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SMS Steering Module for Coupling Waves and Currents, 2: M2D and STWAVE

by Adele Militello and Alan K. Zundel

PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) described herein provides guidance on coupling the two-dimensional (2-D) circulation model M2D (Militello et al. in preparation) with the steady spectral wave model STWAVE (Smith et al. 2001) through the Surface-Water Modeling System (SMS) (Zundel 2002). Coupling of models is an efficient and accurate means of calculating wave-driven currents, setup and setdown, and wave-current interaction in nearshore regions, including tidal inlets. Procedures and options for coupling M2D and STWAVE within the SMS are described and an example application is provided.

BACKGROUND: Waves and currents can interact strongly in nearshore environments. Specifically, wave transformation and breaking induces strong currents, particularly over shallow regions such as ebb shoals and in the surf zone. Tidal currents at inlets are also strong and can modify wave properties, with wave steepening and possibly blocking during ebb, and lengthening during flood. The Coastal Inlets Research Program (CIRP) of the U.S. Army Corps of Engineers (USACE) has developed modeling systems to calculate tidal circulation (currents and water level) and wave transformation. These processes can be simulated independently or as coupled systems for calculation of wave-current interaction and wave-driven currents. The SMS provides tools for model application development, and coupling is conducted within a component called the Steering Module. The Steering Module was designed to allow users to have complete control over the level of interaction between wave and circulation models, and to automate coupling tasks. This CHETN is the second in a series that describes coupling of circulation and wave modeling. The first of this series (Zundel et al. 2002) provides information on coupling the finite-element circulation model ADCIRC (Luettich et al. 1992) with STWAVE.

The SMS is a graphical interface for developing computational grids, embedding their input information (such as bathymetry), setting up model runs, launching simulations, and post-processing results (Zundel 2002). Presently, the Steering Module can couple M2D and STWAVE (Militello et al., in preparation) as well as ADCIRC and STWAVE (Zundel et al. 2002). M2D is a time-dependent, 2-D finite-difference circulation model (Militello et al., in preparation) that calculates water-surface elevation and two horizontal components of the current on a rectilinear grid. Forcing for M2D can include any combination of water-surface elevation, water-surface elevation and velocity, flow rate, tidal constituents, radiation-stress gradients, and wind. If forcing from a regional model is available, the SMS provides for automated application of regional solutions as M2D boundary conditions (Militello and Zundel 2002; Militello et al., in preparation).

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14. ABSTRACT This Coastal and Hydraulics Engineering Technical Note (ERDC CHETN-IV-60) provides guidance on coupling the two-dimensional (2-D) circulation model M2D with the steady spectral wave model STWAVE through the Surface-Water Modeling System (SMS). Coupling of models is an efficient and accurate means of calculating wave-driven currents, setup and setdown, and wave-current interaction in nearshore regions, including tidal inlets. Procedures and options for coupling M2D and STWAVE within the SMS are described and an example application is provided.					
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STWAVE is a steady-state spectral wave model that computes wave transformation on a constant-spaced, rectilinear grid. Input information for STWAVE includes a bathymetric grid and wave spectra applied at the offshore boundary. Wind and current fields can be entered as optional inputs to STWAVE.

This CHETN describes coupling of M2D and STWAVE within the SMS Steering Module. Guidance is provided on coupling strategies and entering information into the Steering Module. An example application is also provided. Familiarity with M2D and STWAVE is assumed, as well as knowledge on how to set up the respective simulations within the SMS. The reader is referred to the following documents for supporting information: M2D User's Guide (Militello et al., in preparation), STWAVE User's Guides (Smith et al. 1999; Smith et al. 2001), and the SMS User's Guide (Zundel 2002).

GENERAL GUIDANCE: M2D operates on a rectilinear grid that can have variable spacing. Grid orientation is described by an angle of deviation from geographic coordinates. This angle is automatically computed by the SMS and saved in the M2D control file. If the angle of deviation is 0 deg, then positive x and y axes are directed toward the east and north, respectively. STWAVE operates on a grid that is oriented with the positive x axis directed toward and normal to the shore, and the y axis directed alongshore. The respective grid orientations must be taken into consideration when developing M2D and STWAVE models that are to be coupled. Typically, M2D and STWAVE grids must be developed separately, although within the same SMS project, and from the same bathymetric data set. Figure 1 provides three examples of possible M2D and STWAVE grid orientations.

In areas of the computational domain in which interaction between M2D and STWAVE is expected to be strong, such as at inlets and the surf zone, grid resolution specific for each model should be similar and appropriate for the scales of the hydrodynamic processes that are significant for the project at hand. For example, if accurate calculation of the longshore current is a goal of the modeling effort, then both grids should be set up to have several cells across the width of the surf zone. Resolution will then be sufficient to accurately calculate wave transformation processes and to calculate cross-shore distribution of the wave-driven current.

Coupling M2D and STWAVE in a time-dependent mode is conducted by providing a steering interval, that is, the duration of M2D simulation time elapsed between STWAVE runs. A series of STWAVE spectra are provided and wave properties are calculated at the specified steering interval during the time-dependent M2D simulation.

