Waves Initiative within SEACOOS

Executive Abstract

The waves initiative supported by SEACOOS has provided a significant database on directional wave climate for a number of near-shore locations in the region. This is an important contribution in itself that provides information required by coastal engineers and managers who must plan for sustainable development along the SE coastline that will be impacted by sea level rise in response to changing global climate. In addition, real-time wave data provided by this initiative has been utilized by NOAA/NWS local weather forecast offices in their surf-zone and rip-current forecasts. As part of this initiative, a field experiment was organized which evaluated the ability of WERA HF radar to provide wave height information. Although preliminary, the results were encouraging and placed some initial bounds on the confidence to be associated with empirically derived wave height information so that these data will soon be available as an operational product (at least for the calibrated site in SE FL). Furthermore, through the SEACOOS effort, expertise within the region has been has been coordinated that led to other collaborations in basic research (e.g., an NSF-funded project in the SABSOON area) and other recent RCOOS funding by NOAA (Carolina RCOOS).

In addition to the successes there have also been some shortcomings. The waves initiative was a later addition to the SEACOOS, developed after the main working groups and thematic areas were established. As a result the program was never developed to its full potential due to limited funds available. Realizing this, SEACOOS attempted to expand the initiative from a limited-scope observational activity to a wider system with forecasting capabilities though the development of partnerships with various federal organizations and other stakeholders. However, due to differing priorities between various parties and between sub-regions in the SE, this was not achieved.

A major outcome of the SEACOOS activity has been the realization by the waves group that future application endeavors require a full integration of modeling, observations and data management around the theme of the initiative (e.g., waves) to achieve an integrated project. The SEACOOS Waves Initiative was developed predominantly as observational activity with limited modeling and data management inclusion. Furthermore, it is the author's view that given limited funds, experimental activities are best progressed when resources are at a single testbed site within the region with participation by all partners and stakeholders from the whole region. Once the product has been fully developed and the science validated, then its implementation as a fully operational product in other areas of the region can be achieved through the transfer of the technical experience acquired.

Introduction

Surface waves are an important physical mechanism responsible for a number of oceanic processes ranging from mixing and CO_2 exchanges between the ocean and the atmosphere, to sediment transport and coastline evolution. The latter and other associated coastal processes are of considerable societal and economic interest, especially given various scenarios of global climate and local relative sea level changes. In addition surface waves can strongly impact operational procedures such as search and rescue, navigation and protecting public safety in nearshore waters and at beaches.

Although not an exclusive thematic area initially, the realization that surface wave parameters are important for both rescue and safety as well as issues of coastal erosion and navigational hazards in the region, SEACOOS initiated a program and provided resources for the

incorporation of a wave measurement program with the vision to proceed to the area of wave forecasting.

The wave measurement program focused on three general areas:

(i) Utilization of existing sites for the provision of wave information (e.g., SABSOON towers).

(ii) Development of new sites in the nearshore (e.g., Jannette's Pier, NC; Springmaid and Folly Beach Piers, SC, Tybee Island, GA) with focus on directional wave measurements.

(iii) Adaptation of existing technology (i.e., WERA Radar) for wave measurements and its subsequent evaluation for use as an operational product.

Items (i) and (ii) were initiated as a proof of concept activities while item (iii) was carried out later on in the project.

The ultimate goal of the surface wave initiative within SEACOOS was to:

(1) Create a directional wave data set for several nearshore areas for use as design criteria for sediment transport and coastal engineering studies. Although needed, directional wave information is often not available and the expense for collection of such data is prohibitive for individual coastal counties and property owners. In addition, there is often a mismatch between the time frame for decision-making (weeks to months) and that required to collect such data (multiple-years).

(2) Provide these data real-time to the public and other stakeholders for operational purposes and decision-making.

(3) Use the collected data for the development and calibration of regional wave forecast systems that require high resolution in their domains and local data for their calibration.

