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Towards a regional coastal ocean observing system: An initial design for the Southeast Coastal Ocean Observing Regional Association

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ABSTRACT

A conceptual design for a southeast United States regional coastal ocean observing system (RCOOS) is built upon a partnership between institutions of the region and among elements of the academic, government and private sectors. This design envisions support of a broad range of applications (e.g., marine operations, natural hazards, and ecosystem-based management) through the routine operation of predictive models that utilize the system observations to ensure their validity. A distributed information management system enables information flow, and a centralized information hub serves to aggregate information regionally and distribute it as needed. A variety of observing assets are needed to satisfy model requirements. An initial distribution of assets is proposed that recognizes the physical structure and forcing in the southeast U.S. coastal ocean. *In-situ* data collection includes moorings, profilers and gliders to provide 3D, time-dependent sampling, HF radar and surface drifters for synoptic sampling of surface currents, and satellite remote sensing of surface ocean properties. Nested model systems are required to properly represent ocean conditions from the outer edge of the EEZ to the watersheds. An effective RCOOS will depend upon a vital "National Backbone" (federally supported) system of *in situ* and satellite observations, model products, and data management. This dependence highlights the needs for a clear definition of the National Backbone components and a Concept of Operations (CONOPS) that defines the roles, functions and interactions of regional and federal components of the integrated system. A preliminary CONOPS is offered for the Southeast (SE) RCOOS. Thorough system testing is advocated using a combination of application-specific and process-oriented experiments. Estimates of costs and personnel required as initial components of the SE RCOOS are included. Initial thoughts on the Research and Development program required to support the RCOOS are also outlined.

1. Introduction

The definition of the structure of the U.S. Integrated Ocean Observing System (IOOS) has been developed in large part through the actions of Ocean.US, an interagency planning office established in 2000 to advance the development of IOOS. The U.S. coastal ocean component of the IOOS is envisioned to consist of a federal network (the "National Backbone") which will provide sustained support for *in situ* and satellite remote sensing observations, predictive models, and data management elements on the national scale, augmented by regional coastal ocean observing systems (RCOOSs) (Ocean.US, 2002). Each RCOOS will be an integral component of its respective regional association (RA) of stakeholders (*viz.*, data providers and users), which in turn is

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a member of the National Federation of Regional Associations (NFRA) (Ocean.US, 2004). Through the RA, the RCOOS will be responsive to regional and local needs and augment the National Backbone accordingly. As a pioneering activity associated with the regional development of a coastal ocean observing system (COOS), the Southeast Atlantic Coastal Ocean Observing System (SEACOOS; Seim et al., 2003) has considered the scientific and technical design criteria of the operational RCOOS that will be a central element of the Southeast Coastal Ocean Observing Regional Association (SECOORA). SECOORA and its RCOOS are required to be fully interactive and interoperable with other regional associations, especially with the neighboring GCOOS for the Gulf of Mexico and MACOORA for the mid-Atlantic, as well as with the National Backbone provided by the federal agencies (Fig. 1). Discussed here are preliminary thoughts on the design of a RCOOS for SECOORA, some aspects of how this RCOOS may interact with the National Backbone, and how elements of the RCOOS will transition to certified components of IOOS.

The SEACOOS program began in 2002 and was a prototype RCOOS for the region. To establish support for IOOS the program engaged representatives from public (state and federal), academic and private sectors through a series of public workshops and through directed outreach activities (see www.seacoos.org). These outreach activities were the basis for subsequent definition of regional priorities established by SECOORA. SEACOOS conducted an initial inventory of observing activities and significantly augmented the existing observing infrastructure; established a regional data management and developed a quality assurance/quality control protocol for regional data sharing; and supported several modeling teams. The subsystems functioned in a coordinated fashion to provide a demonstration information portal for the region. However, funding for SEACOOS was not permanent and the assets it supported cannot be maintained without a new funding source. The experience of the SEACOOS program does provide a valuable perspective on how a more operational RCOOS program should be structured and is largely the basis for the views expressed herein.

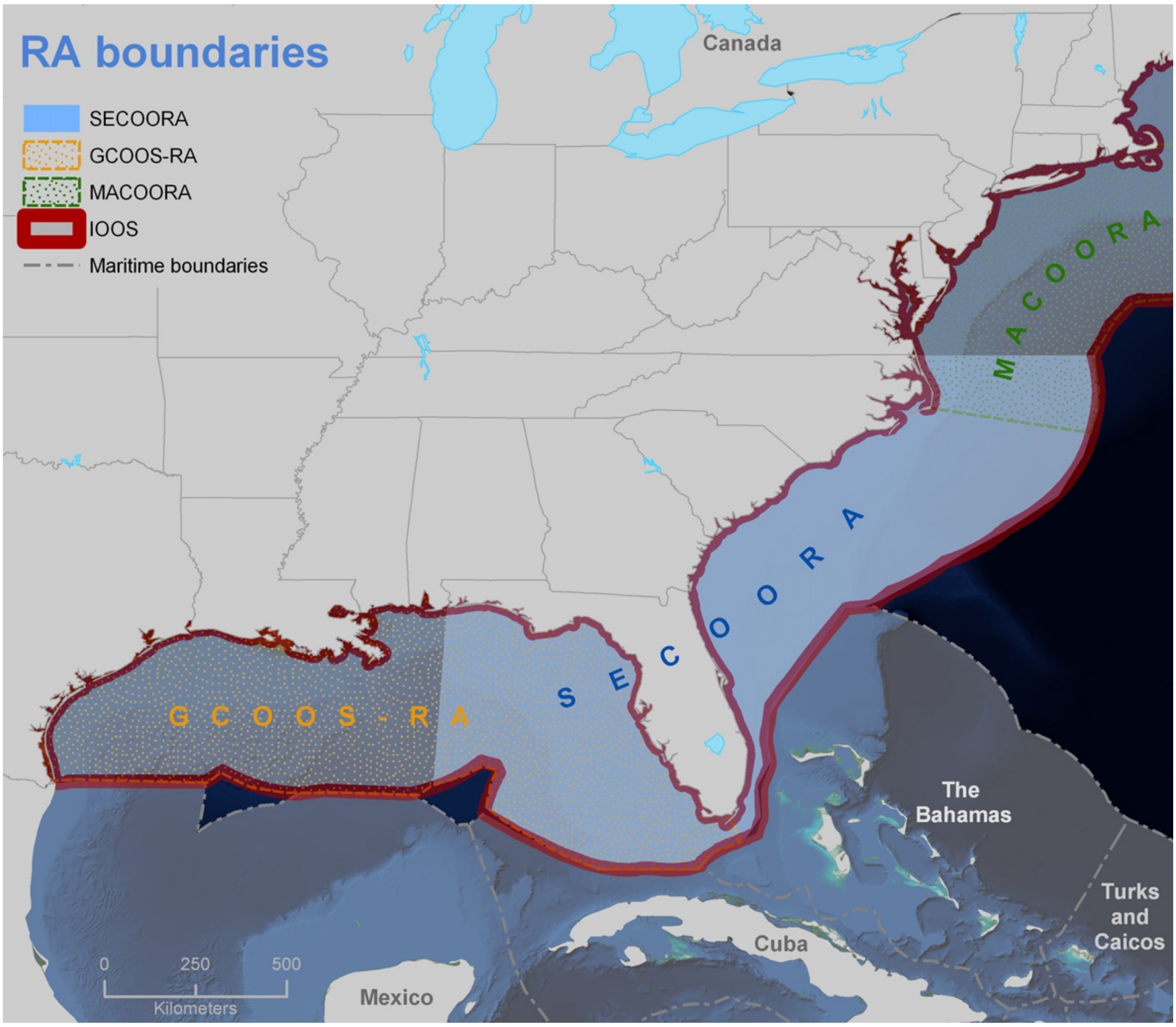

Fig. 1. Approximate boundaries of regional associations (RAs) and the coastal component of the U.S. Integrated Ocean Observing System (IOOS). CaRA does not overlap with SECOORA and is connected oceanographically through international waters.

Given the evolving nature of national IOOS planning, the SE RCOOS design proposed herein is based on a number of assumptions concerning critical RCOOS design issues.

- Federal agency (or community) plans for melding and evolving the National Backbone architecture, which is composed initially of several hundred component federal programs, will emerge so that fully credible plans for the RCOOS architecture can be developed.
- A Concept of Operations (CONOPS) will be established at the national level, which will clarify how the National Backbone will interface with the RCOOS. A number of key issues to be addressed are discussed below.
- With an established CONOPS, the balance between centralized and distributed approaches (at both the national and regional levels) in observing, modeling/prediction, and information management sub-systems can be resolved.
- The National Oceanographic and Atmospheric Administration (NOAA — principal federal agency responsible for ocean monitoring)-sponsored IOOS conceptual design effort is anticipated to provide a framework for federal agencies to resolve critical IOOS system design issues. It will then be possible to move RCOOS planning well beyond the initial design proposed here.

The intent of the RCOOS design presented here is to help advance the establishment of the U.S. IOOS, specifically with respect to one of its regional components. A key challenge for development of the IOOS is coordination between existing programs within a number of federal agencies; this process is only beginning and there is no definitive leadership specifically charged with advancing system design. Therefore the RCOOS design proposed here does not distinguish between regional and National Backbone assets, rather these are presented in terms of an initial overall design. A number of observing, modeling and information management assets presently exist in the region, but these are diverse and the stability of funding to maintain these elements varies widely. Consequently, full documentation of the existing system is complicated and beyond the scope of this paper. The intention here is rather to portray the basic set of observing system elements in the region upon which further development can build, and propose an initial system design based on consideration of the major application themes this will serve and key characteristics of the SE coastal ocean. It should also be noted that this initial RCOOS design also does not include a detailed implementation plan or an attempt to assess the potential economic benefits of the system, each of which would represent a significant undertaking requiring extensive cross-discipline engagement.

