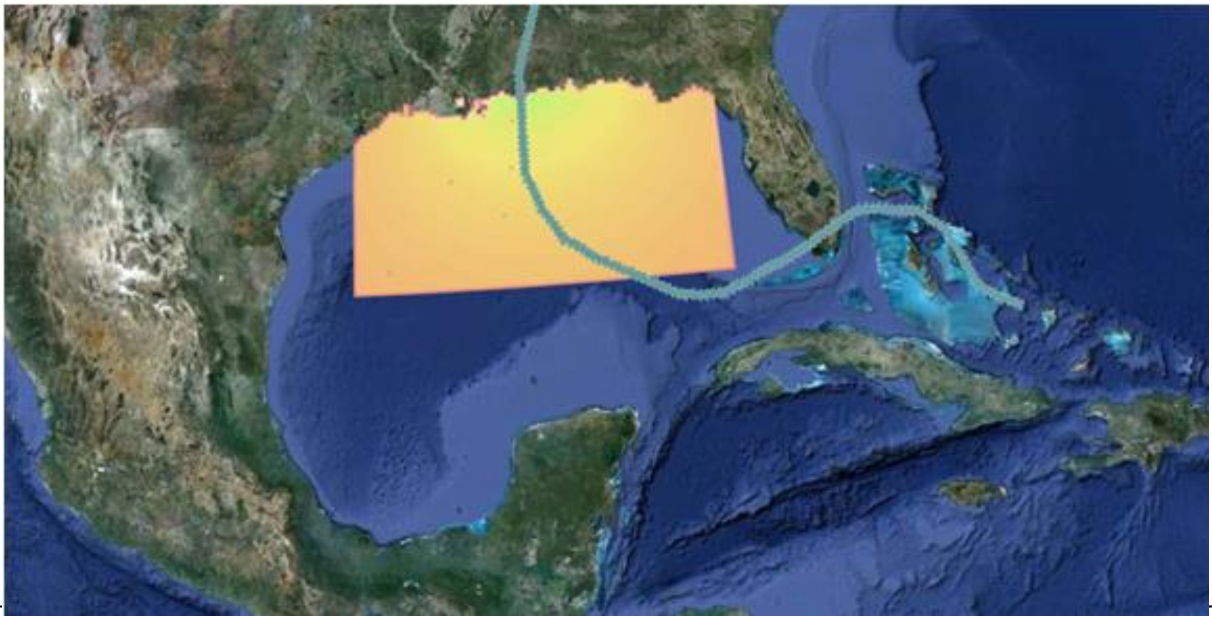
v. 12.1

SMS 12.1 Tutorial

WAve prediction Model (WAM)



Objectives

This tutorial will show how to create various WAM simulations from 2D Cartesian grids.

Prerequisites

- Overview Tutorial

Requirements

- WAM
- STWAVE
- Map Module
- Scatter Module
- Cartesian Grid Module

Time

- 60–90 minutes

1 Introduction

The global ocean WAve prediction Model (WAM), developed and maintained in part by the Engineering Research and Development Center (ERDC) of the United States Army Corps of Engineers (USACE) is a third generation wave model. WAM predicts directional spectra as well as wave properties at user specified output locations in the model domain throughout a simulation. The model requires a wind field for the desired simulation period as input.

Given these wind fields, WAM can predict the directional spectra generated by coastal storms at locations near the shore or engineering structures. These wave spectra can play a significant role in the flooding and damage caused by coastal storms as they are compounded on surges associated with the storm.

WAM is designed for large scale domains and runs in geographic coordinates. WAM can be used to generate spectral boundary conditions for a nearshore wave model. This tutorial includes an optional section which runs STWAVE using spectra from WAM.

In this exercise, previously generated wind data will be used.

2 Loading Input Data Files

The WAM model requires a wind field to drive the simulation. For this case, a previously computed wind field will be loaded for a simulation of a simulated storm which mimics the path of Hurricane Katrina from 2005.

1. Select *File* | **Open** to bring up the *Open* dialog.
2. Locate and select the file "WAMin.sms" in the data files folder for this tutorial. Click **Open** to import the file.

This project includes a grid covering the Northern Gulf of Mexico with datasets which define the wind directions at 10 meters and the sea level pressures for each hour for a period of time from August 23, 2005 at 6 pm to August 30, 2005 at 6 pm (seven days). Several coverages and a shapefile depicting the shoreline are also part of the project.

3. Click on the the "Sea level pressure" scalar dataset under Scatter Data in the Project Explorer to activate it so the wind data can be visualized.
4. The storm enters the domain around 6 pm on the 26th of August, so select time steps in that range to see the wind and pressure fields.

