Nonlinear and Dissipation Characteristics of Ocean Surface Waves in Estuarine Environments

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LONG-TERM GOALS

The overall goal of this work is the development of computational modules for the dissipation of surface wave energy due to expanses of bottom mud and marshland vegetation. The computational modules would represent both the dissipative effects on the surface waves and the effects of dissipation on other processes of wave transformation and evolution. In addition these modules would allow for feedback between the surface wave and the energy dissipating feature.

OBJECTIVES

1) Develop processes models of the physics of dissipation in estuarine areas.
2) Use optimized ensemble simulations to represent effects of dissipation on wave processes.
3) Develop and test low-dimension, reduced representations of estuarine effects for inclusion into operational wave models.

4) Develop experimental versions of operational wave models.

APPROACH

We will first work to develop computational models for detailed, phase-resolved predictions of wave dissipation in estuarine areas. These models will include various mud proxy models (viscous fluid, viscoelastic semi-rigid bed, Bingham plastic) for wave/mud interaction and mud-induced dissipation. These proxy models for mud dissipation have fairly broad-banded responses over a large swath of wave frequencies, so they can be expected to inhibit various nonlinear interactions in the random wave field. The task here will be to surmise whether this frequency dependence is scalable or self-similar over a range of frequencies, conditions or proxies. In addition the feedback between surface and lutocline waves will be investigated to determine whether or not these interactions have an effect on surface wave energy; allowing for surface-lutocline interaction can potentially *redirect* surface wave energy rather than simply dissipate it. A similar line of inquiry will be performed for wave-vegetation interaction, though the expected parameter space for this phenomena may be significantly reduced compared to mud dissipation. These models will be validated with available data.

To make this suitable for a random wave spectral model (as most operational wave models are), we must find ways of randomizing our results with the deterministic models. One possible method would be the use of a neural network approach, which uses data from the models to establish a "training set" which helps predicts future behavior. The neural network mapping strategy of Krasnopolsky et al. (2002) will be one candidate for use; it was used for the Wavewatch-III © model, and should be available for use here.

In addition, and in concert with the project "Development of Numerical 3-Wave Interactions Module for Operational Wave Forecasts in Intermediate-Depth and Shallow Water" (PI: Sheremet; co-PI: Kaihatu) we will investigate physically-justifiable reduced dimension models which will retain the dominant components of wave-mud-vegetation interaction but will also allow for more expedient calculation. Furthermore, for further application of the model to a wider range of areas, we are also investigating the dissipation of waves over steep bathymetry, such as reefs.

Finally we will make use of the models developed above to create experimental versions of operational models. This will allow us to test the physics in the developed models while using the general framework of operational wave models. We will conduct robustness tests of the system to determine the conditions under which the new models exhibit sub-optimal behavior. We will also work with the NCEP and NAVO (if available) operational forecasters, as well as the scientific community at the Naval Research Laboratory (NRL) and Engineering Research and Development Center (ERDC) to insure smooth incorporation of these developments into their operational run stream.

The TAMU team consists of the PI (Kaihatu); an M.S. students (Mr. Aravinda Venkattaramanan); and two Ph.D. students (Ms. Samira Ardani and Mr. John Goertz). Ms. Ardani is working on quantifying the performance of nearshore nonlinear models with field data and reforumlating them for more comprehensive performance. Mr. Goertz is quantifying the dissipation which occurs over steep bathymetry. Mr. Venkattaramanan is investigating nonlinear wave processes through vegetation. The UF team consists of Alex Sheremet (PI), Miao Tian and Cihan Sahin (Ph.D. students) who are working on modeling nonlinear wave evolution in dissipative environments (mud), and the response of sea bed to wave action. In addition, a research assistant scientist (Justin Davis) has been working on testing a directional nonlinear wave code and implementing this into the WAVEWATCH-III model.

WORK COMPLETED

We have used Duck94 data to compare the performances of several models: the consistent model of Freilich and Guza (1984); the dispersive nonlinear model of Kaihatu and Kirby (1995) and Kaihatu (2001); the transformed dispersive nonlinear model of Eldeberky and Madsen (1999); and the hybrid model of Mase and Kirby (1992). All models are based on triad near-resonant interactions for the nonlinearity, but differ in the details. The Freilich and Guza (1984) model is weakly dispersive, in line with the assumptions behind the Boussinesq equations from which it was derived. The Kaihatu and Kirby (1995) model is also a triad interaction model with fully dispersive shoaling and nonlinear coefficients. The Kaihatu (2001) and Eldeberky and Madsen (1999) models are related to the Kaihatu and Kirby (1995) model, but use different methodologies to make up a particular shortcoming of the earlier model: an incomplete transformation between the velocity potential and the free surface elevation.

