Observing and Modeling Processes on the Continental Shelf and Slope

Introduction

The waters of continental shelf and slope environments are the connections between the land-dwelling human population and the world's oceans. Most marine resources used by humans come from these regions, and impacts from human activities on them continue to grow. Examples are decreasing fish stocks, extraction of minerals and petroleum, and increasing pollution. Our coastal seas also impact us, through severe marine weather events, storm surge, and extreme wave activity, among others. It is important that we understand the processes occurring in these regions, both to mitigate our effects on coastal regions and to understand how to live with them in a safe and sustainable fashion.

Several research efforts in the Department and the IMS focus on shelf and slope processes, and some of these programs have histories reaching back for decades. Both observational and modeling approaches are employed, and processes under study range from circulation, hydrography and air-sea interaction to biogeochemical processes, geology and ecology. A number of these studies have been discussed in the sections above. In this section we describe principally physical oceanographic projects.

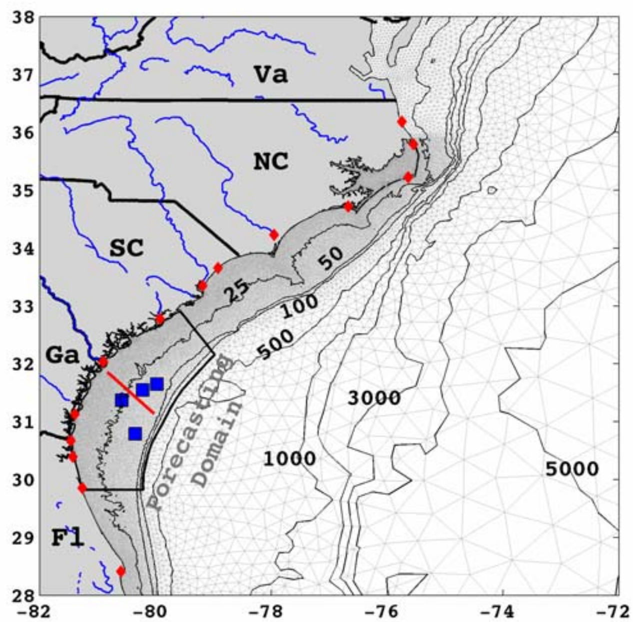


Figure 3.28: A typical finite element model domain for the southeastern coast of the Unites States. The smaller triangles indicate higher spatial resolution that is concentrated on the continental shelf and in the estuaries and tidal inlets along the coast. The numbered contours are the depths in meters. Red diamonds are locations of National Ocean Service water level gauges. Blue squares mark the location of the operating SABSOON towers. The "Forecasting Domain" is used in data-assimilation studies that assimilate coastal water level and SABSOON velocity observations. The red line is the transect location shown in Figure 3.29.

Ocean Processes Numerical Modeling Laboratory (OPNML)
(Cisco Werner and Brian Blanton)
The OPNML employs recent advances in coastal ocean modeling in studying a variety of physical and biological processes including tidal propagation, larval recruitment and population dynamics, general circulation and hydrography. Additionally, forward and inverse (data assimilating) versions of the models are used in the development of coastal ocean prediction systems in the South Atlantic Bight (SAB) region of the eastern United States coast. The primary tool for this

research is a suite of finite element ocean models that allow flexible resolution of a variety of spatial scales that incorporate ocean tides to estuarine dynamics (Figure 3.28).

A digital monthly climatology of the South Atlantic Bight (Blanton et al, 2003) has been developed that incorporates 50 years of regional observations of temperature and salinity (TS). The resulting mean monthly TS fields serve as initialization fields for baroclinic simulations in the SAB as well as background fields against which to determine anomalous months (Aretaxabaleta et al, 2005). Figure 3.29 shows the August climatological mean temperature and the August 2003 observed cool water temperature anomaly from the cross-shelf transect in Figure 3.28. These conditions were present through out much of the SAB during the summer of 2003, and the dynamic causes and effects are being investigated.

