NUMERICAL SIMULATION AS GUIDANCE IN MAKING TSUNAMI HAZARD MAP FOR LABUAN ISLAND

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ABSTRACT

At the northeast end of the South China Sea, tsunamis may be generated by the earthquakes along the eastward dipping subduction zone known as the Manila Trench. Tsunamis generated by major earthquakes in this zone are expected to affect Malaysian coastal areas especially in Sabah and Labuan Island. In this study, a numerical simulation of tsunami in Sabah and Labuan Island coast is conducted using a modeling code called TUNAMI-N2 (Tohoku University's Numerical Analysis Model for Investigation of Near-field tsunami, No.2) to calculate the tsunami waveform at the output points. Two types of numerical simulations are performed in this study: (1) a numerical model based on uniform grid systems in Cartesian coordinate with 1 arc-minute and 30 arc-seconds bathymetry data and (2) a numerical model based on the nested grid system in Cartesian coordinate using non-linear theory with four different spatial grid sizes. Three scenarios of fault rupture are considered in the Manila Trench for the earthquakes with magnitudes of M_w 8.0, 8.1 and 8.5. Results of the both methods are compared and it is found that the tsunami amplitude is larger than those with use of smaller grid size of bathymetry data. However, finer bathymetry and topography data are required for better and more accurate modeling. A computational instability problem is introduced and discussed in this paper in order to obtain a better solution and stable condition in the numerical simulation. Finally, guidance for making a tsunami hazard map in Labuan Island is discussed.

Keywords: Tsunami simulation, Manila Trench, Sabah and Labuan Island, Tsunami Hazard Map.

1. INTRODUCTION

In view of the tectonic setting, likelihood of tsunamigenic earthquakes occurrence in the South China Sea which is close to the coastal areas of west Sabah is quite limited. As such, there is no or little threat of local tsunami to these coastal areas. At the northeast end of the South China Sea, however, tsunami may be generated by the earthquakes along the eastward dipping subduction zone marked by the Manila Trench. This is a zone with a potential to generate large earthquakes in the South China Sea and further will generate tsunami which affects coastal area in Sabah and Labuan Island. The purpose of this study is to conduct the trans-oceanic propagation of tsunami expected from the Manila Trench, and then investigate the tsunami height and arrival time based on MMD tidal gauges located in Sabah and Labuan Island area. Next, the tsunami hazard assessment in the Labuan Island will be discussed for guidance in making tsunami hazard map for the Labuan Island region.

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2. DATA AND METHOD OF COMPUTATION

2.1. Tsunami Simulations, Bathymetry and Topography Data

We used Tohoku University's Numerical Analysis Model for Investigation of Near-field tsunamis (TUNAMI-N2) codes developed by Disaster Control Research Center (DCRC), Tohoku University of Japan (Imamura et al., 2006; Koshimura, 2010) for modeling propagation and inundation of tsunami in coastal area of Sabah and Labuan Island. The tsunami height and arrival time are compared between 3 scenario earthquakes which will be described in the next section; using uniform grid of 1 arc-minute bathymetry data, uniform grid of 30 arc-seconds bathymetry data, and nested grid data which consists of 4 regions as shown in Figure 1. We used bathymetry data from General Bathymetric Chart of the Ocean (GEBCO) (https://www.bodc.ac.uk/data/online_delivery/gebco/). We also used nautical chart for the simulation using the nested grid. For the calculation of inundation area for simulation using the nested grid, we obtained data from Shuttle Radar Topography Mission (SRTM) (http://www2.jpl.nasa.gov/srtm/) for Region 3 and topography data from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (http://asterweb.jpl.nasa.gov/) for Region 4. The detailed computation regions and the data used for the simulations are shown in Table 1.

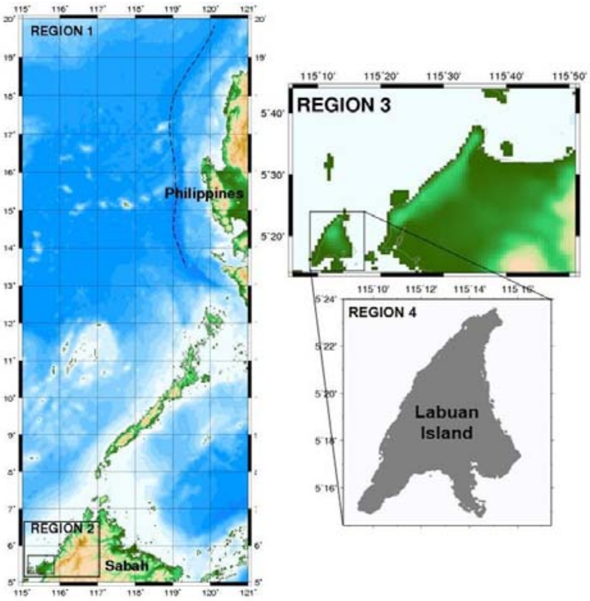

Figure 1. Computation area using nested grids.

