Data-Driven Boundary Correction and Optimization of a Nearshore Wave and Hydrodynamic Model to Enable Rapid Environmental Assessment

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LONG-TERM GOALS

The present project is part of a comprehensive effort by the PI, his students, and collaborators at the Naval Research Laboratory to increase the robustness and viability of the Delft3D model suite as an operational forecasting tool, and aid its continued transition to Navy forecasting centers. Prior projects have focused on determining the model's response to characteristics and sample sizes of bathymetric information. The present project focuses on determining the effect of boundary errors on model response, and the development of methods to ameliorate these issues.

OBJECTIVES

The objectives are:

1) Investigate the effect of boundary forcing errors on the model response.
2) Implement a 1D wave driver on the lateral boundaries.
3) Develop methods for correcting the boundary errors to optimize model accuracy.

APPROACH

Among the recent enhancements to the utility of the Delft3D model for nearshore process simulation include the implementation of Neumann lateral boundary conditions (Roelvink and Walstra 2004), which allow for flow to enter and leave the lateral boundaries with no artificial circulation. This boundary condition is formulated by reducing the flow equations in the hydrodynamic model to a single dimension, which has the effect of setting conditions on the *gradient* of the velocities rather than on the velocities themselves. For wave-induced flow, however, one consequence is the need to have a wave-model grid that is significantly wider than the hydrodynamic model grid; this is done in order to keep irregularities in the forcing away from the boundaries of the hydrodynamic model. However, SWAN, the wave model for Delft3D, requires significant iterative steps, and as such is a computational chokepoint for forecast turnaround.

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Our work is divided into two parts. The first part will look at the effect of errors along the boundary, seeking a balance between computational efficiency and erroneous computation. The second part looks for ways of correcting the errors along the boundary, using data in the domain to perform this correction.

One aspect of the error analysis we are investigating is the effect of reducing the lateral extent of the wave model domain. We first analyze the effect that small deviations from complete satisfaction of the Neumann boundary condition have on the hydrodynamic predictions. This is done first by perturbing the equations describing the lateral boundary condition by a small error, and examining the growth or decay of that error, analogous to Chen and Svendsen (2003) for the case of errors in the flow velocity at the boundary. We then indirectly impose a deviation from the satisfaction of the zero Neumann boundary condition by incrementally shortening the lateral extent of the wave model grid, and determining the effect on the model results. Finally, Monte-Carlo-style generation of the perturbed lateral boundary conditions will offer a view of probabilistic growth or decay of errors in the domain. The analysis of the error, whether deterministically or randomly generated, will require some method of looking at the multi-dimensional tendencies of the error and some estimation of the scsles most vulnerable to error, rather than just the deviation between model and data. To this extent, we will use spatio-temporal analysis methods such as Empirical Orthogonal Function (EOF) analysis to determine the overall scales of motion in the flow field and the extent of the variation of their response to the errors.

Statistical information on the errors along the boundaries will be useful for the second aspect of the project, which involves the development of methods to correct these forcing errors using data taken within. A Kalman-filter-style (Van Dongeren 2008) assimilation and correction system will be investigated for use herein to perform this boundary correction; later implementation of simplified versions of this model will likely lead to the use of adjoint methods for this.

Mr. Boyang Jiang (B.S. Hydropower Engineering, Hohai University, Nanjing, PRC) is the graduate assistant in primary charge of this work. He is the second in an envisioned line of students working on various aspects of the Delft3D model while pursuing graduate degrees at Texas A&M University, and is performing the majority of the evaluative work.

WORK COMPLETED

As a baseline for comparison, we first compared the model, using an optimum setup (no regard to computational time) to data from the Duck94 experiment. We used as much of the experimental time frame as tenable, and performed the comparisons to the wave and current meter arrays installed in the surf zone. We then perturbed the setup from the ideal configuration and investigated the effect on the overall accuracy statistics as well as more detailed metrics such as spatial variability of waveheight and flow velocity.

We used an analytic perturbation analysis to determine the growth in error in the predictions given error in the forcing along the lateral boundaries. The resulting series of differential equations, when solved, will yield this anticipated growth. We have also begun developing the EOF routines for the analysis of the velocity fields and outlining the design of the assimilation system.

