STUDY ON TSUNAMI INUNDATION SIMULATION IN THE NORTHWESTERN COAST OF SABAH, MALAYSIA

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ABSTRACT

Tsunami simulations and inundation analyses are conducted on the northwestern coast of Sabah by assuming earthquake along the Manila Trench (MT) proposed by Salcedo (2010). TUNAMI (Tohoku University's Numerical Analysis Model for Inverstigation) code is used. To calculate tsunami propagation and inundation we perform numerical simulations of linear and nonlinear shallow water wave equations in a spherical coordinate system with four different spatial grid sizes of 60, 20, 6.6667 and 2.2222 arc-sec. As output points, 24 tide gauge stations are assumed along Kudat coastal areas. Seven scenarios with different moment magnitudes are considered to perform tsunami simulations. Earthquake source regions are divided into four segments, MT1, MT2, MT3, and MT4. Single and multi segmentation are used to assess the scenario earthquakes for all three target areas, Kudat Peninsula, Balambangan Island and Banggi Island. Computation results show that the tsunami heights are larger with large slip on the fault. We found that the slip on the segment MT1 is not sensitive for the tsunami height to the coastal area of northwest Sabah. We also found that the most significant tsunami is expected from MT4, as well as MT3 and MT2 cause large tsunamis.

Keywords: Scenario earthquakes, Manila Trench, Tsunami height and travel time, Inundation, Sabah, Kudat.

1. INTRODUCTION

Seismic zones in Indonesia and the Philippines bordering Malaysia are active with frequent earthquakes and have significantly put Malaysia at risk of earthquakes from far field. Since the convergence rate related to the subduction zone of the Manila Trench is high, the potential of larger tsunamigenic earthquakes cannot be neglected. Megathrust earthquakes from the Manila Trench with large scale of magnitude 9.0 or greater can lead to an extremely large thrust fault that could generate a widespread tsunami which can cause tsunami to reach the northwestern part of Sabah.

2. DATA

Bathymetry and Topography Data

Bathymetry data are obtained from General Bathymetric Chart of the Oceans (GEBCO)

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(https://www.bodc.ac.uk/data/online_delivery/gebco/) of 30 arc-second grid size and from digitized nautical chart (Ridzuan, 2010) for the finest computational regions. Topographic data were obtained from Shuttle Radar Topography Mission (SRTM) for all three selected target areas, Kudat Peninsula, Balambangan Island and Banggi Island.

Scenario Earthquakes and Computational Dimensions

Seven scenarios are considered to perform tsunami simulation for all three target areas. From the study by Salcedo (2010), earthquake source region in the Manila Trench (MT) is divided into four segments, MT1, MT2, MT3 and MT4 given by Bautista (2001), as shown in Figure 1. Table 1 shows the list of scenario earthquakes using single fault and multi segmentations for this study. The top depth for all scenarios is assumed to be 0 km. We used a nested grid system with four layers (Figure 1). The grid sizes used for regions Region 1 (R1), Region 2 (R2), Region 3 (R3) and Region 4 (R4) are 60, 20, 6.6667 and 2.2222 arc-second, respectively. Temporal grid size (Δt) of 1.0 s is used to stabilize the numerical computation. Total duration of calculation is 480 min with 28,800 number of time steps.

