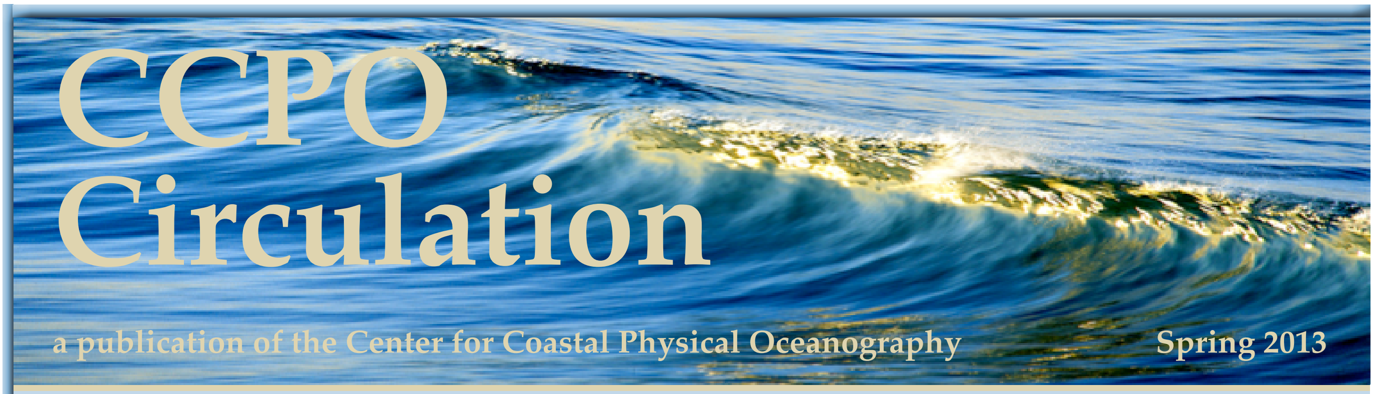

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Physical Modulation of Dissolved Oxygen in Chesapeake Bay

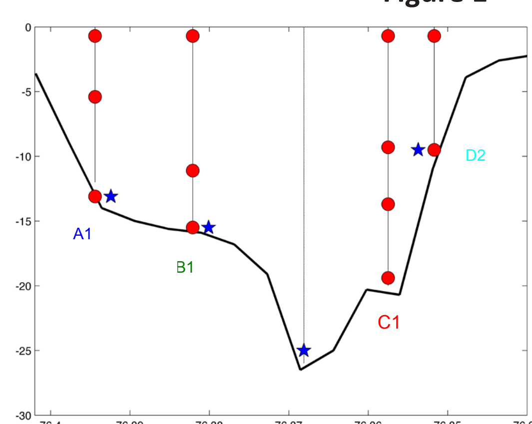
by Dr. Malcolm Scully

Every summer, the bottom waters in the central portion of Chesapeake Bay experience low dissolved oxygen (hypoxia) or the complete lack of dissolved oxygen (anoxia) for extended periods of time. Nutrients that enter the Bay fuel the growth of algae during the spring and early summer months. When the algae die and sink to the bottom, their decomposition utilizes oxygen. The strong density gradient between the fresh surface waters and salty bottom waters prevents oxygen introduced at the surface from mixing down into the bottom waters, leading to hypoxic or anoxic conditions. There is considerable evidence showing that hypoxic volumes began increasing during the early 1980s and remain above pre-1980s levels today. It is generally accepted that the increased nutrient loads that are delivered to the Bay have fueled increased algal growth leading to more extensive low-oxygen conditions. Yet, studies that directly correlate nutrient loads to inter-annual variations in hypoxic volume often fail to explain the majority of the variability.

Through funding by the National Science Foundation, I have been investigating how physical forces modulate dissolved oxygen in Chesapeake Bay and contribute to the unexplained inter-annual variability in hypoxic volume. During the summer of 2011, I conducted an intense field campaign to document the interactions between physical processes and dissolved oxygen concentrations. This work included extensive ship-based surveys, as well as moored instrumentation maintained at a mid-Bay cross-section from mid-May through mid-September. *(cont'd. on page 2)*

Malcolm Scully examining a mooring containing oxygen sensors.

