A High Resolution Nearshore Wave Model for Northwestern California

NWS Cooperative Project
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Section 1: Summary of Project Objectives

The objective of this proposal is to implement a nearshore, regional wave forecasting model in order to: (1) populate NWS IFPS grids with high-quality wave forecast data for a section of coastal Northern California, and (2) develop an effective forecast model of the wave hazard at the entrance to Humboldt Bay, California. The model for (1) will hereafter be referred to as the Coastal Waters Wave Model, and the model for (2) will be referred to as the Bar Forecast Model.

A concomitant objective of the project was to demonstrate the usefulness of high resolution nearshore wave models for forecasting of wave conditions and related hazards in other coastal regions throughout the nation.

Section 2: Project Accomplishments/Findings

Project Accomplishments

1. The most significant accomplishment of this project has been to demonstrate the value of high resolution near shore wave modeling to the mission of the National Weather Service and NOAA. Early results from this project led to an important collaboration with the Coastal Storms Program of the Office of Science and Technology. This has brought additional funding to the Eureka/HSU effort (including additional buy-in from the Western Regional Center), and it has led to significant funding of additional efforts at the Portland, OR, and Jacksonville, FL Weather Forecast Offices. These efforts, and others, have led to the development of a national NWS team dedicated towards working on moving these technologies

into operations throughout the National Weather Service offices with coastal and ocean forecast responsibilities.

2. The funding support from COMET for this project, as well as the preliminary successes demonstrated by the NWS and HSU team, led to a significant expansion of the wave hazards program. We have developed collaborations with several other institutions, agencies, and local user groups, including:

   (a) US Navy, which, through Naval Research Laboratory (NRL) wave modeler Erick Rogers, helped improve our implementation of the wave modeling software (Rogers and NRL have subsequently expanded their participation, through additional funding and investment, to develop similar wave model applications on the eastern seaboard);
   (b) US Army Corps of Engineers, which loaned us a 2-dimensional wave measuring buoy for over a year to help us collect observational data (the buoy was deployed roughly 3 nautical miles west of the entrance to Humboldt Bay);
   (c) Scripps Institution of Oceanography (University of California, San Diego), whose Coastal Data Information Program (CDIP) helped us maintain and deploy the Army Corps wave buoy, undertook all of the data telemetry, archiving and user access, and subsequently supplied a replacement wave buoy when the Army Corps buoy was returned to its owners;
   (d) D.G. Energy Systems, a company which owns the local Fairhaven power plant, which is providing $12K per year to Scripps to pay for recurring costs in support of the wave buoy maintenance and data telemetry;
   (e) local fishermen from the Humboldt Bay region, who provide information on wave conditions around the entrance to the bay on a voluntary basis, using standardized forms developed by the Eureka Weather Forecast Office.

   In summary, we believe that this project represents exactly the kind of success story that the COMET program seeks to support. Our COMET-funded project has not only provided seed money to support the development of improved and useful nearshore wave hazard forecasting, it has also provided substantial leverage to both enhance monitoring of nearshore wave conditions off northern California and engage the scientific and local user communities.

3. The Coastal Waters Wave Model has been fully integrated into the IFPS operational environment. This model is driven by the forecaster-developed Graphical Forecast Editor (GFE) wind grids to ensure that the best possible wind forecast data are used. Where GFE wind grids are currently not available (offshore waters), the Eta 12 wind data is used. The Ocean Prediction Center is expected to be producing GFE wind grids over the offshore waters in 2007. The operational implementation of the Coastal Waters Wave Model was designed to utilize these forecast grids when they become available.

4. Output from the Coastal Waters Forecast Model is post processed, or partitioned, to produce spatially and temporally consistent wave grids that can be used directly

to populate the official forecast grids. These grids are produced for the wind wave and three most energetic swell groups. This output approach was developed based on work done by Jeff Hansen at the US Army Corps of Engineers, Field Research Facility. The implementation of this approach into operational forecasting was also done in collaboration with Jeff Hansen. Partitioning of the wave grids facilitates the use of this wave model output in the modern gridded forecast environment being used the National Weather Service. The use of this partitioning approach is the first to be done in real-time wave forecasting, and represents an important innovation resulting from this project.

