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Grid Nesting with STWAVE

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PURPOSE: The purpose of this Coastal and Hydraulics Engineering Technical Note (CHETN) is to describe new grid nesting capabilities in Steady-State Spectral WAVE Model (STWAVE). Background information about advantages of grid nesting and the previous nesting capabilities are given first. Then, the improved nesting capability is described, and an example application is discussed. Last, input and output for the upgraded STWAVE (Version 4.0) is described, and the Web site to download the STWAVE executable and user manual is given.

BACKGROUND: Large wave model grid domains are needed in many applications to minimize boundary impacts on the area of interest, collocate input wave boundary information with the grid boundary, or to model regional processes. Fine model grid spacing is required to resolve complex bathymetry and current fields. Wave model execution time is linearly related to the number of model grid cells, so a large domain together with fine grid resolution leads to long computational times – even for a relatively efficient model like STWAVE. To reduce computational time, grid nesting can be applied. A coarse grid can be used in an offshore region where the bathymetry is less complex and wave-bottom interactions are smaller, and a fine grid can be used in the nearshore where complex bathymetry and current fields may cause significant modifications to the wave field over short distances. High model resolution provides a more accurate description of the bathymetry (given that sufficient bathymetry data is available) and a more accurate numerical solution as the finite differencing interval (Δx) is decreased. Another advantage of grid nesting is that simulations with the coarse offshore grid can often be used to drive multiple nearshore grid simulations, e.g., modifications of nearshore bathymetry, application of nearshore storm surge or tides, and application of tidal currents. The advantage of grid nesting is to minimize computational requirements and maximize accuracy.

Grid nesting has been applied in the past with STWAVE by saving wave spectra from one location on a coarse offshore grid and then feeding that wave spectrum as input along the entire offshore boundary of the nearshore grid. This approach is sufficient if the bathymetry at the offshore boundary of the nearshore grid is well behaved (depth is approximately constant on the boundary) and the longshore extent of the nearshore grid is relatively small (so that the wave conditions are approximately constant along the boundary). For larger regional applications or applications with variation in wave characteristics along the nested grid boundary, a more sophisticated grid nesting capability is required. For these applications, output spectra from the coarse grid must be saved at several locations and interpolated onto the nearshore grid boundary. This technical note describes the new grid nesting implementation in STWAVE.

NESTING METHOD: A coarse offshore STWAVE grid is used to transform offshore waves to the boundary of a nearshore grid. Wave spectra from the coarse grid are saved at user-selected points that coincide with the offshore boundary of the nearshore grid. A separate STWAVE model run is then initiated to interpolate the coarse grid spectra onto the nearshore grid and model the nearshore wave transformation. Accomplishing the nesting in two steps provides extra flexibility: a) multiple nearshore runs can be initiated using a single offshore, coarse-grid output to represent multiple nearshore bathymetries (i.e., project alternatives), water levels, or current fields, and b) the same interpolation techniques can be applied to nearshore model input from other models, databases (Wave Information Studies), or even field measurements. The key change to STWAVE for grid nesting is implementation of a subroutine that interpolates spectra from a coarse spatial resolution to a fine resolution on the nearshore grid boundary. Two interpolation options are available in STWAVE:

Linear Interpolation. The most straightforward interpolation method is linear. The energy density for each wave spectrum frequency-direction bin on the fine grid offshore boundary is bi-linearly interpolated from the same bins of the adjacent spectra on the coarse grid. The bilinear interpolation weights the spectra based on the relative spatial separation distances. If points saved from the coarse grid are sufficiently dense to define the variation in the spectra along the nested grid offshore boundary, linear interpolation gives good results.

Morphic Interpolation. If wave directions vary by 10-15 deg or more from grid point to grid point on the coarse grid, linear interpolation can cause smearing or even splitting of the directional distribution. Figure 1 shows an example of linear interpolation of two directional distributions with a 40-deg difference in peak direction. Although this is an extreme case, it illustrates a potential problem with linear interpolation for cases where either the coarse-grid spectra are widely spaced or the bathymetry is very complex. To preserve the shape of the directional distribution, a morphic interpolation method was developed.

