

# On Coastal Ocean Systems, Coupled Model Architectures, Products and Services: Morphing from Observations to Operational Predictions or from “COOS” to “COOPS” or rather to “OPS”

L. Pietrafesa<sup>1</sup>, M. Davidson<sup>2</sup>, T. Karl<sup>3</sup>, D. Dickey<sup>1</sup>, E. Buckley<sup>1</sup>, L. Xie<sup>1</sup>, M. Peng<sup>1</sup>, S. Bao<sup>1</sup>, H. Liu<sup>1</sup>, J. Kinder<sup>1</sup>, J. Bichy<sup>1</sup>, T. Dodson<sup>1</sup>, J. Epps<sup>1</sup>, D. Stanfield<sup>1</sup>, C. Gabriel<sup>1</sup>, M. Fletcher<sup>4</sup>,  
<sup>1</sup> North Carolina State University, <sup>2</sup> NOAA Coastal Services Center, <sup>3</sup> NOAA National Climatic Data Center, <sup>4</sup> University of South Carolina

**Abstract:** A case is made that the national process of special appropriations monies to establish the coastal observing component of the integrated ocean observing system (IOOS) network is not well organized and without substantive value, given the way that it has been orchestrated. Alternatively, a case is made that the special appropriations monies could and should be better spent in pursuit of the establishment of the national backbone that is needed to greatly improve atmospheric, oceanic and coastal “weather” forecasting, broadly defined, for ecosystem management and to document climate variability and change in coastal zones. Part of the problem is historical and cultural. An example of a sub-regional effort to focus on societal needs is presented by way of example to show that university partners (to federal agencies) could have an important role to play in the future of ocean and coastal observing and prediction systems and networks.

## I. Introduction

While the federal government invested heavily in its weather modernization build out of the 1980s and 1990s, there was little attention paid to the ocean or coastal environs directly; either in the air or in the water. Presently those observing deficiencies are being addressed in an awkward, un-coordinated special appropriations process which captures resources from federal agency line appropriations in order to purport to build coastal networks which would constitute the coastal ocean observation system (COOS) component of the Integrated Ocean Observing System initiative (IOOS). The consensus rationale for the special appropriation set-asides is that coastal communities are in dire need of additional data and information is presently available through conventional federal and state agencies. This has also been the mantra of several programs that have captured directed special appropriations funding out of the United States (U.S.) Navy’s Office of Naval Research (ONR) research and operations budget; an agency that does not have the mission or responsibility of providing data or information to the public, but rather is focused on research to provide new technology to the “operational” Navy. The question is: can the needs of the targeted agencies, specifically the National Oceanic & Atmospheric Administration (NOAA), and ONR, be well served by these “special” programs.

This paper presents a description of some cultural pitfalls that may be impeding the direction, progress and future success of these special allocation programs. If there are real partnering opportunities and advantages to these alliances they must be acknowledged by the target federal agencies, specifically NOAA, if they are to succeed and prosper. The alternative may be a missed window of opportunity in building a national monitoring network that has value to NOAA and to the citizenry of the U.S. at national to sub-regional scales. Albeit, the discussion points to a subset of regional programs with attention to the negatives, pitfalls, challenges, opportunities and advantages of the loosely structured federal agency and university community partnership. An example of one such program is presented by focusing on an emerging coastal network in the region of the Carolinas.

## II. Background and Present Setting

The lead domestic agency charged with providing coastal environmental data and information to the nation is the National Oceanic & Atmospheric Administration (NOAA). NOAA is also the principal target of the special appropriations process. In FY06, some \$138M of these monies were been spent in support of this national patchwork quilt of so-called COOSes. There are several fundamental problems with the special allocations process and the low likelihood of success for these COOSes in general unless important changes occur throughout the national ocean sciences community. Cultural changes must also occur within federal agencies, particularly NOAA if the monies are to be spent in a more constructive fashion. In present FY07 House language, NOAA is encouraged to formally request monies from Congress in support of building out ocean and coastal observing systems. At the

# Report Documentation Page

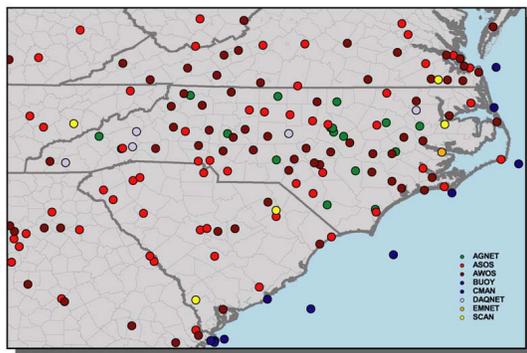
Form Approved  
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE <b>01 SEP 2006</b>		2. REPORT TYPE <b>N/A</b>		3. DATES COVERED <b>-</b>	
4. TITLE AND SUBTITLE <b>On Coastal Ocean Systems, Coupled Model Architectures, Products and Services: Morphing from Observations to Operational Predictions or from COOS to COOPS or rather to OPS</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>North Carolina State University</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release, distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002006. Proceedings of the MTS/IEEE OCEANS 2006 Boston Conference and Exhibition Held in Boston, Massachusetts on September 15-21, 2006, The original document contains color images.</b>					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>UU</b>	18. NUMBER OF PAGES <b>10</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

