MANUAL
Tsunami Simulation/Visualization Code
NAMI DANCE NESTED DOMAIN version5.9

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PREFACE

NAMI DANCE is a computational tool developed by Profs Andrey Zaytsev, Ahmet Yalciner, Anton Chernov, Efim Pelinovsky and Andrey Kurkin especially for tsunami modeling. It provides direct simulation and efficient visualization of tsunamis to the user and for assessment, understanding and investigation of tsunami generation and propagation mechanisms. It is developed by C++ programming language by following leap frog scheme numerical solution procedures (Shuto, Goto and Imamura) and has several modules for development of all requirements. In addition to necessary tsunami parameters, NAMI DANCE also computes the distributions of current velocities, fluxes and their directions at selected time intervals, relative damage levels according to drag and impact forces, and it also prepares 3D plots of sea state at selected time intervals from different camera and light positions, and animates the tsunami propagation from source to target.

The following is the general information about the interface of NAMI-DANCE.

Important note: This manual is for NAMI DANCE version 5.0 and later. The developers do not take any responsibility if any hardware/software/network damage of the users property. The users accept the following term of conditions.

1. There is no warranty for the program, to the extent permitted by applicable law. Except when otherwise stated in writing the copyright holders and/or other parties provide the program "as is" without warranty of any kind, either expressed or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose. The entire risk as to the quality and performance of the program is with you. Should the program prove defective, you assume the cost of all necessary servicing, repair or correction.
2. The user must inform the developers if any output of using NAMI DANCE will be published or presented.
3. If the user encounters any bug while using NAMI DANCE he/she must contact the developers for solutions.
4. The user must reference NAMI DANCE and the developers Zaytsev, Chernov, Yalciner, Pelinovsky, Kurkin.

CONTENT:

1. METHOD IN TSUNAMI MODELING

State-of-the-artand Phases of Tsunami Modeling

Tsunami is one of the most important marine hazards generally triggered by earthquakes and/or submarine/subaerial landslides. In general, tsunami might affect not only the area where it is generated but add:alsoat substantial distance away from generation region. Tsunami science needs close cooperation between basic and applied sciences and also from international to local level authorities. The tsunami modeling and risk analysis are necessary for better preparedness and proper mitigation measures in the framework of international collaborations. Better understanding, wider awareness, proper preparedness and effective mitigation strategies for tsunamis need close international collaboration from different scientific and engineering disciplines with exchange and enhancement of existing data, development and utilization of available computational tools.
Modeling is one of the essential components of tsunami studies in scientific and operational level. Tsunami modelling has several phases in which exchange and enhance of available earthquake and tsunami data, bathymetric and topographic data in sufficient resolution, selection of possible or credible tsunami scenarios, selection and application of the validated and verified numerical tools for tsunami generation, propagation, inundation and visualization must be covered.

In general, there are several unique phases of tsunami modeling for a specific region.

2. BRIEF HISTORY AND CAPABILITIES OF NAMI DANCE

Tsunami numerical modeling by NAMI DANCE is based on the solution of nonlinear form of the long wave equations with respect to related initial and boundary conditions. There were several numerical solutions of long wave equations for tsunamis. In general the explicit numerical solution of Nonlinear Shallow Water (NSW). Equations are preferable for the use since it consumes reasonable computer time and memory, and also provides the results in acceptable error limit. The most important development in tsunami modeling has been achieved by Profs. Shuto and Imamura by developing model TUNAMI N2 and opened to the use of tsunami scientists under the umbrella of UNESCO (Imamura, 1989, Shuto, Goto, Imamura, 1990, Goto and Ogawa, 1991). TUNAMI N2 determines the tsunami source characteristics from earthquake rupture characteristics. It computes all necessary parameters of tsunami behavior in shallow water and in the inundation zone allowing for a better understanding of the effect of tsunamis according to bathymetric and topographical conditions. NAMI DANCE has been developed by Profs. Zaytsev, Chernov, Yalciner, Pelinovsky and Kurkin using the identical computational procedures of TUNAMI N2. Both codes are cross tested also verified in international workshops specifically organized for testing and verifications of tsunami models (Synolakis, Liu, Yeh, 2004, Yalciner et. al., 2007b). These models have been applied several tsunami application all over the world (some of references are Yalciner et. al. 1995, 2002 a,b,c 2007 a,b, Zahibo et. al. 2003 a,b) As well as tsunami parameters, NAMI DANCE computes

i)   tsunami source from either rupture characteristics or pre-determined wave form,

ii)   propagation,

iii)   arrival time,

iv)   coastal amplification

v)   inundation (according to the accuracy of grid size),

vi)   distribution of current velocities and their directions at selected time intervals,

vii)   distribution of discharge fluxes at selected time intervals,

viii) distribution of water surface elevations (sea state) at selected time intervals,

ix)   relative damage levels (Froude Number and its square) according to drag force and impact force,

x)   time histories of water surface fluctuations at selected gauge locations,

xi)   3D plot of sea state at selected time intervals from different camera and light positions,

xii) Animation of tsunami propagation between source and target regions (Yalciner et. al., 2006b, 2007b).
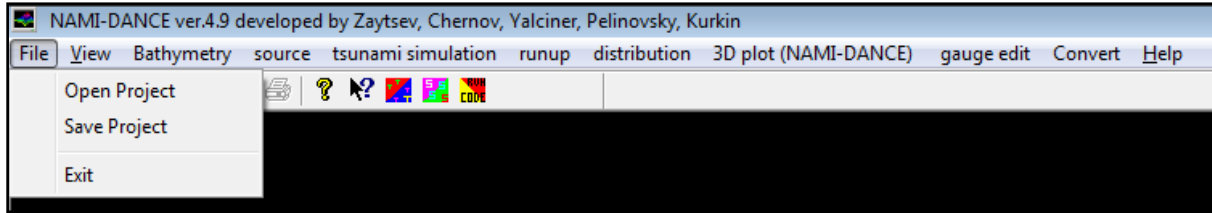
3. FILE/VIEW/BATHYMETRY PANELS

3.1. "File" Menu

Figure 1 : File menu

Using "*File*" menu, projects can be opened and saved in "*.xnp*" format. The project file contains type of input files, transparency percent, image file, landslide color, color palettes loaded for landscape and water, multipliers and camera position (also dynamic positions and camera target). User can save the parameters on 3D Plot panel and can load (Open) using "File" menu when NAMI DANCE is used next time.
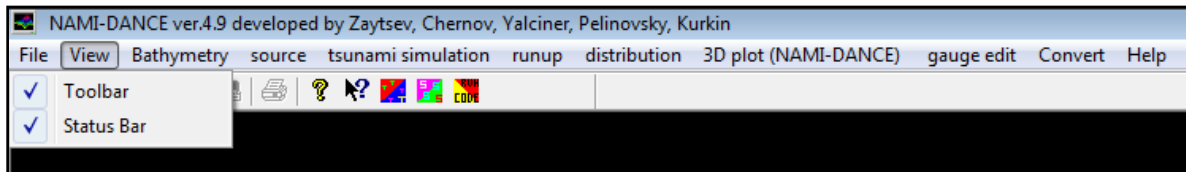
3.2. "View" Menu

Figure 2 : View menu

Display of the toolbar and status bar can be selected using "*View*" menu.

3.3. "Bathymetry" Menu

Determination of Grid Size and Bathymetry Processing
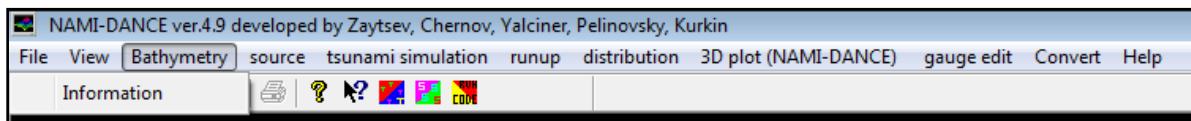

Figure 3 : Bathymetry menu

"Bathymetry" window allows determination of grid size and bathymetry processing.
After entering the maximum and minimum GPS coordinates (longitude-latitude of left bottom and right top corners of the domains) and grid step of your study domain, click "Obtain" button. Then, you can read/obtain number of grid points in the latitudinal (Northing) and longitudinal (Easting) directions in your domain (i.e. grid sizes along X and Y directions). Sea bathymetry must be positive, and topography must be negative.
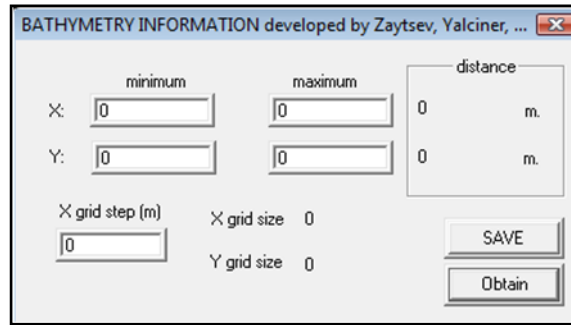
Figure 4 : Bathymetry information window

4. PROCESSING BATHYMETRIC DATA

NAMI DANCE program uses the bathymetry of the area as input data. The bathymetry of the area is usually stored as data files. These files consist of three values; x coordinate, y coordinate and the depth values. However data files are typically randomly spaced files and these data must be converted into an evenly spaced grid before using as input file of the program. To convert into a grid file, a program called Surfer is used.

Surfer is a contouring and 3D surface mapping program that runs under Microsoft Windows. It quickly and easily converts your data into outstanding contour, surface, wireframe, vector, image, shaded relief, and post maps. Further information can be found and also purchased at the website of Golden Software; http://www.goldensoftware.com .

Below is the procedure for converting the bathymetry data file to grid file by SURFER.
1. Start Surfer.
2. Click on the **Grid |Data** command to display the **Open** dialog.
3. Specify the name of the XYZ data file which is the bathymetry data of the area, and then click OK.
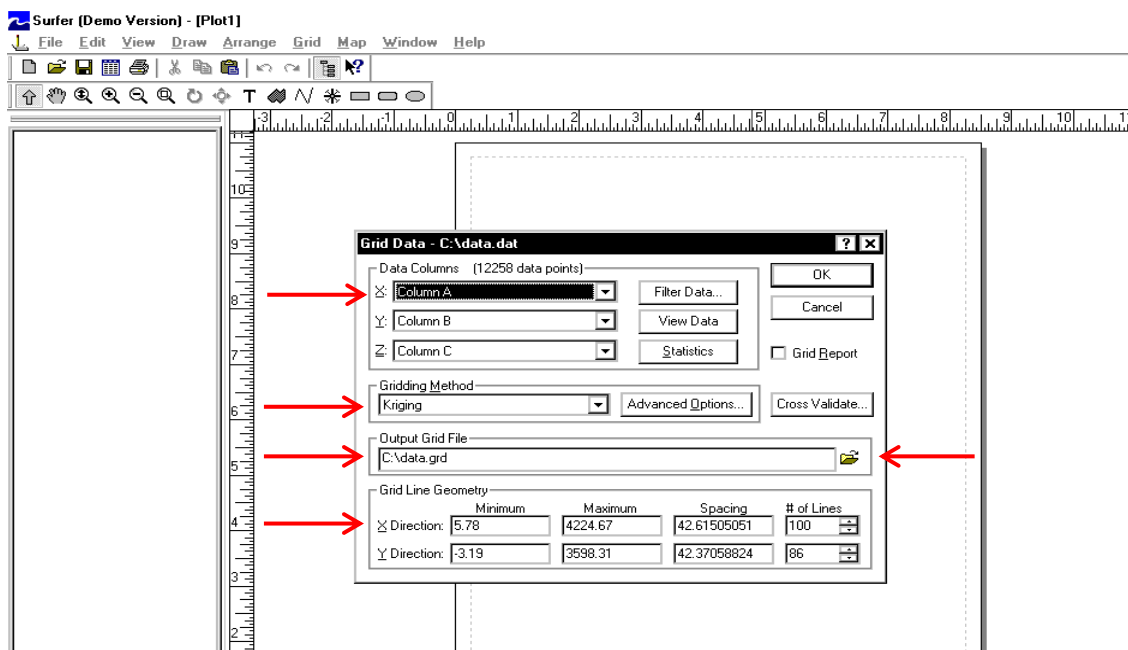4. In the **Grid Data** dialog, specify the parameters for the type of grid file you want to produce.

Figure 5 : Grid data on Surfer

The Grid Data Dialog

When creating a grid file you can usually accept all of the default gridding parameters

Data Columns

Individually specify the columns for the X data, the Y data, and the Z data. **Surfer** defaults to *X:* Column A, *Y:* Column B, and *Z:* Column C, which represent the x coordinate, y coordinate and the depth, respectively.

Gridding Method

The gridding method should be set to Kriging which is the recommended gridding method with the default linear variogram. This is actually the selected default gridding method because it gives good results for most XYZ data sets.

Output Grid File

Choose a path and file name for the grid in the *Output Grid File* group by clicking the button ⌂ (shown by an arrow). **Save Grid As** dialog will be opened. You can type a path and file name or browse to a new path and enter a file name in the box. TUNAMI N2 and TUNAMI N3 require a specific file format for the output grid file which is ASCII grid file format. To change the file format, use the drop down Save as type menu and choose GS ASCII (*.grd) format as shown below. Then click "Save" and return to Grid Data menu.
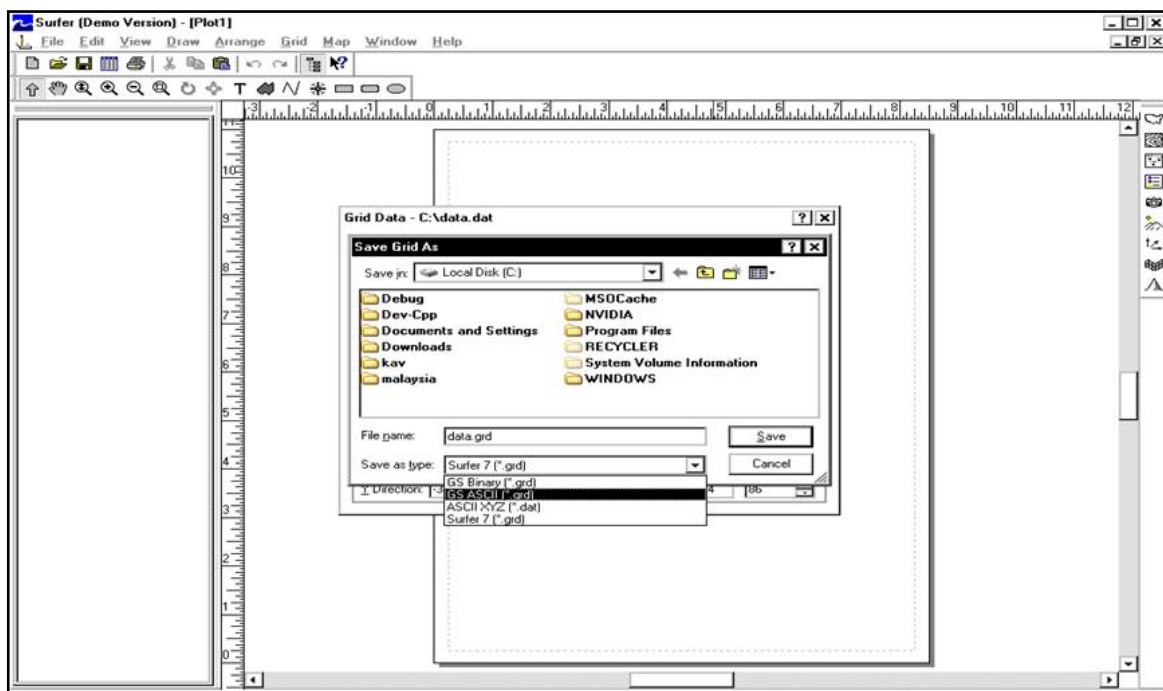

Figure 6 : ASCII Grid File Format (.grd)

ASCII Grid File Format

ASCII grid files [.grd] contain five header lines that provide information about the size and limits of the grid, followed by a list of Z values. The fields within ASCII grid files must be space delimited (nonlimited??).

The listing of Z values follows the header information in the file. The Z values are stored in row-major order starting with the minimum Y coordinate. The first Z value in the grid file corresponds to the lower left corner of the map. This can also be thought of as the southwest corner of the map, or, more specifically, the grid node of minimum X and minimum Y. The second Z value is the next adjacent grid node in the same row (the same Y coordinate but the next higher X coordinate). When the maximum X value is reached in the row, the list of Z values continues with the next higher row, until all the rows of Z values have been included.

The general format of an ASCII grid file is:

Id	The identification string DSAA that identifies the file as an ASCII grid file.
nx ny	nx is the integer number of grid lines along the X axis (columns)
	ny is the integer number of grid lines along the Y axis (rows)
xlo xhi	xlo is the minimum X value of the grid
	xhi is the maximum X value of the grid
ylo yhi	ylo is the minimum Y value of the grid
	yhi is the maximum Y value of the grid
zlo zhi	zlo is the minimum Z value of the grid
	zhi is the maximum Z value of the grid
grid row 1 grid row 2 grid row 3 ………..	These are the rows of Z values of the grid, organized in row order. Each row has a constant Y coordinate. Grid row 1 corresponds to ylo and the last grid row corresponds to yhi (i.e. the first row in the grid file is the last row on the map). Within each row, the Z values are arranged from xlo to xhi.

Table 1 : General format of an ASCII grid file

The following example grid file is ten rows high by ten columns wide. The first five lines of the file contain header information. X ranges from 0 to 9, Y ranges from 0 to 7, and Z ranges from 25 to 97.19. The first Z value shown corresponds to the lower left corner of the map and the following values correspond to the increasing X positions along the bottom row of the grid file. This file has a total of 100 Z values.

```
DSAA
10 10
0.0 9.0
0.0 7.0
25.00 97.19
91.03 77.21 60.55 46.67 52.73 64.05 41.19 54.99 44.30 25.00
96.04 81.10 62.38 48.74 57.50 63.27 48.67 60.81 51.78 33.63
92.10 85.05 65.09 53.01 64.44 65.64 52.53 66.54 59.29 41.33
94.04 85.63 65.56 55.32 73.18 70.88 55.35 76.27 67.20 45.78
97.19 82.00 64.21 61.97 82.99 80.34 58.55 86.28 75.02 48.75
91.36 78.73 64.05 65.60 82.58 81.37 61.16 89.09 81.36 54.87
86.31 77.58 67.71 68.50 73.37 74.84 65.35 95.55 85.92 55.76
80.88 75.56 74.35 72.47 66.93 75.49 86.39 92.10 84.41 55.00
74.77 66.02 70.29 75.16 60.56 65.56 85.07 89.81 74.53 51.69
70.00 54.19 62.27 74.51 55.95 55.42 71.21 74.63 63.14 44.99
```

Figure 7 : An example of grid file

Grid Line Geometry

Grid line geometry defines the grid limits and grid density. Grid limits are the minimum and maximum X and Y coordinates for the grid. Grid density is usually defined by the number of columns and rows in the grid. The *# of Lines* in the *X Direction* is the number of grid columns, and the *# of Lines* in the *Y Direction* is the number of grid rows. By defining the grid limits and the number of rows and columns, the *Spacing* values are automatically determined as the distance in data units between adjacent rows and adjacent columns.

5. Click OK and the grid file is created. During gridding, the status bar at the bottom of the **Surfer** window provides you with information about the progress of the gridding process.