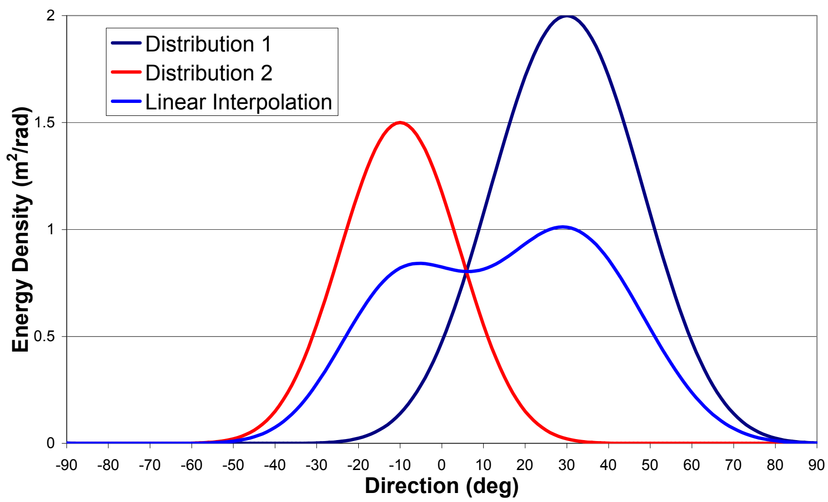

Figure 1. Linear interpolation of directional distribution

The morphic interpolation includes the following steps:

- Directional distribution for each frequency is interpolated from a 5-deg resolution to a 1-deg resolution using a cubic-spline interpolation. This allows better directional accuracy for the final interpolated directional distributions.
- As illustrated in Figure 2 (with the two input distributions shown in Figure 1), the peak direction is removed from the directional distribution, so that the resulting peak directions are zero.
- The directional distribution is bilinearly interpolated as shown in Figure 2.
- The peak direction is bilinearly interpolated from the peak direction of the two input directional distributions, and the interpolated distribution is shifted to the calculated peak direction (Figure 3).
- These steps are repeated for each frequency in the spectrum and then the directions are decimated back to the standard STWAVE 5-deg resolution.

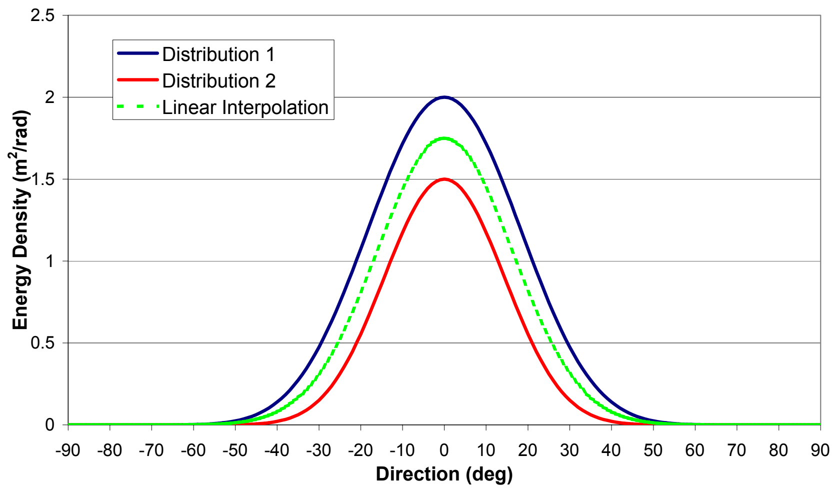

Figure 2. Linear interpolation of directional shapes

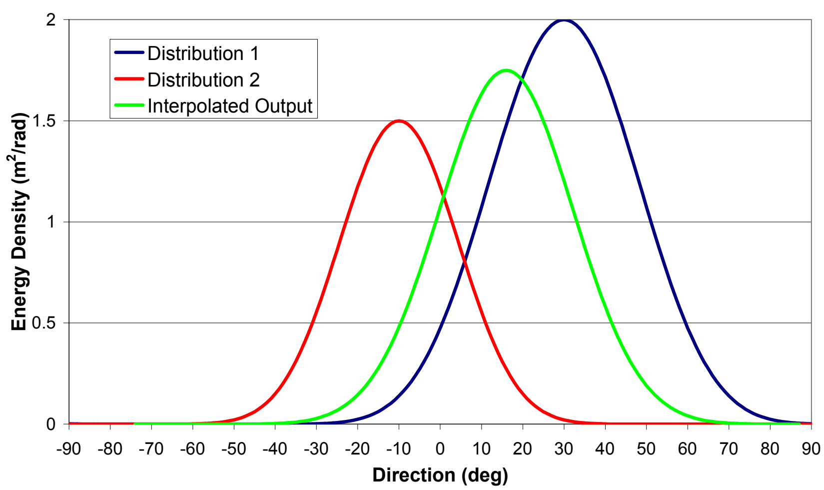

Figure 3. Result of morphic interpolation (compare with linear result in Figure 1)