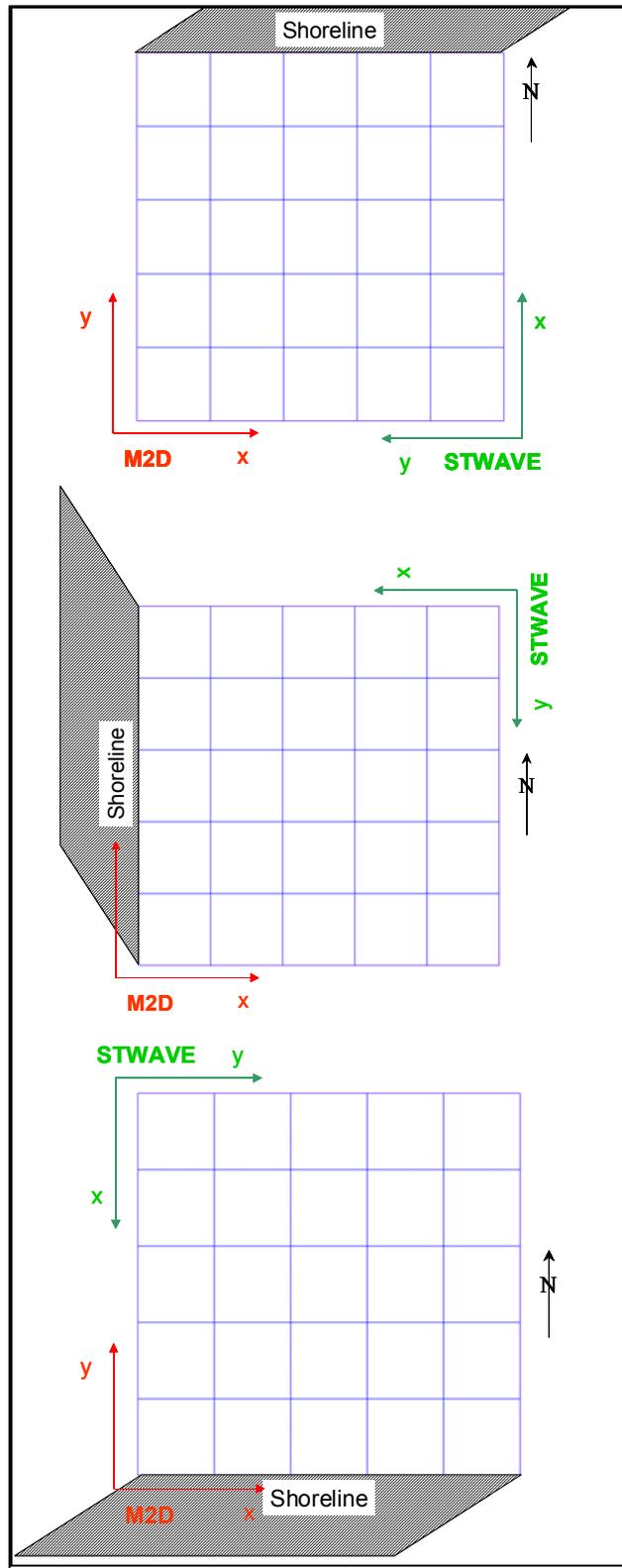


Figure 1. Examples of M2D and STWAVE grid configurations

MODEL COUPLING: There are seven possible steering types for coupling M2D and STWAVE. These steering types are defined as either one-way or two-way interactions, depending on whether information is being passed from one model to another, or if information exchange is occurring between both models. Exchange of three variable fields is possible:

- a. Radiation-stress gradients passed from STWAVE to M2D for calculation of wave-driven currents.
- b. Total water depth passed from M2D to STWAVE for including the influence of water-surface elevation on wave properties.
- c. Current fields passed from M2D to STWAVE for calculation of wave-current interaction (modification of waves by the current).

The user must decide on which combination of variables to pass between models, depending on project requirements. A description of when each interaction is appropriate to model is found in the first CHETN of this series (Zundel et al. 2002). Steering types available for M2D and STWAVE are as follows:

- a. 1-way steering: Radiation stress gradients from STWAVE provided to M2D.
- b. 1-way steering: Depths from M2D provided to STWAVE.
- c. 1-way steering: Currents from M2D provided to STWAVE.
- d. 1-way steering: Depth and currents from M2D provided to STWAVE.
- e. 2-way steering: Radiation stress gradients from STWAVE provided to M2D and depths from M2D provided to STWAVE.
- f. 2-way steering: Radiation stress gradients from STWAVE provided to M2D and currents from M2D provided to STWAVE.
- g. 2-way steering: Radiation stress gradients from STWAVE provided to M2D and currents and depths from M2D provided to STWAVE.

Steering options are selected by checking boxes in the Steering Module dialog for each type of interaction needed for the specific simulation (Figure 2).

STEERING IN SMS: Coupling of M2D and STWAVE is automated by the SMS Steering Module, which alternates M2D and STWAVE runs and controls passage of variable fields between the models. Variable fields are mapped between models according to the steering type specified by the user. If radiation-stress gradients are passed to M2D, the coupling process is invoked by initially running STWAVE twice to provide radiation-stress gradient fields to M2D over the duration of the steering interval. M2D is then launched and run for the first steering interval. If variable fields are specified to be mapped to STWAVE, then this task is completed at the end of the steering interval to provide currents and/or water levels to STWAVE. From this

point forward, STWAVE and M2D are alternately run, with the specific mapping conducted between model simulations.

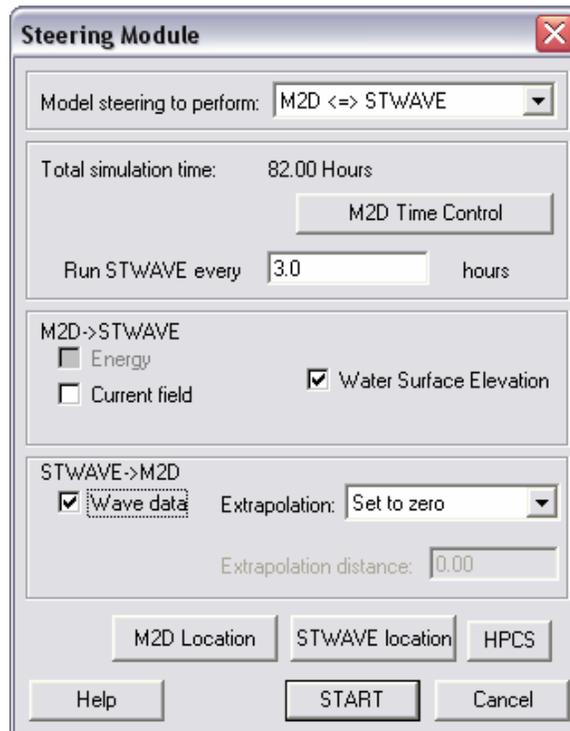


Figure 2. *Steering Module dialog*

Radiation-stress gradient files saved for M2D by the Steering Module contain two fields, one from the n th STWAVE run and one from the $n+1$ st STWAVE run, where n is the STWAVE run number. The two STWAVE runs correspond to the starting and ending times of the next M2D interval to be run. During M2D runs, radiation-stress gradients are linearly interpolated through time. Radiation-stress gradients are saved as x- and y-components that have been mapped and rotated as necessary to correspond to the M2D grid orientation.

