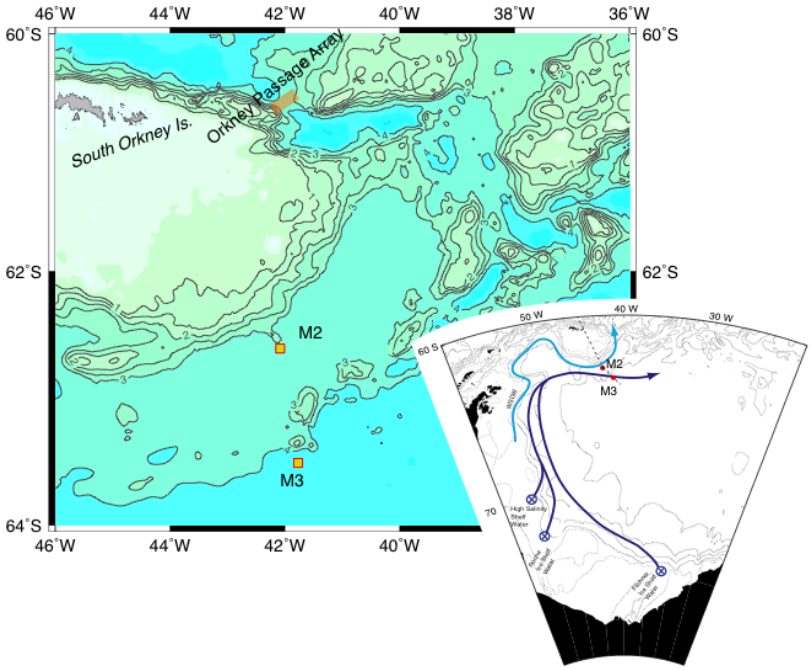

Figure 1. Weddell mooring locations, and schematic of deep and bottom water flow from source regions to the mooring array.

2. Scientific and Observing System Accomplishments

The Weddell Sea and Orkney Passage moorings were serviced in March 2011 during cruise JR252 on the BAS vessel RRS James Clark Ross. Mooring M3 was successfully recovered and redeployed. Mooring M2 was not recovered, but a replacement mooring was redeployed at the same location. The three Orkney Passage moorings were recovered and replaced with a new network of 5 moorings with higher spatial resolution across the Orkney Passage. The work plan for the period 1 July 2011 – 30 June 2012 included:

1. calibration of moored sensors recovered during the March 2011 cruise.
2. processing of data recovered during the cruise and subsequent distribution of the data on the project web site.
3. upgrading of the existing data set and web products to conform to the recently adopted netdCDF-based Climate and Forecast data format
4. continued analysis of the Orkney Plateau and Orkney Passage time series in collaboration with our BAS colleagues
5. Preparation for the next mooring cruise, planned for austral summer 2012/2013.
6. Evaluation of methods for allowing more frequent data capture from the moorings.

This project generally addresses two Observing System deliverables:

• Ocean Heat Content and Transport, to better understand the extent to which the ocean sequesters heat; to identify where heat enters the ocean and where it emerges to interact with the atmosphere; and to identify changes in thermohaline circulation and monitor for indications of possible abrupt climate change

• Air-Sea Exchanges of Heat, Momentum, and Fresh Water, to identify changes in forcing functions driving ocean conditions and atmospheric conditions; and to elucidate oceanic influences on the global water cycle.

As noted in the Project Description, the formation of deep and bottom water in the Weddell Sea is a key component of the oceanic branch of the climate system, representing major polar sites of air-sea fluxes of heat and freshwater, changes in which are reflected in the integrated thermohaline properties of the Weddell deep and bottom waters exiting the gyre where we have established this project's moored observing systems.

For deliverables 1-4 above – sensors returned from the field in 2011 have been sent to the manufacturer for calibration and refurbishment. Some of the instruments required extensive repair, having been in the field since 1999. Processing of the data returned from mooring M3 has been partially completed; final data will be produced upon return of the instruments now under repair and calibration. Preliminary data from M3 has been placed on the project web site. Data from previous deployments has been submitted to OceanSITES (platforms designations NW2 and NW3). Collaboration with our BAS colleagues continues, but due to poor data return from the 2011 recovery, we do not yet have sufficient new data to produce successor manuscripts to those published last year.

Preparations for the next cruise (item 5.) have garnered most of our attention this reporting period, in part due to the long lead times required for logistics staging out of the Falkland Islands. Changes in our normal procedures have been dictated by disruptions in shipping routes, and the combining of unrelated field programs on the BAS vessel altering schedules and logistics requirements.

We continue to pursue the goal of providing near real time data from the moorings (Deliverable 6) by coordinating with an ongoing engineering effort of the Instrumentation Group of AOML's Physical Oceanography Division (PhOD). They are developing a method for periodically retrieving data from moored sensors: the Adaptable Bottom Instrument Information Shuttle

System (ABIISS – see http://www.aoml.noaa.gov/phod/instrument_development/abiiss/index.php). Conversations with the ABIISS group during the last COD Annual PI meeting indicated that development of the system is behind schedule due to budget constraints, so a prototype system is not yet available for deep water deployment in 2013. We continue to keep in touch with the ABIISS team, while concurrently investigating other new technologies such as the Liquid Robotics Wave Glider (liquid.com) with acoustic modem technology for annual data upload. This technology is still maturing, but representatives from Liquid Robotics have expressed a keen interest in aiding in the development of Southern Ocean-capable wave gliders to assist in data collection.

