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SMS Steering Module for Coupling Waves and Currents, 1: ADCIRC and STWAVE

by Alan K. Zundel, Mary A. Cialone, and Thomas J. Moreland

PURPOSE: The Coastal and Hydraulics Engineering Technical Note (CHETN) herein describes the purpose and functionality of the steering module in the Surface-Water Modeling System (SMS). The steering module was developed to automate repetitive user tasks and required data sharing between circulation and wave propagation numerical models. Procedures and processes for operating the steering module are summarized, and an example demonstrates hydrodynamic coupling within the steering module.

BACKGROUND: In the vicinity of inlets, waves encounter substantial currents, in particular, as an opposing current during ebb tide and as a following current during flood tide. The current modifies the wavelength, height, and period (Jonsson 1990; Smith, Resio, and Vincent 1997; Smith 1999). Such currents are produced by the tide, wind, and waves. Similarly, waves breaking over the ebb shoal and nearshore at an inlet create wave-induced currents and changes in water-surface elevation. Thus, for a general situation with waves and currents meeting at an arbitrary angle, currents change the wave properties, and the waves modify the currents (Militello et al. 2000). These processes, called wave-current interaction, are application dependent. The Coastal Inlets Research Program (CIRP) of the U.S. Army Corps of Engineers (USACE) is developing coupled modeling systems to represent the major processes of waves, currents, and wave-current interaction. For a long-term simulation, the coupling of circulation and wave models to represent the wave-current interaction is tedious and error prone if done manually. The purpose of the steering module is to specify and control the coupling automatically. At the first stage, CIRP is developing the means to couple the hydrodynamic processes. Future work will involve coupling of waves, currents, sediment transport, and morphology change.

The SMS is a pre- and postprocessor developed for operating various numerical hydrodynamic models (Zundel 2000; Militello and Zundel 1999). The SMS software package allows users to create and edit meshes and grids, set up and save model input files, run numerical model simulations, and view model solutions. At present, the steering module couples the ADvanced CIRCulation (ADCIRC) model (Luettich, Westerink, and Scheffner 1992) and the STEady-state spectral WAVE model (STWAVE) (Resio 1988; Smith, Sherlock, and Resio 2001). Future work will couple other USACE circulation and wave models via the steering module. ADCIRC is a time-dependent, finite-element numerical model that computes water-surface elevations and velocities at grid nodes. ADCIRC can be forced by several processes simultaneously, including gradients in wave radiation stress. STWAVE is a steady-state finite-difference model that calculates wave spectra at each cell in a rectangular grid. STWAVE is driven by offshore wave spectra and local winds and has provision to accept optional current vector fields.

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The steering module facilitates input/output sharing, as well as interpolation, between ADCIRC and STWAVE. ADCIRC can be forced by input of the wave radiation stresses produced by STWAVE, in addition to the tidal- and wind-induced currents. The current fields computed by ADCIRC can serve as input to STWAVE to simulate wave transformation on a current.

The following describes general guidance for running ADCIRC and STWAVE, the steering process, the procedure for performing steering simulations, and gives an example of a steering module simulation. Familiarity with the ADCIRC and STWAVE models is assumed. Generation of input files for ADCIRC and STWAVE is not a trivial process. The reader is referred to the ADCIRC (Luettich, Westerink, and Scheffner 1992) and STWAVE (Smith, Sherlock, and Resio 2001) reference manuals for a list of the required files and details on the file formats. Model input files are required before the steering module can be queried. The reader is referred to the SMS (Zundel 2000) reference manual for details on the methodology for generating these files.

GENERAL GUIDANCE: ADCIRC is usually run with a “ramp” period. This allows wind, tide, and wave forcing to be gradually applied to the circulation model domain over some time period, usually 1 to 5 days, rather than shocking the system with stresses all at once. (The length of the ramp period is dependent on the size of the water body being modeled.) Because wave radiation stresses are one of these forcing functions, they are applied gradually until the end of the ramp period is reached.

STWAVE is a steady-state model, that is, there is no time-dependence. We approximate a dynamic simulation by linking several STWAVE simulations together. The time spacing of these linkages (or the wave model time-step) can be large (1-3 hr) because wave conditions vary at a more gradual rate than tide conditions and can be assumed to be approximately constant for the longer time period. Similar to the ADCIRC ramp period, the STWAVE simulations should bracket the time interval of interest and transition from low-energy conditions to peak wave conditions to allow for a gradual buildup of wave-induced currents.

The finite-element and finite-difference grid resolutions should be comparable in the “overlap” region. (Generally the STWAVE domain is a subset of the ADCIRC domain.) Typically, about 10 STWAVE grid cells of 25-50 m have been found to adequately resolve the surf zone and discern the gradients in wave stress. ADCIRC node spacing should be approximately the same as the STWAVE cell size to maintain the integrity of the wave stress gradient.

