Operational Assimilation into UUV and UAV Observations

Dr. Christopher Wackerman
1200 Joe Hall Drive, P.O. Box 990, Ypsilanti MI 48197
phone: (734) 480-5413 fax: (734) 480-5367 email: chris.wackerman@gd-ais.com

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LONG-TERM GOALS

To provide a capability to extend limited observations of local waves and currents into a larger domain using physics-based models within the littoral zone. It is anticipated that UUVs and/or UAVs would be used to provide the local observations, and the tool would be able to be run quickly on a laptop.

OBJECTIVES

The objectives of the proposed program are to utilize video from UAVs in the littoral region to generate estimates of wave conditions and bathymetry. This would be the first step to the more long-term goals, which would require incorporating UUV and in situ observations as well as estimating currents. The proposed program will have three parts.

(1) Develop a ray-trace based solver for the wave action balance equation that will allow prediction of shoaling wave spectra given the local bathymetry and currents, and will allow the assimilation of wave observations inside the domain into the wave field coming into the domain that would reproduce the observations.

(2) Using the ray-trace solver developed above, generate estimates of wave conditions and bathymetry from video observations of breaking waves.

(3) Using the ray-trace solver developed above, generate estimates of wave conditions from video observations of non-breaking waves (i.e. seaward of the surf zone).

APPROACH

(1) Development of the ray-trace wave action equation solver

Previous ONR programs have developed solvers for the wave action balance equation, which describes the evolution of wave spectra as the wave propagate through a current field and through local bathymetry changes. For this program, these codes will be modified to include shoal conditions, and the energy balances in the code will be able to re-produce what the SWAN model has as sources and sinks of wave energy. The assimilation code will be based on standard variational calculus to develop the gradient of the error (mis-match between simulated and observed wave conditions) with respect to the wave field at the boundary, and then a conjugate gradient search engine will be developed that utilizes this gradient. This will be tested using simulated data and, if available, in situ wave observations of shoaling waves from previous ONR experiments (including Sandy Duck '97 and NCEX).

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(2) Assimilation of video observations of breaking waves

The wave action equation solver will contain loss of energy due to breaking during shoaling. A forward model for optical intensity as a function of breaking will be developed, and then used to find the local bathymetry and wave height that can reproduce the observed breaking. We anticipate working closely with NRL/SSC to utilize their pole-based video data of breaking waves in a number of locations as test data for validation. In addition NRL/SSC will provide UAV video data as an additional test set.

(3) Assimilation of video observations of non-breaking shoaling waves

A forward model for generating optical modulations for non-breaking waves will be included into the system. This will be used to assimilate video of waves seaward of the surf zone into estimates of wave heights. NRL/SSC is developing a bathymetry algorithm based on wave dispersion that we anticipate incorporating and merging with the surf zone algorithms developed earlier. The final code will be able to incorporate UAV observations throughout the littoral region.

WORK COMPLETED

This program started late in CY '07, so the first year is not yet complete. We have developed the ray-trace solver to the wave action balance equation for shoaling waves and incorporated the sources and sink terms that are in the SWAN model. This required some modifications to the SWAN approach, since the ray-trace solver does not have the entire wave spectrum available at each time. This means that we need to have a different method of incorporating the spectral integral parameters that are in SWAN. We use scaled versions of the equilibrium spectrum integrals (which we calculated initially) where the scale factor comes from a comparison of the spectrum value for the given spectral location we are calculating versus the equilibrium spectrum value at the same frequency location. We have done a comparison between SWAN and this model for a linear beach and a quasi-monochromatic wave and have shown that they are identical (i.e. we can reproduced the SWAN result). We are currently performing a comparison between SWAN and our model for a more realistic beach (the actual bathymetry measured at Duck, N.C.) and a more realistic wave spectrum (a Pierson-Moskowitz wind-wave spectrum). We are also in the process of contacting other ONR investigators to see if historical data of wave spectra from shoaling waves are available from previous experiments as validation cases. In particular we are focusing on Sandy Duck '97 and NCEX. If available, we will use these data to compare shoaling wave spectra to model outputs. Before the end of the first year we will also develop the assimilation code that will take observations of wave spectra within the domain and determine the incoming wave field that

RESULTS

We have completed the ray-trace solver for the wave action balance equation and compared results to SWAN for a linear beach and a quasi-monochromatic wave field. We generated wave spectra as a function of distance from shore (and thus water depth) for each model and calculated the peak wave length (via a weighted integration of the spectrum) from each set of spectra. A comparison is shown in Figure 1 where there is essentially no difference between SWAN (blue line) and the ray-trace code (referred to as Wabe in the figure). Figure 2 then shows a comparison of significant wave height between the two models. The ray-trace code (again referred to as Wabe in the figure) was run with two different values for the gamma parameter that is in the SWAN energy dissipation model for breaking waves. Note that the value of 0.6 essentially reproduces the SWAN plot. Finally, Figures 3 and 4 shows a comparison of the spectra locations and shapes for different water depths. Although the scaling of the spectra are different (due to the way they are output) the locations of peaks in wave number and the shape of the spectra are essentially identical.