RESULTS

Figure 1 shows a comparison of Duck94 data to predictions from the model. The model setups differed in that two different longshore extensions of the wave model grid were used in conjunction with the hydrodynamic grid. These are represented by the ratio A/B, where A is the length of the extension of the wave model grid on either side of the flow grid, and B is the overall longshore extent of the flow model grid (thus the total longshore extent of the wave model grid is 2A+B). The higher the ratio A/B, therefore, the longer the overall extent of the wave model grid and, presumably, the more accurate the representation of the Neumann lateral boundary condition. It is seen here that for a five percent reduction in A/B ratio, the model results have not been significantly affected.

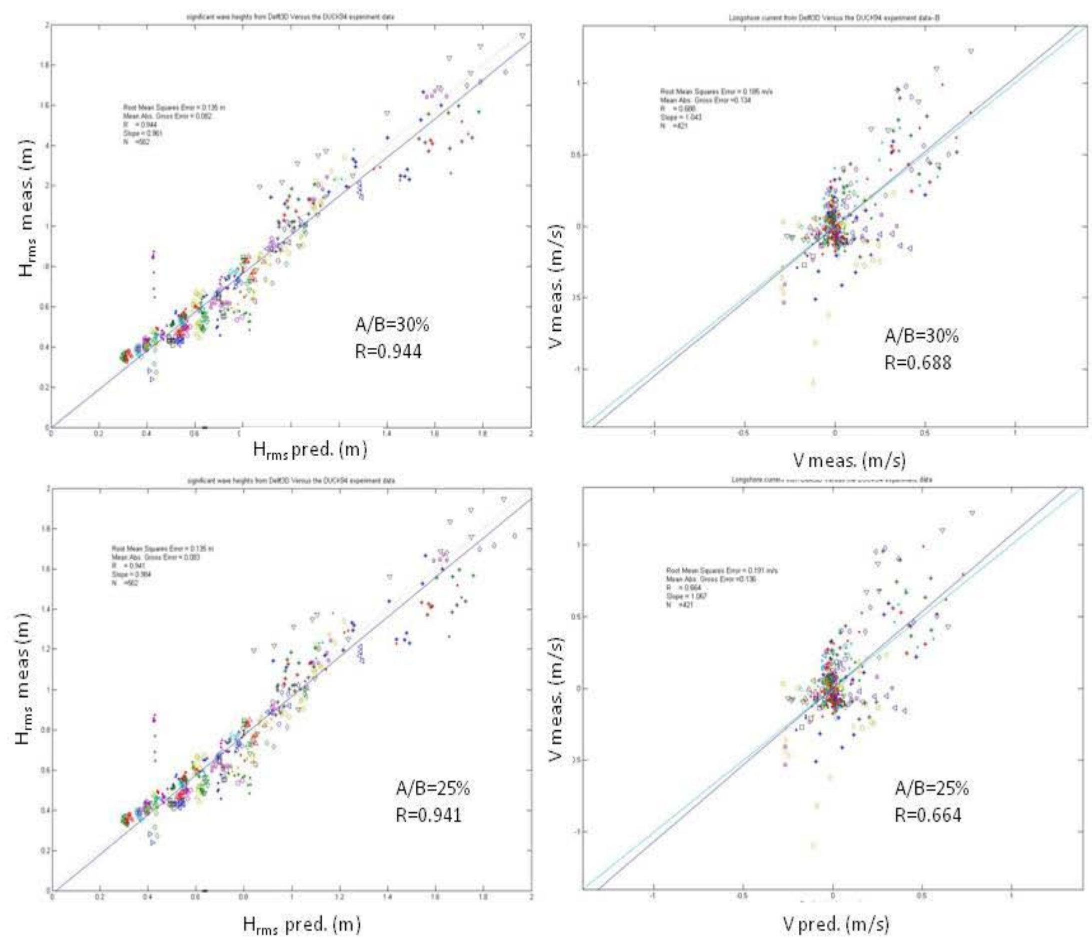

Figure 1. Comparison of H_{rms} and V to Duck94 data, measured vs. predicted values, from Delft3D using two different grid setups. Longshore length of wave model grid is 2A+B. Longshore length of hydrodynamic model grid is B. Top: A/B=30%; waveheights (left) and longshore currents (right). Bottom: A/B=25%; waveheights (left) and longshore currents (right).