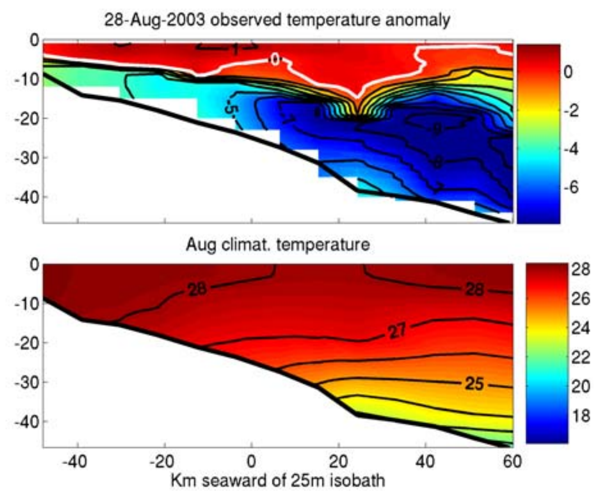
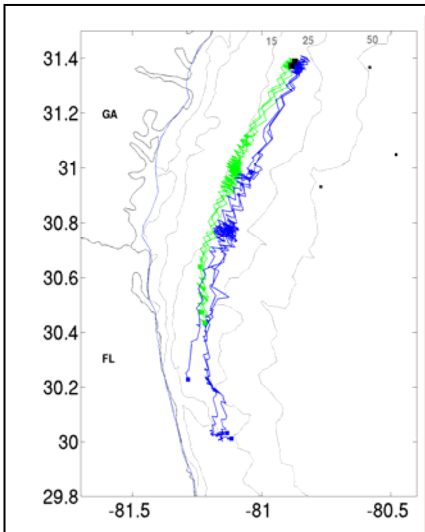


Figure 3.29: August 2003 observed temperature anomaly (top) and the August temperature from the SAB climatology.

Model-based methods are being used to examine the connectivity between larval spawning grounds and larval recruitment sites in the SAB. Figure 3.30 (left) shows observed and modeled drifter tracks along the Georgia coast. These results are helping to understand the design of networks of Marine Protected Areas (MPAs) along the SAB continental shelf (Edwards et al, 2005). Cod are an important commercial fishery in the Gulf of Maine region. Figure 3.30 (right) shows the 24 hour growth rate of cod, based on a larval cod trophodynamic model and the observed temperature and prey field distributions on Georges Bank for April



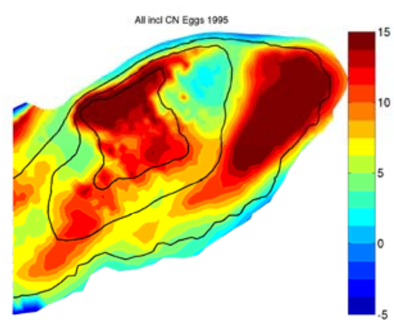


Figure 3.30, left: Observed (blue) and modeled (green) drifters off the Georgia coast over the period 4 October through 4 November 2000.

Figure 3.30, right: Daily growth rates of cod larvae on Georges Bank.

1995 (Runge et al, 2005). Collaborators include R. Luettich, H. Seim (UNC-CH); J. Runge (UNH); D. Lynch (Dartmouth College), J. Quinlan (Rutgers).

Nonlinear internal waves

(Alberto Scotti)

Nonlinear internal waves are widespread in coastal waters. The combination of nonlinearity and short wavelength makes their observation and modeling a challenging subject. Scotti has collaborated with several colleagues to develop observational and modeling tools needed to overcome these difficulties. From the observational point of view, nonlinear internal waves are unusual in that they are coherent phenomena with a horizontal wavelength that can be as small as few tens of meters, and with frequencies of the order of minutes. In collaboration with R. Beardsley (WHOI) and B. Butman (USGS), we showed that the standard approach to interpreting ADCP output fails when the wavelength of the nonlinear waves approaches the beam separation. What apparently represents a liability of the instrument can be turned into an asset, because the spreading beams can be used as a directional antenna to measure direction and speed of propagation. With the aid of a modified post-processing algorithm, we can then recover the "true" velocity signal from the instrument output. We used this technique to study the energetics of internal waves in Massachusetts Bay. With J. Pineda (WHOI), we used the same technique to provide for the first time a high-resolution "radiography" of a train of internal waves of elevation with recirculating cores propagating along the bottom in the shallow reach of Massachusetts Bay (see Figure 3.31).

