

Sensors, Instrumentation and Observing Systems Development

Introduction

Sampling of estuarine and oceanic properties is often a difficult endeavor because of the harsh conditions present. Surface waves, biofouling, species diversity, and sample sensitivity all complicate measurement programs. Compounding this challenge is the remarkable number of properties that can be observed. These range from physical characteristics to the application of genetics and nanotechnologies to marine ecosystems. Advances in sensor technology and observing systems are an essential component to enabling new discoveries in the marine sciences. A number of faculty members are involved with technological development of sensors or the development of observing system elements. Some of their work is reviewed below.

Faculty

Many of the faculty members in Marine Sciences at UNC-Chapel Hill are engaged in sensor, instrumentation, and observing system development. These developments are designed to help monitor and investigate physical and biogeochemical processes as well as aquatic ecosystem components and monitoring. Highlighted below are efforts from marine biologists/ecologists Rachel Noble in developing new techniques for rapid detection of microbes and Hans Paerl in developing routine system-wide monitoring efforts (ModMon and FerryMon) and identifying ecological indicators (ACE INC; described in previous sections). Work by geochemist Chris Martens in measuring atmospheric radon (described in above sections) demonstrates the range of scientific problems addressed in the ever-growing field of biogeochemistry. A number of the physical oceanography faculty are engaged in observing system development: from John Bane's instrumented aircraft to conduct simultaneous ocean/atmosphere sampling to Rick Luettich's buoyed sampling systems (in the Neuse River and off Cape Lookout) and Harvey Seim's multi-purpose electronics package and exploration of real-time, long-range high-frequency (HF) radar to map shelf and Gulf Stream surface currents.

Airborne Observing System for Shelf and Inshore Waters, (John Bane) (ONR, NOAA, NSF, NASA). An instrumentation system has been developed to observe the oceanographic and meteorological processes in the coastal zone (Figure 3.34). The system is flown onboard a light, general aviation, twin-engine aircraft, and it provides measurements of atmospheric temperature, humidity, pressure and wind (onboard, *in-situ* sensors); sea surface temperature (remotely sensed), subsurface ocean temperature (deployed AXBTs), upper ocean color (remotely sensed) and upper ocean UV (remotely sensed). The system has been used in several projects during the past eleven years to study southerly surges in the summertime marine atmosphere off the US west coast,

oceanic and atmospheric conditions off the southwestern US coast during the 1997-98 El Niño, Gulf Stream and continental shelf temperature structure and variability in the South Atlantic Bight, and wind-driven coastal upwelling off the northwestern US. It has also been used for instrumentation development in partnership with NASA Wallops, in a project that flew several missions over Pamlico Sound and the coastal waters out to the Gulf Stream off Cape Lookout. The new sensors are hyperspectral UV spectrometers that promise to give fast, remote sensing of harmful algal blooms in the coastal environment.