5. CREATING THE INITIAL WAVE FROM DIFFERENT SOURCES

Source Menu

"Source" window allows you to create the initial wave using the fault parameters. There are two different options as "User defined" and "Rupture" under the "Source" menu as shown in figure below.
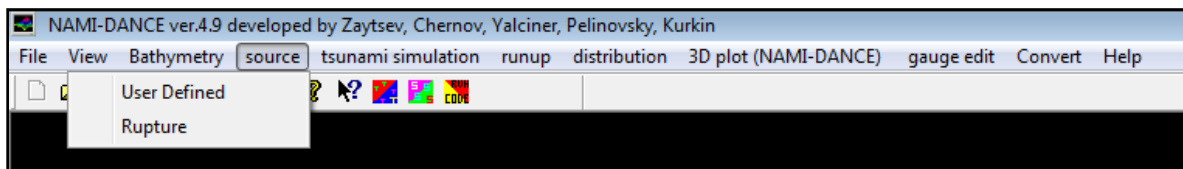

Figure 8 : Source menu

"Rupture" Option:

In order to generate the initial wave due to an earthquake;

1. On the "Source"menu, click "Rupture".

2. In "The name of the bathymetry file (input)" box, enter the name of the bathymetry file you want to use, or browse to locate the file.

3. In "The name of tsunami source file (output)" box, enter the name of the output file which is going to generateinitial wave (tsunami source) file, such as initialwave.grd, or browse to locate the file.

4. In the start point and end point of fault axis boxes, enter the coordinates of the start and end points of the fault.

5. In the "Parameters of fault" boxes, enter the requested parameters according to the data of the fault which produced the earthquake. Definitions of the fault break parameters are:

i)   Epicenter coordinates
ii)   Length of the fault (L)
iii)   The width of the fault (W)
iv)   Strike angle, the direction of the fault axis from North (Clockwise) (θ)
v)   The dip angle (δ)
vi)   The rake (slip) angle (λ)
vii)   Vertical displacement of the (slip) fault (D)
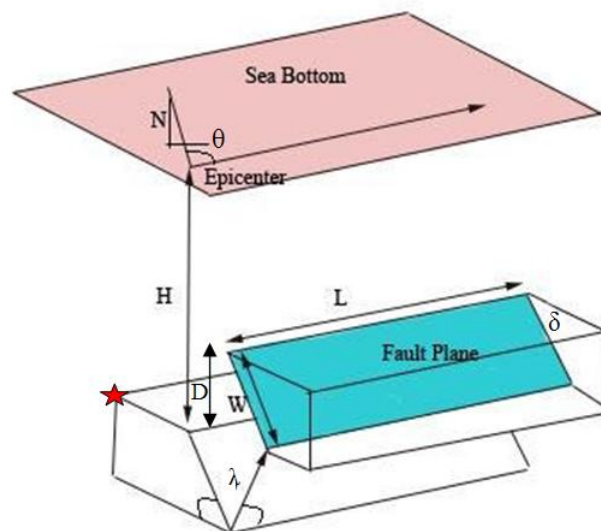viii)   Focal depth (H)

Rupture characteristics:

Figure 9 : Origin of the movement of the fault planes

Important note: The symbol ★ on the above figure shows the origin of the movement of the fault planes. In the "Source/Rupture" panel of NAMI DANCE (in the figure below) epicenter coordinates are assumed to be located at the origin (★) by NAMI DANCE as used in TUNAMI N2.

6. Click "Run" to generate the initial wave.
7. If you want to save the parameters, click "Save". The window will be closed. In order to generate the initial wave, open the seismic fault window and click "Run".

Figure 10 : Seismic source inputs

"User Defined" Panel:

In order to generate an initial wave due to an impact or another arbitrary disturbance in elliptical shape with leading elevation or depression wave condition, you can use user defined option.

1. On the "source" menu, click "user defined".

2. In "The name of the bathymetry file" (input) box, enter the name of the bathymetry file you want to use, or browse to locate the file.

3. In "The name of tsunami source file" (output) box, enter the name of the output file which is going to generateinitial wave (tsunami source) file, such as initialwave.grd, or browse to locate the file.

4. Enter the "grid step" which is the distance between two grid nodes of the bathymetry file in meters.

5. Enter "amplitude of center", "length of major axis" and "length of minor axis", "amplitude of leading wave" and "width of leading wave". Don't forget to put a tick in the box near "for simulation with leading wave" option. These parameters are shown in the figures below.

TOP VIEW

W_1 : Width of the leading wave
L_{major} : Length of the major axis
L_{minor} : Length of the minor axis

SIDE VIEW

a_c : amplitude at center
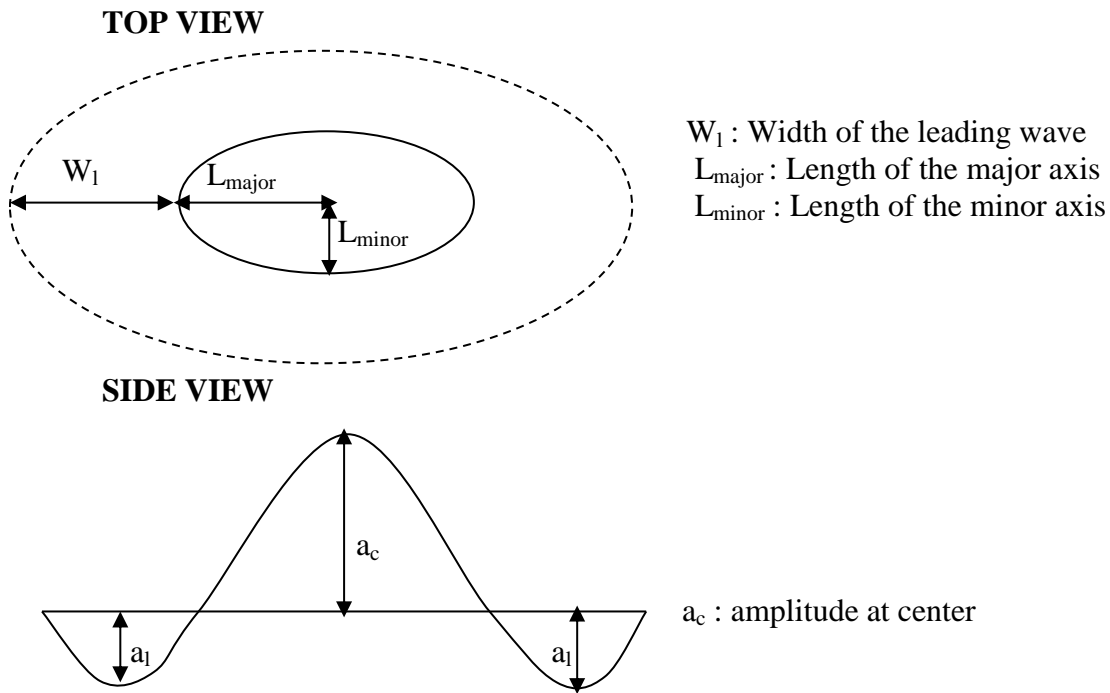
Figure 11 : Top and Side view of a wave

6. Click "Run" to generate the initial wave.

7. If you want to save the parameters, click "Save". The window will be closed. In order to generate the initial wave, open the "test fault" window and click "Run".
Sea bottom subsidence may be observed along the strike slip faults at some locations where the step over occurs. This is called pull apart mechanism as given in Figure.
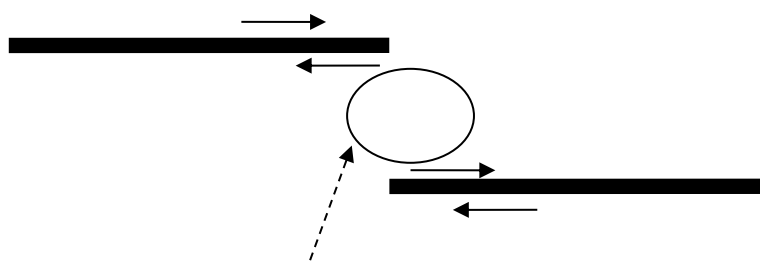
Figure 12   **: Subsidence at the tensile stress area**

Similarly the caldera collapse of volcanoes can be inputted with this module.

6. GENERATING THE SEASTATE AT SPECIFIC TIME INTERVALS OF TSUNAMI DURING SIMULATION

"Tsunami simulation" option is used in order to generate the sea state at specific time intervals of tsunami.
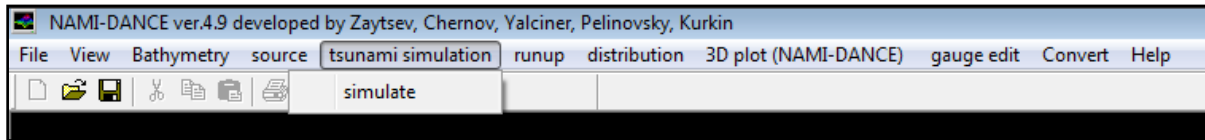
Figure 13 : Tsunami simulation menu

<u>Source Files</u>

1. On the "tsunami simulation" menu, click "simulate".
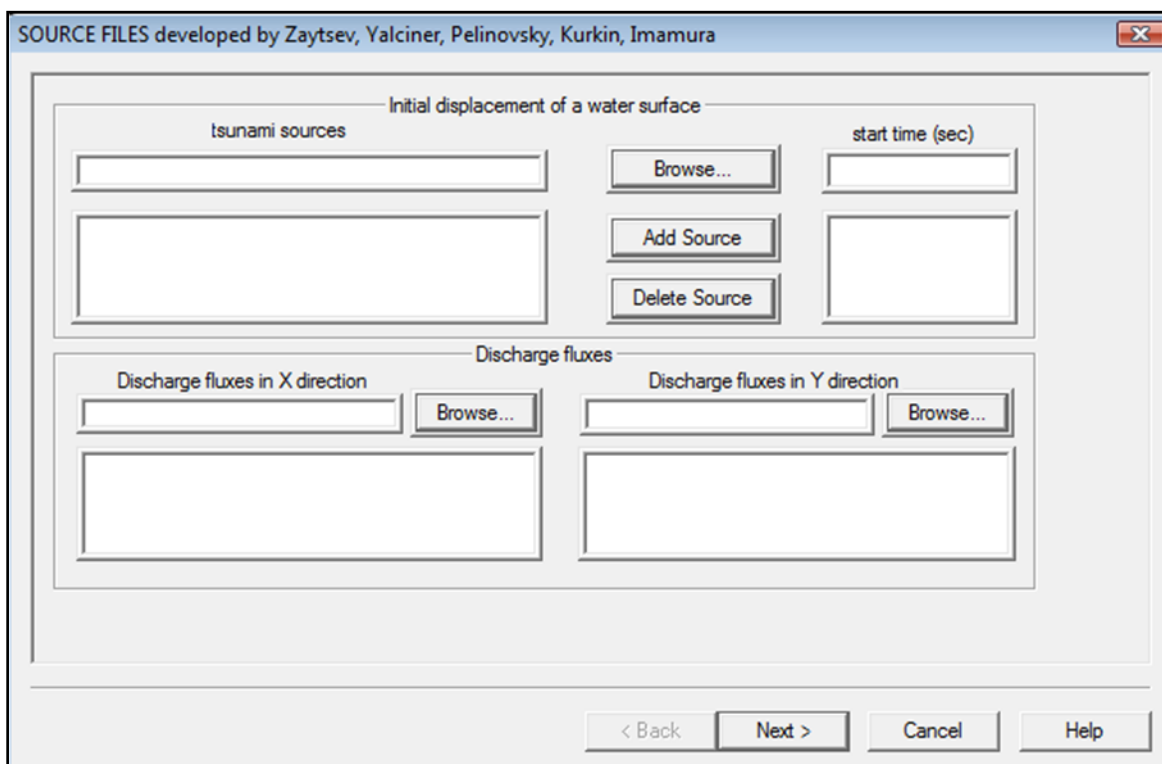
Figure 14 : Source files window

2. In the Source Files window, browse for tsunami source file. Chose your source file and click "open".
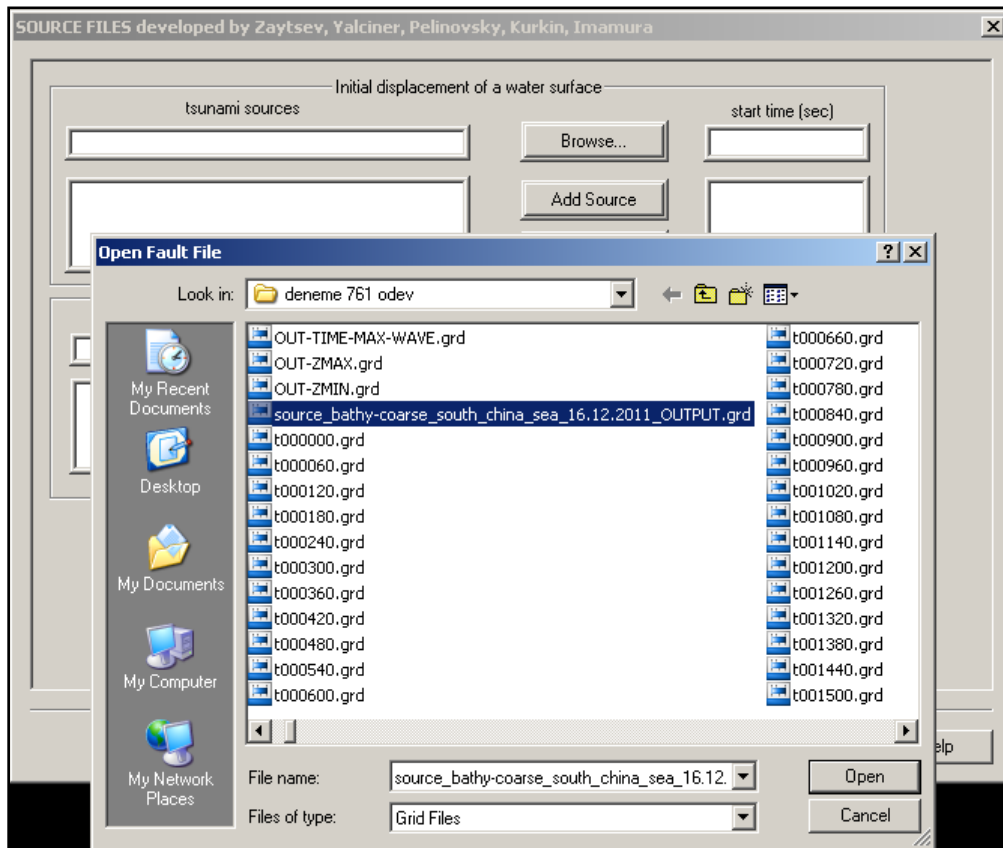
Figure 15 : Source file as an input file

3. Enter the time when the disturbance occurs. If it is an earthquake, this is the time the fault is broken.
4. Click "Add Source"
5. If there is more than one source of disturbance at different times for the event, repeat the steps above until all the source files are listed on the menu.
6. If there are "Discharge fluxes in X/Y direction" which apear in governing equations as M and N. Browse them also in the discharge fluxes section.
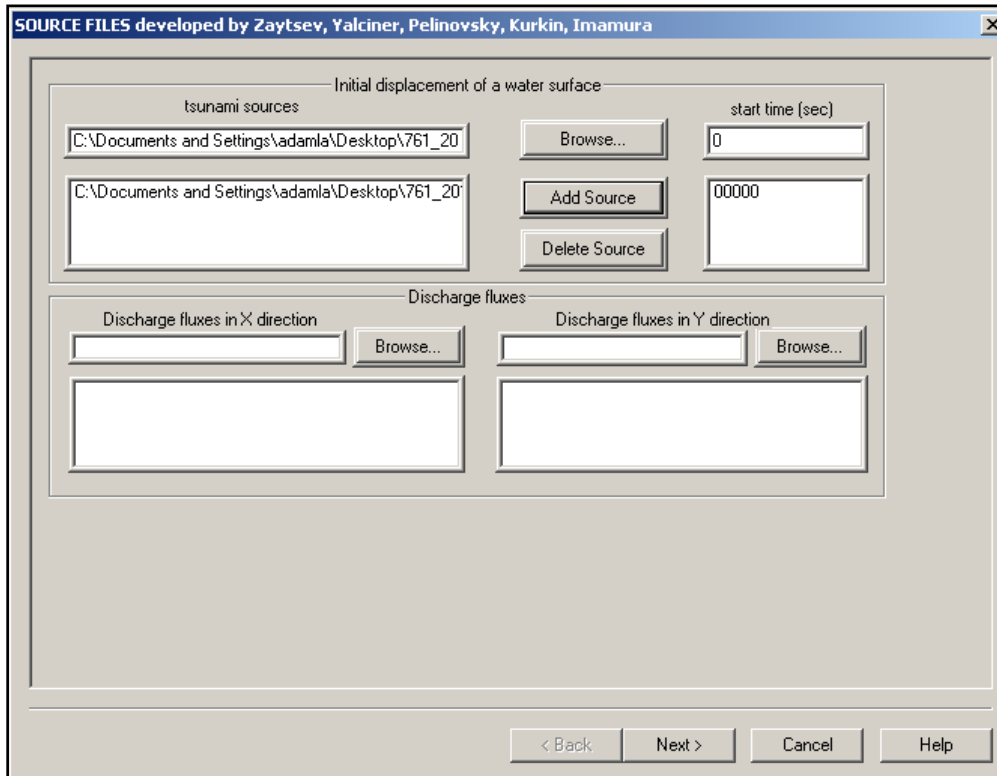
Figure 16 : Added Source File

7. Click "Next".

Bathymetry & Gauge Input
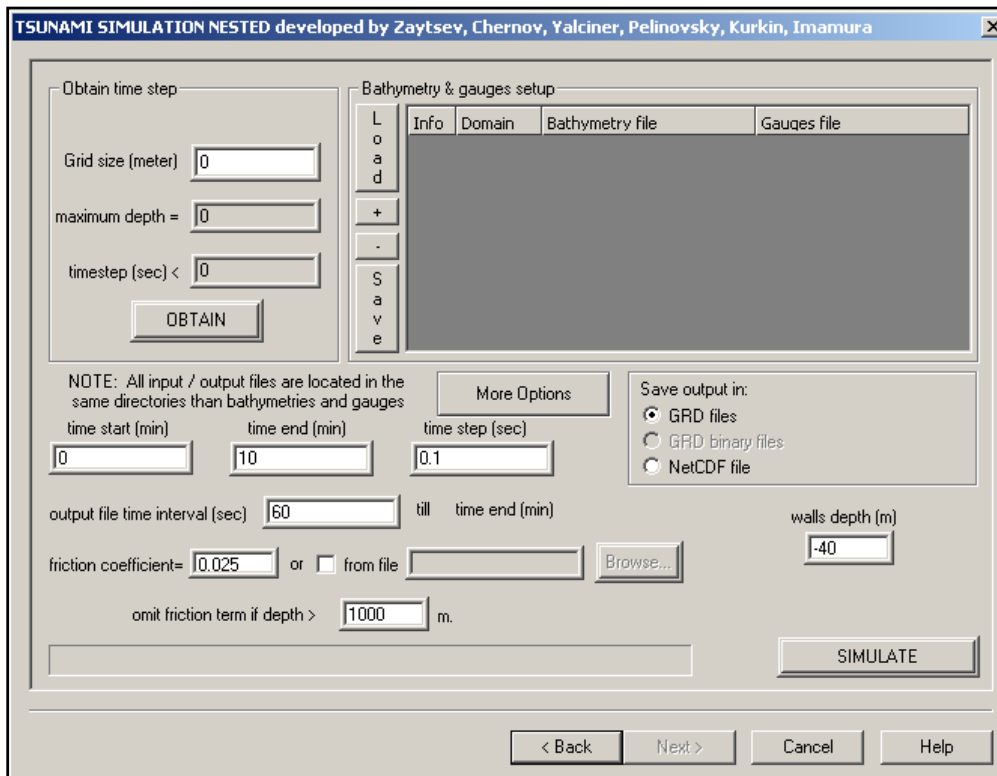
Figure 17 : Bathymetry & Gauges & Time Inputs