3 Defining the WAM Domain

A WAM simulation requires a Cartesian grid in geographic coordinates to define the scope of the computations. In this section, this grid will be created. The wind data drives the WAM simulation, so the domain of this model must lie within the grid which defines the wind field.

For this example, the same domain will be used. First it's necessary to create a new WAM coverage. This can be done by creating a new coverage, or by copying the PBL coverage. The storm track information from the PBL coverage is not required, but the grid frame is needed.

To create the coverage:

1. Right-click on *Map Data* and select **New Coverage** from the menu. This opens the *New Coverage* dialog.
2. Scroll to the bottom and select *WAM* as the coverage type and name the new coverage "WAM_Katrina".
3. Click **OK** to close the dialog. The new "WAM_Katrina" coverage will appear in the Project Explorer.

3.1 WAM Grid Frame Properties

The grid on which the wind data is defined consists of cells with dimensions of 0.1 x 0.1 degrees. For this application, WAM will use this same resolution, though the two resolutions do not need to match. The WAM grid should be the same size or slightly smaller than the grid with the wind data so that every cell in the WAM grid contains wind data.

To specify the WAM grid position, size, and resolution, adjust the grid frame properties from which SMS will generate the grid by doing the following:

1. Select the "WAM_Katrina" coverage to make the map module active.
2. Using the **Create 2-D Grid Frame** tool, click out a grid frame in the same general area where the "Synethetic_KATRINA" grid is located.
3. Using the Select 2-D Grid Frame tool, double-click on the icon in the middle of the grid frame (or right-click and select **Properties**) to open the *Grid Frame Properties* dialog.
4. Make the following changes:
   - *Origin X* to "-94.9"
   - *Origin Y* to "25.1"
   - *I size* to "11.3"
   - *J size* to "6.3"
   - *Cell size* in both directions: "0.1"
5. Click **OK** when done to close the *Grid Frame Properties* dialog.

3.2 Interpolating to Cartesian Grid

With a grid frame defined, the WAM domain can now be generated by doing the following:

1. Right-click the "WAM_Katrina" coverage and select *Convert* | **Map → 2D Grid** from the drop down menu to bring up the *Map → 2D Grid* dialog.
2. Under *Depth Options,* set the *Source* to "Scatter Set", then click on the **Select…** button to bring up the *Interpolation* dialog.
3. Under the *wnat_bathy* scatter set, select "Z" as the dataset on the top right portion of the dialog.
4. Change the *Single Extrapolation Value* to "-2.0". This assigns a negative depth (land) to WAM cells created outside the scatter set.
5. Click **OK** to close the *Interpolation* dialog.
6. Click **OK** to close the *Map → 2D Grid* dialogs.
7. A message will appear indicating that isolated cells have been found in the land region. Click **OK**.
8. Hide the display of the "WAM_Katrina" coverage. (The grid to represent WAM is needed, but the grid frame doesn't need to be displayed.)

4 WAM Parameters

The WAM grid has been created, but has not yet had parameters assigned to it. Most of the parameters for running WAM are specified on a grid level and a few others are specified on a simulation level (when using multiple grids shown later). The grid options include computation parameters, time steps, output times, output field types, and spatial input options. The output field types and spatial inputs have their own sections below.

4.1 General Options

The computation parameters include several options that can affect the quality of the simulation and runtimes. Using the shallow water depth model, depth refraction, or depth and current refraction model requires a smaller time step and increases runtime.

The WAM model is subject to what is referred to as the CFL condition. A larger time step results in shorter run times, but lower stability. The CFL condition is a measure of anticipated stability and a prediction for convergence in solving partial differential equations numerically. The time step must be small enough to assure that input energy from the wind and transferred wave energy can more cleanly pass from cell to cell and does not skip cells as the input fields change.

If the time step is too large, energy may be moved through cells without being tracked appropriately. Decreasing the time step resolves this problem but results in longer run times, so the time step should be selected to maintain stability in as short a run time as possible.

In order to better see the WAM grid and assign WAM parameters, do the following:

1. Click on the “WAM_Katrina_Grid” to make it active, then right-click on it and select **Zoom to Grid**. SMS will refresh the display centered on the WAM grid. The contours of bathymetry should be displayed as well.
2. Right-click on the “WAM_Katrina_Grid” in the Project Explorer and select **Options** to bring up the *Grid Options* dialog.
3. In the *Grid Options* dialog, there are three tabs: General, *Output* and *Spatial Input*. In the *General* tab, make the following changes: Set the *Title* to “Sample WAM_Katrina”.
4. Set the *Water depth model* under *Model Options* to “Deep”. The model options affect model stability. See the WAM documentation to get an explanation of the differences between the deep and shallow water options.
5. The WAM model includes the capability to simulate refraction of waves caused by interaction with the ocean bottom and interaction with currents. For speed, leave *Refraction model* set to “Not used”.
6. WAM can simulate wave breaking. Leave *Breaking* checked on for this calculation.