5. The Bar Forecast Model was completed as proposed so that it incorporates all the major physical processes that result in hazardous wave conditions at the entrance to Humboldt Bay. These processes include: (1) the wave conditions along the boundary of the very high resolution domain that covers the harbor entrance, (2) the sea floor bathymetry at the harbor entrance, (3) the local wind wave processes, and (4) the tidal current that results from the flooding and ebbing of Humboldt Bay. The latter of these was the most challenging and represents an important innovation resulting from this project.

6. Coupling of the SWAN wave model and a recently developed ADCIRC current model for Humboldt Bay was accomplished through the development of some software code, called CurPro, that facilitates a one-way coupling of the two models. This type of coupling only incorporates the impact of the current has on the waves and does not yet address the impact that the waves have on the current (through radiation stress gradients). This effort does, however, represent the first such coupling of a wave and current models to forecast hazardous wave conditions at an entrance bar.

Project Findings:

1. Evaluation of the Coastal Waters Wave Model, performed during the summer of 2005, showed that it improves the accuracy of wind wave forecasts and results in a significant reduction in the effort needed to produce the forecast. Evaluation of accuracy of the Coastal Waters Wave Model is ongoing.

2. Deficiencies in the partitioning of the Coastal Waters Wave Model output have been identified and are being addressed. Specifically, the partitioning struggles to produce temporally consistent wave grids during transitional periods when one wave system is moving out of the domain and another is moving into the domain. This is a problem that faces all partitioning approaches, even the simplified methods that are only applied at a few discrete points. The Coastal Waters Wave Model partitioning is performing marginally well during these conditions and it is anticipated that a small amount of training will be needed to enable forecasters to recognize, and mitigate for, the instances when the partitioning is struggling to properly identify wave systems.

3. Wave breaking predictions from the Bar Forecast Model were compared against observations made by trained observers roughly a half-dozen times during the 2004/2005 winter. The model correctly predicted breaking wave conditions one hundred per cent of the time, with only a small number of false alarms (where the model predicted breaking that was not actually observed). Preliminary comparisons from the current (2005/2006) winter period have shown the wave height and period are also very accurately being forecast by the Bar Forecast Model.

4. We have determined that other currents (e.g., wind-driven currents) also need to be incorporated into the model because they influence how the net ocean flow interacts with the sea floor bathymetry. For example, a northward coastal current tends to push the ebbing tidal flow northward onto the outer shoal. This process makes the waves on the outer shoal hazardous. The model currently does not capture wind-driven currents and therefore is not able to predict this hazard. Efforts are currently under way to incorporate local wind data into the current model so that the wind-driven current will be resolved.

5. The version of the SWAN model used for this project does not incorporate diffraction. This is the process that causes wave directions to change based on energy exchange along the wave crests, usually associated with waves interacting with obstructions with a vertical, or nearly vertical orientation (the classic example is waves passing through an opening in a vertical sea wall). This was not expected to be an issue for the entrance to Humboldt Bay but it was found that a portion of the entrance channel cannot be modeled without considering diffraction. Fortunately, the most recent version of SWAN does incorporate diffraction and efforts are underway to use this version of the model.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

Benefits to the Department of Commerce, NOAA, and National Weather Service.

The majority of human activity in the marine environment - which includes the loss of life and property - occurs within 20 miles from shore. Unfortunately, and ironically, this is about the point at which the simple wave modeling tools used by many forecasters can no longer provide useful guidance. Furthermore, the processes that take place in this near shore region significantly impact life and property in the beach zones and adjacent land areas. This includes coastal flooding caused by storm surge, coastal erosion, so-called ‘sneaker waves’ that kill many people per year on the west coast, and rip currents that are a major source of fatalities around the nation. Collectively, these issues should constitute the highest priority for many coastal offices because they result in more death and property damage than all of their other weather events combined. Improving forecasts in this region, however, is severely limited by the lack of observations, deficiencies in marine training, and most importantly, the lack of adequate model guidance.

The primary reason that the National Weather Service is struggling to improve forecast accuracy in this critical marine region is the lack of adequate model guidance.
The existing state of such guidance in the near shore region, to put it in perspective, is analogous to severe weather detection before the advent of weather radar. Marine forecasters are aware that physical processes are occurring in the near shore region, but they have no way to quantitatively account for them in their forecasts. This project addressed this issue by advancing the science and operational technology associated with forecasting waves throughout the near shore region, by providing a planning tool for transiting the hazardous entrance bar of Humboldt Bay, and by providing the technological advances that will facilitate the development of similar tools for the entrance bars of economically significant ports such as San Francisco Bay and the Columbia River.