1. In order to load the bathymetry file, click 'plus sign (+)' in the Bathymetry&Gauges Setup part. In the opening window, enter the name of the bathymetry file in the "Open bathymetry file" box or browse for the location of the file and then choose the bathymetry file.
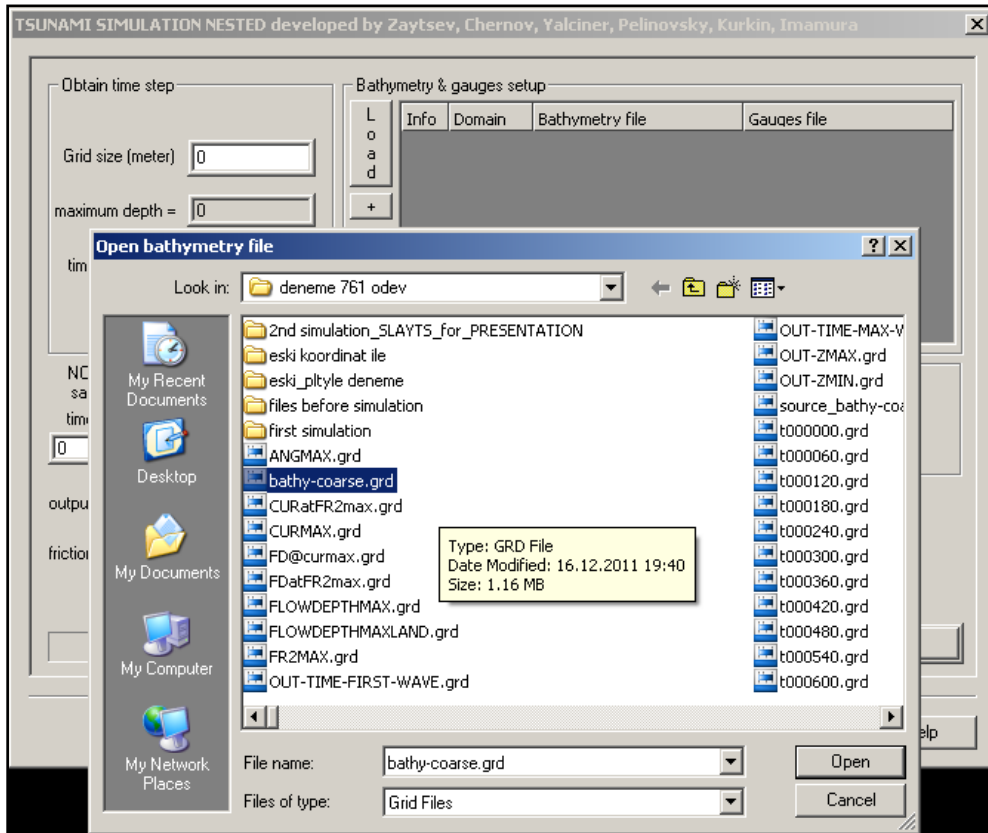
Figure 18 : Bathymetry File as an Input File

2. Enter the name of the gauge file in the "Open gauges file" box or browse for the location of the file and choose the required gauge file. You do not need to enter gauge file to perform the calculation. Gauge file is needed only when warter surface fluctuations are needed at the specific coordinates (numerical gauge locations). The authors suggest the user input a gauge file containing the name and coordinates of numerical gauge points. Thos are included in the OUT-SUMMARY-RESULTS.dat file which is helpful or decision makers.
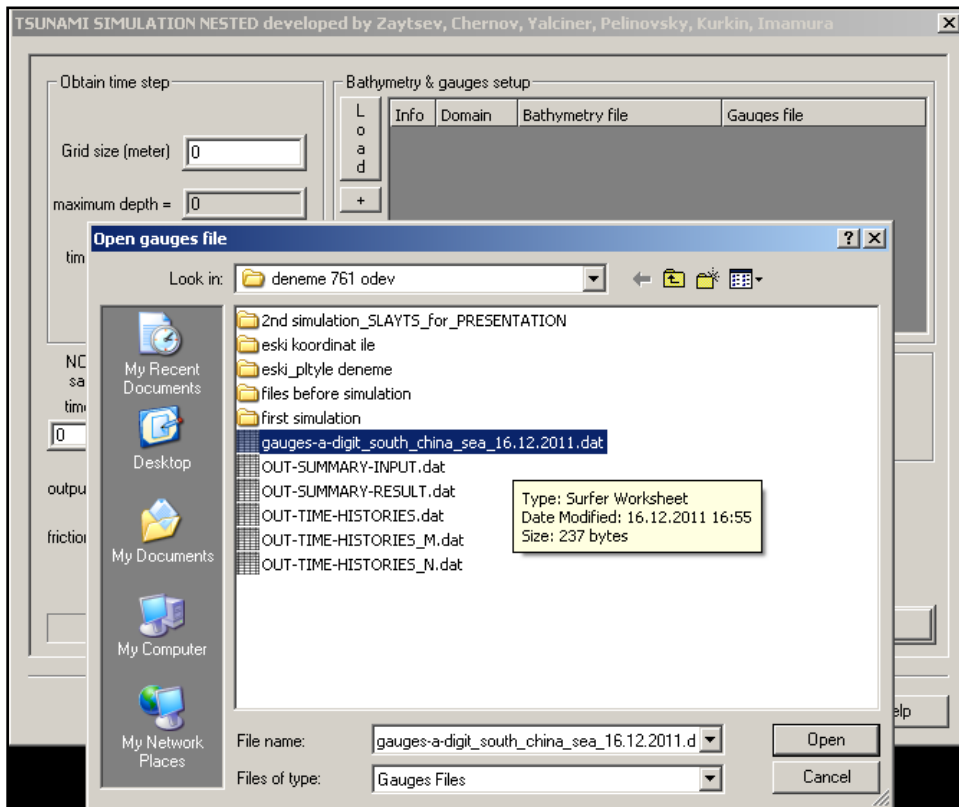
Figure 19 : Gauge File as an Input File

3. Put a click on the box for "Nonlinear cartesian shallow water equations" in the types of equations window. And press 'OK' in the window.
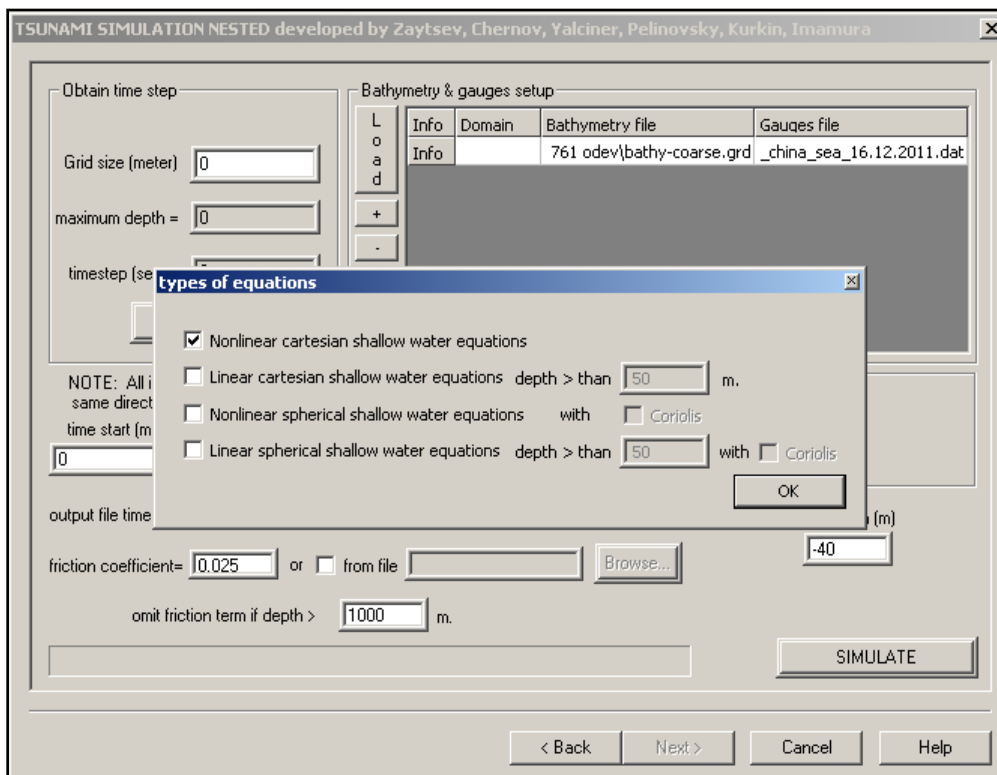
Figure 20 : Shallow Water Equation Types

4. The bathymetry and gauge file is added in the list now as seen in the following figure.
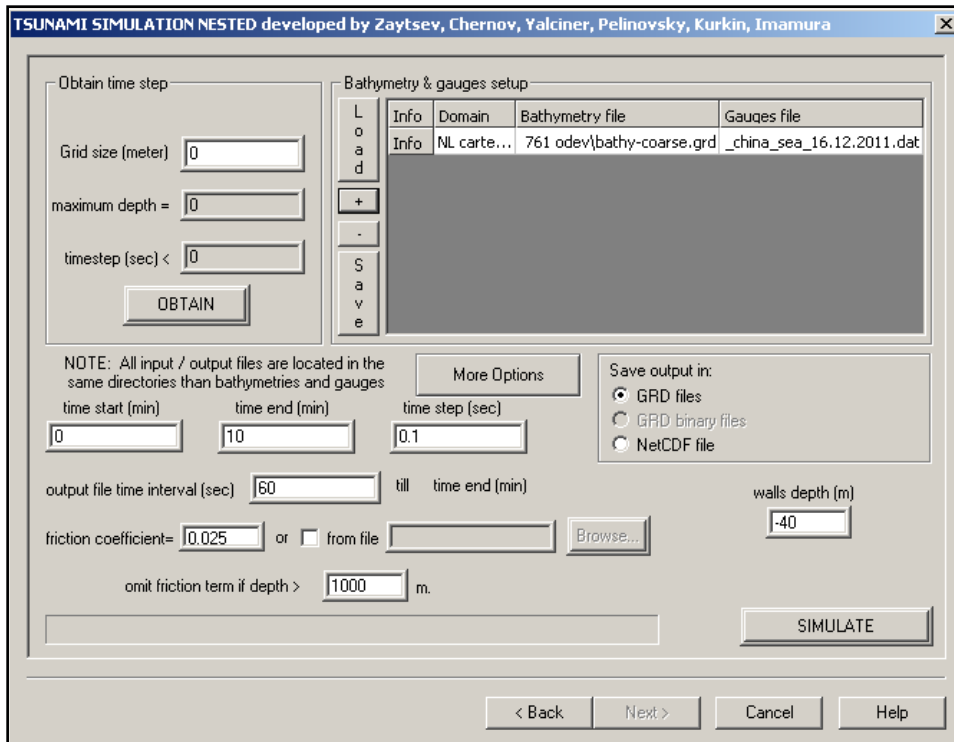
Figure 21 : Added Bathymetry File

5. To obtain the suggested time step for calculation use the "OBTAIN" option. It automatically computes the grid size of the bathymetry files (in Nested Domains if inputted) in meter and automatically provide the maximum depth from bathymetry files and calculate the necessary time step in second.
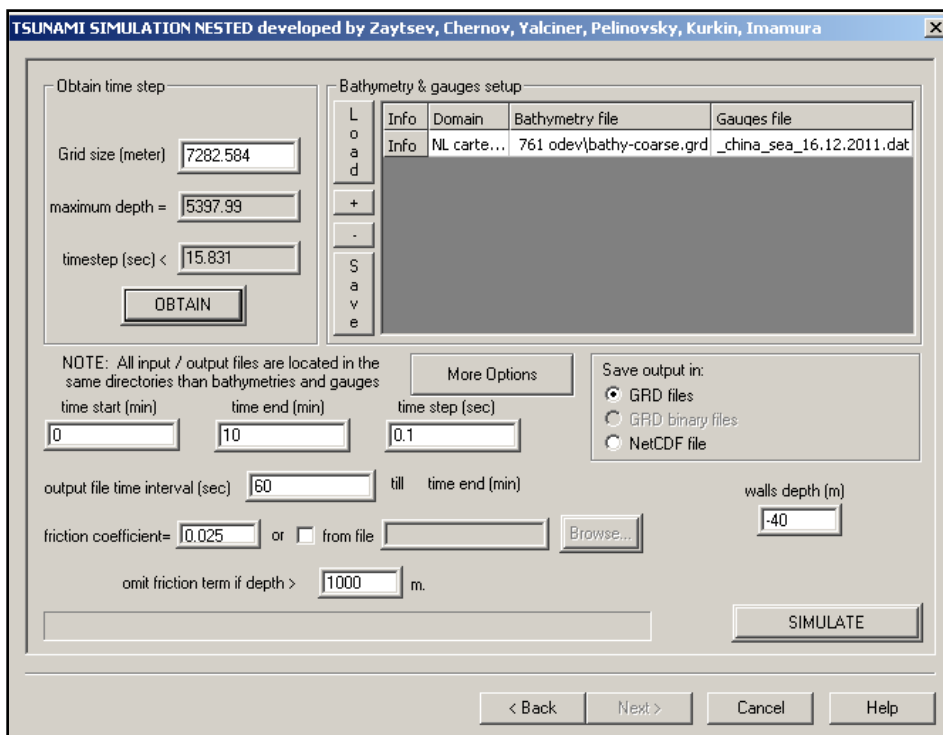
Figure 22 : Time step calculation

6. Enter the obtained time step value in the "time step (sec) <" box into the "time step (sec)" in the lower part of the window. Use a smaller time step value than the obtained time step value.
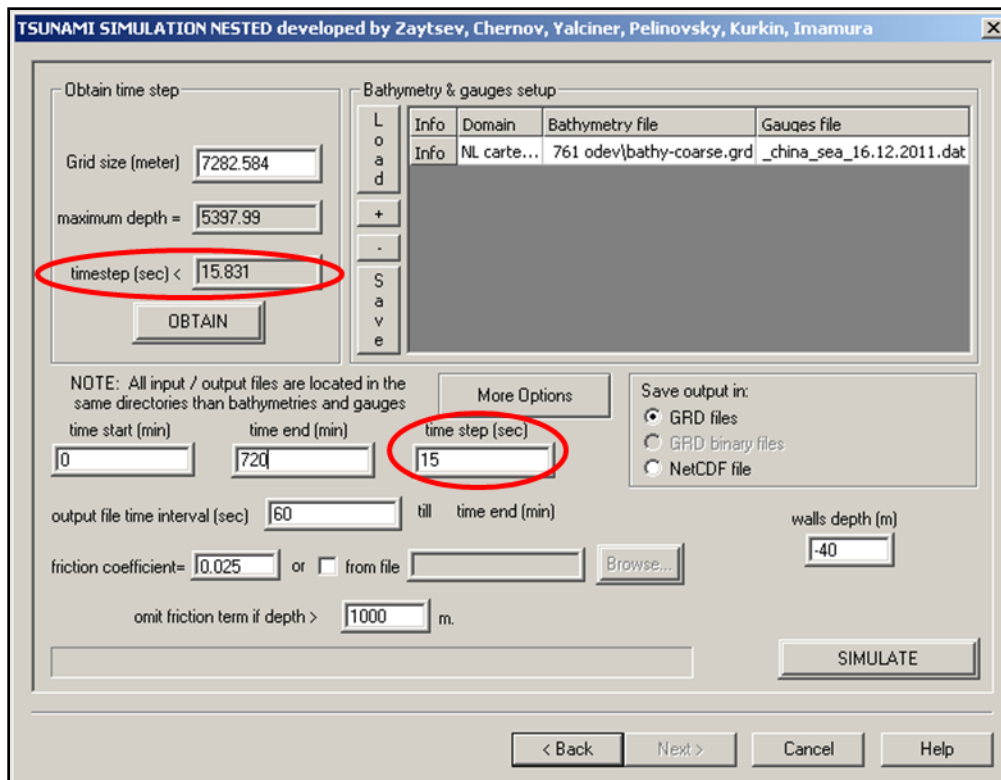
Figure 23 : Obtained Time Step Value and Input Time Step Value

7. Enter the start and end time of the simulation in the "time start (min)" and "time end (min)" boxes on the left of "time step (sec)" box in the lower part of the window.

8. Enter the time step for the output files in the "output file time interval (sec)" boxes which will show the sea state at the entered time intervals.

Note: If you enable ASCII GRD box, then NamiDance produces the output files of the water elevation (and velocities and fluxes) in the ASCII GRD format of Golden Software Surfer (Version 8 or lover).

If you enable Binary GRD box, then NAMIDANCE produces the output files of the water elevation (and velocities and fluxes) in the binary format of Golden Software Surfer (Version 8 or over).

If the user wants to save outputs in NetCDF (Network Common Data Form) format, then the corresponding check box should be clicked by the user.

The user can control additions input output options from MORE OPTIONS panel.

