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Coastal and Ocean Modeling Testbed Applications

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Abstract—The Southeastern Universities Research Association (SURA) is involved in the research, development, and transition of ocean models from exploratory/advanced research to operations. The SURA Coastal and Ocean Modeling Testbed (COMT) program uses the science of collaboration to apply advances made by the coastal ocean modeling research community to improve operational ocean products and services. The long-range vision of the program is to increase the accuracy, reliability, and scope of operational coastal and ocean forecasting products. Accurately modeling surface gravity waves in the coastal ocean is especially important to help protect property and to save lives. This paper highlights recent advances in wave modeling by principal investigators that have supported the COMT program [1]. The four pillars of COMT are basic and applied research, technology transition, archival of discoverable information, and dissemination of data standards and software tools.

1. Introduction

A gravity wave field consists of a large number of single wave components each characterized by wave height, period, and direction [2]. Short waves such as wind waves and swell are modeled differently than long waves such as surf beats, seiches, tides, and tsunamis.

Wind wave modeling involves the use of numerical techniques to simulate sea states. Traditional wave models used by oceanographers and engineers are provided in Table 1. Wave models are forced by winds and include nonlinear wave interactions, whitecapping, depth induced wave breaking, and frictional dissipation. The model output generally consists of wave height, wave period, and direction statistics. The Coastal Ocean Modeling Testbed (COMT) program has run the Simulating WAves Nearshore (SWAN) model over large sections of the Eastern Atlantic Ocean, Caribbean Sea, and Gulf of Mexico as well as in several nearshore applications. Wave hindcasts and forecasts are extremely important for the maritime industry and coastal construction. For example, wave model output may be used to support vessel planning (e.g., docking, optimal ship tracking), search and rescue, forces on structures and for the further modeling of sediment transport, erosion, and accretion.

COMT has been especially important to understand variations in wave model results that may arise from differences in wind forcing and differences in parameterizations of physical processes. Future efforts may include data assimilation, and numerical techniques used to solve the wave action evolution equation.

Table 1. Wave Models

Name	Primary Use
WAVEWATCH III® (WW3)	Operational wave predictions, the current version includes shallow water parameters.
SWAN	Short crested waves in coastal and inland regions.
Delft3D	Short wave generation, sediment transport, morphological changes, ecological processes, and water quality
WW3 includes global and regional nested grids. SWAN has been run regionally and locally. Delft3D is often used to simulate local hydrodynamic conditions.	

2. Input

Wave models benefit from information derived from satellite altimeters, wave buoys, or other models to describe sea states. The COMT program continues to use data from networks such as the NDBC Ocean Observing System of Systems and the U.S. Integrated Ocean Observing System. Important data were collected from wave buoys, acoustic wave and current profilers, acoustic Doppler current profilers, and pressure sensors during tropical cyclones such as HUGO (1989), ANDREW (1992), MARILYN (1995), GEORGES (1998), LENNY (1999), KATRINA (2005), IKE (2008), ISAAC (2012), and SANDY (2012). The use of real data for exploring model parameter choices generally improves model skill as opposed to simply relying on boundary conditions obtained from previous forecasts or climatological data.

The wave model skill is especially sensitive to forcing by accurate wind fields. The desired input is a time-varying map of wind speed and directions. C-MAN Stations, NDBC buoys, remote sensors such as QuikSCAT, SSM/I or ERS2 and forecast models are all important sources of wind data. In the open ocean where there are significant wave current interactions, inputs should include reliable information on the total current (includes permanent currents, tidal, inertial, and hydraulic currents). In polar regions, waves are also affected by sea ice and icebergs. In shallow and intermediate depth the effect of bathymetry and islands must be considered. It is noted that many model applications do not include such effects, partly due to limitations associated with model resolution.