A concomitant issue associated with marine wave model guidance is the incorporation of model guidance into the operational environment. This applies to the near shore environment and throughout the oceans. Current model guidance is not provided in formats that are intuitive and immediately useful. Furthermore, the output data format has not been modernized to meet the needs of the gridded forecast paradigm. Forecasters must manually create marine grids in many cases, with the model predictions only serving as a rough guide. This is a poor use of forecaster resources and leads to errors and reduced accuracy. This project addressed this issue through the inclusion of partitioning methods that provide wave model output that can be used directly in the forecast environment used in National Weather Service offices.

Collectively, this project has benefited the National Weather Service, specifically, by providing tools that can reduce the loss of life in the marine environment. It has benefited NOAA by enhancing the agency's ability to provide society's needs for weather information, and it has benefited the Department of Commerce by supporting the nation's commerce with information for safe, efficient, and environmentally sound transportation.

Benefits to other federal agencies

The Department of Homeland Security, United States Coast Guard, Sector Humboldt Bay will use the Bar Forecast Model for both their own operations and to directly advise mariners about hazardous wave conditions. As this technology is transferred to other sites, additional Coast Guard Sectors will benefit from advanced prediction of these hazards. Efforts are currently under way to apply this technology at the entrance bars for San Francisco Bay and the Columbia River.

The Department of Defense, US Army Corps of Engineers, Southwest Pacific Division will use the Bar Forecast Model for both their operations and engineering analysis. The Corps of Engineers performs annual maintenance dredging in Humboldt Bay, including the entrance bar. The Bar Forecast Model will aid the Corps of Engineers in the scheduling and positioning of their dredging vessel thereby reducing the hazard and cost associated with their operations. Wave conditions in the vicinity of the Humboldt Bay

Bar played a role in an oil spill in 1998. The oil spill occurred when the ship's dredge apparatus collided with the hull of the ship due, in part, to wave induced rolling. This accident highlights the value of a Bar Forecast Model for dredging operations. The Humboldt Bay Bar Forecast Model also adds to the body of knowledge regarding tidal inlets that the Corps of Engineers uses for both dredging planning and coastal engineering analysis. The effort employs methods in real-time that have traditionally been used only for engineering analysis. By doing so, this effort has made it possible to evaluate and validate the performance of these models during a broad range of conditions.

Benefits in non-scientific areas such as customer service improvement.

This effort piloted a methodology to identify a customer need and then analytically evaluate that need to arrive at the most appropriate product or service. The methodology employs private-sector product development methods along with forensic analysis of weather related fatalities.

Specifically, we examined all the circumstances leading up to the decision that put someone in harm's way. We consider where they were, where they were going, what they were doing, the culture associated with their activity, and any other relevant factors. Through this process, we search for opportunities where a forecast tool could foster a different and safer decision making process compared to the one that resulted in a maritime casualty.

The basic need for a bar forecast model for Humboldt Bay was identified over ten years ago. At that point, there were bar forecasts being produced at two locations on the West Coast, the Columbia River Bar and the Neah Bay Bar. These forecasts were based on obsolete technology and they did not result in a graphical bar forecast. Consequently, they provided very little resolution of the wave hazards in time or space. Through the customer needs assessment methodology described above, it was determined that the existing solutions would not adequately mitigate the loss of life associated with hazardous entrance bars, nor would it yield significant increases in transportation efficiency. For example, it was identified that short-cuts were often taken by mariners during quiet wave periods and that this behavior was a common contributor to maritime casualties. This indicated the need to characterize the hazard throughout time and space at a high resolution, enabling mariners to see which short-cuts were dangerous during the forecast period. This determination is what led to the proposed project to develop a physically based high resolution near shore wave model.

The development of the above customer service assessment methodology was begun at the start of this project. It was subsequently enhanced and applied to other customer needs, resulting in service improvements that earned a Department of Commerce Bronze Medal for the Eureka Weather Forecast Office.

