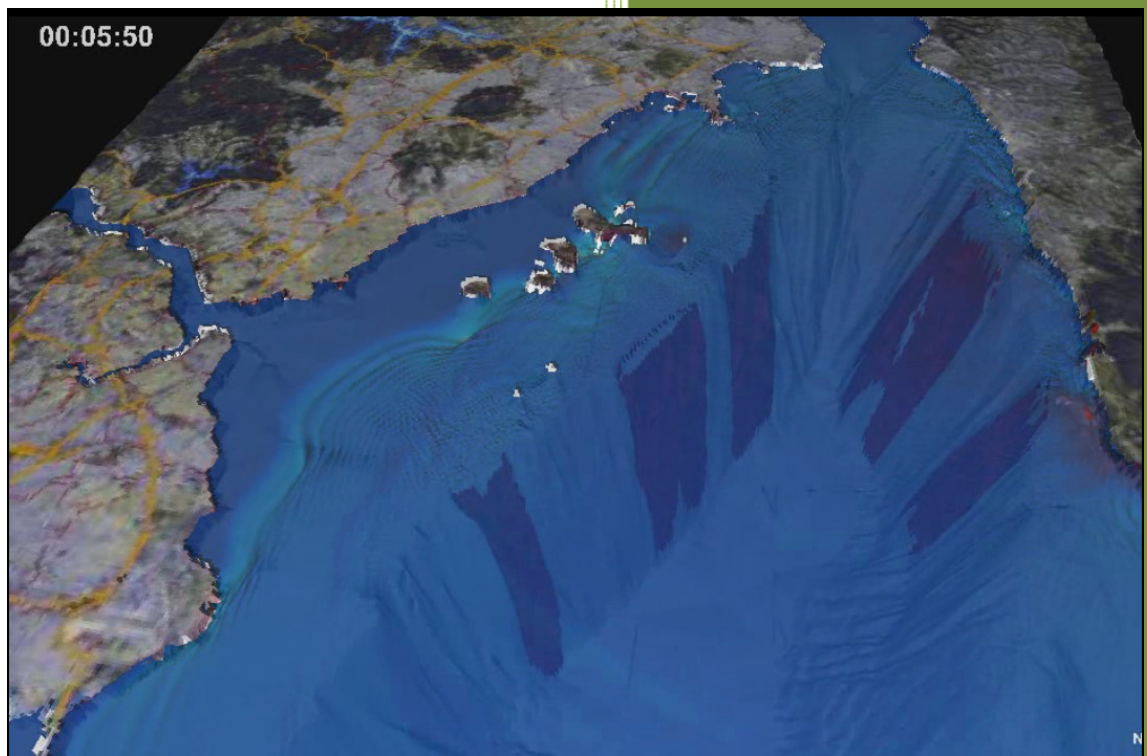


**April/2008**

**MANUAL**  
**NAMI DANCE version 4.0**



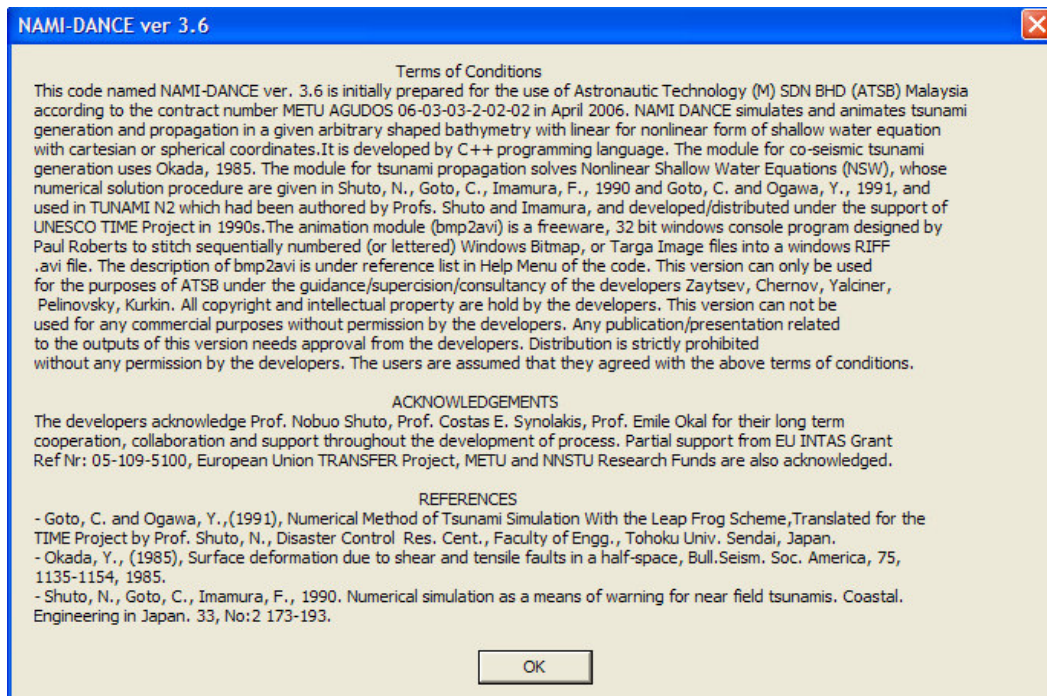
**Middle East Technical University  
Civil Engineering Department  
Ocean Engineering Research Center  
Ankara / Turkey**

**Nizhny Novgorod State Technical  
University n.a. R.E. Alekseev,  
Department of Applied Mathematics,  
Nizhny Novgorod / Russia**

## 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 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 4.0. 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.

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# **1. METHOD IN TSUNAMI MODELING**

## **State-of-the-art and 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 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 Appendix A.

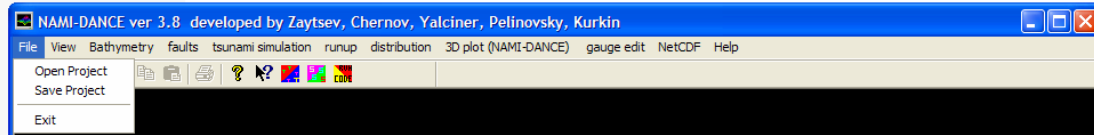
## 2. BRIEF HISTORY AND CAPABILITIES OF NAMI DANCE

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 is preferable for the use since it uses 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 water surface elevations (sea state) at selected time intervals,
- viii) relative damage levels according to drag force and impact force,
- ix) time histories of water surface fluctuations,
- x) 3D plot of sea state at selected time intervals from different camera and light positions, and
- xi) animation of tsunami propagation between source and target regions (Yalciner et. al., 2006b, 2007b).

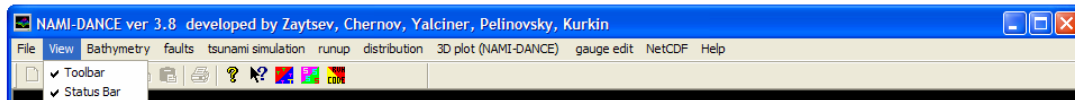
### 3. FILE/VIEW/BATHYMETRY PANELS

#### 3.1. “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.

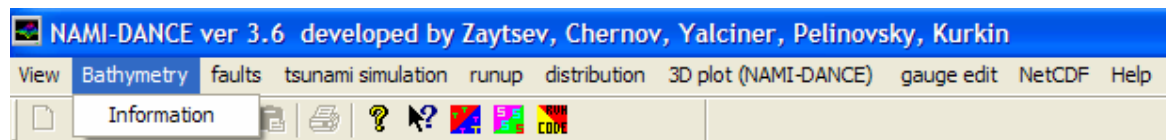
#### 3.2. “View” Menu



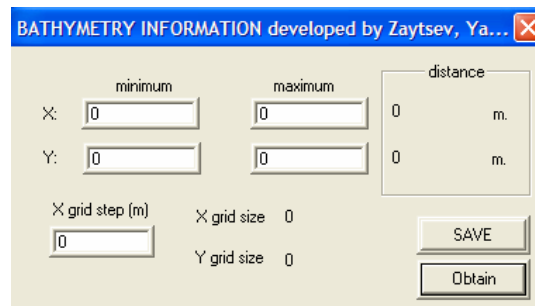
Display of the toolbar and status bar can be selected using “View” menu.

#### 3.3. “Bathymetry” Menu

##### Determination of Grid Size and Bathymetry Processing



“Bathymetry” window allows determination of grid size and bathymetry processing. After entering the maximum and minimum GPS coordinates (lon-lat) 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.