3. Representation

Waves are generally described as a spectrum, where the sea surface is decomposed into waves of varying frequencies using the principle of superposition. Waves are also separated by their direction of propagation. Model domains can range in size from local, regional to global scales. Smaller domains can be nested within a regional or global domain to provide higher resolution for a region of interest such as a coastal bay. The sea state evolves according to physical equations that are based on a spectral representation of the conservation of wave action. Calculations include wave propagation, advection, refraction (by bathymetry and currents), shoaling, and a source function which allows for wave energy to be augmented or diminished. Forcing generally includes wind forcing, nonlinear transfer, and dissipation by whitecapping. Wind and other atmospheric data are typically provided from a separate atmospheric model from an operational weather forecasting center. For intermediate water depths the effect of bottom friction should also be added. Further, for open ocean models dissipation of swells (without breaking) has been shown to be a very important term.

Spectral wave information can be used to support a variety of operations from coastal construction to offshore alternative power generation. Wave spectra are used in design criteria for shoreline protection structures. Coupled models can also be used to investigate whether or not structures such as groins and jetties will alter the natural processes of the beach, since these types of shore protection often lead to erosion on adjacent stretches of the coast, which also increases the risk of flooding. Representative ocean wave spectra may be used to generate time-series of wave surface displacement data for individual wave energy converters that are deployed in a wave park.

4. Output

The output from a wind wave model is a description of the wave spectra, with amplitudes associated with each frequency and incident wave direction. Results are typically summarized by the significant wave height, which is the average height of the one-third largest waves, and the period and incident direction of the dominant wave.

Data and information from the COMT collaboration website may be accessed from http://testbed.sura.org/datatable. As an example of data which could be used for severe weather planning are operational ocean wave predictions and wave buoy data from Hurricanes IKE (see Fig. 1 and Fig. 2) and GEORGES (see Fig. 3). Wave heights generated by IKE decrease as they propagate into shallow water owing to white capping, depth-induced wave breaking, and bottom dissipation [3]. As an example from the Caribbean Sea, are operational coastal surge and wave predictions and wave buoy data from Hurricane GEORGES, which made landfall on the SE of Puerto Rico. Significant surges were generated by GEORGES as the system moved over the reef shelf, strengthened by momentum transfer from wave breaking in shallow water [5].

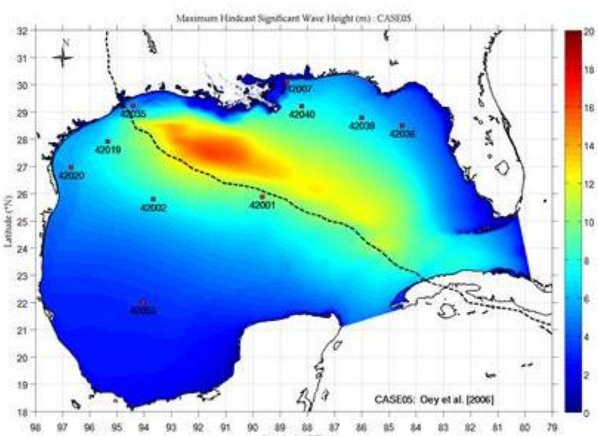

Figure 1. Model derived significant wave heights (m) during Hurricane IKE (2008) that re-strengthened in the Gulf of Mexico (obtained from [3]). Model output is in close agreement with NOAA's mid Gulf of Mexico 3-meter discus buoy.

5. Coupled Models

Coupled models may be used to support theoretical investigations of the mechanisms behind physical phenomena from waves, tides, and shallow water processes to climatic change. Wind waves also act to modify currents and atmospheric properties through frictional drag of near-surface winds and heat fluxes. Two-way coupled models allow the wave activity to feed back into the circulation and upon the atmosphere. An example U.S. Geological Survey project that is focused on understanding coastal erosion is the Coupled Ocean – Atmosphere – Wave – Sediment –

Figure 2. NDBC Station Number 42001. 3-meter discus buoy moored in the mid Gulf of Mexico, 180 nm south of Southwest Pass, LA at a depth of 3,365m. A maximum significant wave height of 9.25m was observed at 12:50 PM CST on September 8, 2008 during Hurricane IKE.