10. Click "Simulate".
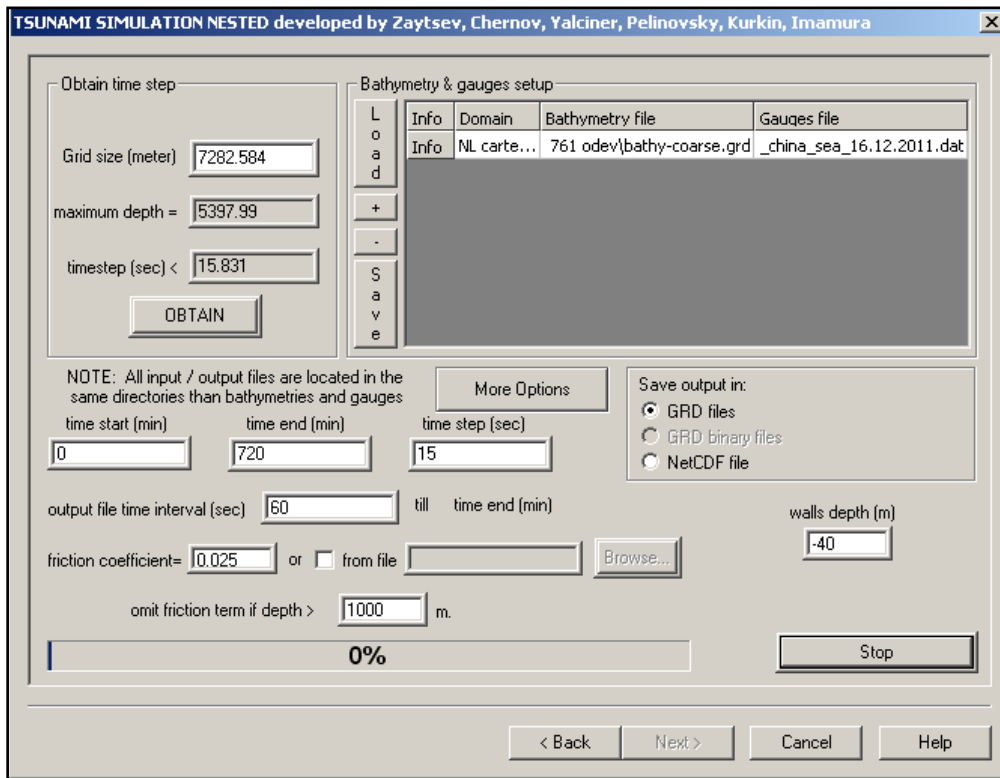
Figure 24 : Start of the Simulation Process
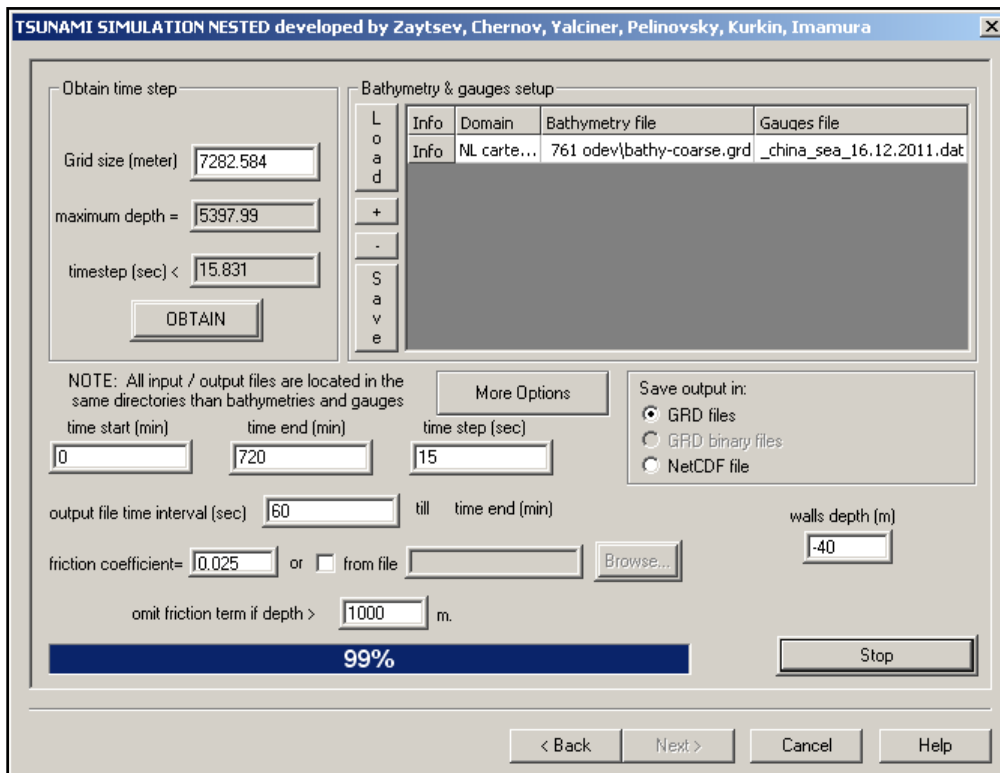
Figure 25 : End of the Simulation Process

11. After the simulation ends, close the box from the cross sign (x) at the right top edge or click the cancel box.
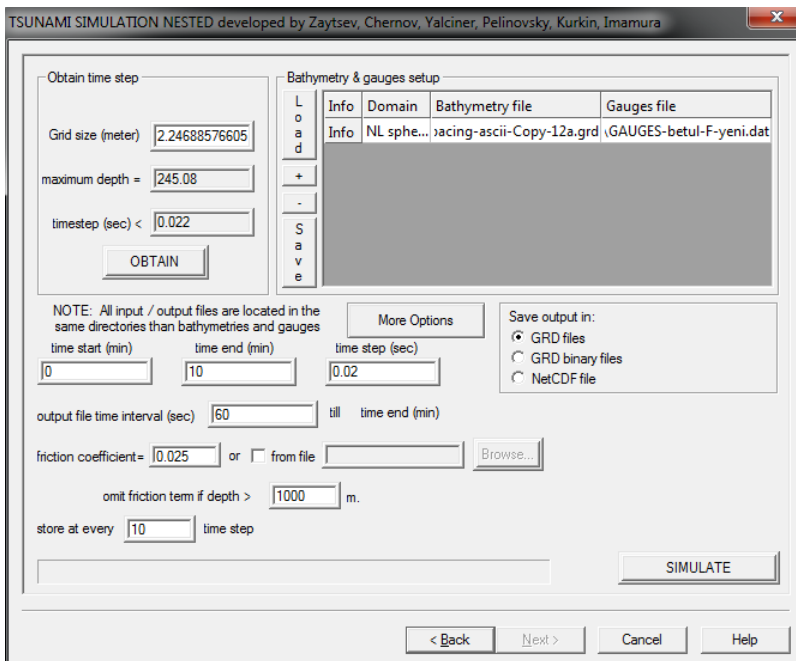
Figure 26 : Completed Simulation Process

Important Note:

It is essential that the User must check the spatial grid size value of the bathymetry file. The spatial grid size is obtained from INF Button at left of the bathymetry file name box. The OBTAIN Button must be clicked to see the required maximum value of the time step for stable simulation.

More Options Panel
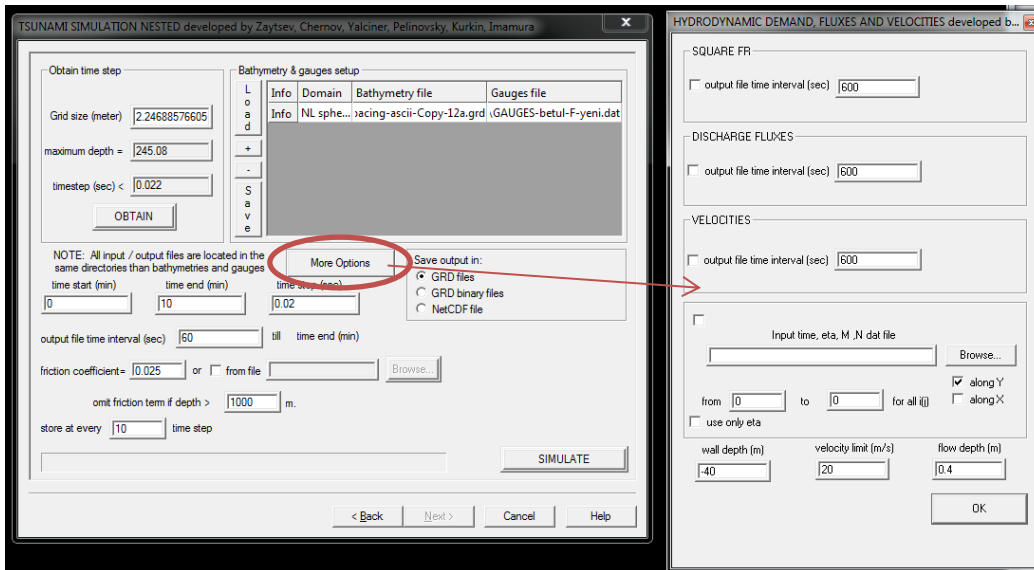
Figure 27 : Output request panel for Square Froude Number, Velocity and Discharge Fluxes at different times and also input from boundary and also limitation of wall depth, velocity and flow depth
Note:n "More options" section, Froude number, current velocities and discharge fluxes can be outputtedat every grid point at specified time intervals if the check boxes are enabledand required time intervals are put in the box in second unit by the user. The maximum values of these parameters computed during simulation are also stored by NAMI DANCE at the end of the simulation.

The wall depth: The user can also put a wall at a certain depth of elevation. Wall depth is a depth/elevation where a vertical impermeable barrier is located. No wave motion is permitted behind this barrier. If you want to put a barrier at land, insert *negative* depth.

The user can also put a limit of velocity which may have high values at very shallow flow depth conditions. The default value of velocity limit is 20 m/sec.

The user can also put a limit to the computation for the very small flow depths. The default value of the flow depth limit is suggested to be 0.4m. The computation is not performed for the flow depth less than thie inputted limit.
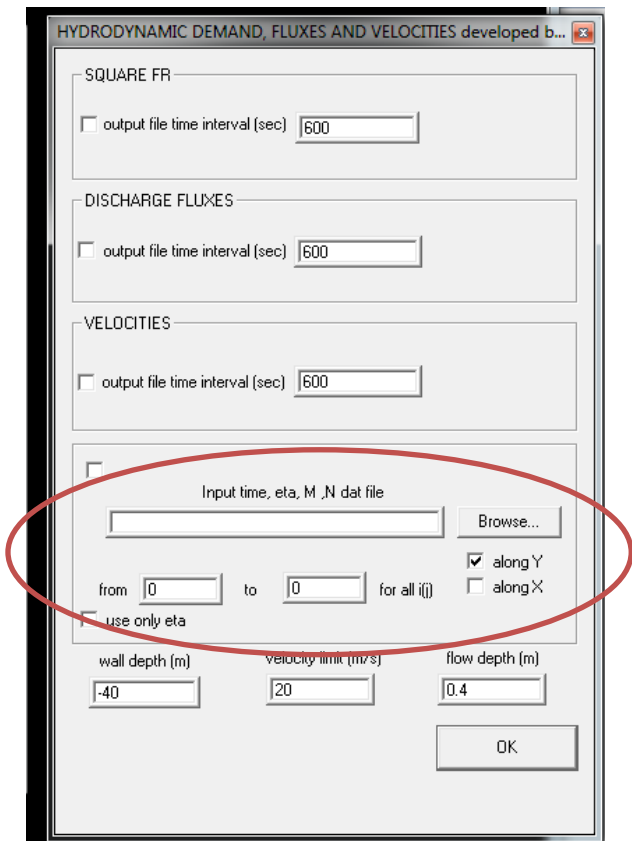
Figure 28a : Input the wave from the boundary (border of the largest domain) with a 4 column file (time, eta, M, N)

The wave input from any border can be controlled from the above panel.
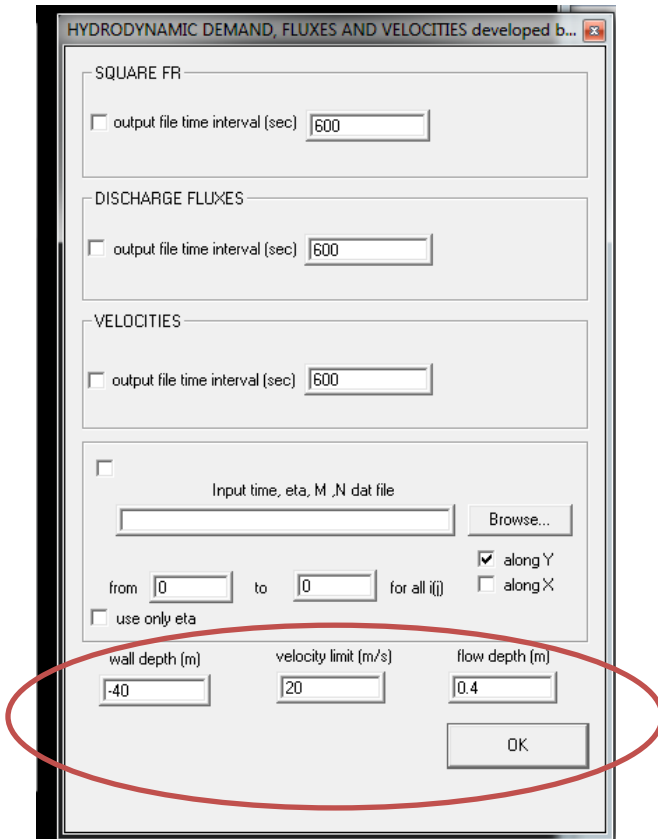
Figure 29b : Control of the wall depth and velocity and flow depth if required.

7. RUNUP CALCULATION

"Runup" Menu
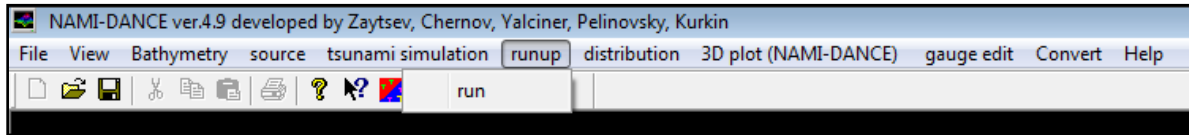
Figure 30 : Runup menu

When you click run up button, NAMI DANCE opens the following panel in which the maximum values (+ve amplitudes) of the water surface computed throughout the simulation (file name OUT-TIME-HISTORIES.grd) must be opened from the respective BROWSE button. (First ROW)

The user must also assign a file name by using the BROWSE button on the second row for storing the maximum +ve amplitudes near the shoreline of the selected rectangular area. The borders of the rectangular area are inputted by filling the respective boxes below. If the user requires the amplitudes along horizontal direction (easting) he/she must enable the check box of Along X. Othervise the checkbox Along Y must be enabled.
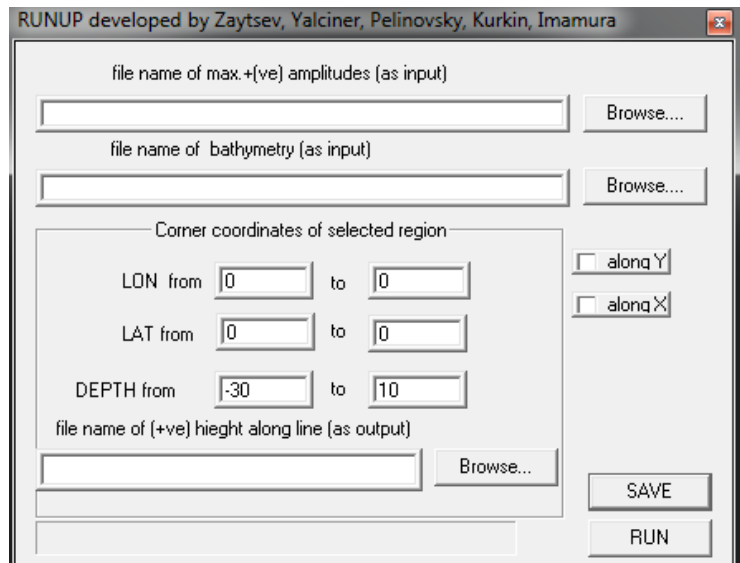
Figure 31 : Amplitude parameters

Important Note: The run-up module of NAMI DANCE is designed to analyze the distribution of the maximum tsunami amplitudes inside the selected rectangular area along the coastal line. There are some limitations of the computations in run up menu. if the user needs to use runup menu, it is strogly recommended that the user must contact the developers (yalciner@metu.edu.tr).

8. CALCULATING DISTRIBUTION OF RUN-UP VALUES

1. On the distribution menu, go to "1 event" to calculate the distribution of the run-up for one event or go to "All event" to calculate the distribution of run-ups for more than one event.
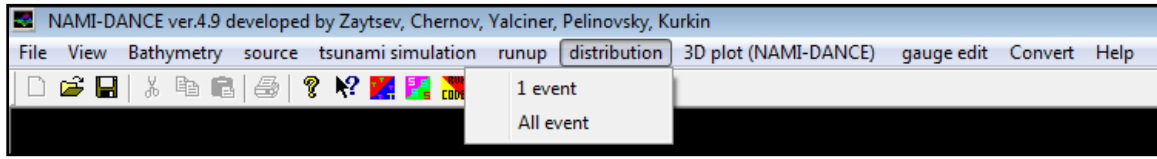
Figure 32 : Distribution menu

"1event" option:
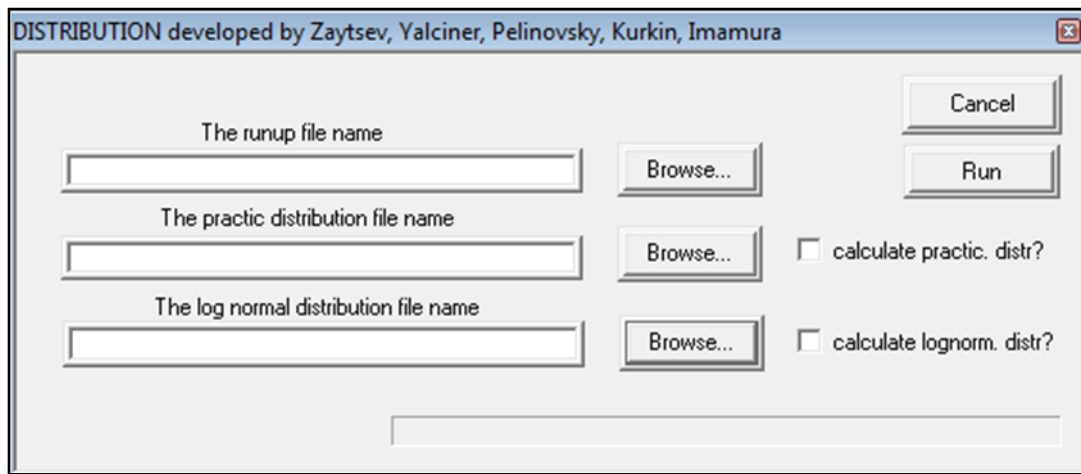
Figure 33 : Single Event Option and Distribution File Inputs

1. Enter the name of the run up file on "The runup file name" box or use browse to locate the file.
2. Put a tick in the "calculate practic.distr?" box if you want to calculate the practical distribution run up and enter the name of the "practic distribution file" in the box or use browse to locate the file.
3. Select the "calculate lognorm. distr?" box if you want to calculate the log normal distribution of run up and enter the name of the "log normal distribution file" in the box or browse to locate the file.
4. Click "Run".

Important Note: The distribution module of NAMI DANCE is designed to compute the probabilistic distribution of the maximum tsunami amplitudes inside the selected rectangular area along the coastal line. There are some limitations of the computations in distribuiton module, if the user needs to use runup menu, it is strogly recommended that the user must contact the developers (yalciner@metu.edu.tr).

"All event" option:
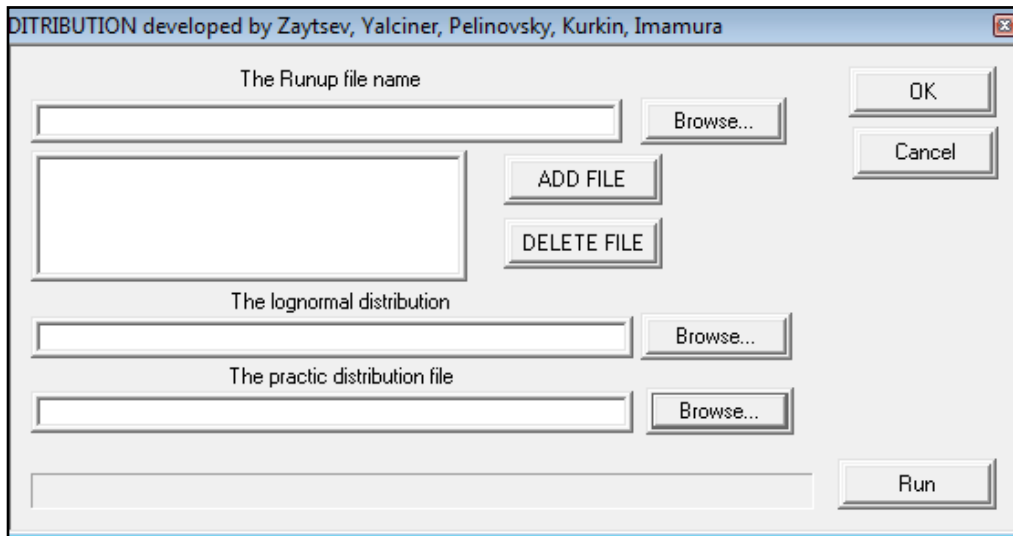
Figure 34 : All Event Option and Distribution File Inputs

1. Enter the name of the run up file on "The Runup file name" box or use browse to locate the file.
2. Click "add file" to add the selected file to the list.
3. Repeat 1 and 2 until you have all the runup files you need on the list.
4. To delete a file from the list, select the file that you want to delete and click "delete file".
5. Enter the name of the "practic distribution file" in the box or use browse to locate the file.
6. Enter the name of the "log normal distribution file" in the box or browse to locate the file.
7. Click "Run" to get both of the distributions for the selected runup files.
8. Click "OK" to close the box.