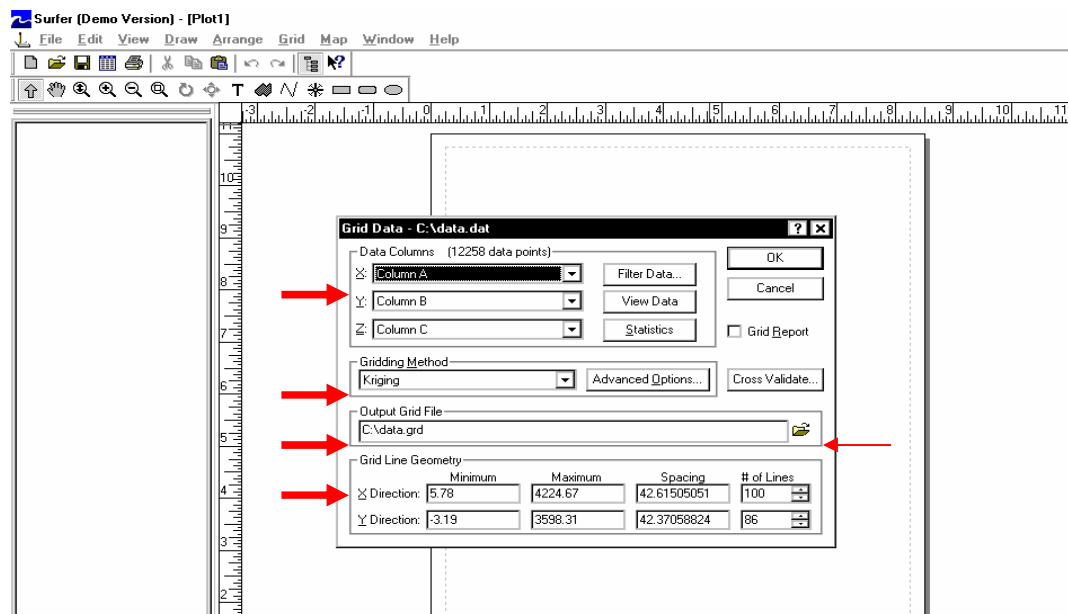
## 4. PROCESSING BATHYMETRIC DATA

NAMI DANCE program uses the bathymetry of the area as input data. The bathymetry of the area is usually stored as data files. This file consists of three values; x coordinate, y coordinate and the depth values. However data files are typically randomly spaced files and this 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.



## The Grid Data Dialog

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


### Data Columns

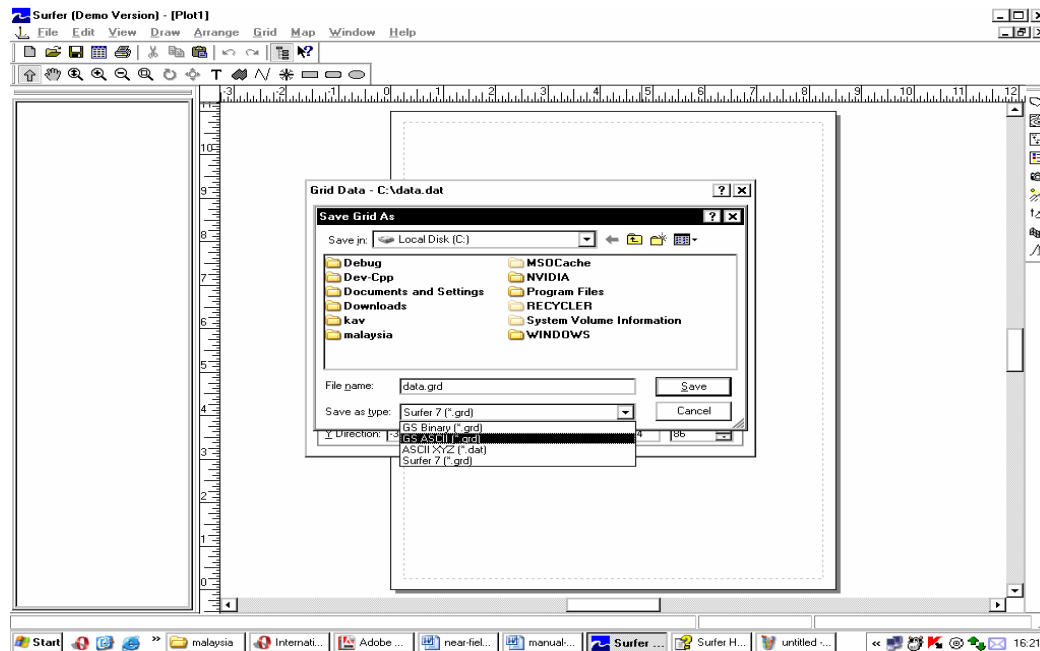
Individually specify the columns for the X data, the Y data, and the Z data. **Surfer** defaults to X: Column A, Y: Column B, and Z: Column C, which represents the x coordinate, y coordinate and the depth respectively.

### 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.



### **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.



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:

ld	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.

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

### 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

### Faults Menu

“Seismic fault” window allows creating the initial wave using the fault parameters. There are two different options as “test” and “seismic” under the “faults” menu as shown in figure below.

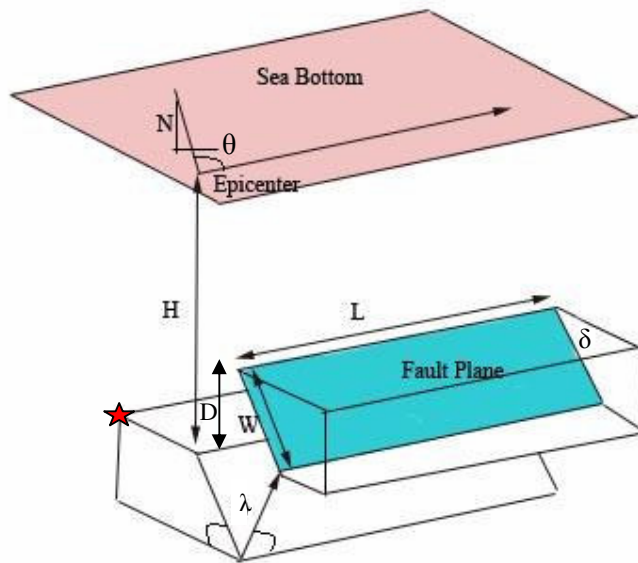


### “Seismic Fault” Option:

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

1. On the “faults” menu, click “seismic fault”.
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 be the generated initial wave 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) ( $\theta$ )
  - v) The dip angle ( $\delta$ )
  - vi) The rake (slip) angle ( $\lambda$ )
  - vii) Vertical displacement of the fault (D)
  - viii) Focal depth (H)

Rupture characteristics:



**Important note:** The symbol ★ on the above figure shows the origin of the movement of the fault planes. In the “Fault/Seismic” panel of NAMI DANCE (in the figure below) epicenter coordinates are assumed to be located at the origin (★) by NAMI DANCE.

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”.

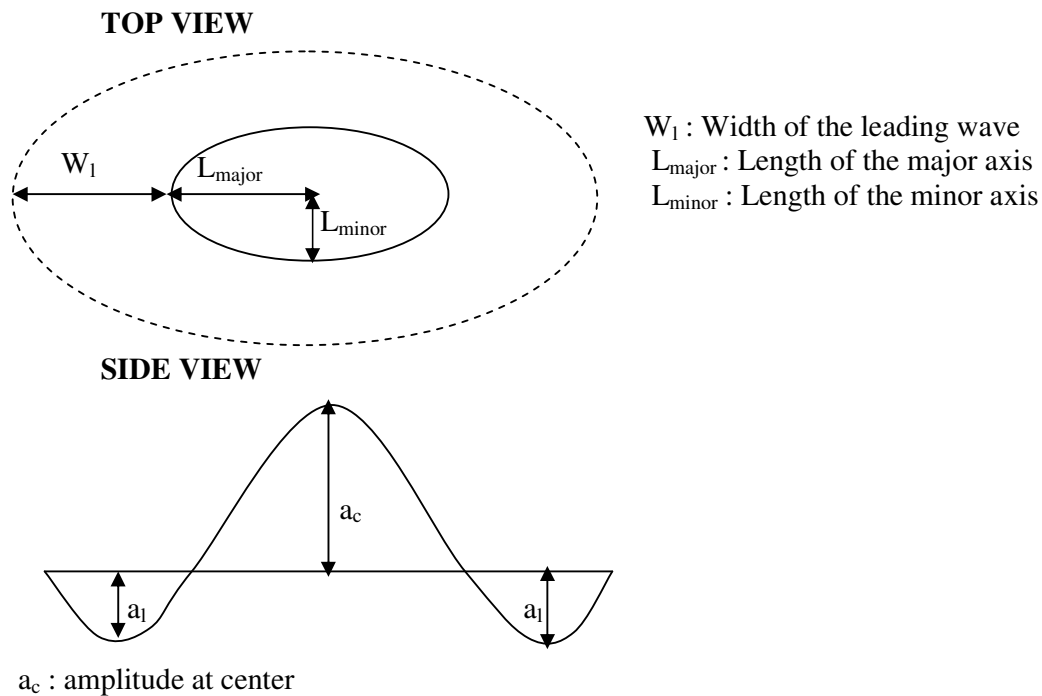
The screenshot shows the 'SEISMIC SOURCE' software interface with the following parameters and controls:

- The name of bathymetry file (input):** 'Inf' with a 'browse...' button.
- grid size (meter):** '150'.
- The name of tsunami source file (output):** Empty field with a 'browse...' button.
- Buttons:** 'Save', 'Cancel', and 'Run'.
- Earthquake epicenter:**
  - X coordinate: '50'
  - Y coordinate: '20'
- Parameters of fault (top right):**
  - strike angle (deg. CW): '315'
  - focal depth (km): '10'
- Parameters of fault (bottom left):**
  - MAGNITUDE: '0' with an 'Obtain' button.
  - fault length (km): '0'
  - fault width (km): '0'
- Parameters of fault (bottom right):**
  - dip angle (degree): '10'
  - rake angle (degree): '110'
  - displacement (meter): '10'

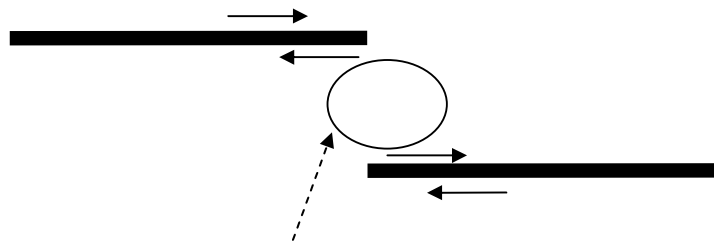
### “Fault Test” Panel:

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 test fault option.

1. On the “faults” menu, click test “fault”.
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 be the generated initial wave 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.



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.



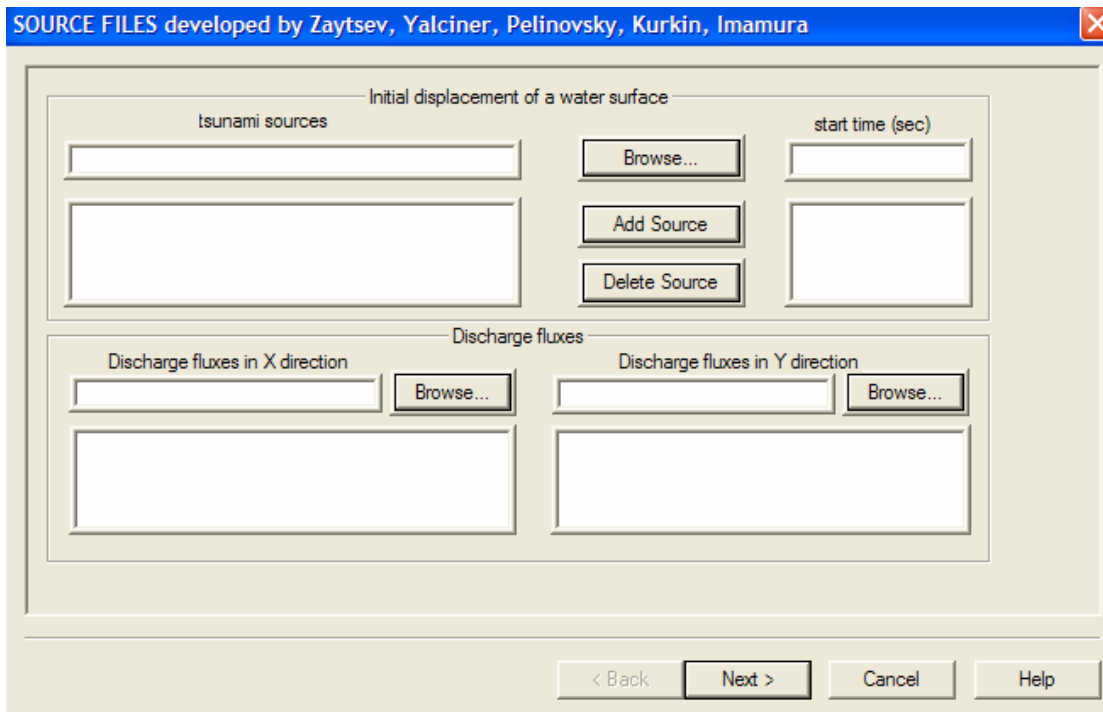
**Figure 4.2** Subsidence at the tensile stress area

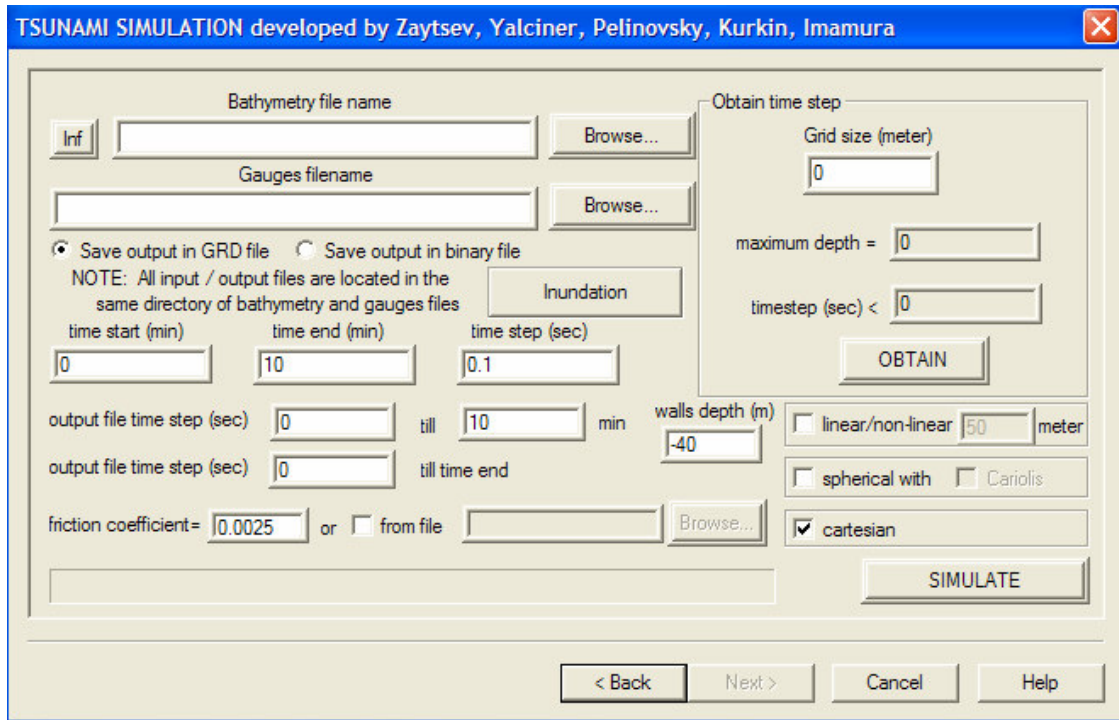
## 6. GENERATING THE SEA STATE AT SPECIFIC TIME INTERVALS OF TSUNAMI DURING SIMULATION

“Tsunami simulation” option is used in order to generate the sea state at specific time intervals of tsunami.



1. On the “tsunami simulation” menu, click “simulate”.
2. Browse for tsunami source 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”. Browse them also in the discharge fluxes section.
7. Click “Next”.





1. Enter the name of the bathymetry file in the “Bathymetry file name” box or browse for the location of the file.
2. Enter the name of the gauge file in the “Gauges filename” box or browse for the location of the file. You do not need to enter gauge file to perform the calculation. Gauge file is needed only when sea state at a specific coordinate is wanted.
3. To obtain the time step for calculation use the “Obtain time step” option. Enter the grid size of the bathymetry file. Click “Obtain”. The program will automatically get the maximum depth and calculate the time step.
5. Enter the obtained time step in the “time step” box. Use a smaller time step than the obtained value.
6. Enter the start and end time of the simulation in the “time start” and “time end” boxes in minutes.
7. Enter the time step for the output files in the “output file time step” boxes which will show the sea state at the entered time intervals. If you want to have sea states at the same time intervals throughout the simulation enter the same time step for both of the boxes and do not change the second box which is initially set as 10 minutes.
8. If you want to work with two different time steps, enter the first time step in the “output file time step” and enter the required time after which the time step will change in the second box so that from the start of the simulation till this time, the time step in the first box will be used. Then enter the second time step you want for the rest of the simulation.
9. Enter the “wall depth”. Wall depth is a depth 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.
10. Click “Simulate”.
11. After the simulation ends, close the box.

