SEACOOS Observing Working Group

1. Overview

The primary charge for the SEACOOS Observing Working Group (OWG) has been to provide *in situ* and remote observations to support state variable estimations for the SE coastal ocean and atmosphere. SEACOOS made a significant investment in observations, particularly in the first three years of the program when equipment purchases and deployment expenses represented a major portion of the SEACOOS partner budgets. Although obvious gaps in spatial coverage remain in the SE coastal ocean, the SEACOOS OWG efforts significantly augmented the existing federal *in situ* observing assets in the SE. SEACOOS partners also operated the only HF-radar installations in the region, providing surface current coverage in contrasting coastal ocean environments. The ability to obtain sustained near real-time *in situ* observations was demonstrated, notably for a number of variables that were not routinely measured at NOAA buoys when SEACOOS was initiated (e.g., subsurface temperature and salinity, currents throughout the water column). A pilot program incorporating regional capabilities in satellite remote sensing into the SEACOOS data portal was conducted. SEACOOS partners also conducted several successful test-bed efforts that could provide models for incorporating ongoing R&D for observing system technologies into a regional COOS program.

It is not attempted to detail the full scope of OWG activities here. Rather, this section is intended to illustrate the breadth of these efforts, and provide insight into a number of pragmatic "lessons learned" are relevant to future RCOOS operations and program development. During the SEACOOS program, considerable experience has been acquired in the sustained operation of a range of *in situ* sensors, instrument platforms, and supporting power, communications and mechanical infrastructure. Deployment procedures have been tested and refined, and maintenance strategies, using several transportation options, have been evaluated. In addition to the operational lessons learned, a number of programmatic issues are also noted, with regard to both the activities within the OWG and the SEACOOS program as a whole.

In terms of future RCOOS development, the SEACOOS OWG activities have shown a number of the potential roles for academic institutions in the design, operation and ongoing evaluation of observing system components. Beyond demonstrating capabilities for acquiring sustained observations, research findings based on SEACOOS observations and modeling have contributed to a scientific rationale for an initial SE RCOOS design (Seim *et al.* MS in review; and Appendix ** in the initial SECOORA Business Plan); an indication of the ongoing science advisory role academic partners can play in a future SE RCOOS. In addition, based on this pilot RCOOS effort, it is also clear that improved and sustained observing capabilities strongly complement both basic and applied research. The research value of the observing system is evident in the substantial leveraging of SEACOOS resources by the partner institutions. Additional research support in turn contributed to the development and maintenance of the system. Many components of the SEACOOS observing program have been supported from multiple funding sources. Partner institutions also made significant contributions in infrastructure and facilities to SEACOOS, as well as partial support of experienced personnel who have been key contributors to the OWG program. Few key technical and engineering personnel involved in the OWG activities have been supported solely by SEACOOS funds. Such leveraging of SEACOOS resources has played a significant role in the deployment and maintenance of *in situ* observing assets and was essential to the SEACOOS satellite remote sensing effort.

This section describes the range of *in situ* observing elements deployed by SEACOOS partners and a pilot program in which regional satellite remote sensing capabilities were incorporated into SEACOOS. HF-radar evaluation and a pilot application effort in near-shore directional wave measurements are discussed in more detail in separate sections which follow. While, for sake of brevity, only coordinators of various aspects of the observing program at various institutions are noted here, as the preceding discussion indicates, these efforts could not have progressed without the essential contributions of many others. The importance of retaining a core pool of experienced technical support personnel at the partner institutions is one of the fundamental lessons learned.

2.1. Summary of OWG activities.
The initial activities of the SEACOOS OWG reflected the origins of the program. The SEACOOS observing efforts built upon several existing sub-regional efforts based at SE academic institutions. These programs had been initiated through prior funding from various programs. Sustaining and building out from these existing assets was a central to the initial development strategy adopted for *in situ* observations, augmented by support of additional partners and observing assets as the program grew.

At the start of SEACOOS program, the most advanced sub-regional observing effort was that of the Coastal Ocean Monitoring and Prediction System (**COMPS**; *http://comps.marine.usf.edu/*) at the University of South Florida (USF), directed by Robert Weisberg and Mark Luther. COMPS was formally initiated in 1995 in response to coastal flooding events in West Florida that were forced by tropical and extra-tropical storms, building on the experience with previous pilot moorings on the shelf (Cole et al, 2003). Initial support for the development effort came from federal agencies (MMS, ONR) and the State of Florida. Sources of subsequent support in addition to SEACOOS included the NOAA ECOHAB program, Pasco County (Florida), the Florida Fish and Wildlife Commission and the NOAA COTS program. The coastal ocean system is complemented by a Physical Oceanographic Real-time System monitoring system for Tampa Bay that was initiated in 1990 with NOAA NOS funding (Tampa Bay **PORTS**; *http://ompl.marine.usf.edu/PORTS*, coordinated by Mark Luther). At the start of the SEACOOS program, COMPS was operating an integrated observing/modeling network. The deployed observing assets included three buoys with surface telemetry (real-time), two internally recording bottom-mount packages (delayed mode reporting) and ** shore stations.

University of Miami RSMAS observing activities that were initially brought into SEACOOS were the HF-radar measurements of surface currents (Nick Shay's group; *http://isotherm.rsmas.miami.edu/wera/*), development work on an ADCP/CTD profiling package (Bill Johns), and partnership with the *Explorer of the Seas* project (*http://www.rsmas.miami.edu/rccl/*), in which a Royal Caribbean cruise liner was equipped with meteorological, optical and oceanographic instrumentation (Ed Kearns, later Rod Zika).