Important Note: The distribution module of NAMI DANCE is designed to compute the probabilistic distribution of the maximum tsunami amplitudes inside the selected rectangular area along the coastal line. There are some limitations of the computations in distribuiton module, if the user needs to use runup menu, it is strogly recommended that the user must contact the developers (yalciner@metu.edu.tr).

9. 3D PLOTTING

Important Note:

In order to accelerate visualization capability of NAMI DANCE, it is strongly recommended that you should check/change 3D Plot settings of your video card. *"24-bit depth buffer"* option in video card settings should be enabled. To enable this option:

1. Open "*Display*" in Control Panel.
2. On the **Settings** tab, click **Advanced**.
3. Open video card tab, go to OpenGL settings.
4. Select the check box to enable *"24-bit depth buffer"*

All modern video cards support this option. For more information read manual for your video card.
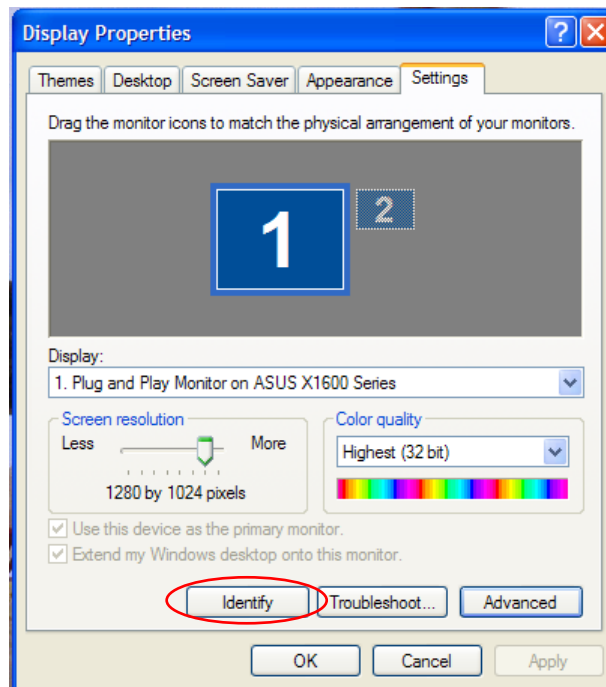
Figure 35 : Display Options

9.1 Plotting the Sea State at a Specific Time

1. Enter the name of the "bathymetry file in the bathymetry file name (input)" box or use browse to locate the file. If you want to use a different color for the topography, select the color by clicking the "color" button next to the bathymetry file name box.
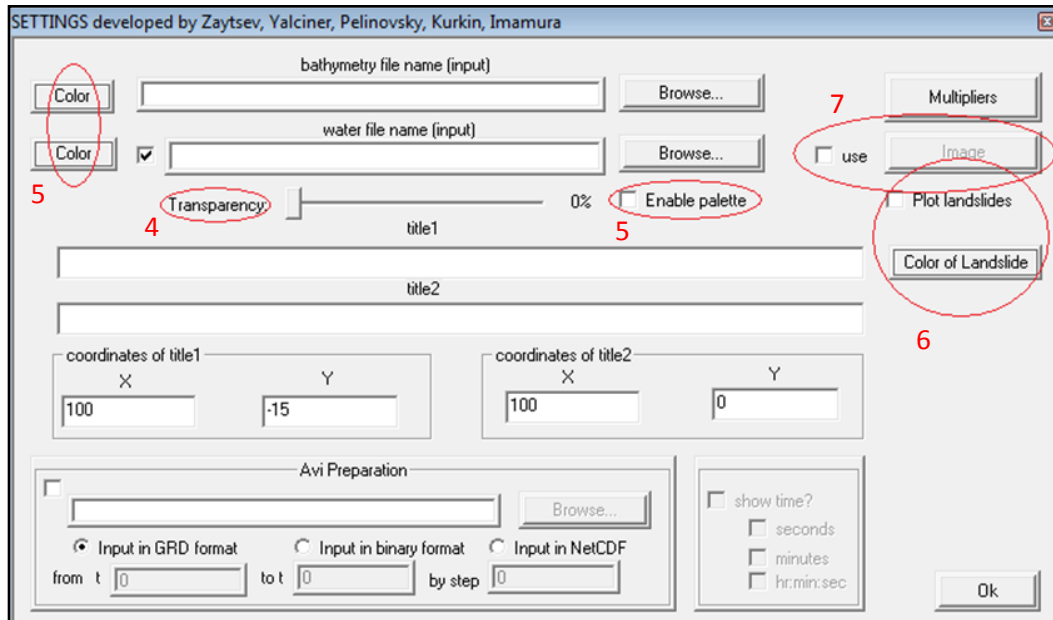
Figure 36 : Settings for Plotting Operation

2. Put a tick in the box next to **"water file name (input)"** box in order to plot the sea state at a specific time.

3. Enter the name of the water file (input) for the specific time you want to plot or locate file using browse from sea state (t*******.grd) files.

4. Water color can be set as transparent by increasing the "**Transparency**" percentage.

5. Put a tick in the "**Enable palette**" box to set the water or landscape color using palette. You can insert an additional layer or delete an existing one. You can load an available palette, or modify palette and save for future uses. Palette can be loaded from "Color" buttons for landscape or water.
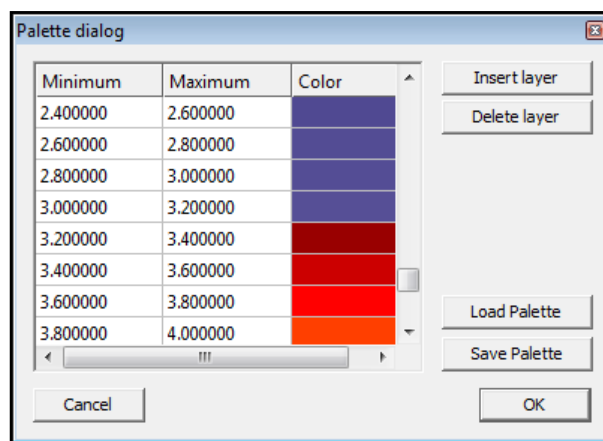
Figure 37 : Palette dialog for Plotting

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6. If the animation contains landslides, put a tick in the "**Draw landslides**" box.

Note: In order to use "**Draw landslides**" **menu please contact the developers, because landslide movement must be prepared in different time steps.**

7. Convenient texture file can be used as topography color by checking the use "**Image"** box and browse for the file   to be used as texture. The texture file may be a satellite image. The file coordinates must match exactly with bathymetry coordinates. Also, the texture resolution must be the same with screen resolution.

Figure 38 : Texture File Name

8. To enter titles for the simulation, use the "**title1**" and "**title2**" boxes.

9. Enter the coordinates of the starting point of the titles using "coordinates of title1" and coordinates of title 2" boxes.

9.1.1 Multipliers

In some applications, if the land topography has very high elevations and the wave height is not so high comparing to the land topography, it will not be possible to visualize the tsunami wave and land topography in the same plane, since there is a high difference between their order of magnitudes. Therefore, it will be necessary to use a multiplier for land in order to decrease the heights of topography. The opposite case, that is having high values for wave amplitude and not significantly high elevations in land topography. The same procedure also will be applied in this case.

Click on the "Multipliers" button in order to decrease/increase the heights of certain parameters (see the figure below for "Multipliers" panel).

- Enter a value in the "multiplier of topography" box to decrease/increase the heights of the topography.

- Enter a value in the "multiplier of wave amplitude" box to increase the height of the waves to get a well defined sea state.

- Enter a value in the "multiplier of bathymetry" box to decrease/increase the heights of the bathymetry.

- Enter a value in the "truncation level of land topography" box if you want to truncate the higher mountains or to have a certain truncated level after high elevations. This application provides not to plot the higher mountains and only show them at a certain truncated level approximately at the amount of hundred meters. These multipliers do not alter the original calculations.
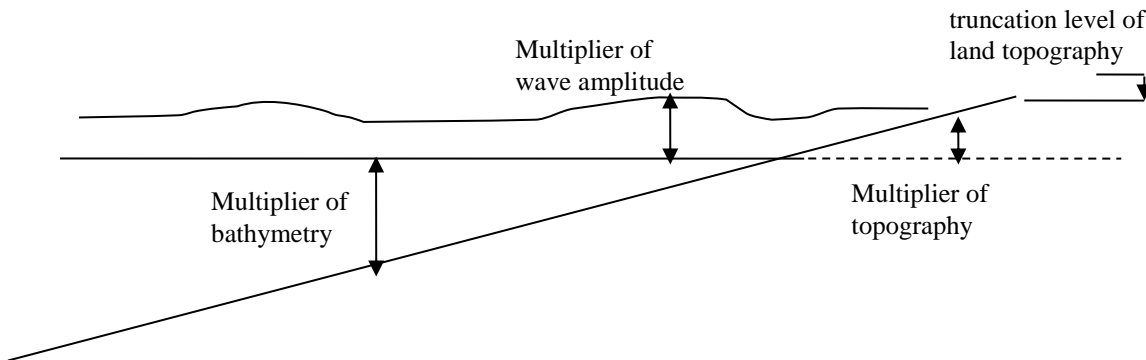
Figure 39 : Topography
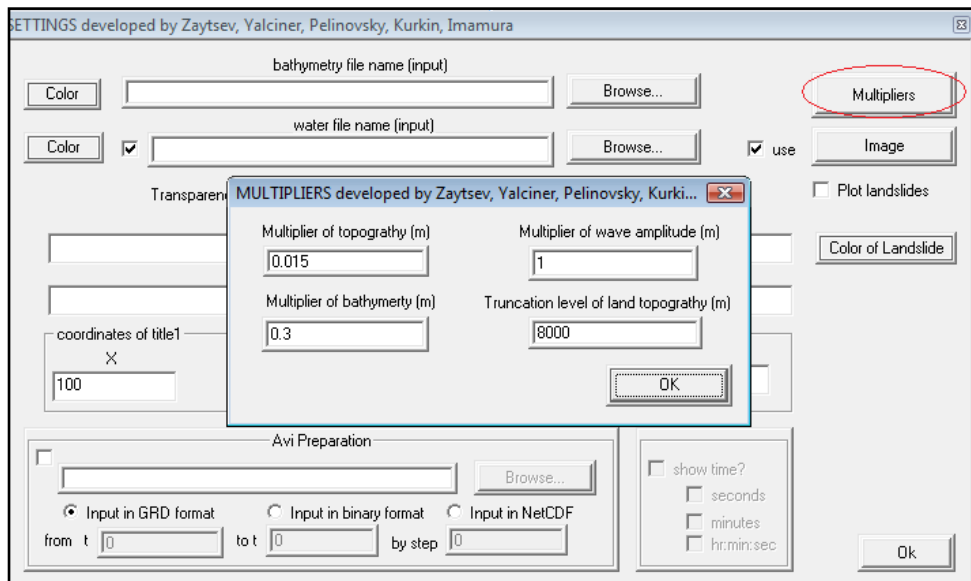
Figure 40 : Multiplier Inputs

9.1.2 Preparing BMP Plots for Animation

1. Enter the name of the bathymetry file in the **"bathymetry file name (input)"** box or use browse to locate the file. If you want to use a different color for the topography, select the color by clicking the color button next to the bathymetry file name box.

2. Put a tick in the box near "**avi preparation**" option in order to plot several sea state files having a specific time interval.

3. Enter the start and end time of the simulation in seconds. You can either start the simulation when t is 0 or at any second within the duration of original simulation time. In order to produce plots of sea states at different times, you must use the times of the output grid (t******.grd) files.

4. Enter the time step for simulation. This number should be equal to or multiplier of the time step used in the output water file time step.
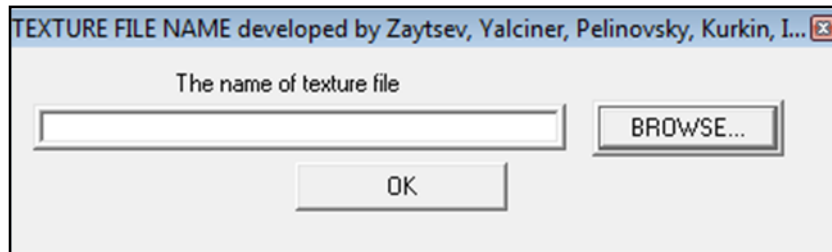
5. To enter titles for the simulation, use the "**title1**" and "**title2**" boxes.

6. Enter the coordinates of the starting point of the titles.

7. Enter the multipliers as described in case 6 in "TO PLOT THE SEA STATE AT A SPECIFIC TIME" part.

8. In order to show the time of the sea state, select the "show time?" box and chose the unit of time.

10. Select "OK".

9.2 Sample Applications for Indicating the Effect of Multipliers on Visualization

Trial 1:
Multiplier of topography (m) = 0.008
Multiplier of wave amplitude (m) = 15
Multiplier of bathymetry (m) = 1
Truncation level of land topography (m) = 8000

Result 1:
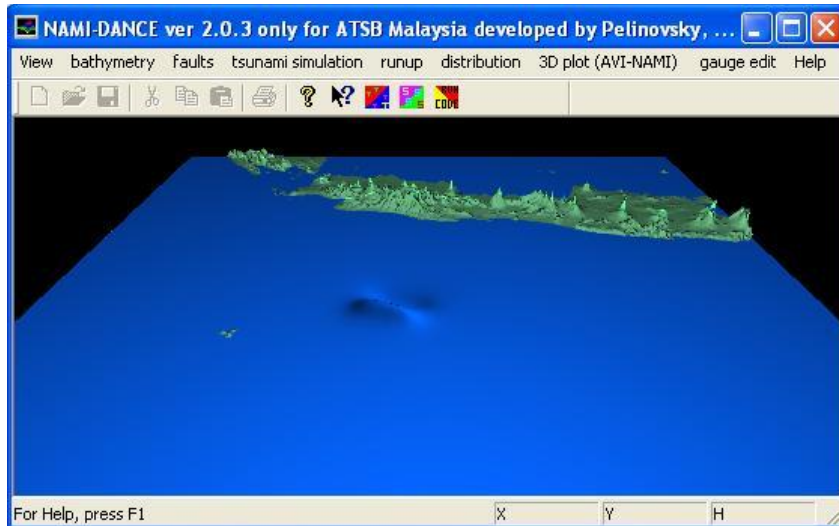
Figure 41 : A sample Application for Multiplier Effects

Trial 2:
Multiplier of topography (m)= 0.1
Multiplier of wave amplitude (m)= 15
Multiplier of bathymetry (m)= 1
Truncation level of land topography (m)= 8000

Result 2:
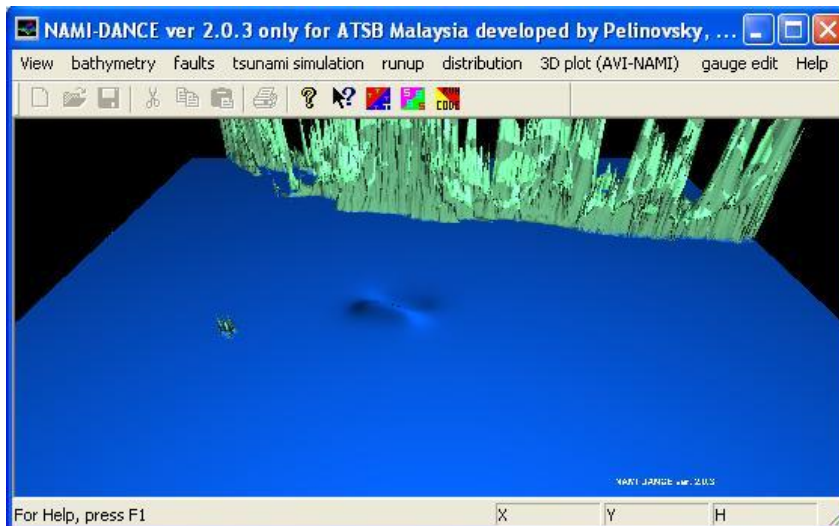
Figure 42 : A Sample Application for Multiplier Effects

Trial 3:
Multiplier of topography (m)= 0.008
Multiplier of wave amplitude (m)= 50
Multiplier of bathymetry (m)= 1
Truncation level of land topography (m)= 8000

Result 3:
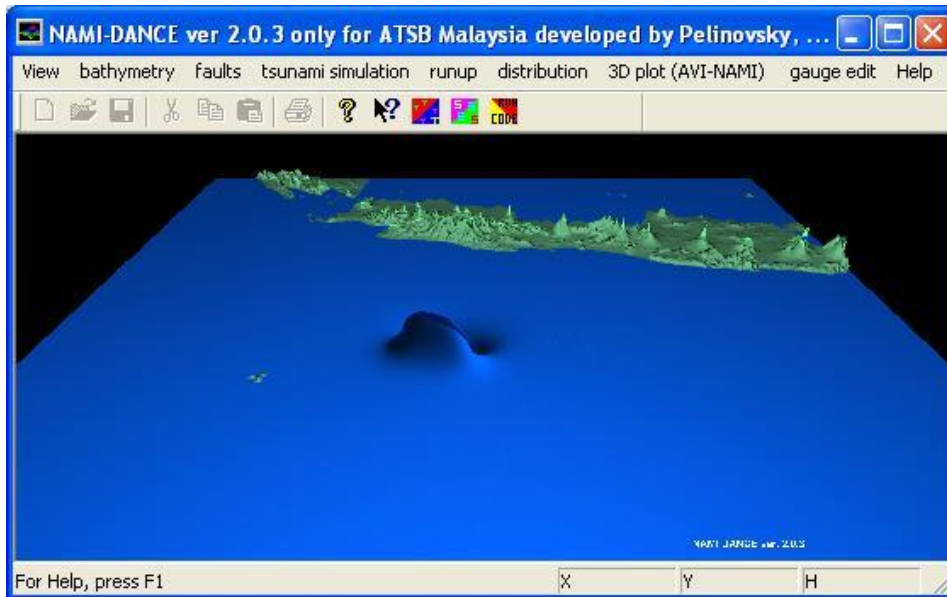
Figure 43 : A Sample Application for Multiplier Effects

Trial 4:
Multiplier of topography (m)= 0.008
Multiplier of wave amplitude (m)= 15
Multiplier of bathymetry (m)= 1
Truncation level of land topography (m)= 1