7. The *Test level* is a control for output diagnostics and is mostly used for model debugging. For now leave this set at “0” which is the minimal diagnostic output level.
8. Leave the *Create restart file* option checked. This causes WAM to create a restart file to continue analysis at a future time.

Under *Model time steps*, *Max CFL* is displayed in red with a value of “2.33”. SMS computes the maximum CFL value based on the propagation time step, cell size, refraction model, and the water depth model. All three parameters are interconnected. If the computed maximum CFL is above the threshold of “1.0”, it will appear red and these parameters should be changed until a stable condition is achieved (it will appear green when this happens). Each time the model parameters and time steps are changed, SMS recomputes the *Max CFL* for the simulation.

9. For simplicity, and to have a round number for the time step for this tutorial, change *Propagation* to “300 seconds” (or “5 minutes”), which gives a *Max CFL* of “0.78”.
10. Under *Model time steps,* set *Source* to “300 seconds” (or “5 minutes”) to match the propagation.

It is not required that this time step match, but it matches here for convenience. Normally, a time step would be used to smoothly transition the wind fields. This time step controls how frequently the WAM simulation updates the forcing terms. The input wind files were saved at 60 minute output. WAM interpolates between these intervals to attain a smaller forcing time step.

11. Set the *Output wind* to “60 minutes” (or “1 hour”).
12. Under *Output time steps*, set *Spatial Datasets* to “1 hour”. This controls how frequently WAM will save the spatially varied quantities. Viewing these quantities give feedback on the WAM simulation.
13. Set *Spectra* to “1 hour”. This controls the interval between times that WAM saves spectral output at specified locations. These spectra will be used to drive STWAVE in later simulations.
14. Set *Close/reopen files* to “12 hours”. This tells WAM to group the output data into files containing 12 hours worth of output each. These files will be created in the directory for the WAM grid and will be named “*IntOutYYYYMMDDHH*” and “*SpectraOutYYYYMMDDHH*”. Continue to the next section.

4.2 Output Options

WAM supports a variety of output options, specified in the *Output* tab of the *Grid Options* dialog. Switch to the *Output* tab, and scroll down to the bottom of the options list to see different descriptions of Swell and Sea waves.

Sea waves are generated in a local area by the wind that is currently blowing. Swell waves are waves that have traveled into an area after being generated by previous winds in other areas. There may be swell present even if there is no wind and no sea waves.

For production models, the WAM developers recommend all the output options be left on, resulting in large output files. In order to keep file sizes smaller for this tutorial, turn off everything except:

- Wind speed at 10m
- Wind direction
- Significant wave height
- Wave peak period
- Wave mean period
- Wave direction
- Directional spread
- Spectra of total sea
- Sea spectra
- Swell spectra

Continue to the next section.

4.3 Spatial Inputs Options

The third tab in the *Grid Options* dialog allows specification of spatially varied input to the WAM model. Switch to the *Spatial Inputs* tab and make the following changes:

1. Ignore the *Ice cover data* and the *Currents data* sections as they are not needed for this tutorial.
2. In the *Wind data* section, click on the **Select…** button to bring up a *Select Dataset* dialog.
3. Select the “Wind velocity at 10m” dataset then click **Select** to close the *Select Dataset* dialog.
4. Click **OK** to exit the *Grid Options* dialog.

5 WAM Simulation

With the WAM grid constructed and the grid options specified, it is time to create a simulation. With SMS, multiple WAM simulations can be created in the same project. Each simulation must be associated with a WAM grid, but more than one simulation can use the same grid.

5.1 Simulation

To create the WAM simulation:

1. Right-click in a blank spot at the bottom of the Project Explorer and select *New Simulation* | **WAM**. A "WAM" entry is made in the tree with a folder named *Simulations*, and a default simulation, named "Simulation", is created.

