Incorporation of Surface Wave Effects into a Coastal Ocean Circulation Model

Lian Xie
Department of Marine, Earth and Atmospheric Sciences
North Carolina State University, Box 8208
Raleigh, NC 27695-8208
Phone: (919) 515-1435 fax: (919) 515-1683
email: lian_xie@ncsu.edu

L. J. Pietrafesa
Department of Marine, Earth and Atmospheric Sciences
North Carolina State University, Box 8208
Raleigh, NC 27695-8208
Phone: (919) 515-3717 fax: (919) 515-7802
email: leonard_pietrafesa@ncsu.edu
Award # : N00014-98-1-0652
http://cfdl.meas.ncsu.edu/ONR_report.html

LONG-TERM GOAL

Our long term goal is to improve coastal ocean predictions and understanding of currents, particle trajectories, water level, waves and tides, and other sea state and hydrographic properties by developing an advanced ocean current and trajectory simulation system. We are particularly interested in how our model products can be used in the coastal region for advanced warning of ocean conditions so life and property can be protected.

OBJECTIVES

We wish to improve upon the current state of ocean current and trajectory prediction in the coastal zone by developing an **a**dvanced **c**urrent and **t**rajectory **s**imulation **s**ystem (ACTSS) which incorporates the effects of surface waves into a coastal ocean circulation model. At the end of this project, ONR and the scientific community should have a state of the art coastal ocean wave-current model for a variety of coastal applications, and hence an enhanced capability to predict the ocean currents and sea state in the coastal zone.

APPROACH

We adopted a three-pronged approach: 1) numerical modeling, including circulation modeling, wave modeling and coupled current-wave modeling; 2) data assimilation and model verification, including using remote-sensing data from satellite and radar, in situ high-resolution measurements from the DOE OMP (Department of Energy Ocean Margins Program), and data from other ONR field projects; and 3) theoretical modeling.

Our emphases are on the separate and combined effects of waves and tides on coastal ocean currents and interactions with the atmosphere and bottom, via three processes: 1) direct wave-current interaction via radiation stress and Stokes drift; 2) effects of waves on wind stress; and 3) coupled effects of waves,

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Incorporation of Surface Wave Effects into a Coastal Ocean Circulation Model**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **North Carolina State University,Department of Marine, Earth and Atmospheric Sciences,Raleigh,NC,27695-8208**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

tides and currents on bottom stress. The effect of wave-induced wind stress is incorporated into the circulation model by using the empirical model of Donelan (1993) to compute the surface roughness length which will then be used to estimate the drag coefficient over the water surface. The effect of surface waves on bottom stress is estimated via a drag-splitting formulation (Christofferson et al., 1985). The formulation for radiation stress is according to Longuet-Higgins et al. (1964). We also wish to incorporate the wave-induced Stokes drift effect into the circulation model according to Huang (1979).

WORK COMPLETED

We began working on this project on May 1, 1998. During the first six months of this project (May 1 - October 30, 1998), we completed the following work.

- The Princeton Ocean Model (POM, Blumberg and Mellor, 1983) and a third-generation wave model (WAM III, Komen et al., 1993) have been enhanced and ported to the study area which extends from Charleston, South Carolina to Chesapeake Bay, Virginia (Figure 1).