Figure 1



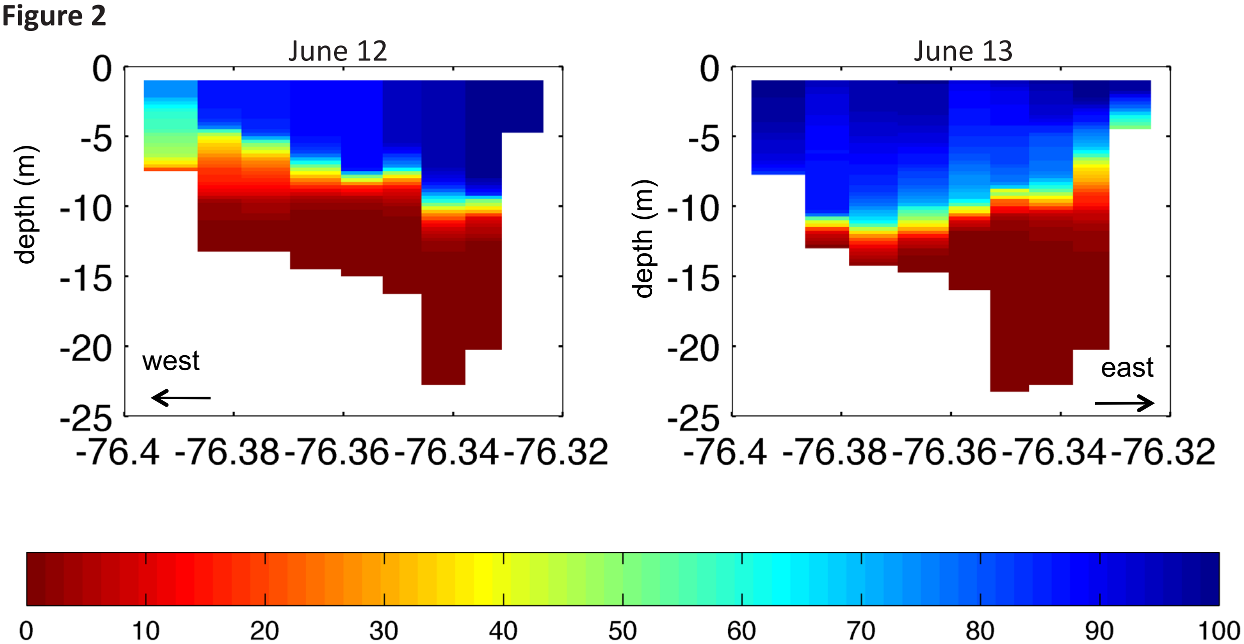
The moorings (shown in figure 1 above) contained CTDs, dissolved oxygen sensors and a suite of current profilers. The time series of bottom dissolved oxygen recorded at the moorings provides a dramatic example of how winds impact dissolved oxygen concentrations in Chesapeake Bay.

When the moorings were deployed in mid-May, bottom dissolved oxygen concentrations had already dropped to near hypoxic levels. Bottom waters remained largely devoid of dissolved oxygen throughout the summer until Hurricane Irene moved up the coast in late August. As the hurricane came closer and wind speeds increased, oxygenated waters arrived first at bottom waters along the western shore and progressed eastward during the storm. This is clearly not just direct vertical mixing, but the combination of vertical mixing with wind-driven circulation. Because of the track of Hurricane Irene, the winds over Chesapeake Bay were almost entirely from the north throughout the storm. Thus, the Ekman transport was directed toward the west, causing downwelling along the western shore bringing oxygenated waters from the surface to the bottom along the western shore.

In contrast, upwelling of bottom water had to occur along the eastern shore to replace the surface waters driven to the west. Thus, low oxygen bottom water was forced to the surface. The bottom sensor at Mooring D was destroyed during the storm, but the surface sensor reveals a large decrease in oxygen concentration as the storm intensified, consistent with upwelling at this location. The strong surface mixing rapidly oxygenated the low-oxygen water that upwelled along the eastern shore. When the winds began to abate, this newly oxygenated water sloshed back to west, providing an influx of oxygen to bottom waters. The fact that the bottom dissolved oxygen concentrations did not begin to increase at Mooring C until wind speeds began to decrease is consistent with oxygenated water from the eastern shore sloshing back to the west.

While Hurricane Irene provides a dramatic example of how low-oxygen waters slosh back and forth as part of the mixing process, this also occurs during weaker winds typical of summertime conditions. Figure 2 shows the across-estuary distribution of dissolved oxygen collected by ship-based surveys that were roughly one day apart during the summer of 2011.