The morphic technique is applicable only for single peaked wave spectra because the entire distribution is shifted based on a single peak direction. This technique is appropriate for climatic wave transformation studies where a parametric spectral shape is applied based on wave parameters.

NESTING EXAMPLE: To test the nesting scheme, three idealized cases were developed. The cases consist of a plane beach with a slope of 0.004, offshore depth of 16 m, and three different sized elliptical shoals with the long axes parallel to the shoreline. The shoals were centered on the 8-m depth contour, and the depth at the top of the shoal was 4 m. Shoal dimensions are given in Table 1. The large shoal bathymetry is illustrated in Figure 4. The domains were modeled with three grids (250-m coarse grid, 25-m fine grid, and 25-m nested grid, with the nest occurring at the peak of the shoal). Nested grid simulations were run with both linear and morphic interpolation, with each simulation consisting of 24 input wave conditions. The peak periods ranged from 6 to 18 sec, the peak directions ranged from 0 to 45 deg, and the wave heights were 2 m. The TMA spectral shape

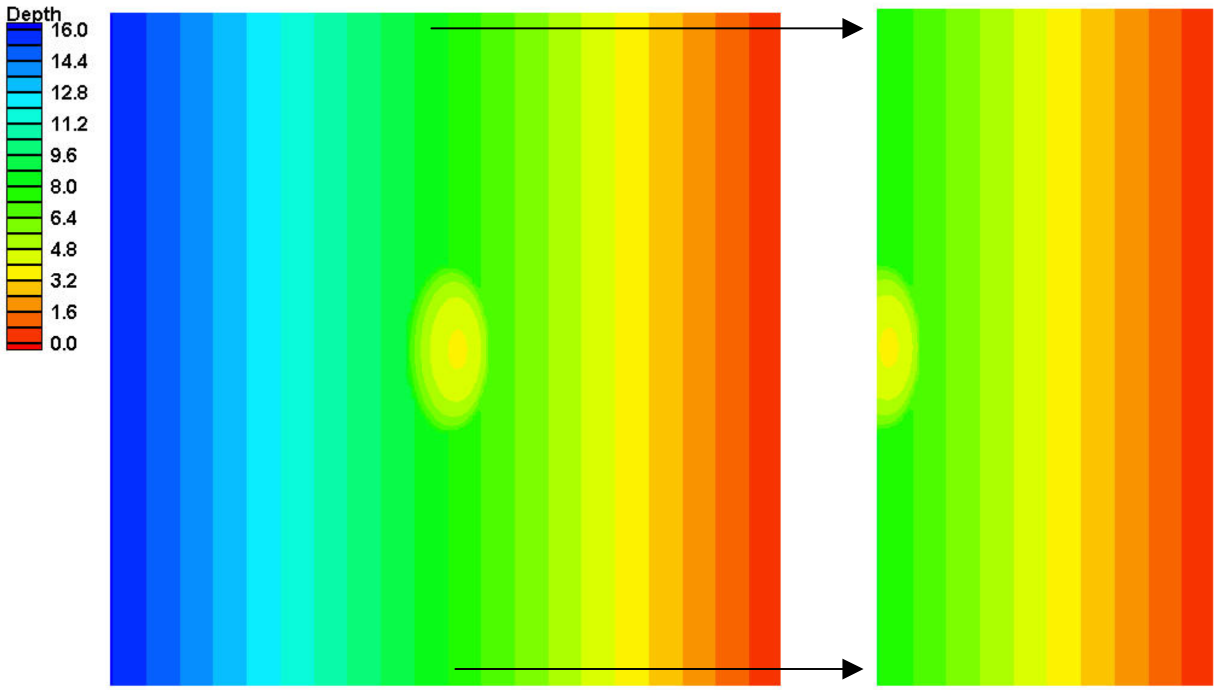

Figure 4. Large shoal bathymetry (parent and nested grids)