The South Atlantic Bight Synoptic Offshore Observational Network (**SABSOON**; *http://www.skio.usg.edu/research/sabsoon/*), coordinated by the Skidaway Institute of Oceanography (SkIO) was initiated in 1998 with funding from the National Oceanographic Partnership Program (NOPP). This project focused on utilizing U.S. Navy towers on the Georgia continental shelf (part of a flight training range) as platforms for offshore meteorological and oceanographic observations. Harvey Seim was the lead P.I. for the NOPP project, and his engagement continued after moving to the University of North Carolina, with Jim Nelson subsequently coordinating the SkIO activities. The initial SABSOON effort was coupled with another NOPP project that developed a "limited area" physical circulation model for the shelf area encompassing the SABSOON sites (Dan Lynch, Dartmouth College, lead-P.I.). This was subsequently extended in the SEACOOS-supported modeling work at the University of North Carolina. Another partner in the initial NOPP project was Charlie Barans of the South Carolina DNR, who developed an UW video system for fisheries research. This was continued as part of SEACOOS ("Fishwatch"; http://oceanica.cofc.edu/FishWatch), with George Sedberry coordinating following Barans' retirement in 2005.

A number of additions to the near real-time observing network were made during the SEACOOS program, including both *in situ* and remote sensing capabilities. *In situ* observing activities at UNC (*http://nccoos.org/platforms/platforms*) included a buoy deployment near Cape Lookout (Rick Luettich, Harvey Seim), establishing a pier station (Mike Muglia) and glider deployments (Harvey Seim). The initiation of a pilot near-shore surface waves program brought in new partners. George Voulgaris (USC) deployed ADCP/wave instruments cabled to two piers on the South Carolina coast, and Paul Work (Georgia Institute of Technology, Savannah campus), deployed a directional wave buoy, reporting in near real-time, off Tybee Island, GA (near the Savannah River entrance). HF-radar capabilities were expanded, with additional deployments by UM in SE Florida (Year 2), USF on the West Florida Shelf (Years 2-3), UNC near Cape Hatteras, NC (Year 2-3) and SkIO/USC on the GA/SC coast (Years 3-4). Starting in Year 2, satellite remote sensing download and processing capabilities at USF and UM were engaged in a pilot regional satellite remote sensing effort, coordinated with development of web visualization products at USC. Key contributors to the SEACOOS satellite remote sensing effort (described below) were Frank Müller-Karger and Chuanmin Hu from the Institute for Marine Remote Sensing at USF, Ed Kearns (and later Bob Evans) at UM RSMAS and Charlton Purvis at USC.

While representing a significant investment, the scope of the *in situ* and remote sensing programs within SEACOOS was constrained. It was recognized from the beginning of the program that SEACOOS resources would not be sufficient to fill all significant gaps in spatial coverage for *in situ* observations and HF radar coverage in the SE. Also, other sub-regional systems were developing, notably the Caro-COOPS and CORMP programs with buoys deployed off South Carolina and in Onslow Bay, NC, as well as shore stations. Thus, as a prototype RCOOS program, the development philosophy of the SEACOOS OWG was to test diverse platforms in a range of SE coastal ocean environments, building out from existing assets, and to enhance the test-bed capabilities in the region. This approach served to develop a pilot regional observing network and provided extensive experience in sustained operations of a variety of observing assets. Given the funding history of the SEACOOS program, this appears to have been a prudent strategy. While there was considerable build-out of OWG assets in Years 1-3, budget reductions in Years 4 and 5 (to about 83% and 27% of Year 3 levels, respectively ***check #s* **) constrained capabilities to service and maintain what had been deployed and to retain key technical personnel. Adjusting to these budget reductions would have been a greater challenge for a more dispersed network and larger personnel pool.

Based on the experience acquired in the five years of the SEACOOS program, a number of "lessons learned" can be defined that are relevant to the development strategy for a future RCOOS. These are summarized below in terms of both operational and programmatic issues.

2.2. The range of observing assets deployed and operated in SEACOOS.

As indicated in the preceding section, a diverse array of *in situ* and remote assets for near real-time observations has been supported through SEACOOS. OWG activities carried out by the partner institutions have included:

- *In situ* measurements from buoys, offshore towers, coastal stations, ships and autonomous gliders;
- Remote measurement of surface currents (and surface waves) using shore-based HF-radar;
- Satellite remote sensing;
- Observing technology development and field trials, including profiling floats, fixed position profilers, and underwater video for monitoring fish; and evaluation of initial ADCP results from NDBC buoys;
- Development and sustained deployments of supporting infrastructure for the observing network, including various power, telemetry, and mechanical systems;
- Experience with a large cruise liner as a volunteer observing ship (VOS) in a COOS context (the Royal Caribbean *Explorer of the Seas*); and,
- Opportunistic observing activities, including acquisition of near real-time surface drifter data (including through a cooperative agreement with Horizon Marine, a private industry data collector), and ship surveys in response to specific events or targeting specific features observed in satellite imagery.

Brief descriptions of each of these classes of observing assets are provided in the following section, grouped according to the deployment platform utilized.

The status of real-time observations in the SE coastal ocean at the start of the SEACOOS program is indicated in Figure 1. As noted above, the starting point for the SEACOOS OWG program was several existing sub-regional efforts. Through SEACOOS and other sub-regional programs in the SE (Caro-COOPS, CORMP) there has been considerable augmentation of the NOAA NDBC/NOS shelf and shore stations in terms of spatial coverage ("dots on the map"), and in terms of the range of variables measured. This includes subsurface temperature and salinity, ADCP current profiles, surface radiometry, and some basic *in situ* optical measurements. The primary mission for the NDBC buoys and CMAN stations has been to support marine weather forecasting, and it is only recently that an expansion of the buoy measurements to include currents, directional waves and subsurface temperature and salinity has been undertaken.

Figure 2 illustrates the spatial distribution of real-time observations in the SE coastal ocean as of [***recent date***] and nominal coverage of surface currents provided by HF-radar. Internally recording (delayed mode reporting) instrument have also been deployed by SEACOOS partners both to provide important time series records in areas not covered by real-time assets, and as part of various test-bed efforts. Non-federal assets (SEACOOS, Caro-COOPS, CORMP) presently represent some ** % of the sites for real-time *in situ* observations in the SE, and, to date, SEACOOS partners have operated all of the HF-radar systems in the region.

2.3. Observing platforms employed in SEACOOS.
A detailed description of the mechanical, power, communications, data acquisition and instrumentation systems associated with the *in situ* deployment packages utilized in SEACOOS is beyond the scope of the present document. Rather, here these are briefly described in terms of the complete packages, highlighting the range of observing activities conducted by the OWG. This also provides some background in terms of the range of field experience acquired by SEACOOS partners for discussion of the challenges and operational "lessons learned" that follows.