same time and perhaps as a step forward, the university community could consider not being so self centered and introspective and open up itself up to being service-research focused. Contemporaneously, NOAA, which does not have the broad in-house technological expertise that the national network of universities possess, might look to the value of allowing universities to test new technologies, fail and succeed, and adopt and make operational what works better; as appropriate. Universities are familiar with trying and failing, but also with trying again until success is achieved. That is part of the academic process.

The NOAA National Weather Service (NWS) is a poster child for needed, demanded and required federal organizations. It is a solid example of what an agency, either federal or state, could and should be in support of serving the needs of the citizenry of the nation. Another example of a federal agency in kind is the United States (US) Postal Service (USPS). There are other examples, but these are amongst those with which the public can readily identify. Both have to deliver routinely or operationally. Albeit, the USPS has never had a successful business model and the NWS had never seriously considered the justification, rationale or strategy for a greater presence in the ocean or coastal areas of US waters. By way of comparison, there are the order of 14,000 land based atmospheric monitoring sites across the nation and but 140 marine buoys and CMAN stations in coastal waters including the Atlantic and Pacific coasts, the Gulf of Mexico, Alaska, Hawaii and the Great Lakes; a 100/1 ratio (Figure 1 for the region of Virginia to Georgia, by way of example). The issue of course is that knowledge of and forecasts for coastal weather, either the “weather” or higher frequency, smaller spatial events, is very important in both the coastal atmosphere and coastal waters. Basically the reasons are two-fold: 1<sup>st</sup>, there are many people living in these zones (Figure 2 for the coastal counties of North Carolina, by way of example); and 2<sup>nd</sup>, there have been many weather related events which have had enormous economic impacts in these coastal zones (Figure 3); particularly the Maryland to Texas swath.



The land components (note the impressive presence of the NC SCO ECONET) And the existing Federal assets. So to answer the previous Q: Why build out along the coast? Because we have such a sparse presence.

Figure 1. Land and Coastal Ocean Federal and State based Atmospheric and Ocean Observing System assets in the SE and southern MAB states.

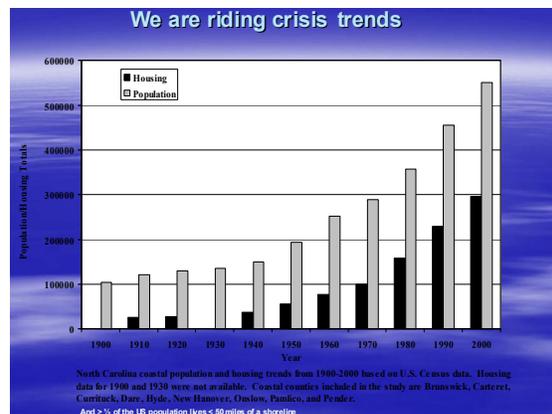


Figure 2. Growth in population and housing in NC coastal counties; going from linear to exponential.

Would more and better information coming routinely from these coastal regions improve NOAA NWS National Centers for Environmental Prediction (NCEP) forecasting capabilities? In 2004, the NOAA NWS NCEP requested and NOAA Science Advisory Board commissioned an external study of the status and value of NCEP ocean modeling and all that it entails. In its comprehensive evaluation and as documented in its report (NOAA SAB Ocean Modeling Report, 2005), the case for a greatly expanded ocean and coastal observing array was a resounding “yes”. The data are needed for more comprehensive in-situ spatial and temporal coverage, for providing actual, real coastal environmental state parameter conditions, for ground-truthing satellite sensors, none of which directly measure the parameters of interest, initializing atmospheric and oceanic numerical models, for driving and validating weather forecast numerical model output, for conducting hindcasts and retrospective analyses, for now-casting and for improved forecasting. Moreover, if interactively coupled air-sea models are to be run routinely on the NCEP computational platforms, data must be collected on both sides of the navi-face at the same place at the same time. Historical perspective is of value here, because a cultural separation has existed for at least six decades, if not longer, and it has impeded progress.