In this study, the temporal grid sizes (Δ*t*) were set to 2.0 s for uniform grid computations and 0.3 s for nested grid computation, which satisfy the CFL condition. Total duration of the calculation is 480 min which has time steps of 14,400 for computational time in uniform grid simulations and 96,000 for the nested grid simulation. Tsunami waveforms were calculated at 18 tide gauge stations along Sabah and Labuan Island coast as target points to obtain tsunami heights and arrival times.

Table 1. Computation regions and data used for simulation using nested grids.

Region	Region 1	Region 2	Region 3	Region 4
Latitude	5°-20°N	5.15°-6.65°N	5.235°-5.735°N	5.240°-5.400°N
Longitude	115°-121°E	115.05°-117.05°E	115.100°-115.850°E	115.146°-115.290°E
Bathymetry data	GEBCO 30 arc-sec	GEBCO 30 arc-sec	Nautical chart	Nautical chart
Topography data	GEBCO 30 arc-sec	GEBCO 30 arc-sec	SRTM	ASTER
Resolution	27 arc-sec	9 arc-sec	3 arc-sec	1 arc-sec
Grid dimension	800 x 1999	800 x 600	900 x 600	520 x 577

2.2. Scenario Earthquakes in the Manila Trench

In this study, we investigated earthquake mechanisms such as seismic faults along the Manila Trench. One earthquake scenario is proposed by Zaty (2007) in which the magnitude is M_w 8.0. Top depth of the fault is 25km. On the other hand, the subduction zone of the Manila Trench might reach the west coast of Mindoro Island. Generally, it is known that the tsunami energy propagates perpendicular to the fault strike. The trench axis in this area existed from northwest to southeast. Therefore, the direction perpendicular to the fault strike is expected to become the southwestern direction. The Sabah and Labuan Island coast are located to this orientation. Consequently, the tsunami created by the earthquake along the west coast of the Mindoro Island might affect the Sabah and Labuan Island coast. Regarding this seismic fault of the Mindoro Island, we assumed the length of the fault to fit the trench axis. Due to this, we assume two more earthquakes scenarios (M_w 8.1 and 8.5), in which the fault area consists of two fault segments. The fault parameters for these scenarios are listed in Table 2.

Single fault was applied in Scenario 1, while multi faults were applied in Scenario 2 and Scenario 3. For the worst scenario in this study (M_w 8.5), we compare results obtained from the uniform grid simulation with the ones obtained from the nested grid simulation. In every scenario, as simulation Cases a, b and c we used 1 arc-min of bathymetry data, 30 arc-seconds of bathymetry data and nested grid, respectively. The fault parameters are estimated using equations for dip-slip faults in subduction regions proposed by Papazachos et al. (2004). The dip angle of the fault plane is assumed equal to 30° proposed by Bautista et al. (2001).

Table 2. Faults parameters for each scenario earthquake.

No.	Magnitude M_w		Length (km)	Width (km)	Strike (°)	Dip (°)	Rake (°)	Slip (m)	Top Depth (km)	Latitude (°)	Longitude (°)
1	8.0		162.2	70.8	0	30	90	2.19	25	13.8	119.5
2	8.1	North	162.2	70.8	0	30	90	2.19	25	13.8	119.5
		South	96	41.9	315	30	90	1.29	20	13.2	120.2
3	8.5	North	305.5	101.2	0	30	90	4.57	25	13.8	119.5
		South	96	41.9	315	30	90	1.29	20	13.2	120.2

3. RESULTS AND DISCUSSION

3.1. Tsunami Propagation toward Labuan Island

Here we show the snapshots of tsunami propagation only for Cases 1a, 2b and 3c in Figure 2. For Scenario 1, in shallow coastal area especially near Mindoro, tsunami wave propagation moves wider and crosses faster to Sulu Sea. The first negative wave reaches Manila Bay while positive wave reaches Mindoro coast facing the tsunami source. The positive wave reaches Sabah coast at 2 hours and 40 minutes after the earthquake and Labuan Island coast 3 hours after the earthquake.