Table 1
Example Shoal Dimensions

Shoal	Longshore Dimension, m	Cross-shore Dimension, m
Large	2000	1000
Medium	1000	500
Small	500	250

was used with the parameters suggested by Smith, Sherlock, and Resio (2001). Figure 5 shows an example large-shoal simulation wave field from the fine grid and the coarse grid, and Figure 6 shows the nested grid with morphic and linear interpolation from the coarse grid. The coarse grid has seven points resolving the shoal and cannot represent the wave pattern in the lee of the shoal (maximum wave height of 2.6 m compared to 3.2 m on the fine grid). The nested grid applications provide a reasonable representation of the full fine grid simulation (maximum wave heights of 3.1 m compared to 3.2 m for the fine grid), with approximately a 50 percent reduction in computational time (input boundary spectra had 250-m spatial resolution). The nested grid simulations could be improved to exactly match the fine grid by placing the nesting boundary offshore of the shoal.

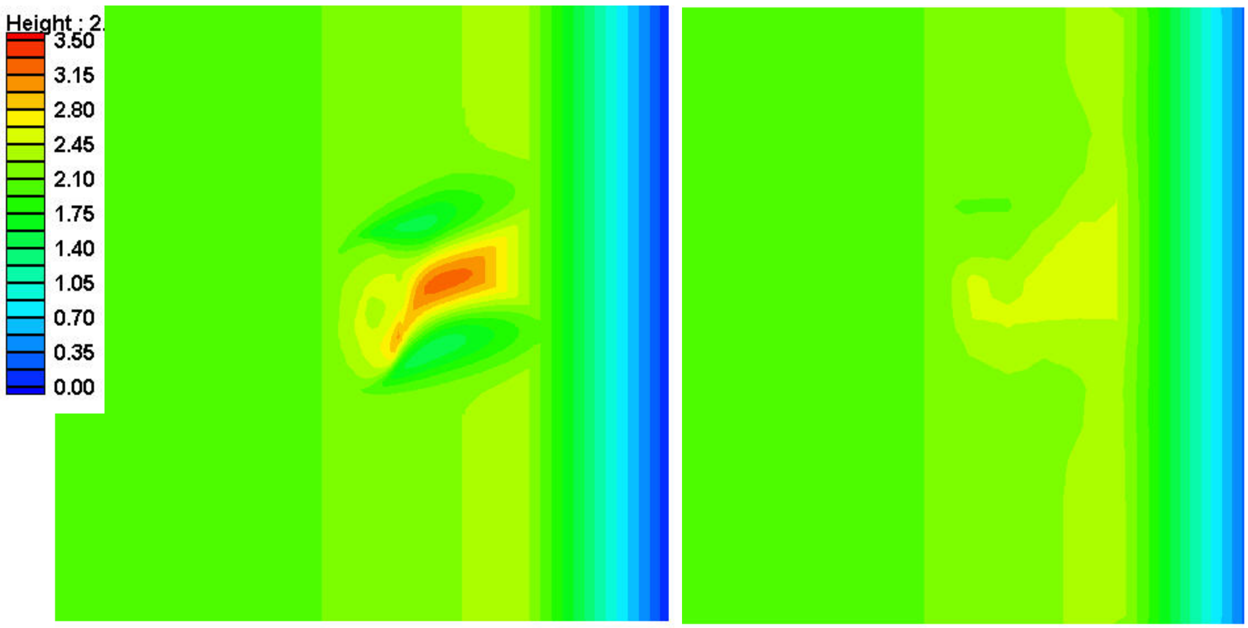

Figure 5. Fine (left) and coarse (right) grid wave heights for H_{mo}= 2 m, T_p = 18 sec, Θ = 30 deg