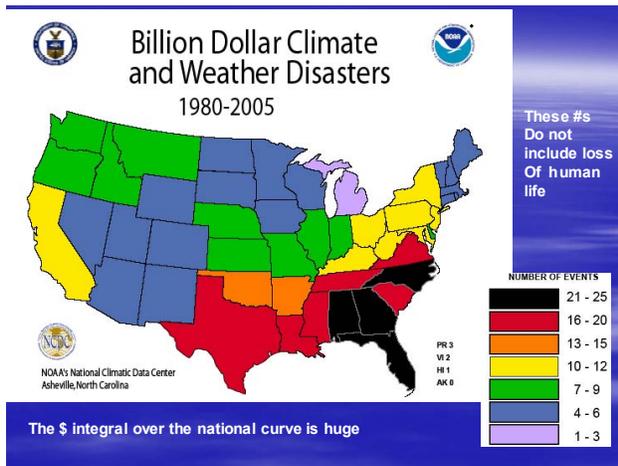


Figure 3. \$B weather related events over the period 1980-2005. States in red and black have lead the national hit parade.

As a practical imperative of World War II, the federal government called for the creation of a federally funded, university based national research program in both the ocean and atmospheric sciences. The challenges of not knowing when to cross the English Channel because of a lack of ability to properly forecast the atmospheric and oceanic “weather” nearly compromised the Allies invasion of Normandy. Clearly that experience showed that the U.S. needed a far more ambitious national atmospheric and oceanic research enterprise with an associated strategy to transfer the results of the research to new operational forecast tools. The outcome of this was the creation of the U.S. Navy’s Office of Naval Research (ONR) in 1946. Following the immediate success of the ONR enterprise the U.S. National Science Foundation (NSF) was created using the ONR template, but including all of the hard and soft sciences, mathematics and engineering. Here is the story of the resulting diverging tracks.

Across the atmospheric sciences community the challenge in the mid-1940s was viewed as one that merged education and the training of line weather forecasters and was focused at the undergraduate level, but was also accompanied by graduate education programs in which research was conducted. This emergence of a national network of principally undergraduate programs was then followed, in the late 1950s, by the creation of a national consortium of universities, the University Corporation for Atmospheric Research (UCAR) and a national laboratory, the National Center for Atmospheric Research (NCAR) funded by NSF. Both UCAR and NCAR and the wide-ranging university community have prospered with this arrangement in which large research facilities are centered at the NCAR headquarters in Boulder, CO. The UCAR and NCAR pair is an example of a good idea being put forward for a common cause and deemed a successful model.

The ocean sciences community responded to the ONR and NSF opportunities with the creation of a number of coastal laboratories and in many cases, university programs that specialized in graduate education and research. These major ocean sciences programs acquired sea going vessels and some obtained block funding from ONR and NSF to support institutional infrastructure. These institutions competed for block funding, sent rotators to serve as ONR and NSF program managers, and interacted collaboratively when conducting complementary experiments on NSF University Oceanographic Laboratory System (UNOLS) cruises. The UNOLS model has been very successful. Albeit, to date the ocean sciences community is not fully integrated with the Joint Oceanographic Institutions (JOI), the Consortium for Oceanographic Research and Education (CORE) and the National Association of Marine Laboratories (NAML) principally speaking for the sectors of the national community that they represent.

Students graduating from the atmospheric sciences programs were hired by and large by the U.S. Weather Bureau while those from the ocean sciences institutions were hired by other universities. Thus the dye was cast, the atmospheric sciences academic programs were traditional, with a strong base of undergraduates and associated graduate programs; many tied to NCAR via UCAR. Faculty had conventional appointments since there was a strong undergraduate teaching presence and graduate students could be funded on both research and teaching assistantships. Alternatively, the oceanic sciences academic community, save for several outlier institutions, was principally focused on grant and contract funded research with each institution having to build out its own infrastructure on federal funding and overhead receipts derived from indirect costs charged to the federal agencies by the universities. Faculty appointments were to a large degree based on soft money, not a stable sustainable situation and graduate students were supported as research assistants with very few teaching assistantships available.

With the creation of NOAA in the early 1970s and the emergence of the NOAA National Weather Service and given the national network of Weather Forecast Offices (WFOs), there were expanded opportunities for the nation's atmospheric sciences undergraduate majors to be employed as line-forecasters at the WFOs. The undergrads were trained with the principal goal of becoming line forecasters. Thus the tradition and challenge of forecasting became foundational to the culture of atmospheric scientists. This was not the case on the oceanic sciences side of the house. Here, by and large there were few undergraduate majors and those graduates either went off to graduate school or found employment in other fields or in the U.S. Coast Guard, etc. So the tradition established in the ocean sciences was one of research in the pursuit of new knowledge and more research. That was and remains the status quo, for the most part with no real appreciation for line forecasting, by and large, across the ocean sciences community, save for NAVOCEANO. This history and tradition still plagues the ocean sciences community as it takes on this new challenge in literally un-chartered waters. It has also greatly impacted the build-out of the observing networks.