There are three available “steering types” for ADCIRC/STWAVE steering: one-way ADCIRC→STWAVE (arrow indicates ADCIRC is passing data/information to STWAVE), one-way STWAVE→ADCIRC (arrow indicates STWAVE is passing data/information to ADCIRC), and two-way coupling, ADCIRC↔STWAVE (double arrow indicates information is passed from one model to the other and vice versa). Each of these linkages are used for specific applications and are described next.

ONE-WAY ADCIRC→STWAVE STEERING: For one-way ADCIRC→STWAVE steering, current data generated by ADCIRC are saved and passed as input to the STWAVE simulation. This condition is used when and where currents impact waves, but waves only weakly impact

currents. Strong tidal currents in an inlet can greatly change wave conditions, particularly ebb currents (Cialone and Kraus 2001). Therefore, this option may be selected if examining waves and currents in an inlet environment. Note that this condition assumes that the ebb shoal is deflated so that wave breaking and wave-induced currents are not significant.

For the one-way ADCIRC→STWAVE steering, the ADCIRC simulation is segmented into shorter simulation times corresponding to the STWAVE run interval. For example, if the total ADCIRC simulation time is 1 day and STWAVE is set to run every 2 hr, ADCIRC will be run 12 times with each run performing calculations on 2 hr of time-steps. Considering the example of a 1-day ADCIRC simulation and running STWAVE every 2 hr, the steering process begins with an STWAVE run at hour 0 (with no current input) and then an ADCIRC run from hour 0 to hour 2. This is considered a “cold start” simulation since there is no previous condition read into the ADCIRC model. After the ADCIRC run is completed, the steering module reads the ADCIRC currents file (named fort.64) and spatially interpolates the values from the current field solution to the STWAVE grid. The steering module then saves the necessary files to run STWAVE at hour 2. After the STWAVE run is completed, ADCIRC is run again with the simulation time set from 0 to 4 hr. Because a final condition (hot start) file was generated at the end of the previous ADCIRC run (hour 2), the present ADCIRC simulation runs from hour 2 to hour 4 using the previously saved information as a starting condition. This process of alternately running ADCIRC and STWAVE is continued until 1 day of simulation time has been completed.

ONE-WAY STWAVE→ADCIRC STEERING: For one-way STWAVE→ADCIRC steering, wave radiation stress gradients generated by STWAVE are saved as input to the ADCIRC simulation. This condition is used when and where waves impact currents, but currents only weakly impact waves. Breaking waves along the open coast, particularly obliquely incident storm waves, can induce strong longshore currents. Breaking waves are a major forcing mechanism along open-coast regions; therefore, this option may be selected if examining waves and currents in an open-coast environment (distant from inlets).

Again, the example of a 1-day ADCIRC simulation, running STWAVE every 2 hr is considered. The steering process begins with an STWAVE run with input spectra corresponding to time 0. After STWAVE is completed, the STWAVE model is run again with input spectra for hour 2. The steering module spatially interpolates the radiation stress solution from STWAVE to the ADCIRC mesh for both hour 0 and hour 2 and saves an input radiation stress file for ADCIRC (named fort.23). The ADCIRC model is then run with this wave radiation stress gradient input file. Note that ADCIRC temporally interpolates radiation stress gradients between hour 0 and hour 2 during the 2-hr ADCIRC simulation. After ADCIRC is completed, the STWAVE model is run again with input spectra for hour 4. At this point the steering module spatially interpolates the radiation stress solution at hour 4 to the ADCIRC grid and updates the radiation stress file (fort.23) to include data for hour 2 and hour 4. The next ADCIRC simulation is from hour 2 to hour 4 using the hot start at hour 2. This process of alternately running STWAVE and ADCIRC is continued until 1 day of simulated time has been completed.

TWO-WAY ADCIRC↔STWAVE STEERING: For two-way ADCIRC↔STWAVE steering, both ADCIRC current data and STWAVE wave data are shared between the models. This condition is selected if currents modify waves and waves modify currents. Strong tidal

currents in an inlet can change local wave conditions, particularly for waves encountering an ebb current. If the ebb shoal is fully developed, wave breaking and wave-induced currents can also be significant. Therefore, this option may be selected if examining waves and currents in an inlet environment where the ebb shoal is well developed (for example see Figure 1) or if examining waves and currents over a large domain that includes inlet and open coast regions. The process for two-way passing is the same as one-way STWAVE→ADCIRC steering except that ADCIRC currents are interpolated to the STWAVE grid at the end of each ADCIRC run.