(4) Implement wave forecasting capabilities with high spatial resolution to resolve wave condition variability in the nearshore.

Overall, the project has been partially successful in achieving goals (1) and (2). The primary limitations being breaks in data coverage were related to operational difficulties explained elsewhere by the OWG and in subsequent sections. Another limitation has been the number of systems required to provide sufficient resolution in wave climate data sufficient to resolve the regional and sub-regional variations. Goals (3) and (4) were not advanced significantly within SEACOOS due to lack of coordination and/or effective collaboration at the various federal and regional levels. Within the SE region, there were areas that had developed wave forecasting capability (e.g., Jacksonville, FL, funded through NWS) but had no data to ground-truth the system. On the other hand, there were regions with operating stations but had no forecast capabilities to be ground-truthed with the available data.

Also, the wave measurement program was a later addition to the overall SEACOOS program. As a result, coordinated effort between the three modeling, observation, and data management working groups needed to fully develop the application was not developed. The integration and dissemination of wave data relied more on the data dissemination efforts of individual PIs and institutions than on a centralized effort.

Coordination Efforts

Given the wide interest of the surface wave observations and forecasts among research, coastal management and emergency management communities an attempt to explore the needs of the various federal partners and the possible contributions that an RCOOS can make in this area was explored. SEACOOS sponsored a one-day meeting that took place at the University of South Carolina, Columbia, SC (January 26th, 2005) to discuss the issue of Wave Measurements and Forecasting within the SE region. Federal affiliate representatives from NOAA/NDBC and USACE ERDC/CHL were present. The interest of NOAA/NWS in wave prediction was also recognized at the time, but no representative was present in that meeting. From the local research groups, representatives from the University of South Florida, University of Miami, Skidaway Institute of Oceanography, University of South Carolina, University of North Carolina at Wilmington and University of North Carolina at Chapel Hill were present.

During the meeting all federal affiliates present expressed an interest in the wave efforts and indicated their support for this. Presentations described the USACE ERDC/CHL activities in the area of wave measurements and its interest for a coordinated wave measurements initiative for the east coast in general and the southeast in particular, especially since the latter is an area frequently influenced by the development of tropical storms and hurricanes. The USACE / NDBC / Univ. of California CDIP collaboration was referred as a very productive collaborative effort that works very well for the state of California. It was identified that some of the ingredients that have made this a success are the support by the State of California and by congressional representatives, as well as appreciation of the role of waves in controlling coastal erosion. The latter has been the result of long–term research on the west coast. i It could be summarized that the engagement of user's groups in California (including state government and private citizens) has been instrumental in the success of the cooperative program. In contrast, there has not been such a coordinated effort within the southeast to promote the need for wave measurements.

During this meeting the important role of NOAA/NDBC in providing wave measurements and data portals was noted, as well as the role of NOAA/NWS in the area of wind and wave forecasting (through NCEP). Given the mandate for the local NWS offices to provide the public with forecasts of surf and rip current conditions, they are also important users of local and regional wave information.

In the area of numerical modeling, it was recognized that the state of California has been the pioneer in wave forecasting, especially in the area of swell waves. A number of numerical models (STWAVE, SWAN, WAM/WaveWatch III, REF-DIF(S), CREST, etc) exist and have been used by a variety of researchers. Some of them are more widely used than others and individual organizations and/or researchers have their favorite numerical models. For example, in southern California REF-DIF is employed for predicting swell conditions, while in Jacksonville, FL, a local wave forecasting system was developed by NRL with funds from NWS (through the Coastal Storms Initiative). It was clear during the meeting that currently there is not a consensus on model use and protocol and that this will need to be established.