The case made for the need for ocean and coastal observing systems is that they are a national imperative based on meeting societal needs. To large degree the U.S. Commission on Ocean Policy spoke to that in general ocean centric terms. However, the rationale for why and how to build the COOSes is not well based. Words such as "improving marine services", "predicting hurricanes" and so on are basically without substance. A comprehensive rationale could be: to provide better operational forecasts of atmospheric and ocean "weather" (used broadly to mean high frequency events in both air and water); to document and predict coastal impacts of weather events to environmental systems and human systems; to document the impacts of human alterations on coastal systems; for under-girding the data and information bases on which to conduct ecosystem management decision making; and to document climate variability on regional to sub-regional scales. But this will require an ocean sciences culture trained in the mechanics of diagnostic retrospectives, of conducting observation simulation experiments, of doing prognostic driven modeling experiments and of the process of operational "forecasting". To 0<sup>th</sup> order this rationale must also include the challenge of building, deploying and sustaining coastal observing systems which must operate reliably and routinely report data in near real time. These are cultural challenges to the ocean sciences community.

The good news is that many universities now offer undergraduate curricula in either or both atmospheric and ocean sciences and they would only have to agree to begin offering new courses in operational ocean forecasting. UCAR may want to promote this nationally amongst its member institutions. Clearly future NOAA NWS WFOs will need to have forecasters familiar with coastal weather given the population density in coastal zones (Figure 2) and the impacts of heavy weather in these zones (Figure 3). Further as the ability to forecast more environmental state variables advances, real time environmental data will become a necessary commodity and forecasters skilled in the ocean sciences will need the data and information. Likewise to predict the impacts of past events, lodged in the historic record on today's and tomorrows human altered systems requires in-depth knowledge of the bio-geo-chemistry of those systems. So there is a compelling case to be made for changes to be made in university curricula in the ocean and marine sciences (and more broadly the ecosystem/ecological sciences) that would support the needs and demands of the emerging ocean and coastal observing systems and networks.

### III. Status: Pitfalls and Challenges

Deploying and sustaining observing networks should not be the ultimate goal of ocean and coastal observing systems. From the perspective of NOAA, the federal agency that is the principal target of the special appropriations funds, the true goals of the establishment of these observing systems must include, but not be limited to, improvements in operations and operational forecasting, to support ecosystem management and to document climate changes, leading to the provision of new products and services as proposed in the NOAA SAB NCEP Ocean Modeling Report of 2005. The paper argument for why additional observing systems are needed has been established. We need not revisit those here. However a blueprint for a rational, well organized, well coordinated, community wide accepted plan has not been established. Nor is it being considered by the university community at large. Albeit, the concept of Regional Coastal Ocean Observing Systems (RCOOSes) has evolved and been pushed as the organizational regional unit which should be created and then sewed together at inter-regional boundaries to create the national network. There are eleven of these regional networks. In the face of this emerging opportunity, universities have agreed to agree and form alliances up and down the coasts. But the creation of the sub-regional programs has not yet resulted in associated, conforming systems that are governed by the same rules; and are thus basically compatible and capable of being seamlessly merged. The rationale for where and what observing systems are needed has been given appropriate consideration by Ocean.US which has had workshops on this very issue.

One of the pitfalls is that typically one of the first things that a university with traditional marine or ocean sciences academic programs does when it received special appropriation monies is to immediately undertake a build out its

infrastructure, with personnel, supplies and so on. Does NOAA really care about any of these expenditures of money? “Yes” in that monies that could have been spent in support of the agency’s mission are viewed as being squandered. The university may actually decide to establish an observing program and a modeling program, but without any tradition or skill set in those areas it will have to buy technicians and faculty experts from other institutions in kind to build up this capability. Moreover, rather than planning for what should be an up front commitment to spending a certain percentage of the overall COOS special appropriations to buying the equipment necessary to build and build out whatever array is to be constructed, the institutions may leave this until last; when the money has by and large been spoken for other institutional purposes. These purposes generally do not consider the needs of NOAA; which is basically and fundamentally, getting the 2<sup>nd</sup> “O” in COOS established.

To appreciate what the agency actually needs to better meet its mission, one must have familiarity with that agency. In the case of the national COOS earmarks, the agency of choice has been NOAA. While an ONR earmark in support of the COOS concept does carry a responsibility for meeting the needs of the operational U.S. NAVY, this implies doing research that is in the NAVY’s interest. But NOAA is an operational and environmental resource management mission agency and the rationale for a COOS can only be made based on the contribution that the local COOS will make in building capacity for and enabling NOAA to better meet its mission. Here a familiarity with what the NWS does in land should guide what the COOSs do offshore. First there is the need to define what type of data and information are needed over what spatial scales. To know this one must have knowledge of the processes of fundamental importance to NOAA in the domain of interest. Next is the choice of instruments, platforms, sensors and communications systems. Then one must determine how do actually physically build the array. Next, the process by which vessels are selected, acquired and scheduled must be addressed. Then, complete backup systems must be acquired for replacement at regularly scheduled maintenance cruises and or when there are failures at a specific location. This is a requirement of system performance, all components of which must function reliably and routinely. Finally a QA/QC data assessment and modeling architecture must be put in place to evaluate the quality and to then utilize the incoming data in real time.