Figure 1. Inlet and breaking waves on the fully-developed ebb shoal at Ocean City, MD

Individual Model Grid and Input File Creation Procedure. Before invoking the steering module, the ADCIRC mesh, STWAVE grid, and other necessary input files must be loaded into the SMS. These simulations can be created or read from previous modeling sessions (Zundel 2000). To open a previously generated simulation, select *File | Open* and select the project file created for your project (for example, *myfile.spr*). The *.spr file is an SMS project file that references all of the files that are part of a modeling session. This project file may reference the ADCIRC grid, control, and forcing files; it may reference the STWAVE grid, control and spectral energy files; or it may include both. All STWAVE files may also be accessed via a simulation file (such as *mystwavefile.sim*). Individual files may also be opened one at a time.

The coordinate systems used by the ADCIRC and STWAVE models causes a complication in coupling them. Usually, the coordinate system for an ADCIRC mesh is Geographic NAD 83, while the STWAVE grid is usually defined in State Plane coordinates. For consistency in visualization, we convert the ADCIRC mesh to State Plane. ADCIRC still performs its calculations in geographic coordinates, but the solution is displayed in State Plane. To perform the conversion select *Edit | Coordinate Conversions...* (Figure 2). In the *Coordinate Conversion* dialog, click the *Current Options...* button. In the *Coordinates* dialog, select *Geographic NAD 83 (US)* for the *horizontal system*. Select *Local* for the vertical system and *Meters* for units. Select the *OK* button to return to the *Coordinate Conversion* dialog. In the *Convert to:* section, select *State Plane NAD 83 (US)* for the horizontal system. The State Plane zone is selected and

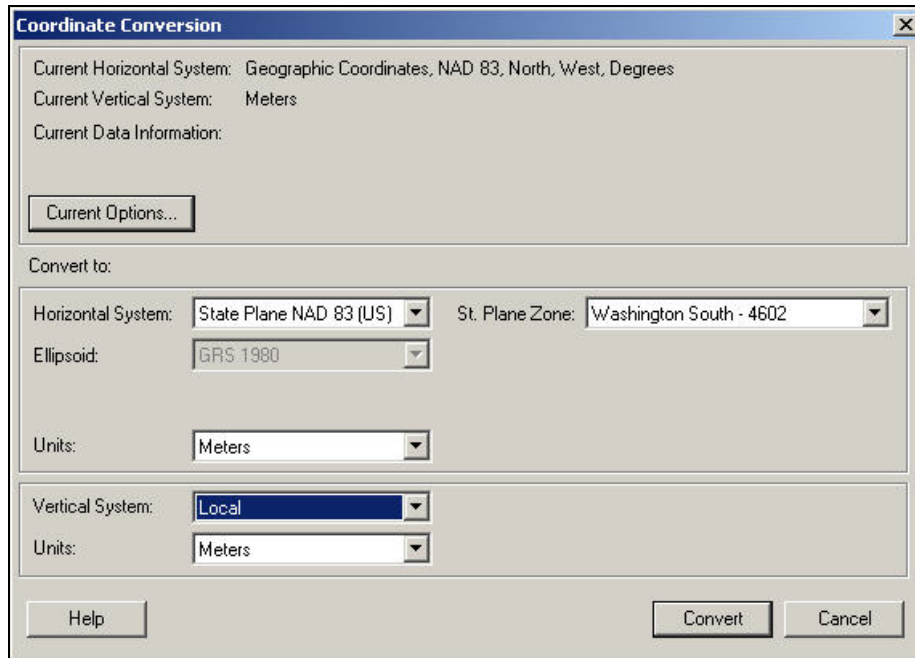


Figure 2. Coordinate conversion dialog box

the units are *Meters* as required by STWAVE. Select *Local* for the vertical system and *Meters* for the units. Select the *Convert* button to perform the conversion. The ADCIRC mesh is now in State Plane coordinates. Again, although we have performed the coordinate conversion in SMS, the ADCIRC files remain in geographic coordinates and the ADCIRC run is still made in spherical coordinates. The coordinate conversion was performed in this case only to facilitate interpolation between the ADCIRC mesh and the STWAVE grid and make visualization operations consistent. With all the necessary input files created and assembled in the SMS, the steering module can be queried.

Setting Steering Module Options and Initiating Simulations. To set the steering module run options, select *Data | steering module*. The *steering module* dialog appears for ADCIRC⇌STWAVE Steering (Figure 3). Each line in this Figure is explained herein. The *Total Simulation Time* is the length of the simulation specified in the ADCIRC control file (fort.15). The *ADCIRC Time Control...* button is a link to the *Time Control* dialog shown in Figure 4. In this dialog, the user can set all time control parameters for the simulation. If the steering type selected involves passing ADCIRC currents to STWAVE, the Global Velocity must be set to output for the entire ADCIRC simulation time so that STWAVE will have currents from ADCIRC at all requested times. The field *Run STWAVE every ___ hours*, controls the simulation interval between STWAVE runs. The input spectra file for STWAVE created for this example includes wave conditions at a 2-hr interval. The steering module time interval must be specified to match the input file. Thus, Figure 3 shows an entry of 2.0 to run STWAVE every 2 hr.