One potential drawback of a pure data-model comparison is that there is no method for determining whether a bad comparison is due to a slight spatial shift in the prediction of a highly-variable model field, or complete inadequacy of model physics or numerics. Figure 2 shows the flow field near the boundary for several values of A/B. As the ratio becomes smaller, irregularities in the forcing field from the waves begins to effectively pollute the interior of the hydrodynamic model domain. This is demonstrated by the development of an eddy in the domain, which strengthens as A/B reduces. Despite this, the patterns elsewhere seem reasonably similar, indicating that reliance on a data-model comparison alone may not raise issues of concern elsewhere in the domain.

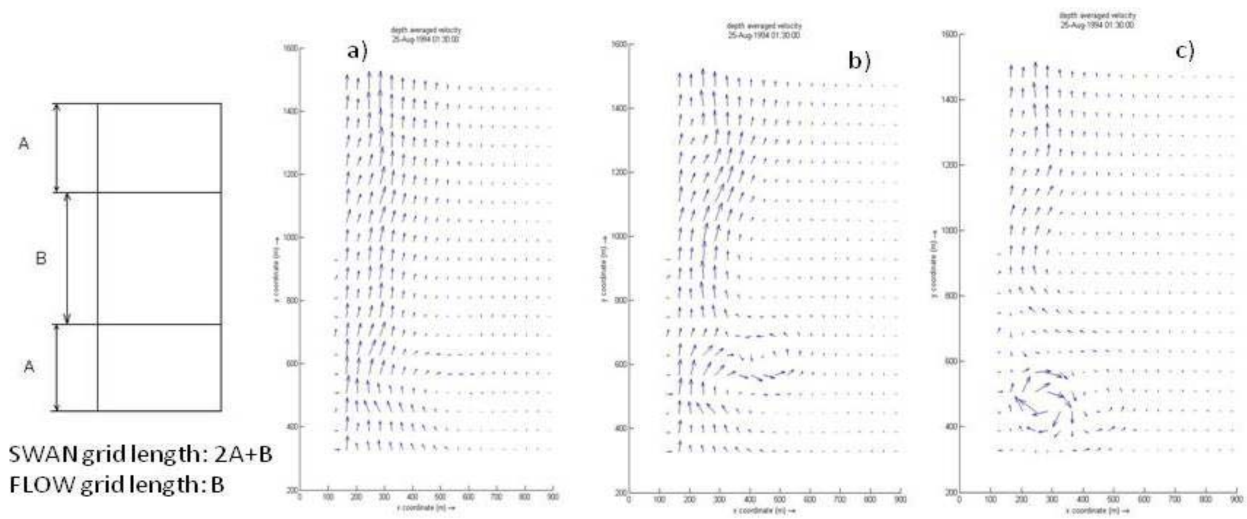

Figure 2. The effect of reduction of the lateral extent of the wave grid on the simulation of wave-driven currents over Duck94 bathymetry. The grid extents A and B are defined on the left. Shoreline is on the left of each plot of velocity vectors. a) A/B=50%. b) A/B=18.8%. c) A/B=5%.

IMPACT/APPLICATIONS

As mentioned above, this work will impact the way the Delft3D model is set up and run at operational Navy centers. It is also addressing a central question concerning the density and sampling of data for model input, which relates to the nature of the model and its response to over-or-underspecification of input fields, parameters, and/or forcing.

RELATED PROJECTS

This project is related to the goals of two other projects:

Estimation of Surf Zone Bathymetry using Small Unmanned Aerial Systems RTP (PI: Dr. K. Todd Holland, Naval Research Laboratory). This project was envisaged as providing tools, findings and methodologies which could potentially support the RTP operations and/or ehance the value of the work completed under the RTP.

Data Assimilation and Sampling Strategies in Nearshore Model Optimization and Validation (PI: Dr. Y. L. Hsu, Naval Research Laboratory). The two projects share many of the same goals, and the PIs have been working closely together to ensure mutual benefit.

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