Using Hydrodynamic Models to Interpret Remote Sensing Images of the Sea Surface

James T. Kirby
Center for Applied Coastal Research
University of Delaware
Newark, DE 19716
phone: (302) 831-2438 fax: (302) 831-1228 email kirby@udel.edu

Robert A. Dalrymple
phone: (302) 831-6531 fax: (302) 831-1228 email rad@udel.edu

Grant Number: N00014-97-1-0283
http://www.coastal.udel.edu

LONG-TERM GOALS

Our goals are to develop methodologies for determining bathymetry in the nearshore zone, using various types of remotely sensed images of the water surface as input. We are particularly interested in the surf zone, where linear water wave theory provides a poor description of the behavior of individual wave crests.

OBJECTIVES

The objectives of the project are to:

(1) Develop a synthetic data set, based on Boussinesq wave model predictions, representing a number of cases of waves propagating over characteristic nearshore bathymetries.

(2) Compare model results to available Sandy Duck field data.

(3) Study the feasibility of solving the inverse problem for bathymetry from measured surface data, using a wave model to determine wave phase speeds and wave-induced height and velocity fields.

APPROACH

In order to do the inverse problem, which involves using surface waves and wave-induced currents to determine bathymetry, the Boussinesq model FUNWAVE (with new treatment of wave breaking and shoreline runup) has been further enhanced by incorporating periodic lateral boundaries and a directional, random wavemaker to represent the offshore wave source in the field. This version of the model has been used to study the longshore current, shear instabilities of longshore currents generated by multiple directional waves, and the generation of edge waves at a beach.

As a continuation of the model application/verification, much of the effort in the second year of the project has been focusing on the comparison of the Boussinesq model prediction with the DELILAH field measurements as well as laboratory experiments on longshore currents (Chen et al., 1999). Satisfactory agreement between the numerical results and field measurements has been found.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**
4. TITLE AND SUBTITLE **Using Hydrodynamic Models to Interpret Remote Sensing Images of the Sea Surface**		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) **University of Delaware,Center for Applied Coastal Research,Newark,DE,19716**		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

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)**	**4**	

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

Several new depth inversion methods have been developed since Dalrymple et al (1998) and tested using synthetic data (Kennedy et al., 1999a), based on an assumption that dense surface elevation and velocity maps of the water surface could be obtained at two closely spaced times. Since such complete environmental data is unlikely to be obtained, an alternate method has been developed that requires two snapshots of either the surface velocity or the surface elevation to perform the depth inversion. This method has been tested for one horizontal dimension using synthetic data (Misra et al., 2000). However, due to the continued unavailability of interferometric synthetic aperature radar (INSAR) data, it is unlikely that work will continue on this topic.

WORK COMPLETED

To aid in the accurate representation of nearshore phenomena, Boussinesq wave equations with considerably improved nonlinear behavior have been derived, tested, and implemented in the Boussinesq model (Kennedy et al., 1999b; Kennedy et al., 2000a). Further formulations leading to improvements in vorticity and shoaling are being considered.

The enhanced Boussinesq model, including sequential and parallel computing codes, provides a working tool for the realistic reproduction of the free surface and the underlying wave-induced currents measured in the surf zone, as judged by comparisons of the model prediction with the DELILAH measurements (Chen et al., 2000b,c). Figure 1 illustrates the computed wave field and the unsteady longshore current with southeast incident waves. A comparison of the numerical model results with the measurements along a cross-shore transect is shown in lower panels. The agreement is fairly good. We notice from the model results that the presence of scour trough under the FRF pier has significant effects on the wave field in the area adjacent to the pier (observed by Elgar and Guza in their ONR Coastal Dynamics project). The combined wave refraction/diffraction by the seabed depression results in longshore verifications of wave incidence and wave height at the shoreline near the pier, which leads to the meandering of the alongshore current. One striking result of the simulation is its prediction of the large longshore current shoreward of the bar crest as found during the DELILAH field experiment.

The inverse modelling work is proceeding using video time series from ARGUS stations, supplied by Rob Holman. A coupled Boussinesq-video method that uses no assumption of wave linearity is under development. In addition to nearshore bathymetry, it is anticipated that information about nearshore circulation, wave period and direction will be natural byproducts, along with some information about the directional spread. Possibly, wave height may be inferred.

RESULTS

An improved Boussinesq numerical modelling code for nearshore waves and wave-induced currents is presently available. The source code and user's manual of the Boussinesq model have been made available to the research and engineering community through the Center of Applied Coastal Research web page and the FUNWAVE 1.0 Documentation and User's Manual (Kirby et al., 1998).

Several depth inversion schemes have been developed for INSAR type data or for surface elevation data obtained at two separate times. These schemes will be published within a year.

A major result of the work to date is that the depth inversion problem is solvable, given a reasonable amount of initial data (surface elevation, for example). It is not necessary to have both the water surface and the surface water particle velocity vectors–all variables that uniquely initiate a Boussinesq model.