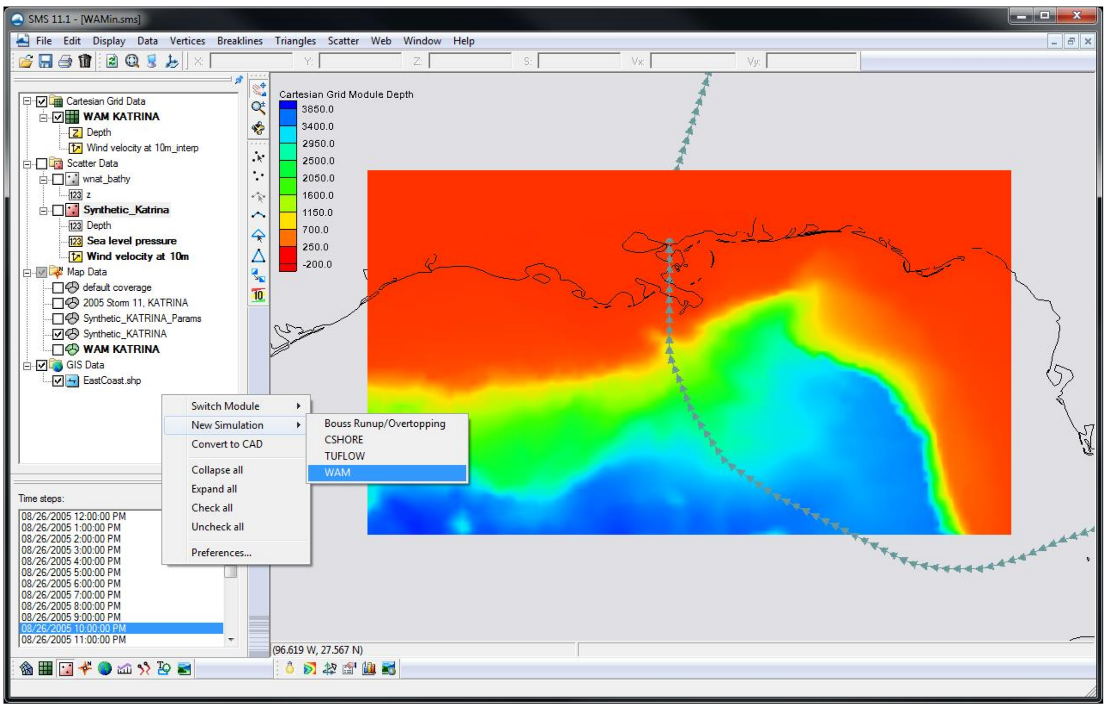


Figure 1 Creation of the WAM simulation by right-clicking in the project explorer.

2. Rename the simulation by right-clicking on "Simulation" in the *Simulations* folder and selecting the **Rename** command. Give the new simulation the name "WAM_Katrina".

3. Click and hold on the "WAM_Katrina Grid" object in the Project Explorer, then drag it onto the new "WAM_Katrina" simulation. A link to the "WAM Katrina Grid" appears below the simulation name in the Project Explorer.

5.2 Simulation Parameters

To set up the simulation, do the following:

1. Right-click the "WAM_Katrina" simulation and select **Model Control...** from the drop down menu. The *Simulation Model Control* dialog will appear.

2. For this simulation, leave *Number of frequencies* at the default of "25" and Number of directions at the default of "24". The first defines the extent of the

spectral grid. Each frequency is 10% larger than the previous frequency. With 25 frequencies the maximum frequency is 0.4114 which corresponds to approximately a 2.5 second wave. The second determines the size of the directional bin in the spectra. The default of 24 corresponds to a 15 degree bin.

3. Define the resolution and range of the spectral grids that will be created by WAM. The *Lowest frequency* band defines all the frequencies in the grid. Each frequency is defined by the frequency before it, so this is an important parameter. Use the default value of “0.0417728”. This corresponds to approximately a 24 second wave. It is the minimum recommended value (longest wave period). The WAM documentation has some guidance in choosing the right starting frequency band.
4. Under *Simulation run times*, Change *Start* to “08/26/2005 1:00:00 PM”. This corresponds to about the time the storm is approaching the domain. More time before the storm arrives may be included if currents are being used.
5. To expedite the run times in this exercise, set *End* to “08/28/2005 9:00 AM” instead of going the full length of the storm. The seven day simulation takes just over an hour to run on a typical desk top machine. Reducing the run time allows running a model to see the output. (Note: If time permits, models can be rerun with longer time ranges. Remember to stay inside the range of times for which wind data exists.)
6. Switch to the *Spectra* tab and make sure that the *Run type* is set to “Cold Start”. If a previous run is being used as a starting point, and a hot start file was saved, the hot start option may be chosen.
7. Leave the other model parameters at default values. Click **OK** to exit the *Simulation Model Control* dialog.

6 Exporting WAM Files, Saving Project and Running WAM

Now all the necessary information for a WAM simulation run has been entered into SMS. It is time to save the project and run WAM.