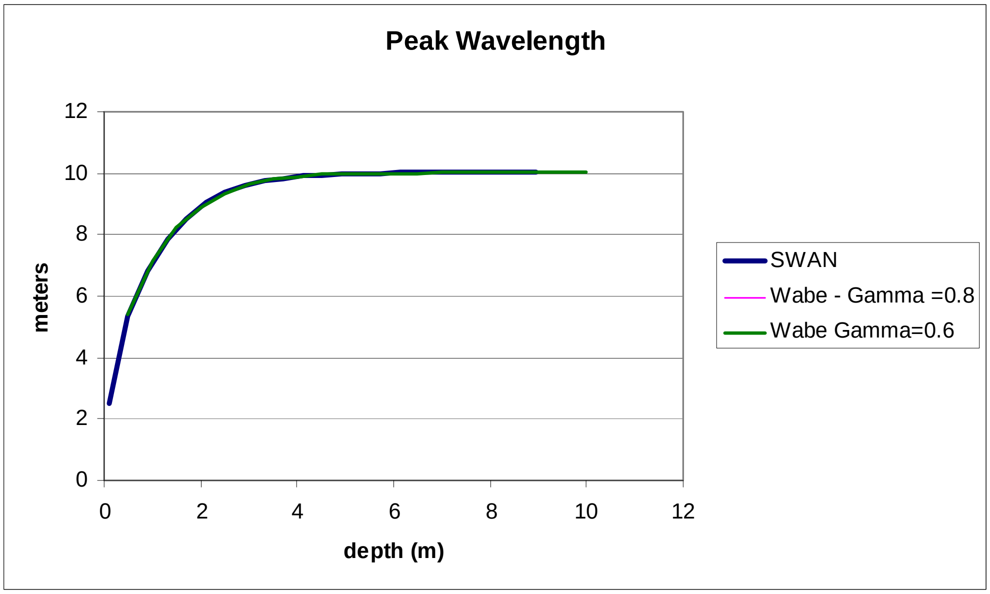

Figure 1: Comparison of the peak wave length of the spectra as a function of the water depth for the spectra. The SWAN model results are in blue and the ray-trace model results (referred to as Wabe) are in pink and green. Note that they are essentially equivalent.

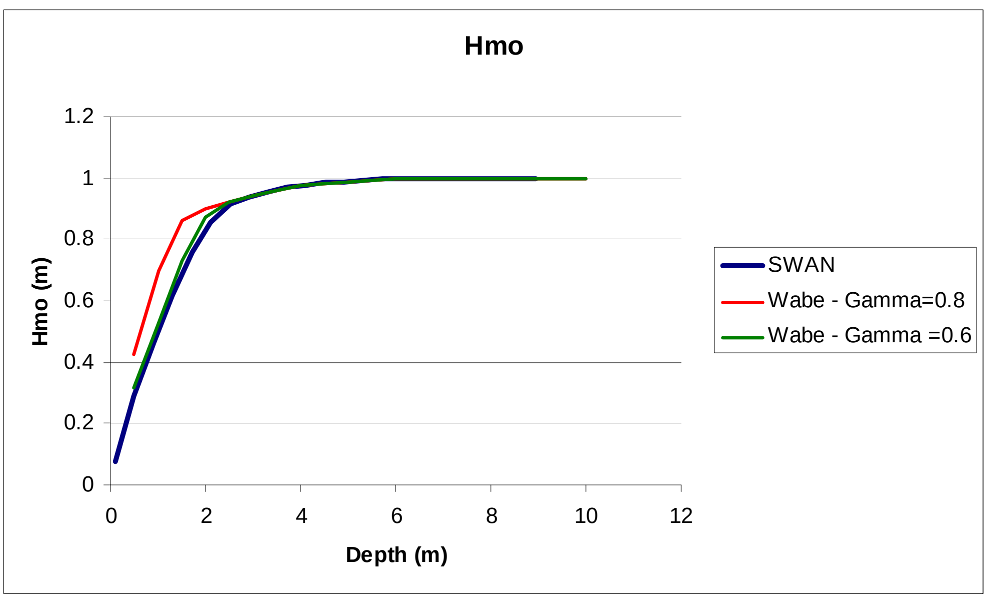

Figure 2: Comparison of significant wave height (Hmo) between SWAN (blue line) and the ray-trace code (Wabe) for two different values of the gamma parameter in the SWAN energy dissipation model for breaking waves. Note that the Wabe run with gamma = 0.6 is essentially identical to SWAN