Figure 2



Dissolved oxygen percent saturation from two crossings of central Chesapeake Bay, (left) June 12, 2011 and (right) June 13, 2011.

The survey conducted on June 12 followed a period of moderate winds from the south. Following the survey on the 12th, the winds reversed and blew from the north with peak speeds of roughly 20 knots. Following the wind event from the south, the oxygenated surface waters are displaced toward the east, with low-oxygen water upwelling onto the western shoal. There is even a hint that this low-oxygen water has been mixed with surface waters along the western shore. The picture is reversed after the winds from the north on June 13, with oxygenated surface waters deflected toward the western shore and low-oxygen water upwelling along the eastern shore. ***(cont'd. on page 7)***

Notes from the Director

John Klinck,
Professor
and Director,
CCPO

One characteristic of oceanography that appeals to me is the wide range of sciences involved in the study of the ocean. Even though my early training was in math and physics, I have learned on the job a bit about biology, chemistry, earth science and other subjects. In many ways, the traditional subject divisions in oceanography are artificial and divisive.

We see in this newsletter that Malcolm is working on issues of dissolved oxygen which is a clear combination of chemistry and circulation. Eileen and I are working on economics of a clam fishery. Several of us are involved in the ongoing sea-level-rise and climate change activity on campus which is a blend of oceanography, engineering, politics, economics, sociology, and other specialties. While it is not necessary for all of us to know all of these topics, it is important for us to at least understand the vocabulary (jargon) and the tools used by these other specialties so that we can collaborate across disciplines. We still need to have a firm grasp of the core of one of the parts of science, but it is important to understand other topics. This broader scope of activities seems to be a future direction for the group at CCPO.

A Rare Antarctic Winter Cruise

By Dr. Diego Narváez

My trip began on a hot, humid Friday afternoon at the end of July. Five airports, 6,000 miles, and 30 hours later, I arrived in Punta Arenas, Chile, one of the southernmost cities in the world. With snow on the ground and temperatures below 0°C, it already felt like Antarctica. The research cruise was part of NOAA Fisheries' U. S. Antarctic Marine Living Resources (AMLR) program. AMLR cruises have been conducted for over 25 years on the Antarctic Peninsula, with sampling stations from south of King George Island to the east of Elephant Island. However, this was the first AMLR winter cruise. It was also the first time the cruise was onboard the NSF's ice breaker *R/V Nathaniel Palmer.* Therefore, one of the main objectives was to become familiar with the ship operations and the icy conditions of the study area.

For this cruise, the sampling stations were located mostly around Elephant Island, one of the few areas with low ice concentrations adequate for navigation. The chief scientist for the cruise was Dr. Christian Reiss, a former OEAS-ODU graduate student, who is now with NOAA.

Diego Narváez onboard the R/V Nathaniel Palmer.

It took us four days to reach the first station. Because of the bad weather conditions in the area, the *Palmer* headed to Admiralty Bay in King George Island and then to Maxwell Bay in search of a protected area to perform the calibration of the acoustic system used for krill and fish stock assessment. Once the calibration was made, we headed to the sampling stations. The goal was to perform 6-8 stations along 5-6 transects. At the beginning of the sampling stations, we tried to do CTD cast and net towing within the ice-packed areas, but the time to navigate between stations tripled, and it was too risky to put the net into the water.

My job was with the CTD-water sampling group. We collected water samples from the Niskin bottles attached to the rosette to examine for micronutrients and salinity analysis. I also ran water samples through the salinometer and did some processing of the data that was being collected. Polar research is not my area of expertise, so it was interesting to interact with the scientists that are experts in this field. The other groups worked on krill sampling, lipids extraction, acoustics, bird and mammal observation, and phytoplankton. The following days were pleasant and uneventful.

The *Palmer* began heading north to Punta Arenas and in three days, we were back on land enjoying the sun. After a couple of weeks in Chile visiting my family, I returned to the hot, humid weather of Norfolk, which I had really missed. I'm very grateful to Dr. Christian Reiss for the invitation to the cruise and to Dr. Eileen Hofmann, CCPO, for allowing me to have this opportunity. Without any doubt, this research cruise was one of the best and most rewarding experiences of my life.