2. Anticipated functions and applications

The RCOOS component of SECOORA (SE RCOOS) will be responsible for providing reliable coastal oceanography information services for the states of North Carolina, South Carolina, Georgia, and Florida. These services are broad, complex, and sophisticated, and to provide these, the RCOOS will need to build robust partnerships among the academic, federal, state, and private sectors. The RCOOS must follow IOOS design principles, including the free exchange of data, adherence to community standards, and certification for operational status.

Many user communities, too numerous to enumerate in detail here, will benefit from enhanced RCOOS information services (see www.ocean.us and www.secoora.org). However, these can be categorized into three broad thematic application areas.

- *Marine Operations*. This includes topics of: safe and efficient ship routing, offshore oil and gas operations, fishing, and sand and gravel mining; effective search-and-rescue; efficient offshore aquaculture, waste disposal, and energy operations.
- *Coastal Hazards and Emergency Management*. This includes topics of: storm winds, precipitation, and waves; storm surge and coastal inundation; rip currents; and beach erosion and hazardous material mitigation operations (oil and toxic chemical spills).
- *Environmental and Ecological Management.* This includes topics of: ecosystem-based management of living marine resources; design and monitoring of Marine Protected Areas; detection of global change; monitoring and predicting water quality, hypoxia, and harmful algal blooms.

SECOORA has chosen to make search and rescue, coastal inundation and fisheries management its initial priority applications. Although the required space–time resolution, spatial–temporal coverage, and timeliness of information delivery vary widely between applications, information on the physical environment (wind, waves, current, temperature, salinity, sea level and turbulence) constitutes the common denominator for all of these thematic application areas. For example, for ecosystem-based fisheries management, the functioning of marine ecosystems depends upon physical habitat attributes (e.g., variability in temperature, salinity, currents, and turbulence) and the horizontal and vertical advective and turbulent transports of nutrients and organisms. This type of information is thus by design the first to be incorporated into the RCOOS, recognizing that if the RCOOS is to satisfy its full mandate, there will need to be a subsequent expansion of chemical, biological and geological observations, generation of mapped fields of natural habitats, species distributions and human activities, and further development of a range of predictive models.

A common need for most applications is predicted Lagrangian trajectories (simulated, hindcast, nowcast, and/or forecast). Examples include search-and-rescue, oil spill mitigation, and fisheries management (e.g., design of Marine Protected Areas and estimation of larval dispersal). To be accepted as reliable products, the predicted trajectories need to be accompanied by various estimates of uncertainty (“error bars”). While real-time *in situ* and satellite and coastal HF radar remote sensing are essential ingredients for coastal ocean forecasting, numerical models are necessary to provide assured spatial and temporal coverage, and for prediction capability (simulations, hindcasts, nowcasts, and forecasts).

In addition to the application themes described above, researchers and educators are not to be overlooked as important users of RCOOS information and contributors to the development process. Researchers can provide useful feedback on the RCOOS system performance and how this information advances understanding of the regional environmental and ecological systems. Using COOS products, educators can build awareness of the coastal ocean environment in the general populace, and contribute to a broader appreciation of the societal issues associated with environmental policy options.

The main goal of the RCOOS is to ensure the availability of environmental and ecological data (observed and predicted) adequate to meet the needs of the broad user community (e.g. timeliness, space–time resolution and coverage, accuracy, error metrics, variables). To achieve this goal, the principal objectives for the RCOOS are to ensure the existence and full interactions of (1) a regional network for *in situ* observations that delivers quality real-time, 3D data; (2) regional infrastructure for satellite and coast-based remote sensing data processing and utilization that delivers synoptic surface 2D fields in near real-time; (3) a coordinated network for numerical ocean prediction that delivers 3D simulations, hindcasts, nowcasts and forecasts of quantifiable accuracy; and (4) an information management system that provides rapid access and/or delivery of information to a variety of users. In the context of IOOS planning documents, each of these components would be considered "subsystems" within the overall RCOOS design. Additionally, (5) it is proposed herein that forecast, analysis, synthesis and product development centers that use output from the information management system to create value-added products should be established in coordination with existing federal facilities and private entities to ensure that COOS information is used as broadly and efficiently as possible.

Given the main goal and principal objectives outlined above, a number of the major functions for the RCOOS can be defined.

- Constitute regional infrastructure required for the timely acquisition, access, and dissemination of observational and model/predicted data and information products describing the coastal ocean and surface marine weather conditions.
- Provide technical oversight for the implementation and ongoing operations of the RCOOS subsystems, including: distributed *in situ* observations; satellite and shore-based remote sensing data acquisition and analysis; numerical modeling and prediction; and information management.
- Conduct the systems engineering analyses required for the evolution of the regional component of the IOOS "system of systems." This would include performing coastal ocean Observing System Simulation Experiments (OSSEs) to guide the design and refinement of the *in situ* observing subsystem and weigh the merits of alternative designs.
- Coordinate with the operators and managers of the National Backbone to ensure complementary operation and evolution of the national and regional observing, modeling, and information management sub-systems.
- Foster and coordinate a R&D program to assess performance and upgrade components of the prediction system, to better utilize this information in a range of applications, including detecting changes in the natural system, and to maximize the synergy between R&D and operations.
- Organize and conduct regional scale scientific observational and numerical experiments to advance understanding of natural systems, quantify the accuracy of the observing and modeling subsystems, and facilitate enhancements of the observing and modeling subsystems.
- From time-to time, perform re-analyses with upgraded models, data assimilation schemes, and observational data bases to provide best estimates of ocean fields for diagnostic studies of climate variability, coastal ocean change, and regional system dynamics;
- Support the development and growth of the regional value-added environmental information industry.
- Implement guidance received from advisory groups or committees formed by SECOORA.

The RCOOS design that follows describes each of the RCOOS subsystems, covering both the National Backbone and regional components and discussing present assets and future directions.

3. An initial design

Development of a complete system will likely take decades. What is described herein is an initial design to be implemented over a 5-year timeline that concentrates on developing a viable information system for the continental shelf region of the SECOORA domain. Thorough testing of the adequacy of the system to satisfy the needs of the chosen applications is anticipated to result in revisions after the 5 year buildout. Designing an RCOOS for the SE US that can effectively address the IOOS societal goals requires consideration of a number of factors, including the SE environmental/oceanic setting, existing capabilities, and anticipated resources. Implementation of the SE RCOOS will be an incremental process. Due to the range of temporal and spatial scales over which coastal ocean processes operate, use of both observations and models is essential for creation of a robust and multi-purpose estimation (or prediction) system. The range of applications implied by the broad societal goals for the IOOS also dictates that a "nested" strategy will be required for the allocation of resources. Some degree of subregional to local focus will also be required for the RCOOS to serve in an R&D role for the RA (e.g., conducting data assimilation experiments, and providing technology testbeds).

While the initial focus for observations in the developing RCOOS will be physical variables, this does not imply that the RCOOS will serve only as a physical oceanographic estimation system. Rather, this reflects the present state of sensor development and maintenance issues for the existing biological and chemical sensors, and recognition of the importance of physical processes for driving biogeochemical and ecological processes. As more robust, cost-effective technologies become available for measuring chemical and biological properties, these will be incorporated into the RCOOS in a coordinated, multidisciplinary manner. Given the close coupling of physical processes with biogeochemical processes in the coastal ocean, an initial physics-based RCOOS observational design will also serve interdisciplinary needs, including implementing ecosystem-based management practices in the SE coastal ocean.

Within an initial build-out plan, the majority of applications envisioned to be served by the RCOOS can provide predictive capabilities through the development of a set of models:

> *Physical state models*. These include models for circulation (3D time-varying representations of coastal ocean currents, sea level, temperature and salinity), waves

(2D representation of the surface gravity wave field and sediment transport), and the marine atmosphere (3D time-varying representation of the coastal atmosphere). Enhanced spatial resolution can be provided and/or improved through the nesting of models. The model set includes tidal and storm surge inundation models (separate or components of circulation models) capable of incorporating wetting and drying and that can accurately represent the flooding of lowlands during high-water events (e.g., hurricanes, extra-tropical cyclones).

Biogeochemical and ecosystem models. These must be coupled to circulation models for prediction of nutrient fluxes and the responses of various trophic levels to environmental variability. The existing models are complicated, have many free parameters, and require a broad spectrum of observations to calibrate and validate. It will likely require many years of R&D to develop full operational capabilities in this area.

Socio-economic models. This broad class of models would address a range of topics, including the role of humans in the coastal ocean ecosystem (e.g., changes of land and water use, changes in population distributions), how socio-economic systems may respond to manifestations of climate and global change in the coastal ocean, and the broader implications of alternate management strategies. Some simple implementations exist but development of models that interface and are eventually coupled to physical state and biogeochemical/ecosystem models will also require many years of R&D to develop full operational capabilities.

In this context, a core function for the RCOOS is to support the modeling systems through adequate observations to validate and verify and maintain model accuracy and to provide an information system that enables timely access to all information available from the region. The intent of this section is to outline major design criteria for the SE RCOOS. The preliminary RCOOS design presented below considers key oceanic characteristics of the region and the core variables required for a basic description of the physical system. This provides the rationale for an initial distribution of fixed shoreline and offshore *in situ* observational assets in the SE coastal ocean that will complement the existing elements of the National Backbone in the region. Also discussed is the important role to be played by additional observational methods in the SE RCOOS, including coastal HF radar, satellite remote sensing, profiling floats and gliders, surface drifters, support vessels and vessels of opportunity. Proposed design principles and a number of recommendations for development of modeling and information management subsystems follow. This outline represents a starting point, recognizing that development of the RCOOS will occur in concert with the evolution of the National Backbone, and with input from the broad constituent base that makes up SECOORA.