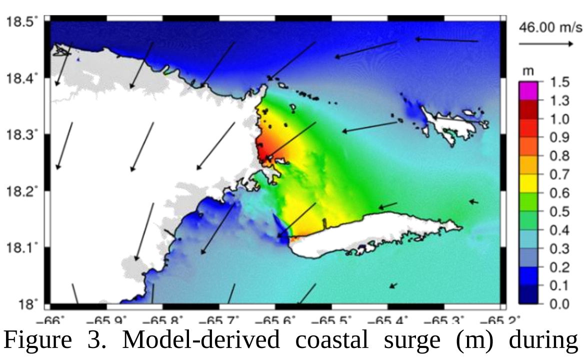

Figure 3. Model-derived coastal surge (m) during Hurricane GEORGES (1998) over the SE of Puerto Rico and the island of Vieques. Arrows indicate wind velocity vectors (obtained from [5]).

-Transport (COAWST) modeling system [6]. Coupled models such as COAWST allow researchers to simulate interactions between foreshore, nearshore, and offshore sediment transport processes. Information from the Weather Research and Forecasting model, Regional Ocean Modeling System, SWAN, and the Community Sediment Transport Modeling Project [7] are integrated by COAWST. Several examples of coupled models used during the COMT project are listed in Table 2. Future researchers may use coupled models to separate natural variability from anthropogenic effects, which would be especially useful to mitigate the effects of sea level rise.

Table 2. Coupled models.

Model System	Benefits
FVCOM+SWAN	Deep and shallow surface waves
ADCIRC+SWAN	Characterizing storm surge
SLOSH+SWAN	Coastal surge analysis
Delft3D+SWAN	Water flow and waves
ADCIRC+ *WAVEWATCH III*®	Improve nearshore simulations of inundation
The added features obtained through coupling are helping to generate actionable surge information.	

Numerous researchers, e.g., [1], [3], and [8], working with COMT have applied wave (e.g., SWAN and *WAVEWATCH III*®) and circulation (e.g., ADCIRC, FVCOM, and SELFE) models to produce timely products characterizing extreme events that support decision makers. Comparisons of the above coupled wave and circulation models to observations (e.g., tide gage data) during nor'easters have showed similar accuracies.

Archives that highlight wave heights and breaking waves during storms, storm surge during the passage of hurricanes, or river and coastal inlet plumes in synchronization with favorable winds are especially useful for contingency planning and coastal zone management. The COMT archive is intended to help validate new models that can be run for future events or other purposes. The COMT archive may allow data innovators, who want to use model output to develop integrated products, to help operators anticipate the impacts of extreme events. COMT output can support exercises that help Commanders determine when to sortie Navy Ships from Homeports to avoid hurricanes such as SANDY that occurred during 2012.

6. Verification

The verification of coastal wave models is challenged by factors such as changing wind fields, shoreline shape, and bathymetry. Thus, coastal systems are not closed and the ensuing model results are specific to selected times and spaces. Model results can be confirmed through comparison with observations and other models, but the intercomparison is inherently limited. Therefore, their predictive value should be continuously evaluated.

COMT provides an archive of observational data and model output during significant historical coastal flooding events. Important input, output, and representations are provided to support model comparisons. Since the extent of inundation is a function of factors such as inland topography, vegetation, geomorphology, and coastal structures, geospatial information is provided in the archive. Such information is especially helpful to understand direct inundation (the water level exceeds the land elevation), overtopping (water flowing over berms, dunes, and other barriers), and breaching (barriers are broken by waves). This combined information is important to determine different inundation paths.

The archive includes input data, model output, and/or observational data that can be used for skill assessments. Future efforts may explore using this information to support contingency planning (e.g., marine spill response, search and rescue, and use to support marine operations such as trans-ocean tows of large structures). The archive has been produced using the oceanographic community's leading numerical models, whose outputs in some applications characterized important phenomena such as inundation, waves in a seaway, and sediment transport.