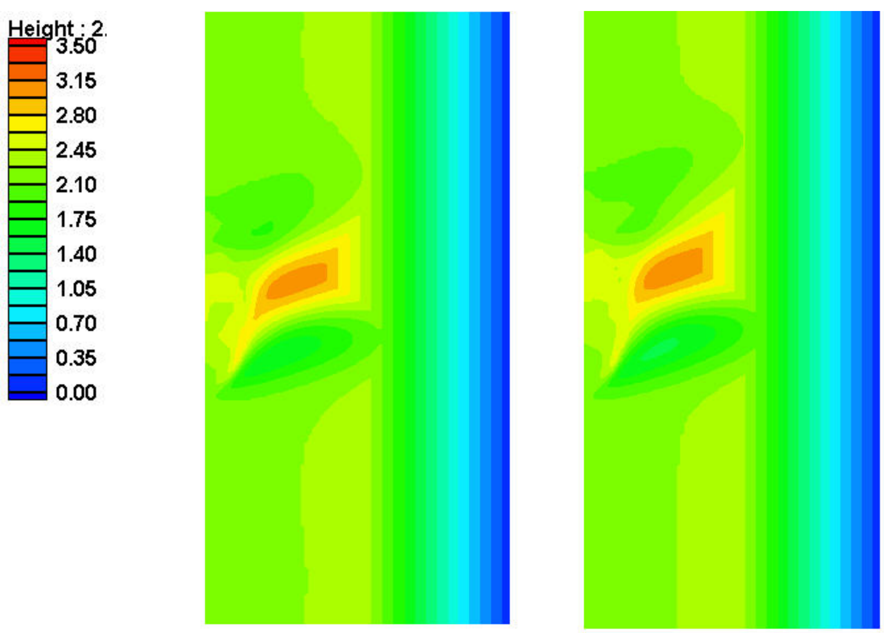

Figure 6. Morphic (left) and linear (right) nested grid wave heights for H_{mo}= 2 m, T_p = 18 sec, Θ = 30 deg

Figures 7 and 8 show the bias and root-mean-square (RMS) errors for the wave heights and mean directions, respectively, for the region shoreward of the crest of the shoal and seaward of the surf zone for all shoal configurations and all 24 wave conditions. The errors are calculated for the common grid cells (all three grids) outside the surf zone (because wave heights in the surf zone are purely depth limited, error statistics in that region are not considered). For the large shoal, the morphic interpolation reduces the RMS error and bias by half in comparison to coarse grid results. For the medium and small grids, the extent of the influence of the shoal is significantly reduced, so the overall error is also smaller (although the local error behind the shoal is greater). As the coarse grid resolves less and less of the shoal (seven cells for the large shoal, three cells for the medium shoal, and one cell for the small shoal), the inaccuracies of the input from the coarse grid to the nested grids cause the error for the coarse and nested grids to be similar. The conclusion from these examples is that the morphic interpolation is most accurate and should be used for simulations with a single wave train. Linear interpolation provides comparable accuracy and is appropriate for complex spectral shapes. Nesting is best applied offshore of complex features, such as the elliptic shoal used in this example, but provides reasonable results even for the boundary condition on the shoal. Features that are on the order of the coarse grid spacing or smaller, such as the small shoal, cannot be well represented through grid nesting. To include these features, the coarse grid must have higher resolution or the fine grid must extend seaward of the feature.