We have also continued our work on incorporating vegetation effects into nonlinear models. These lead to interesting behavior because, like mud, the dissipation is strongly frequency dependent. In the case of vegetation, the dissipation rate mechanisms used (Kobayashi et al. 1993; Mendez and Losada 1999) are based on the Reynolds number, the evaluation of which is somewhat ambiguous in an irregular wavefield. We have attempted several different methods for determining the optimum estimate for Reynolds number. We have also received several data sets from the Coastal and Hydraulics Laboratory of the US Army Corps of Engineers of wave propagation over synthetic vegetation in the laboratory, and are presently using these data for validation purposes.

We are also continuing our work investigating the breaking of waves over steep slopes. In particular, we are investigating ways of determining dissipation from laboratory measurements and evaluating the probabilistic characteristics. This is an alternative to many other probability-based dissipation methods which use Rayleigh distributions on waveheights to infer dissipation characteristics.

We have used parabolic nonlinear models which incorporate dissipation by mud to determine the effect of wave directonality on wave-mud interaction along the central Louisiana coast. A sensitivity study of wave evolution over a mud patch (representative of the field situation) using waves arriving at different directions was performed.

The 1D (shore perpendicular) nonlinear triad interaction model (based on Agnon and Sheremet 1997) has been extended to allow waves approaching the shore from any angle, including all attendant interactions across both frequency and directions. This system of equations is solved over a 2D frequency (f) and shore parallel wave number (κ) space. The original code has been restructured to optimize memory and allow more expedient operation.

RESULTS

Nonlinear Wave Model Verification: The comparisons of the weakly dispersive and fully dispersive nonlienar triad models to Duck94 data proved to be somewhat inconclusive. We had anticipated that the dispersive models would replicate the shoaling process of waves at Duck with more fidelity than the weakly-dispersive models. However, no such clear indication was apparent. It is possible that the dispersive nature of the nonlinear terms in the fully dispersive models may cause the interactions to detune and negatively impact the energy transfer. The model does not have a natural asymptote to a Stokes-type wave in deeper water. We are presently working on a reformulation of the model which might allow better behavior in deeper water.

Incorporation of Vegetation-Induced Dissipation: The vegetation-induced dissipation mechanisms of Kobayashi et al. (1993) and Mendez and Losada (1999) were included in the nonlinear wave model of Kaihatu and Kirby (1995). The model was first compared to the data of Dubi and Torum (1995). For this data set, only the room-mean-square waveheights were published; it was shown that the model with the dissipation model of Mendez and Losada (1999), which accounted for vegetation motion, performed best. Wave spectra from the model was also calculated. These are shown in Figure 1. Present work involves model validation with the USACE data set, including comparisons of skewness and asymmetry over the vegetation field.

Directional Effects in Wave-Mud Interaction: A sensitivity study was performed with a parabolic nonlinear wave model to determine how comparisons of Louisiana shelf wave-mud interaction data and model would fare if wave direction were accounted for. One example for a wave propagating at 30 degrees to shore normal is shown in Figure 2. This comparison evidences improved comparison relative to those propagating at shore normal. Present work includes processing directional data from the central Louisiana site to obtain the actual wave directions.

Nonlinear Directional Model: The optimized implementation of the model of Agnon and Sheremet (1997) has been tested and is presently being evaluated. At the moment we are focused on the model's sensitivity to frequency-directional resolution, since this has a direct impact on computational time and efficacy in incorporation into a larger scale predictive model such as WAVEWATCH-III. Figure 3 shows a JONSWAP spectrum with a cosine-squared distribution, remapped into (f, κ) space, evolved by the model from a water depth of 10 m to 2 m.

IMPACT/APPLICATIONS

The present research extends the predictive capability of the Navy's wave forecasts by treating areas that are far removed from the non-cohesive sedimentary environments which have underpinned work in wave propagation. These mechanisms, when incorporated into operational Navy wave prediction models, can improve operational predictions in shallow, muddy areas or areas with steep bathymetry.

RELATED PROJECTS

This work is done in collaboration with ONR funded research (PI: Sheremet) to develop sediment transport forecasting capabilities for muddy areas.