6.1 Exporting WAM Files and Saving Project

Before exporting the WAM files and running WAM, save the project. This is where the run information will be stored.

1. Select *File* | **Save As...** to bring up the *Save As* dialog.
2. Enter a *File name* of “WAMout.sms” then click **Save**.
3. Right-click on the “WAM_Katrina” simulation and select **Export WAM Files**. This command creates a folder named “WAM” in the project folder. This “WAM” folder contains a folder for each simulation, named for the

simulation. In this case, there is only one simulation, named "WAM_Katrina", so the WAM folder includes a single folder named "WAM_Katrina". This folder includes folders for each input grid and the wind input. Since the "WAM_Katrina" simulation includes only a single grid, two folders are created. The first is named "WAM_Katrina Grid", which is the name of the grid previously created, and second is "WindInput", which contains all wind files. The process will take up to a minute because SMS resaves the wind data formatted for WAM to use.

6.2 Running WAM

Now that the project has been saved, it is time to run WAM.

1. Right-click on the "WAM_KATRINA" simulation and select **Launch WAM**.

There are three WAM executables including "WAM_Preproc", "WAM_Chief", and "MAP_TO_RASTER". The model wrapper launches each of these in turn (they are order specific) as seen in Figure 2. Once each process is complete, the bar for that process will turn green.

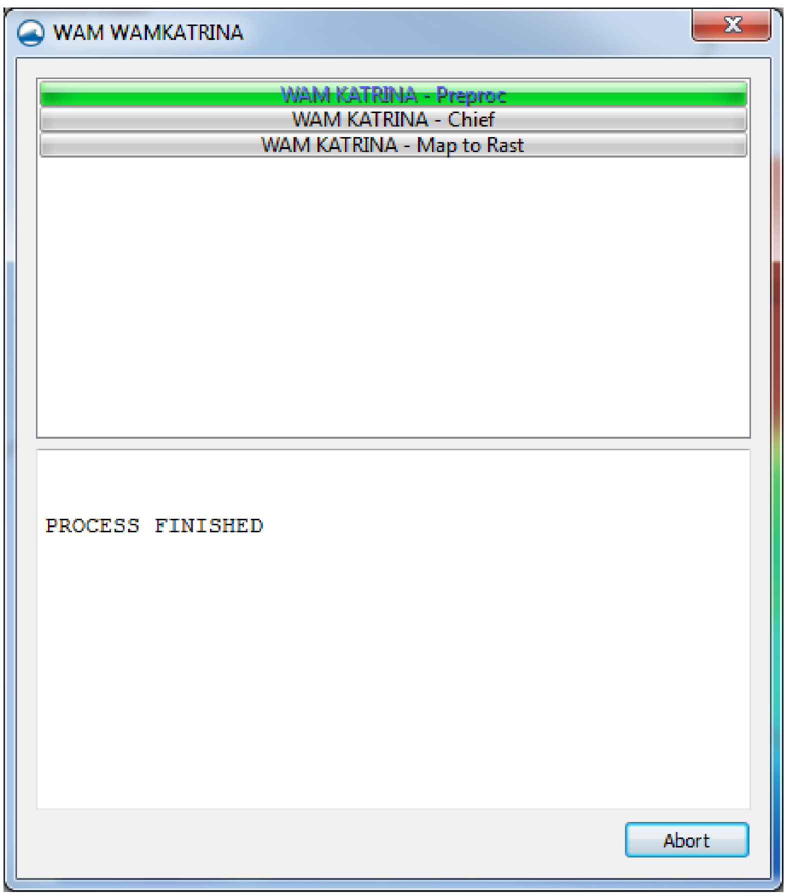


Figure 2 WAM Simulation Run showing the different WAM executables.

"WAM_Preproc" reviews the grid and creates two files, "Grid_info" and "Preproc prot". The "prot" file is an ASCII dump of the model process. If desired, open this in an editor to verify that the model was executed and didn't detect problems. The "Grid_info" file is used in the next phase of the simulation.

"WAM_Chief" is the main process of WAM and takes the bulk of the run time. The process does not output any diagnostics as it runs, so the model wrapper cannot pass along progress information as the model runs. This process creates a "prot" file, an ASCII dump of the model process that can be reviewed in an editor. It also outputs three series of solution files. Each of these includes a particular type of output for a specified simulation interval.

In this case, the specified a "Close / reopen files:" interval of 12 hours, so each solution file will contain 12 hours of data. The filename includes the time at the end of the simulation interval contained in that file. Therefore, the string "20050824060000" indicates the file contains data with time values from 2005 August 23 at 7 pm through August 24 at 6 am.