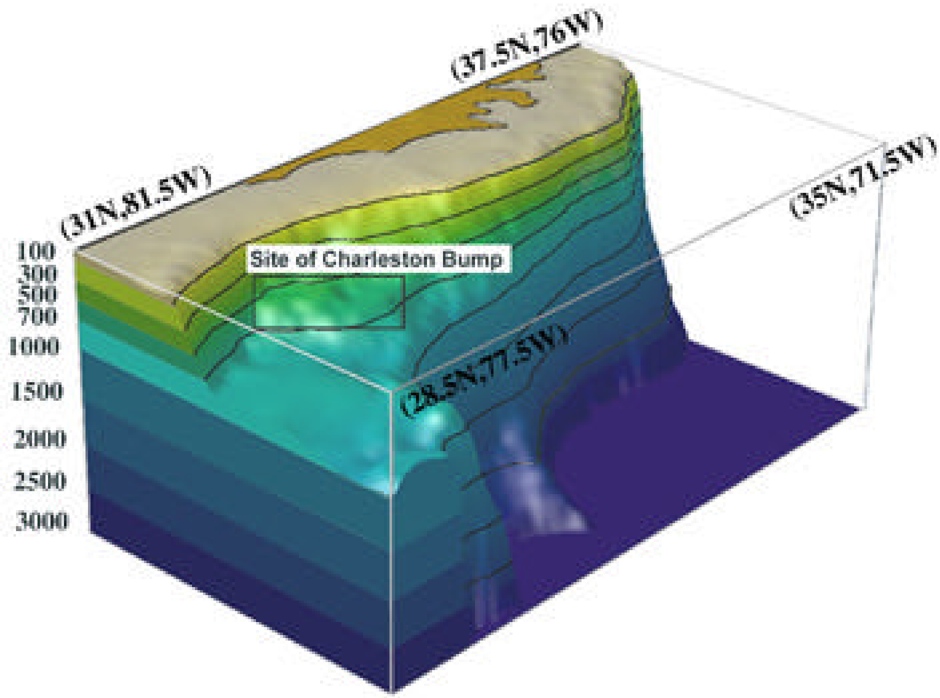

Figure 1. Model domain for the test experiments.

- The POM and the WAM models were tested independently for hurricanes Fran of 1996 and Bonnie of 1998.
- A coupler has been developed to link POM with WAM. At the present, this link is from WAM to POM only. The coupled wave (WAM)-current (POM) model will be referred to as the ACTSS test version or ACTSS0. At each time step of POM, the following coupling procedure is implemented:

a) WAM is run with prescribed surface wind field; b) the predicted wave field is used to modify the drag coefficient; c) the wind stress field is re-computed by incorporating the effects of waves; d) the modified wind stress field is used to run POM.

- The coupler was tested under uniform wind and idealized bathymetric conditions.
- The coupler was tested under realistic wind and bathymetric conditions in a hindcast mode for hurricane Fran and a forecast mode during hurricane Bonnie.
- A database was setup to archive existing wind, waves, current and other hydrographic data in the study area. Analysis of these data is proceeding well.

RESULTS

The responses of coastal ocean to moving tropical cyclones (hurricanes Fran and Bonnie) were studied by using the test version of ACTSS (ACTSS0). We found that the storm-induced variability of ocean temperature and currents exhibit two main frequency bands (Figure 2). One is located near the local inertia frequency and the other is between 5 to 7 days. Near inertia-frequency ocean response to moving storms is well documented. However, the mechanism for the low-frequency (5-7 day) oscillation is still unclear. Sensitivity experiments with and without the Gulf Stream indicated that non-linear interactions between the Gulf Stream and the storm-induced motion played an important role in the generation of the 5-7 day oscillation.