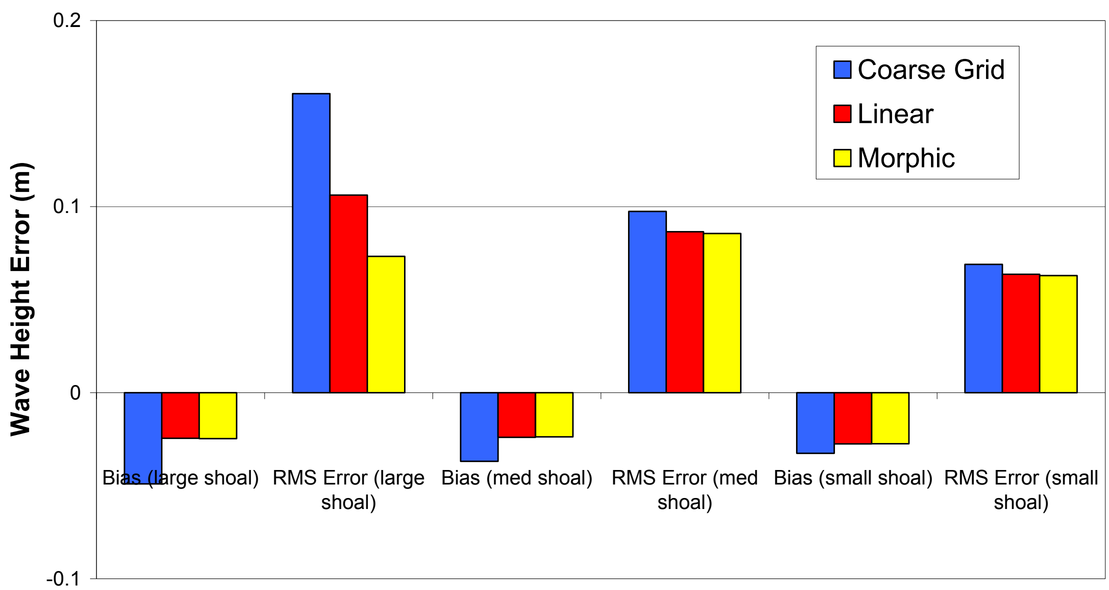

Figure 7. Wave height error for coarse grid and with nesting using linear and morphic interpolation

INPUT AND OUTPUT FOR STWAVE VERSION 4: STWAVE Version 4.0 includes the capability to nest grids as discussed in this technical note. Implementation of grid nesting requires changes to the STWAVE model parameter (options) and simulation files. The changes to the options file make the new version of STWAVE incompatible with older input options files, but the old files can be updated to the new version with the addition of parameter IBND, as described in the following paragraphs. The format for the NEST file is also given.

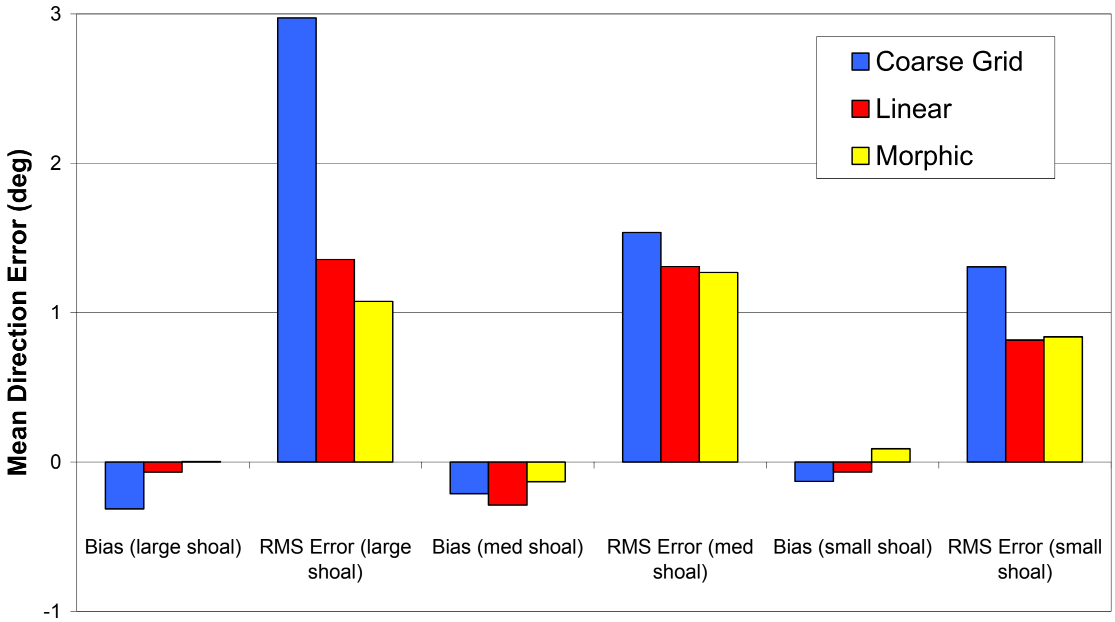

Figure 8. Wave direction error for coarse grid and with nesting using linear and morphic interpolation

Model Parameter File. A sample model parameter file for the coarse grid runs used in the examples is given in Figure 9. The first line in the file is the model parameters (detailed descriptions are given by Smith, Sherlock, and Resio 2001):