HYDRODYNAMIC DEMAND, FLUXES AND VELOCITIES developed b...

hydrodynamic demand

output file time step (sec) 0 till 0 min

and time step (sec) 0 till 0 min

velocities

output file time step (sec) 0 till 0 min

and time step (sec) 0 till 0 min

discharge fluxes

output file time step (sec) 0 till 0 min

and time step (sec) 0 till 0 min

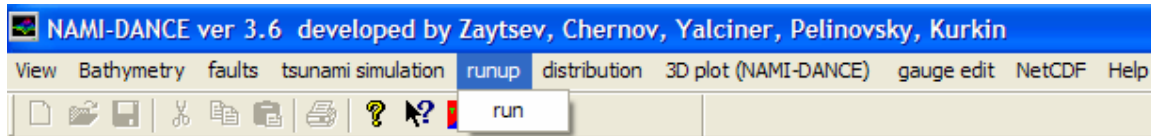
OK

**Note:** If inundation panel is activated NAMI DANCE computes Current velocities, discharge fluxes and their directions at every grid point at given time intervals at the above menu. It also computes hydrodynamic demand at every grid point at specified time intervals. The maximum values of these parameters computed during simulation are also stored.



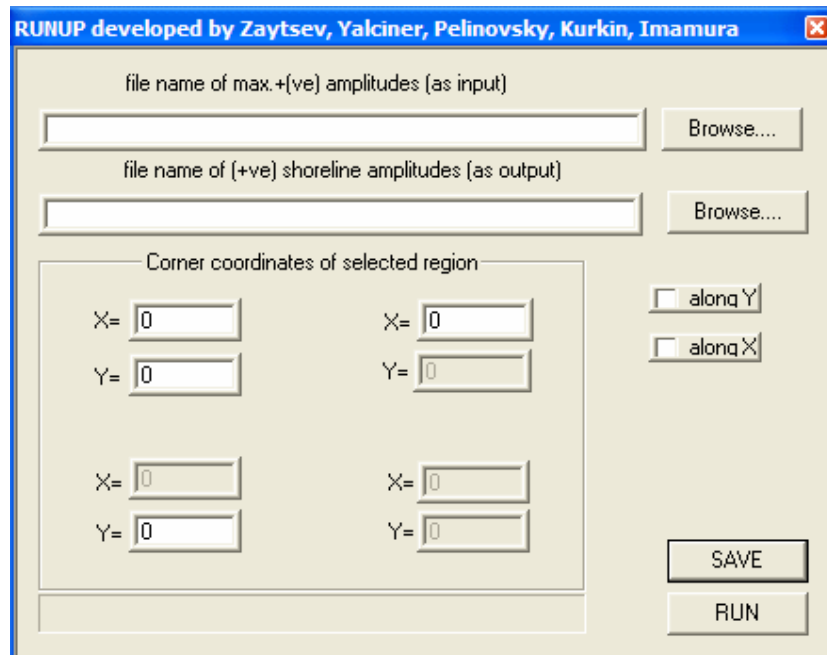
## 7. RUNUP CALCULATION

### “Runup” Menu



When you click run 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. Otherwise the checkbox Along Y must be enabled.



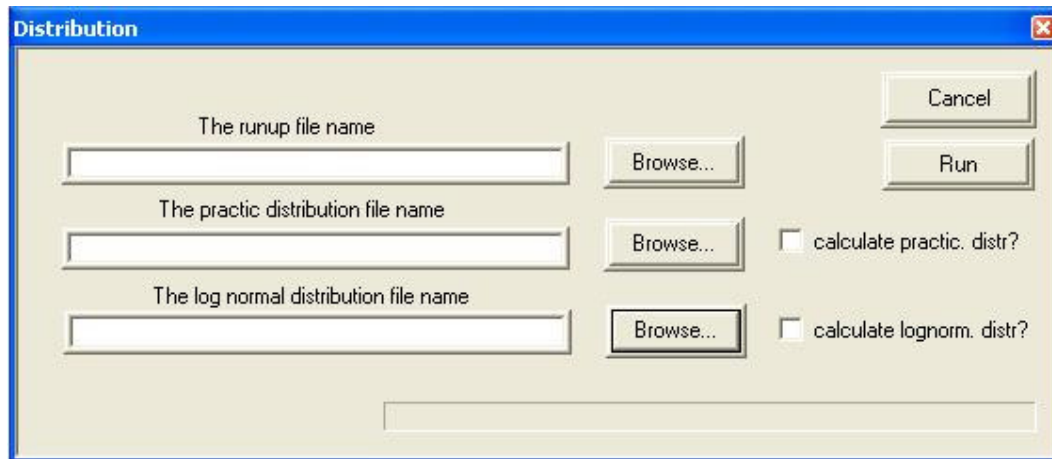
**Note: In order to use run-up menu please contact the developers.**

## 8. CALCULATING DISTRIBUTION OF RUN-UPS

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.



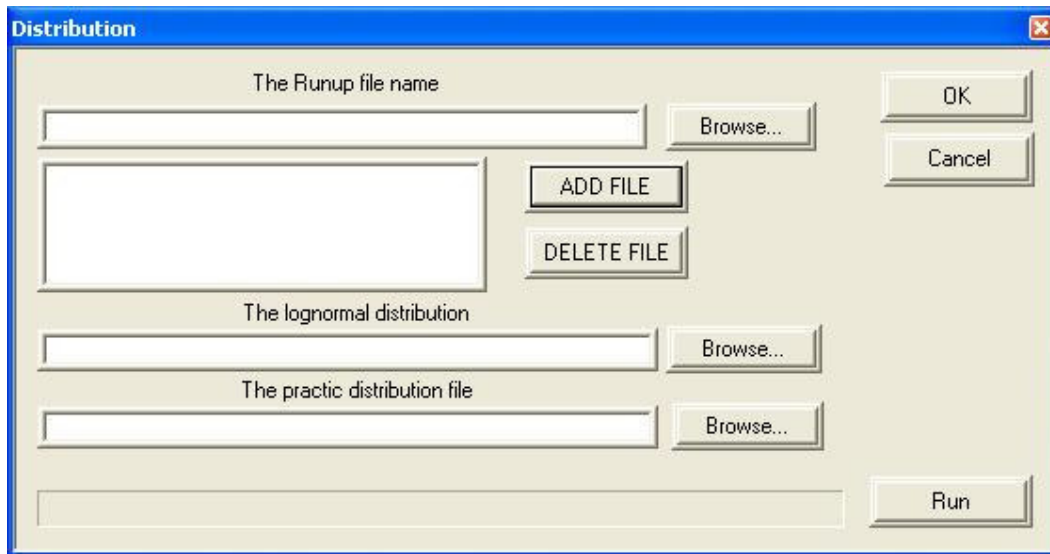
**“1 event” option:**



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”.

**Note: In order to use distribution menu please contact the developers.**

**“All event” option:**



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.