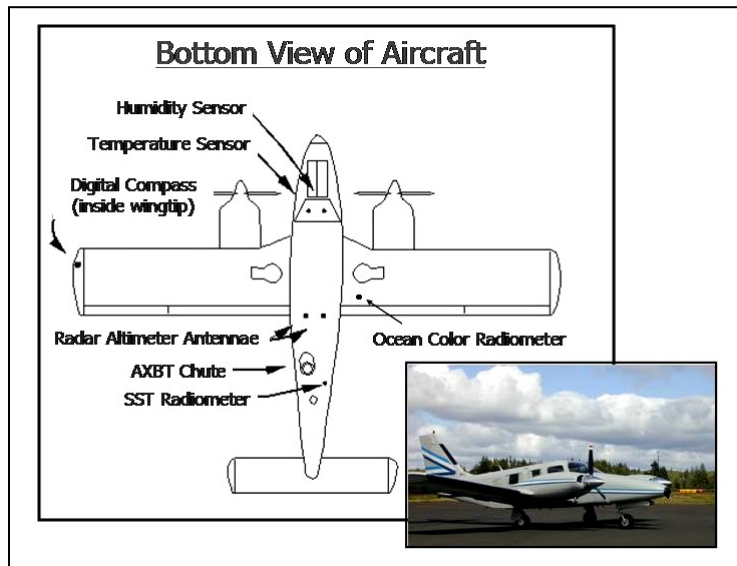


Figure 3.34. A schematic showing sensors used in the aircraft observing system developed by J. Bane for oceanic and atmospheric research. The Ocean Color Radiometer is a NASA-designed hyperspectral instrument that can determine several constituents in the surface waters below the aircraft. The inset shows the light, twin-engine aircraft used since 1994 in several research programs.

Profiling Buoy System for Shallow Waters (*Rick Luettich, H. Paerl, students*) (EPA). Luettich has developed a profiling buoy system for shallow inner shelf and estuarine studies. It is comprised of a buoy mounted, computer controlled winch system that raises and lowers a CTD/multi-parameter probe. Cell phone communications enable near real time transmission of data to shore. Two of these systems have been deployed in the Neuse River Estuary over the past several years and have documented the occurrence of wind driven upwelling along the shores of the estuary and the role that this plays in bringing low oxygen water to the surface (potentially impacting pelagic fisheries populations in the system). These profiling buoys have also documented a pervasive vertical migration of the chl-a maximum in the water column from near surface to near bottom on a daily time scale and characterized the meteorological conditions for which the system becomes well-mixed over the depth. Under these mixing conditions the chl-a maximum is completely disbanded and bottom resuspension is widespread.

Offshore Buoy and Mooring System (*Rick Luettich, H. Seim, students*) (SEACOOS). As part of the SEACOOS program, Luettich is also collaborating with H. Seim to develop the Lookout Shoals Research Buoy. An uninstrumented buoy was deployed in early January off the Cape Lookout Shoals; this will soon be followed up with a fully instrumented buoy (Figure 3.35). The completed buoy system will consist of a bottom tripod containing a CTD and ADCP measuring mean currents through the water column

and the surface wave field. The buoy will host a mid-depth and near surface CTD, and an extensive array of meteorological sensors. The buoy and bottom tripod will communicate via an acoustic modem and the buoy will communicate with shore via an Iridium satellite communications system and a cellular phone system.

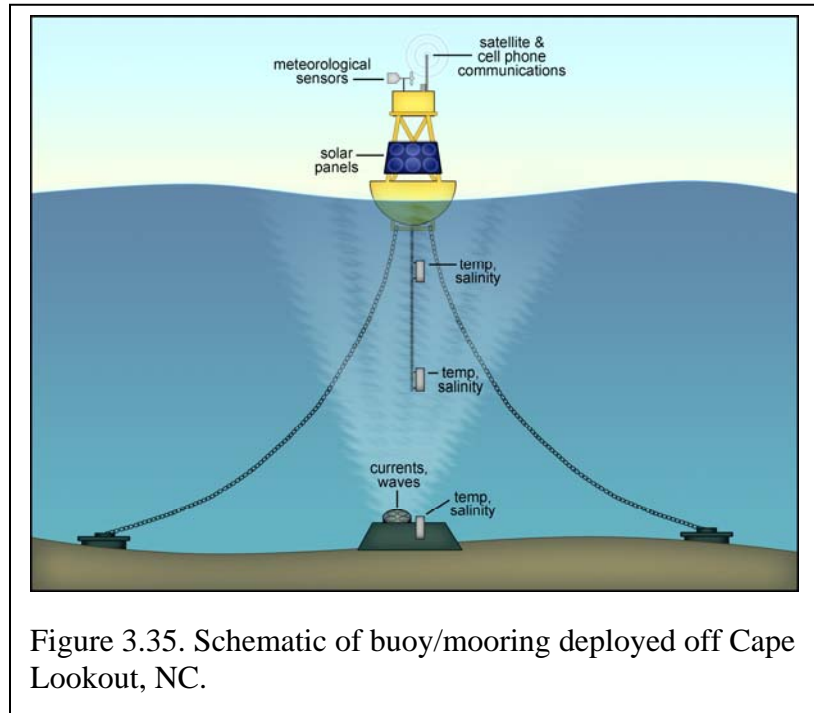


Figure 3.35. Schematic of buoy/mooring deployed off Cape Lookout, NC.