Result 4:
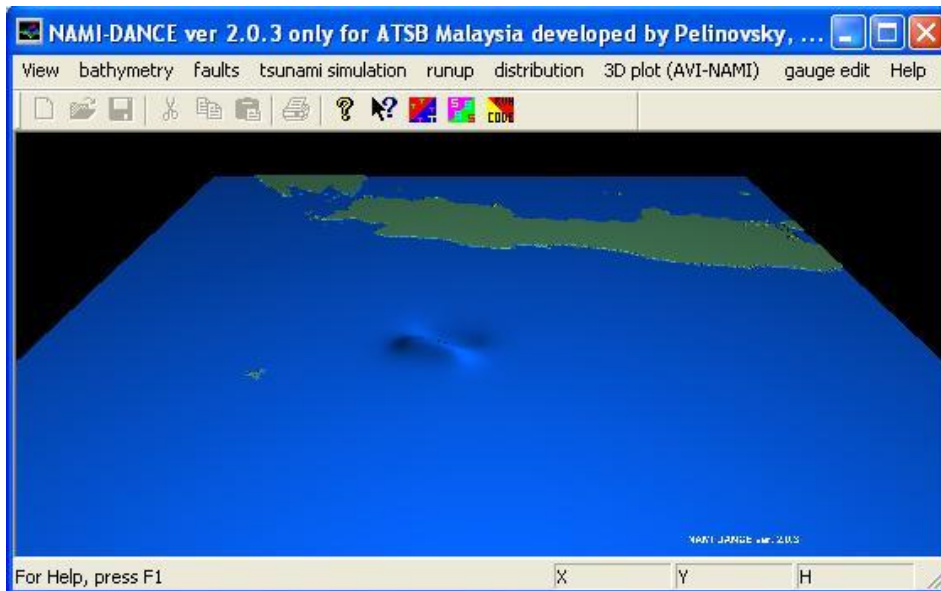
Figure 44 : A sample Application for Multiplier Effects

9.3 Camera Settings

1. On "3D Plot (AVI NAMI)" menu, go to "Camera Position" option.
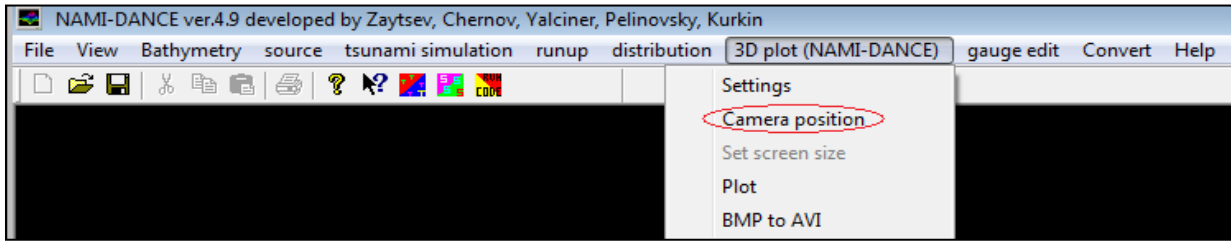
Figure 45 : 3D Plotting menu
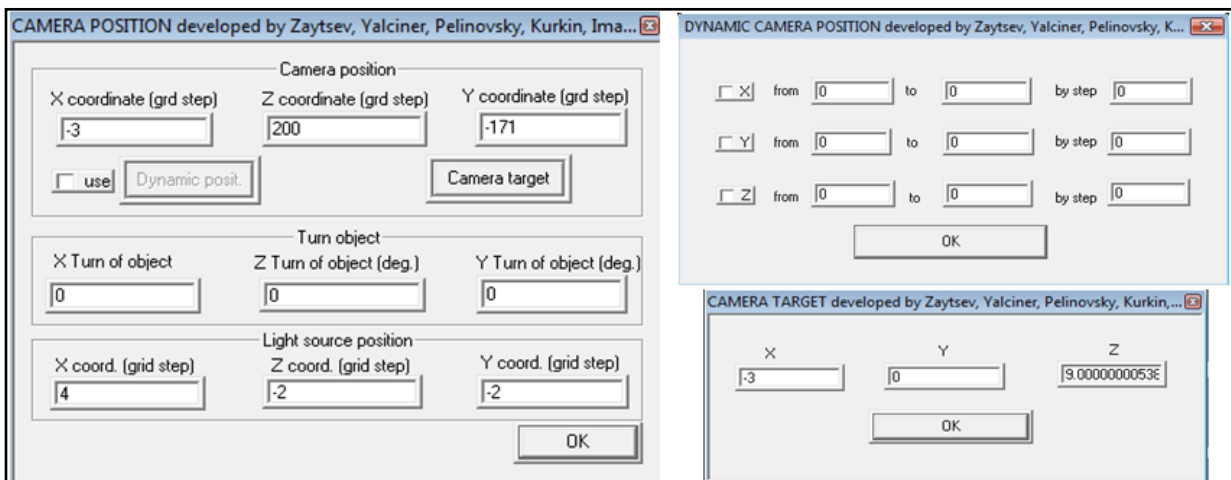
Figure 46 : Camera Position for Plotting

2. Enter coordinates in the coordinate boxes to locate the camera to get the desired view of the output files.
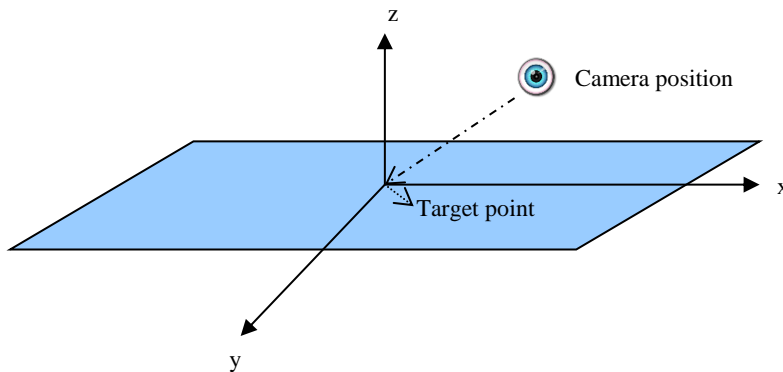
Figure 47 : Location of the camera and target point

3. Enter values in the Turn object to turn the output file to get the desired view of the output files.
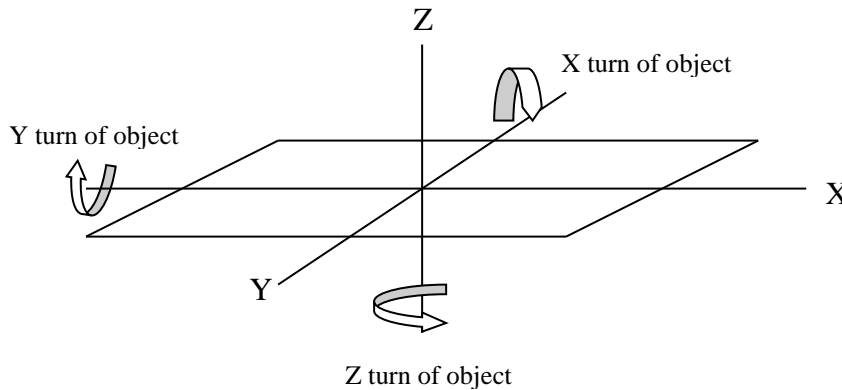
Figure 48 : Turn Directions for Plotting

4. Enter coordinates of the light in the Light source position boxes to locate the light source to get the desired view of the output files.
5. Click "OK".
6. On "3D Plot (NAMI DANCE)" menu, go to "Plot" to plot the output files with the selected properties of view. This plotting may take some time.
7. After plotting, the location of the image can be changed by using mouse. Scroll button can be used for zooming in and out.

9.4 Creating Animations from the Output Files

1. First plot output files for animation using the guideline given above.
2. On "3D plot (AVI-NAMI)" menu, go to "BMP to AVI" option.
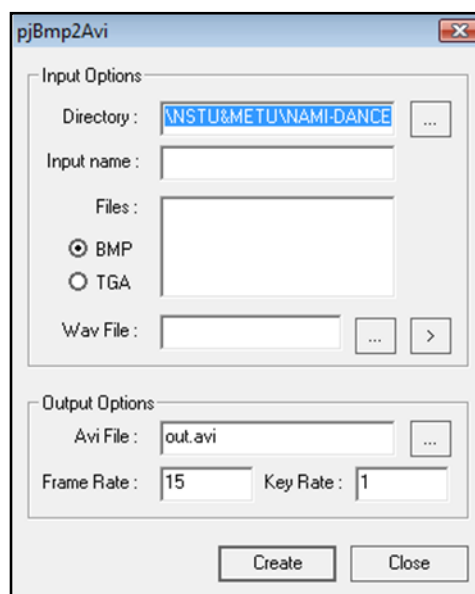
Figure 49 : Creating Animation using Output Files

3. Enter the name of the directory or locate it by clicking the "…" button next to the "directory" box. Once this name is entered, the program automatically shows the bmp files in this directory as a list in the "Files" box.

4. By default, BMP option is selected. If not, select the "BMP" option on the "Input Options" menu.

5. If you want to insert music to the animation, enter the name of the file in the "Wav File" box or locate the file using the "…" button.

6. Enter the name of the avi file in the "Avi File" box which is going to be the output simulation file or locate it using "…." button.

7. Enter the frame rate and the key rate on output options menu.

8. Click "Create".

9. Select a type of compressor (codec) to create the simulation file. The types of codec depend on the types of codec you have in your hard disk. Change the codec settings to get the desired view for the simulation.

10. Click "OK" to generate the simulation.

10. CREATING A GAUGE POINT FILE

As given above, if the time histories of water surface fluctuations at selected location (gauge points) are needed, the file containing the name and coordinates of the gauge points can be prepared externally or by NAMI DANCE In order to create the gauge file by NAMI DANCE there are two options i) "gauge point" and ii) "gauge installation" under Gauge Edit panel.

"gauge point locator" option:

1. On "gauge edit" menu, go to "gauge point locator" option.
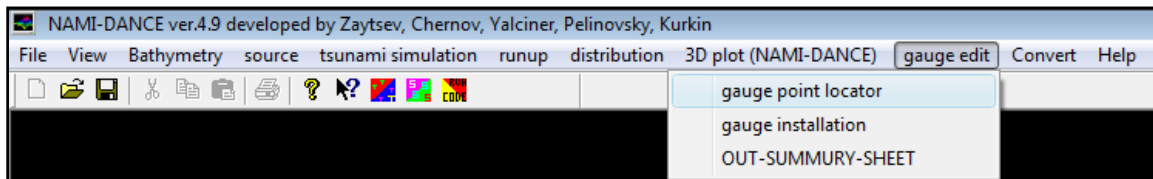
Figure 50 : Gauge Edit Menu

2. Enter the name of the bathymetry file in "The bathymetry file path" box or use the "browse" option for locating the file. Click on the box next to it.
3. Enter the name of the gauge point file in "The gauges point file path" box in which the coordinates of the locations will be stored or locate the file using browse option. Click on the box next to it.
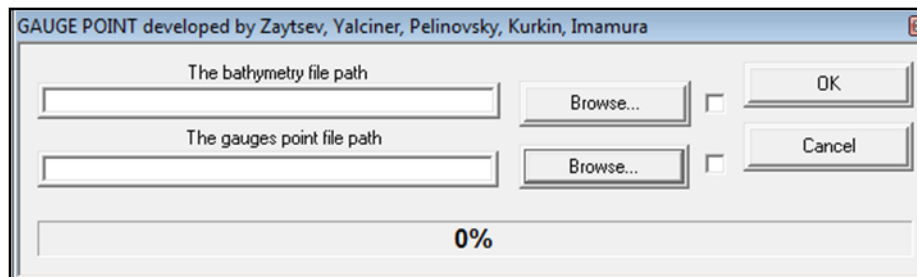
Figure 51 : Gauge Point File control panel

4. Click "OK".
5. The screen will show the bathymetry file.
6. Click the location you want to add to the gauge file on the screen.
7. Write the name of the location in the box appeared on the screen and click "OK". Then it saves the cordinate and name of the location in the gauge file.
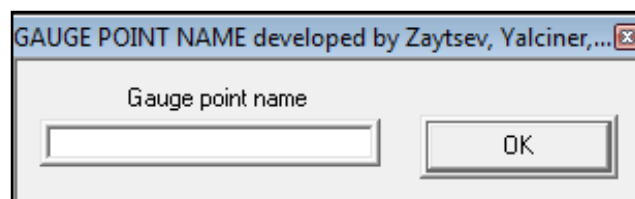
Figure 52 : Name of the numerical Gauge Point

"gauge installation" option:

This option is developed if the user needs to locate the gauge points at a certain depth inside a certain rectangular area. The depth and the corners of the rectangular area can be inputted by this option as described in the following.

1. On "gauge edit" menu, go to "gauge installation" option. Gauge file autocreator will appear.
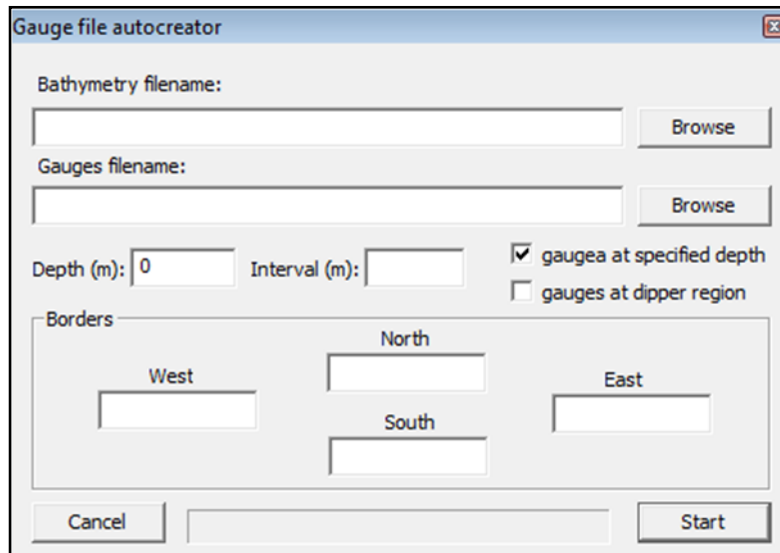
Figure 53 : Gauge File Autocreator

2. Enter the name of the bathymetry file in "bathymetry filename" box or use the "browse" option for locating the file. Click on the box next to it.
3. Enter the name of the gauge point file in "gauges filename" box in which the coordinates of the locations will be stored or locate the file using browse option. Click on the box next to it.
4. Enter a value for the required depth of the gauge points near "Depth" box.
5. Enter a value for the distance between the adjacent gauge points near the "Step" box.
6. Enter north, south, east and west borders of the area where gauge points will be selected from.
7. Click "Start" and the gauge point file should appear in the selected directory.

"OUT SUMMARY SHEET"
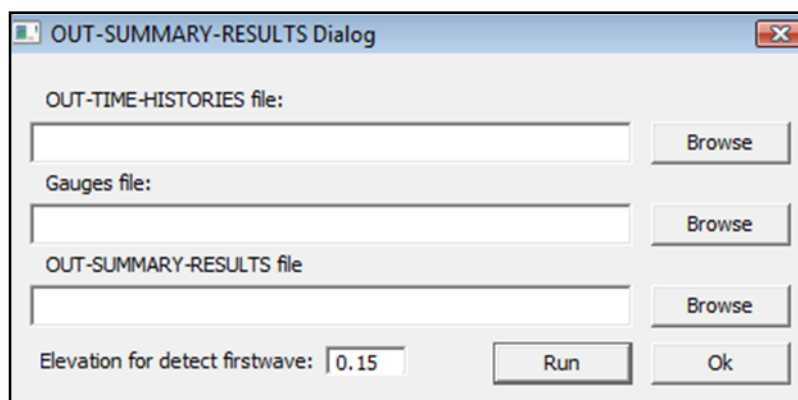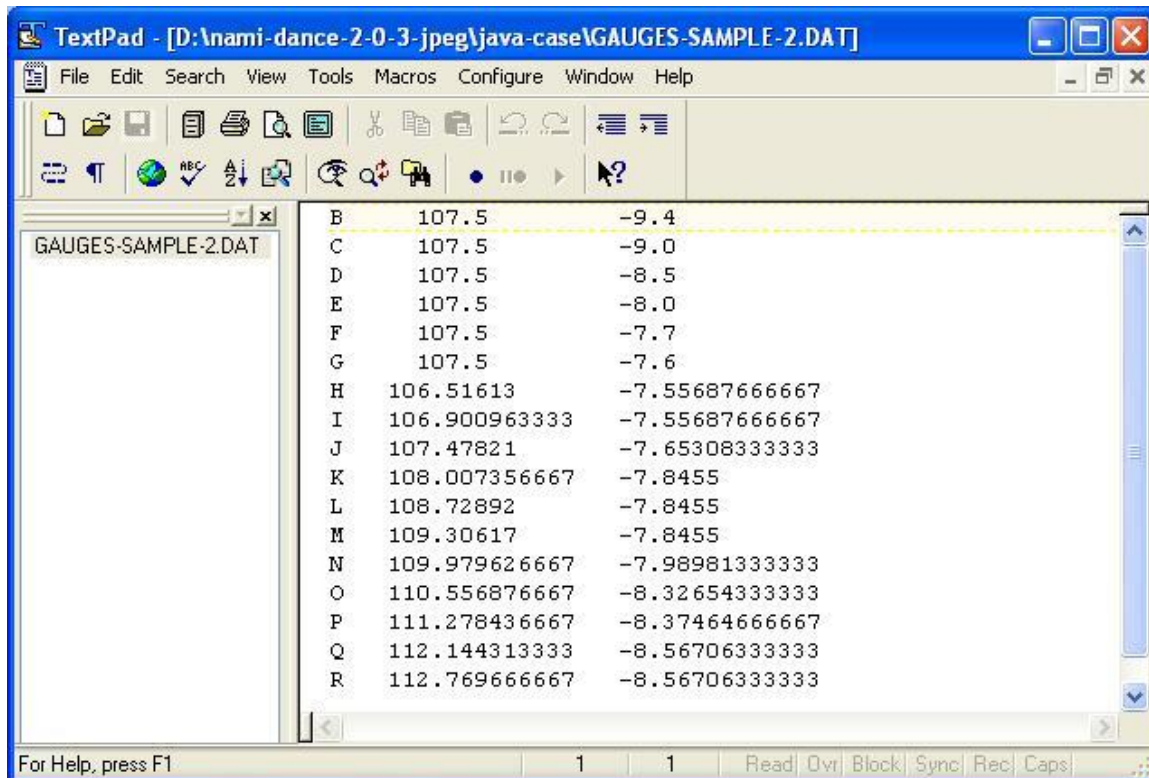
Figure 54 : Out-Summary-Results

In order to obtain "OUT SUMMARY RESULTS" file OUT TIME HISTORIES and gauges files must be inserted using Browse button. After selecting an elevation for detection of the first wave in meters is also entered, click "Run"."OUT SUMMARY RESULTS.dat" file should appear in the respective directory. This file contains the coordinates and depths of gauge points, the arrival times of first and maximum waves and maximum negative and positives wave amplitudes occuring at the gauge points. This file is also considered as the summary sheet of the simulation results.

NAMI DANCE can also generate a file named OUT-SUMMARY-INPUT.dat which shows the user's selections and inputted parameters or files used in the simulation.