#### IV. An Example of a Regional COOS that has the potential to become a Prototype Regional COOP

In the coastal region of North and South Carolina (the Carolinas), the centerpiece goal of the Carolinas Coastal Ocean Observation and Prediction System (Caro-COOPS) is the routine, and thus “operational”, on-line provision of reliable data and readily usable products. These data and products are available on line ([www.carocoops.org](http://www.carocoops.org)) and cover present, future and past temporal periods in nested spatial domains and are packaged to include: 1) near real time scrubbed data; 2) near real time data driven model information; 3) the prediction of coastal state variables and processes over hours to days; 4) archives of past coastal ocean and atmospheric state variables; and 5) retrospective model event results. To that end, the Coastal Ocean Research & Monitoring Program (CORMP) is a regional program complementary to Caro-COOPS. The history and merging of these two programs is presented in Fletcher et al (2006) at this conference.

Contemporaneous to the creation of Caro-COOPS, the Climate and Weather Impacts on Society & the Environment of the Carolinas program ([www.CWISE.org](http://www.CWISE.org)) is creating land and ocean based state variable products in the Carolinas in a manner complementary to Caro-COOPS. The land and ocean based CWISE products will merge in a transparent manner with the product data sets. So both CWISE and coastal ocean observing systems are laying the groundwork to incorporate predictions of land based and ocean based meteorological and oceanic state variables into the development of modern, new tools that are intended to provide support to the public, managers, and industry. New data products based on mathematically derived relationships such as winds, waves, water levels, circulation, river discharge, storm surge, flood inundation, and rip-tides are presented or will shortly be developed. Thus these “COOS” systems can rapidly morph into and become “COOPS” systems. NOAA will directly benefit from this.

The top priority for Caro-COOPS has been to maintain and sustain the existing network. Optimum operation of existing systems is ensured through regular maintenance, sufficient spare equipment for routine rotations or emergency replacements, and support infrastructure, including ships, warehouse space, and piers. Two turnarounds of the offshore component of the network are done annually. Routine maintenance of the recovered buoys includes sensor cleaning to clear fouling and calibration to ensure accuracy, data downloading from the on-site dataloggers, battery replacement, troubleshooting of datalogger and telemetry electronics, and refurbishment of the buoy and mooring components, as needed. However, here resources have not been properly identified for system build-out. This shortcoming must be rectified or the further value to NOAA will be curtailed. A Caro-COOPS mooring is shown in Figure 4. Plans are to make the mooring single leg and acoustic in data delivery. Additionally, the new buoy system’s structure will employ a single-point mooring design and have a larger flotation hull, tower, and waterproof instrument well. Another new feature of this mooring will be use of an acoustic modem for data

transmission from instruments on the seafloor. In Figure 5 we see the existing assets and what the essential backbone array should be based on the arguments presented below. These systems are different than the conventional NDBC buoy which does not contain an upward looking ADCP nor is capable of collecting directional wave spectra. Here, advancing new technologies, testing new mooring systems, instrument sensors and communications systems in the ocean environment, is a proper role for an academic partner to NOAA.

Field inspections of the coastal water level stations (WLS) are done quarterly, with annual maintenance and operation and maintenance of the Caro-COOPS WLS meet all NOAA NWLON standards and are done in collaboration with NOAA CO-OPS. CO-OPS support includes performing inspection and acceptance testing of the Caro-COOPS systems, calibrating the acoustic water level sensors, and preparing and configuring the systems for deployment by staff at the Field Operations Division, Chesapeake, VA. CO-OPS also provides technical support in the operation and documentation of the stations and the processing and analyses of the data. A NOAA-approved contractor, Martek, Inc. Scientific Cons, assists in periodic trouble-shooting and annual maintenance of the WLS systems. Here, academic, federal and industry partners all play key roles.