Current fields saved for STWAVE are taken from the last global output of velocity saved by M2D from the most recent steering interval. These fields are mapped and rotated as necessary to account for any coordinate system or resolution differences in the M2D and STWAVE grids.

Total depth fields saved for STWAVE are taken from the last output of the global water-surface elevation file and the M2D grid file, which provides the ambient depth. These fields are summed at each M2D cell and mapped to the STWAVE grid.

INITIATING MODEL STEERING: The Steering Module can be invoked after M2D and STWAVE grids have been loaded into SMS and all model setups have been conducted. M2D and STWAVE grids must be defined within the same Cartesian coordinate system and must be in SI units (STWAVE and M2D only operate in SI units). Mapping of variable fields between

models requires that the domains overlap in the area where coupling is to be calculated. Domain extents of the two models are not required to be identical.

In the coupling process, global M2D output is required and timing should correspond to steering intervals for the most accurate coupling if STWAVE is receiving currents or water levels. Output frequency can be greater than the steering interval. To specify M2D global output, the *M2D Model Control* dialog is invoked (Figure 3). Global velocity and water-surface elevation output files will be written if their selection boxes are checked and the prefix for output file names are supplied. Times for global output are specified by invoking the *Choose Time* dialog (Figure 4) from the *M2D Model Control* (Figure 3).

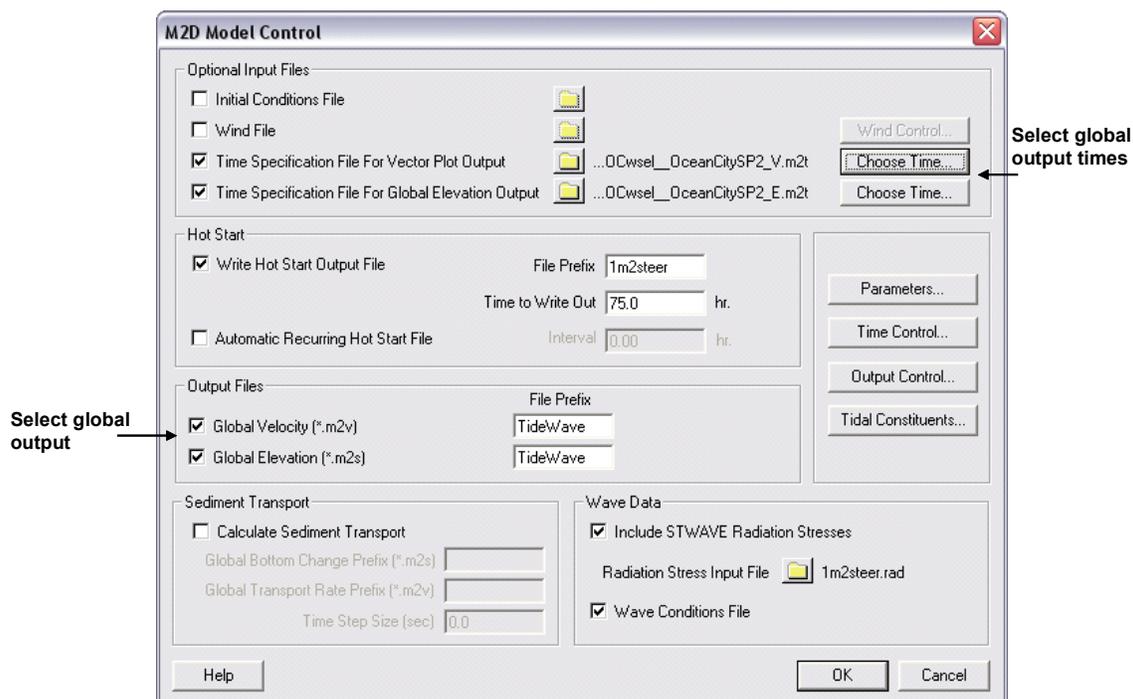


Figure 3. *M2D Model Control* dialog

After all model setup for M2D and STWAVE is complete, the *Steering Module* dialog (Figure 2) is invoked. The user must specify which variables are transmitted between models by clicking on the appropriate boxes in the *Steering Module* dialog. If the STWAVE grid is smaller than the M2D domain, the user may elect to extrapolate radiation-stress gradient fields beyond the STWAVE domain to prevent a sharp reduction of radiation-stress gradients at the location of the STWAVE grid boundary. Alternatively, if extrapolation is left as the default selection of **Set to Zero**, then no extrapolation of the radiation-stress gradients is conducted.

The user has the option of specifying to SMS the locations of the M2D and STWAVE executables by clicking on the **M2D Location** and **STWAVE Location** buttons. A browser dialog will be invoked from which the user can select the directory where each executable resides.

After all Steering Module options have been selected, the steering process is launched by clicking **Start** in the *Steering Module* dialog. A progress screen (Figure 5) will be shown giving the overall percent completion, the STWAVE run number, a plot of wave height, and the percent completion of the present M2D run. Updates for STWAVE and M2D alternate as each model is run.