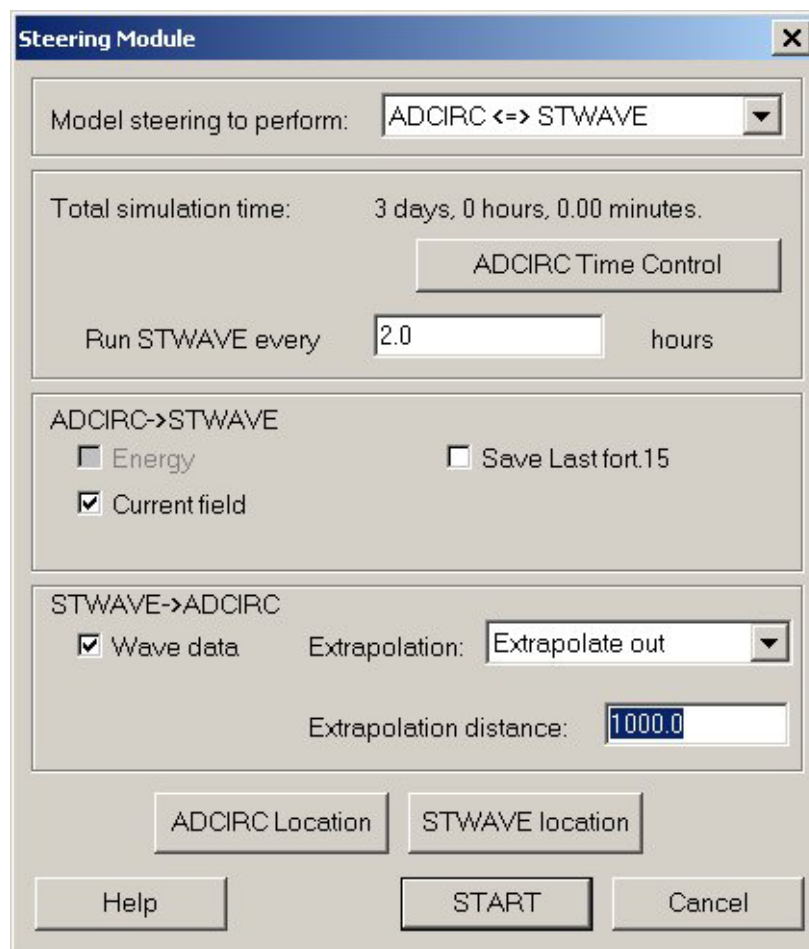


Figure 3. The *steering module* dialog for ADCIRC ↔ STWAVE coupling

For one-way ADCIRC → STWAVE steering, the box marked *Current field* is checked. For one-way STWAVE → ADCIRC, *Wave data* is checked. For two-way steering, the *Current field* and *Wave data* boxes are both checked. The box labeled, *Save Last fort.15*, sets the option of whether to keep the last ADCIRC control file or replace it with the original control file. This option allows the user to see the latest control file if ADCIRC crashes or ends prematurely. The original file can still be retrieved; SMS copies it in the model directory and names the copy origfort.15. Because the STWAVE domain is almost always smaller than the ADCIRC domain, there are two options for extrapolating the STWAVE solution to the ADCIRC mesh. If Extrapolation is *Set to zero*, radiation stress values for all elements in the ADCIRC mesh outside of the STWAVE grid domain are set to zero. This option is applicable for special conditions such as in sheltered regions. If the extrapolation option is set to *Extrapolate out*, the user must also specify a transition distance. The steering module then transitions from the value at the edge of the STWAVE grid to zero by means of a standard sigmoidal function. Because this method maintains a continuous transition, it is preferred to the *Set to zero* option.

To start the steering module, the locations of the model executables must be specified. The *ADCIRC location* and *STWAVE location* buttons specify where the model executables reside on the host computer. When the *Start* button is selected, the steering module saves the appropriate

Time Control

Simulation Time Control

Ramp Function Value: days

Reference Time: days

Wave Equation Time:

Weighting Factors:

Start Day:

Time Step: sec.

Run Time: days

Specify: ☒ Run Time (days)
☐ End Time (days)

Constituent:

Start Day:

Output Every: Time Steps

End Day:

Time Control

Harmonic Analysis

Recording Station Elevation

Recording Station Velocity

Recording Station Concentration

Recording Station Meteorological

Global Elevation

Global Velocity

Global Concentration

Global Wind Stress

Help OK Cancel

Figure 4. The ADCIRC *Time Control* dialog

files and launches the first model simulation. After each STWAVE simulation, SMS interpolates the radiation stress gradients to the ADCIRC grid and saves the radiation stress input file for a subsequent ADCIRC simulation. After each ADCIRC simulation, the steering module interpolates current values from the ADCIRC mesh to the STWAVE grid and saves the current file for a subsequent STWAVE simulation.