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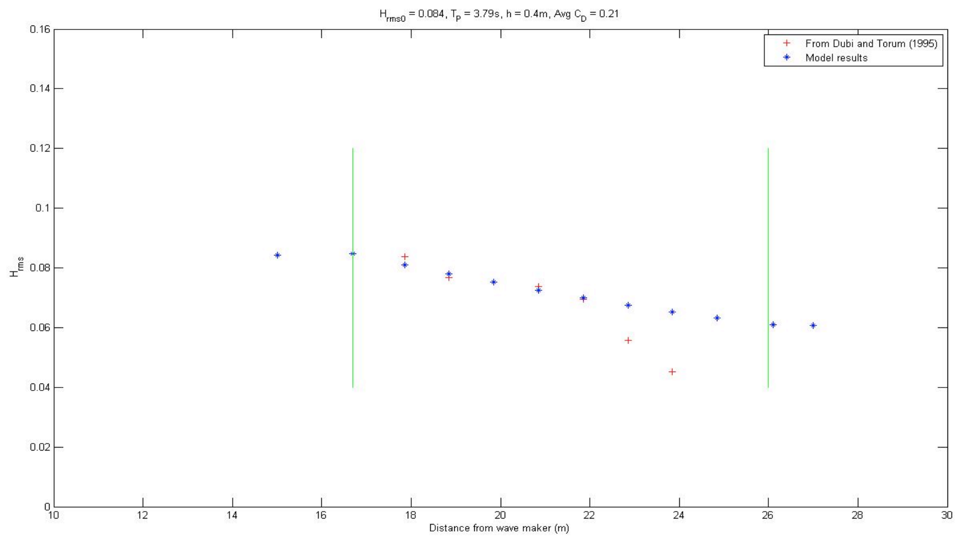

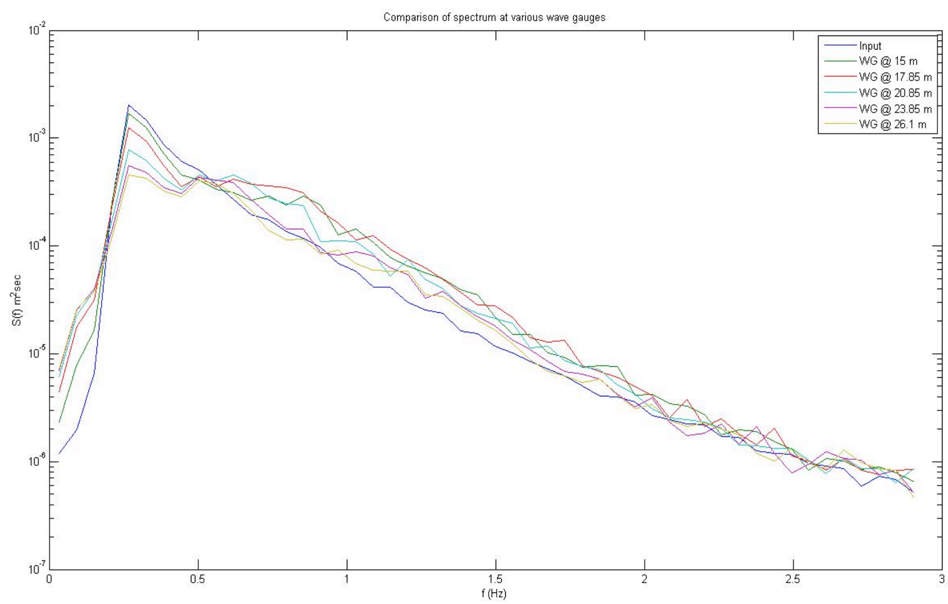

Figure 1: Comparison of nonlinear wave-vegetation model to data from Dubi and Torum (1995). Top: Comparison of H_{rms} – data shown in red. Bottom: Spectra from the wave model – broadening of the spectrum with distance through the vegetation field is evident.