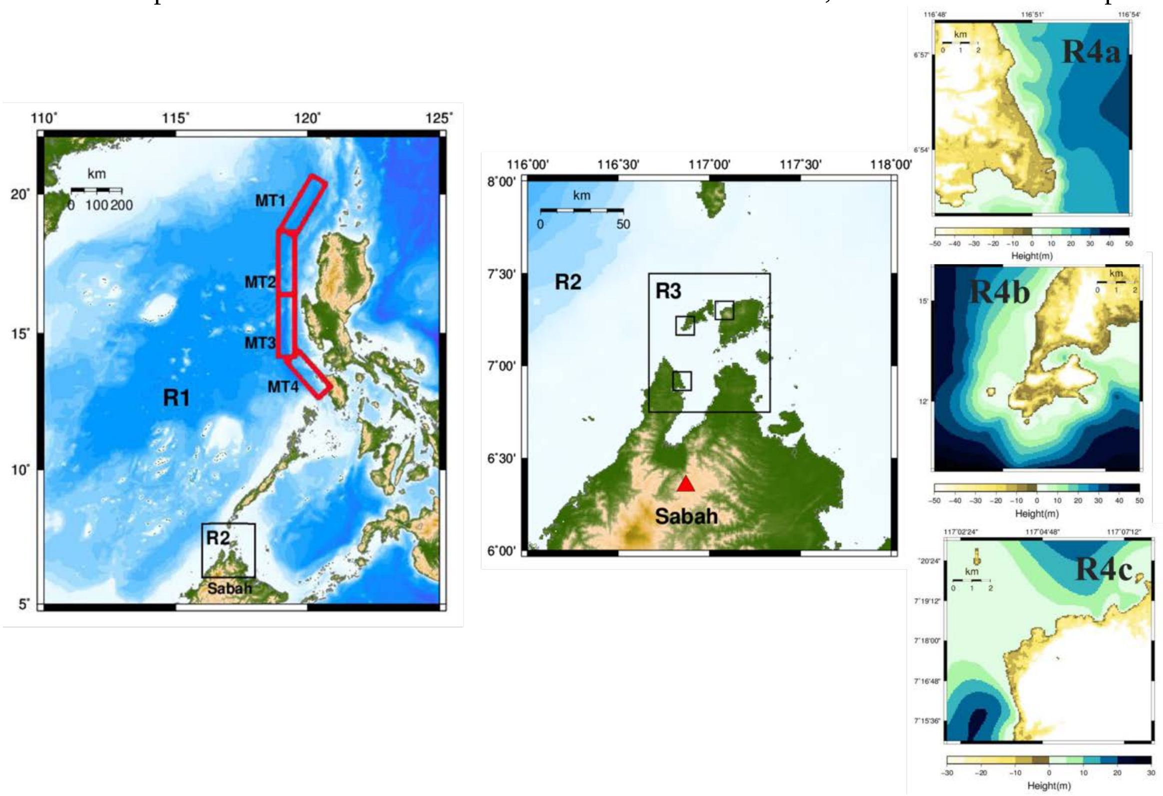

Figure 1. Earthquake source region in the Manila Trench (MT) and computational domain Regions 1 (R1), 2 (R2), 3 (R3) and 4 (R4a, R4b, R4c).

Table 1. Parameters for the scenario earthquakes.

Scen.	**Single Segmentation**	**Mw**	**Slip amount (m)**	**Scen.**	**Multi Segmentation**	**Mw**	**Slip amount (m) for all segments**
1a	MT4	8.1	2.63	2a	MT4+MT3+MT2	8.8	10.0
1b	MT4	8.4	10.0	2b	MT4+MT3+MT2	9.0	20.0
1c	MT4	8.6	20.0	3a	MT4+MT3+MT2+MT1	8.9	10.0
				3b	MT4+MT3+MT2+MT1	9.1	20.0

Figure 2 shows the 24 tide gauge stations along target coastal area settings for computational dimensions in each region.