2.3.1. Fixed position *in situ* assets.
Buoys
Several classes of buoys were deployed by SEACOOS partners (locations in Fig. 2).

USF: The evolution of the buoy systems deployed by USF from the early 1990's to present is described in Cole et al. (2003). These are single point moorings, modeled after the 3 m discus buoy design employed by NOAA NDBC. The most advanced buoys in the COMPS array are configured to measure air-sea interactions, with meteorological sensor packages (based on the IMET or ASIMET packages), supplemented to include long- and short-wave radiometers and precipitation), surface and subsurface temperature and conductivity sensors and a buoy-mounted (downward directed) ADCP. Data are logged locally and also transmitted hourly via GOES satellite. Buoy servicing has been primarily performed using *[** R/V Sun Coaster? elaborate a bit on configurations; vessel(s) **]*

UNC: UNC began exploring buoy options in 2003 when it became clear that access to Navy towers off North Carolina was not likely to be granted. Initially purchase of an NDBC buoy was explored, but at the time NDBC was not willing to support both directional wave and ADCP observations. The estimated cost was also deemed to be high (less so in retrospect). Subsequently, UNC-CH partnered with the Institute of Marine Sciences (Moorehead City, NC) for deployment off Cape Lookout. The buoy hull was purchased from the University of Maine/Gulf of Maine Ocean Observing System (GoMOOS). A bottom tripod package (ADCP, CTD) communicates with the buoy via acoustic modem, requiring a 2-point mooring to restrict the buoy watch circle around the mooring package. Other buoy instrumentation and electronics packages were designed with the intention of providing alternatives to costly alternatives, notably the ASIMET package. Data acquisition used both a Single Board Computer (SBC) running the Windows CE operating system designed at UNC-CH (initially intended for tower deployment) and a Tattletale system developed at IMS. Several real-time communications options have been tested. The deployment location proved to be beyond range of cell phone from shore. Freewave radio is presently being tested, but requires a relay point on a shore tower. Iridium modem communications have achieved baud rates beyond specs when working well, but the communications link through the SBC proved problematic, possible due to the number of protocol layers to be supported. A buoy deployed in spring 2005 was damaged in Hurricane Isabelle in late summer 2005. The near-water environment for electronics packages and instruments has proven to be a challenge, and approaches to protect these are ongoing. Buoy deployment and servicing for the UNC/IMS buoy utilized the [** *vessels? adequate? ***].

GIT Savannah: As part of the pilot SEACOOS waves program, a commercial directional wave buoy (Triaxys) was deployed by GIT, Savannah near Tybee Island, Georgia in a water depth of about 12 m. The location is near the shipping channel leading up the Savannah River to the Port of Savannah. Tybee Island also has the major recreational beach for Savannah, with a considerable tourist business, and site of periodic beach nourishment. The top half of the spherical buoy housing is transparent plexiglas, and contains a set of solar panels to charge the on-board batteries. The buoy was ordered with cell phone and Iridium communications and used an Iridium SIMM card provided by SEACOOS. A separate internally recording ADCP package (RDI with wave module) was deployed near the Triaxys buoy for three months in 2005 and showed a good match in wave parameters reported by these two different approaches. On the operational side, the spherical Triaxys buoy is low profile, without a mast or radar reflector. In an area of heavy boat traffic, this can be a problem. Although the initial deployment site was thought to be out of the main boat traffic lanes, the buoy was apparently hit on two and probably three occasions. Also, the mooring hardware for this shallow-water buoy (including a heavy rubber damper section) appears to require replacement at about 6-month intervals. The buoy broke free on three occasions when the deployment extended beyond 6 months. A programmed cell phone notification when the updated position left a defined watch circle allowed a rapid small vessel response to tether the buoy until it could be recovered on two occasions. However, on another, communications were inoperative until after the buoy had been blown across the shelf by strong offshore winds and entrained in the Gulf Stream. Intermittent Iridium fixes over the following ** months tracked the buoy into the mid-North Atlantic.

<u>Upgrade of other buoys to real-time.</u> SEACOOS also provided DOD Iridium SIMM cards obtained through ONR to the Caro-COOPS program to enable real-time communications for *** buoys deployed off South Carolina. The performance of the Iridium communications option is summarized below.

Offshore Navy towers.
Through the SABSOON project, SkIO and partners had been granted access to a set of U.S. Navy towers that are part of a flight training range on the continental shelf off Georgia (operated from the Marine Corps Air Station, Beaufort SC). Access is on a "not-to-interfere" basis with regard to Naval operations. The Navy towers provided a number of advantages compared to buoys, notably capabilities for substantial on-site power generation, established high-bandwidth, two-way communications (a microwave system links the three central platforms and shore), and helicopter landing decks (accommodating helicopters with payloads of about 800-1000 lbs). SkIO has installed and maintained meteorological and *in situ* oceanographic instruments on three towers, oriented in an oblique cross-shelf transect (in water depths of 26 m, 33 m and 44 m). Power and communications bandwidth from the existing Navy systems were allocated to SkIO on two of the towers (larger "master" platforms) with power supplemented with additional solar panels installed by SkIO. On the more offshore "remote" platform, the Navy systems were more limited and separate power (solar panels, wind turbine, batteries, controller) and communications (microwave link to the nearest "master" tower) for SABSOON was installed by SkIO. UNC also designed and deployed a self-contained instrument package on the SE "remote" platform (R4 tower) on the Georgia shelf (45 m depth).

The Georgia towers are not the only offshore structures maintained by the Department of Defense in the SEACOOS domain; other Navy ranges are located off Key West, Florida and off North Carolina. The UNC package on the Georgia tower (R4) was originally intended as test package for deployment on Navy towers off North Carolina. Unfortunately access to that range was never granted. Access to the Navy platforms off Georgia for SEACOOS observations was very much the result of the interest and support of the Beaufort Range Manager and was not due to a more general DOD policy to support coastal ocean observations. Although other potentially significant infrastructure is maintained in the U.S. coastal ocean by the DOD and other federal agencies, these groups have not yet been effectively engaged for support of IOOS/COOS programs on the national level.

