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

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LONG-TERM GOALS

Our goal is to develop methodologies for determining bathymetry in the nearshore zone, using various types of remotely sensed images of waves as input. These methods obviate the need for direct measurements in the field, which can be both costly and hazardous. We are particularly interested in the surf zone, where linear wave theory provides a poor description of the behaviour of individual wave crests. An ancillary goal is to improve the current Boussinesq model, such that it provides the necessary inputs with appropriate accuracy.

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 Field Research Facility (FRF) field data.
3. Study the feasibility of solving the inverse problem for bathymetry from measured surface data, using a Boussinesq wave model to determine wave phase speeds and wave-induced height and velocity fields.
4. Improve the applicability and performance of nearshore Boussinesq wave and current models.

APPROACH

A two-pronged approach has been taken toward the goal of inferring nearshore properties using hydrodynamic models and remotely sensed measurements. The first direction looks to improve our representation of nearshore hydrodynamics, while the second uses these models to interpret remotely sensed images of the nearshore.

As an example of the first approach, we have improved prediction of wave height for shoaling waves in the nearshore (Kennedy *et al.*, 2000c). This was accomplished by generalising previous formulations of the Boussinesq wave theory to exploit degrees of freedom that had not previously been utilised. The new formulation has a significantly improved shoaling range, with no drawbacks. An example of the second approach is that of Misra *et al.* (2000), where a quasi-frozen assumption was used with Boussinesq equations in order to infer water depths from two time-lagged images of the water surface. Together these twin approaches have led to significant improvements in our capabilties to predict nearshore hydrodynamics and to use this to infer water depths.

WORK COMPLETED

There have been numerous recent results improving our basic representation of nearshore hydrodynamics using Boussinesq equations. Some of the earlier completed work gave us the capability to predict a wide variety of phenomena including wave shoaling, breaking, setup, runup and wave-induced currents (Kennedy *et al.*, 2000a; Chen *et al.*, 2000a). This improvement of the Boussinesq model from a pure wave transformation tool to a comprehensive nearshore hydrodynamics model represents a significant advance. We now have the capability to represent a very wide variety of nonlinear nearshore phenomena such as unsteady rip currents and longshore currents with good accuracy (e.g. Chen *et al.*, 1999, 2000b).

More recent work has concentrated on improving the basic accuracy of the Boussinesq formulations used. The extensions of Kennedy *et al.* (2000b) gave significant improvements in the representation of nonlinear waves with no significant complications. Similarly, Kennedy *et al.* (2000c) gave a wide variety of improvements, from improved shoaling in intermediate depths to increased accuracy in representing wave speeds in relatively deep water. This paper also detailed some simplified higher order equations, which can give some higher order accuracy, but only show lower order terms (also Kennedy *et al.* 2000d). Some of these changes have been implemented in a parallel version of FUNWAVE written in High Performance Fortran. A different approach has led to the improved representation of vertical vorticity in the model equations (Chen *et al.*, 2000b, Gobbi *et al.*, 2000). These have been implemented, and provide improvements over older formulations. Representation of nearshore hydrodynamics using Boussinesq equations is improving steadily.

Comparisons with field and laboratory data show a good representation of nearshore wave height and wave-induced cross-shore and longshore currents (Chen *et al.*, 1999, 2000b, 2001). In its present form, the model is now capable of predicting wave heights, directions, nonlinear interactions, breaking, runup, and wave-induced currents with reasonable accuracy. Unsteady processes are particularly well described compared to other wave transformation models.

Inversion models have been developed for radar data that had previously been assumed to be available. These include Dalrymple *et al.* (1998), which looked at several different linear inversion methods. Using a Boussinesq model, Kennedy *et al.* (2000b) developed a method to find water depths using two lagged snapshots of water surface elevations and velocities. Misra *et al.* (2000) used a “quasi-frozen” assumption to arrive at a simpler technique that required snapshots of either surface velocities or elevation. All of these were tested using synthetic data, as field data was unavailable. This lack of data has led us to discontinue work on radar-based inversions.

We are now using video-based inversion techniques, inferring nearshore bathymetries (and indirectly nearshore hydrodynamics) by matching wave phase speeds and breaking patterns. Figures - show preliminary work (Kennedy *et al.*, 1999) using data supplied by Rob Holman of Oregon State

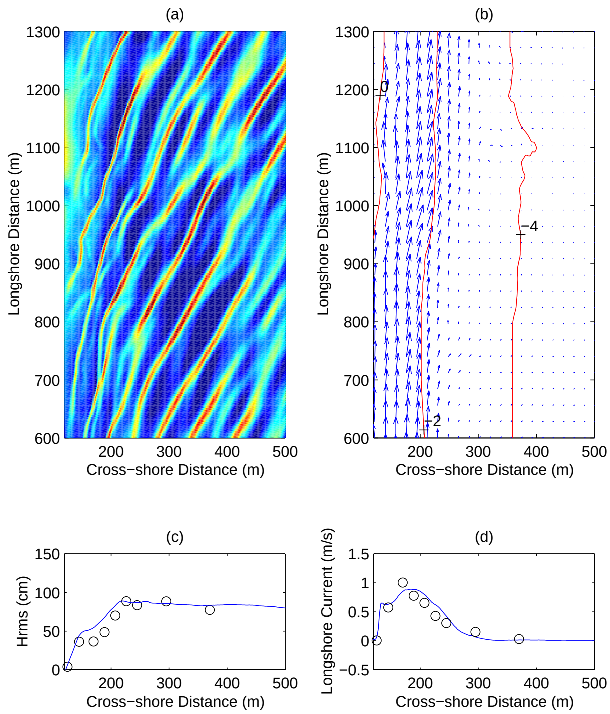

Figure 1: Computed instantaneous water surface (a); Wave-averaged current vectors (b); measured and computed H_{rms} (c); computed and measured mean longshore current (d) during DELILAH at Duck, NC.