IPRP = 1 for propagation only, 0 for wind source terms
ICUR = 1 for wave-current interaction, 0 for no currents
IBREAK = 1 to print indices for breaking, 0 to not print indices
IRS = 1 to calculate radiation stresses, 0 to not calculate stresses
NSELCT = number of output spectral points
IBND = 0 for single point boundary input, 1 for linear boundary interpolation, and 2 for morphic boundary interpolation. IBND is a new STWAVE input that is required in Version 4.0. A value of IBND = 0 is used for the coarse offshore grid, and a value of 1 or 2 is used for a nested grid.

```
1  0  0  0 2 0
10 7
11 7
17
9  1
9  2
9  3
9  4
9  5
9  6
9  7
9  8
9  9
9  10
9  11
9  12
9  13
9  14
9  15
9  16
9  17
```

Figure 9. Sample offshore coarse grid options file for nested grids

Following the model parameters are the I,J locations for saving wave spectra (NSELCT paired values). The last section of the parameter file is the optional output locations for grid nesting. This is new in Version 4.0. The first number is the number of output nesting points (NEST), and it is followed by NEST paired I,J locations where spectra are saved for grid nesting. In the sample file in Figure. 9, NEST = 17 and the nesting output is saved along the entire ninth column of the coarse grid. The output points do not need to be evenly spaced, so they can be more closely spaced in regions of more complex bathymetry. Presently, the nesting locations must be specified directly by the user, but in the future, the Surface-Water Modeling System (SMS) (Brigham Young University Environmental Modeling Research Laboratory 1997) will automate the process of selecting nesting locations. For a nearshore nested grid, parameter IBND is set equal to 1 or 2, and the last section (starting with NEST) is omitted. If NEST = 1, then nesting is based on a single input point on the boundary and no interpolation is required. For NEST = 1 cases, the output nesting file from the coarse grid is the input spectral file to the nested run (with no modification required). All input in the parameter file is free format, i.e., at least one space separates parameters on a line.

```
STWAVE        0.0000         0.0000         0.0000
DEP       coarse_l.dep
OPTS      coarse.std
SPEC      test.eng
WAVE      coarse_l.wav
OBSE      coarse_l.obs
NEST      coarse_l.nst
```

Figure 10. Sample coarse grid simulation file for grid nesting

Simulation File. Simulation files specify input and output file names for an STWAVE run. In the past, simulation files have been optional (then STWAVE reverts to default file names). To run nested grids, the grid origin and orientation are provided in the simulation file, so the simulation file is required. A sample simulation file is shown in Figure 10. The file is the same as in previous versions of STWAVE with the addition of the NEST file. This is the file where output spectra from coarse grid simulations are saved for nesting. For the fine grid simulation, the nesting output file from the coarse grid simulation becomes the spectral input file, and the NEST line is not required. For the example in Figure 10, the corresponding fine grid spectral input would be specified in the simulation file as "SPEC coarse_l.nst". The first line of the simulation file must begin with "STWAVE" to specify that the run is for STWAVE and provide the grid origin (x and y coordinates) and grid orientation (degrees counter clockwise from east). In the sample file shown in Figure 10, the origin is set as (0,0) and the orientation is zero. This input line has a format (A6, 3f15.5). Remaining input lines of the simulation file are free format. The origin and orientation are used in STWAVE only to determine the relative locations of the coarse and nested grids. The coarse grid values are saved into the NEST file to bring into the nested grid application.

The origins and orientations are used to determine the geometry for interpolation, so it is critical that the origin and orientation values be specified correctly for the coarse and nested grids. For grids generated in SMS, these parameters are set automatically, based on the coordinate system specified for the bathymetry. In typical applications, orientations for the two grids may be the same, but origins will differ. STWAVE defines bathymetry and wave parameters at the center of each grid cell. The STWAVE origin is located on the offshore grid boundary as shown in Figure 11. Note that the grid origin is located along the outside grid cell faces and not in the cell centers. For the nested grid simulations shown in this technical note, the coarse grid origin was (0, 0) and the orientation was 0 (grid spacing of 250 m). The nested grid origin was (2,112.5 m, 112.5 m), and the orientation was 0 (grid spacing of 25 m). The nested grid origin was selected to align cell centers of the coarse grid and every tenth nested grid cell for direct comparisons (e.g., the center of cell (9,1) on the coarse grid is located at (2,125.0 m, 125.0 m), so to match cell centers with the nested grid