For the magnitude of M_w 8.1 in Scenario 2, the tsunami wave traveling to southwestern direction is a bit higher. The coastal area will be badly hit by the tsunami in the Philippines becoming more extensive especially at the coast facing the tsunami source. The positive wave reaches Sabah coast at 2 hours and 40 minutes after the earthquake and Labuan Island coast almost at 3 hours after the earthquake. The small difference in magnitude of the earthquake and tsunami propagation direction is not much influential to the tsunami arrival time in Sabah and Labuan Island because much of the tsunami energy have been dissipated by the time while they approach to this area.

In the worst scenario (magnitude M_w 8.5), the tsunami propagation is compared between simulations using bathymetry of 1 arc-minute (Case 3a), 30 arc-seconds (Case 3b) and nested grid simulation (Case 3c). Most Philippine coast area facing the earthquake will be hit badly by the tsunami. Subsequently, the tsunamis will move towards Sabah coast and reach Kudat at after 2 hours and 38 minutes. Because of the shallow coastal area in Labuan Island, the tsunami wave arrive Labuan Island coast at about 3 hours after the earthquake.

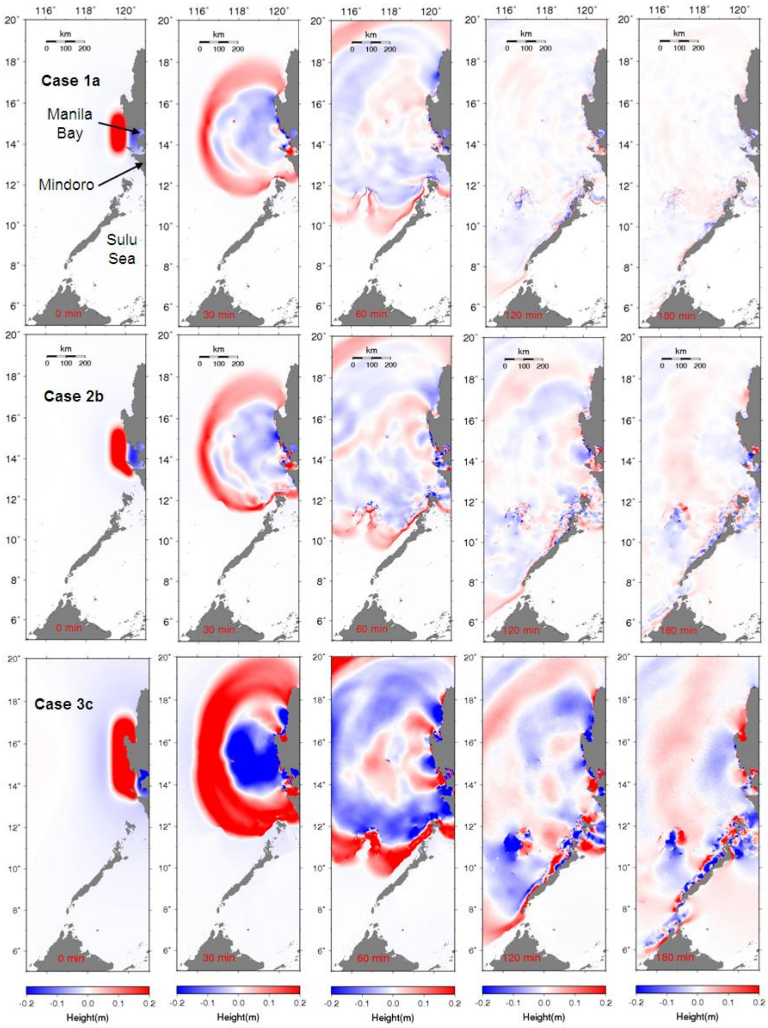

Figure 2. Snapshots of tsunami propagation at 0 (initial condition), 30, 60, 120 and 180 min for Case 1a (top), Case 2b (middle) and Case 3c (bottom). Tsunami height scale is crimped to 0.2 m.

3.2. Maximum Tsunami Heights and Travel Times

As shown in Figure 3, the maximum tsunami height calculated by using bathymetry data of 30 arc-seconds is always higher than the one obtained by using bathymetry data of 1 arc-minute. From all scenarios, tsunami heights simulated at tide gauges facing to the South China Sea are slightly higher than other areas. In the Sabah coast, the highest tsunami obtained is 0.47 m at TG03 which is located near Kota Belud. The second highest tsunami obtained is 0.36 m at TG02 which is located near Kota Kinabalu. In Labuan Island coast, the highest tsunami was calculated at TG12 with 0.45 m which is located near Kerupang Village at the east part of Labuan Island.