3.1. Regional characteristics

The basic design of a RCOOS for the SE US coastal ocean must take into account a number of key geographic and physical characteristics of the region that control coastal ocean processes. These include:

- The presence of a western boundary current system (the Loop Current–Florida Current–Gulf Stream) along the shelf margin throughout most of the SE states (Florida–Georgia–South Carolina–North Carolina) coastal ocean, including the influence of its meandering jet and front and the mesoscale eddies it sheds;
- A wide range of shelf widths, from <10 km to >100 km;
- Several major estuaries and coastal lagoons (e.g. in Florida: Apalachicola, Tampa Bay, Charlotte Harbor, Florida Bay, Indian Lagoon, St. Johns River; in Georgia: Altamaha River, Savannah River; in South Carolina: Broad River, St. Helena's Sound, Charleston Harbor; and in North Carolina: Cape Fear River, Albemarle–Pamlico Sound) that exchange physical and biogeochemical properties and biota with the open shelf;
- Variable input of freshwater to the coastal zone from distributed SE river (and groundwater) sources, with the additional influence of the Mississippi River on the region that create cross-shelf density gradients (e.g., Blanton et al., 1994);
- Seasonal patterns of heating and cooling that result in widely varying cross-shelf density structure which influence exchange with the deep ocean (e.g. Oey et al., 1987; Lee et al., 1991; Weisberg et al., 2005);
- The influence of synoptic weather systems, and especially major episodic storm events, including easterly waves and tropical cyclones in summertime and extra-tropical cyclones and frontal systems in wintertime, in producing turbulent mixing, coastal upwelling and downwelling, and other transient flows (e.g., Weisberg et al., 2005); and
- A highly variable diurnal and semidiurnal tide regime that is dominant in certain shallow water regimes (He and Weisberg, 2002; Blanton et al., 2004).

The coastal ocean is inherently variable in time and space, thus a central objective of the RCOOS must be estimation of the fundamental properties (state variables) that characterize the condition of the coastal ocean, and are required for forecasting its future state. Physical oceanic variables include temperature, salinity, density, sea level, pressure and velocity. Atmospheric variables include surface winds, surface heat and moisture fluxes, and sea level barometric pressure. Necessary boundary conditions for characterizing and forecasting the physical state of the coastal ocean also require estimates of net surface heat flux (measurements of short- and long-wave surface radiation, air and surface sea temperature, and relative humidity) and freshwater fluxes (evaporation, precipitation, river discharge, and groundwater discharge in some areas).

3.2. The observing subsystem

Since ocean processes are three-dimensional, time-dependent, and occur on many space–time scales, no single measurement system (*in situ* or remote) will be sufficient for describing any of the ocean state variables. A “multi-platform, multi-variable” observational approach is required, integrated with models (including data assimilation approaches). Furthermore, the fundamental value of continuous time series data should be recognized in the design process, such that real-time telemetry systems are backed up with internal recording of data, and delayed-mode and historical data are also integrated into the regional data management structure.

The following sections describe the existing observing system and proposed observing system broken out by observing platform. The inventory of existing assets indicates a wide range of observing activities shoreward of the coastline in estuarine waters; because of this little augmentation is proposed. On the continental shelf there is a relatively sparse set of observing assets; the federally-funded program provides some measure of atmospheric and ocean surface properties but provide no subsurface observations except for some experimental current profilers. Regional and subregional programs like SEACOOS have effectively doubled the number of observing platforms on the continental shelf and provide the only near real-time subsurface observations. As examples of the impact made by the regional programs, SEACOOS HF radar provide surface currents over more than 20,000 km^2 where no other observations exist, and regional buoys and moorings increase the number of locations where bottom temperature is monitored from zero to fifteen. Because the only sustained observing elements in the coastal ocean are the federally-operated assets, the proposed observing system design focuses on implementing consistent regional coverage to provide reliable information on physical ocean state that can also be used to assess the accuracy of coastal ocean models.

3.2.1. Coastal stations

Existing federally operated coastal stations, largely established by NOAA (in particular the National Water Level Observation Network of the National Ocean Service and the Coastal Monitoring Automated Network of the National Weather Service), US Geological Survey, National Park Service, and US Army Corps of Engineers are geared primarily to sea level and coastal meteorology. Within Florida the Water Management Districts also support a large number of water level gages. The distribution of stations that are tidally-influenced (Fig. 2) indicates that these stations provide a solid foundation for further development of shore stations by the RCOOS, which should be approached in coordination/partnership with federal agencies and state and local coastal management and emergency response agencies. At present three areas in Florida are heavily instrumented, the St. Johns River/Jacksonville area in the NE of the state, the Everglades in the south, and the Tampa Bay area on the west coast.

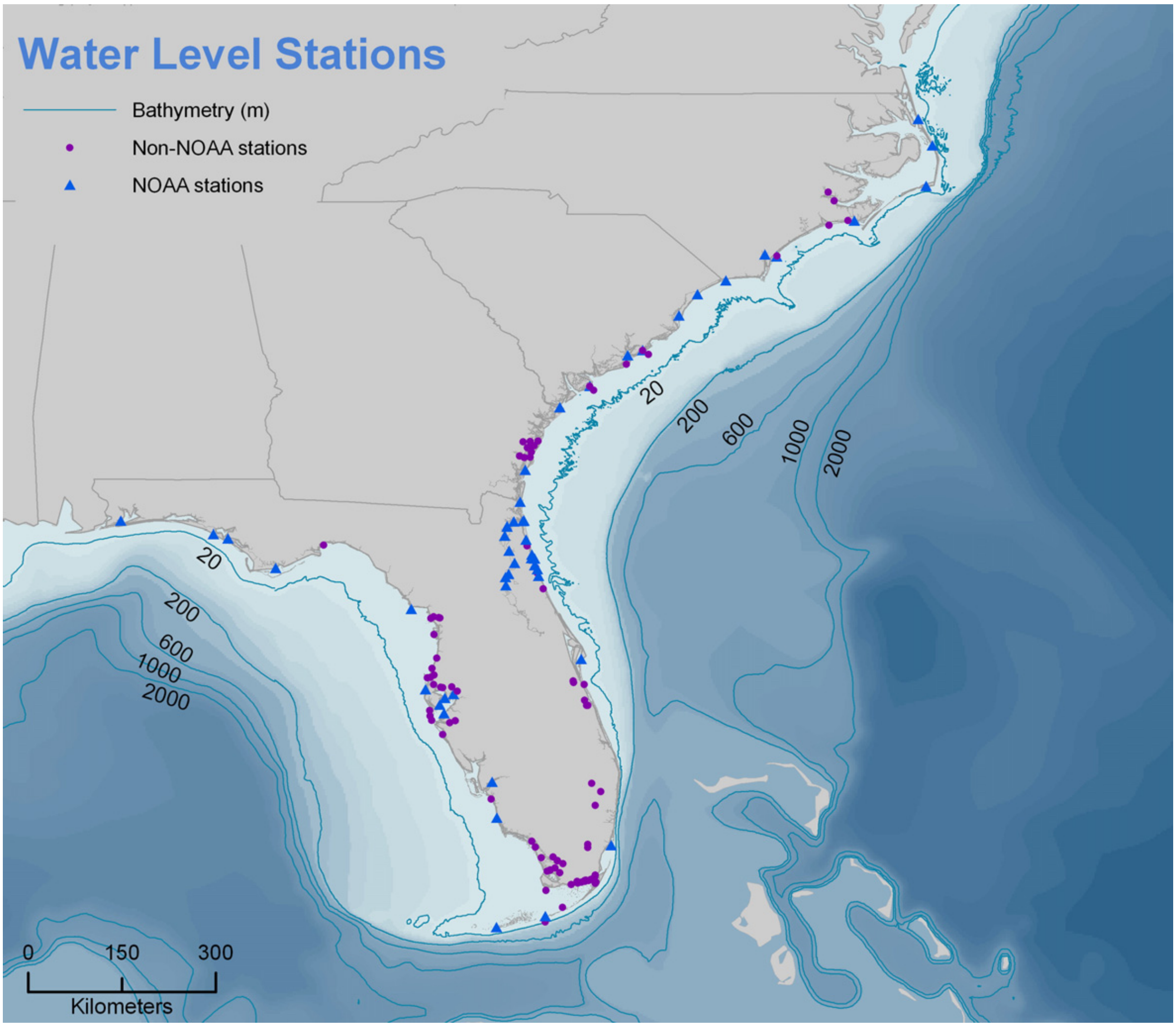

Fig. 2. Distribution of existing water level observation stations that are tidally influenced.

Noticeable gaps in coverage exist along the east coast of Florida and in the Big Bend of NW Florida. Augmentation of water level stations in these locations and at commercial ports is warranted, since even small changes in water depth can impact the efficiency and safety of deep-draft vessel operations. Ten additional water level station should be sufficient to fill the existing major gaps. Further regional partnering with the NOAA Physical Oceanographic Real-Time System (PORTS) program could be an effective approach in the ports. In terms of spatial coverage, there is a need for sufficient coastal water level stations to assess the predictive skill of both (1) high-resolution coastal inundation models, and (2) lower resolution coastal ocean circulation models. For coastal inundation/storm surge applications, there is a practical need to "oversample" sea level, since many stations are subject to failure of instruments or communications during major storm events.