Section 4: Benefits and Lessons Learned: University Partner Perspective

This project evolved and grew significantly from the time it was initially funded to its completion. In the early stages, it was merely a basic model application for predicting wave hazard conditions at the entrance to Humboldt Bay. In the end, the project provided significant improvements in nearshore predictions as well; it helped leverage real-time monitoring of wave conditions in the nearshore, first through a buoy loaned from the Army Corps of Engineers and then through the installation of a buoy maintained by Scripps Institution of Oceanography; it also helped leverage additional resources from NOAA's Ocean Storms Initiative to support our efforts in nearshore wave modeling.

We particularly appreciated COMET's flexibility in allowing us to adapt our budget and some of our activities to emerging opportunities. We feel the project and the public have benefited substantially and our efforts have been enthusiastically received in the local, regional, and research community.

While we were unable to identify an appropriate graduate student to participate this program, we were very pleased to identify and fund three talented undergraduate students, two from Humboldt State University's (HSU) Environmental Resources Engineering program and one from the Computer Information Systems program. All three brought different skills to the project and performed remarkably well. We were all pleased with how this worked out and firmly believe these students did as well as any graduate student would have. The only thing that did not come out of the project, from the University's perspective, was a graduate thesis and a MS degree. However, our institution also prides itself on its undergraduate programs and practical experiences for students, so there is no real disappointment at our end.

(Two of these undergraduates are now in graduate school and the third is preparing to apply for grad school.)

The project has, quite naturally, fostered closer ties collaborations between Humboldt State University and the National Weather Service Forecast Office in Eureka, California. The University Principal Investigator, for example, plans to apply for a small local grant to fund students to help validate the model results through visual observations at the entrance to Humboldt Bay. We are also investigating opportunities to install a commercial radar-based, near-real-time wave monitoring system near the entrance to the bay, to provide further model validation of wave hazards.

We also recognize that NWS and HSU provide complementary resources. NWS has core responsibilities to meet and credibility with the public; HSU has the academic interest in solving applied research problems and can provide a path for students (potential future employees) for obtaining training to support these activities.

In more broad terms, this project, along with a number of other high-profile, large-scale marine-related observing programs involving HSU, has provided by substantial visibility and synergy for marine-related research at Humboldt State University and in the

Humboldt Bay region. These other projects include CI-CORE (cicore.mlml.calstate.edu; funded through NOAA COTS), PaCOOS (www.pacoos.org; in development, ultimately with federal funding through NOAA], COCMP (www.cocmp.org; California state-funded(and the atmospheric baseline observatory at Trinidad Head (http://www.cmdl.noaa.gov/obop/THD/; funded through NOAA/ESRL/GMD). We are hopeful that the developing string of successful collaborations with NOAA and other government agencies will precipitate the development of a NOAA-University institute through Humboldt State University.

Section 5: Publications and Presentations

Crawford, Greg, Troy Nicolini, Douglas Saucedo, Eve-Marie Devaliere, and Erick Rogers, "A high resolution nearshore wave and bar forecast model for Humboldt Bay, California", presented at the 2005 World Conference on Natural Resource Modeling, Arcata, California, June 14-18, 2005.

Nicolini, Troy, and G. B. Crawford, "High resolution nearshore wave modeling in Humboldt Bay", presented at the Humboldt Bay Symposium: A Regional Perspective to Restoring Physical and Ecological Processes in Humboldt Bay, Arcata, California, March 14-15, 2005.

Nicolini, Troy, G. B. Crawford, E. Rogers, T. Williams, E.-M. Devaliere, and D. Saucedo, "A high resolution nearshore wave model and bar forecast model for northwestern California", presented at the Sixth Conference on Coastal Atmospheric and Oceanic Prediction and Processes, 85th AMS Annual Meeting, San Diego, California, January 9-13, 2005.

Saucedo, D., G.B. Crawford, and T. Nicolini, "Validation of a nearshore wave model in a harbor entrance with a dynamic wave and littoral process environment", presented at the Sixth Conference on Coastal Atmospheric and Oceanic Prediction and Processes, 85th AMS Annual Meeting, San Diego, California, January 9-13, 2005. [This prepared paper was presented due to a prior cancellation and does not appear in the abstract listings]

Crawford, G.B., and N. Claasen (invited presentation), "Waves and tides near the entrance to Humboldt Bay", Humboldt Bay Symposium: What We Know, What we Don't Know, and What We Need to Know for the Future. Eureka, CA, March 22, 2004.