As shown in Figure 4, the first positive wave of tsunami could reach the coastal area in about 2 hours and 38 minutes. The earlier tsunami arrives at the northern part of Sabah, the further it will propagate to the west part. In each scenario, the tsunami will arrive at each target point slightly earlier with the use of smaller grid size in the simulations.

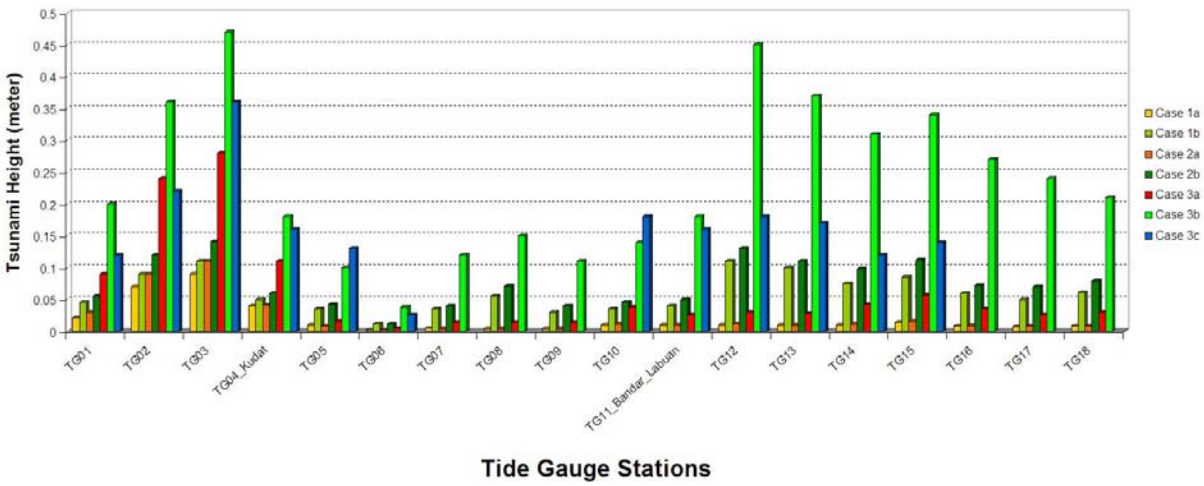

Figure 3. Maximum tsunami heights at each tide gauge station for all cases.

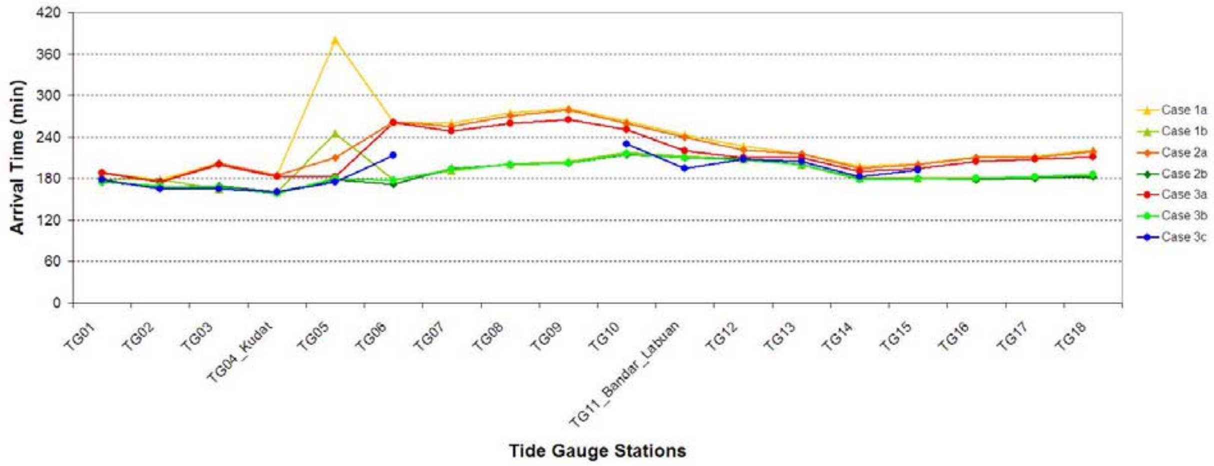

Figure 4. Tsunami positive wave travel times estimated at each tide gauge station for all cases.