Furthermore the wave forecasting issue is constrained by the resolution required various users of these products. Although no explicit recommendations came out of the meeting, the need for some organization and further action was established. The discussion could be summarized as follows:

1) Wave measurements and prediction constitutes an important link between offshore atmospheric and oceanographic conditions and the nearshore. Waves impact a wide variety of coastal users ranging from recreational users (e.g., surfers, beach goers), to the local municipality (with interests and responsibilities relating to coastal erosion, permitting for development, and beach safety) to the federal level (with interests including navigation, fisheries, search and rescue).

2) NOAA/NDBC has good experience in maintaining offshore sites for the measurement of waves and it might be the organization best suited for providing wave information that can facilitate data assimilation / verification for large-scale domain numerical models.

3) Nowcasting and forecasting of nearshore wave conditions requires resolution that is dictated by the gradient in offshore wave and wind patterns and by bathymetry and coastline morphology. It is likely that a number of high-resolution wave transformation models would be needed for different areas. These models could be maintained and run by regional associations, obtaining their boundary conditions from the larger scale federal backbone modeling and measurement activities.

The meeting concluded that regional associations and the federal partners could greatly benefit by collaboratively working toward development of a high resolution wave forecasting system. A straw-man proposal for such a partnership was outlined, based on resolution criteria. It was proposed that Federal affiliates could provide measurements in the open ocean (deep water waves) and continue integrating meteorological models to provide the large-scale wave forecast. Regional associations could contribute key local, nearshore measurements important to particular constituents and also run high resolution models that are integrated with the larger scale models. The development work required to achieve the described work that regional associations could contribute significantly were identified as:

(i) Evaluations of existing wave measurement technology and make sure that wave parameters from different systems are consistent.

(ii) Continue ongoing measurement programs and develop new programs in order to start building climatologies for variety of coastal areas that can be used later to evaluate model performance.

(iii) Develop a unifying data product capitalizing on the CDIP experience.

(iv) Select two or three areas for test beds in the SE which have different wind/wave forcing and different bathymetry to be used for extensive measurements and wave model evaluation. From such an exercise, a model or a suite of models might emerge that are suitable for use in routine operational forecasting mode.

(v) Develop the procedures, protocols and technologies required to make these wave-forecasting systems transferable to different areas through out the SE with the ultimate goal (10 year plan) to have the whole SE covered.

Although these items were brought up for discussion in subsequent SEACOOS workshops, it was deemed as too large of an effort to be undertaken by SEACOOS alone. Partnering with and leveraging funds from federal organizations was proposed as a strategy by which SEACOOS might achieve the above-mentioned goals.

Overall, while the wave discussions at the Columbia meeting and later workshop sessions laid out a path for developing a coherent wave program for the SE, the synergy envisaged in those meetings never developed. Rather, for the most part, individual organizations proceeded with carrying out parts of the plan. One group effort that developed out of discussions at the Columbia meeting and SEACOOS workshop was a field experiment in SE Florida to evaluate the use of the WERA HF radar system for wave measurements. Given the leveraged nature of this effort and limited scope of funding available, this was referred to as the "mini-waves experiment" and it is briefly explained in the next section.

The SEACOOS-sponsored "mini-waves experiment"

The development of empirical methods for extracting basic wave parameters (Hs, T) from single-site HF radar backscattered Doppler spectra is invaluable as it can provide larger coverage areas than dual-radar techniques or single measurement locations. In addition to the expanded coverage, these methods require substantially less bandwidth for transmission of results if local on-site processing is implemented. However the empirical methods require in-situ calibration in order to scale the ratio between 2^{nd} and 1^{st} order signals to wave height and period.

For this purpose SEACOOS funded a waves experiment with multi-institution participation where two Tri-axys wave buoys and 5 acoustic wave sensors (ADCPs and ADPs) were deployed within the coverage region of two Wellen Radar (WERA) stations offshore of SE Florida in the spring of 2005. The in-situ data were used to calibrate the radar returns and set necessary empirical coefficients for routine computation of wave parameters.