7. Reanalysis

Historic data and archived model output are useful for a variety of scientific applications. Hindcasts involve the use of historical data (or closely estimated inputs for past events) to assess how well output matches known results. A retrospective analysis may also be conducted by combining all available observations with a physical model to describe the model domain over decades. One might use wave observations from the International Comprehensive Ocean Atmosphere Data Set (ICOADS) and other models to build monthly, interannual, and multi-decadal wave climatologies or atlases.

The COMT program included the comparison of sea level and waves for four regional-scale models, i.e., ADCIRC+SWAN, SLOSH+SWAN, Delft3D+SWAN, and ADCIRC+WAVEWATCH III® in the Caribbean Sea. These intercomparisons highlighted the importance of using hindcast best winds rather than a parametric wind model. Further, this research highlighted improvements in SLOSH modeling of inundation by incorporating wave effects from a parametric wave model in its surge calculations.

8. Applications

Coastal flooding is largely a natural event, however human influence on the coastal environment can alleviate or exacerbate the negative consequences. NOAA reports that a majority of U.S. coastal areas will face 30 or more days of flooding each year due to impacts from sea level rise by 2050 [9]. For this reason, COMT archives might be developed to support resilience assessments in locations such as those listed in Table 3. COMT can use model output and data such as NOAA water level records to investigate and qualify the influence of sea level rise on inundation.

This research is especially important to planners responsible to mitigate the effects of coastal flooding, especially increases in nuisance flooding that is currently being experienced as a consequence of sea level rise.

Table 3. Key locations for resilience assessments.

Geographic Location	Affected City
Mid Atlantic Bight	Boston, MA; New York, NY; Philadelphia, PA; Baltimore, MD; and Washington, D.C.
South Atlantic Bight	Norfolk, VA; Wilmington, NC; and Charleston, SC
Gulf of Mexico	New Orleans, LA; Tampa, FL; Houston & Corpus Christi, TX.
Caribbean	*Puerto Rico,* northern U.S. Virgin Islands, Naval Station Guantanamo Bay
West Coast	Bremerton, WA; Holy Cross, WA; Longview, WA; Bay City, OR; Portland, Oregon; Petaluma, CA; Los Angeles, CA, and San Francisco, CA
Flooding and inundation is a concern for small, low and flat islands, especially coral atolls that are found in the Caribbean (~ 15) and Pacific (~ 400). These islands are highly vulnerable to elevated sea levels caused by tropical cyclones.	

Communities that are particularly vulnerable to inundation and flooding will find that combined access to historical information (e.g., water level fluctuations), *in-situ* data (wave buoy records and hydrographic surveys), imagery (waterlines and digital elevation models), and numerical model output (spatially extensive) are essential to effective risk management and assessing resiliency. COMT will ultimately provide an archive for selected sites that could be used as another tool to develop plans to reduce vulnerabilities and adapt to change. SURA is presently planning to use the archive to develop scenarios that help planners ensure that they are resilient against future flooding and inundation events.

SURA's role in collaborative science ensures that it remains knowledgeable on state-of-the-art ocean and atmospheric modeling efforts, and can make recommendations to operational organizations such as NOAA concerning model issues, transition processes, and policy. SURA has ongoing plans to provide model assessments for the NOAA Integrated Ocean Observing System and government-university-industry partnerships involved with coastal resilience. Primary tasks help to assess and coordinate planned wave model transitions from exploratory/advanced development to operational status to ensure coherent program integration. The COMT program helps to ensure a systematic and efficient transition approach is maintained for wave and circulation models.

SURA also intends to develop the COMT archive to support mitigation decisions that could range from moving critical infrastructure farther inland to developing environmentally sustainable shore protection.

9. Conclusions

The COMT Program works collaboratively with partners from government, academia, and the private sector. Scientific communications (e.g., [1], [3], [4], [10], and [11]) are used to recommend ocean/atmosphere modeling techniques and data assimilation priorities for operational use.