Rapid Microbial Detection in Recreational Waters (*Rachel Noble*) Monitoring of recreational beaches for fecal contamination is currently performed using culture-based technology that requires >1 day for laboratory analysis. New methods have been developed that have the potential to reduce the measurement period to < 1 hour. These methods generally involve two steps, target capture and detection. Target capture refers to removal, tagging, or amplification of the microbial group of interest (or some molecular/chemical/or biochemical signature of the group) to differentiate it from the remaining material in the sample. Three classes of capture methods have been explored: 1) Surface and whole-cell recognition methods, including immunoassay techniques and molecule-specific probes; 2) Nucleic acid methods, including polymerase chain reaction, quantitative PCR, nucleic acid sequence based amplification and microarrays; and 3) Enzyme/substrate methods utilizing chromogenic or fluorogenic substrates. Detection involves optical, electrochemical or piezoelectric technologies to quantify the captured, tagged or amplified material. The biggest technological hurdle for all these methods is sensitivity, as EPA's recommended bathing water standard is less than one cell per ml and most detection technologies measure sample volumes less than 1 ml. This challenge is being overcome through addition of pre-concentration or enrichment steps, which have the potential to boost sensitivity without the need to develop new detector technology. The second hurdle is demonstrating a relationship to health risk, since most new methods are based on measuring cell structure without assessing viability, and may not relate to

current water quality standards that were developed in epidemiology studies using culture-based methods. Enzyme/substrate methods are most likely to be the first rapid methods adopted because they are based on the same capture technology as currently-approved EPA methods and their relationship to health risk can be established by demonstrating equivalency to existing procedures. Demonstration of equivalency may also be possible for some surface and whole-cell recognition methods that capture bacteria in a potentially viable state. Nucleic acid technologies are the most versatile. However, they measure nonviable structure and will require inclusion in an epidemiological study to link their measurement with health risk.

ModMon: a Comprehensive, Long Term Water Quality Modeling and Monitoring Program for the Neuse River Estuary, (Hans Paerl, Rick Luetlich) (North Carolina Department of Environment and Natural Resources). ModMon is a coordinated, multidisciplinary state, university and industry estuarine environmental modeling and monitoring program. This effort is a result of the Senate Select Committee hearings on River Water Quality and Fish Kills, legislative requests for assistance from university scientists in solving state environmental problems, and university initiatives to enhance research in areas of critical importance to state water quality management and planning. ModMon has been designed to provide a water quality model of the Neuse River Estuary (NRE) that is evaluating alternatives for reducing nitrogen loading. ModMon is also a crucial source of data for evaluating a Total Maximum Daily (nitrogen) Load (TMDL), required by the EPA for controlling unwanted symptoms of eutrophication in the NRE (algal blooms, hypoxia, food web disruption). To achieve these goals, the monitoring component is obtaining field data for calibrating and verifying the model and advancing our understanding of relationships between nutrient loading, eutrophication and water quality. Field data are obtained by both ship-based and in stream continuous multiple sensor (YSI 6800) measurements of temperature, salinity, pH, turbidity, dissolved oxygen and chlorophyll (fluorescence), complemented by laboratory analyses of inorganic and organic nutrients (C, N, P), diagnostic (of algal taxonomic groups) photopigments, and molecular markers for microbial groups involved in nutrient cycling and production dynamics.