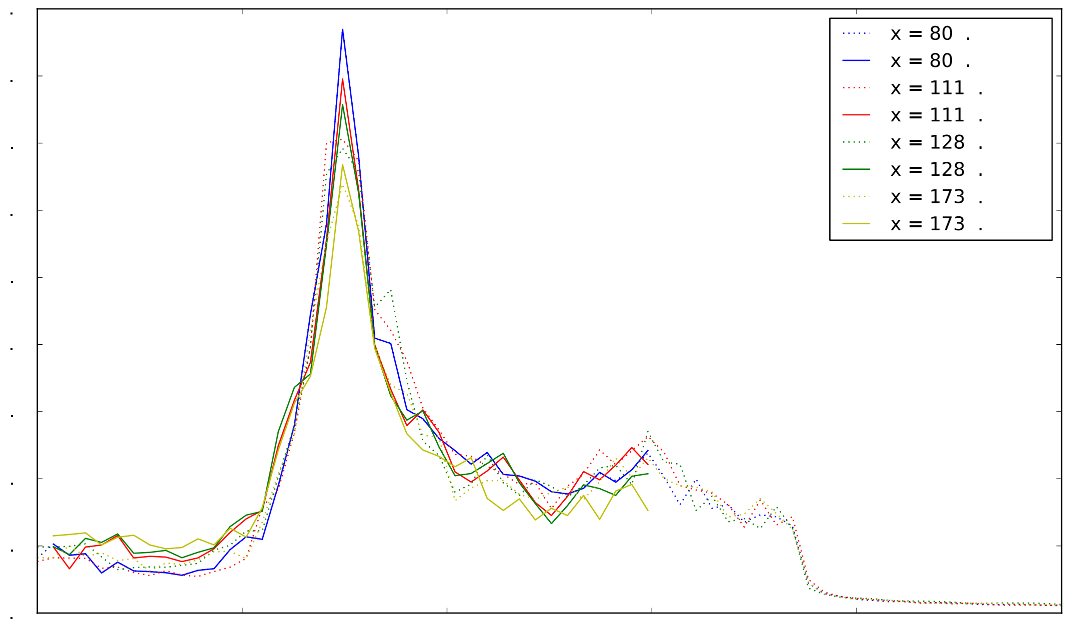

Figure 2. Comparison of spectra from parabolic nonlinear wave model (solid line) to data from Louisiana shelf experiment (dotted line). Input waves were oriented 30 degrees to shore normal; comparisons to data here are more favorable than those oriented normal to shore.

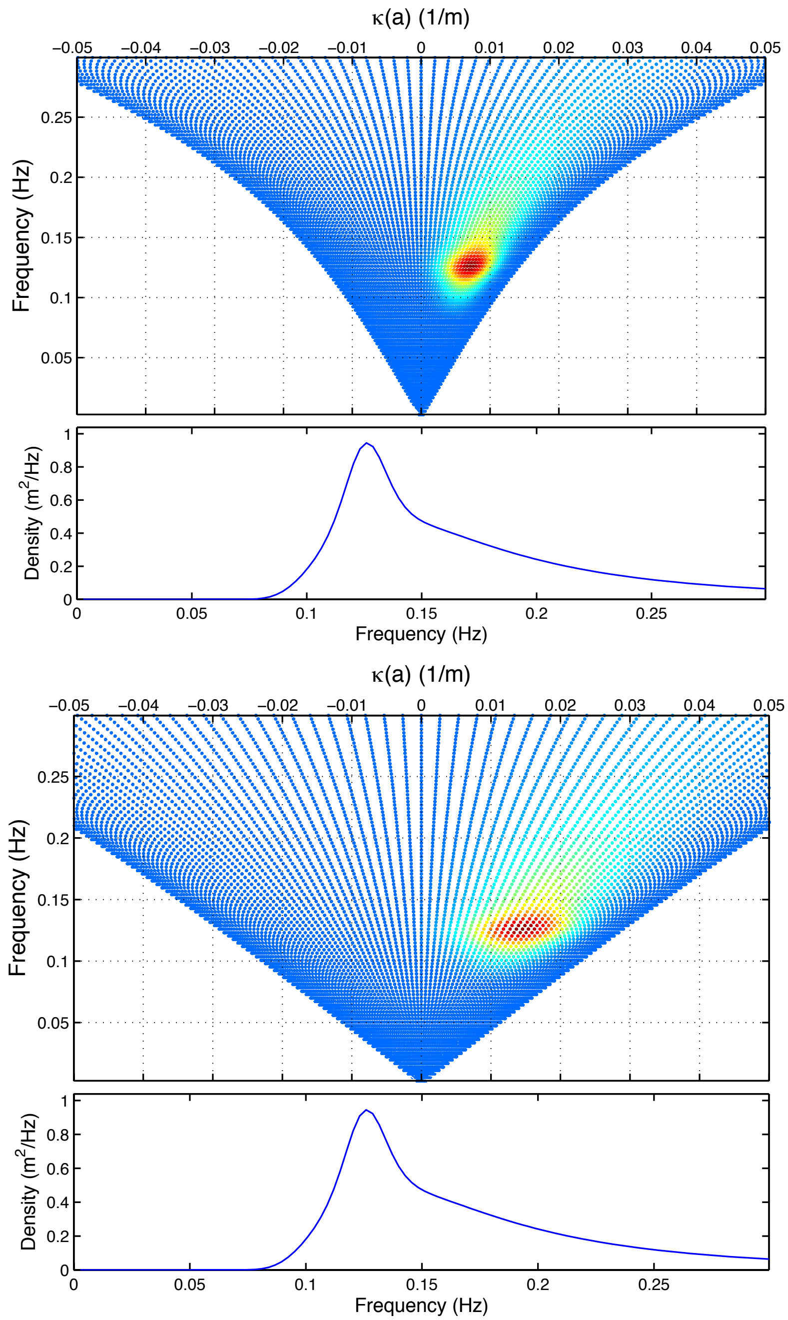

Figure 3. Output from the nonlinear directional wave model. Top: Initial condition – directional spectrum at h=10m remapped into (f,κ) space. Bottom: Model output at h=2m.