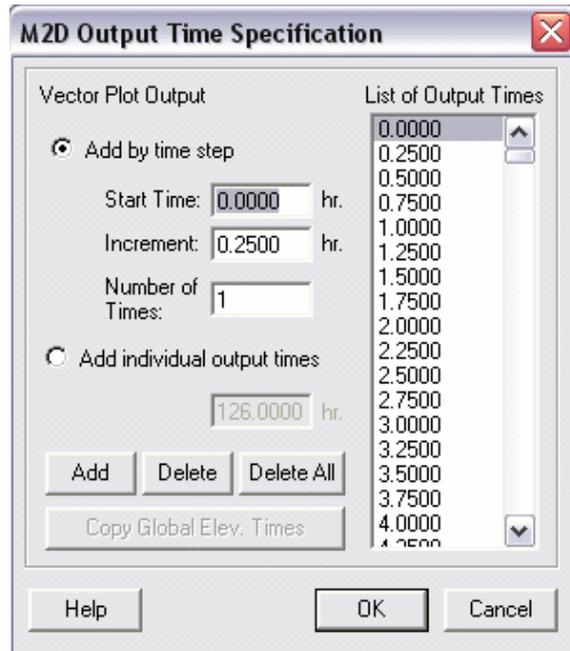


Figure 4. M2D Output Time Specification dialog

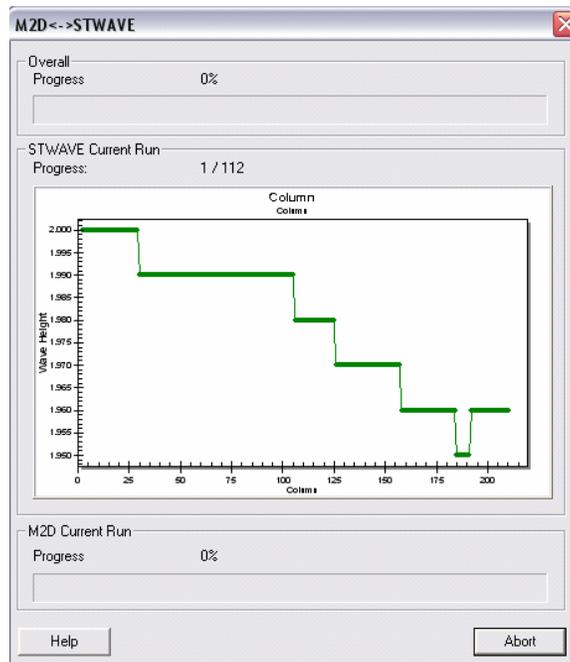


Figure 5. Steering Module progress screen

If files remain in the run directory from a previous steering simulation, SMS will query the user on whether to start the simulation from the beginning or hot start using previously-saved results (Figure 6). SMS will automatically detect the last model run and the last steering interval available as a starting point for hot starting the simulation. The user must select the starting option, and then click **OK** to continue.

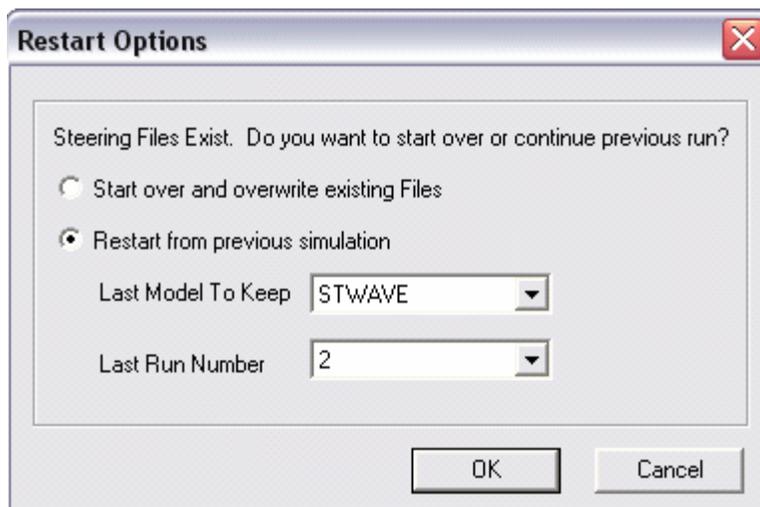


Figure 6. *Restart Options* dialog

EXAMPLE APPLICATION: To demonstrate the coupling capability, an example application at Ocean City Inlet, MD, is provided. In this example, the focus is on calculation of tide- and wave-driven currents at the inlet and ebb shoal, as well as adjacent nearshore areas. Because there is an interest in model coupling in the vicinity of Ocean City Inlet, the STWAVE domain is smaller than the M2D domain (Figure 7). This relative domain size was specified to reduce STWAVE computation time. Bathymetry at the inlet and ebb shoal is shown in Figure 8. M2D grid resolution ranged from 30 m in the inlet to 120 m at the seaward edge of the grid. Cell sizes in the STWAVE grid were specified at 30 m.

The simulation was run for a duration of 60 hr with a steering interval of 1 hr. Input wave conditions (bulk parameters) were height = 2 m, period = 8 sec, and direction = 15 deg relative to shore normal. (SMS generated an input spectra from these parameters.) M2D forcing was extracted from a pre-existing regional ADCIRC solution (Militello and Zundel 2002) that encompasses Chesapeake Bay, Ocean City Inlet and its back bays, and Delaware Bay. In this example, radiation-stress gradients were passed to M2D and total water depth was passed to STWAVE.

The first two STWAVE simulations were calculated at the ambient depth (water-surface elevation = 0 m) because no M2D computations had taken place yet. Figure 9 shows the wave height and direction for the ambient depth. Large sand bars modulate the wave height and direction, with wave heights varying significantly along the shoreline. Waves peak at the outer edge of the ebb shoal and break there. Waves also propagate over the northern, deeper part of the ebb shoal, then shoal and break as they approach the shallower, southern shoal area.