Model comparisons with Integrated Ocean Observing Systems that include wave buoys, ocean current and surface meteorology buoys, tide stations, and other ocean and atmosphere observations are critical. In some locations, where there are data gaps, model simulations are especially important to provide planners with spatially extensive information on waves, flooding, and inundation.

Future efforts by the SURA COMT should support the review, quantitative verification, and gap analyses of model transition plans (general and specific) in the ongoing demonstration and operational implementation phases. COMT archives should be designed to ensure that model output and associated transition plans are responsive to operational needs.

10. Acknowledgment

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11. References

[1] Luettich, R.A., L.D. Wright, R. Signell, C. Friedrichs, M Friedrichs, J. Harding, K. Fennel, E. Howlett, S. Graves, E. Smith, G. Crane, and R. Baltes, 2013, Introduction to Special Section on the U.S. IOOS Coastal and Ocean Modeling Testbed, J. Geophys. Res. Oceans, 118, pp 1-10.

[2] Nichols, C.R., and R.G. Williams. Encyclopedia of Marine Science. New York: Facts On File, 2009

[3] Huang, Y., R. H. Weisberg, L. Zheng and M. Zijlema (2013), Gulf of Mexico hurricane wave simulations using SWAN: Bulk formula based drag coefficient sensitivity for Hurricane Ike. J. Geophys. Res., 2012JC008451, doi: 10.1002/jgrc.20283.

[4] Zheng, L, R.H. Weisberg, Y. Huang, R.A. Luettich, J.J. Westerink, P.C. Kerr, A. Donahue, G. Crane, and L. Akli (2013), Implications from Comparisons Two and Three Dimensional Model Simulations for the Storm Surge of Hurricane Ike. J. Geophys. Res., 2013JC008861, doi: 10.1002/jgrc.20248

[5] Andre J. van der Westhuysen et al. A Wave, Surge, and Inundation Modeling Testbed for Puerto Rico and the U.S. Virgin Islands: Year 1 progress. In: 95th AMS Annual Meeting, Phoenix, AZ, 4–8 January 2015.

[6] COAWST: A Coupled-Ocean-Atmosphere-Wave-Sediment Transport Modeling System, Woods Hole Coastal and Marine Science Center, United States Geological Survey, Available online. URL:

http://woodshole.er.usgs.gov/operations/modeling/COAWST/. Accessed December 30,2014.

[7] Community Model for Coastal Sediment Transport. Woods Hole Coastal and Marine Science Center, United States Geological Survey, Available online. URL: http://woodshole.er.usgs.gov/project-pages/sediment-transport/. Accessed December 30, 2014.

[8] Chen, C., R.C. Beardsley, R.A. Luettich Jr., J.J. Westerink, H. Wang, W. Perrie, Q. Xu, A.S. Donahue, J. Qi, H. Lin, L. Zhao, P.C. Kerr, Y. Meng, B. Toulany, 2013. Extratropical storm inundation testbed: Intermodel comparisons in Scituate, Massachusetts, Geophys. Res., 118, 5054-5073, doi:10.1002/jgrc.20397.

[9] Sweet, W. and J. Park, 2014. From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. Available online. URL: **http://onlinelibrary.wiley.com/enhanced/doi/10.1002/2014EF000272/**. Accessed on December 20, 2014.

[10] SURA. Workshop entitled, "Understanding and Modeling Risk and Resilience in Complex Coastal Systems," October 29 & 30, 2014, Southeastern Universities Research Association, 1201 New York Ave. NW, Washington, D.C.

[11] Luettich, R.A. et al. The IOOS / SURA Coastal and Ocean Modeling Testbed (COMT). A Wave, Surge, and Inundation Modeling Testbed for Puerto Rico and the U.S. Virgin Islands: Year 1 progress. In: 95th AMS Annual Meeting, Phoenix, AZ, 4–8 January 2015.