3.3. Computation Problems of Instability and Results in Labuan Island

Figure 5 shows some instability for Case 3c of simulation due to joining of two different spatial grids between Region 3 and Region 4 in the nested grid computation. For this result, we neglect observation of tide gauges TG07, TG08, TG09, TG16, TG17 and TG18 for the Case 3c which are affected by this computation instability, which could not cause low accuracy for the tsunami evaluation in Labuan Island. Although we have the instability problem at the boundary, the result for the analysis should be reasonable. Therefore, based on the numerical simulation, we could obtain the result that the highest tsunami calculated in Labuan Island is 0.45 m at TG12 for Case 3b using bathymetry of 30 arc-seconds in uniform grid. So, there is no observation of inundated area in Labuan Island area obtained from the simulation. We used a transform software which is developed by Fortner Software to investigate boundary condition between coastal and land area of Region 4 in the nested grid as shown in Figure 6. In the raster data for Region 4 which covers the area of Labuan Island, the minimum elevation step for the topography data form ASTER is 1 m. For that reason, there will be no inundated area shown in the simulation. In order to obtain more consistent and better results for the tsunami computation, the use of detailed and accurate bathymetry as well as topography data should be essential with a small grid size, and is much more effective in the numerical computation.

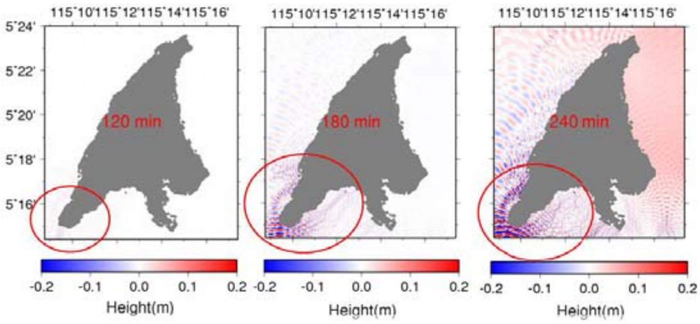

Figure 5. Snapshots with instability using the nested grid of Region 4.

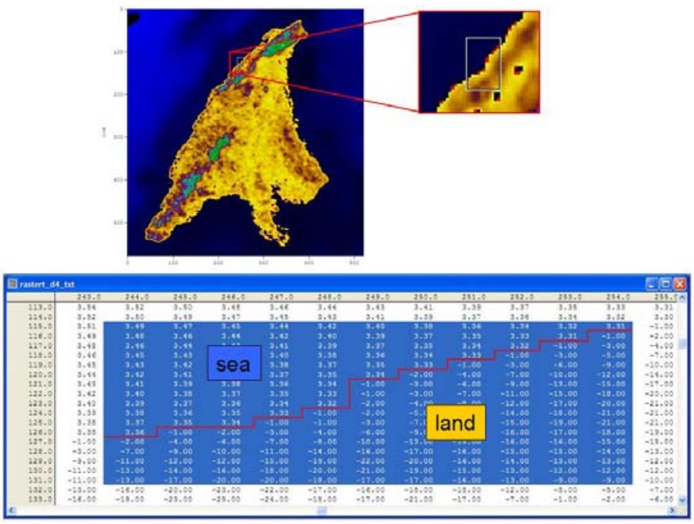

Figure 6. Analysis of boundary condition between land and sea in the numerical computation.

3.4. Tsunami Hazard Map

From the simulation, we can obtain parameter such as tsunami travelling time, maximum and minimum water level at each output point and tsunami velocity which is important to estimate the damage that may occur as a result of the tsunami. Lifeline facilities and residents living near the coastal zone should be well prepared for the disaster. Hence, the tsunami hazard map containing the information of the evacuation area, the route for evacuation and the information about the tsunami should be prepared and disseminated to the residents especially in the vulnerable areas.

4. CONCLUSIONS

We found that the fault ruptures along the shore of Philippines will generate a strong directivity of tsunami energy to propagate toward countries around the South China Sea and a very small effect to the coastline of Sabah and Labuan Island because most of their energy would have been dissipated by the time while they approach the west coast of Sabah. It is noticed that the tsunamis arrived earlier in each scenario with use of smaller grid size in the simulations. As the results, the tsunami heights of about 0.47 m are calculated at the west part of Sabah and 0.45 m are calculated at the eastern part in Labuan Island facing the South China Sea.

5. RECOMMENDATION

The most important aspect to be tackled in the future is to improve the computed results for tsunami height and travel time in the model by using more detailed and accurate bathymetry as well as topography data which is essential for tsunami numerical computation. A more efficient technique and modification to the program may be necessary to reduce computational instability in the simulation. In addition, few other scenarios should be studied to determine the effect of changes in top depth of faults to estimate tsunami risk in the Sabah and Labuan Island coast.

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