Comparison of wave heights and directions for lower (-0.50 m) and higher (0.51 m) water levels are displayed in Figures 10 and 11, respectively. During lower water, waves do not propagate as readily over the ebb shoal, resulting in smaller waves there. Wave breaking takes place on the outer shoal area, reducing wave energy over the shoal, and strong refraction takes place at the southern portion of the ebb shoal. When the water level is higher, waves can propagate over the shoal and break closer to shore in the southern shoal area. Wave refraction over the southern ebb shoal is evident, but is not as strong as during the lower water level. North of the inlet, the wave height patterns are similar for lower and higher water levels, although the distance from the breaker line to the shore is smaller at the higher water level, as expected.

The plots of wave fields at the different water levels demonstrate that mapping of the total water depth to the STWAVE grid allows the model to respond to varying water depth. Wave propagation, breaking, and refraction patterns vary with changes in depth. In this example, the largest variation takes place over the ebb shoal. Nearshore areas also have depth-dependent wave properties. Differences in the wave properties at varying tidal heights result in changing patterns of radiation stress gradients, which are applied in the momentum equations by the circulation model. Current patterns induced by combined tide and wave forcing are described next.

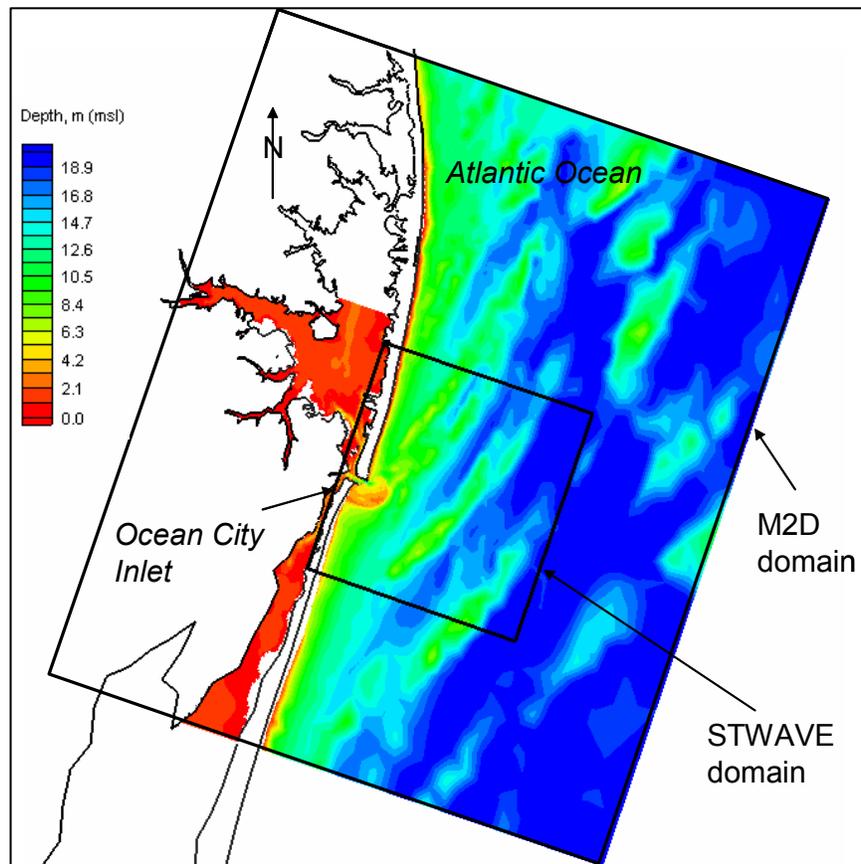


Figure 7. Ocean City Inlet M2D and STWAVE domains

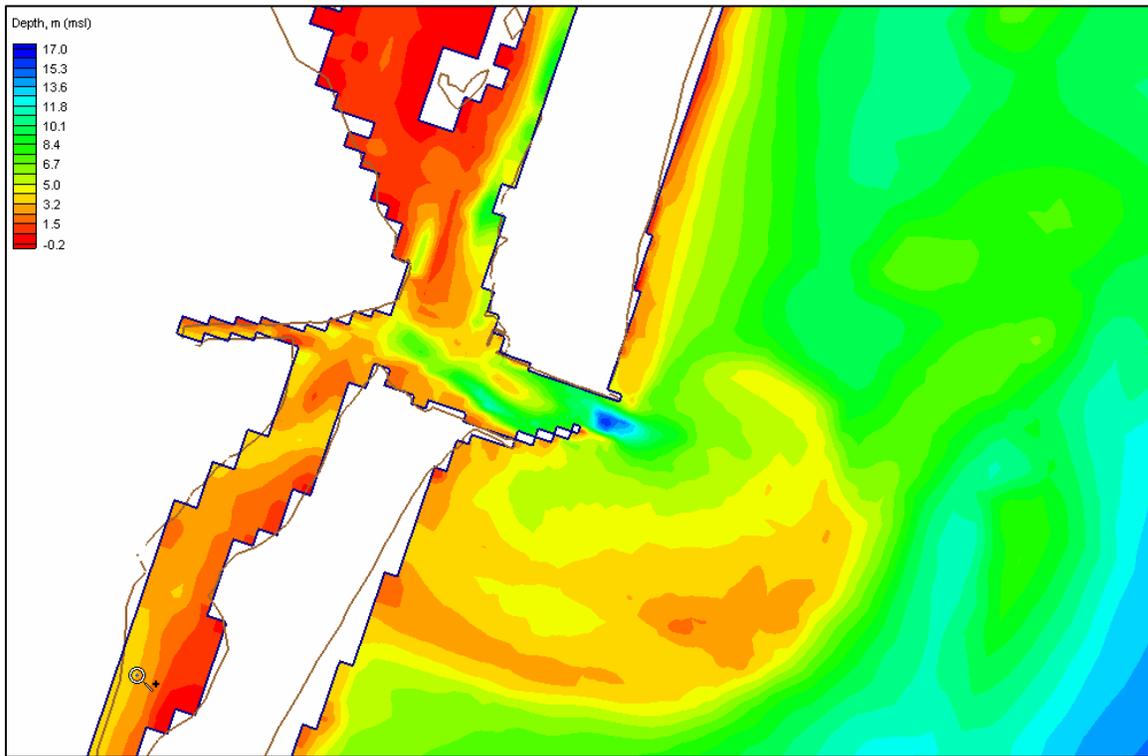


Figure 8. Ocean City Inlet and ebb shoal bathymetry

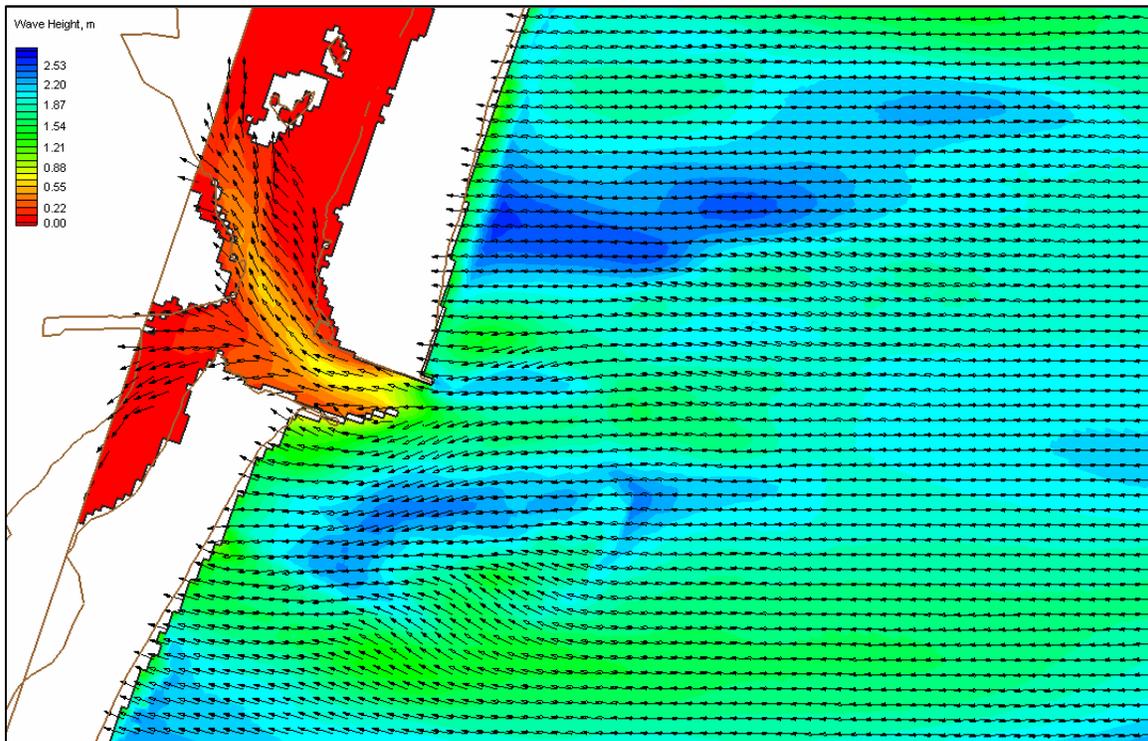


Figure 9. Wave height and direction for ambient water depth (water-surface elevation = 0 m), hr 0

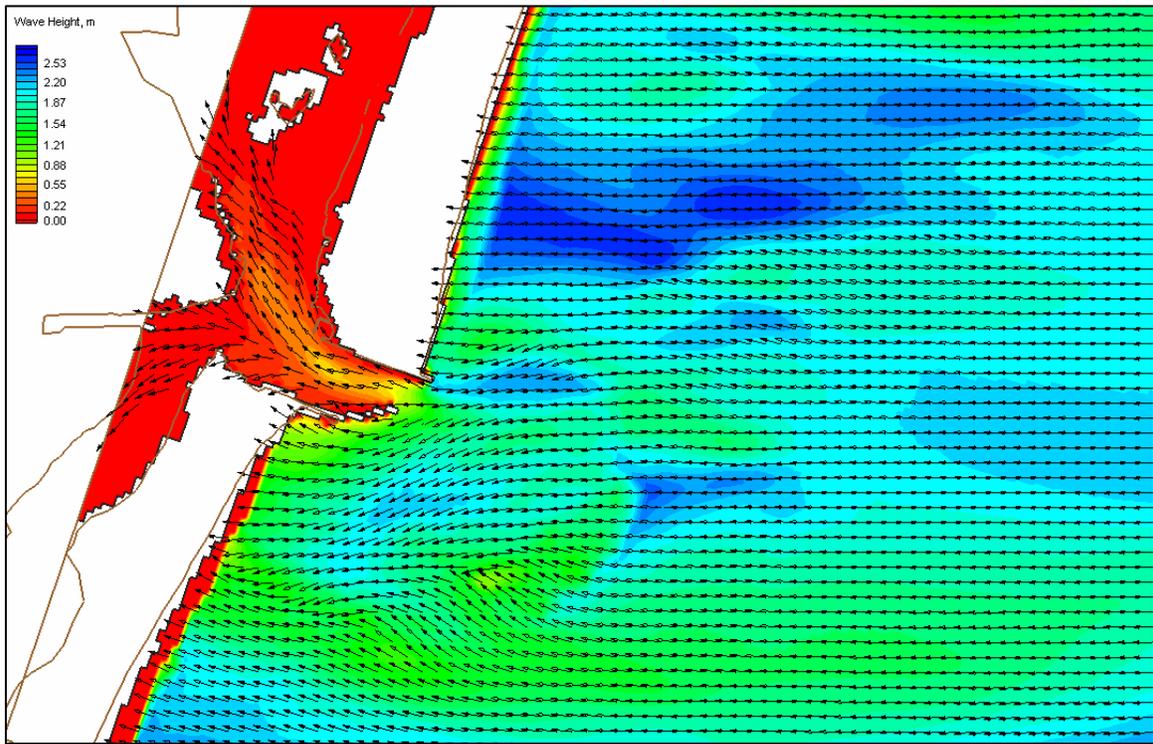


Figure 10. Wave height and direction for water-surface elevation ≈ -0.50 m, hr 41