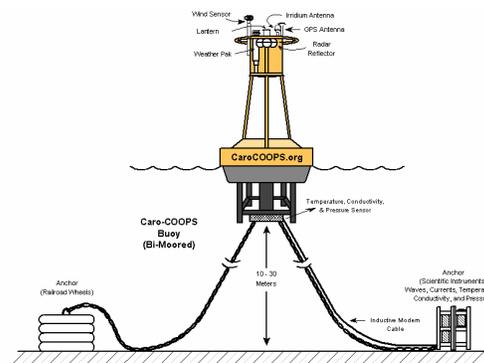


Figure 4. NCSU Caro-COOPS mooring

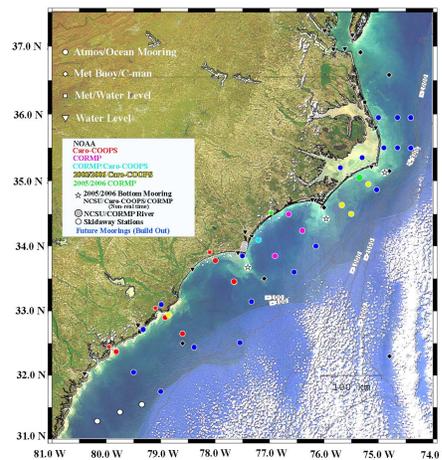


Figure 5. A proposed backbone Carolinas array; present and future

As part of the Caro-COOPS field program, a dedicated test-bed buoy was deployed at a location convenient to get to by ship outside of Charleston Harbor. New sensors and/or systems are being field tested in temporary, short-term deployments of a spare moored buoy (Figure 5). The 1<sup>st</sup> system tested was an acoustic modem to transmit data from the ADCP to a buoy datalogger. The 2<sup>nd</sup> system tested was a sea trial of a real time reporting bottom mounted directional wave system. Data from the test instruments are transmitted to the buoy engineering laboratory at NCSU. A comparison of the data from the wave system at the test buoy with waves data from the NDBC Buoy 41004 show good agreement in the data despite different technologies and slightly different sampling times (30 minute difference). No wave direction data are reported from NDBC Buoy 41004, so wave direction comparisons are not possible. Given repeated failures and following testing, mechanical wind vane sensors on all of the Caro-COOPS buoy systems were replaced with ultrasonic wind sensors, which have no moving parts and utilize an acoustic time-of-travel principle to determine wind speed and gusts. Integrated with very precise, flux-gate compasses to determine wind direction on a moving platform, it is expected that these modules will perform more accurately and be considerably more robust physically than their predecessors. These tests constitute a proper role for a university partner of NOAA.

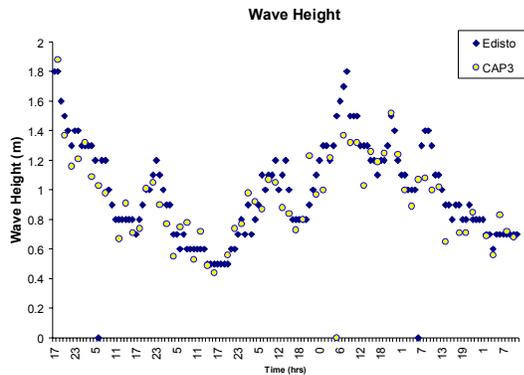


Figure 6. Wave height data comparison of the Test Mooring and NDBC Buoy 41004 May 11-17, 2006.

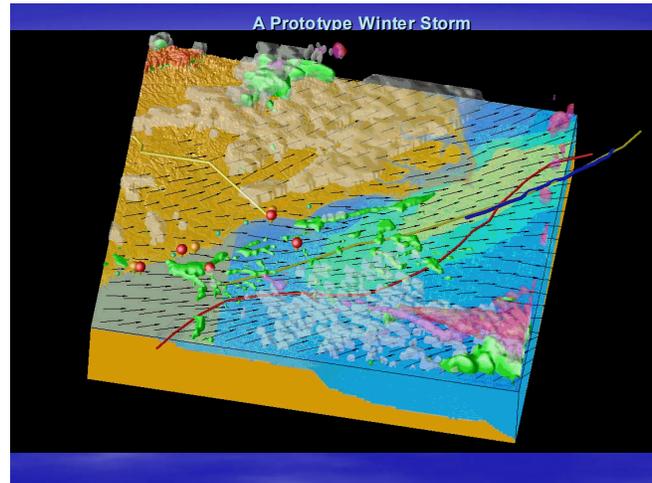


Figure 7. NCSU ETC model output showing Caro-COOPS assets and the prime region of cyclogenesis in the Carolinas

NCSU technicians will evaluate a GOES satellite telemetry system and a solar panel auxiliary power system for the buoys. Primary and secondary communications systems are necessary in the case of failure of either the DoD Iridium system or in case of partial failure of the power system. NOAA will provide Caro-COOPS with access to the GOES system. A small solar array will be incorporated into the overall power system to meet the additional requirements of the GOES system and to power an emergency system to be used in case of primary generation system failure. Current plans are to deploy a test buoy with the GOES system and solar panels to evaluate both. This is a proper role for a university partner to NOAA.

NCSU studies have shown that air-sea flux data will detect the onset or intensification of winter-time extra-tropical cyclone (ETC) events. As seen in Figure 7, data from a built-out Caro-COOPS array (the region of no existing red-pins) would give warning of the onset and be assimilated into coupled atmospheric-ocean models already running at NCSU. NCEP needs more data from the data-starved Carolinas, the epi-center of cyclogenesis on the U.S. eastern seaboard. This finding will be shared with NOAA NCEP and NOS to build the case for a denser monitoring network as a part of IOOS. Moreover, as part of CWISE, a new operational storm genesis or intensification detection tool is being developed and once completed, will be transferred to regional NOAA NWS WFOs. This type of experimental coupled modeling is a proper role for university partners with NOAA.