GAUGES FILE DETAILS

The gauge location data is saved as *.dat file and contains the names, x and y coordinates of the gauge locations within the area. Names of the locations will be written without having any space between words and without quotation marks. Next, the x coordinate and the y coordinate of the location will be written in decimals. There should be space between the name of location, x coordinate and y coordinate. Do not use tab button for having space between location name and coordinates that the program cannot read the gauge file properly. South and west coordinates will be shown with a minus sign. A sample gauge file is shown in the figure below:The name of gauge location must not have any blank in the name.

Figure 55 : Coordinates of Gauge Stations (x and y)

11. CONVERTING FILE TYPES
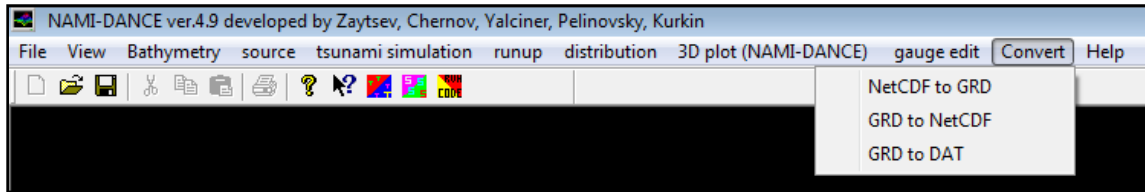
Figure 56 : Convert Menu

From "Convert" menu, conversions from 'NetCDF to GRD' , 'GRD to NetCDF' and "GRD to DAT" are possible.

There are two types of conversion. First conversion type is for bathymetry files. The bathymetry file without any extension (for example "*gridA.*") can be converted to "*bathymetry.grd*". Next conversion type is for water elevation files. "*t******.grd*" files can be extracted from files with extension "*.nc*". Also bathymetry or water elevation "******.grd*" files can be converted to XYZ format "******.dat*" files.

Browse for input and output (export) files.
Click *'Run'* to start and click *"Stop"* to cancel the operation.
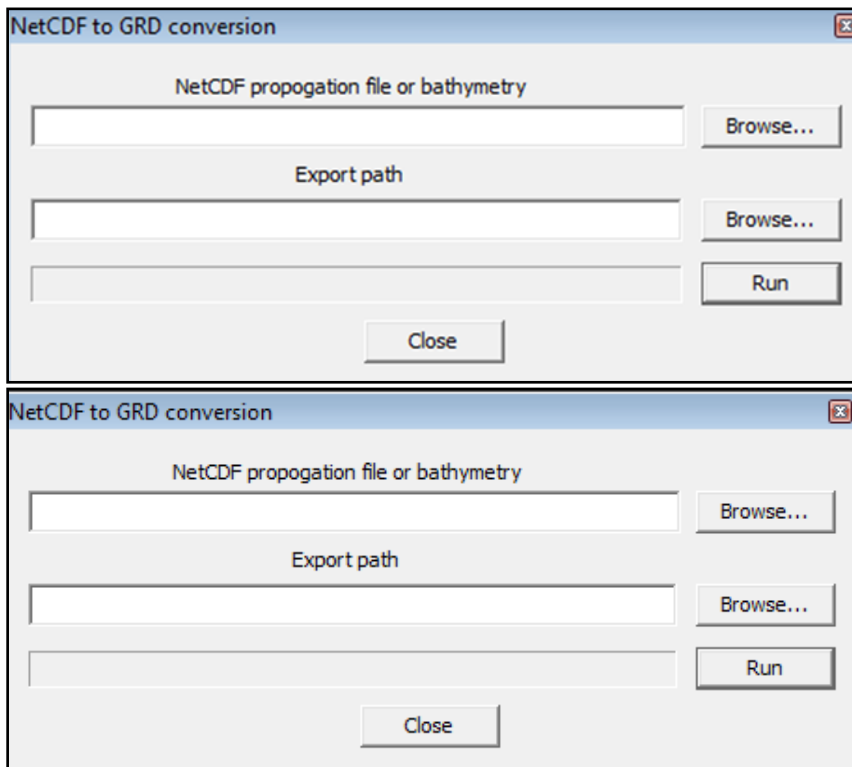
Figure 57 : NetCDF Conversion
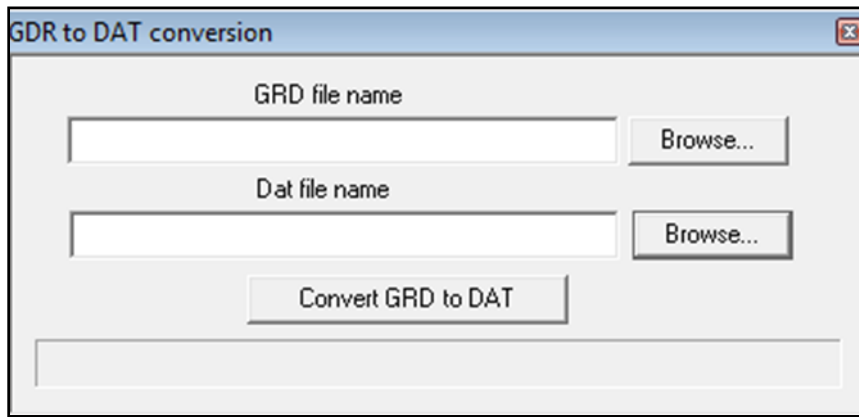
Figure 58 : Grd to Dat Conversion

Note: In order to proper use of "Convert" menu, please contact the developers.

12. EXPLANATIONS OF THE INPUT AND OUTPUT STRUCTURE:

INPUT FILE LIST:

File Name (not case sensitive)	Content
bathy.grd	Water depth (bathymetry) and elevation (topography) values at each grid points (sea area is (+)ve and land area (-)ve (m).
Gauges.dat	The coordinates of each gauge locations.
source.grd	The tsunami source file including water surface elevations at grid points computed from rupture parameters or other mechanisms (landslide, caldera collapse etc.) from source menu of NAMI DANCE or externally.
border-eta-M-N.dat	Time histories of water level, M, N at the border (4 column file; in the form of time eta, M, N). (time in seconds, elevation in meters and discharge fluxes in m^3/sec/m). Note that the time interval in this file must coincide withthe time step of the simulation.

OUTPUT FILE LIST:

File Name (not case sensitive)	Content
OUT-SUMMARY-INPUT.dat:	The brief summary of the input parameters.
OUT-SUMMARY-RESULT.dat:	The summary table for decision makers containing the computed wave characteristics at the gauge locations.
OUT-ETA-MAX.grd	The maximum positive wave amplitudes (water eleveations) at every grid point computed during simulation duration (m).
OUT-ETA-MIN.grd:	The maximum negative wave amplitudes (water eleveations) at every grid point computed during simulation duration (m).
OUT-FLOWDEPTHMAXLAND.grd	The computed maximum flow depth at land at the grid points at land (inundation zone) (m).
OUT-CURMAX.grd	The computed maximum current velocity during simulation at every grid point (m/sec).
OUT-ANGMAX.grd	The angle of the computed maximum current velocity during simulation at every grid point (degrees CW from North).
OUT-M-MAX.grd	Computed maximum discharge flux in horizontal direction (East-West) at each grid point (m^3/sec/m).
OUT-N-MAX.grd	Computed maximum discharge flux in horizontal direction (South-North) at each grid point (m^3/sec/m).
OUT-MN-flux-MAX.grd	Computed maximum total discharge flux at every grid point during simulation at every grid point (m^3/sec/m).
OUT-ANGLE-MN-MAX-flux.grd	Angle of computed maximum total discharge flux at every grid point during simulation at every grid point (m^3/sec/m).
OUT-FR2U.grd	The computed maximum values of FR^2 (Square of Froude Number) in horizontal direction at every grid point (m/sec).
OUT-FR2V.grd	The computed maximum values of FR^2 (Square of Froude Number) in vertical direction at every grid point (m/sec).
OUT-FR2MAX.grd	The computed maximum values of FR^2 (Square of Froude Number) at every grid points (dimensionless).
OUT-FRMAX.grd	The computed maximum values of FR (Froude Number) at every grid point (dimensionless).
OUT-FDRAG_MAX.grd	The computed maximum drag force. at every grid point
OUT-FLOWDEPTHMAX.grd	The computed max flow depth at every grid point in the computational domain (m).
OUT-FD@curmax.grd	The flow depth at the grid points at the time of maximum current (m).
OUT-FDatFR2max.grd	The flow depth at the grid points at the time of maximum value of the FR^2 (Square of Froude Number) (m).
OUT-CURatFR2max.grd	The current velocity at the grid points at the time of max value of the FR^2 (Square of Froude Number) (m/sec).
OUT-TIME-FIRST-WAVE.grd	The arrival time of the first wave at every grid point (min). When water level changes + or -0.15m, it is assumed that first wave arrived.
OUT-TIME-MAX-WAVE.grd	The arrival time of the maximum wave elevation at every grid point (min).
OUT-time@curmax.grd	The time of occurrence of the maximum current at every grid point (min).
OUT-timeatFr2max.grd	The time of the occurrence of the maximum FR^2 (Square of Froude Number) at every grid point (min).
t000000.grd	Distribution of water surface elevations at every grid points at the time of 000000 (sec). Note that the numbers in teh file name represent the time in seconds here and in the following.
CUR000000.grd	Current velocity at every grid points at the time of 000000 (sec).
ANG000000.grd	Angle of the curresponding current at every grid points at the time of 000000 (sec).
DT000000.grd	Hydrodynamic Demand (FR2) at every grid points at the time of 000000 (sec).
MT000000.grd	Discharge flux in horizontal direction at every grid points at the time of 000000 (sec).
NT000000.grd	Discharge flux in vertical direction at every grid points at the time of 000000 (sec).
UT000000.grd	Current velocities in horizontal direction at every grid points at the time of 000000 (sec).
VT000000.grd	Current velocities in vertical direction at every grid points at the time of 000000 (sec).

	Time histories of
OUT-TIME-HISTORIES_CUR.dat	Current velocity at gauge locations.
OUT-TIME-HISTORIES_ETA.dat	Water surface elevation at gauge locations
OUT-TIME-HISTORIES_FR.dat	Froude number FR in horizontal direction at gauge locations
OUT-TIME-HISTORIES_FR2.dat	Square of Froude number FR^2 in horizontal direction at gauge locations
OUT-TIME-HISTORIES_M.dat	Discharge flux in horizontal direction at gauge locations
OUT-TIME-HISTORIES_N.dat	Discharge flux in vertical direction at gauge locations
OUT-TIME-HISTORIES_MN-flux.dat	Discharge flux (total) at gauge locations
OUT-TIME-HISTORIES_MN-flux-ANGLE.dat	Angle of discharge flux at gauge locations
OUT-TIME-HISTORIES_U.dat	Current velocity in horizontal direction at gauge locations
OUT-TIME-HISTORIES_V.dat	Current velocity in vertical direction at gauge locations

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APPENDIX A: METHOD IN TSUNAMI MODELING

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State-of-the-artand Phases of Tsunami Modeling

Tsunami is one of the most important marine hazards generally triggered by earthquakes and/or submarine/subaerial landslides. In general, tsunami might affect not only the area where it is generated but also substantial distance away from generation region. Tsunami science needs close cooperation between basic and applied sciences and also from international to local level authorities. The tsunami modeling and risk analysis are necessary for better preparedness and proper mitigation measures in the framework of international collaborations. Better understanding, wider awareness, proper preparedness and effective mitigation strategies for tsunamis need close international collaboration from different scientific and engineering disciplines with exchange and enhancement of existing data, development and utilization of available computational tools.

Modeling is one of the essential components of tsunami studies in scientific and operational level. Tsunami modelling has several phases in which exchange and enhance of available earthquake and tsunami data, bathymetric and topographic data in sufficient resolution, selection of possible or credible tsunami scenarios, selection and application of the validated and verified numerical tools for tsunami generation, propagation, inundation and visualization must be covered.

In general, there are several unique phases of tsunami modeling for a specific region. They are summarized in the following.

Phase 1: Catalogue and literature survey on the historical tsunamis

Catalogue and literature survey must be done and the followings must be delivered.
The paleotsunami study (coastal trench study) by the expert paleotsunami geologist(s) at the selected region(s) must also be kept in the agenda which may provide some findings about traces of some historical tsunami events for comparison and assessment of the level of historical events.

Main deliverables must be:
i) The length of historical time for which tsunami reports and records,
ii) Evaluation of reliability of the historical documents,
iii) Estimates of run-up heights of historical events from the collected data and information and paleotsunami studies.

Phase 2: Determination/development of bathymetry/topography data

The bathymetric and topographic data in digital form from available navigational charts, conventional and multi beam bathymetric measurements, digital elevation models, satellite images must be collected and bathymetry/topography for the region must be developed. The coordinates of existing shoreline, nearshore bathymetry and land topography must also be measured and added to the bathymetry topography database. The database must also be in

sufficient resolution in GIS based format, especially nearshore and shallow regions with an accuracy of at most30m and 1-5m in horizontal and vertical dimensions respectively.

Main deliverables must be:
i) Digital data of bathymetry and topography in sufficient accuracy and in GIS based format.

Phase 3: Determination of current land use plans in GIS based format

The digital land use plans of the study area in GIS format are necessary for accurate and applicable results of tsunami modelling. The distribution of coastal and marine structures must be located in the plans. An example list of important structures can be; residential buildings, commercial centers, industrial plants, open areas, educational buildings, health services, social, historical, cultural and public areas/buildings, monuments, fire stations, offices of security service, communication centers, infrastructures near shoreline (waste water discharge systems, fresh and waste water network), support units, transportation structures (piers, breakwaters, coastal protection structures, all types ports, harbors, marinas, small craft harbors, fishery harbors, shelters, railway stations, passenger terminals, airport, heliport etc.), agricultural areas, areas of solid wastes, treatment plants.

Main deliverables must be:
i) Digital database of coastal, marine and other important structures in GIS format together with vulnerability levels.
ii) Building density map.

Phase 4: Determination and characterization of probable tsunami sources,

Characteristics, dimensions and locations of near field and far field submarine and/or coastal faults and landslide prone regions must be identified and
i) Inventory of near (<50 km) and far (>50 km) tsunamigenic (tectonic and slope-failure related) sources,
ii) Characterization of tsunami faults,
iii) Characterization of identified unstable bodies, submarine landslides and possible tsunamigenic seafloor deformations must be determined. This is a difficult task and needs much discussion among marine geologists and earth scientists, since uncertainities in the underlying fault rupture and landslide processes are large.

Main deliverables must be:
i) Fault maps,
ii) Submarine/subaerial landslide maps,

Phase 5: Computing the tsunami source characteristics from using estimated rupture characteristics and landslide characteristics
Developing and/or using valid, verified, advanced computational tools for computing the tsunami source parameters with sufficient accuracy and reliability as for the input of tsunami modeling.

Main deliverable must be:
i) Initial fluid displacements and velocity fields of the tsunami sources.

Phase 6: Determination of study domains for modeling

Nested grid system covering nearfield and far field sources and also the coastal communities must be to be generated.

Main deliverable must be:
i) Digital data of bathymetry and topography of each study domain in sufficient accuracy and required format.

Phase 7: Simulation and computing all necessary tsunami parameters
Phase 5 provides data of the initial conditions of tsunami source (i.e., initial fluid displacements and velocity fields), for the computational model(s) to be used propagation of tsunamis in the open sea and their coastal amplification and runup at shallower regions and on land in the study regions. This phase is the most important phase of tsunami modeling, since scientific based techniques and tools are essential for the best possible quantification.

Use state-of-the-art numerical models to simulate tsunami propagation from the source to shoreline and runup location. This phase must briefly cover
i)   tsunami scenarios
ii) use of validated and verified tsunami propagation and inundation model(s)
iii) simulation and analysis of relevant historical tsunamis,
iv) simulation of predefined tsunami scenarios and their analysis,
v)   tsunami impact micro zoning,
vi) Inundation mapping for selected coastal regions.

The main deliverables of tsunami simulations are
i) Tsunami propagation maps for selected scenarios
ii) Time histories of water level fluctuations at selected locations
iii) Arrival time distributions of first wave along shoreline
iv) Arrival time distributions of maximum wave along shoreline
v) Distributions of magnitude and direction of maximum currents
vi) Distributions of maximum positive amplitudes
vii) Distributions of maximum negative amplitudes
viii) Distribution of inundation distances
ix) Distributions of relative impact forces

Phase 8: Inundation Mapping
The maps providing the information of the estimated hazard zone parameters such as design flow elevation (DFE) and maximum velocity, related to deterministic and probabilistic tsunami scenarios must be prepared according to the numerical outputs of tsunami modeling. These maps give comparisons of these estimates with one another and with the available manuals and guidelines and also show estimated borders of inundation.

Phase 9: Probabilistic analysis
Probability of occurrence of each tsunami source must be determined. By compilation of the model results of each scenarios, the probabilities of certain runup and inundation distances of tsunamis near the coastal region of the project must be determined in this task.
Phase 10: Dissemination of Results
In order to define the probable effects of tsunamis along its probable inundation areas, the coastal topography with land use plans, showing sensitive and vulnerable regions and structures

must be taken into account. Using the probabilistic and/or deterministic approaches and their results on arrival time, maximum positive amplitudes near shoreline, shoreline velocities and estimated runup and inundation distances, the potential effects of probable tsunamis must be estimated for the preparedness issues.

Phase 11: Animations and 3D visualizations of selected tsunami scenarios
By using advanced numerical modeling for visualization, awareness, preparedness and dissemination of the results and making them to be wider applicable, there must be the series of audio-visual products and educational/training materials showing the behavior and possible effects of tsunamis in the region.

Maps, visual materials are used and by using advanced animation programs, the propagation of selected tsunami(s) and its arrival to coastal regions will be shown as 3D movies for the educational purposes.

The main deliverables are:
i) The database of all processed and produced data,
ii) Illustrative maps,
iii) Visual materials 2 and/or 3D still images and video animations,
iv) Educational and training materials

Phase 12: Providing data and specific information to authorities for developing guidelines and mitigation measures in accordance with the land use plans

In terms of provisions of technical codes for the coastal and marine structures and facilities, the development of codes and standards for infrastructures against hazards is a problem at international level.

Using estimated runup values, coastal and overland velocities, and their estimated frequency of occurrences to express the modeling results and consider the distribution of vulnerability, sensitivity and importance of coastal and marine structures, the specific methods and work plan must be proposed for better understanding, awareness, preparedness and proper mitigation measures for the authorities and experts.

NAMI DANCE APPLICATIONS

APPENDIX B: GLOSSARY IN TSUNAMI MODELLING

Aftershock: An earthquake that follows a larger earthquake or main shock and originates at or near the focus of the larger earthquake. Generally, major earthquakes are followed by a larger number of aftershocks, decreasing in frequency with time.

Amplitude: The rise above or drop below the ambient water level as read on a tide gage.

Arrival time: Time of arrival, usually of the first wave, of the first wave of the tsunami at a particular location.

Attenuation - a reduction in wave amplitude.

Average period (Tav, Tz) - Average zero down-crossing wave period. The average period of the waves observed, weighted by wave energy.

Average Wave Height (Hav) - Average zero down-crossing wave height. The average height of the waves observed.

Breaker - A wave that has reached maximum steepness and is breaking.

Body wave: A seismic wave that travels through the interior of the earth and is not related to a boundary surface.