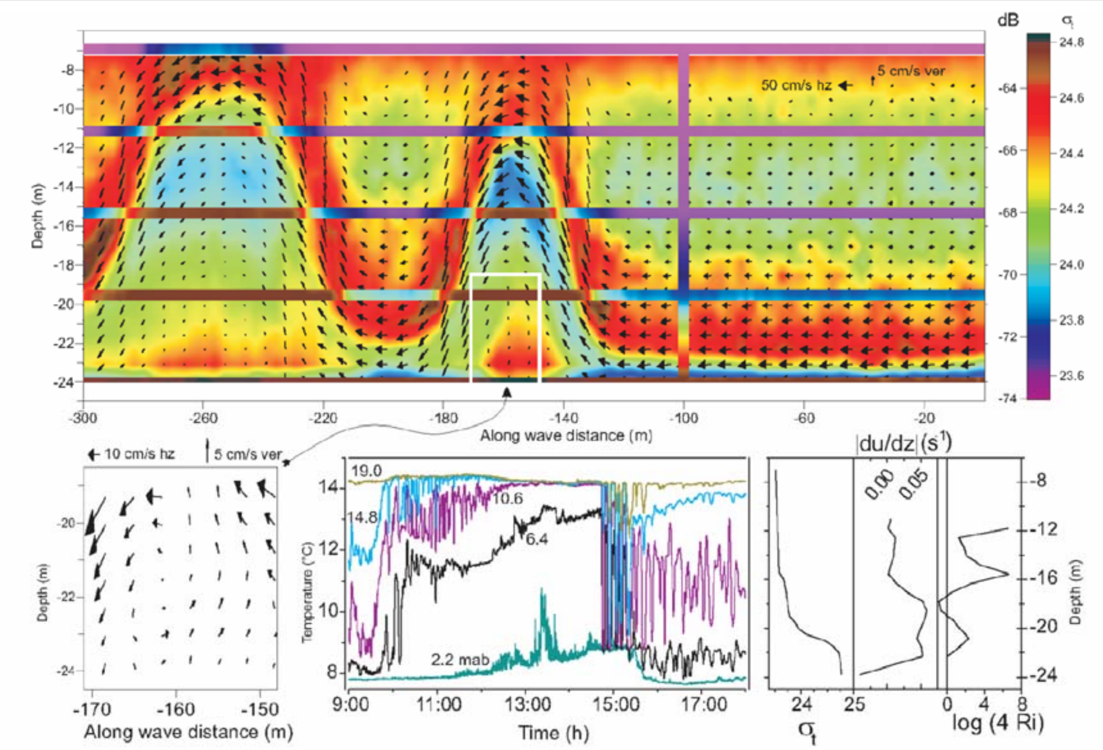


Figure 3.31: Internal wave "radiography" on internal waves in Massachusetts Bay, including current, temperature, density, vertical shear and Richardson number (Ri).

The short horizontal scales associated to nonlinear waves represent a challenge from the modeling point of view as well. In this respect, we are taking an innovative approach to numerical modeling by adapting techniques originally developed in the context of gas-dynamics. The idea is to take advantage of the fact that at any given time, waves occupy only a modest fraction of the domain, and to use numerical grids that self adjust in real time to provide high resolution only where waves are present. This work is in its early stage of development; it is a collaboration with M. Minion and S. Mitran, (Mathematics Department, UNC), with funding from ONR.

Scotti is also involved in the modeling of small-scale sediment transport induced by surface gravity waves. The work, funded by NSF, is in collaboration with the experimental group led by K. Kiger (Univ. Maryland-College Park). We are developing models of particle-bottom interaction to be included in state-of-the-art Large Eddy Simulation models. Scotti also collaborates with colleagues in the math department (R. Camassa, R. MacLaughlin) on problems of large scale mixing in the ocean.