New Directions in Marine Ecosystem Research

A Discussion on the Growing Cooperation Between Physical and Social Sciences

by Dr. Eileen Hofmann

There is increasing recognition that human activities are important drivers of change in the world's ocean and that humans are in turn affected by ecosystem changes. This recognition has motivated changes in the traditional approaches used to study marine ecosystems (Figure 1). Many of the research programs now being planned include explicit components directed at understanding socio-economic effects and interactions, and their feedbacks to marine ecosystems. This evolution in how marine ecosystems are viewed is at the forefront of international global environmental change research and is being incorporated into planning for future research efforts. One such effort, Future Earth, is being planned as a 10-year international research initiative that is focused on developing the knowledge for responding to the risks and opportunities of global environmental change and moving toward global sustainability.

Addressing the many important issues of human-ocean interactions requires a community of scientists who can work at the interface of natural and human systems (trans-disciplinary research) a community that does not now exist. The Integrated Marine Biogeochemistry and Ecosystem Research (IMBER) project, a global environmental change research program co-sponsored by the International Geosphere-Biosphere Programme and the Scientific Committee on Oceanic Research, has undertaken initiatives that are intended to foster the development of this community. Two recent activities have focused on providing trans-disciplinary training. The first was a summer school in 2012 that was focused on human-nature interactions in the marine world, which brought together scientists from the disciplines of resource economics, social science, marine ecosystem modeling, climate modeling, and Earth system modeling. The second will occur in January 2013 as part of the IMBER IMBIZO (a Zulu word meaning a gathering) series.

The IMBIZO consists of workshops that explore the linkages and interactions between humans and ecological and biogeochemical systems in the continental margins and open ocean. The IMBIZO will bring together scientists from a range of natural and social sciences. The IMBER Human Dimensions Working Group, which is focused on the two-way interactions between human and ocean systems, provides the longer term view and focus for developing human-natural science linkages.

The need for sustainable and secure sources of food, water, energy and other ecosystems services is transforming the way marine ecosystem research will be done. Participation in research initiatives that are being planned for the future will require marine scientists to have familiarity with social science and economic concepts, and vice versa.

Figure 1

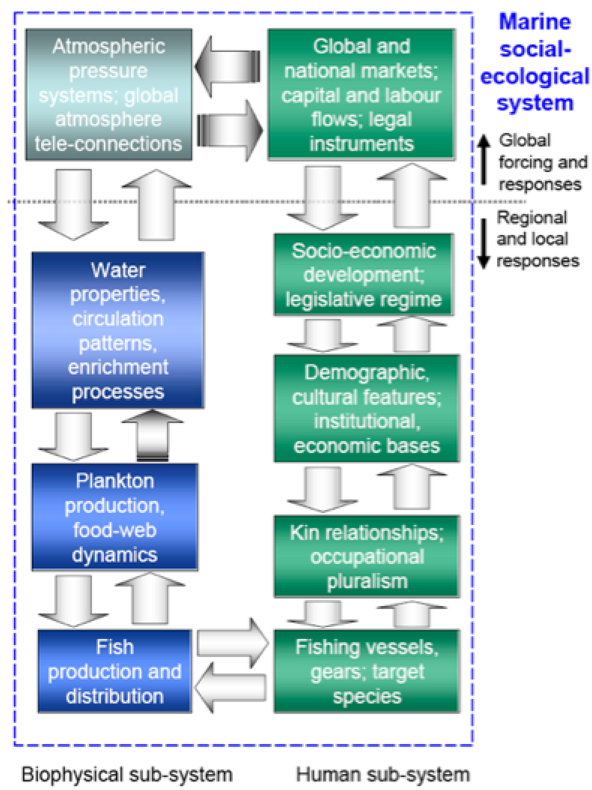


Fig. 1 Schematic showing characteristics and process within the biophysical and human social fishing systems of marine social-ecological systems, and their interactions and connections (figure from Perry et al., 2010, in: Marine Ecosystems and Global Change).

Internship Aboard the NOAA Ship *Okeanos Explorer*

William Boll
CCPO M.S. student

Late in the spring semester of last year, I saw an announcement posted for an internship sponsored by the Virginia Sea Grant. They were looking for two students to board the NOAA Ship *Okeanos Explorer* (Figure 1) to collect acoustic data in the Northwest Atlantic for future scientific research. With the backing of ODU's oceanography department, I knew I had a favorable chance of being selected for this great opportunity. In less than a month's time, I was offered the internship, selected from hundreds of worthy applicants.