3.2.2. Fixed moorings

As noted above, the SECOORA domain includes regions with very narrow shelves (near DeSoto Canyon, the SE Florida shelf from Key West to West Palm Beach, and near Cape Hatteras) and broad, gently sloping shelves (off West Florida and in the central South Atlantic Bight). Obviously the deployment of observational assets will have to take this variability in shelf width and coastal ocean properties into account. For the broader shelf sub-regions, three basic subdomains can be defined (Atkinson et al., 1983; Lee et al., 1989; Weisberg et al., 2005):

- A baroclinic outer shelf/slope zone where the physical state is directly influenced by the boundary current (Loop Current/Florida Current/Gulf Stream) to within a distance equal to the baroclinic Rossby radius of deformation;
- An inner shelf/coastal zone where the water column is shallow enough that there is interaction between surface and bottom Ekman layers (either by overlap or by divergence) and wind, wave, and tide forcing are significant; in many locations, there is also a near shore zone in which the influence of relatively fresh estuarine outflows leads to additional buoyancy-driven flows;

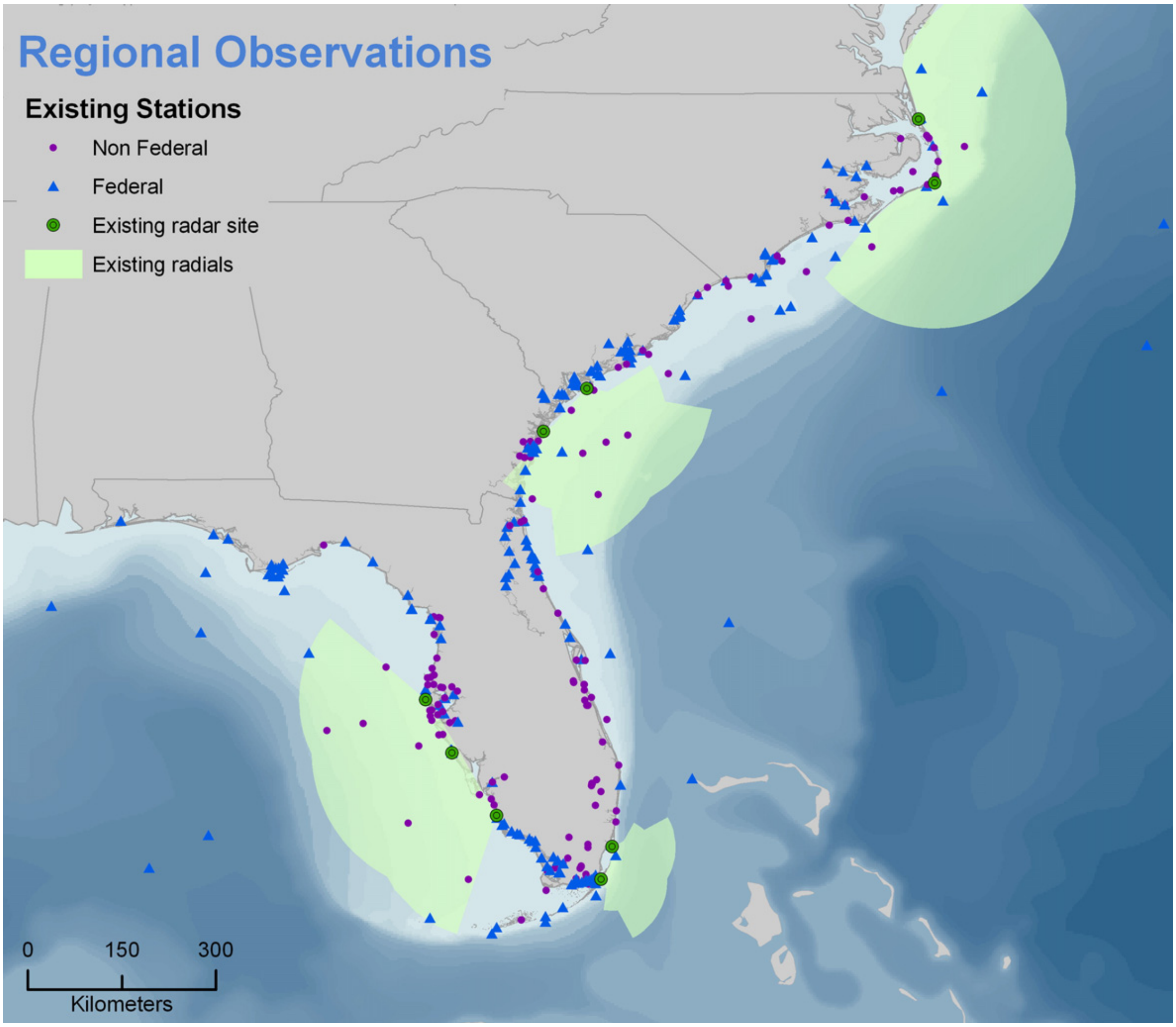

Fig. 3. Depiction of the existing observing subsystem showing coastal stations, buoys, and radar coverage. Note that all radar sites are non-federal. Not shown are additional measurement sites that do not include real time telemetry.

- An intermediate/mid-shelf zone (if the shelf is wide enough to separate the inner and outer portions) where circulation is largely forced by winds and tides.

Existing shelf observation platforms include the buoys and coastal stations of the National Data Buoy Center (NDBC) and a collection of academically-supported subregional systems off the west coast of Florida, off Georgia, and off the Carolinas (Fig. 3). The types of sensors each platform supports varies but in general the NDBC buoys emphasize meteorological instrumentation and currently provide limited ocean measurements. Coverage of oceanic variables is very sparse with the possible exception of near-surface temperature.

Based on the above considerations of the ocean physics, a regular array of moored or fixed platform offshore observing elements distributed over the SECOORA domain is advanced (Fig. 4). A detailed description of possible platform and instrument configurations is beyond the scope of this discussion. Here the focus is on an initial distribution of these assets on the continental shelf and a set of core variables to be measured. The proposed initial array consists of a series of cross-shelf deployments, at roughly 150 km spacing in the along-shelf direction, and linked, to the extent possible, to seaports, major topographic anomalies, and other special features. The along-shelf spacing is needed to resolve variability in the circulation; many features of coastal circulation in the SE occur at this scale or smaller (e.g. Florida Current and Gulf Stream meanders; Lee and Mayer, 1977; Brooks and Bane, 1983; Lee et al., 1991; Shay et al., 1995, 1998; Peters et al., 2002). For all but the narrowest shelves, each cross-shelf section would have three measurement sites, supplemented in the near-shore with additional deployments at major locations of estuarine outflow or population centers. The core set of instrumented buoys or platforms should all be equipped for measurements of temperature and salinity at multiple depths, current profiles, wind, and some should be equipped to determine directional waves and net surface heat flux. Given the ten existing NDBC buoys there is a need for an additional 50 moorings under this scenario.

Full water column measurements of current, temperature and salinity in each of the three coastal ocean regimes defined above are necessary to specify the flow and hydrographic

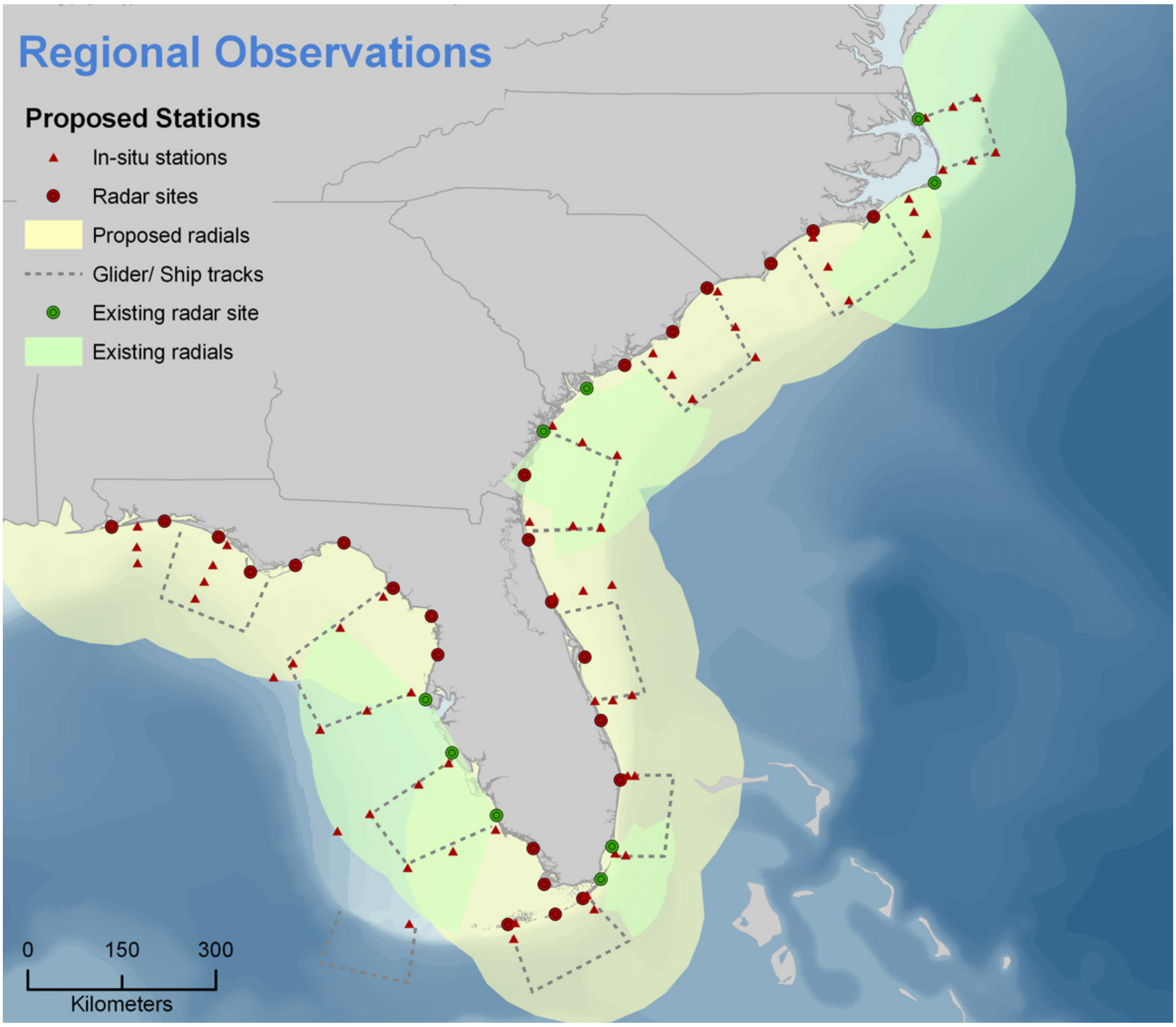

Fig. 4. Proposed observing subsystem asset distribution to provide region-wide coverage on the continental shelf from HF radar, *in-situ* moorings and glider or ship transects. Note: these transects are for discussion purposes only. Local phenomenology will lead to finer tuning of the RCOOS array.