Water Quality Monitoring by NC Ferry (FerryMon), (Hans Paerl) (NCDENR, NCDOT). North Carolina's Albemarle-Pamlico Estuarine System (APES) is the US's second largest estuary and a critical habitat for its southeastern Atlantic fishery. Three ferries that traverse APES (see Figure 3.36) have been equipped with a flow-through system that

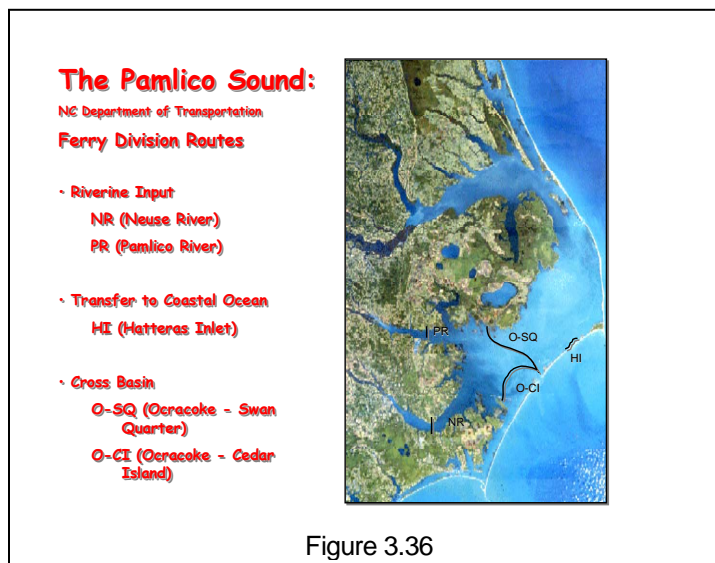


Figure 3.36

includes a multi-probe sensor and an automated water sampler to assess surface water quality trends. This program, FerryMon (www.ferrymon.org) also provides salinity, temperature, dissolved oxygen, turbidity, pH, nutrient and diagnostic photopigment data for calibrating and verifying modeling and remote sensing of APES. GPS-based data are downloaded nightly. Intensive temporal and spatial data obtained from the ferry routes provide an environmental baseline and are used to assess the patterns and variability in surface water hydrography, nutrients and phytoplankton biomass and composition. The three ferry routes currently being monitored include the Cedar Island-Ocracoke ferry which crosses the southern Pamlico Sound and Ocracoke Inlet, the Swan Quarter-Ocracoke ferry which crosses the central Pamlico Sound, and the Neuse River ferry, which makes 40 crossings crossing per day between Cherry Point and Minnesott Beach. FerryMon is evaluating ecosystem-level responses to environmental perturbations, including hurricanes, and is being used to calibrate remote coastal ocean color sensors. This also provides a model system for assessing water quality over a wide range of spatial and temporal scales.

Autonomous Single Board Computer Acquisition System (*Harvey Seim, SEACOOS*). Seim has been developing a data acquisition system for use on offshore platforms (in particular, Navy towers associated with Tactical Aircrew Combat Training Systems, or TACTS) and on buoys. The system was originally conceived as a simplified, stand-alone version of the monitoring systems on the SABSOON towers, to be used on non-SABSOON platforms that lacked any supporting infrastructure (a number of the towers on the SABSOON range provide power and microwave communications). The system uses a single board computer (SBC) as the main computational engine and addressable serial communications (RS485) to sensors wherever possible to enhance expandability. Solar cells provide power and Iridium is used for wireless transmission to shore (Figure 3.37).

A full meteorological suite is hosted (short- and long-wave radiation, air temperature and humidity, barometric pressure, rain gauge, dual wind speed and direction) and can also accommodate an ADCP and multiple CTDs. A nearly unique aspect of the system is the use of a Windows CE operating system on the SBC and the use of a PPP connection, rather than zmodem or xmodem connection, for Iridium. The remarkably high bandwidth communications (in excess of 19200 baud) the system has achieved is suspected of being a result of the use of PPP and an ISP but, as yet, is not fully understood. Future deployments are planned for other offshore Navy ranges in the region (off NC and the FL Keys) but some technical and logistical issues must be resolved before these can occur.