At the time, I still considered myself as being fairly new to the oceanographic community. With a background in physics, one of my major interests is in continuous mediums. The importance of the earth's oceans and how they impact the planet is what drew me to this field. Oceans provide the foundation for the most extensive food web in the world, affect climate patterns, and provide a source of renewable energy. Currently, my studies focus on energy transfer within a density stratified water column. Many factors determine how well the process takes place and on some instances, the oceanic bottom must be taken into consideration.

Aboard the NOAA Ship *Okeanos Explorer*, I was able to collect bathymetric data that maps the lower bounds of the oceanic medium. I observed the geophysical structures that affect ocean circulation and saw how the movements help to shape the structures themselves. My assignment was to process and filter raw data, collected acoustically below the ship's hull. I knew the information I gathered would be beneficial to the scientific community, as well as assist in the safety of maritime and military navigation.

David Packer, a marine ecologist from NOAA and the National Marine Fisheries Service, was the primary investigator aboard the NOAA ship *Okeanos Explorer.* He is particularly interested in habitats that may house deep sea corals. We worked closely to determine which areas of investigation consisted of a "hard bottom". He explained that corals are typically found at these locations. We used the intensity of the backscatter data collected as a determinant of which areas would be of greater interest. My team was only one part of a series of explorations that had a main focus of categorizing habitats that house a wide variety of organisms in order to help create protective policies for those regions (Figure 2). As an intern, I was required to produce a poster that captured the essence of the expedition to help educate the public and future interns about the research performed by NOAA. The overall experience was great and I would recommend it to anyone studying the ocean.

Figure 1. NOAA Ship Okeanos Explorer. Image courtesy of NOAA Office of Ocean Exploration and Research. Known as "America's ship for ocean exploration" the NOAA Ship Okeanos Explorer is not a research vessel. Dedicated solely to exploration, the ship conducts operations around the globe, mapping the seafloor and characterizing largely unknown areas of the ocean.

Figure 2. Group aboard the NOAA Ship Okeanos Explorer. William Boll is third from right.

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The challenges of understanding and managing changing marine social-ecological systems. (2012). R. I. Perry, A. Bundy, **E. E. Hofmann,** Co-Editors, *Current Opinion in Environmental Sustainability*, *4*(3).
End-to-End Modeling: Toward Comparative Analysis of Marine Ecosystem Organization. (2012). J. H. Steele, **E. E. Hofmann,** D. J. Gifford, Co-Editors, *Progress in Oceanography*, 102.
Ecology of Infectious Diseases – Oysters and Estuaries. (2012). **E. E. Hofmann**, Guest Editor, *Journal Marine Research*, *70*(2-3).

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Dinniman, M. S., J. M. Klinck & **E. E. Hofmann.** (2012). Sensitivity of Circumpolar Deep Water transport and ice shelf basal melt along the west Antarctic Peninsula to changes in the winds. *Journal of Climate 25,* 4799-4816. doi:10.1175/JCLI-D-11-00307.1
Ezer, T. & W. B. Corlett. (2012). Is sea level rise accelerating in the Chesapeake Bay? A demonstration of a novel new approach for analyzing sea level data. *Geophysical Research Letters 39,* L19605. doi:10.1029/2012GL053435.
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Narváez, D. A., J. M. Klinck, E. N. Powell, **E. E. Hofmann,** J. Wilkin, & D. B. Haidvogel. (2012). Modeling the dispersal of eastern oyster (*Crassostrea virginica*) larvae in Delaware Bay. *Journal of Marine Research 70*(2-3), 381-409.
Narváez, D. A., J. M. Klinck, E. N. Powell, **E. E. Hofmann,** J. Wilkin, & D. B. Haidvogel. (2012). Circulation and behavior controls on dispersal of eastern oyster (*Crassostrea virginica*) larvae in Delaware Bay. *Journal of Marine Research 70*(2-3), 411-440.
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Wang, Z., D. B. Haidvogel, D. Bushek, S. E. Ford, **E. E. Hofmann,** E. N. Powell, & J. Wilkin (2012). Circulation and water properties and their relationship to the oyster disease MSX in Delaware Bay. *Journal of Marine Research 70*(2-3), 279-308.