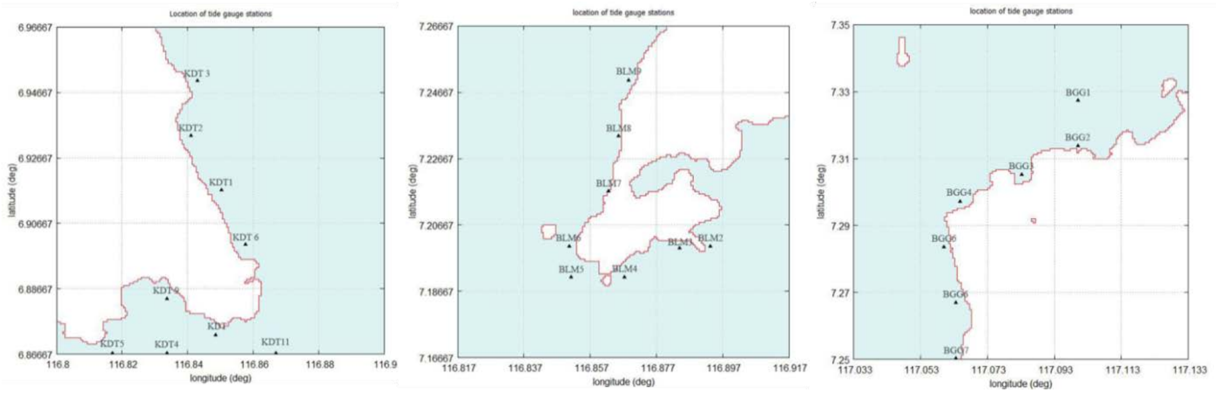

Figure 2. Tide Gauge location along coastal area Kudat Peninsula for R4a (left), Balambangan Island for R4b (center) and Banggi Island for R4c.

3. THEORY AND METHODOLOGY

3.1. Shallow Water Equations (SWE)

Governing equations in linear shallow water with spherical coordinate system are expressed by (Nagano et al., 1991)

$$\frac{\partial \eta}{\partial t}+\frac{1}{R\cos\theta}\left[\frac{\partial M}{\partial \lambda}+\frac{\partial}{\partial \theta}(N\cos\theta)\right]=0 \qquad \frac{\partial M}{\partial t}+\frac{gD}{R\cos\theta}\frac{\partial \eta}{\partial \lambda}-f_c N=0 \qquad (1)$$

$$\frac{\partial N}{\partial t}+\frac{gD}{R}\frac{\partial \eta}{\partial \theta}+f_c M=0$$

The momentum equations in non-linear shallow water with spherical coordinate system are expressed by

$$\frac{\partial M}{\partial t}+\frac{gD}{R\cos\theta}\frac{\partial \eta}{\partial \lambda}+\frac{1}{R\cos\theta}\frac{\partial}{\partial \lambda}\left(\frac{M^2}{D}\right)+\frac{1}{R\cos\theta}\frac{\partial}{\partial \theta}\left(\cos\theta\frac{MN}{D}\right)+\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}=0$$

$$\frac{\partial N}{\partial t}+\frac{gD}{R\cos\theta}\frac{\partial}{\partial \theta}(\cos\theta\eta)+\frac{1}{R\cos\theta}\frac{\partial}{\partial \lambda}\left(\cos\theta\frac{N^2}{D}\right)+\frac{1}{R\cos\theta}\frac{\partial}{\partial \lambda}\left(\frac{MN}{D}\right)+\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}=0 \qquad (2)$$

,where θ is latitude, λ is longitude, M and N are discharge fluxes in the direction of latitude θ and longitude λ, D is the still water depth, η is the elevation of the water surface, g is the gravitational acceleration, R is the radius of the earth, f_c is Coriolis parameter of $f_c = 2\omega \sin \theta$, ω is the rate of angular rotation and n is Manning's roughness (n = 0.025 in this study).

4. RESULTS AND DISCUSSION

4.1. Seafloor Deformation

Sea surface deformation is assumed as the instant uplift or subsidence of the seismic deformation of the sea floor. Figure 3 shows the initial tsunami height for some scenario earthquakes.

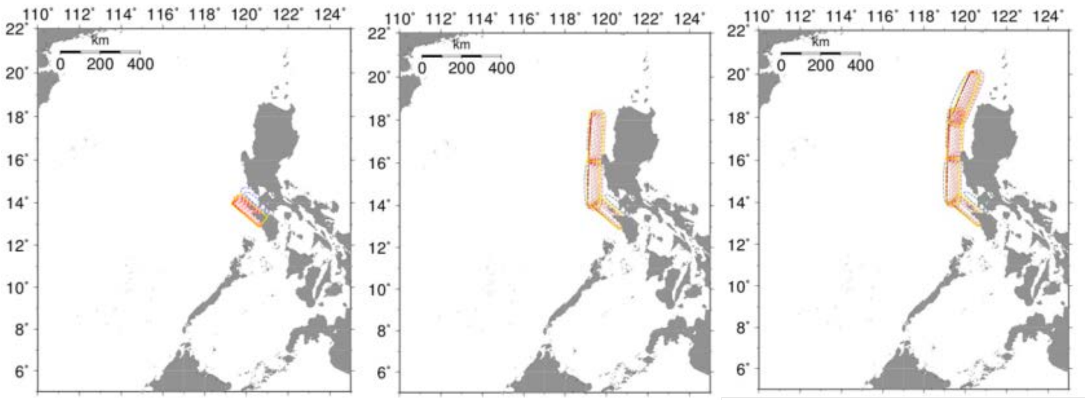

Figure 3. Seafloor deformation as initial tsunami height for Scenarios 1a (left), 2a (middle) and 3a (right). Contour interval of surface deformation is 0.2m.