(temperature, salinity, and density) fields. The surface and bottom Ekman layers warrant particular attention given their roles in cross-isobath exchange (Lee et al., 1991; Weisberg and He, 2003). Full water column measurements are also required to assess key processes, including boundary current interactions on the shelf-slope, exchange at the shelf break between the coastal ocean and the deep ocean, coastal responses to local wind forcing, transport of organisms by internal tides, and direct estuarine interactions with the coastal ocean.

Another essential observation throughout the coastal ocean domain is surface winds. Due to the complication of land–sea interactions, the quality of numerical weather predictions over the coastal ocean can often be compromised (He et al., 2004). Most *in situ* moorings or platforms should therefore be equipped with surface wind and barometric pressure sensors. The complete suite of sensors required for heat flux estimates (incoming short- and long-wave radiation, air and sea temperatures, relative humidity) should be supported at a distributed subset of the offshore sites.

Other ancillary measurements are recommended (although not required at all sites), the foremost among these being surface waves. Directional wave spectrum measurements at the shelfbreak can provide the boundary conditions needed for coastal ocean wave models (O'Reilly and Guza, 1998), and wave measurements nearshore can be used both to gauge the performance of these models and provide real-time data of immediate societal importance. Provisions for incorporation of additional chemical, geological and biological sensors, as these evolve, should also be included in the design of instrument, power, and communications packages.

Not addressed in this initial mooring design is an observation program for the slope and deep-water regions of the domain. The presence of the western boundary current makes these areas particularly challenging environments in which to maintain conventional moorings. Coordination with the National Backbone will be critical to deploying and maintaining an adequate array of slope and deep-water moorings and a leading role for NDBC and associated federal agencies in establishing this portion of the regional network will be strongly encouraged by SECOORA. Other possible observing technologies include cable-based transport estimates and inverted echo sounders.

Additional moored and fixed platform *in situ* assets (not represented here nor budgeted for below) will likely be positioned in areas of regional and local interest (e.g., major ports and shipping lanes, inshore areas subject to shoreline erosion and rip currents, and Marine Protected Areas) and supported through local initiatives. Measured variables at these sites will necessarily be tailored to the local applications (e.g., directional waves, wind, and nearshore currents). There may also be a need for strategic (or "targeted") observational arrays in critical locales to support the requirements of data assimilation. It is recognized that the RCOOS should provide some discretion in the organization of observational resources to serve local needs, and to best exploit available resources and infrastructure, including those supported by the National Backbone and state and local agencies.

3.2.3. Coastal high frequency (HF) radar

Coastal HF radar mapping of surface currents provides one of the more important of the potential RCOOS measurement systems, offering a field of surface velocity vectors as opposed to the point measurements typical of fixed offshore assets (Paduan et al., 2004). Two commercially available systems are operated in the SECOORA domain by academic institutions, CODAR and WERA, each offering varying range and resolution based on frequency and bandwidth (Fig. 3). There are presently no HF radar installations operated by federal agencies. HF radar is a topic area where the RCOOS can play an important role in technology assessment. Given the wide range of shelf widths off the SE U.S. and the rather unique oceanic configuration of a western boundary current on the continental slope, careful assessment of options to provide HF radar coverage over the entire region is advisable. Regional coverage using long-range systems is critical to achieve because of their ability to discern the position of the boundary current and its influence on the shelf and is a necessary first stage of development (Fig. 4). In addition to surface currents, continued evaluation of other potential products from HF radar (such as a spatial grid of directional wave estimates from WERA — Wyatt et al., 2005) should be pursued. Deploying HF radar on islands or offshore platforms and transmitting shoreward should also be tested as a means to provide nearshore surface current coverage that is otherwise difficult to obtain, especially for convex coastlines. Assuming the existing radar systems will continue to be operated, an additional 30 installations are needed to provide region-wide coverage.

3.2.4. Satellite remote sensing

While not an asset class to be deployed, operated or controlled by the RCOOS, satellite remote sensing represents a critical resource for coastal ocean applications. Sea surface temperature, surface ocean color products (including upper layer chlorophyll and suspended materials), sea surface height, surface winds and other products from passive and active satellite sensor systems are routinely available. Such satellite information is being used for assimilation into models and for descriptive purposes. While the satellite programs themselves would not be an RCOOS function, RCOOS support for utilization of satellite data and production of enhanced products, tuned and/or calibrated to regional applications, will provide strong justification for continued federal agency support of satellite missions targeting the coastal ocean. In the SE coastal ocean, applications of passive satellite imagery could include detection of near-surface phytoplankton blooms (some of which may be harmful algal bloom species), identifying and tracking waters of riverine origin and episodic cross-shelf transport, and detection of sediment resuspension events. An RCOOS role in the support of regional capabilities for downloading, processing, and distributing satellite data, as well as for analysis products and presentation tools, will be critical for effective integration of the satellite information with *in situ* observations and application in regional modeling programs.

3.2.5. Profilers and gliders

The conventional method for observing 3D fields of temperature, salinity, and other properties (such as chlorophyll and nutrients) is by ship survey. This approach is, however, slow (and often non-synoptic) and costly. At present there are no regularly scheduled spatial surveys occurring on the continental shelf in the SECOORA domain. Needed are techniques for synoptic mapping at intervals sufficient for assimilation into models, particularly for the internal density (T/S) field. Through a combination of profiling floats, moored profilers, autonomous underwater vehicles (AUVs), and gliders it should be possible to obtain regular (i.e., routine, standardized, and sustained) mapping of the vertical and horizontal T/S structure, as well as that of other variables with the addition of appropriate sensors. Several systems are presently being assessed in field trials in the SE. It is envisioned that an appropriate mix of platforms would be used to occupy offshore transects that align roughly with the mooring lines (Fig. 4). Ten operation areas are envisioned, each with a offshore leg that in most cases will be sampled while moving with the western boundary current.

3.2.6. Ship transects

Since robust, accurate, automated biogeochemical sensors will likely not be available near-term, it will be necessary to include some repeated shipboard surveys of biogeochemical variables and biota. Such surveys should be designed to optimize synergy with the deployed observational elements and real-time prediction systems, and take into account what is known of natural variability in the coastal ocean. There may also be a role here for airborne surveys equipped with remote sensors, expendable profilers, and other air-deployable systems.

3.2.7. Voluntary observing ships

With the large volume of commercial shipping and recreational boating activity in the SE, it may be possible to obtain additional valuable regional coverage by installing automated instrumentation packages on a voluntary basis, as has been done in the International SeaKeepers program on a global scale on private vessels (www.seakeepers.org) and on commercial vessels such as the *Explorer of the Seas* cruise liner (Williams et al., 2002; Wanninkhof et al., 2007). On the more local scale, the FerryMon project in North Carolina (Ensign and Paerl, 2006) has made use of an inshore ferry as a monitoring platform.

3.2.8. Surface drifters

Satellite-tracked surface drifters provide a quasi-Lagrangian view of surface circulation and, with caveats regarding their performance relative to Lagrangian trajectories (not necessarily surface-confined), provide excellent tools for surface trajectory analyses. Drifters are essential for establishing the error attributes of predicted trajectories; conversely, they are invaluable for estimating the dispersive properties of varying coastal ocean circulation regimes. Nearshore deployments can be useful for filling data gaps in coastal HF radar coverage, and for examining connectivity between adjacent estuaries and sources of fresh water along many sections of the SECOORA domain. A regular program of drifter releases on the shelf that complements existing drifter programs in deep water should be initiated. Release of drifters from various locations in the domain is suggested, using 150 drifters per year (e.g. monthly releases at a dozen locations). Deep water examples are the collation of drift tracks by the Atlantic Oceanographic and Meteorological Laboratory, NOAA and those tracks made available by Horizon Marine, Inc in the Gulf of Mexico. Coordination with the US Coast Guard, the marine services industry and NOAA will maximize coverage.

3.2.9. Additional general recommendations for the observing subsystem

The preceding view of the elements needed to provide reasonably comprehensive coverage, and enable thorough testing of the observing system, does not consider the large number of organizations that can contribute instrumentation. To address this concern, a number of general recommendations regarding the observing subsystem are made to SECOORA.

- Coordinate with elements of the National Backbone on the location of additional federal observing assets, in particular for shelf break/slope and deep-water sites offshore, and in the areas of major ports inshore.
- Continue the dialog with NDBC, and develop a dialog with other contributors (e.g., NOAA CO-OPS) to the National Backbone, on regional priorities for enhancements of sensor suites on existing *in situ* fixed and moving platforms.
- Coordinate with the National Backbone entities to secure the core support required to sustain the *in situ* observing component of the RCOOS. Critical elements include ship time for deploying and servicing offshore systems and regional calibration centers for at least the basic suite of meteorological and oceanographic sensors.
- Promote robust regional capabilities in satellite remote sensing, including capabilities for near real-time data acquisition, processing and distribution, and help coordinate development and validation of regionally “tuned” satellite remote sensing products.
- With guidance from Ocean.US, ensure that the contributors to the RCOOS meet national standards for data quality and performance;
- To enhance the efficiency of SE observational activities, exchange of information (within the RA and nationally/ internationally) on sensors, supporting infrastructure (e.g., power, telecommunications, deployment hardware), and operational procedures should be supported (e.g., meetings of technical and engineering personnel; web-based forums).
- Promote new observing system technology (e.g., autonomous vertical profilers, nutrient sensors or shallow water acoustic tomography), and as part of the RCOOS R&D effort, support regional testbeds to critically evaluate observational technologies, and pilot studies that target specific applications for RCOOS information.