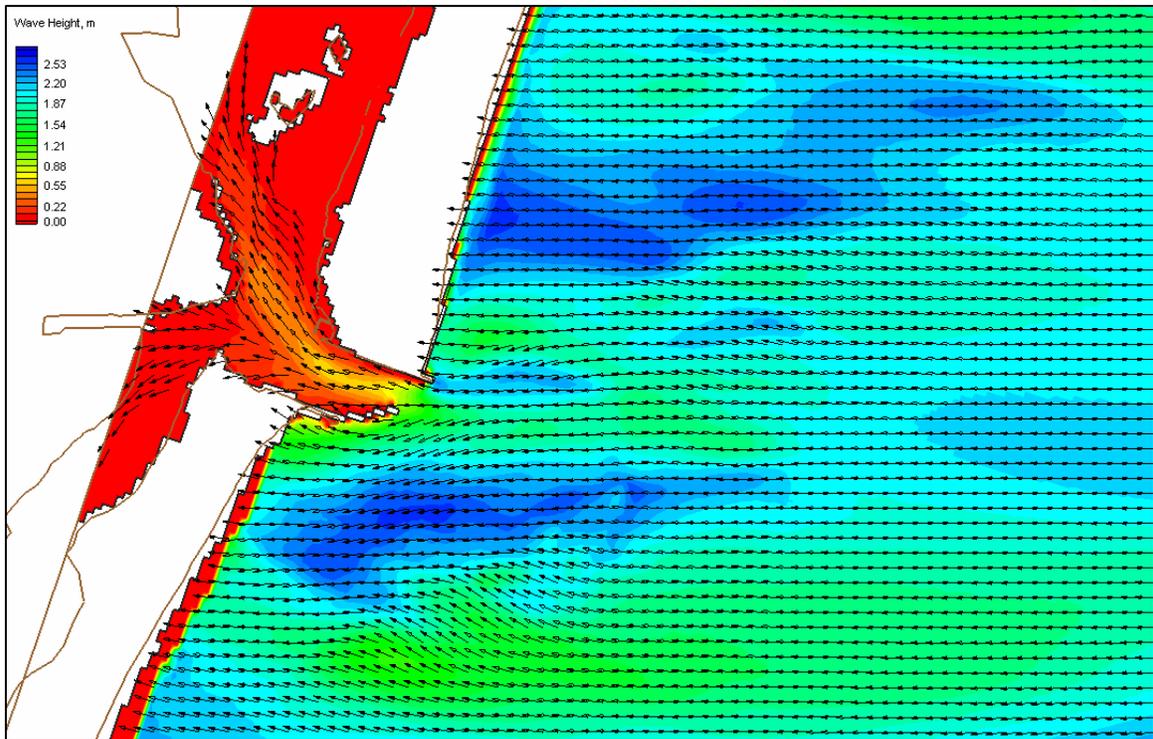


Figure 11. Wave height and direction for water-surface elevation ≈ 0.51 m, hr 48

Current speed and direction at lower water and ebb tide are shown in Figure 12. Wave breaking on the outer ebb shoal creates a strong current there. The inlet ebb jet collides with the wave-driven current on the outer ebb shoal, deflecting it toward the northeast. Strong wave-driven currents are evident in the nearshore zones north and south of the inlet, and on the southern portion of the ebb shoal. An area of weak current is located south of the south jetty, in the shadow zone north of where the wave-driven current from the ebb shoal approaches the shore.

Current speed and direction at higher water level and flood tide are shown in Figure 13. The wave-induced current on the outer and mid-ebb shoal propagates in roughly the same direction as the flooding tidal current. Thus, flood currents at the inlet entrance are enhanced by the presence of the waves. Wave-driven currents in the nearshore areas and on the southern ebb shoal are well developed. However, the area of strong wave-driven current is smaller at the higher water level as compared to the lower water level owing to the difference in wave propagation, transformation, and breaking patterns over the ebb shoal.

DISCUSSION: This CHETN has described coupling of the 2-D circulation model M2D and the steady spectral wave model STWAVE by the SMS Steering Module. This type of coupling is advantageous for applications in which currents, water level, and waves have a significant influence on one another. The SMS automates model coupling by mapping wave radiation-stress gradients to the M2D grid and water level and current velocity to the STWAVE grid. Control over the level of coupling is given fully to the user, who can select between seven combinations of steering options, and specify the time interval for coupling. Smaller steering intervals provide tighter coupling between the models, reducing the error of time lag for STWAVE, but increases overall computation time.

Coupling of M2D and STWAVE has been conducted for Ocean City Inlet, MD. Tide forcing for M2D was taken from an existing regional ADCIRC model solution. Two-way coupling was conducted in which total depth from M2D was provided to STWAVE, and radiation-stress gradients from STWAVE were passed to M2D. Wave properties were demonstrated to vary with tide stage, particularly over the ebb shoal. Current fields, driven by both tide and waves, were significantly different over the ebb shoal at higher and lower water levels.

POINTS OF CONTACT: Questions about this CHETN can be addressed to Dr. Adele Militello at (707) 444-2173 or CoastalAnalysis@cox.net, to Dr. Alan K. Zundel at (801) 378-2812 or Zundel@byu.edu, or to Ms. Mary A. Cialone at (601) 634-2179 or Mary.A.Cialone@erdc.usace.army.mil. This CHETN was produced under the Inlet Modeling System work unit of the Coastal Inlets Research Program. For information about the Coastal Inlets Research Program, please contact the Program Manager, Dr. Nicholas C. Kraus, at (601) 634-2016 or Nicholas.C.Kraus@erdc.usace.army.mil.