4.2 Maximum Tsunami Heights and Tsunami Travel Time

4.2.1 Region 4a - Kudat Peninsula

The maximum height of 1.6 m occurs at KDT2 for Scenario 2b and 1.4 m at KDT1 for Scenario 3b. For the worse case scenarios of moment magnitude Mw more than 9.0, all tide gauge stations record high tsunami waves of more than 0.8 m. Figure 4 shows the maximum tsunami heights and tsunami travel times at all tide gauge stations in Kudat Peninsula corresponding to all the scenarios.

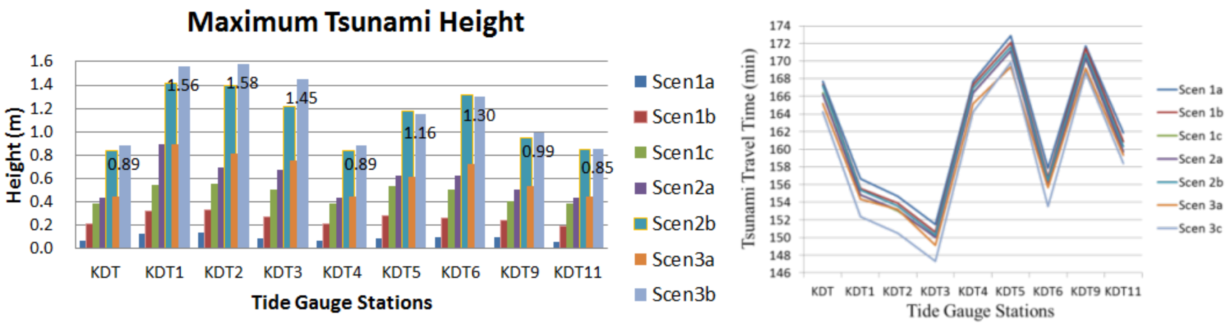

Figure 4. Maximum tsunami heights at tide gauge stations for all earthquake scenarios in R4a (left) and tsunami travel times (right).

4.2.2 Region 4b – Balambangan Island

Figure 5 shows the maximum tsunami heights and tsunami travel time at all tide gauge stations in Balambangan Island corresponding to all the scenarios. The maximum wave height calculated for Scenario 2b and 3b are 2.7 m and 2.6 m, respectively, at tide gauge station BLM8.

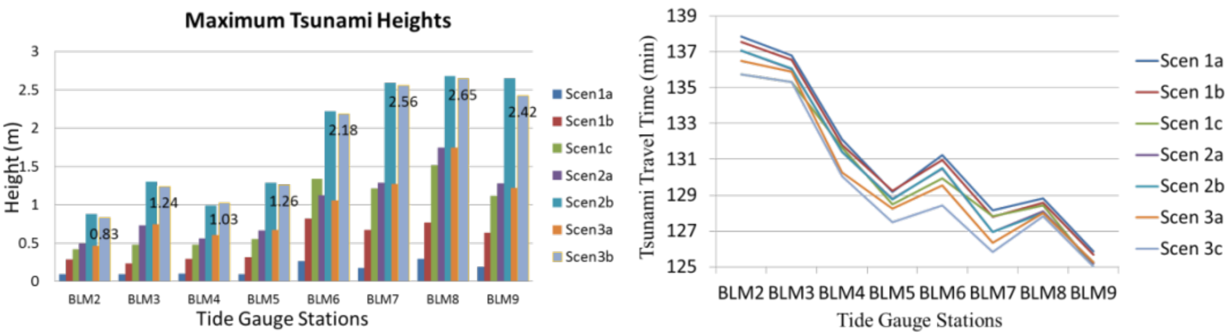

Figure 5. Same as Figure 4, but in R4b.