Data availability

a. Are your data distributed in real time on the Global Telecommunications System?
No – the mooring sites are covered by pack ice for up to 9 months of the year, so surface buoys or other real time transmission technology is not feasible here.

b. Where do your real time data reside? Are the data available online?
The data are not collected in real time.

c. Where do your delayed mode data reside? Are the data available online? What is the date of the most recent data available publicly?
Data collected after each mooring rotation are made available on line at the project web site. Preliminary data up through the most recently collected 2011 data are available.

d. Where are your data archived and with what frequency? Data are archived at both the project web site and the Ocean SITES data portal as final processing is completed, typically 1 year following collection.

e. What is the web site where the data for your program can be accessed? *Project web site ( ); OceanSITES data portal:*

f. Have you successfully retrieved your program's data from the website or Data Assembly Center where your data reside, just to ensure the accessibility of the data? *Data submitted to the OceanSITES portal has not yet been indexed and made publically available pending their review of our submission. Data is accessible from the project website.*

g. Do you have a data management plan for the data collected as part of your project?
Yes – the plan can be viewed on the project website
(http://www.ldeo.columbia.edu/res/div/ocp/CORC-ARCHES/cm_data/DataManagementPlan.pdf).

2.1. Outreach and Education

While this project does not have a specific education component, we continue to strive to engage undergraduate and graduate students in the data analysis activities as the time series data sets mature.

This project is administered under the Cooperative Institute for Climate Applications and Research (CICAR), located at the Lamont-Doherty Earth Observatory. Public outreach is managed in part by CICAR via its affiliation with LDEO and Columbia's Earth Institute and their active outreach programs. The CICAR website (http://cicar.ei.columbia.edu/) maintains

project information, announces education opportunities, and announcements of research-related events, seminars and talks for the public.

3. Publications and Reports

3.1. Publications by Principal Investigators

None during this reporting period.

3.2. Other Relevant Publications

The following recent publications cite one or more publications resulting from this project. Numbers in brackets at the end of the citation indicate which project publication is cited from the following list:

1. Gordon, A. L., B. Huber, D. McKee, and M. Visbeck, 2010: A seasonal cycle in the export of bottom water from the Weddell Sea. *Nature Geosci*, **3,** 551-556.
2. McKee, D. C., X. Yuan, A. L. Gordon, B. A. Huber, and Z. Dong, 2011: Climate impact on interannual variability of Weddell Sea Bottom Water. *J. Geophys. Res.*, **116**. doi:10.1029/2010jc006484
3. Meredith, M. P., A. L. Gordon, A. C. Naveira Garabato, E. P. Abrahamsen, B. A. Huber, L. Jullion, and H. J. Venables, 2011: Synchronous intensification and warming of Antarctic Bottom Water outflow from the Weddell Gyre. *Geophys. Res. Let.*, **38**

Årthun, M., K. W. Nicholls, K. Makinson, M. A. Fedak, and L. Boehme, 2012: Seasonal inflow of warm water onto the southern Weddell Sea continental shelf, Antarctica. *Geophys. Res. Let.*, **39**. [1]

Fahrbach, E., M. Hoppema, G. Rohardt, O. Boebel, O. Klatt, and A. Wisotzki, 2011: Warming of deep and abyssal water masses along the Greenwich meridian on decadal time scales: The Weddell gyre as a heat buffer. *Deep Sea Research Part II: Topical Studies in Oceanography*, **58,** 2509-2523. [1,3]

Frajka-Williams, E., S. A. Cunningham, H. Bryden, and B. A. King, 2011: Variability of Antarctic Bottom Water at 24.5 degrees N in the Atlantic. *J. Geophys. Res.-Oceans*, **116**. [3]

Kerr, R., K. J. Heywood, M. M. Mata, and C. A. E. Garcia, 2012: On the outflow of dense water from the Weddell and Ross Seas in OCCAM model. *Ocean Science*, **8,** 369-388. [1,2,3]

Kida, S., 2011: The Impact of Open Oceanic Processes on the Antarctic Bottom Water Outflows. *J. Phys. Oceanogr.*, **41,** 1941-1957. [1]

Mathiot, P., N. C. Jourdain, B. Barnier, H. Gallee, J. M. Molines, J. Le Sommer, and T. Penduff, 2012: Sensitivity of coastal polynyas and high-salinity shelf water production in the Ross Sea, Antarctica, to the atmospheric forcing. *Ocean Dynamics*, **62,** 701-723. [1]

Meehl, G. A., J. M. Arblaster, J. T. Fasullo, A. Hu, and K. E. Trenberth, 2011: Model-based evidence of deep-ocean heat uptake during surface-temperature hiatus periods. *Nature Clim. Change*, **1,** 360-364. [2]

Meredith, M. P., and Coauthors, 2011: SUSTAINED MONITORING OF THE SOUTHERN OCEAN AT DRAKE PASSAGE: PAST ACHIEVEMENTS AND FUTURE PRIORITIES. *Rev. Geophys.*, **49**. [1,3]

Miller, M. D., J. F. Adkins, D. Menemenlis, and M. P. Schodlok, 2012: The role of ocean cooling in setting glacial southern source bottom water salinity. *Paleoceanography*, **27**. [1]

Wang, Q., S. Danilov, E. Fahrbach, J. Schröter, and T. Jung, 2012: On the impact of wind forcing on the seasonal variability of Weddell Sea Bottom Water transport. *Geophys. Res. Let.*, **39**. [1,2]