**Note: In order to use distribution menu please contact the developers.**

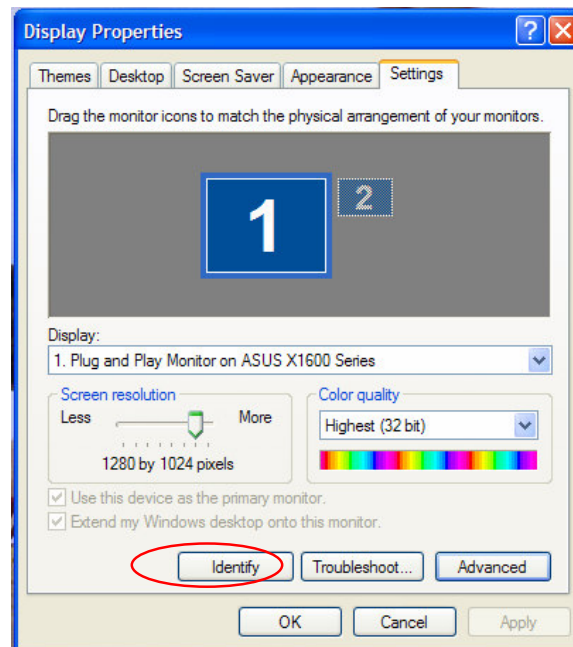
## 9. 3D PLOTTING

### **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:

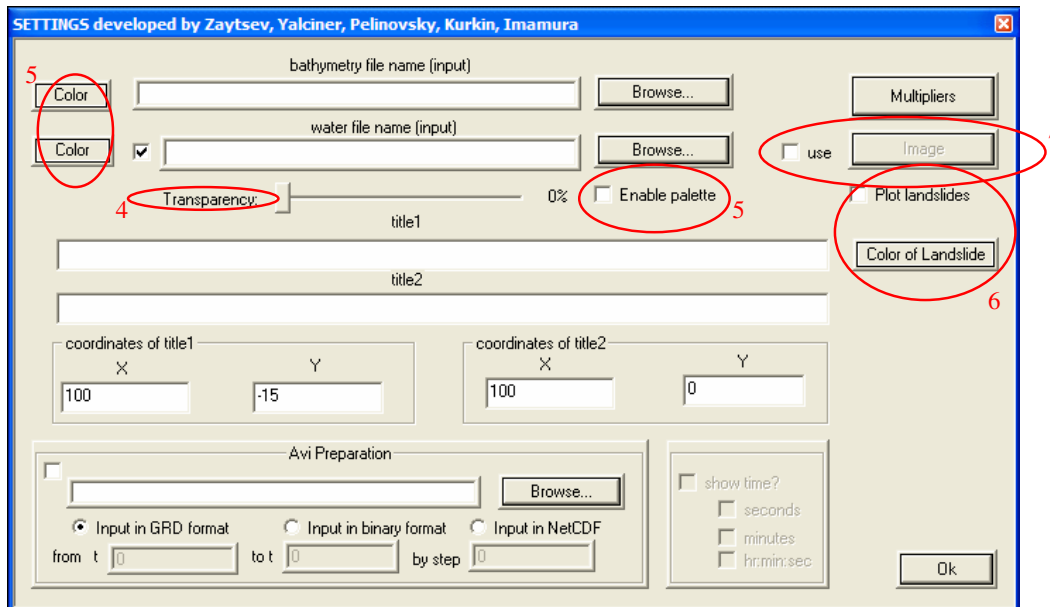
1. Open “*Display*” in Control Panel.
2. On the **Settings** tab, click **Advanced**.
3. Open video card tab, go to OpenGL settings.
4. Select the check box to enable “24-bit depth buffer”

All modern video cards support this option. For more information read manual for your video card.



## 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.

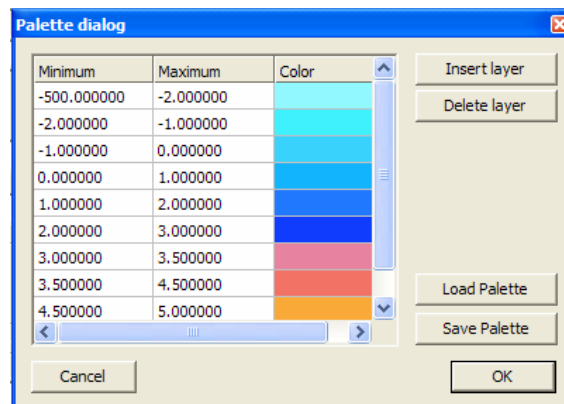


2. Put a tick in the box next to “**water file name (input)**” box in order to plot the sea state at a specific time.

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.

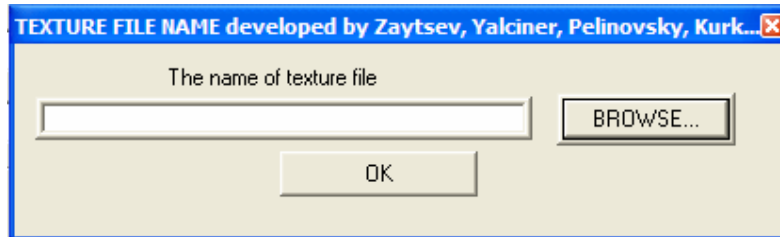
5. Put a tick in the “**Enable palette**” box to set the water or landscape color using palette. You can insert an additional layer or delete an existing one. You can load an available palette, or modify palette and save for future uses. Palette can be loaded from “Color” buttons for landscape or water.



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.



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

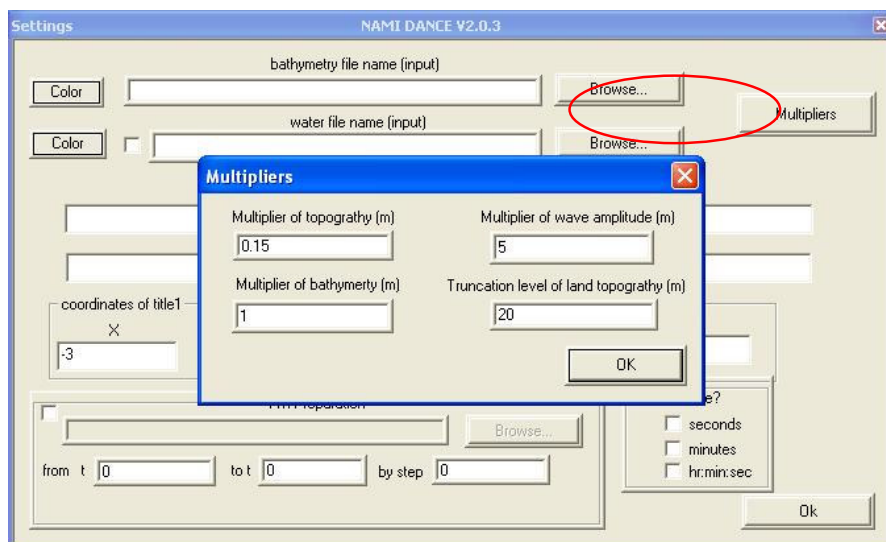
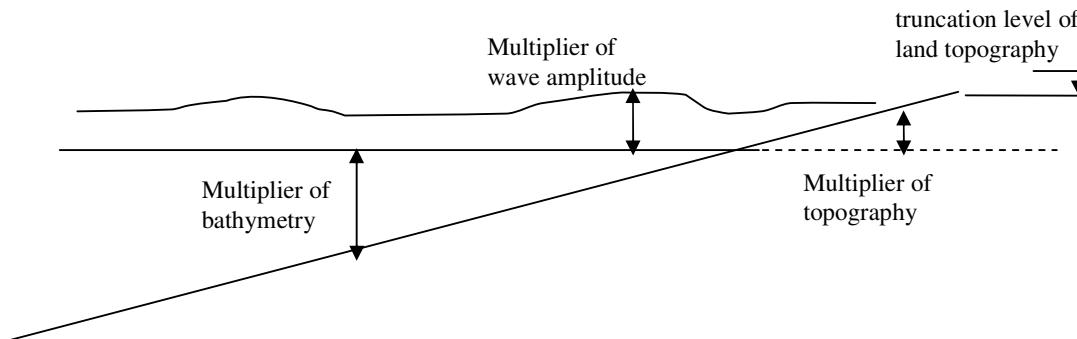
9. Enter the coordinates of the starting point of the titles using “coordinates of title1” and “coordinates of title 2” boxes.