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Bromwich, D., L.-S. Bai, **M. S. Dinniman,** E. Gerber, K. Hines, D. Holland, **J. M. Klinck,** J. Nicolas, & C. Yoo, The ACCIMA Project - Coupled Modeling of the High Southern Latitudes, 26th International Forum for Research into Ice Shelf Processes (FRISP), Utö Värdshus, Sweden, June 12-14, 2012.
Bromwich, D., K. Hines, L.-S. Bai, J. Nicolas, D. Holland, **J. M. Klinck, M. S. Dinniman,** C. Yoo, & E. Gerber, The ACCIMA Project - Coupled Modeling of the High Southern Latitudes, XXXII SCAR Open Science Conference, Portland, OR, July 16-19, 2012.
Dinniman, M. S., J. M. Klinck, & W. Smith Jr., Sensitivity of modified Circumpolar Deep Water in the Ross Sea to changes in the winds and atmospheric temperatures, 26th International Forum for Research into Ice Shelf Processes (FRISP), Utö Värdshus, Sweden, June 12-14, 2012.
Ferguson, J., J. Ashford, **A. Piñones, M. S. Dinniman,** J. Torres, & C. Jones, Testing connectivity of a fully pelagic forage fish, Antarctic silverfish, along the West Antarctic Peninsula and South Orkney Shelf using otolith chemistry and particle-tracking simulations, XXXII SCAR Open Science Conference, Portland, OR, July 16-19, 2012.

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Hofmann, E.E., J.M. Klinck, M.S. Dinniman, A. Piñones, & T. Ballerini, Antarctic Peninsula Pelagic Assemblages - Climate Effects, Southern Ocean Sentinel Workshop, Hobart, Tasmania, May 7-11, 2012.

Hofmann, E. E. & E. J. Murphy, Southern Ocean Ecosystem Studies, Southern Ocean Sentinel Workshop, Hobart, Tasmania, May 7-11, 2012.

Hofmann, E. E., E. J. Murphy, & K. Drinkwater, Arctic and Antarctic Oceanography, Workshop on The Effects of Climate Change on Advective Fluxes in High Latitude Regions, Yesou, Korea, May 14, 2012.

Hofmann, E. E., Benthic invertebrates – habitats, human impacts, management, lecture at ClimECO3 Summer School on "A View Towards Integrated Earth System Models. Human-nature Interactions in the Marine World", Ankara, Turkey, July 23-28, 2012.

Hofmann, E. E., Individual-based models, lecture at ClimECO3 Summer School on "A View Towards Integrated Earth System Models. Human-nature Interactions in the Marine World", Ankara, Turkey, July 23-28, 2012.

Mack, S., S. Springer, **M. S. Dinniman,** L. Padman, & **J. M. Klinck,** Diurnal tidal effects on sea ice concentration in the Ross Sea from AMSR-E satellite data and a regional ocean model, XXXII SCAR Open Science Conference, Portland, OR, July 16-19, 2012.

Piñones, A., E. E. Hofmann, K. L. Daly, **M. S. Dinniman & J. M. Klinck,** Effects of circulation and climate change on early life stages of Antarctic krill, Second International Symposium on Effects of Climate Change on the World's Oceans, Yesou, Korea, May 15-19, 2012.

Piñones, A., E. E. Hofmann, & M. S. Dinniman, The fate of biological hot spots in a changing climate, XXXII SCAR Open Science Conference, Portland, OR, July 16-19, 2012.

Piñones, A., E. E. Hofmann, D. Costa, K. Goetz, J. Burns, **M. S. Dinniman**, **& J. M. Klinck**, Characterization of temporal and spatial variability in hydrographic conditions in the Ross Sea from instrumented seals, XXXII SCAR Open Science Conference, Portland, OR, July 16-19, 2012.

Springer, S., L. Padman, & **M. S. Dinniman**, Modeling mass loss through basal melting in the Ross Ice Shelf frontal zone, XXXII SCAR Open Science Conference, Portland, OR, July 16-19, 2012.

Piñones, A., E. E. Hofmann, & M. S. Dinniman, The fate of biological hot spots in a changing climate (oral presentation), SCAR XXXII Open Science Conference, Portland, OR, July 16-19, 2012.