The initial demonstration of the real-time interdisciplinary forecast concept for Caro-COOPS has been the NCSU based real-time prediction and analyses of storm surge, flooding, and inundation in advance of and during the passage of coastal storms. This has and will continue to improve warnings and provide local officials with the information needed for mitigation, preparedness, and prevention measures. To improve these forecasts, NCSU has developed an anti-symmetric wind model. Results of the new asymmetric hurricane wind model were compared against buoy observations and HRD hurricane surface wind analysis and showed that our model improves forecast performance. The model was presented recently by Bao and colleagues at the American Meteorological Association conference on Tropical Cyclones in Monterey, CA in 2006. The new wind model has also been used to create a new “% probability of inundation maps” product in advance of a hurricane making landfall; a new tool for emergency managers and WFOs created by an academic partner.

The importance of the asymmetric hurricane wind field advance for storm induced surge, flood and inundation cannot be understated because accurate forecasts of the latter require highly representative wind fields. NCSU has developed operational, working CD ROMS of the asymmetric hurricane wind field and the surge, flood and inundation models for WFO forecasters and held a tutorial workshop for WFO SOOs and MICs. The CD ROMS can be used for individual forecast guidance of specific past or in advance of future hurricane events. This is a powerful example of the value and utility of the creation and transfer of new operational forecast capabilities that have been developed via Caro-COOPS. Here university scientists have a proper role to play.

One of the critical challenges in Caro-COOPS has been in providing wave field information in near real time, as well as model forecasts, which are so important for commerce, fishing, and recreation in the region. We have focused on four separate efforts: conducting wave field modeling during the passages of hurricanes; making wave

forecasts in the presence of varying waves over variable topography; making wave forecasts in the region of the Gulf Stream Front and beyond; and providing wave information as both “now-casts” and “forecasts” across the Carolinas domain and at specific locations. Advances have been significant for each. We are also attempting to utilize actual observations of the wave field using bottom mounted ADCPs that measure the wave field as an outcome of its interactions with the current field to forecast future wave conditions. To properly predict the wave field, we must analyze the effect of currents on waves, the effect of waves on currents and surge, and the interactive coupling between them. In Figure 8 we see the change in inundation due to including waves in the NCSU modeling and in Figure 9, the goodness of NCSU wave forecasts made directly from the data is shown. The next step is to.

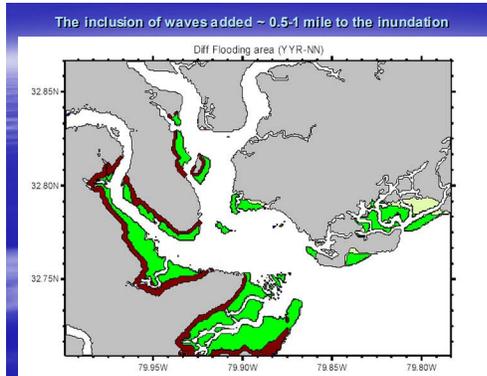


Figure 8. Change in inundation at Charleston During passage of Hugo in 1989.

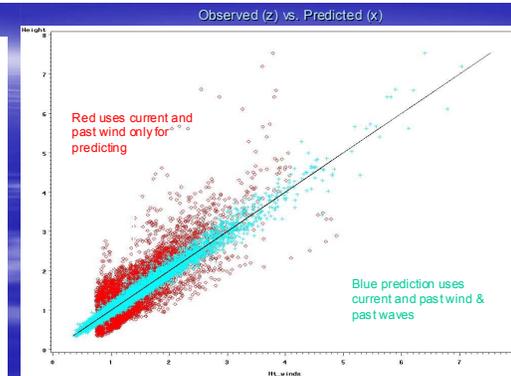


Figure 9. Forecasting waves at coastal observing sites using past and present wind and wave data.

utilize these data to separate out those data that are linked to the formation of Rip Tides/Currents so that we can advance the state of the Rip forecast system for regional NWS WFOs, which has real value to the public.

In our partnership with the NOAA Cooperative, CWISE, we have taken advantage of new QA/QC methodologies developed to evaluate data streaming in via coastal piers and buoys. We have taken advantage of new statistical experimental prototype predictions of state variables developed in CWISE that will produce new services to be provided via the Internet. We have also developed a new methodology to focus on processes of importance to regional super-regional stakeholders, to determine where and what kinds of new observing systems are needed in order to establish the essential observing backbone needed by NOAA to better meet its’ mission. Figure 10 shows the distribution of waves at NOAA NDBC Buoy 41004 and the QA flagging point. The transfer and implementation of this procedure could have great value to NOAA and other federal agencies; an important university contribution. NOAA NCDC has been a national champion of assessing data on the fly and this methodology may have important applications to NOAA data assessment; particularly those streaming in from next generation satellites.