ADCIRC circulation model

(Rick Luettich)

Luettich has collaborated with Dr. J. Westerink (Univ. Notre Dame) on the development of the ADCIRC circulation model, which solves the shallow water equations for either two- or three-dimensional flows using a finite element discretization in space; it is highly parallelized to run on multiprocessor/high performance computers. Consequently, ADCIRC is very well suited for applications covering large areas while at the same time providing detailed representations of coastal areas including inlets, sounds and estuaries. The model is widely used in the academic, governmental and private sector for tidal and storm surge studies. Data bases developed with ADCIRC by Luettich and colleagues are also widely used to provide offshore tidal boundary conditions for localized coastal modeling studies. Recent significant applications of ADCIRC by Luettich and colleagues include: a comprehensive study of hurricane induced flooding in the southern Louisiana/New Orleans region, tidal characteristics in the South Atlantic Bight, physical flow characteristics and associated biological transport in the vicinity of Beaufort Inlet, NC, and a nowcast/forecast system for tides and storm surge in the Western Atlantic and Gulf of Mexico. Luettich's laboratory has also engaged actively in inner shelf observational studies (Figure 3.32), including a detailed study of current patterns in the vicinity of Beaufort Inlet, a coupled bio-physical study of blue crab migration in the Bogue Sound/Beaufort Inlet system (discussed above) and a study of the seiching characteristics of Pamlico Sound, NC. [Collaborators: J. Westerink, Univ Notre Dame; R. Forward, DUML; D. Lynch, Dartmouth; D. Eggleston, NCSU; H. Seim, C. Werner, B. Blanton, J.Hench, H. Paerl, various students, UNC-CH. Funding: NSF, NOPP, EPA, US Army COE.]