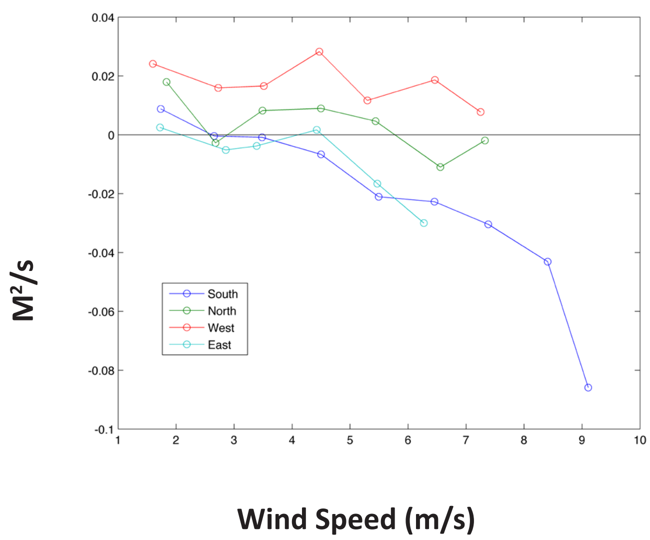
St-Laurent, P., J. M. Klinck, & M. S. Dinniman, Comparing the Oceanic Heat Transport to Antarctic Ice Shelves for Two Generic Continental Shelves, 26th International Forum for Research into Ice Shelf Processes (FRISP), Utö Värdshus, Sweden, June 12-14, 2012.

PHYSICAL MODULATION OF DISSOLVED OXYGEN IN CHESAPEAKE BAY *(continued from page 2)*

The sloshing back and forth of the low-oxygen water is important because it brings low oxygen water up towards the surface. This lateral sloshing is largely driven by winds that blow along the axis of the Bay (north-south). In contrast, winds that blow across the Bay (east-west) create significantly less lateral water movement. As a result, across-estuary winds are less effective at supplying oxygen to hypoxic bottom waters. Using the moored oxygen sensors deployed during the summer of 2011, the total hypoxic area measured at the cross-section was estimated. The time rate of change in the hypoxic area was then averaged both as a function of wind speed and wind direction (Figure 3).

Under weak winds, hypoxic area generally increased, independent of direction. However, as wind speed increased, winds from the south decreased hypoxic area the most. In contrast, winds from the west always increased hypoxic volume. This result is consistent with the analysis of a 60-year time series of hypoxic volume that I recently published (Scully, M. 2010, *Journal Physical Oceanography*, *40,* 1435-1440). In this paper, I found that inter-annual variations of hypoxic volume were strongly correlated to the total time that winds blew from the west during the summer. But this paper could only speculate about reasons for this correlation. The measurements collected during the summer of 2011 are consistent with my previous analysis and provide a detailed explanation for why summer wind direction is so important to water quality in Chesapeake Bay.

Figure 3



Time rate of change in hypoxic area as a function of wind direction.

Center for Coastal Physical Oceanography
Spring 2013 Seminar Series

During the academic year, CCPO invites distinguished scientists to present seminars, which take place in Room 1202 on the first floor of the Engineering & Computational Sciences Building, Old Dominion University. Lectures begin at 3:30 p.m., with a reception prior at 3 p.m. Eileen Hofmann, professor of oceanography, coordinates the seminar series. Specific topics are announced one week prior to each seminar; abstracts can be found at www.ccpo.odu.edu/seminars_spring2013.html.

DATE	SPEAKERS
January 21	No Seminar - Martin Luther King Jr. Day
January 28	Kunio Sayanagi, Hampton University
February 4	Jennifer Francis, Rutgers University
February 11	Nicholas Nidzieko, UMCES Horn Point Laboratory
February 18	Stefanie Mack, CCPO
February 25	Willett Kempton, University of Delaware
March 4	David Bruce, NOAA; Joe Rieger, Elizabeth River Project; Tommy Leggett, Chesapeake Bay Foundation
March 11	No Seminar - ODU Spring Break
March 18	Guillaume Martinat, CCPO
March 25	Oscar Schofield, Rutgers University
April 1	Walker Smith, VIMS
April 8	Frank Rack, University of Nebraska-Lincoln
April 15	Gangfeng Ma, Department of Civil and Environmental Engineering, ODU

CCPO Circulation is published three times a year. Please contact the editor, Stephanie Paul, for more information at 757-683-4945 or stephanie@ccpo.odu.edu.

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