3.3. The modeling subsystem

At present there are no regional scale coastal ocean circulation, storm surge or surface gravity wave modeling activities that enjoy sustained support; the modeling efforts that are sustained are those that occur on a national or ocean basin scale. An example of the circulation models available is the Hybrid Coordinate Ocean Model (HYCOM, Chassignet et al., 2007). Though an impressive depiction of the basin-scale ocean, the existing implementation is limited to water depths greater than 15 m (and hence does not represent nearshore or inland waters at all), does not include tidal forcing and provides only a daily output. These types of basin-scale models are vital because they can provide boundary conditions for coastal models but there is an obvious need for regional-scale modeling efforts. The SEACOOS program included three subregional modeling efforts that advanced the understanding of requirements for routine modeling and are the basis for the design principles below.

Given the present state of development of regional-scale modeling systems for the SE coastal ocean, it is proposed that the initial focus be on creating, testing and operationalizing model systems to predict the physical state of the coastal ocean. The three ocean components to be emphasized are circulation modeling, storm surge modeling, and surface gravity wave modeling. There is also a need for regional-scale atmospheric modeling to better incorporate coastal ocean–atmosphere interactions. In all cases, adequate resolution to address specific applications is to be achieved through nesting regional or subregional scale models within national modeling systems. How best to achieve adequate resolution will need to be determined through thorough testing, but at a minimum there should be some redundancy in effort. It is suggested that several modeling groups in each of the modeling component areas be supported initially.

Based on the experiences gained through SEACOOS of operating three subregional-scale circulation models to nowcast coastal ocean conditions, a series of design principles are suggested.

- The importance of simulation experiments (e.g. OSSEs) to aid with the evolving design of the RCOOS should be recognized (e.g. Lynch et al., 2004). These will also contribute to the overall systems engineering approach for the RCOOS design.
- The diversity of the model/prediction subsystem should be embraced. No one model is sufficient for the range of desired applications and this diversity provides the potential for ensemble forecasting.
- A hierarchical, distributed approach to operational modeling/prediction sub-systems should be followed. For example, Global-NCOM and Atlantic-HYCOM models can be subsampled for regional-scale circulation estimation products (Mooers et al.; 2005; Aretxabaleta et al., 2007; Barth et al., 2008). Similarly, even higher-resolution local-scale models can use output from subregional models for open boundary conditions (Weisberg and Zheng, 2006a).
- The RCOOS design should foster the further evolution of modeling/prediction sub-systems. This would include: accommodation of the nesting of very high-resolution inner shelf and estuarine/lagoonal models (e.g. Weisberg et al., submitted for publication); the coupling of dynamical models (coastal mesoscale meteorological, coastal hydrological, and coastal wave models); the coupling of (one-way, embedded) application models (e.g., ecosystem, sediment transport, and wave models); and the utilization of advanced numerical modeling methods (e.g., data assimilation schemes, non-hydrostatic models, and unstructured and adaptive grids).
- The RCOOS modeling program must encompass both comprehensive baroclinic operational circulation models (essential for advective and turbulent transport estimates, water quality and ecosystem models) and integrated barotropic operational tide (He and Weisberg, 2002; Blanton et al., 2004), storm surge (Weisberg and Zheng, 2006b), and wave models (essential for coastal inundation estimates, sediment transport models).
- Output from subregional model/prediction sub-systems (together with in situ and satellite remote sensing observations) should be directed to sub-regional marine forecast centers. These should be operated in a partnership fashion with the NWS Weather Forecast Offices, value-added industry, media, and academia.

The models needed to predict the physical state of the coastal ocean have information requirements beyond the observations already identified. Access to accurate measures of freshwater fluxes (from rivers, precipitation and groundwater) is needed for the circulation models to accurately represent the mass field. For storm surge modeling, high resolution bottom and coastal topography is required, registered to appropriate datums and with sufficient spatial resolution to support local emergency management needs. High resolution bottom topography in the surf zone and nearshore is needed for surface gravity wave models to accurately represent modifications of the wave field near the coastline. Where existing information is lacking (e.g. poor quality bottom topography) the RCOOS can advocate for improvements.

3.4. The information management subsystem

Information Management (IM) is fundamental to the operation of the RCOOS. Establishing a network of local-to-regional-to-national-to-global IM systems will enable the collection, aggregation, accessing, utilization, archival, and dissemination of coastal ocean data and information products. This has been an area of emphasis in Ocean.US IOOS planning. To advance the IOOS Data Management and Communications (DMAC) Subsystem, it will be necessary to establish a coordinated and cooperative network among the various regional systems and the users of IOOS products. New capacities will be needed to establish this network and ensure its functionality at a range of temporal and spatial scales. The IOOS DMAC is envisioned to comprise the following components (described in the first IOOS Development Plan, Ocean.US, 2006).

- *Metadata* — These data describe data sets for the national system, including development and use of a common vocabulary, identification of required metadata fields, agreement upon sites for publication of metadata, and commitment to publish metadata in a timely fashion.
- *Data Discovery* — The capacity for searching and locating desired data sets and products and for manipulating accessed data must be established.
- *Data Transport* — Data and products must be capable of transport over the Internet in a transparent, interoperable manner.
- *On-Line Browse* — Data must be readily accessed and evaluated through common Web browsers.
- *Data Archive* — Mechanisms for secure, short-term and long-term data storage must be established.
- *Data Communications* — The communications infrastructure for accessing and transporting data and data products must be identified and maintained to meet standards.

Regional and subregional observing systems in the SECOORA region have established a number of the necessary components described by IOOS DMAC. Where the capability for addressing specific requirements does not yet exist, progress has been made in identifying and characterizing those needs, with a view towards "filling the gaps." In general, efforts focused primarily in SEACOOS, with support from the Carolinas Coastal Ocean Observing and Prediction System (Caro-COOPS), have established a system that enables the aggregation, access, and dissemination of real-time and delayed-mode data from *in situ* observations, model output, and remotely sensed imagery. This aggregation and subsequent visualization of distributed data requires development of a process that can be utilized by other regional and subregional systems, and can help the community push towards interoperability. The steps being taken to establish this system of aggregated data include:

- Inventory of existing and potential data types;
- Identification of standard data ontologies, file formats, and transport protocols;
- Software for data applications and for interfacing different applications; e.g., Web mapping;
- Database schemas for the variety of data types.

Experience has shown that an effective approach towards a regional IM system is to engage distributed information providers through standards that promote interoperability. This type of construct has been commonly termed a "service-oriented architecture." Each of the observation and model data providers should be required to adhere to a set of standards and practices that enable information exchange among and between all of the partners. There is also a need to have a central aggregation site or hub that is a clearing house for standards and that maintains a database of the aggregated information and/or links to data sources. This central hub need not be physically located in a single location but does require a single presence on the Internet. Given the volume of information involved and the vulnerabilities related to natural and other hazards, it is strongly recommended that at least two physical locations be established that can support the central site activities. Two sites would enable a minimum level of redundancy and fail-over capability in case of interruptions in services.

Thus the design recommendations are that SECOORA should:

- Establish a regional "hub" for RCOOS IM that provides coordination, guidance, and centralized data aggregation, distribution, and storage functions;
- Maintain and strengthen distributed foci of IM expertise at the major observational and modeling sub-system locations. This step will provide in-house management of data, assurance of implementation of standards, and technical support, with assistance from the central hub;
- Establish one or two back-up sites to provide redundancy and ensure continuous operations in case of infrastructure failures at the central hub;
- Establish an agreement with a NOAA archive(s) (e.g., National Ocean Data Center or National Climatic Data Center) for long-term security and archival of observational and model data. Separate regional archives are needed for more "specialized" or region-specific data products (e.g., data aggregations, high-resolution model outputs);
- Identify robust satellite telemetry system(s) for transmission of real-time data, and establish or secure the necessary land-based connectivity and bandwidth for information dissemination;
- Identify appropriate standards with respect to common vocabulary, metadata format and content, metadata publishing protocol, data formats, and transport protocols; and
- Establish a portal that serves as a single site for accessing regional IOOS observational data and model/prediction products, as well as links to other user-targeted portals that utilize/provide specialized treatments of regional data.

3.5. Forecast analysis, synthesis and product development (FASPD) centers

It is critical that the RCOOS conduct an ongoing assessment of the robustness, utility and efficiency of the observing system. One possible mechanism to accomplish this objective is to initiate a set of functional centers whose mission is to utilize the information flow from the information management subsystem to develop higher level products. These activities may be best accomplished by virtual entities, drawing on expertise from across the region and engaging all sectors, including the system operators, in an assessment of the RCOOS. A variety of efforts can be envisioned. One which provides a strong connection to existing hazards awareness would be forecast centers, involved in the analysis of *in situ* and satellite remote sensing data and model output to make synoptic maps to address sub-regional scale events (e.g., harmful algal blooms, oil spills, anomalous freshwater discharge events, hypoxia). The NWS Weather Forecasting Offices, value-added industry, media, and academia should be partners in these centers where, through interactions with various user communities, valuable experience can be gained for the iterative design of the RCOOS. Establishing regional FASPD centers could play an important role in the development of application-specific products, including ongoing analyses of the function of the RCOOS, as well as analyses of coastal ocean processes.

3.6. A concept of operations (CONOPS) for SE RCOOS

Roles and responsibilities of the RCOOS must be defined with respect to those of the federal entities of the National Backbone, relevant state and local agency activities (such as coastal emergency management) and private industry. While much of the formal development of such a CONOPS will take place at the national level and over a period of time, the RCOOS will need to be engaged in this process. There are a number of questions to be addressed, including: How much redundancy will be required to meet standards for robustness and resilience? Who will perform forecaster functions? Will there be collocation of personnel?