Bore: Traveling wave with an abrupt vertical front or wall of water. Under certain conditions, the leading edge of a tsunami wave may form a bore as it approaches and runs onshore. A bore may also be formed when a tsunami wave enters a river channel, and may travel upstream penetrating to a greater distance inland than the general inundation.

Capillary Wave - A wave in which the velocity of propagation is a function of the surface tension of the water. Wind waves of wavelength less than about 2.5 cm (1") are considered capillary waves.

Continental Crust: Outermost solid layer of the earth that forms the continents and is composed of igneous, metamorphic, and sedimentary rocks. Overall, the continental crust is broadly granitic in composition. Contrast with oceanic crust.

Continental Drift: The theory, first advanced by Alfred Wegener, that the earth's continents were originally one land mass called Pangaea. About 200 million years ago Pangaea split off and the pieces migrated (drifted) to form the present-day continents. The predecessor of plate tectonics.
Convergent Plate Boundary: See subduction, and subduction zone.

Crest - The highest point on a wave.

Crest Period (Tc) - the average time between successive maxima, or crests. Calculated from moments of wave frequency spectrum as Tc = square root of (m_2/m_4) .

Crust: The outer layer of the earth's surface.

Deep Water Wave - A wave for which water depth is greater than one half the wave length. Ocean wind waves are negligibly affected by the bottom in deep water.

Dip: The angle between a geologic surface-for example, a fault plane-and the horizontal. The direction of a dip can be thought of as the direction a ball, if placed upon the tilted surface, would roll. Thus, a ball placed on a north-dipping fault plane would roll northward. The dip of a surface is always perpendicular to the strike of that surface.

Diffraction - A wave process in which energy is transmitted along wave crests. When a wave train passes a barrier, diffraction causes energy to propogate into sheltered regions behind the barrier.

Dispersion of Waves - The tendency of longer waves to travel faster than shorter waves due to the proportionality between wave phase speed and wave length.

Divergent Plate Boundary: The boundary between two crustal plates that are pulling apart (e.g. sea floor spreading).

Dominant Wave Period - The period corresponding to the frequency of maximum variance as represented by a wave frequency spectrum.

Duration - In terms of wave growth, the time over which the wind blows at a constant velocity.

Earthquake: Shaking of the earth caused by a sudden movement of rock beneath its surface.

Earthquake swarm: A series of minor earthquakes, none of which may be identified as the main shock, occurring within a limited area and time.

Elastic wave: A wave that is propagated by some kind of elastic deformation, that is, a deformation that disappears when the forces are removed. A seismic wave is a type of elastic wave.

Epicenter: That point on the earth's surface directly above the hypocenter of an earthquake.

ETA: Estimated Time of Arrival. Computed arrival time of the first tsunami wave at coastal communities after a specific earthquake has occurred.

Fault: A weak point in the earth's crust where the rock layers have ruptured and slipped.

Fetch - In terms of wave growth, the distance on the ocean over which the wind blows at a constant velocity.

First arrival: The first recorded signal attributed to seismic wave travel from a known source.

First motion: Initial motion of the first wave, a rise in the water level is denoted by R, a fall by F.

Focal zone: The rupture zone of an earthquake. In the case of a great earthquake, the focal zone may extend several hundred kilometers in length.

Focus: That point within the earth from which originates the first motion of an earthquake and its elastic waves.

Foreshock: A small tremor that commonly precedes a larger earthquake or main shock by seconds to weeks and that originates at or near the focus of the larger earthquake.

Free field offshore profile: A profile of the wave measured far enough offshore so that it is unaffected by interference from harbor and shoreline effects.

Frequency - a measure of the number of oscillations or cycles per unit time; the reciprocal of the time duration (period) of an oscillation. (A wall outlet in North America, for example, has a voltage oscillation frequency of 60 cycles/s.)

Fully-DevelopedSea - A sea state in which waves have reached maximum energy. Additional energy added to the spectrum is dissipated by wave breaking.

Gravity Wave - A wave in which the velocity of propagation is a function of gravity. Water waves over a few inches in length are considered gravity waves.

Group Velocity - The velocity at which wave energy propagates. In deep water, it is equal to half the velocity of the induvidual waves in the group.

Harbor resonance: The continued reflection and interference of waves from the edge of a harbor or narrow bay which can cause amplification of the wave heights, and extend the duration of wave activity from a tsunami.

Harmonic - a quantity whose frequency is an integral multiple of the frequency of a periodic quantity to which it is related.

Height - The vertical distance between a wave crest and the next wave trough.

Horizontal inundation distance: The distance that a tsunami wave penetrates onto the shore, measured horizontally from the mean sea level position of the water's edge. Usually measured as the maximum distance for a particular segment of the coast.

Harmonic Tremor: A continuous release of seismic energy typically associated with the underground movement of magma, often preceding volcanic eruptions. It contrasts distinctly with the sudden release and rapid decrease of seismic energy associated with the more common type of earthquake caused by slippage along a fault.

Hypocenter: The calculated location of the focus of an earthquake.

ICG/ITSU: The International Coordination Group for the Tsunami Warning System in the Pacific, a United Nations organization under UNESCO responsible for international tsunami cooperation.

Intensity: A measure of the effects of an earthquake at a particular place on humans and/or structures. The intensity at a point depends not only upon the strength of the earthquake

(magnitude) but also upon the distance from the earthquake to the epicenter and the local geology at that point.

Inundation: The depth, relative to a stated reference level, to which a particular location is covered by water.

Inundation area: An area that is flooded with water.

Inundation line (limit): The inland limit of wetting measured horizontally from the edge of the coast defined by mean sea level.

Intermediate Water Wave - A term used to describe waves that are neither deep water nor shallow water waves. For both of these cases, equations for waves can be easily approximated. Waves are usually considered in intermediate water when the ratio of the water depth to wave length is between about 1/20 and one half (1/2) .

ITIC: InternationalTsunamiInformationCenter established in 1965. Monitors international activities of the PacificTsunamiWarningCenter and assists with many of the activities of ICG/ITSU.

Kinetic energy - the energy of an object or parcel of fluid by virtue of its motion. Kinetic energy is proportional to mass and the square of the speed.

Leading-depression wave: Initial tsunami wave is a trough, causing a draw down of water level.

Leading-positive wave: Initial tsunami wave is a crest, causing a rise in water level. Also called a leading-elevation wave.

Leeward - The direction toward which the wind and waves are going.

Liquefaction: The process in which a solid (such as soil) takes on the characteristics of a liquid as a result of an increase in pore pressure and a reduction in stress. In other words, solid ground turns to jelly.

Lithosphere: The rigid crust and uppermost mantle of the earth. Thickness is on the order of 62 miles (100 kilometers). Stronger than the underlying asthenosphere.

Local/regional tsunami: Source of the tsunami within 1000 km of the area of interest. Local or near-field tsunami has a very short travel time (30 minutes or less), mid-field or regional tsunami waves have travel times on the order of 30 minutes to 2 hours. Note: " Local" tsunami is sometimes used to refer to a tsunami of landslide origin.
method in the TriAxys Directional Wave Buoy.

Marigram: Tide gage recording showing wave height as a function of time.

Marigraph: The instrument which records wave height.

Maximum wave height (Hmax) - This is the largest peak to trough height seen during a record. Mean zero down-crossing wave height.

Mean Lower Low Water (MLLW): The average low tide water elevation often used as a reference to measure runup.

Mean Wave Direction (Dm)- Overall mean wave direction in degrees obtained by averaging the mean wave angle (theta) over all frequencies with a weighting function S(f). Theta is calculated by the KVH

Ms: Surface Wave Magnitude. Magnitude of an earthquake as measured from the amplitude of seismic surface waves. Often referred to by the media as "Richter" magnitude.

Mw: Moment Magnitude. Magnitude based on the size and characteristics of the fault rupture, and determined from long-period seismic waves. It is a better measure of earthquake size than surface wave magnitude, especially for very large earthquakes. Calibrated to agree on average with surface wave magnitudes for earthquakes less than magnitude 7.5.

Magma: Molten rock beneath the surface of the earth. Molten rock erupted at the surface is termed "lava."

Magnitude: A quantitative measure of the strength of an earthquake. Magnitude is calculated from ground motion as measured by seismograph and incorporates the distance of the seismograph from the earthquake epicenter so that, theoretically, the magnitude calculated for an earthquake would be the same from any seismograph station recording that earthquake. This is a logarithmic value originally defined by Wadati (1931) and Richter (1935). An increase of one unit of magnitude (for example, from 4.6 to 5.6) represents a 10-fold increase in wave amplitude on a seismogram or approximately a 30-fold increase in the energy released. In other words, a magnitude 6.7 earthquake releases over 900 times (30 times 30) the energy of a 4.7 earthquake - or it takes about 900 magnitude 4.7 earthquakes to equal the energy released in a single 6.7 earthquake! There is no beginning nor end to this scale. However, rock mechanics seem to preclude earthquakes smaller than about -1 or larger than about 9.5. A magnitude -1.0 event releases about 900 times less energy than a magnitude 1.0 quake. Except in special circumstances, earthquakes below magnitude 2.5 are not generally not felt by humans. See also Richter scale.

Major earthquake: An earthquake having a magnitude of 7 or greater on the Richter scale.

Mantle: The layer of rock that lies between the outer crust and the core of the earth. It is approximately 1,802 miles (2,900 kilometers) thick and is the largest of the earth's major layers.
Micro earthquake: An earthquake having a magnitude of 2 or less on the Richter scale.

Modified Mercalli Scale: Mercalli intensity scale modified for North American conditions. A scale, composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction, designated by Roman numerals. It does not have a mathematical basis; instead it is an arbitrary ranking based on observed effects. Contrast with Richter scale, a type of magnitude scale.

Normal earthquake: An earthquake caused by slip along a sloping fault where the rock above the fault moves downwards relative to the rock below.

Oceanic crust: The outermost solid layer of Earth that underlies the oceans. Composed of the igneous rocks basalt and gabbro, and therefore basaltic in composition. Contrast with continental crust.

P (Primary) wave: Also called compressional or longitudinal waves, P waves are the fastest seismic waves produced by an earthquake. They oscillate the ground back and forth along the direction of wave travel, in much the same way as sound waves (which are also compressional), move the air back and forth as the waves travel from the sound source to a sound receiver.

Period: The length of time between two successive peaks or troughs. May vary due to complex interference of waves. Tsunami periods generally range from 5 to 60 minutes.

Peak period Tp - The period with the maximum wave energy, determined from the wave spectrum.

Phase: The onset of a displacement or oscillation on a seismogram indicating the arrival of a different type of seismic wave.

Phase Velocity - Propogation velocity of an individual wave. In deep water it is proportional to the wave length, otherwise it depends on water depth.

Plate: Pieces of crust and brittle uppermost mantle, perhaps 100 kilometers thick and hundreds or thousands of kilometers wide, that cover the earth's surface. The plates move very slowly over, or possibly with, a viscous layer in the mantle at rates of a few centimeters per year.

Plate boundary: The place where two or more plates in the earth's crust meet.

Plate tectonics: A widely accepted theory that relates most of the geologic features near the earth's surface to the movement and interaction of relatively thin rock plates. The theory predicts that most earthquakes occur when plates move past each other.

Rayleigh wave: A type of surface wave having a retrograde, elliptical motion at the earth's surface, similar to the waves caused when a stone is dropped into a pond. These are the slowest, but often the largest and most destructive, of the wave types caused by an earthquake. They are usually felt as a rolling or rocking motion and in the case of major earthquakes, can be seen as they approach. Named after Lord Rayleigh, the English physicist who predicted its existence.

Recurrence interval: The approximate average length of time between earthquakes in a specific seismically active area.

Record interval - The time between the start of sequential records, which must be greater than the record length.

Record length - The total time required to collect the data for a wave record.

Record offset - The time to offset record start times from the integral multiple of the record interval. For example if the record interval is 30 minutes, and the record offset is -10 minutes, then records will start 10 minutes before each hour and half hour.

Reflection - The process by which wave energy is returned in the opposite direction after a wave strikes an object or a water boundary.

Refraction - The process by which the direction of a moving wave is changed due to its interaction with the bottom topography. Wave heights may be increased or decreased by refraction.

Response function - The correction applied to the spectrum of a record to allow for the frequency dependant errors introduced by the wave buoy and receiver.

Return Period - The average time interval between occurences of wave heights equal to or greater than the height associated with the return period. It is a measure of the infrequentness of higher wave heights.

Richter magnitude scale: The system used to measure the strength or magnitude of an earthquake. The Richter magnitude scale was developed in 1935 by Charles F. Richter of the California Institute of Technology as a collection of mathematical formulas to compare the size of earthquakes. A similar scale was developed in 1931 by Wadati, so it is more appropriate to call such scales "Wadati-Richter" scales. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenters of the earthquakes. On the Richter Scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

Rift system: The oceanic ridges formed where tectonic plates are separating and new crust is being created; also refers to the on-land counterparts such as the East African Rift.

Ring of Fire: A 40,000 kilometer (24,855 mile) band of seismicity including mountain-building, earthquakes, and volcanoes, stretching up the west coasts of South and Central America and from the North American continent to the Aleutians, Japan, China, the Philippines, Indonesia, and Australasia.

Runup: Maximum height of the water onshore observed above a reference sea level. Usually measured at the horizontal inundation limit.

Rupture zone: The area of the earth through which faulting occurred during an earthquake. For very small earthquakes, this zone could be the size of a pinhead, but in the case of a great earthquake, the rupture zone may extend several hundred kilometers in length and tens of kilometers in width.

S (secondary, or shear) wave: A seismic body wave that involves particle motion from side to side, perpendicular to the direction of wave propagation. S-waves are slower than P-waves and cannot travel through a liquid such as water or molten rock.

Sample interval - The time between wave samples. A typical value would be .78125 seconds, or 1.28 Herz for a DATAWELL wave buoy.

Seafloor Spreading: The mechanism by which new oceanic crust is created at oceanic ridges and slowly spreads away as the plates separate.

Seiche: A standing wave oscillating in a partially or fully enclosed body of water. May be initiated by long period seismic waves, wind and water waves, or a tsunami.

Seismic: Of or having to do with earthquakes.

Seismic belt: An elongated earthquake zone, for example, circum-Pacific, Mediterranean, RockyMountain. About 75% of the world's earthquakes occur in the circum-Pacific seismic belt.

Seismic constant: In building codes dealing with earthquake hazards, an arbitrarily-set acceleration value (in units of gravity) that a building must withstand.

Seismicity: Earthquake activity.

Seismic sea wave: A tsunami generated by an undersea earthquake.

Seismic zone: A region in which earthquakes are known to occur.

Seismogram: A written record of an earthquake, recorded by a seismograph.

Seismograph: An instrument that records the motions of the earth, especially earthquakes.

Seismograph station: A site at which one or more seismographs are set up and routinely monitored.

Seismology: The study of earthquakes and earthquake waves.
Shallow Water Wave - A wave for which the depth divided by the wave length is less than approximately 1/20. Equations for waves can be approximated by special equations for such shallow water where waves are strongly affected by bottom depth.

Shoaling - Changes in wave height as waves move into shallow water. Except for a limited depth region, shoaling increases wave heights. Shoaling occurs even if wave heights and directions do not change as a result of wave refraction.

Significant Wave height (Hs,Hmo, H1/3) - This is the average of the highest 1/3 of all waves in a time series. It can be closely approximated from a time series of wave heights as four times the standard deviation of the time series. The value can also be approximated from four times the square root of the area under the energy spectrum of a FFT analysis. This is typically called **Hmo**.

Significant Wave Period (Ts) - The average period of the one-third highest waves in a wave record. The significant wave period is somewhat shorter than the dominant wave period. Calculated from moments of wave frequency spectrum as Ts = square root of (m_0/m_1). In the TriAxys Directional Wave Buoy it is the average period of the significant zero down-crossing waves(s) .

Slip: The relative displacement of formerly adjacent points on opposite sides of a fault, measured at the fault surface.

Spectrum - A method of representing the distribution of wave energy as a function of frequency.

Strike-slip fault: A nearly vertical fault with side-slipping displacement.

Strike-slip earthquake: An earthquake caused by horizontal slip along a fault.

Subduction: The process in which one lithospheric plate collides with and is forced down under another plate and drawn back into the earth's mantle.

Subduction zone: The zone of convergence of two tectonic plates, one of which is subducted beneath the other. An elongated region along which a plate descends relative to another plate, for example, the descent of the Nazca plate beneath the South American plate along the Peru-Chile Trench.

Surf - Waves as they reach the area between the shore and the area where breakers start to occur.

Surface waves: Waves that move over the surface of the earth. Rayleigh and Love waves are surface waves.

Swell - Wind waves that have traveled out of a storm generating area. Swell has longer periods and a smoother appearance than wind waves in the storm area.

Tectonic: Pertaining to the forces involved in the deformation of the earth's crust, or the structures or features produced by such deformation.
Teletsunami: Source of the tsunami more than 1000 km away from area of interest. Also called a distant-source or far-field tsunami.

Thrust earthquake: An earthquake caused by slip along a gently sloping fault where the rock above the fault is pushed upwards relative to the rock below. The most common type of earthquake source of damaging tsunamis.

Tidal wave: Common term for tsunami used in older literature, historical descriptions and popular accounts. Tides, caused by the gravitational attractions of the sun and moon, may increase or decrease the impact of a tsunami, but have nothing to do with their generation or propagation. However, most tsunamis (initially) give the appearance of a fast-rising tide or fast-ebbing as they approach shore and only rarely as a near-vertical wall of water.

TIME: The Center for the Tsunami Inundation Mapping Effort, to assist the Pacific states in developing tsunami inundation maps.

Transform Fault: A plate boundary where one plate slides past another; essentially a large strike-slip fault.

Tremor: Low amplitude, continuous earthquake activity commonly associated with magma movement.

Travel time: Time (usually measured in hours and tenths of hours) that it took the tsunami to travel from the source to a particular location.

Trough - The lowest part of the wave between successive crests.

Tsunami: A Japanese term derived from the characters "tsu" meaning harbor and "nami" meaning wave. Now generally accepted by the international scientific community to describe a series of travelling waves in water produced by the displacement of the sea floor associated with submarine earthquakes, volcanic eruptions, or landslides.

Tsunami earthquake: A tsunamigenic earthquake which produces a much larger tsunami than expected for its magnitude.

Tsunamigenic earthquake: Any earthquake which produces a measureable tsunami.

Tsunami magnitude: A number which characterizes the strength of a tsunami based on the tsunami wave amplitudes. Several different tsunami magnitude determination methods have been proposed.

TWS: Tsunami Warning System, organization of 26 Pacific Member States which coordinates international monitoring and warning dissemination. Operates through ICG/ITSU

UTC: Universal Coordinated Time, international common time system (formerly GMT, Greenwich Mean Time).

Wave Direction - The direction from which a wave approaches.

Wave record - A wave record is a group of continuous data blocks.

Wave sample - A single wave height measurement.

Wind Direction - The direction from which the wind is blowing.

Zero Crossings - Number of waves detected by zero crossing analysis of the demeaned wave elevation record.

Zero Crossing Wave Period (Tz, Tav) - The average time interval between similar direction crossings of mean water level for a wave record. The zero crossing period can also be calculated from the moments of wave frequency spectra. Tz = square root of (m_0/m_2), also called the Mean Spectral Period.

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