While a providing a valuable infrastructure base, the use of Navy platforms came with some constraints. A major structural refurbishment of the towers in 2003-2004 (which included sandblasting and painting) required removal and reinstallation of most of the above-water equipment on the three towers instrumented at the time. This consumed much of the available personnel and transportation resources for those years. Overall, a very good working relationship was developed with the Navy group at the Beaufort MCAS and the contractors who maintain the offshore infrastructure. SkIO benefited considerably from logistic support from the Navy and access to the existing power and communications systems. However, not all proposed installations were approved and although explored in some depth, approval of a separate helicopter contract for SkIO (which would have provided better flexibility in scheduling and cost-savings) was not obtained.

Transportation was a major cost consideration for the tower operations. While the helicopter option was initially cost-effective for many operations compared to research vessel charges (with a 0.75-1.5 h transit time to the SkIO-instrumented platforms compared to a 5.5-7 hours on the *R/V Savannah*), the costs of helicopter transportation increased significantly over the course of the SEACOOS program. This became a serious consideration when budgets were reduced in Years 4 and 5, and the ability to maintain deployed assets was compromised as a result. The lack of an appropriate medium-sized vessel in the SkIO inventory limited the transportation options available, and in retrospect, acquiring an appropriate vessel at the beginning of the program may have provided a better service option. SkIO greatly benefited from access to vessels operated by the NOAA Gray's Reef National Marine Sanctuary on many occasions, but scheduling, especially on short-notice (for unscheduled maintenance) was often an issue.

Shore stations and pier installations.
USF/COMPS: [** fill in here **]

USC: George Voulgaris and colleagues from the Coastal Processes & Sediment Dynamics Lab at USC deployed ADCP units measuring near-shore currents and directional waves 400-500 m off Springmaid Pier (just south of Myrtle Beach, SC) and Folly Island Pier (south of Charleston, SC). The units are cabled to the pier for power and real-time communications. The Springmaid Pier installation was coordinated with NOAA/NOS, which operates a meteorological and water level station at that location, and the Folly Island installation was coordinated with NOAA NDBC, which maintains a C-MAN (meteorological) station on the pier.

UNC: A collaborative effort (partially supported by SEACOOS) between UNC-Chapel Hill, the UNC Coastal Studies Institute, the NC Aquarium Society, the Outer Banks Boarding Company, SurfChex, and NC SeaGrant at Jennette's Pier, Nags Head, NC, deployed a meteorological package (wind speed and direction, barometric pressure, relative humidity, precipitation) observations of air temperature, humidity and wind and surf conditions (web cam). These observations are also displayed at a kiosk at the North Carolina Aquarium (Roanoke Island) as part of a public outreach effort.

2.3.2. Autonomous profilers.
Autonomous observing assets (i.e., untethered, free-vehicles) offer potential as core components of coastal ocean observing systems, particularly in terms of routinely obtaining high-resolution information in the vertical and in terms of regular transects/sections across frontal structures and other coastal ocean hydrographic features. This potential comes with its own set of challenges, some common to fixed position *in situ* systems (e.g., bio-fouling), others unique to the particular mobile platform.

Glider. Through SEACOOS UNC-CH purchased a Webb Electric Slocum glider, delivered in early 2005. A series of unrelated hardware failures caused early termination of the initial set of test deployments; these included failures of attitude and altitude sensors, GPS, and Iridium antenna and a bladder failure that resulted in a leak. This experience does not appear to be typical. For example, UNC personnel helped train UNC-Wilmington personnel to operate a Webb glider that has been used in a number of successful month-long missions. The UNC glider was successfully operated for about 1 month in late summer 2006 near the R4 tower, then was directed to a rendezvous point for pick-up by ship. The quality of Iridium communications and support from the company were judged to be quite good. Beyond hardware failures (apparently unit-specific in this case), the greatest challenge with the glider is programming. While it employs a highly flexible programming environment, this can be confusing to set up. It is also important to note that when deployed on a mission, the UNC glider required nearly full-time support. A spontaneous reset of the glider control program (yet to be resolved) must be promptly corrected or mission failure (and possible loss of control) can result. Also a salinity spiking issue (SeaBird CTD) was evident that is being addressed by the Rutgers University glider group.

Bottom-resting profiler (USF BSOPS) –development funded through other sources, field deployments in COMPS domain; … [** *brief summary?* **]

2.3.3. Surface drifter data._

An exploratory effort to obtain near-real time data from satellite-tracked drifters deployed by private industry was conducted by SEACOOS. Through a cooperative agreement with Horizon Marine, SEACOOS was provided access to drifter information once these had left the Gulf of Mexico (the area of proprietary data concern for Horizon Marine). In return, Horizon Marine was provided with support for OGC data mapping/visualization schemes developed for SEACOOS applications.

*[** need to better describe arrangement with Horizon Marine; what was actually obtained; pluses and minuses of the arrangement **]*

2.3.4. Ship surveys.

The value of having access to ship survey capabilities as part of a regional COOS program is particularly evident in terms of opportunistic sampling of coastal ocean events. These capabilities demonstrate how regional COOS efforts can benefit coastal ocean research and monitoring activities to sample events that may be of direct societal benefit. There are several examples where SEACOOS resources contributed to such efforts:

In the summer of 2003, a major upwelling (cold water) event was documented on the South Atlantic Bight shelf. Ship surveys initiated in the spring (following above-average river discharge) were continued through the summer, in part with SEACOOS funded ship time (surveys opportunistically conducted during installation and servicing cruises to Navy towers). Analyses of hydrographic survey data and fixed platform observations are reported in Aretxabaleta *et al.* (2006), with a follow-on modeling study (Aretxabaleta *et al.* 2007) also largely supported through SEACOOS.