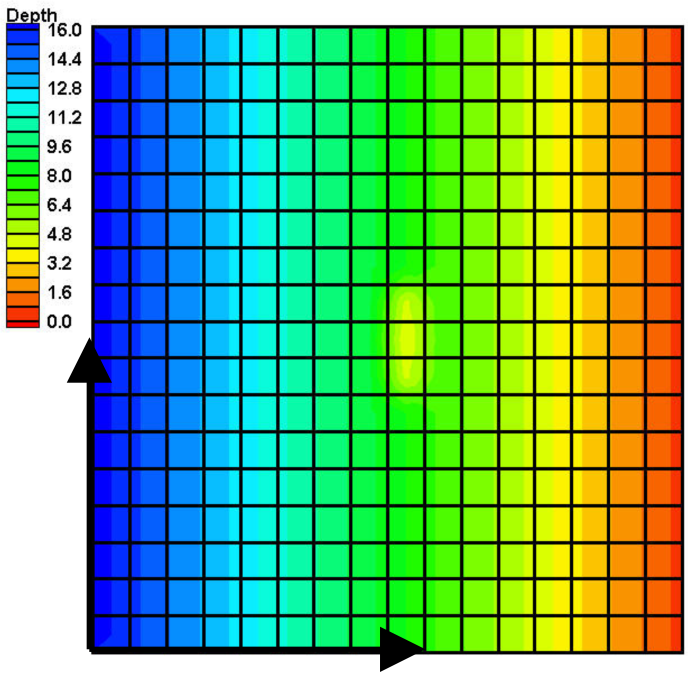

Figure 11. STWAVE grid origin and orientation

cell (1,1), the nested grid origin is half a nested grid cell away at (2112.5 m, 112.5 m)). The orientation of the two grids does not need to be the same, but if the directions differ significantly, energy is lost because of the half-plane definition of the spectrum (Smith, Sherlock, and Resio 2001).

Nest File. The nesting file is an output from coarse grid simulations and input to fine grid simulations. The file format is similar to the STWAVE input wave spectra file (Smith, Sherlock, and Resio 2001). The first line of the file defines the number of spectral frequencies (NF) and directions (NA), the number of nesting points (NEST), and the azimuth of the coarse grid (from the simulation file). Next, the spectral frequencies are given in hertz. For each nesting point and time-step, a header line and the spectral densities are given. The header line contains an integer identifier (IDD), wind speed in meters/second (U), wind direction relative to the STWAVE coordinate system in degrees (UDIR), peak spectral frequency in hertz (FM), water elevation correction in meters relative to the bathymetry datum (DADD), and the x and y coordinates of the nesting point in meters (X_NEST, Y_NEST). The header line is followed by the energy densities in units of meters squared/hertz/radian.

GETTING STWAVE: The most recent STWAVE executable (Version 4.0) and sample input and output files are available on the Coastal Hydraulics Laboratory Web page at:

http://chl.wes.army.mil/research/wave/wavesprg/numeric/wtransformation/stwave.htp

The Web site also provides the STWAVE, Version 3.0, user's manual in PDF format:

http://chl.wes.army.mil/research/wave/wavesprg/numeric/wtransformation/downld/erdc-chl-sr-01-11.pdf

STWAVE Version 4.0 requires some minor changes to the options file from the previous version. At time of publication, these changes have not yet been implemented in SMS. The parameters (.std) file can be modified with a text editor outside of SMS, and SMS can be used for all other functions (grid generation, model runs, and visualization). SMS is being modified to automate and simplify the nesting process.

ADDITIONAL INFORMATION: Questions about this CHETN can be addressed to Dr. Jane McKee Smith (601-634-2079, Fax 601-634-4314, email: *Jane.M.Smith@erdc.usace.army.mil*). This technical note should be referenced as follows:

> Smith, J. M., and Smith, S. J. (2002). "Grid nesting with STWAVE," ERDC/CHL CHETN I-66, U.S. Army Engineer Research and Development Center, Vicksburg, MS. *http://chl.wes.army.mil/library/publications/chetn/*

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Smith, J. M., Sherlock, A. R., and Resio, D. T. (2001). "STWAVE: Steady-State Spectral Wave Model, user's guide for STWAVE Version 3.0," ERDC/CHL SR-01-01, U.S. Army Engineer Research and Development Center, Vicksburg, MS. *http://chl.wes.army.mil/research/wave/wavesprg/numeric/wtransformation/downld/erdc-chl-sr-01-11.pdf*