While the steering process is performed, the dialog shown in Figure 5 is on the screen. This dialog gives real-time updates of the progress of the steering module. The left plot gives the number of iterations vs. time-step for the ADCIRC simulation. The plot on the right side of the dialog shows average wave height vs. grid column for the STWAVE simulation. The large lower window contains the ADCIRC or STWAVE model output to the screen.

Steering Module Output. In addition to model output files, the steering module creates a status file named *steeringstatus.txt*. This file is located in the same directory as the model input files and contains a log of the steering module events. After the steering process is completed, the original input files for ADCIRC are restored. ADCIRC solution files, such as the

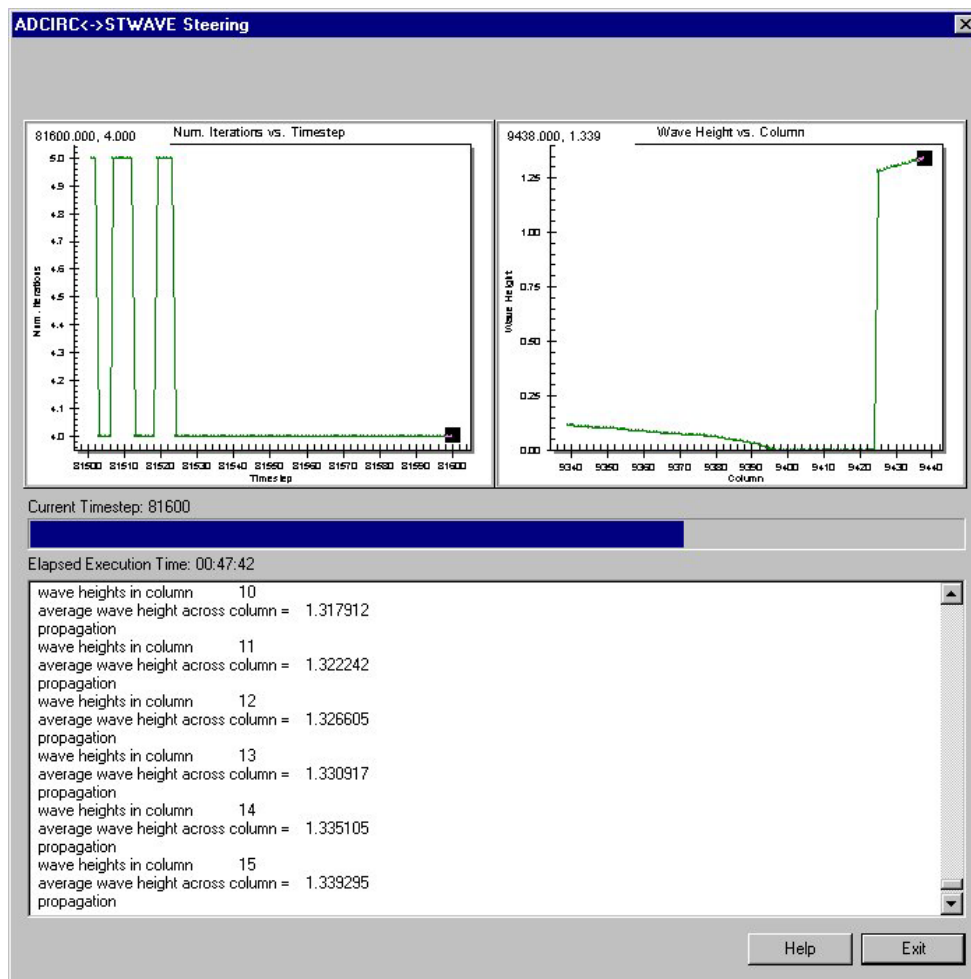


Figure 5. ADCIRC ↔ STWAVE Steering dialog

water-surface elevation file (fort.63) and velocity field file (fort.64) are consolidated and contain data for the entire simulation. All STWAVE simulation files that were created by the steering module are retained and are named 1swsteer.sim for the first simulation, 2swsteersim for the second simulation, etc. For this example, 1swsteer.sim corresponds to hour 0, 2swsteer.sim corresponds to hour 2, etc. The STWAVE output files are also consolidated and contain data for the entire simulation.