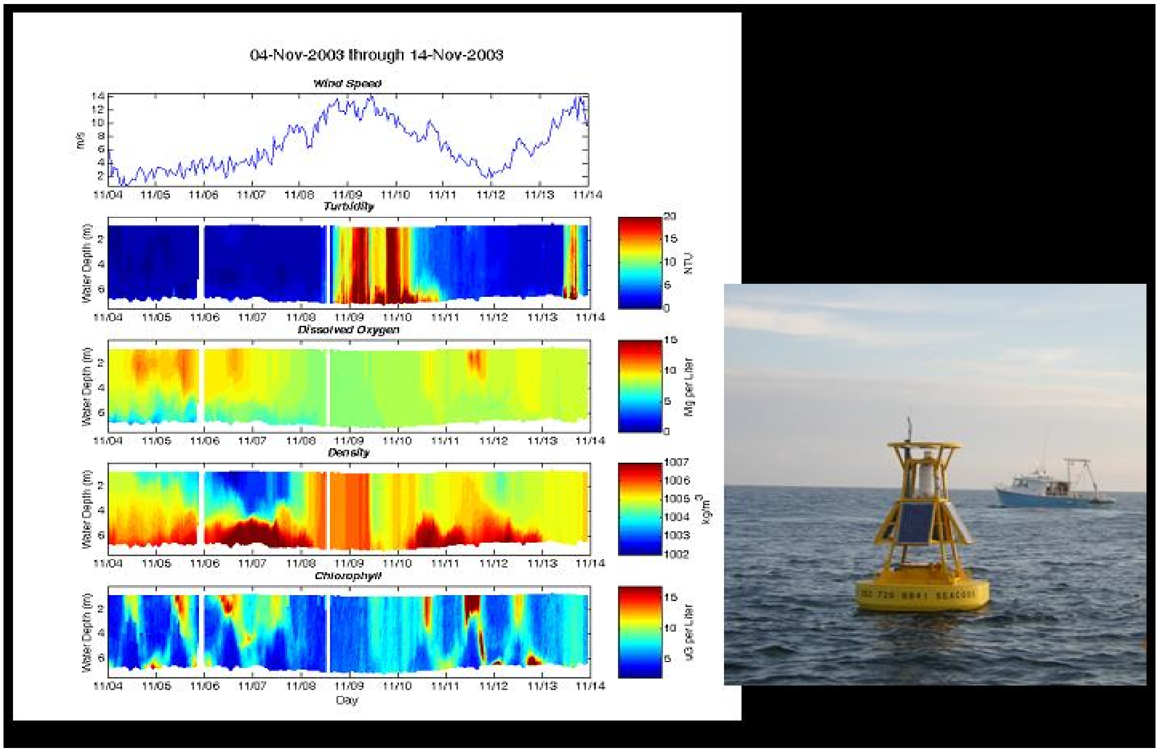


Figure 3.32

Figure 3.32. Left: An example time series of water column properties collected by a profiling buoy system deployed in 7 m of water near the mouth of the Neuse River Estuary. Data indicate that during relatively low winds (< 10 m/s) the water column is density stratified with reduced oxygen concentrations below the pycnocline, relatively low turbidity and a diurnally migrating chl-a maximum. At higher winds (> 10 m/s) the water column mixes rapidly and bottom material is resuspended throughout the water column. Right: The initial deployment of the Lookout Shoals research buoy, January, 2005. The buoy was deployed from IMS's 48' RV *Capricorn*, seen in the background starting for home.

SABSOON, SABLAM and SEACOOS.

(Harvey Seim, Cisco Werner, Brian Blanton and John Bane)

The South Atlantic Bight Synoptic Offshore Observational Network (SABSOON) was initiated in 1998 as a government/academia partnership to develop ocean observatory capabilities off the Georgia coast (Seim, 2000). The focus of the program was to instrument Navy-owned platforms with oceanographic and meteorological sensors to provide real-time information of the coastal ocean state. The program is entering its sixth year and continues to expand (http://www.skio.peachnet.edu/research/sabsoon/tower.php). A number of multi-year datasets now document shelf conditions throughout the year, and are revealing the nature of seasonal and interannual variability and a range of processes on the shelf including internal tides, benthic resuspension events and coherent offshore transport events.

The South Atlantic Bight Limited Area Modeling program was a NOPP-funded follow-on program to the initial SABSOON program that sought to develop a coastal ocean nowcast/forecast system that utilized the real-time SABSOON observations through data assimilation.   It has significantly advanced our understanding of the tidal dynamics in the South Atlantic Bight and begun to clarify the importance (Blanton et al, 2003) and variability of density field on the shelf.

The SEACOOS program (www.seacoos.org) is an ONR-funded effort to plan and serve as a pilot regional coastal ocean observing system (Seim et al., 2003). It involves the simultaneous development of observing, modeling, data management and outreach/education activities in a coordinated fashion to enable a real-time information system for a significant portion of the US coastal ocean. The SABSOON and SABLAM programs were precursors to the SEACOOS regional activity and allowed the program to ramp up quickly. SEACOOS has a broader extent and includes new observing capabilities along the NC coastline (e.g., Stearns et al., 2004) as well as off the east and west coasts of Florida. Funding is provided by ONR and NASA; collaborators include Nelson, Jahnke, (SABSOON); and Lynch, McGuillicuddy and Welsh (SABLAM).

Observation and modeling of circulation, air-sea interaction and meteorological processes *(John Bane)*

Observational and modeling approaches have been used to study circulation, air-sea interaction and meteorological processes in shelf and slope regions along both coasts of the U.S. since the 1970s. These programs have used moored instrumentation, detailed ship surveys, rapid aircraft missions, and satellite data to obtain views of the time-varying, three-dimensional structure of the ocean and atmosphere. The development of techniques to provide synoptic looks at the environment has been emphasized. Another focus has been to obtain simultaneous observations of the ocean and atmosphere to aid in the study of how the systems interact. An example is the 3-D view of the coastal upwelling system off Oregon (Figure 3.33), which was obtained with one aircraft mission lasting < 8 hours. These results are from the NSF-funded CoOP study entitled COAST (Coastal Ocean Advances in Shelf Transport), which has more than a dozen co-principal investigators. Aircraft survey approaches yield reliable "snapshots" of the fluid environment. A series of such views can help visualize the system's temporal evolution. Such surveys are particularly powerful when combined with slower but more detailed ship surveys, time series from moored instrumentation that give the temporal context of the aircraft measurements, and large-area views from satellites. Off the southeast U.S. coast, several flights were made during SABSOON (collaboration with H. Seim) to determine shelf and Gulf Stream thermal structure and variability, and to assess how their signatures are observed at fixed observatory sites.