Both the calibration and validation data sets demonstrated that the empirical extraction of wave parameters was not effective at large angles to the radar boresight. Limiting the observations to those within ±45◦ of the boresight produced reliable estimates in most cases. The accuracy of the wave height observations was significantly improved by incorporating information from two radars to address cases when the waves were moving orthogonally to the radar look direction.

This evaluation exercise is partially a successful outcome of the waves initiative. It helped us in gaining confidence in the significant wave height and period information that can be derived through in-situ processing and this is an offline product of RSMAS at present and it will be incorporated in the routine products of the WERA system. Challenges remain in establishing directional wave characteristics and also in evaluation the radar frequency dependence to the quality of wave measurements. The latter is of particular interest when large range coverage in currents is required and also as it could potentially be a method for measuring offshore wave characteristics without the need of offshore buoy and the maintenance costs associated with it.

Successes of the Wave Program

(1) Various local stations were established at various regions that contributed in the collection of directional waves over the period of the project with coverage ranging from 46% to 60% of the time for the cabled ADCP stations and 62% for the buoy systems. These data have been invaluable in providing wave climatologies in the nearshore (see Figures 1 & 2) for the deployment sites.

(2) Expertise was established in using ADCPs for wave measurements. Particular success was the creating of data display results for ADCP directional wave measurements. These were widely disseminated to various partners within SEACOOS but also were shared with RCOOS within the region.

(3) Comparisons of ADCP- and buoy-obtained wave parameters have shown that the two systems are in very good agreement (see Figure 3).

(4) NOAA/NWS have been utilizing nearshore wave data for guiding them through the nearshore forecasting activities. The data from a variety of wave stations are fed to NOAAPORT by the individual partners and then this is distributed to the NWS local WFOs via the Advanced Weather Interactive Processing System (AWIPS).

(5) The infrastructure of stations established by SEACOOS has been utilized by other entities for data dissemination. An example is the use of the Springmaid wave station infrastructure in SC for the collection and transmission of Dissolved Oxygen data in

the nearshore for the Department of Ocean and Coastal Resources Management in SC.

(6) Local communities have been utilizing the data from the station that is their region. Although no official data exist I had a number of communications with local surfing communities.

(7) The "mini-waves" experiment demonstrated that the WERA technology is promising in providing wave height estimates (see Figure 4) and indicated that a technology test-bed function can be successfully incorporated into the SE RCOOS.

Lessons Learned

(1) The development of nearshore wave products was limited to the assets and methodologies selected by each partner. Although some of these were partially dictated by existing infrastructure, this did result in a lack of uniformity amongst the different products. Some of the uniformity was provided through the channeling of wave data through NDBC.

(2) Cabled systems along the coastline were severely damaged a few times by lightening. Despite the number of protective measures being taken, there has not been an effective protection and this has required considerable expenditures for repairing various elements of the systems (from base stations to underwater units). Limitation of the down-time can occur through the immediate availability of spare systems and personnel (including boats and diving operations) for rapid response.

(3) Data management and dissemination was never integrated as a full product. Partially because of their complexity and partially because of lack of funds, the data processing and management was left to individual PIs with the expertise in the type of data provided by these types of measurements.