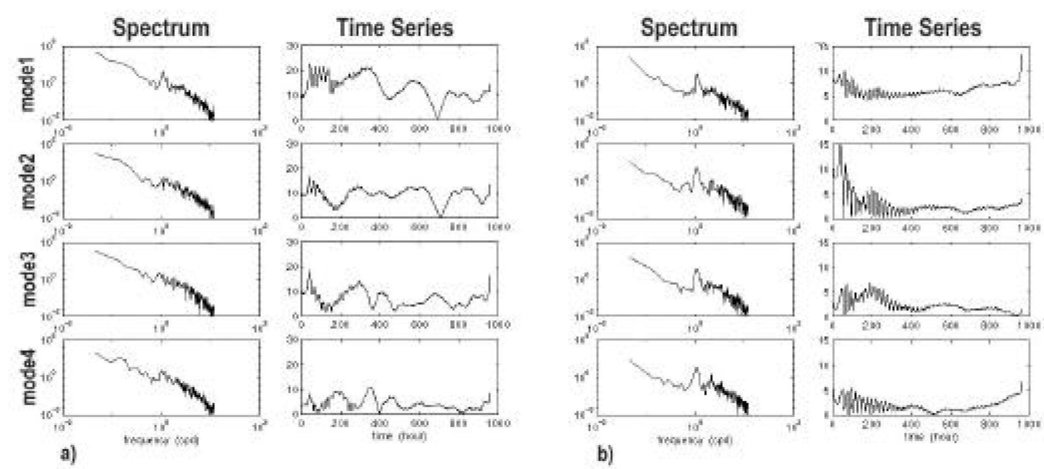

Figure 2 EOF modes of storm-induced SST change. a) with the Gulf Stream, the time series indicate two oscillations (near inertial and 5-7 day frequencies); b) without the Gulf Stream, the lower frequency oscillation is much weaker.

The model predicted storm surge (Figure 3) was also analyzed. The location and height of the peak surge offshore Wilmington, North Carolina during hurricane Fran was verified well against the observed peak surge location and intensity. The peak surge was found to be sensitive to the effects of the wave field. The peak surge predicted by ACTSS0 (3.5-4 m) was 20-30% higher than that predicted by the stand-alone POM (2.5-3 m). We have acquired all NOS coastal sea level data and the NDBC buoy wind and sea state data for further verification of the model results.

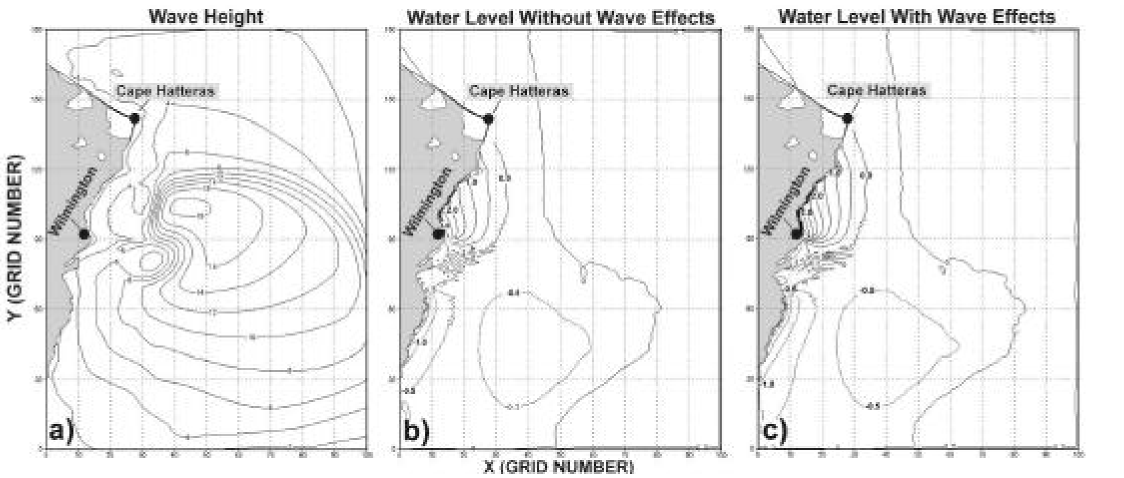

Figure 3. Simulated ocean surface wave and storm surges at 42 h simulation, validated for 2pm EDT September 5, 1996 prior to hurricane Fran's landfall. a) Wave height field; b) storm surge without wave effects; c) storm surge with wave effects.

Test experiments under uniform wind conditions indicated that ACTSS0 and the stand-alone POM would provide nearly identical water level predictions (< 5% difference) when the wind speed is 5 m/s or lower; water levels would differ by 15-20% for order 10 m/s winds, and 20-25% for order 15 m/s winds (Figure 4). However, these numbers are expected to change after wave-induced bottom stress and radiation effects are incorporated into ACTSS.

IMPACT/APPLICATION

ACTSS will be a state of the art coastal ocean prediction system. When it is completed, ACTSS should provide improved predictions of coastal ocean currents and trajectories, which have broad applications in naval research and operations, and in physical, bio-geochemical and geological process studies. Our finding of the existence of a low-frequency (5 -7 day) response of coastal ocean to tropical cyclones, if verified by observations, would provide new insights to the understanding of coastal ocean dynamics under the influence of intense atmospheric forcing.