The three types of output file are:

- "IntOut###" – this is the interval output file. It contains the spatially varied datasets computed by WAM.
- "SpectraOut####" – this is the spectral output file. It contains the spectra at each spectral site, at the output frequency specified for spectral output.
- "Restart###" – this is a series of files which contain information to restart the simulation at a specific point if needed.

"MAP_TO_RASTER" is a utility that converts the data in the "IntOut###' solution files into an HDF5 format so that SMS can read them. This allows for post processing of the datasets. SMS writes a script, "fort.10" (placed in the "WAM_KATRINA Grid" output folder), that instructs this utility to name the solution file "wam_output.h5".

2. Click **Exit** once the simulation run is done.

WAM creates all of its output files in the folder for the grid. In this case that is the "WAM_KATRINA Grid" folder.

7 Viewing WAM Simulation Results

SMS automatically loads the spatial datasets(from "wam_output.h5") and the spectral output when exiting the simulation run window. If the files do not open automatically, the datasets can be opened by selecting *File* | **Open,** browsing to the grid folder, and selecting "wam_output.h5". This simulation did not include any spectral output. This option is discussed in section 9.

7.1 Viewing datasets on the grid

To view the output from WAM:

1. Make sure that the “WAM_Katrina Grid” is selected. Five scalar and two vector datasets should be loaded on the grid, where before there was only the depth. Clicking on a dataset makes it the active, or viewed, dataset. One vector and one scalar can be active at a time (Figure 3).

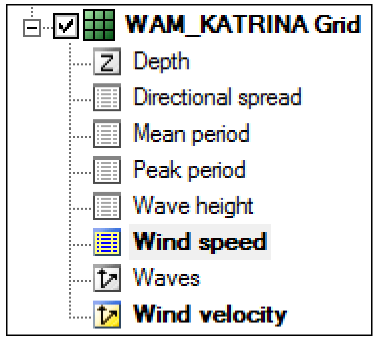


Figure 3 Datasets loaded from “wam_output.h5”

2. To illustrate how to view the output of the WAM model, select “Wave Height” as the active scalar dataset and “Wind velocity” as the vector set. (If the display options were changed, make sure that both contours and vectors are on.) Select “08/26/2005 2:00:00 PM” as the time step. This is one hour after the start of the simulation. The model did not save anything before this time step. While stepping through the time steps in the *Time steps* window, SMS will update the display showing how wind field changes and the wave heights vary over the domain. (Figure 4 shows the solution for “8/27/2005 7:00:00 AM”).

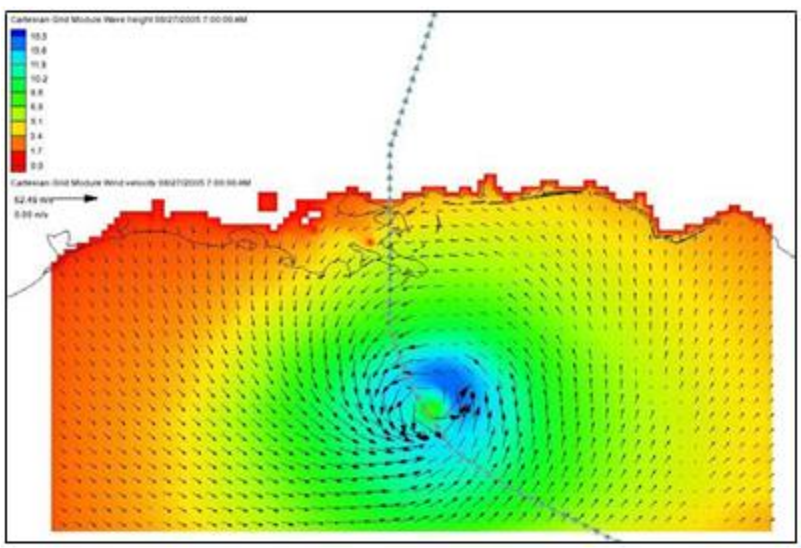


Figure 4 Sample of WAM spatial dataset output

Spend a few minutes stepping through the various datasets created by the WAM model.

8 Nested Simulation

WAM supports the ability to create a coarse grid to cover a large domain, and then define smaller, high resolution grids in specific areas of interest. SMS refers to the coarse grid as a “parent” grid and the small grids as “child” grids. These “nested” child grids allow high resolution investigation of a region of interest without the computational expense of a high resolution grid over the entire basin.