University, showing that this approach can give detailed estimates of bathymetry, particularly in the surf zone where other video-based methods experience problems. It also provides the means of resolving a depth *vs.* current ambiguity which appears in most other inversion methods. However, due to the relatively late switch from radar to video, it has become apparent that this task will not be completed by the end of the project. This has also prevented use of John Dugan's AROSS data. Efforts are now underway to secure additional funding from other sources.

RESULTS

An extended Boussinesq model has been documented and released by our center for general use by the nearshore modelling community. Both source code and users manual are freely available from the Center for Applied Coastal Research through a software support page at http://chinacat.coastal.udel.edu/ kirby/programs/. FUNWAVE has begun to be adopted by numerous external users.

Several depth inversion schemes have been developed and published. These indicate that, given reasonable data, depth inversion is indeed possible using current technology. While best results need estimates of surface elevations and velocities, it is possible to produce reasonable estimates with less complete data sets. However, the data must be both reasonable and available.

IMPACT/APPLICATIONS

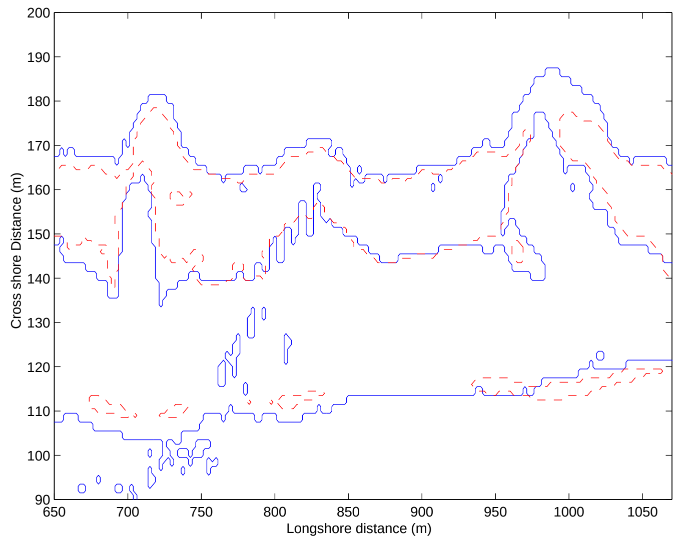

Figure 2: Estimated (- -) and measured (–) wave breaking patterns for final iterated bathymetry.

FUNWAVE provides the nearshore community with a wave model that also predicts wave-induced currents and instabilities. The Boussinesq approach is expected to be viable for many years to come, and will provide estimates of nearshore hydrodynamics with ever-increasing accuracy. FUNWAVE is being used in the NOPP Nearshore Community Model project as a means for creating phase resolved time series of nearshore wave heights and velocities. These are being used to drive simulations of sediment transport and to aid in the parameterization of various processes in wave-averaged models.

Depth inversion schemes allow the remote determination of bathymetry, which is of interest in both military and civilian applications.

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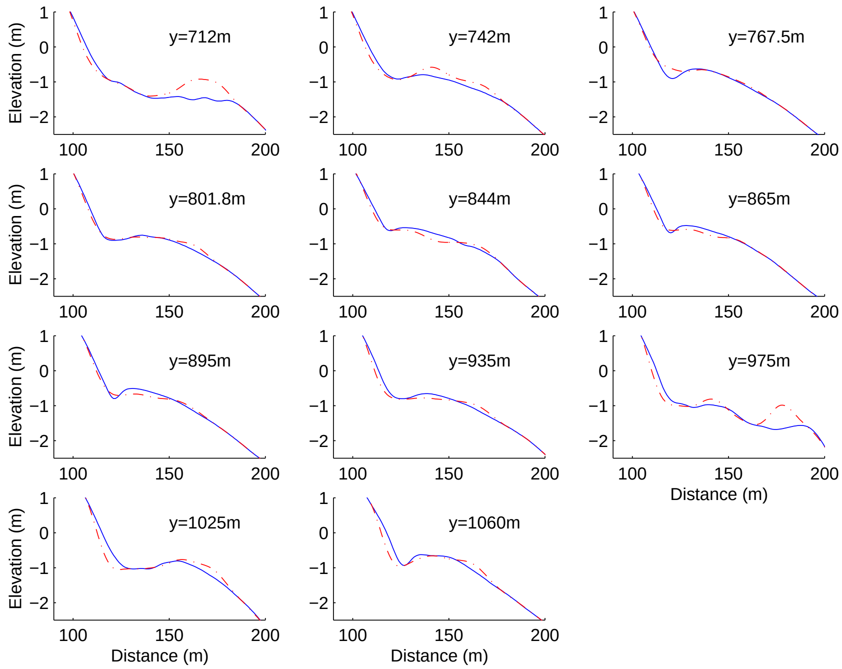

Figure 3: Estimated $(- \cdot -)$ ***and measured*** $(-)$ ***bathymetric cross sections at Duck, NC.***

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