TRANSITIONS

Our experimental storm surge forecast during hurricane Bonnie of 1998 was used by the National Weather Service Raleigh Forecast Office as a real-time storm surge forecast guidance.

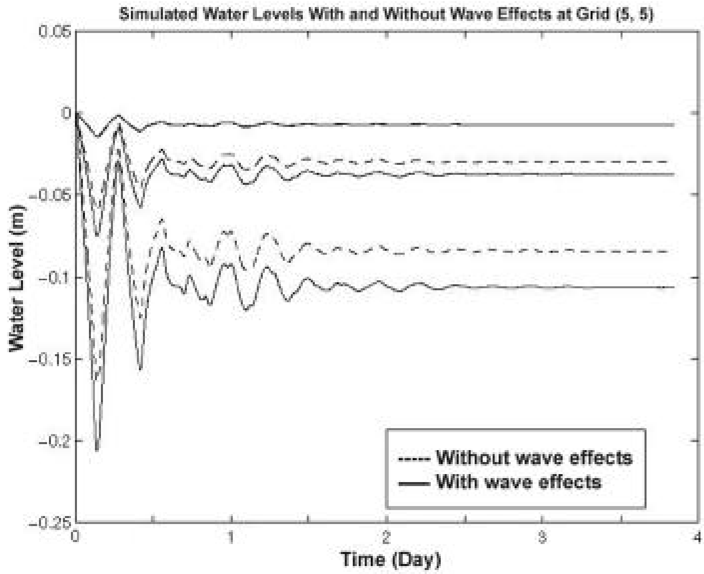

Figure 4. Simulated water levels at Grid point (5, 5) (Fig. 3) under 5 (upper two curves), 10 (middle two curves) and 15 m/s (bottom two curves) southerly winds with (solid curves) and without (broken curves) wave effects.

RELATED PROJECTS

ACTSS will be the centerpiece of a Regional Earth System model (RegESM) that is under development at the Coastal Fluid Dynamics Laboratory of North Carolina State University. Three other components of the RegESM are currently being developed in collaboration with other scientists at NCSU.

1. The coupling of ACTSS to a mesoscale atmospheric model is underway in collaboration with Drs. F. Semazzi and S. Raman (NCSU).

2. Dr. T.S. Hopkins and Dr. L. Xie are collaborating on a project to develop an improved air-sea-ice model for the Arctic Ocean.

3. Dr. D. Eggleston and Dr. L. Xie are developing a physical-biological coupled model to study the recruitment patterns of blue crabs in North Carolina coastal waters and estuaries.

REFERENCES

Blumberg, A.F. and G.L. Mellor, 1983: Diagnostic and prognostic numerical circulation studies of the South Atlantic Bight. J. Geophys. Res., 88, 4579-4592.

Christofferson, J.B. and I. G. Jonssen, 1985: Bed friction and dissipation in a combined current and wave motion. Ocean Engineering, 12, 387-423.

Donelan, M.A., F.W. Dobson, S.D. Smith, 1993: On the dependence of sea surface roughness on wave development. J. Physical Oceanography, 23, 2143-2149.

Huang, N.D., 1979: On surface drift currents in the ocean. J. Fluid Mech., 91, 191.

Komen, G.J., Cavaleri, M Donelan, K. Hasselmann, S. Hasselman, P.A.E.M., Janssen, 1993: Dynamics and modeling of ocean waves. Cambridge University Press, Cambridge, 532pp.

Longuet-Higgins, M.S. and R.W., Stewart, 1964: Radiation stress in water waves, a physical discussion with applications. Deep Sea Research., 11, 529-562.

PUBLICATIONS

Xie, L., C. Zhang, L.J. Pietrafesa, A. Xiu, and K. Wu, Upper ocean response to moving tropical cyclones in the presence of large sea surface temperature gradient and complex topography. Preprints, 23rd Conference on Hurricanes and Tropical Meteorology, American Meteorological Society.