STEERING MODULE EXAMPLE: The following is an example showing results of a steering module application for two-way ADCIRC ↔ STWAVE steering. An idealized inlet configuration was constructed for illustrative purposes. Figure 6 shows the idealized inlet bathymetry (including an ebb shoal) for the ADCIRC and STWAVE domains. Note that the STWAVE domain is a subset of the ADCIRC domain. The ADCIRC mesh contains 126,903 nodes and 252,198 elements with node spacing ranging from 25 m near the inlet to 100 m offshore. The STWAVE grid has 320 cells on-offshore and 600 cells alongshore with a cell size of 25 m. The tidal range and period are 1.5 m and 12.42 hr, respectively, and the obliquely incident (30-deg) wave condition has a significant wave height of 4 m and a peak period of 12 s.

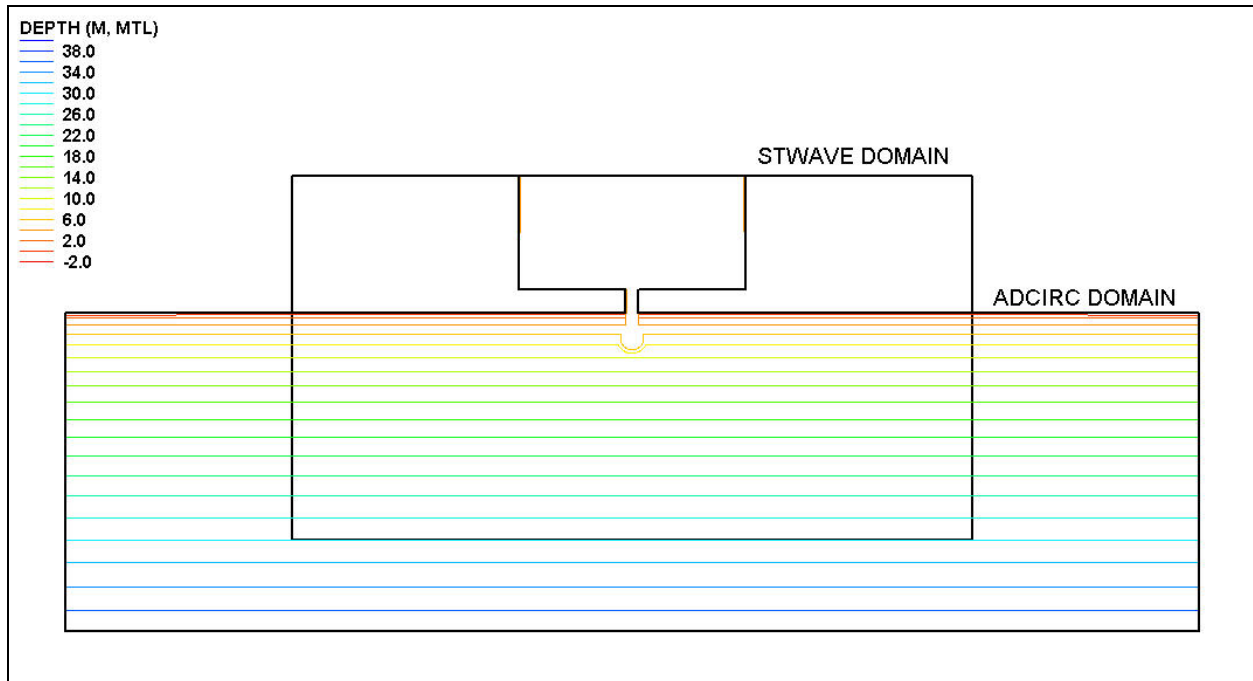


Figure 6. ADCIRC and STWAVE grid domains and bathymetric contours

The steering module simulation was run for 1 day in a two-way steering mode. STWAVE simulations were made every 2 hr for the simulation time period. For comparison, Figure 7 shows wave heights for an obliquely incident 4-m wave with no influence from currents, and Figures 8 shows wave heights influenced by an ebb current. Waves in the ebb shoal region are larger with the opposing (ebb) current than with no current as indicated by the wave height magnitudes (colors). The lengths of the wave-direction arrows are scaled to wave height as well. Figure 9 shows the ADCIRC currents during the ebb phase of the tidal cycle. Of note are: a) the influence of the ebb shoal on circulation, b) the deflection of the ebb jet caused by the obliquely incident waves, and c) the downdrift area where currents are smaller and larger currents are deflected offshore.

CONCLUSION: The SMS steering module provides a means of effectively linking wave and circulation models. The user can run “no steering” between models, “one-way” steering, and “two-way” steering to evaluate the changes in wave propagation and currents. Although the need for including the interactions of currents on waves and waves on currents is application dependent, it is evident that the interactions can be significant, particularly in an inlet environment. The steering model tool makes the evaluation of these interactions simpler.