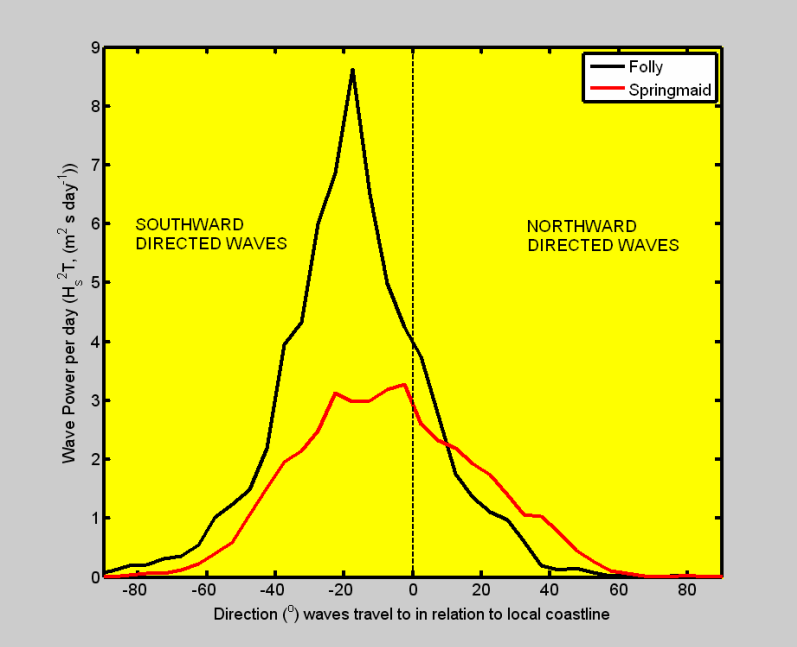

Figure 1. Nearshore wave climatology for two stations (Folly Beach and Springmaid Pier) along the coast of South Carolina. Under the same wind regime, the site at Folly beach receives significantly more energy than the site on Springmaid Pier. In both sides the wave energy is directed southward, indicating a southward dominated longshore sediment transport. (Data from G. Voulgaris, University of South Carolina).

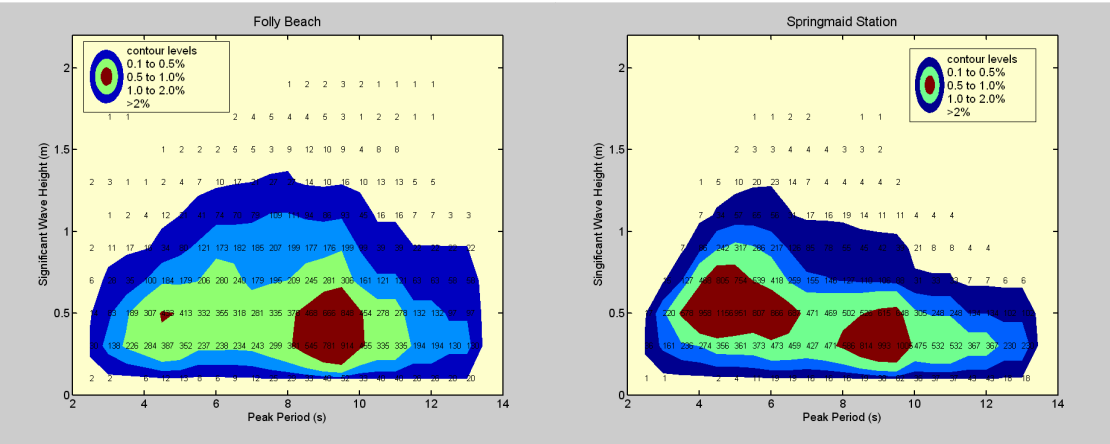

Figure 2. Joint distribution of significant wave height and peak period at Folly Beach (left) and Springmaid Pier (right) along the coast of South Carolina (Data from G. Voulgaris, University of South Carolina).