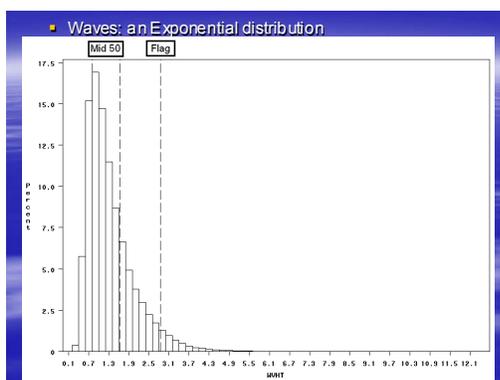


Figure 10. Flagging data on the fly. A data quality check.

A major goal of Caro-COOPS has been to optimize model applications for predictions of hurricane-induced storm surge and inundation across the spatial extent of the Caro-COOPS domain. To that end, new insights were obtained this project period via NCSU running a suite of 1872 tracks comprising Category 1-4 hurricanes running in the regions of Hilton Head, Charleston Harbor and Myrtle Beach to Holden Beach at 15 degree intervals. Inundation products from these initial runs were produced to provide further guidance to emergency managers and to regional

NWS WFOs. This visualized model output is an advance over existing products employed up to this point. We also found that the tracks producing the greatest surge and those producing the largest extent of inundation are not the same. Since surge and inundation are not the same, one must be careful to qualify predictions to emergency response managers. These Storm Maps will be made into an atlas, both hard copy and on the Internet, for access by NOAA CSC patrons and other appropriate users; a proper role for an academic partner.

NCSU has conducted surge and inundation model results for two regional domains in which both GEODAS and LIDAR bathymetric and elevation data sets are available; the Pamlico-Albemarle Sound, N.C. and Hilton Head, S.C. domains. The two domains are very different in that the NC system is a large coastal lagoon while the SC site is a conventional coastal plane system. The model was run for up to 10 hurricane cases for each domain and formal inter-comparisons have been made. First examination of the comparative results show clear differences with the two elevation data bases. This is of great interest to the sponsor of Caro-COOPS, NOAA's CSC which has been a national champion of improving the coastal elevation data base.

NCSU is implementing the next generation suite of atmospheric models for application in Caro-COOPS modeling and for interactive coupling with the circulation models utilized in Caro-COOPS. We will test that possibility and attempt to determine the value of ingesting spatio-temporal surface data into these operational models. NCSU has also implanted and tested the HYCOM circulation model on a regional basis, including the Gulf of Mexico and the Caro-COOPS domain of the Carolinas. We have evaluated the coupling of the systems by numerically recreating the 1987 Harmful Algal Bloom event which began on the west coast of Florida in September and then appeared in NC and SC coastal waters, in that order, in October and November. While this event was conceptually described by Pietrafesa and colleagues, it has never been modeled in its entirety. We proved the concept and will offer to operationalize the model via transfer to the NCEP computational platform; a proper role for an academic partner.

## V. Conclusions

The technological and scientific advances made as a part of the onset and emergence of a regional COOS that has transitioned into a COOP seems very solid. However, the costs of maintaining and building out a COOP are very high; including mooring equipment, mooring platforms and supplies, personnel, and especially ships. Thus the essential back-bone observing array design, from national to regional scales, must be based on known, documented fundamental atmospheric and coastal oceanic phenomena and property distributions and an assessment of where foundational gaps exist in the essential backbone.

The existing and a proposed build-out of the Carolinas Coastal observing network, including Caro-COOPS (and CORMP by association), was presented above in the context of: 1) observing the state variables underlying the environmental processes known to be fundamental to the region; 2) advancing the present state of knowledge of the Carolinas coastal system; 3) advancing the prediction capabilities of coastal processes; 4) advancing the capability of the prediction of impacts of coastal processes on the environment and society of the Carolina coastal region; 5) melding the needs of addressing high frequency, hour to day to week weather scale events, with the requirements of longer period monthly to seasonal to inter-annual to decadal time scales and differential nesting; 6) conducting quality assessment of data on the fly; and most importantly 7) making the case for the backbone build-out.

A fixed percentage of assets must be set aside for expansion of the array if the array is to achieve national backbone status. If but 25% of the \$138M in FY06 funds had been used for observing system equipment then at the nominal cost of a basic system, with both atmospheric and ocean state variable sensors, and with complete back-up could be modestly estimated as \$300K per site. This would have resulted in an 80% increase in the existing national coastal observing network equipment assets in one year alone. Outrageous but true! Instead of allowing the targeted institutions to build up and build out their institutional infrastructure, the U.S. Congressional ear-markers and the federal agencies, specifically NOAA, should demand that a minimum of these precious dollars be spent in the building out of the essential national coastal observing backbone.

Acknowledgements: The National Oceanic & Atmospheric Administration is acknowledged for providing support via the Climate & Weather Impacts on Society and the Environment Cooperative and the Carolinas Coastal Ocean Observing and Prediction Program via the Charleston Coastal Services Center, National Ocean Service, and the National Environmental Space and Data Information Service via the National Climatic Data Center.