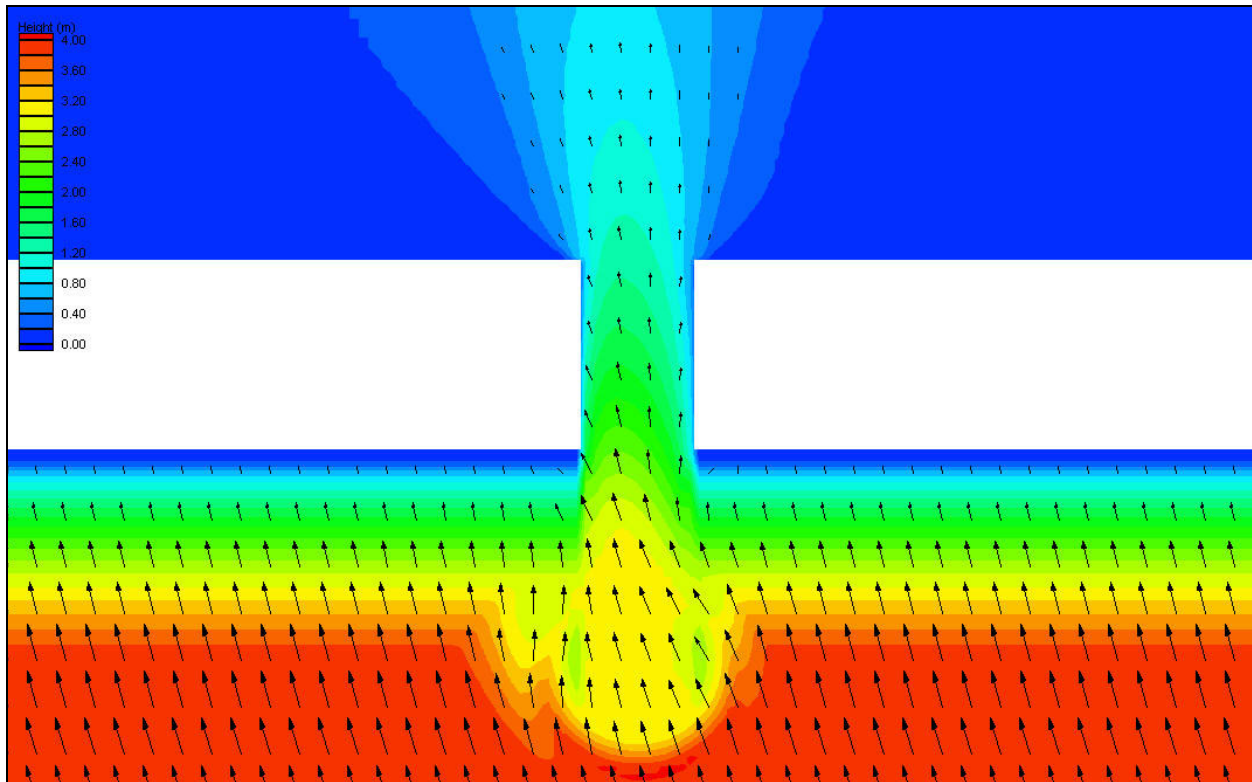


Figure 7. Wave height and angle with no current

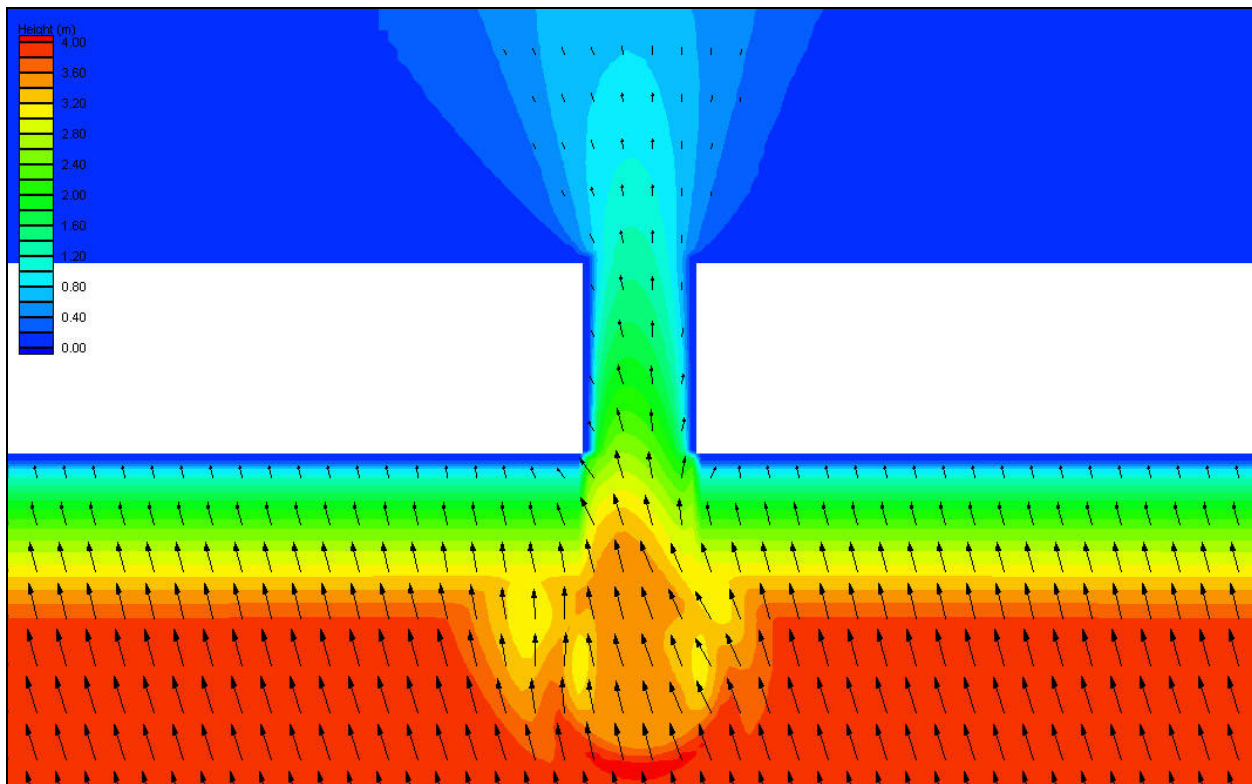


Figure 8. Wave height and angle with ebb current