## 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.



### 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:

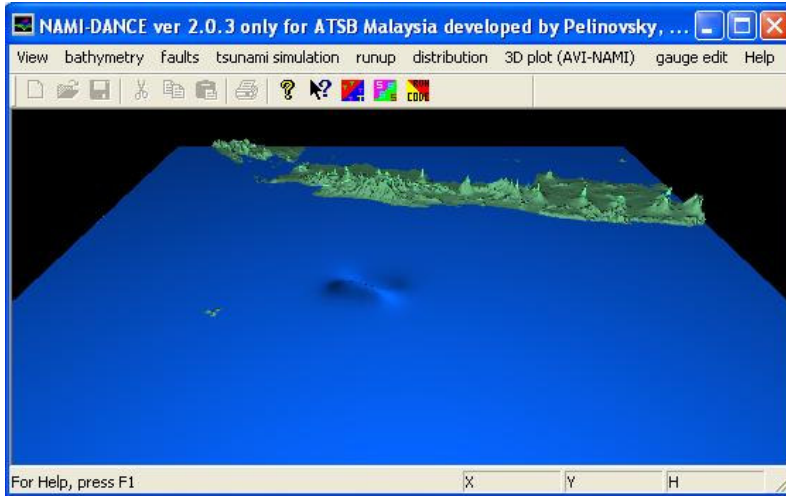
Multiplier of topography (m) = 0.008

Multiplier of wave amplitude (m) = 15

Multiplier of bathymetry (m) = 1

Truncation level of land topography (m) = 8000

### Result 1:



### Trial 2:

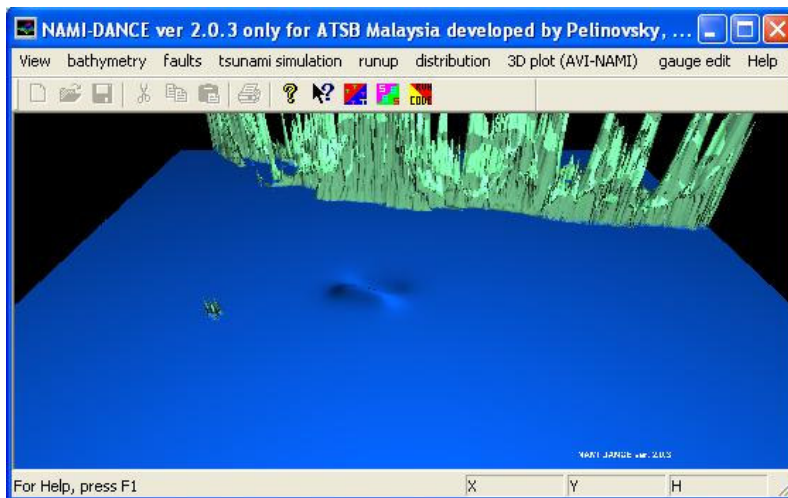
Multiplier of topography (m) = 0.1

Multiplier of wave amplitude (m) = 15

Multiplier of bathymetry (m) = 1

Truncation level of land topography (m) = 8000

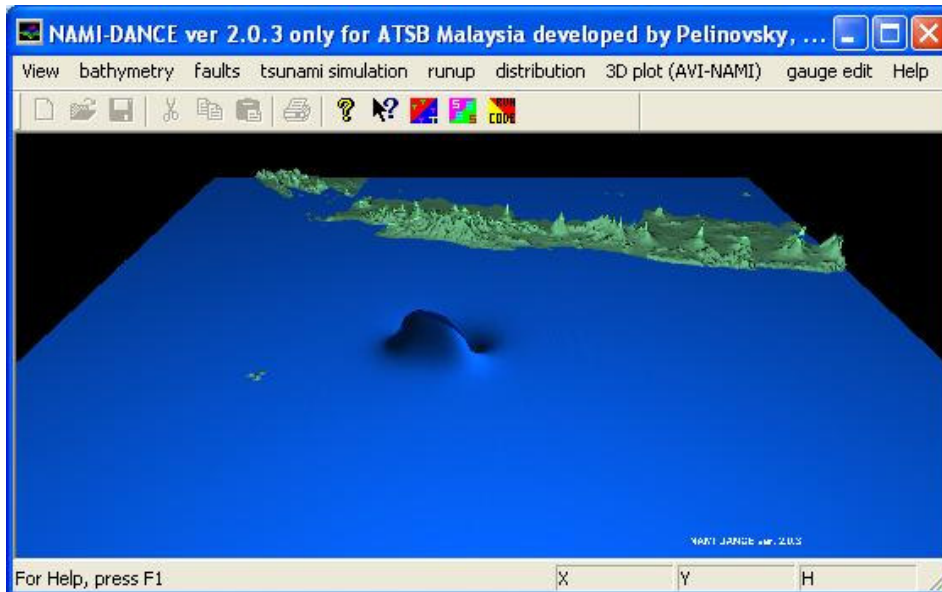
### Result 2:



### 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

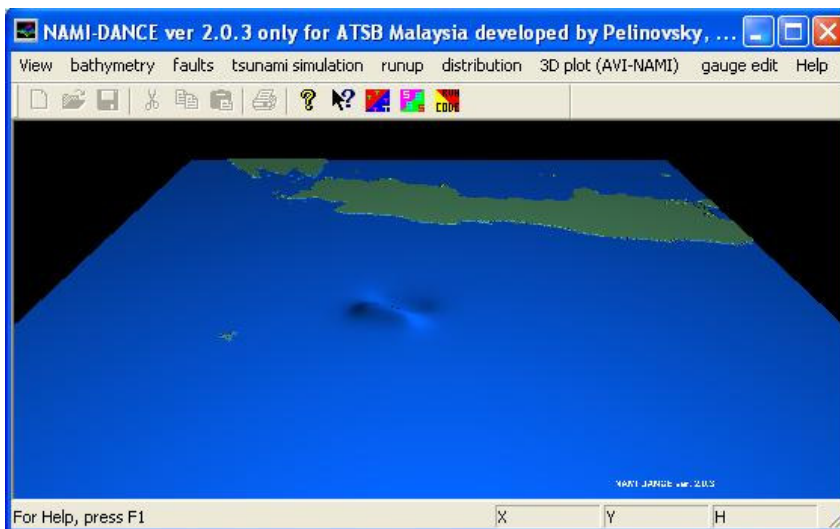
**Result 3:**



**Trial 4:**

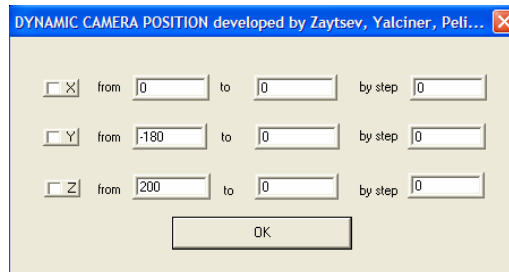
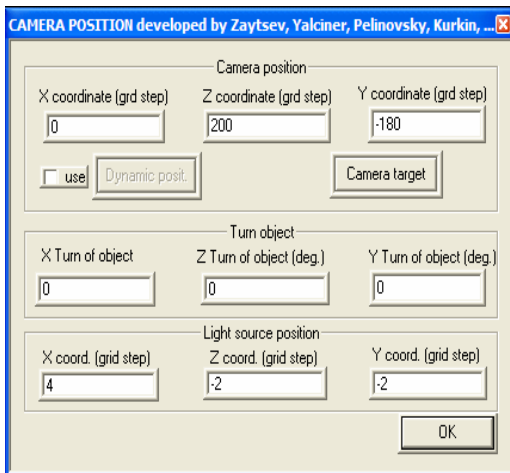
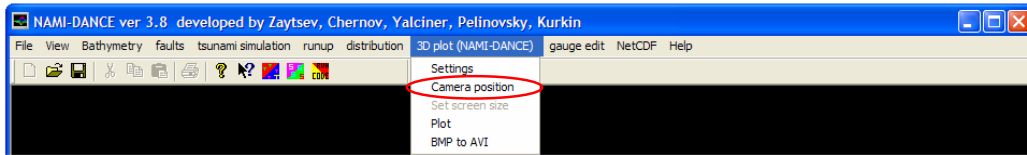
Multiplier of topography (m)= 0.008  
Multiplier of wave amplitude (m)= 15  
Multiplier of bathymetry (m)= 1  
Truncation level of land topography (m)= 1

**Result 4:**

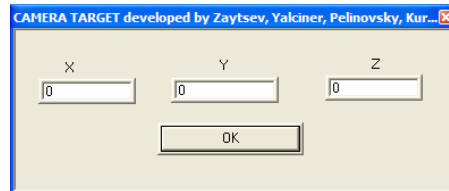


## 9.3 Camera Settings

1. On “3D Plot (AVI NAMI)” menu, go to “Camera Position” option.



2.  
Enter



coordinates in the coordinate boxes to locate the camera to get the desired view of the output files.

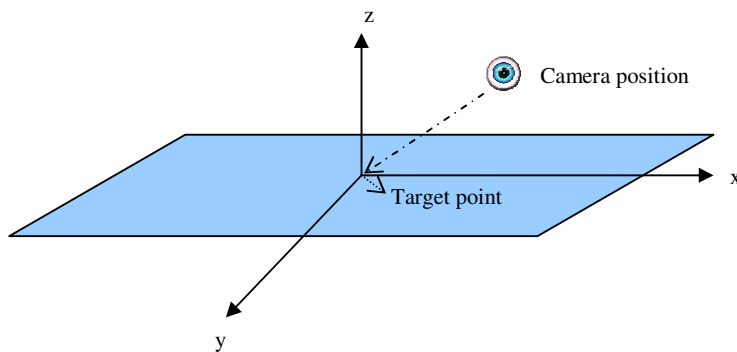
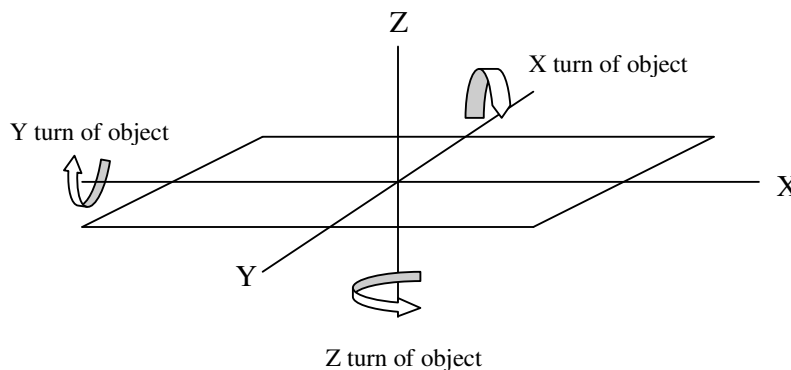