A reasonable option is that the SE RCOOS should be operated as a non-profit operational subsidiary of SECOORA that can contract for needed functions and operate in a distributed fashion. An effective interface with federal operational entities identified as part of the National Backbone must be developed. It is critical to ensure that the RCOOS complements federal and state agency and the valued-added environmental prediction companies in collecting observations, operating models, distributing data products and issuing environmental forecasts and warnings. Utilizing federal agency assets to support the more logistically challenging components of the system (e.g. deepwater moorings, basin-scale modeling, national and international IM coordination) would be a reasonable guiding principle for defining roles and responsibilities in areas of overlapping interest. The RCOOS has a natural role in providing stewardship for the regional system by continually assessing its utility and efficacy in addressing regional needs. Mechanisms must be further developed to deliver RCOOS observations and forecast products through appropriate channels (e.g. the Marine Forecasters of the National Weather Service/NOAA), and make them freely available. With effective engagement, the RCOOS could play an important role in the evolution of the National Backbone, with the RCOOS providing credible assessments of system elements and developing and testing innovations. Another important role for the RCOOS will be to provide quantitative environmental and ecological information based on the analysis of observations and models. Through these functions, the SE RCOOS will become a major regional asset for the environmental and ecological stewardship of the SE coastal ocean.

The typical flow of information anticipated within the RCOOS is shown in Fig. 5. Regional data providers, either observers or models, make data available by adhering to accepted standard and protocols. The regional information management hub then accesses regional data, augments it with data available nationally or internationally, and aggregates information on a variable-by-variable basis for the region, making it broadly available. The FASPD centers enable a variety of additional output products, including data feeds and applications in support of specific missions and synthesized products (e.g. ocean weather maps, climatological fields) in support of the range of users of the information system. Feedback from users must be enabled throughout so that refinements to the system occur in a timely fashion.

4. Implementation strategy

A rough estimate of the elements of an initial regional observing system that will provide regional physical state prediction has been outlined. It is used below to develop a potential budget. However, it is vital to recognize that a thorough testing and evaluation of the system is needed to establish its accuracy for a variety of applications and to refine its design. Two foci should be employed in the testing: with respect to specific applications (e.g. search and rescue, harmful algae blooms) and with respect to specific processes known to play important roles in the regional oceanography. A scientific advisory committee could be utilized to enumerate the critical processes that shape the coastal ocean. Obvious circulation processes that must be resolved include the tides, wind-driven circulation, fresh-water driven buoyant flows and shelf-slope exchange. Pilot programs that test the capabilities of the RCOOS to address specific applications and resolve specific processes can then be defined. The pilot programs should engage appropriate stakeholders to ensure relevance of the products being developed and the science community to ensure fidelity of the observing system. The outcome of the pilot programs should be application-specific products with requirements for observed and modeled data and dataflow that can be the basis for sustained product delivery and served as milestones for successful implementation.

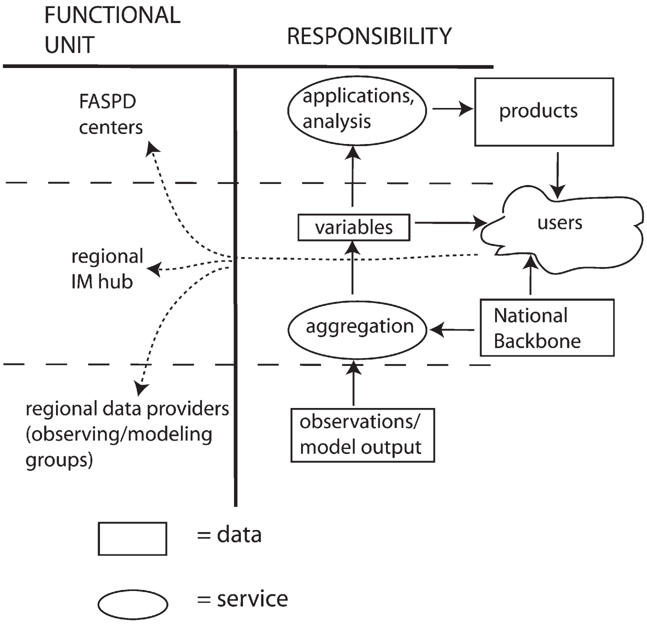

Fig. 5. A depiction of information flow through the various functional units of the RCOOS and the responsibilities of each unit. Users can access information at various levels of synthesis and provide essential feedback on usefulness of the information to all functional units (shown by short dashed line).

5. An initial RCOOS budget

Within a 5 year implementation, the initial system may be most easily created by taking advantage of the R&D components already in place through the efforts of academic institutions. However, these need to move to a more sustainable and operational setting. Rough costs for developing the system are considered below. It is important to note that the budget includes support for all elements that are not currently federal agency assets. In particular, the budget assumes that existing academic R&D infrastructure will not become part of the initial RCOOS. One of the greatest uncertainties in developing the cost of the RCOOS is defining which assets will be the responsibility of the RCOOS and which assets will be the responsibility of the National Backbone, an aspect of the CONOPS discussed above. Of particular concern is the lack of a clearly defined process for deciding how the responsibility for new assets will be allocated. Given this situation, the total cost for growing the system to an initial state of operations is considered here without attempting to identify which entity will bear the responsibility and cost for the assets. It is reasonable to assume the expense will be borne in part by the RCOOS and in part by the National Backbone. The budget has two main categories: an initial infrastructure investment cost and an annual recurring cost. Both are envisioned to apply over a

Table 1
Observing subsystem permanent equipment and recurring costs (in thousands).

Cost type	Details	Unit cost	# units	Equipment	Recurring
Personnel	Buoy — 1 staff/3 buoys	$100/year	20		$2000
	Radar 1 staff/4 radar	$100/year	7.5		$750
	Coastal — 1 staff/5 stations	$100/year	2		$200
	Glider — 1 staff/2gliders	$100/year	6		$600
Equipment	Buoys	$200	50	$10,000	
	Radar	$200	30	$6000	
	Coastal stations	$80	10	$800	
	Gliders	$100	12	$1200	
Supplies	Surface drifters	$2	150		$300
	Supplies/repairs/spares (20% of equip total; 5 year amortization)				$3500
Ship time	Bi-monthly buoy service — 3 days/line, 20 lines, 6 times/year	$7.5/day	360		$2700
Subtotal				$18,000	$9050

5 year period. Supply/travel/repair/spares are anticipated to be approximately 20% of capital costs.

5.1. Operating budget — (exclusive of research and development)

5.1.1. Observing subsystem

Given an approximate along-shelf scale of variability of 150 km and at least three distinct oceanic regimes in the cross-shore, the initial observing subsystem should be composed of roughly 20 cross-shelf lines occupied with fixed and mobile assets. For fixed platforms, these numbers equate to 60 shelf and slope buoys and a number of mobile surveying platforms. Given the 10 existing NDBC buoys in the region, the budget includes the purchase of 50 buoys, hosting instrumentation as described in Section 3.2.2. It is important that all buoys measure winds, currents and temperature and salinity at multiple depths at a minimum. Some fraction of the buoys should also be test platforms for optical, chemical and geological measurements. It is assumed that gliders will be used for spatial surveying, and that each glider will cover three-to-four lines. Allowing for two gliders per set of lines (rotating units between deployment and on-shore servicing) gives a total of a dozen gliders. Glider operations are envisioned to develop over time as they become more proven technology, and are simply an example of autonomous mobile observing that SECOORA should support. Shore station coverage is reasonably uniform with the exceptions noted in Section 3.2.1, hence, 10 additional shore stations are budgeted to fill in obvious gaps. Region-wide coverage with long-range radar will require approximately 30 long-range radars. Permanent observing equipment costs are estimated in Table 1 and total $18 million. The greatest single cost is associated with the buoys.

The estimated personnel requirements to maintain the observing equipment are presented in Table 1. It does not prescribe how these individuals should be grouped (i.e. how many institutions should be involved). Ship-time to support the buoy array and collect additional observations assumes bi-monthly cruises of 3-day durations along each line. Obviously a number of vessels would be required. Ship-time should be used to collect calibration data, service equipment (e.g. buoy servicing, glider turn-arounds, drifter deployment), and conduct surveys for variables not otherwise measured. Annual recurring costs to maintain the observing system are estimated in Table 1 and total $9 million.

5.1.2. Modeling/prediction

A number of modeling efforts are needed. The budget envisions nine small modeling efforts, each with 2 full-time employees and associated hardware. The degree to which modeling groups work on sub-regions (e.g. the west Florida shelf or southern tip of Florida) or sub-topics (e.g. 3D circulation modeling, inundation modeling, a sediment transport model) needs further consideration. How the modeling groups are physically organized should be determined

Table 2
Equipment and recurring costs for the modeling and prediction system (in thousands).

Cost type	Details	Unit cost	# unit	Equipment	Recurring
Personnel	2 staff/model group	$200/year	9 groups		$3600
Equipment	Hardware, connectivity	$250/grp	9	$2250	
Supplies	(20% of hardware + $100K travel)				$350
Subtotal				$2250	$3950

Table 3
Equipment and recurring costs for the information management system (in thousands).

Cost type	Details	Unit cost	# units	Equipment	Recurring
Central site	Staff	$100	5		$500
	Server cluster	$10	10	$100	
	4 TB storage	$200	1	$200	
Backup site	Staff	$100	3		$300
	Server cluster	$10	10	$100	
	4 TB storage	$200	1	$200	
Providers	Server	$10	20	$200	
	Staff	$100	20		$2000
Supplies	(20% of equipment + $80K for travel)				$200
Total				$800	$3000

Table 4
Recurring costs of the FASPD centers (in thousands).