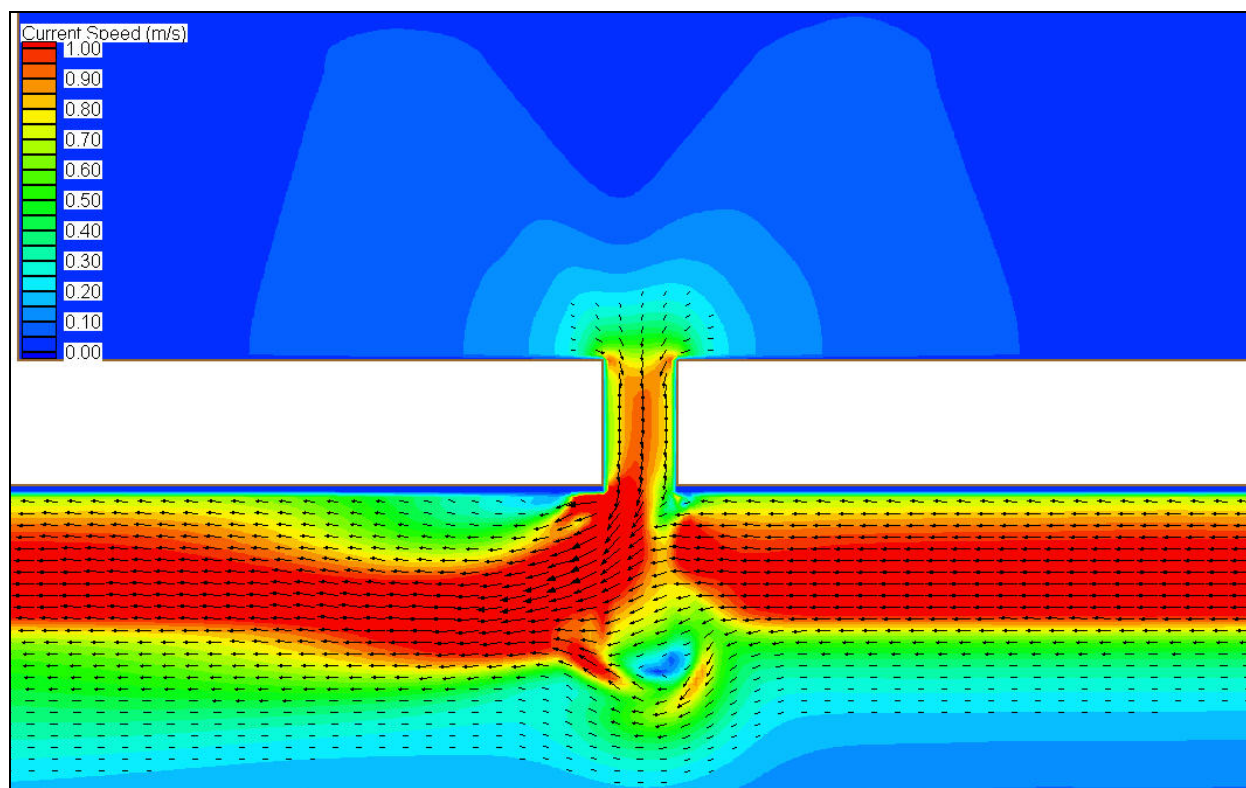


Figure 9. Tidal and wave-induced current pattern during ebb phase of tidal cycle

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