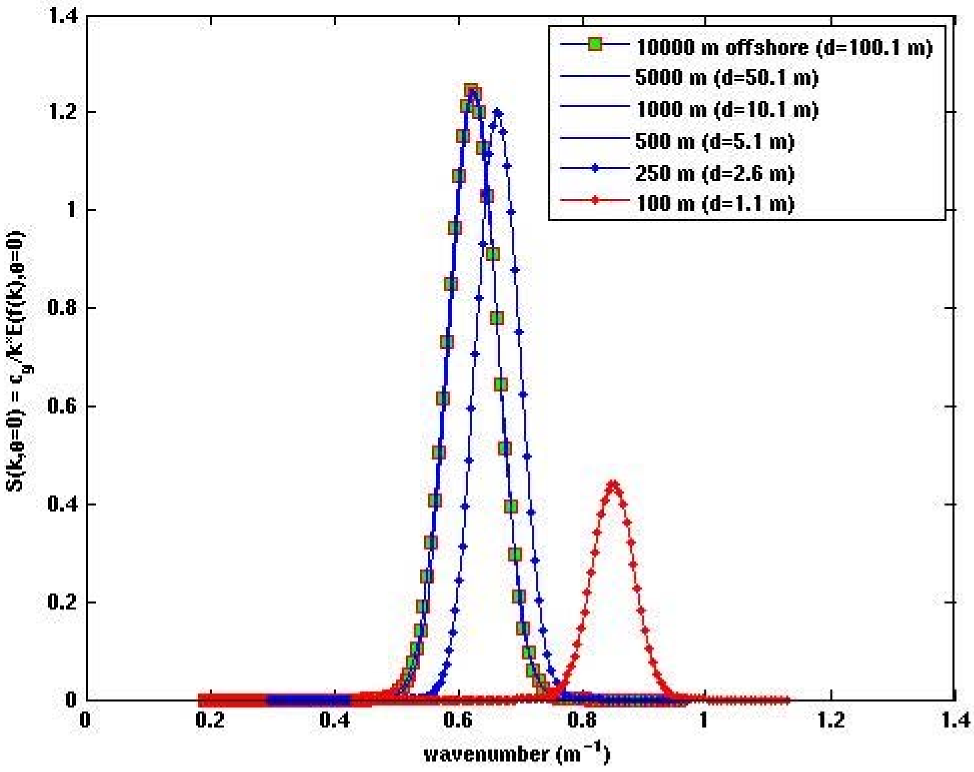

Figure 3: SWAN model output showing cuts through the wave spectra for various water depths (and thus various distances from shore). Depths of 5m and deeper are essentially the same, then the spectrum starts to shift in wavenumber and lose energy for 2.6m and 1.1m depths.

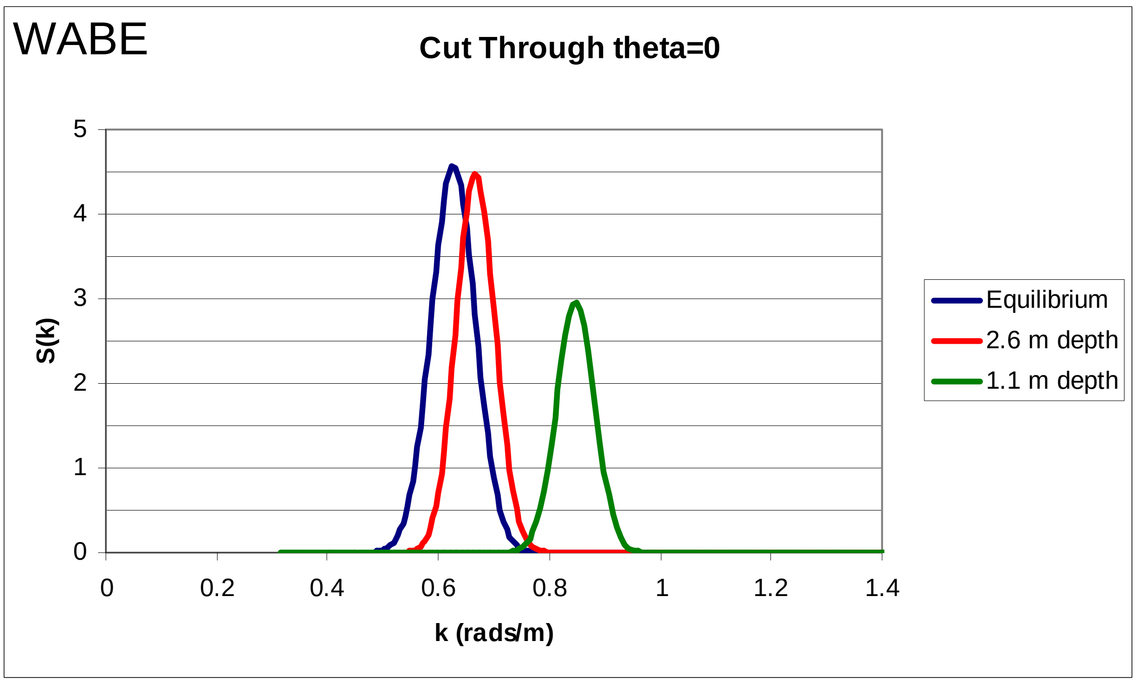

Figure 4: Same as Figure 2 but for the Wabe code. Note however that the spectra are not scaled the same, this is strictly to validate the shape of the spectra.

As mentioned above, we are currently performing the same comparison for more realistic waves and bathymetry.

IMPACT/APPLICATIONS

If successful, these tools will be used by the warfighter to provide a wide-area view of current littoral wave conditions during operations, thus increasing the field-of-view of local assets (such as UAVs).

RELATED PROJECTS

There are no ongoing related projects that are closely identified with this project.