Figure: Location of the camera and target point

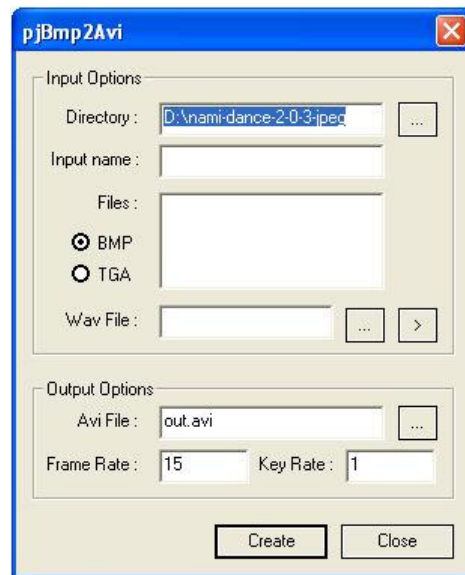
3. Enter values in the Turn object to turn the output file to get the desired view of the output files.



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.

## 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.



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.

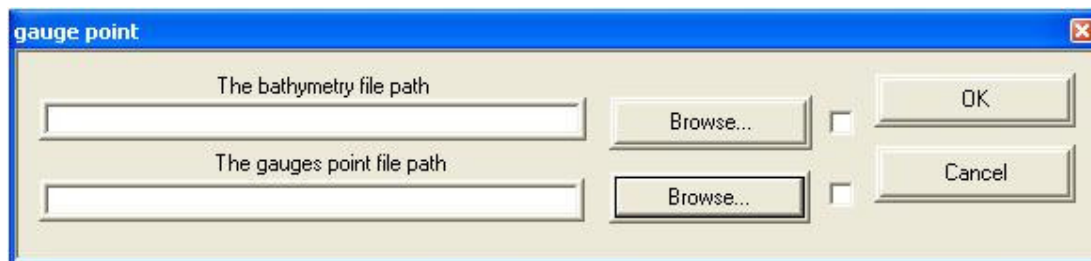
## 10. CREATING A GAUGE POINT FILE

As given above, if the sea state of a specific location is asked, the coordinates of the location should be given to the program in a file which has a predefined format. In order to create this gauge file:

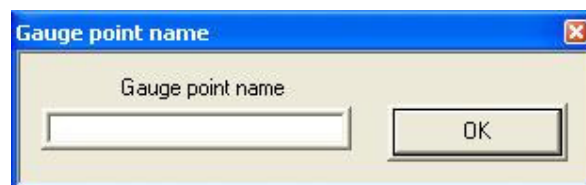
1. On “gauge edit” menu, go to “gauge point” option.



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.

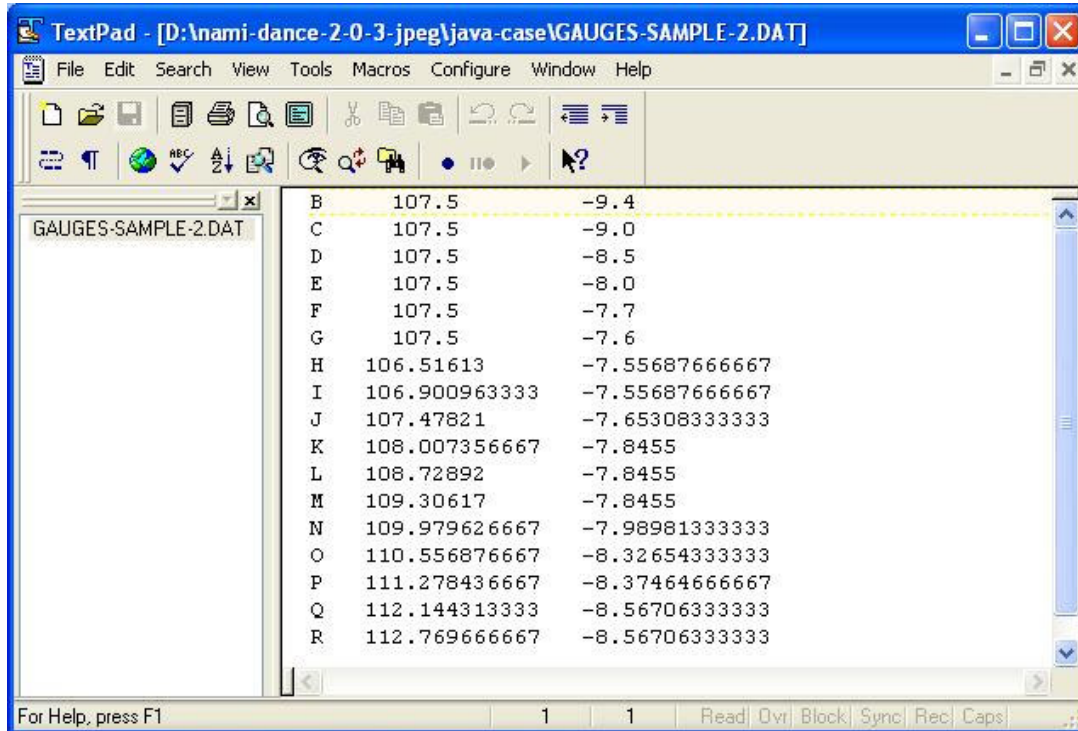


4. Click “OK”.
5. The screen will show the bathymetry file.
6. Click the location you want to add to the gauge file on the screen.
7. Write the name of the location and click “OK”.



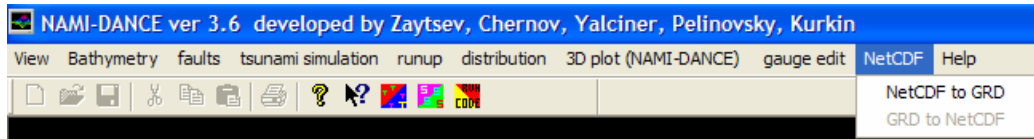
## GAUGES FILE DETAILS

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:



```
TextPad - [D:\nami-dance-2-0-3-jpeg\java-case\GAUGES-SAMPLE-2.DAT]
File Edit Search View Tools Macros Configure Window Help
GAUGES-SAMPLE-2.DAT
B 107.5 -9.4
C 107.5 -9.0
D 107.5 -8.5
E 107.5 -8.0
F 107.5 -7.7
G 107.5 -7.6
H 106.51613 -7.55687666667
I 106.900963333 -7.55687666667
J 107.47821 -7.65308333333
K 108.007356667 -7.8455
L 108.72892 -7.8455
M 109.30617 -7.8455
N 109.979626667 -7.98981333333
O 110.556876667 -8.32654333333
P 111.278436667 -8.37464666667
Q 112.144313333 -8.56706333333
R 112.769666667 -8.56706333333
For Help, press F1 1 1 Read|Ovr|Block|Sync|Rec|Caps
```

## 11. CONVERTING FILE TYPES

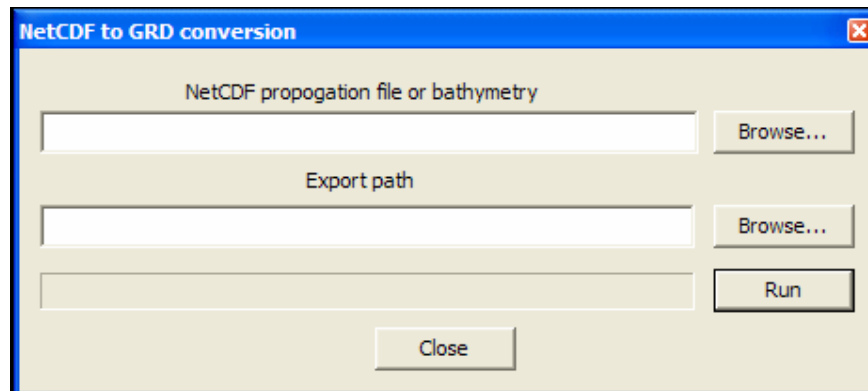


From “NetCDF” menu, conversion from ‘NetCDF to GRD’ is possible.

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”.