Cost type	Details	Unit cost	# units	Equipment	Recurring
3 FASPD centers	Staff — 5 each	$500	3		$1500
Supplies	(20% of total)				$300
Subtotal					$1800

through pilot programs. Modeling equipment costs are estimated to be $2.25 million and annual recurring costs are estimated to be $3.95 million (Table 2).

5.1.3. Information management

The role of information management should be to ensure appropriate aggregation and distribution of information provided from data providers. It may also include connections to information sources deemed critical for the region, but the initial budget does not provide for tailored product development. The budget includes a central site of 10 servers with a 4 TB storage facility and 5 staff, and a backup site with the same hardware and three staff. It includes support for 20 additional staff envisioned to work with data providers; these distributed staff members, together with the staff at the central and backup site, constitute the data managers for the region as a whole. The equipment costs are estimated to be $800,000 and the annual recurring costs to be $3 million (Table 3).

5.1.4. FASPD centers

Focused efforts to use the RCOOS observations and model information for specific applications are needed. To promote this critical mission as a visible component of the RCOOS, creation of a few FASPD centers is advocated. These functional units could be virtual, co-located with other facilities, or with strong industry involvement could be co-sponsored. The need for them has become apparent in trying to provide this type of service within the existing framework, most often through the information management subsystem. Given uncertainties in how best to structure the centers, a rough estimate of the associated cost is $1.8 million in recurring costs for three centers each with 5 staff members (Table 4). Funding for this type of activity, whether through this particular mechanism or not, is essential to the success of the RCOOS because it provides feedback on the value and validity of the observing system.

The total operations budget, not including indirect costs, includes $21.05 million for equipment purchases and $17.8 million per year in recurring costs. The observing system dominates the equipment budget and is roughly half of the recurring costs. An estimate of management costs, assuming 5% of the recurring costs, is $750,000 per year. It is important to note that these figures do not include overhead, typically used to provide infrastructure support for personnel.

Assuming an overhead rate of 50% assessed on non-equipment items, a 5 year budget is presented in Fig. 6. Equipment costs are spread out over the first 2 years. Annual costs range from $31–40 million. Excluding costs associated with the observing subsystem reduces the budget to roughly $15 million per year.

5.2. Research and development

A critical component of the initial system will be assessment and quantification of information quality. SECOORA should

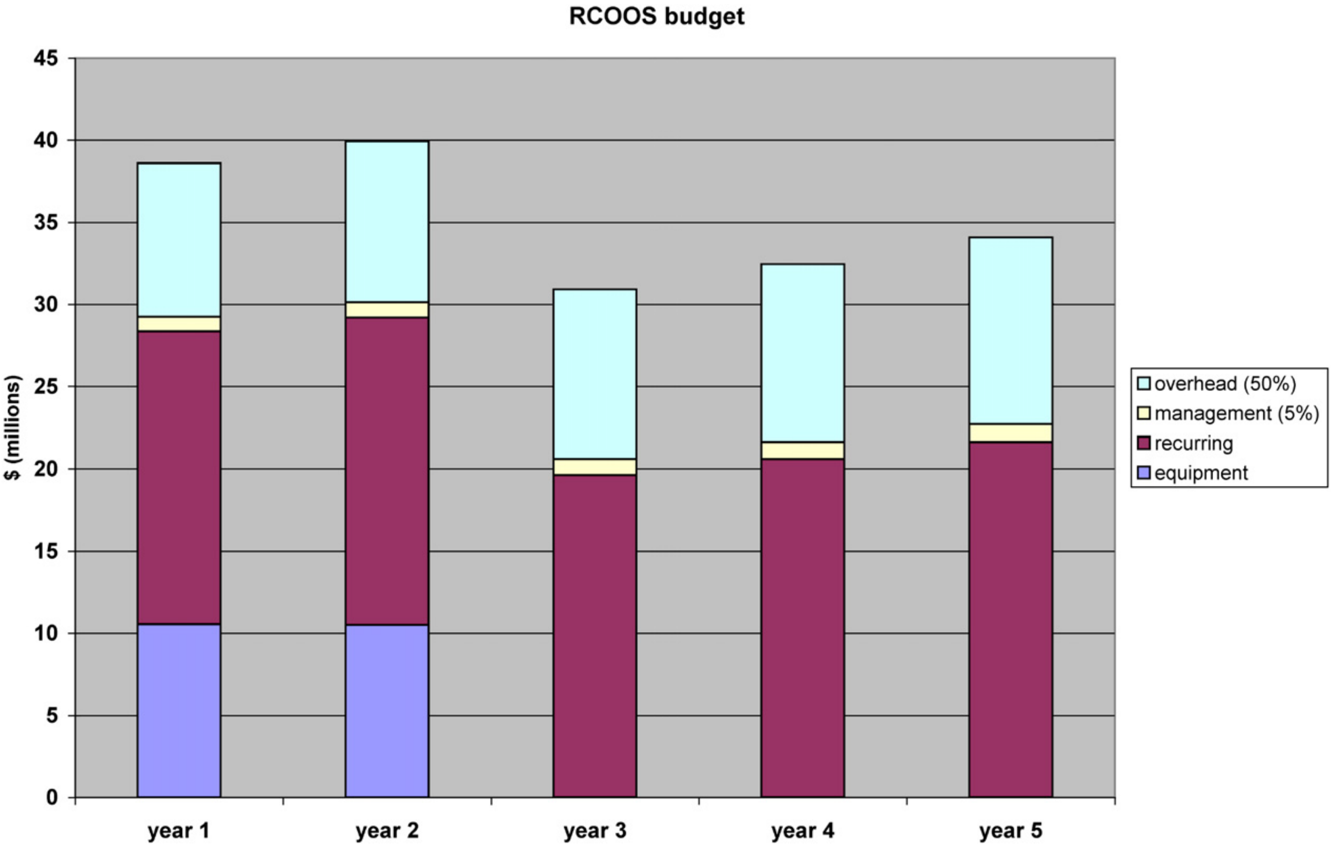

Fig. 6. Tentative 5 year budget for the RCOOS assuming an indirect cost rate of 50%. Equipment costs are divided equally between the first 2 years.

support a strong R&D program to utilize the full system — observing, modeling and IM. Such a coordinated effort will be required to characterize the SE coastal ocean environment, and, through diagnostic studies, to detect any secular changes that may have occurred. Developing a fully integrated system will also be critical for quantifying the accuracy of the model products using the available observations. A regional-scale SECOORA Science Plan should be developed to help guide these efforts. The results of these analyses can be summarized in an annual assessment (a “State of the Southeast Coastal Ocean” report). This program should include historical characterizations and data mining activities as a way to identify and include existing information in a regional database. Specific funding to support IM development in this area may be required.

It is anticipated that it will be essential for SECOORA to establish several high-density observational testbeds operating in the R&D mode for observing and modeling subsystem evaluations.

SECOORA should also allocate R&D funding to pursue growth of the system in priority areas identified by its Board. For example, if beach erosion is deemed a high priority for SECOORA, and it is found that the existing system is not able to provide the type of information required, a R&D program in this area should be funded to explore the best way to augment the observing system to provide the needed information. Many such topics will likely be of supra-regional and national interest, in which case, coordination across RCOOSs will be needed.

It is recommended that R&D funding be at a level of 20–40% of the operational budget for the RCOOS.

6. Conclusion

The rationale and conceptual design of a regional coastal ocean observing system (RCOOS) for the SE US have been presented. An initial RCOOS, composed of observing, modeling and information management subsystems, is described. Close coordination with national level activities is critical to achieve a viable, efficient and functional system. Further dialogue between all relevant parties is needed. The nature and importance of coordinated research and development programs as part of the RCOOS development is emphasized. Given the anticipated range of functions for the RCOOS, it is proposed that centers dedicated to forecasting, analyzing, synthesizing data and model output, and carrying out product development be established as part of the RCOOS implementation. This concept of centers for application development is new and largely unexplored within SEACOOS, but various development activities point to the need for focused effort in this area. An implementation strategy is proposed that emphasizes thorough testing of the integrated observing system, from the perspectives of priority applications to be supported and from the need to advance understanding of critical coastal ocean processes. Based on the initial design a rough budget is developed that indicates a complete regional system will cost $30–40 million/year to operate. It is important to note that for the most part there was no attempt made to identify new elements of the system that may be considered part of the National Backbone. That is, elements of the RCOOS design outlined here include those that would be operated by either the RCOOS or the National Backbone. Appropriate follow-on activities would be refinement of the design based on federal agency input and discussion of the most effective and efficient way to deploy and maintain the assets of the RCOOS, culminating in a detailed implementation plan that identifies yearly objectives and testing protocols to ensure a viable and robust coastal ocean information system for the southeast United States.

List of acronyms

AUV	autonomous underwater vehicle
CaRA	Caribbean Regional Association
Caro-COOPS	Carolinas Coastal Ocean Observing and Prediction System
CODAR	US firm that manufactures direction-finding HF radar systems
CONOPS	concept of operations
COOS	coastal ocean observing system
DMAC	data management and communications
EEZ	economic exclusive zone
FASPD	forecast, analysis, synthesis and product development
GCOOS	Gulf of Mexico Coastal Ocean Observing System
HF	high frequency
HYCOM	hybrid coordinate ocean model
IM	information management
IOOS	Integrated Ocean Observing System
MACOORA	Mid-Atlantic Coastal Ocean Observing Regional Association
NDBC	National Data Buoy Center
NFRA	National Federation of Regional Associations
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OSSE	observing system simulation experiments
RA	regional association
RCOOS	regional coastal ocean observing system
SEACOOS	SouthEast Atlantic Coastal Ocean Observing System
SECOORA	SouthEast Coastal Ocean Observing Regional Association
SE RCOOS	SECOORA Regional Coastal Ocean Observing System
WERA	Wellan Radar

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