Satellite ocean color products provided to SEACOOS by the USF IMaRS group in the summer of 2004 indicated the presence of a distinct plume of Mississippi River water extending into the Straits of Florida and along the inner margin of the Gulf Stream off Georgia. Opportunistic sampling was conducted off the Florida Keys (using a NOAA vessel) and in the Gulf Stream off Georgia (along-track measurements during a SkIO cruise to the Sargasso Sea) and

confirmed that the ocean color feature was indeed a low salinity water, consistent with a Mississippi River origin (Hu *et al.* 2005).
Satellite SST imagery from the SEACOOS web portal was directly accessed from the *R/V Savannah* during a April, 2005 SEACOOS–funded cruise to target a high-resolution CTD/ADCP survey of a transient, sub-mesoscale feature on the Georgia outer shelf (a cold "wedge" extending from the mid-shelf to the shelf break). Although the primary cruise objective had been deployment of a UNC instrument package (near the R4 Navy tower), the shipboard acquisition of near-real time SST imagery from the SEACOOS web portal (in a lat/lon gridded format) enabled a survey of this non-stationary feature to be accomplished during a short (two-day) cruise window (results reported at the winter 2007 ASLO meeting).

2.3.5. Instrumented Cruise Ship – The *Explorer of the Seas*
Prior to the beginning of the SEACOOS program, the University of Miami was involved in a cooperative program with the Royal Caribbean Cruise Line to install and maintain atmosphere and ocean sensors, along with associated data acquisition and communications systems, on the commercial cruise liner, the *Explorer of the Seas.* NOAA AOML and NSF also contributed support for this program. The *Explorer* was outfitted with a fairly extensive set of atmospheric instruments along with a number of ocean sensors (summarized on the project web site; *http://www.rsmas.miami.edu/rccl/facilities.html*). Public outreach has been an integral part of the project, with scientists participating in cruises and interacting with passengers through lectures and explanation of the science systems. The ONR funding package that included the first year of SEACOOS support also included support for the *Explorer* program, and this was incorporated into the SEACOOS program in Years 2-4.

The range of atmosphere and ocean measurements being collected from the *Explorer of the Seas* was well beyond that typically found on voluntary observing ships (VOS), making this an attractive "mobile platform" addition to the SEACOOS observing assets. The SEACOOS E&E group has included outreach/education programs on the vessel. While VOS observations can certainly augment those of a regional observing system, the SEACOOS experience with the *Explorer* program also shows that utilization of a commercial cruise vessel brings its own set of challenges. There have been issues with real-time data flow, the quality of some records, and the continuity of time series within the SEACOOS domain due to shifts in the cruise tracks.

The ADCP current records from the *Explorer* illustrate a number of these challenges. Initially, the *Explorer* alternated on a weekly basis between West and East Caribbean cruise tracks, providing regular transects across the Florida Straits. Of particular oceanographic interest are along-track ADCP measurements (at 38 kHz and 150 kHz, with penetration to about 1000m and 300 m respectively), providing the opportunity for repeated measurements of Florida Current transport. However, the Explorer ADCP data has required a considerable post-cruise processing to remove bad data from the record (Beal et al., in revision). Two major sources of error in the current records were due to inaccurate heading information and bubble contamination of the acoustic data. The bubble effects are exacerbated by the flat-bottom design of the vessel and relatively high cruising speed (24 knots), and are particularly evident during ship maneuvering and in rough seas. Also, in 2005 May-October cruises were shifted to a New Jersey-Bahamas track, thus breaking the continuity of year-round coverage across the Florida Straits. In terms of obtaining research quality data from an extensively instrumented commercial VOS, one of the lessons from the *Explorer* experience is that timely processing and adequate quality control for the data requires dedicated technical support.

2.3.6. Satellite Remote Sensing.

The Remote Sensing Coordinating Committee (RSCC) was formed within SEACOOS during the second year of the program (mid-2003) to incorporate regionalsatellite observations into the SEACOOS data stream. Synoptic satellite observations over the SEACOOS geographic domain were delivered in near real-time to the SEACOOS data portal. Key objectives for this effort were to help interpret variability in time series data from buoys and towers, to constrain heat flux estimates and other boundary conditions for models, and to contribute to validation of model results. Funding for the satellite remote sensing effort was modest and progress in this area very much depended on leveraging existing infrastructure and expertise in the region, notably the satellite download, processing and archiving capabilities, and experienced personnel, at the University of South Florida (IMaRS) and University of Miami (RSMAS).

Remote sensing products have generally been envisioned to be core elements of the IOOS "national backbone" observations. However, specific strategies for incorporating remote sensing activities into regional COOS efforts were not well-defined in IOOS planning at the time the SEACOOS effort was initiated. In this sense, the satellite remote sensing effort within SEACOOS represented something of an "experiment"; that is, a test-bed effort to demonstrate regional capabilities for real-time delivery of high-quality satellite data and derived products and integration with *in situ* data streams. Coordination between remote sensing data providers and data management personnel at USC was essential to aggregation of satellite data from various sources and integration of satellite and *in situ* observations. This experience played an important role in the development of data visualization schemes within SEACOOS (using Open Geospatial Consortium tools). The variables estimated from various satellite sensors and the sources for these data are listed in Table *. Accomplishments from this effort included:

SEACOOS was provided with rapid access (<30 min) to raw high resolution data from low-earth, polar orbiting satellites using download capabilities at USF and UM;

Satellite data products generated using existing algorithms (e.g., SST, surface chlorophyll concentration) were delivered to the SEACOOS web portal in near real-time;

"Cloud-free" optimal interpolation (OI) products for SST and ocean color developed by the Ocean Circulation Group at USF were generated and incorporated into the satellite data stream;

Access for SEACOOS to other satellite data collected and processed outside the SE was established, including QuikSCAT for winds and Topex for sea surface topography from the Jet Propulsion Laboratory (JPL);

Data standards for the satellite remote sensing data were adapted to ensure interoperability with the SEACOOS data management system, and data and image transport mechanisms were developed to optimize throughput for large image and dataset sizes;

Online data query and analysis tools to enable use by non-specialists were introduced.

Table *. Summary of remote sensing data provided to SEACOOS.

Variable	**Sensor**	**Data Access**
IR Sea Surface Temperature	AVHRR, MODIS Aqua, Terra	USF (IMaRS)
Ocean color (chlorophyll)	MODIS Aqua	USF, U. Miami
Marine Winds	QuikSCAT	JPL

RSCC: Ed Kearns (UM); Frank Müller-Karger (USF); Chuamin Hu (USF); Bob Helber (USF); Dwayne Porter (USC); Charlton Purvis (USC); Jim Nelson (SkIO); affililations at the time of RSCC formation.