Browse export path.

Click ‘Run’ to start and click “*Stop*” to cancel the operation.



**Note: In order to proper use of NetCDF conversion, please contact the developers.**

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### 13. REFERENCES

GOTO, C. AND OGAWA, Y., (1991), "Numerical Method of Tsunami Simulation With the Leap-Frog Scheme", Translated for the TIME Project by Prof. Shuto, N., Disaster Control Res. Cent., Faculty of Engg., Tohoku Univ. Sendai, Japan.

OKADA, Y., (1985), Surface deformation due to shear and tensile faults in a half-space, *Bull. Seism. Soc. America*, 75, 1135-1154, 1985.

SHUTO, N., GOTO, C., IMAMURA, F., 1990. Numerical simulation as a means of warning for near field tsunamis. *Coastal. Engineering in Japan*. 33, No:2 173-193.

IMAMURA F., (1989), "Tsunami Numerical Simulation with the staggered leap-frog scheme (Numerical code of TUNAMI-N1)", School of Civil Engineering, Asian Inst. Tech. and Disaster Control Research Center, Tohoku University

YALCINER A., C., (2005) "Marine Hazards and Tsunamis", CE 761 Course Notes, Middle East Technical University Civil Engineering Department, webpage: [yalciner.ce.metu.edu.tr/courses/ce761](http://yalciner.ce.metu.edu.tr/courses/ce761)  
[www.pmel.noaa.gov/tsunami-hazard/terms.html](http://www.pmel.noaa.gov/tsunami-hazard/terms.html)  
[vulcan.wr.usgs.gov/Glossary/Seismicity/earthquake\\_terminology.html](http://vulcan.wr.usgs.gov/Glossary/Seismicity/earthquake_terminology.html)  
[www.seismo.berkeley.edu/faq/gloss\\_0.html](http://www.seismo.berkeley.edu/faq/gloss_0.html)

SYNOLAKIS C.E., BERNARD E.N., TITOV V., KÂNOĞLU U., GONZÁLEZ F., (2007), Standards, Criteria, And Procedures For NOAA, Evaluation Of of Tsunami Numerical Models, NOAA Technical Memorandum OAR PMEL-135  
NOAA web site: <http://www.pmel.noaa.gov/pubs/PDF/syno3053/syno3053.pdf>

NOAA, (2007), Tsunami Vocabulary and Terminology NOAA web site: <http://www.tsunami.noaa.gov/terminology.html>

UNESCO (2006), Tsunami Glossary, UNESCO-IOC. IOC Information document No. 1221 Printed by Servicio Hidrográfico y Oceanográfico de la Armada (SHOA) Errázuriz 254 Playa Ancha Valparaíso Chile Published by the United Nations Educational, Scientific and Cultural Organization 7 Place de Fontenoy, 75 352 Paris 07 SP, France © UNESCO 2006. Paris, UNESCO, 2006.

YALCINER, A.C., KARAKUS, H., OZER, C., OZYURT, G., (2005), "Short Courses on Understanding the Generation, Propagation, Near and Far-Field Impacts of TSUNAMIS and Planning Strategies to Prepare for Future Events" Course Notes prepared by METU Civil Eng. Dept. Ocean Eng. Res. Center, for the Short Courses in University of Teknology Malaysia held in Kuala Lumpur on July 11-12, 2005, and in Astronautic Technology Malaysia held in Kuala Lumpur on April 24-May 06, 2006, and in UNESCO Training on Tsunami Numerical Modeling held in Kuala Lumpur on May 08-19 2006 and in Belgium Oostende on June 06-16, 2006.

KURKIN, A.A., KOZELKOV, A.C., ZAITSEV A.I., ZAHIBO N., AND YALCINER A.C. (2003): Tsunami risk for the Caribbean Sea Coast, *Izvestiya, Russian Academy of Engineering Sciences*, vol. 4, 126 – 149 (in Russian)

SYNOLAKIS, C. E, LIU, P. L. F., YEH, H. (2004): Workshop on Long Wave Runup Models, Organized by NSF in Catalina Island LA, USA, June 2004.

YALCINER, A.C., KURAN, U., AKYARLI, A. AND IMAMURA, F., (1995): An Investigation on the Generation and Propagation of Tsunamis in the Aegean Sea by Mathematical Modeling, Chapter in the Book, "Tsunami: Progress in Prediction, Disaster Prevention and Warning", in the book series of Advances in Natural and Technological Hazards Research by Kluwer Academic Publishers, (1995), Ed. Yashuito Tsuchiya and Nobuo Shuto, pp 55-71

YALCINER, A.C., ALPAR, B., ALTINOK, Y., OZBAY, I., IMAMURA, F., (2002a): Tsunamis in the Sea of Marmara: Historical Documents for the Past, Models for Future, *Marine Geology*, 2002, 190, pp: 445-463

YALCINER, A.C., PELINOVSKY, E.N., TALIPOVA, T.G., KURKIN, A.A., KOZELKOV, A.C., ZAITSEV, A.I., (2002b): A. Tsunamis in the Black Sea: comparison of the historical, instrumental and numerical data. J. Geophys.Research, 2004, vol. 109, No. C12, C12023 10.1029/2003JC002113.

YALCINER, A.C., IMAMURA, F., SYNOLAKIS, E.C., (2002b): Simulation of Tsunami Related to Caldera Collapse and a Case Study of Thera Volcano in Aegean Sea, Abstract Published and paper presented in EGS XXVII General Assembly, Nice, France, April 2002 Session NH8.

YALCINER, A.C., KARAKUS, H., KURAN, U., (2006a): Modeling of Tsunamis in the Eastern Mediterranean and Comparison with Caribbean, Caribbean Tsunami Hazard, World Scientific, Eds: Mercado A. And Liu P. L. F., ISBN 981-256-535-3, pp 326-340

YALCINER, A. C., PELINOVSKY, E., ZAYTSEV, A., KURKIN, A., OZER, C., AND KARAKUS, H., (2006b): NAMI DANCE Manual, METU, Civil Engineering Department, Ocean Engineering Research Center, Ankara, Turkey (<http://namidance.ce.metu.edu.tr>)

YALCINER, A. C., PELINOVSKY, E., ZAYTSEV, A., KURKIN, A., OZER, C., AND KARAKUS, H., (2007a): Modeling and visualization of tsunamis: Mediterranean examples, from, Tsunami and Nonlinear Waves (Ed: Anjan Kundu), Springer, 2007, 2731-2839.

YALCINER, A. C., SYNOLAKIS, C. E. , GONZALES, M., KANOGLU, U., (2007b): Joint Workshop on Improvements of Tsunami Models, Inundation Map and Test Sites of EU TRANSFER Project, June 11-14, Fethiye, Turkey

ZAHIBO, N., PELINOVSKY, E., YALCINER, A.C., KURKIN, A., KOZELKOV A. AND ZAITSEV, A., (2003a): The 1867 Virgin Island Tsunami: Observations and Modeling, Oceanologica Acta, vol. 26, N. 5-6, pp: 609-621

ZAHIBO, N., PELINOVSKY, E., KURKIN, A., AND KOZELKOV A. (2003b): Estimation of far-field tsunami potential for the Caribbean Coast based on numerical simulation. Science Tsunami Hazards. 2003, vol. 21, N. 4, p: 202 -222.

## APPENDIX A

### METHOD IN TSUNAMI MODELING

This document has been prepared as Deliverable of TRANSFER Tsunami Risk AND Strategies For the European Region Instrument: STREP Thematic Priority: Mechanisms of desertification and natural disasters Project no. 037058 (GOCE)

#### **State-of-the-art and 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 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 historic 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 least less than 50m 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 uncertainties 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.

## 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** ( $T_{av}$ ,  $T_z$ ) - Average zero down-crossing wave period. The average period of the waves observed, weighted by wave energy.

**Average Wave Height** ( $H_{av}$ ) - 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** ( $T_c$ ) - the average time between successive maxima, or crests. Calculated from moments of wave frequency spectrum as  $T_c = \text{square root of } (m_2/m_4)$  .

**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 propagate 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-Developed Sea** - 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 individual 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:** International Tsunami Information Center established in 1965. Monitors international activities of the Pacific Tsunami Warning Center 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  $T_p$**  - 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** - Propagation 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 occurrences 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, Rocky Mountain. 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** ( $H_s, H_{m0}, H_{1/3}$ ) - 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 **H<sub>m0</sub>**.

**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  $T_s = \text{square root of } (m_0/m_1)$ . 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** ( $T_z$ ,  $T_{av}$ ) - 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.  $T_z = \text{square root of}(m_0/m_2)$ , also called the Mean Spectral Period.

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