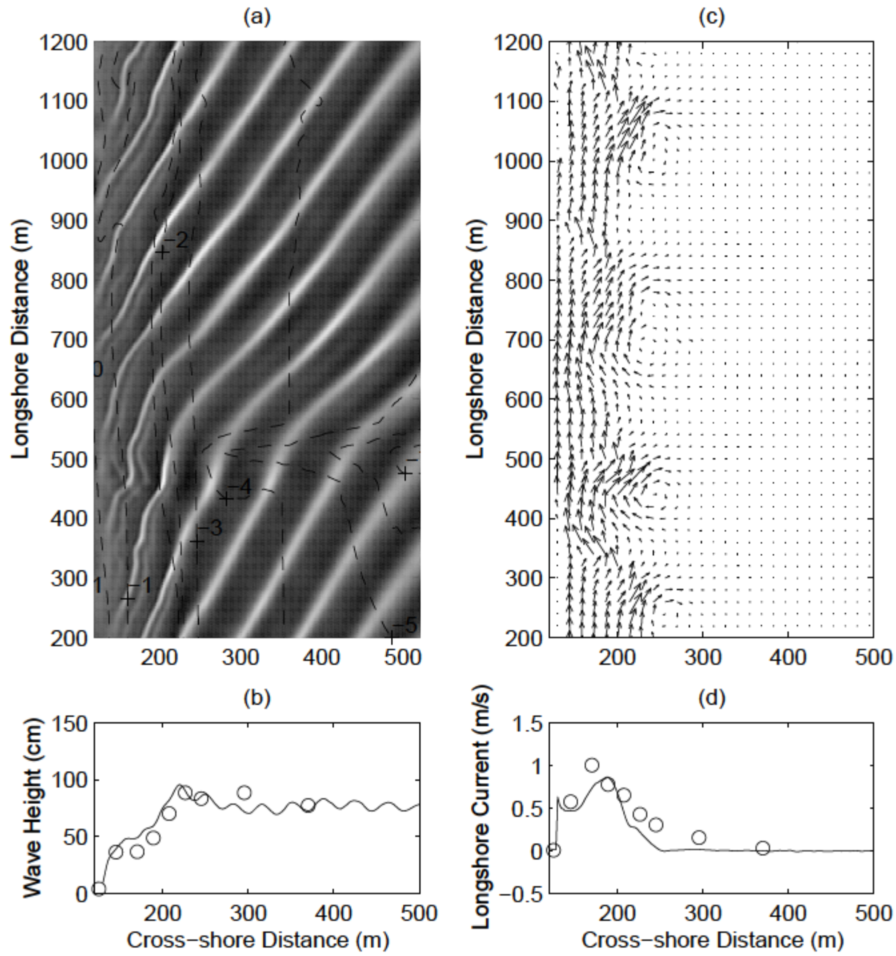

Figure 1: **(a) A snap shot of the computed wave field. The dashed lines are the contour of water depth. (b) Comparison of computed (-) and measured (o) wave height. (c) A snap shot of the underlying current field. (d) Model/data comparison of longshore currents.**

IMPACT/APPLICATIONS

FUNWAVE provides the nearshore community with a wave model that also predicts wave-induced currents and instabilities.

Depth inversion schemes allow the determination of the bathymetry remotely. While this topic has been of concern since the Normandy invasion, modern numerical models of the wave field and new remote sensing platforms permit the development of far more accurate tools.

RELATED PROJECTS

1 – Rob Holman is providing us with video data for remote sensing data to replace the absence of INSAR data.

REFERENCES

Chen, Q., Kirby, J.T., Dalrymple, R.A., Kennedy, A.B., and Shi, F. 2000b. Boussinesq modeling of longshore currents. In preparation for Journal of Geophysical Research.

PUBLICATIONS

Chen, Q., Dalrymple, R.A., Kirby, J.T., Kennedy, A.B., and Haller, M.C., 1999. Boussinesq modeling of a rip current system. Journal of Geophysical Research, 104 (C9): 20,617-20,637.

Chen, Q., Kirby, J.T., Dalrymple, R.A., Kennedy, A.B., and Chawla, A. 2000a. Boussinesq modeling of wave transformation, breaking and runup. II: 2D, in press, Journal of Waterway, Port, Coastal. and Ocean Engineering.

Chen, Q., Kirby, J.T., Dalrymple, R.A., Kennedy, A.B. 2000c. Boussinesq modeling of waves and longshore currents under field conditions. Abstract, 27^{th} International Conference on Coastal Engineering, ASCE, Sydney.

Dalrymple, R.A., A.B. Kennedy, J.T. Kirby, and Q. Chen 1998. Determining Images from Remotely Sensed Images, Proceedings, 26^{th} International Conference on Coastal Engineering, ASCE, Copenhagen, 2395-2408.

Gobbi, M. F., Kirby, J. T. and Kennedy, A., 2000, On the consistency of fully nonlinear Boussinesq models and their ability to predict vertical vorticity fields, Abstract 27^{th} International Conference on Coastal Engineering, ASCE, Sydney.

Kennedy, A.B., Chen, Q., Kirby, J.T., and Dalrymple, R.A. 2000a, Boussinesq modeling of wave transformation, breaking and runup. I: 1D, in press, Journal of Waterway, Port, Coastal, and Ocean Engineering.

Kennedy, A.B., Dalrymple, R.A., Kirby, J.T., and Chen, Q., 2000b. Depth inversion using direct Boussinesq modeling. in press, Journal of Waterway, Ports, Coastal, and Ocean Engineering.

Kennedy, A.B., Kirby, J.T., Chen, Q., and Dalrymple, R.A. 1999b. Boussinesq-type equations with improved nonlinear behaviour. Submitted to Proc. Roy. Soc. A, July.

Kennedy, A.B., Kirby, J.T., Chen, Q., and Dalrymple, R.A. 2000c. Improved nonlinearity in Boussinesq-type equations. Abstract, 27^{th} International Conference on Coastal Engineering, ASCE, Sydney.

Kirby, J.T., Wei, G., Chen, Q., Kennedy, A.B. and Dalrymple, R.A. 1998. FUNWAVE 1.0: Fully Nonlinear Boussinesq Wave Model–Documentation and User's Manual, Research Report No. CACR-98-06, Center for Applied Coastal Research, University of Delaware.

Misra, S.K., Kennedy, A.B., Kirby, J.T. and Dalrymple, R.A., 2000. Determining water depths from surface images using Boussinesq equations. Abstract, 27^{th} International Conference on Coastal Engineering, ASCE, Sydney.