Sea Surface Height	Topex	JPL
Microwave SST	AMSR, TMI	JPL

3.1. Operational & Pragmatic Lessons Learned – Observing Working Group.
To some extent, the range of *in situ* observing assets and deployment platforms utilized in SEACOOS represents the legacy of the origins of the observing program; that is, the initial build-out was based in part on observing assets in place at the start of the program. As a result, uniformity in the *in situ* packages was not emphasized. However, in terms of a proto-type RCOOS, this approach provided considerable experience in: 1) sustained operation of a range of *in situ* packages on buoys, tower platforms and shore stations; 2) deployment and servicing strategies for these packages; and 3) use of a number of real-time communications options. Test-bed activities for several types of autonomous profilers were conducted, including: SEACOOS-supported developmental work at UM for a bottom-mounted ADCP/CTD profiling package; evaluation of ADCP performance on a NDBC shelf buoy (UNC); trials of a commercial glider (Webb Slocum) by UNC; and deployment of a bottom-resting profiler designed and constructed at USF (under separate funding). SEACOOS partners also operated the two commercially available HF-radar systems, Coastal Ocean Dynamics Application Radar (CODAR) and Wellen Radar (WERA) in both broad and narrow shelf settings (described separately below). Some of the major themes that may be identified as common lessons learned from the OWG *in situ* observing efforts and pilot satellite remote sensing effort supported by SEACOOS are listed here.

Deployment and Maintenance of *in situ* Systems.

Personnel are essential "infrastructure" and often a limiting factor for the development, installation and maintenance of *in situ* systems. Given the patchwork funding for support of most technical and engineering personnel, SEACOOS OWG personnel were often multi-tasking at their institutions, as opposed to being organized into full-time, task-specific groups across SEACOOS.

Efficient, sustained operations are vulnerable to personnel turnover at the individual institutions. The collective experience in systems design, development and operations often resided in a relatively small set of key personnel. Thus, systems documentation is critical. Such documentation requires a significant time commitment, one that is often underestimated in the proposal/planning stages. Essential documentation includes mechanical drawings, and circuit diagrams for electrical and electronic systems, as well as maintenance/servicing records that are part of instrument package metadata.

Regular preventive maintenance for all components of the deployed packages is required for sustained operations in the marine environment. While this is perhaps obvious, this must be recognized as a key cost-driver for the *in situ* observing program, representing a increasingly significant portion of personnel time as more *in situ* packages are deployed.

Minimizing downtime for *in situ* observations requires an adequate inventory of spare components for the supporting infrastructure (e.g., power, communications, data acquisition systems), appropriately staged (readily available when and where needed) such that limited maintenance/servicing time at deployment sites can be optimally utilized. This point cannot be overemphasized. The Southeast is exposed to a spectrum of natural stresses that can damage and destroy equipment in the field. Examples include landfall of tropical systems (as the UM HF radar group experienced as a result of Hurricane Wilma in 2005), shoreline erosion (e.g., UNC had to move a HF radar installation near Cape Hatteras) and lightning (significant

lightning damage to equipment has occurred at offshore towers, pier stations and shore-based HF radar installations during the SEACOOS program).
Similarly, an adequate instrument inventory is necessary to ensure that instruments can be rotated out for regular servicing and calibration. Presently calibration/servicing is primarily performed by the manufacturers. Turn-around times are often significant, restricting the instrument pool available for replacement of faulty units. Charges for calibrations (including shipping) can also be a significant recurring expense and must be accommodated in budget planning. Regional resources for calibration of key components of the observing system could be an important contribution from the "national backbone."
Sustained regional glider operations will likely require establishing a glider operations group. Continuous missions will require full-time oversight and capabilities for rapid response in the event of glider failures and for deployments in response to specific events.

Transportation

Adequate maintenance of offshore assets requires both routine (scheduled) and rapid response (unscheduled) access to appropriate transportation options. What is appropriate depends on the deployment platform utilized, local conditions, the available modes of transportation (e.g., ship, smaller vessel, and helicopter in the case of the Georgia Navy towers). There are scheduling issues and trade-offs in cost and transit times associated with each option.
Transportation is a major factor in logistics and budget planning, representing a key cost-driver for sustained offshore observations.
Transportation is a primary consideration for personnel safety. Vessels must be reliable and sufficiently seaworthy to operate under the range of sea states likely to be encountered during deployment and servicing operations, and must be equipped such that the required loads can be handled safely.

Communications and data streams

Iridium Communications -- SEACOOS was provided with ** DOD Iridium SIM cards for real-time communications ...

*[**elaborate on this? performance? issues? **]*

Other general lessons regarding communications include:
Bandwidth remains a key limitation at various points in the communications stream. A notable example is the limited bandwidth of Argos satellite communications for buoys.
There was limited redundancy in communications for the *in situ* systems deployed by SEACOOS. Backup systems are needed for critical system links.
Data logging at the deployment platform (independent of real-time communications to shore) is typically needed to ensure collection of robust time series records. Similarly, while real-time communications has been emphasized in most discussions of COOS programs, the important contribution to understanding coastal ocean processes that can be made by delayed mode reporting (non-real time assets) should be recognized in future RCOOS programs.
Reliance on the IT/communications infrastructure of academic institutions for at least portions of the communications network had both positive and negative aspects. While institution IT infrastructure often represented a significant resource for SEACOOS, the observing system requirements were not necessarily a high priority for university IT groups. For example, system shutdowns and limited access to institution facilities has resulted from emergency response preparations for hurricane threats; a time when maintaining the flow of real-time information is particularly valuable.

Failures in communications often occur on weekends and over holidays. That is, the academic institution system is typically not set up for 24:7 operations.

Satellite remote sensing in SEACOOS.