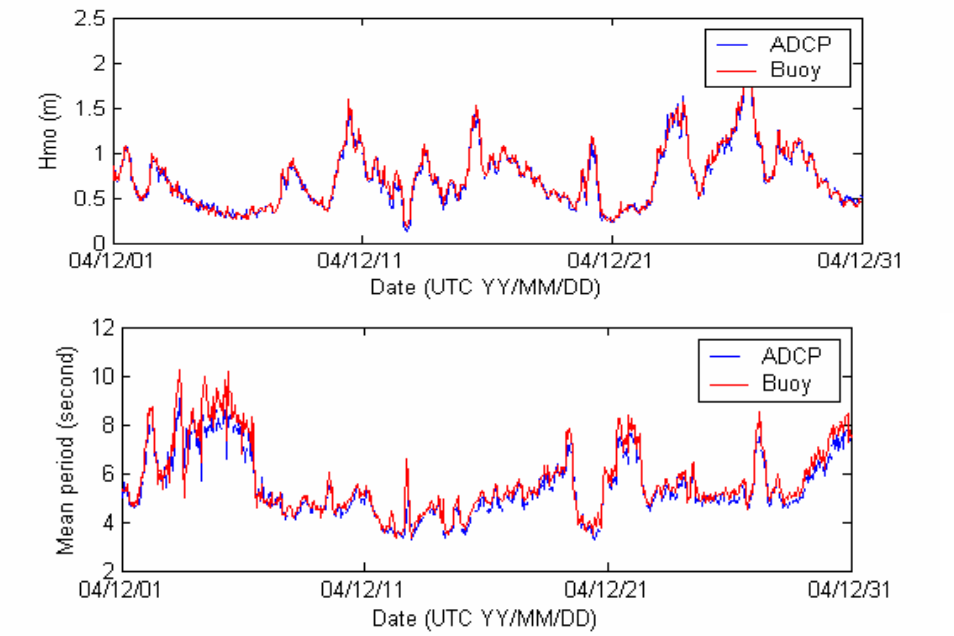

Figure 3. Comparison of energy spectrum-based wave heights and periods estimated by the wave buoy and RD Instruments ADCP (1200 kHz) for December, 2004. The mean of the magnitude of the difference in wave height is 5 cm while the mean difference in wave period is 0.3sec. (Data from: P. Work, Georgia Tech).

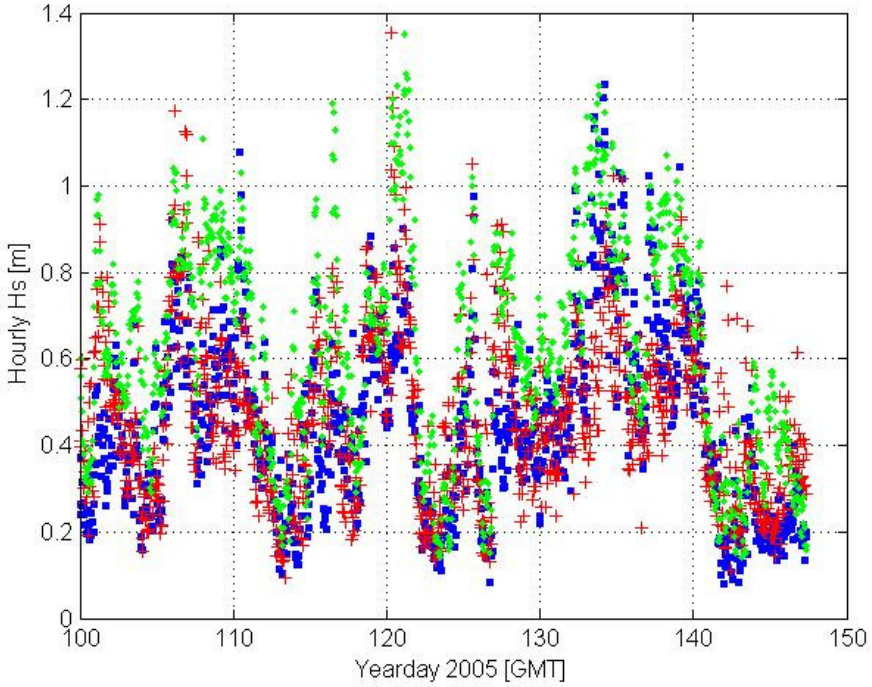

Figure 4. Hourly significant wave height (Hs) estimates from the Tri-axys buoy (●) at 25.49 N, 80.10 W in 15-m of water, and best correlated cell Hs for Crandon WERA station (+) and North Key Largo WERA station Hs (■). (Data from: B. Haus, University of Miami).