8.1 Nested Grid

To create a nested grid:

1. First create a grid frame. Right-click on *Map Data* and select **New Coverage** from the drop-down menu to bring up the *New Coverage* dialog.
2. Select the *Coverage Type* as “WAM” and change the *Coverage Name* to “Nested WAM”. Click **OK** to close the *New Coverage* dialog.
3. Select the newly created “Nested WAM” coverage to make it active.
4. Using the **Create 2-D Grid Frame** tool, click out a grid roughly in the same area as shown in Figure 5.

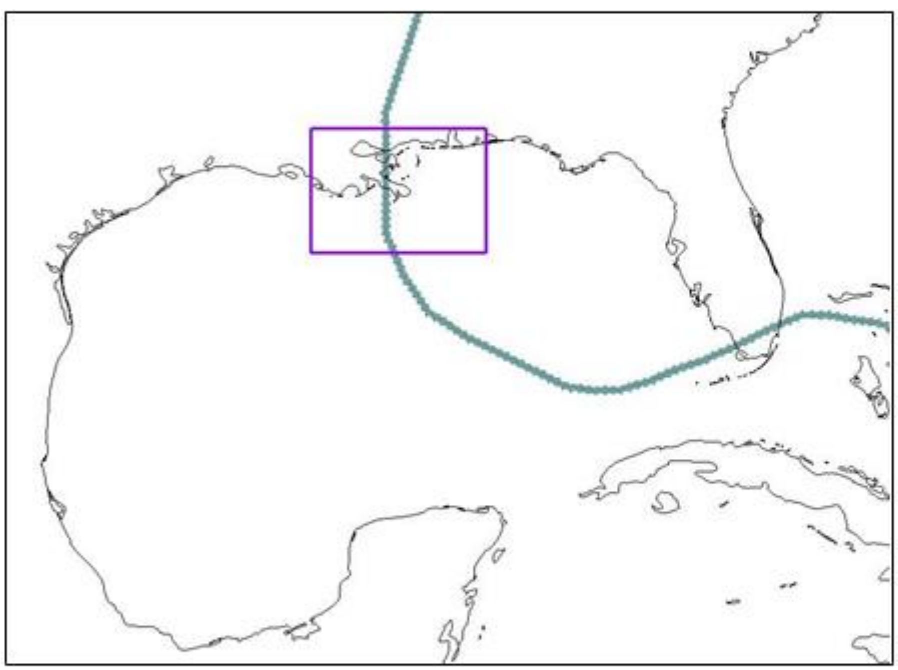


Figure 5 Nested Grid Frame

5. Right-click on the “Nested WAM” coverage and select *Convert* | **Map → 2D Grid** to bring up the *Map → 2D Grid* dialog. The default grid name is “Nested WAM Grid”. The default will be used for this tutorial.
6. Make the following changes:
   - Turn on “Fine Grid” under *Grid Nesting*.
   - Make sure the *Coarse Grid* is set as WAM_Katrina, which is the name of the parent grid. This will change the values for the newly mapped grid, such as the origin and increment, to correspond to cells in the coarse grid.
   - Double the resolution by setting the *Cell size* in both *I Cell Options* and *J Cell Options* directions to “0.05”.
   - Under *Depth Options*, select “Scatter Set” as *Source* and click on the **Select…** button to bring up the *Interpolation* dialog.
   - Select Z as the *Scatter Set to Interpolate From* and change the *Extrapolation Single Value* to “-2.0”. Click **Ok** to close the *Interpolation* dialog.
   - Click **OK** to close the *Map → 2D Grid* dialog and generate the grid.
7. If prompted that some isolated water cells were found on the grid, click **OK** in dialog, as these will not affect any results.

8.2 Grid Options

To set the grid options for this nested grid, do the following:

1. Select “Nested WAM Grid” to make it active and right-click to select the **Options…** command. This will open the *Grid Options* dialog.
2. In the *General* tab, make the following changes:
   - Set the *Title* to “Nested WAM Sample”.
   - Set the *Water depth model* under *Model Options* to “Deep”.
   - Under *Model time steps*, set the *Propagation* time step to “150 seconds”.
   - Set the *Source* time step to “5 minutes”.
   - Set the *Output wind* to “30 minutes”.
   - Under *Output time steps*, set *Spatial Datasets* and *Spectra* to “1 hour”
   - Set *Close/ reopen files* to “12 hours”.
3. Switch to the *Output* tab and turn off everything except:
   - Wind speed at 10m
   - Wind direction

- Significant wave height
- Wave peak period
- Wave mean period
- Wave direction
- Directional spread
- Spectra of total sea
- Sea spectra
- Swell spectra

As before, this is done in order to keep the file sizes more reasonable during the tutorial.