The costs associated with hardware required to collect, process and distribute large-volume satellite data (including receiving stations, processing computers, data storage and network bandwidth) and the personnel necessary to coordinate these activities are well beyond what could be supported through the SEACOOS budget alone. Leveraging the existing resources supported by other agencies and programs (NASA, NOAA, ONR) was the only practical way to include satellite remote sensing in the SEACOOS observing framework. From this experience, a number of points regarding incorporation of satellite remote sensing into a regional COOS can be made:

For many satellite products, the latency (delay time) between image acquisition and when the imagery could be delivered to the regional portal was considerably reduced through use of the regional download and processing capabilities, as opposed to relying on national satellite data distribution systems (e.g., NASA Goddard DAAC;JPL PO DAAC; NOAA Coastwatch).

Redundancy in download, processing and delivery is needed to ensure uninterrupted delivery of satellite data (e.g., hurricanes shut down one or both of the USC and UM facilities during the SEACOOS program).

Some data (e.g., real-time SeaWiFS, RadarSAT) require costly licenses (from order $10K per year to several $1K per image) and it is likely that partnerships will be necessary for inclusion of such data in a future RCOOS.

While the SEACOOS effort was able to demonstrate near-real delivery of satellite data and derived products, a more fully developed program to maintain and improve existing products and develop new regional products would require significant further investment (e.g., to maintain a field validation program). Again, effective partnering with other regional and national programs is likely to be essential for both infrastructure and personnel support.

4. Programmatic Lessons Learned – Observing Working Group.

While the SEACOOS Strategic Plan and Implementation Plan were framed with the expectation of national progress toward a long-term, sustained IOOS program, the SEACOOS program was funded on a year-to-year basis. Thus, the time horizon for OWG planning was necessarily constrained. However, SEACOOS provided enough stability in funding that the OWG effort indicates what might be achieved through academic institution participation with sustained RCOOS funding. The potential for regional cooperative test-bed experiments was demonstrated, notably through the SEACOOS "Mini-Waves Experiment", an activity that was initiated through OWG discussions at the May, 2002 SEACOOS workshop. While there were certainly a number of positive accomplishments, in terms of programmatic "lessons learned", it is also important to note a number of issues regarding OWG functions and activities in SEACOOS.

There largely remained a local or sub-regional focus among the OWG activities of the partners. While build-out of *in situ* assets and test-bed activities occurred, this was primarily in terms of extension of the partner efforts and less so in terms of SEACOOS-wide activities.

Personnel resources were not sufficient to develop a true "Operations Groups" to consolidate support the *in situ* and HF-radar observation activities on a SEACOOS-wide basis; as noted above most personnel were multi-tasking throughout the program.

Satellite remote sensing is inherently regional in scope, and a regionally focused effort could provide the basis for tailoring algorithms for specific regional products and serve application areas by helping to link physical, chemical and biological fields. While, the pilot effort in

SEACOOS showed considerable potential as a regional asset (both for near-real time delivery of satellite products and analysis products); however, the need for further coordinated effort with data management and modeling groups, and engagement with stakeholders to minimize potential conflicts with private sector satellite data product providers was indicated. Focused OWG support of targeted applications areas was limited, and while discussed at workshops, follow-up activities in these areas proved to be difficult to move forward.

The multi-program origins of many of the SEACOOS *in situ* and remote sensing efforts may have contributed to these programmatic shortcomings. Certainly the prior experience of many of the partners was largely in the "PI culture" of individual project funding (which tends to emphasize focus on institutional efforts or even specific components of the observing system). On the other hand, the research background of many participants also contributed to the considerable leveraging of SEACOOS assets that was achieved through linking the SEACOOS activities to complementary research programs. Effective communications in the OWG between institutions was an issue. While there were regular communications at the EXCOM level, other PIs often felt less engaged in the program direction and planning. At the engineering/technical support level, cross-institution interactions in the OWG as a whole were limited. The fact that support personnel were spread thin and often multi-tasking in terms of operational and research tasks was certainly a factor is this; they typically had more than enough to do in terms of keeping up with the local issues. And while there was some participation of OWG support personnel in SEACOOS-wide workshops, opportunities for technical discussion among OWG support personnel was typically limited under the workshop structure, and in many cases workshop participation of technical/engineering personnel was limited due to time/cost considerations. Further RCOOS development will benefit from increased interactions among experienced technical personnel on both regional and national levels.