Improvements in our understanding of the Oregon coastal upwelling system resulting from the combined use of these observational approaches include: (i) recognition of a stable internal boundary layer in the atmosphere immediately above the cool upwelled water that changes the wind stress pattern on the ocean, and thus the upwelling pattern, and (ii) the discovery of how intraseasonal oscillations in the jet stream over the NE Pacific cause wind fluctuations with periods around 20 days that set the dominant temporal scale in the coastal primary and secondary production fields.

Interactions between the ocean and the atmosphere during winter storms over U.S. east coast and Gulf Stream waters have been a topic of both observational and modeling efforts for the past several years. Collaborations with H. Xue, (Univ. Maine) have developed a hierarchy of models culminating in a three-dimensional, coupled atmosphere-ocean model of these processes. The results delineate the development of the atmospheric boundary layer and upper ocean during the passage of a winter cyclone. Of particular interest are: i) that the secondary circulations in the leading edge of the storm's cold front are driven by ocean-to-atmosphere heat flux which in turn more strongly forces the ocean, and ii) that vertical circulation cells in the Gulf Stream are due to coupling between cooling, wind stress, and the larger-scale ocean current field.

Using the aircraft observing system, measurements of primary production and harmful algal concentrations have been made in coastal regions off North Carolina and Oregon. Repeated, detailed surveys off Oregon have shown how the water mass structure can be categorized into four types, based on its color and chlorophyll content. Working over North Carolina inshore and shelf waters, a new hyperspectral sensor that detects the UV band was flown to measure certain harmful algae. These efforts were funded by NASA-WFF and NSF, with ground-truth information collected by the NOAA Southeast Fisheries Center (Beaufort, NC).

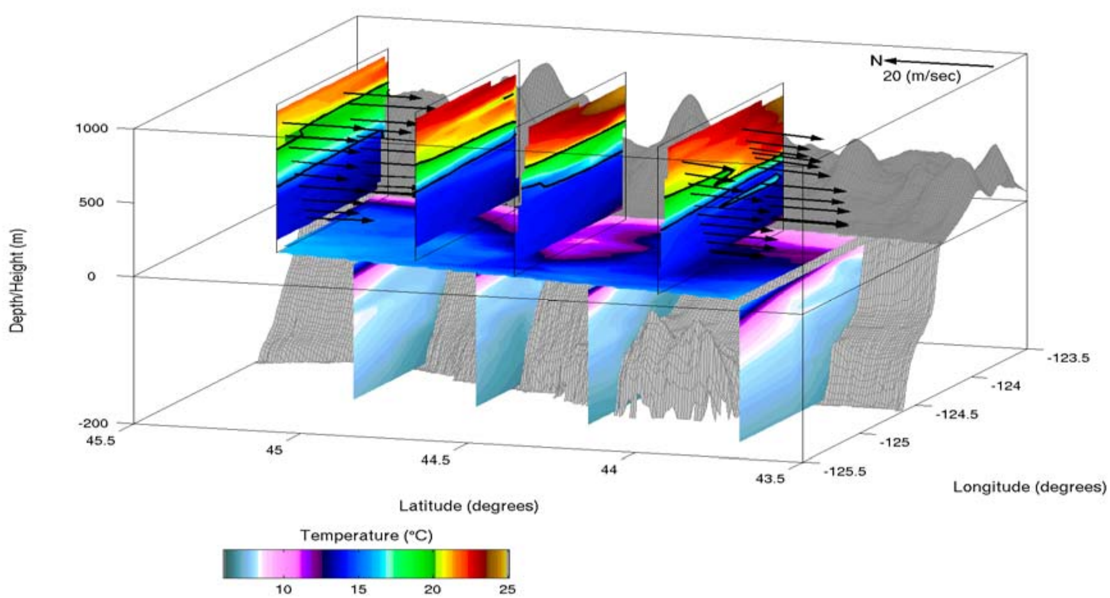


Figure 3.33: Three-dimensional perspective of the upper ocean and lower atmosphere off the coast of central Oregon during a summertime wind-driven upwelling event. Air and water temperatures are shown in color, and strong southward winds are shown with arrows. The sea surface temperature pattern reflects the upwelling in the cool band of water near the coast, and an upwelling jet that has separated from the coast is apparent in the central part of the domain.