4. Switch to the *Spatial Inputs* tab and click on the **Select** button under *Wind data* to bring up the *Select Dataset* dialog.
5. Select the “Wind velocity at 10m” dataset under the *Synthetic_KATRINA*. (As with the coarse grid, *Ice Cover* and *Currents* are not needed.) Click **Select** to close the *Select Dataset* dialog.
6. Click **OK** to close the *Grid Options* dialog.

8.3 Nested WAM Simulation

In nested grid cases, both the nested (fine) grid and the parent (coarse) grid have to be added to the simulation.

1. Right-click on the “WAM_Katrina” simulation and select **Duplicate**.
2. Right-click on the new simulation and **Rename** it as “Nested WAM”.
3. In a similar fashion as before, drag “Nested WAM Grid” onto the simulation. The coarse parent grid named “WAM_Katrina” should already be linked to the simulation.

8.4 Simulation Model Control

To set the parameters:

1. Right-click the “Nested WAM” simulation and select **Model Control** from the drop down menu. This brings up the *Simulation Model Control* dialog,
2. In the *General* tab, change the *Start* time to “08/27/2005 5:00 AM” and the *End* time to “08/28/2005 5:00 AM”. This makes the high resolution grid focus on the day around landfall for the storm.)
3. Switch to the *Spectra* tab and make sure that the *Run type* is set as “Cold Start”.

4. Click **OK** to exit the *Simulation Model Control* dialog.

8.5 Exporting WAM Files, Saving Project, and Running WAM

Saving the project and files works the same for nested simulations as it does with single grid simulations.

1. Select *File* | **Save As…** to open the *Save As* dialog.
2. Enter a *File name* of "NestedWAM.sms" and click **Save**.
3. Right-click on the simulation and select **Export WAM Files**.
4. Right-click on the WAM simulation and select **Launch WAM**.
5. The model wrapper now includes items for both the parent and child grids, and processes will run for both. All six processes will turn green once completed. Click **Exit** once the simulation run is done.

8.6 Viewing WAM Simulation Results for the Nested Grid

The nested grid will now have its own solution data that can be viewed with the same methods used for the parent grid. The solution files for the "Nested WAM Grid" have now loaded in SMS. In the "Cartesian Grid Data" folder named "Nested WAM Grid", there will be several new datasets similar to the ones for the parent WAM grid.

1. Select the scalar dataset called "Wind speed" and the vector dataset "Wind velocity".
2. Go through the different times, beginning at "08/27/2005 6:00:00 AM". Figure 6 shows the nested grid at time "08/27/2005 6:00:00 PM".

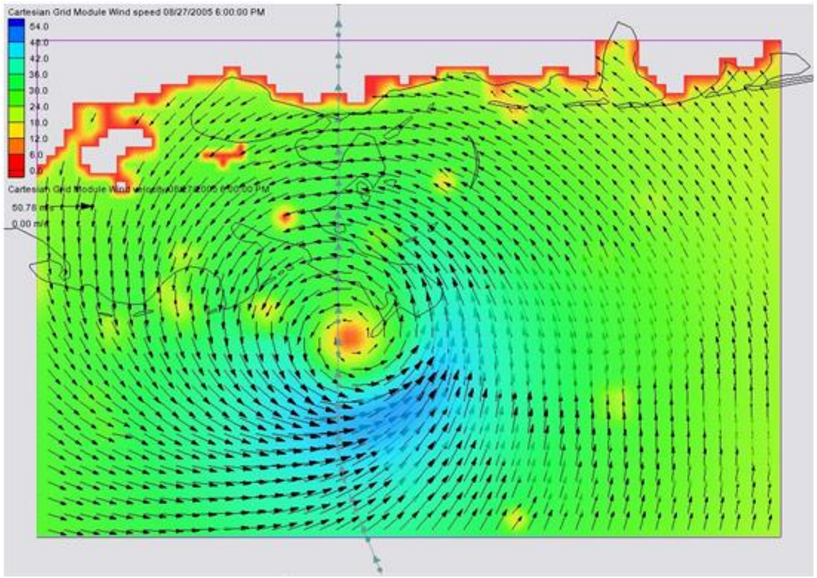


Figure 6 Nested Grid results for wind speed

9 Conclusion

It is important to mention that for the purpose of this tutorial and because of the big sizes of the files created during WAM runs, the extent of the WAM domain was made smaller than would be realistic. For example, in a realistic situation for hurricane Katrina, one might want to extend the WAM domain to cover the whole Gulf of Mexico.

This concludes the WAM exercise.