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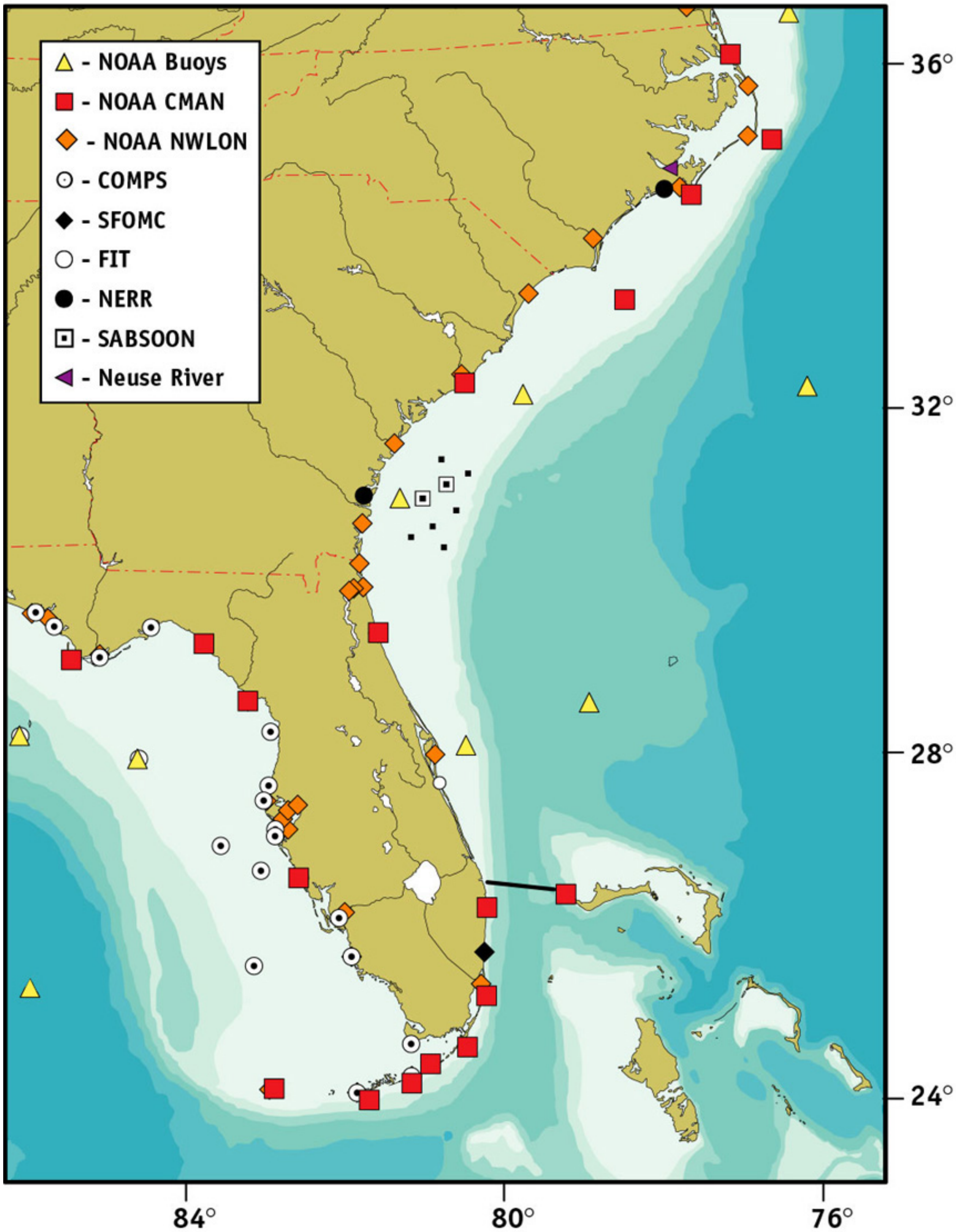
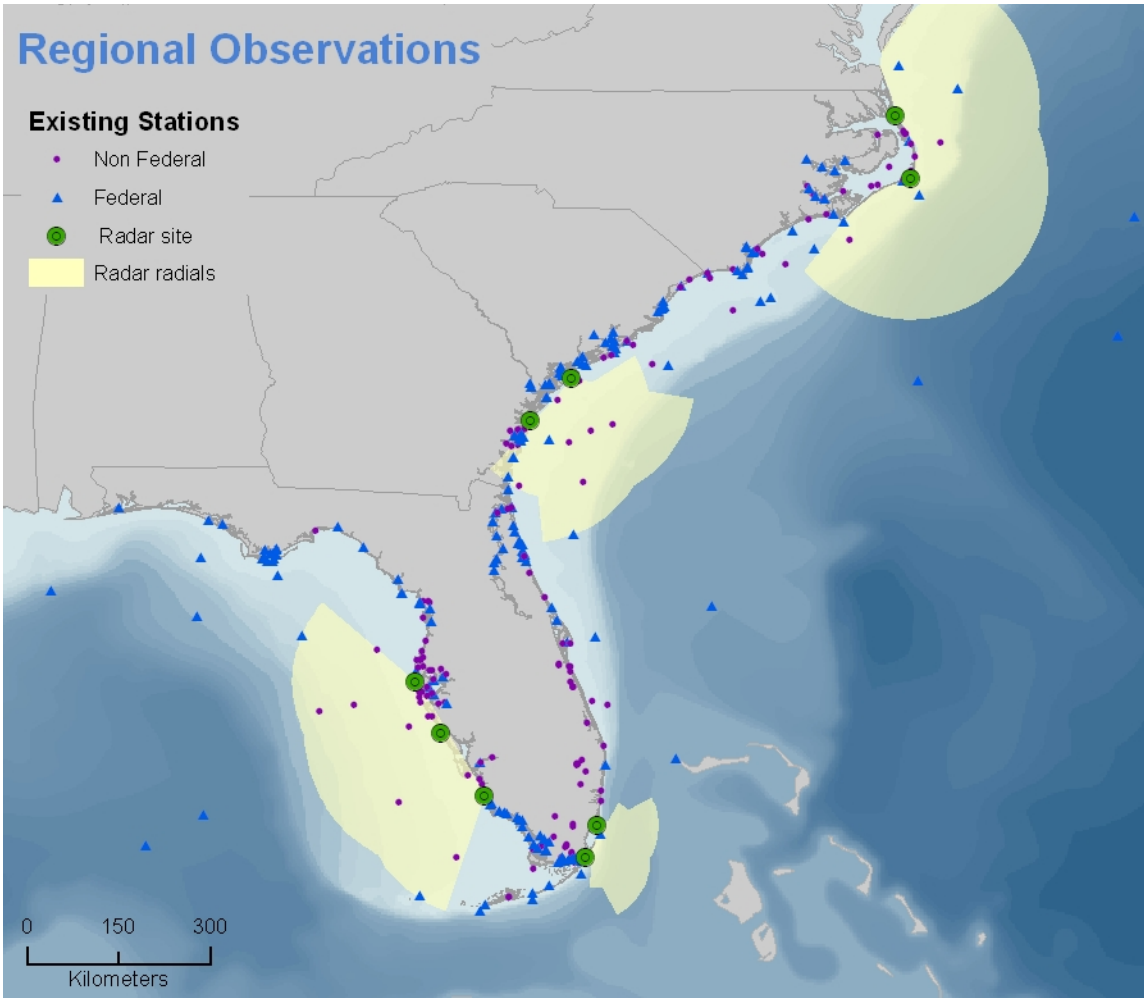


Figure 1. Status of real-time observations in the SE coastal ocean at the time the SEACOOS program was initiated. Locations of NOAA and sub-regional assets are indicated. This does not include the USGS river gauge stations. The figure was originally generated for the SURA SCOOP program, largely through input from the initial SEACOOS partners.



Draft Figure 2. Present status of real-time observations in the SE coastal ocean and approximate coverage areas for HF-radar surface current mapping by SEACOOS partners. Note: this figure includes the USGS water level stations that are tidally influenced. *[** taken from Seim et al. ms; will need some modification to indicate SEACOOS, Caro/CORMP etc **]*