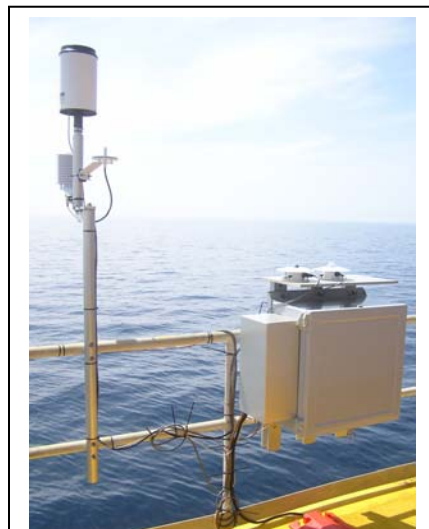


Figure 3.37: SBC-based instrument package (gray box) and one of the instrument staffs (anemo-meters not shown at SABSOON tower R4.

HF Radar on the Outer Banks of North Carolina (*Harvey Seim*) (SEACOOS). A CODAR Ocean Sensors Long Range high-frequency radar system was installed along the Outer Banks in late summer 2003 and has been operating more or less continuously since that time. Two antenna sets are deployed on the Outer Banks, one at the US Army Corps of Engineers Field Research Facility (FRF) in Duck (June, 2003), the other at the US Coast Guard Station at Buxton (August, 2003). Both sites have considerable man-made structures which complicate the deployments but provide needed power and communications infrastructure. The FRF site has been relatively problem free (except for communications problems) and the installation has required only occasional servicing (an antenna relocation following Hurricane Isabel in late 2003). The Buxton site has required regular maintenance as a result of initial permitting issues (with the National Park Service) and severe erosion at the site beginning in early summer 2004. Coverage has varied widely. The variability can be partly attributed to changing antenna locations, radio interference, and ocean conditions. Both sites, which operate at 4.5-5 MHz are affected by moderate to severe noise contamination. Recent software upgrades that enable new visualization tools, have allowed us to begin an investigation of this problem.

Despite these challenges we have been able to produce maps of ocean surface currents off the Outer Banks that include at least the landward edge of the Gulf Stream with some regularity. Initial quality assessments suggest the system captures the subtidal alongshelf flow field reasonably well but tends to under-predict cross-shelf currents. The spatial variation in tidal currents on the shelf is reasonably well captured and compares favorably with model predictions and previous field results. The tidal velocities are under estimated by 10-30%, and is possibly a function of the degree of temporal averaging employed in the processing. Alternative data processing algorithms are being developed.

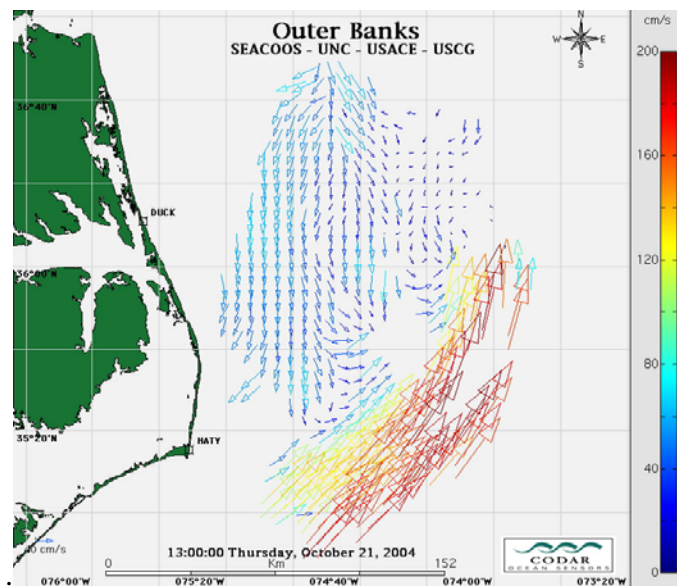


Figure 3.38: Surface current map from mid-day, October 21, 2004 revealing the location of the Gulf Stream and vigorous southward flow on the shelf.