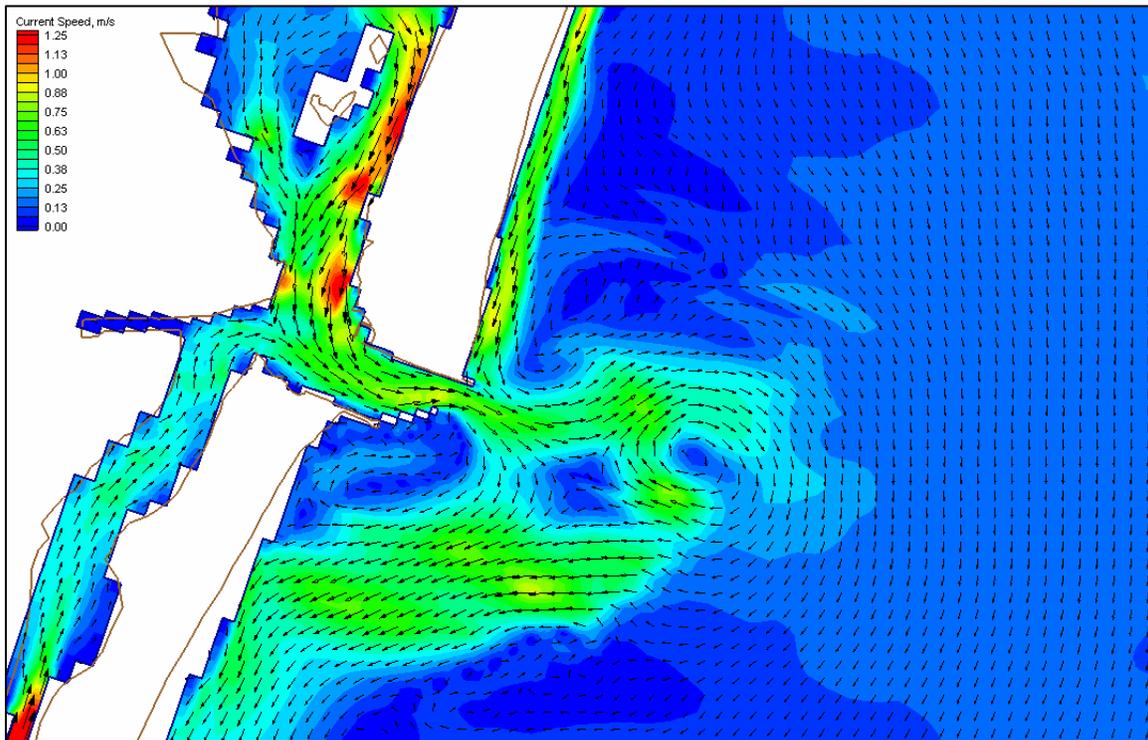


Figure 12. Current speed and direction for water-surface elevation ≈ -0.50 m, hr 41 (ebb tide)

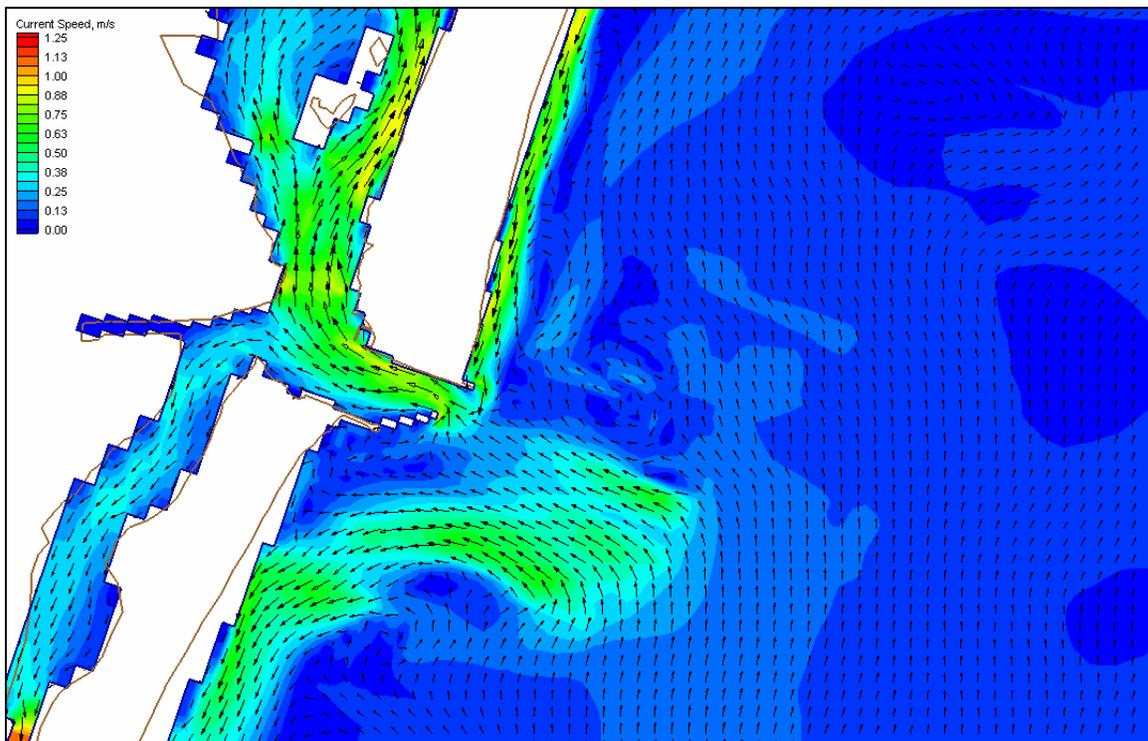


Figure 13. Current speed and direction for water-surface elevation ≈ 0.51 m, hr 48 (flood tide)

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