4.2.3. Region 4c – Banggi Island

The maximum wave height for Scenarios 2b and 3b is about 1.8m at station BGG2. Figure 5 shows the maximum tsunami heights and tsunami travel times at all tide gauge stations in Banggi Island corresponding to all scenarios.

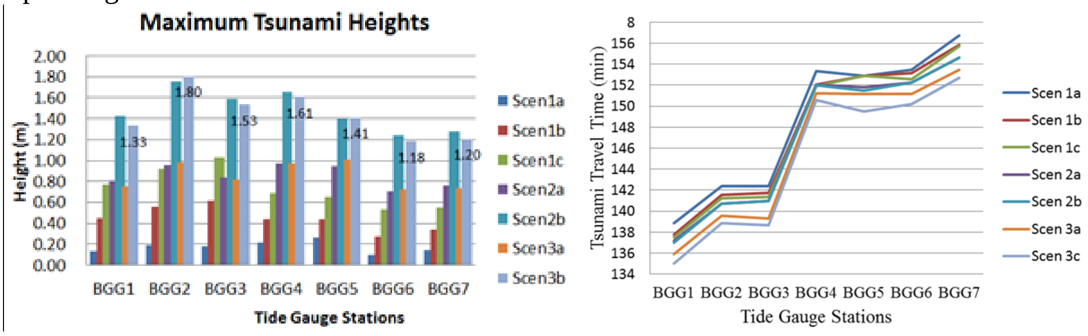

Figure 6. Same as Figure 4, but in R4c.

4.3. Inundation Area

4.3.1 Region 4a – Kudat Peninsula

Figure 7 shows three selected locations namely Kudat Airport, Tanjung Kapor and Kampung Air. For the Scenario 3b, the highest inundation 1.9 m reaches Tanjung Kapor, followed by Kudat Airport up to 1.8 m and Kampung Air at 0.9 m. Kudat Airport is located at the open coast where direct tsunami waves may approach. A narrower bay may cause greater amplification in the case of Tanjung Kapor. Kampung Air which is more secluded and far from tsunami source, has lower result of the maximum inundation height.

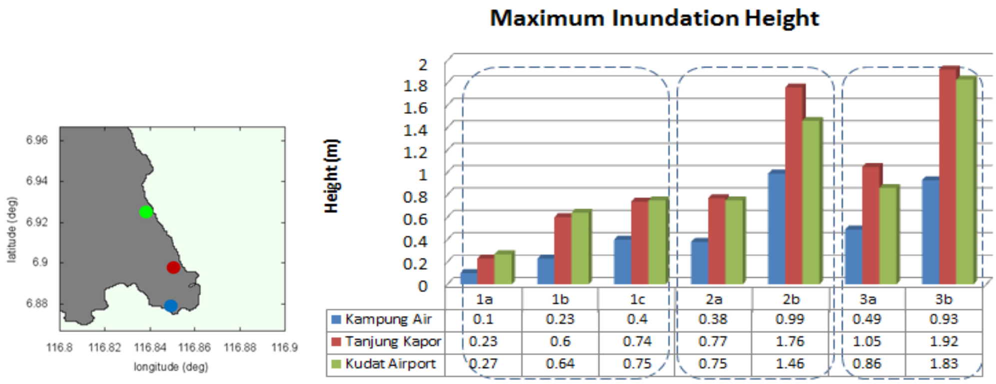

Figure 7. Location of target points and maximum inundation height for R4a. Red, blue and green corresponds to Tanjung Kapor, Kampung Air and Kudat Airport, respectively (left). Region 4a (right).

4.3.2 Region 4b – Balambangan Island

Figure 8 shows two locations of the selected villages namely Kampung Kok Simpul and Kampung Batu Sirih. For worst case Scenario 3b, Kampung Kok Simpul reaches the highest inundation height to 3.0 m and Kampung Batu Sirih at 1.3 m. Kampung Batu Sirih is located at open coast which direct tsunami waves may approach the coast. It is also closest to the Philippines which may be the first area to be affected by a megathrust earthquake tsunami. Tsunami inundation may be governed by the shoreline shape.

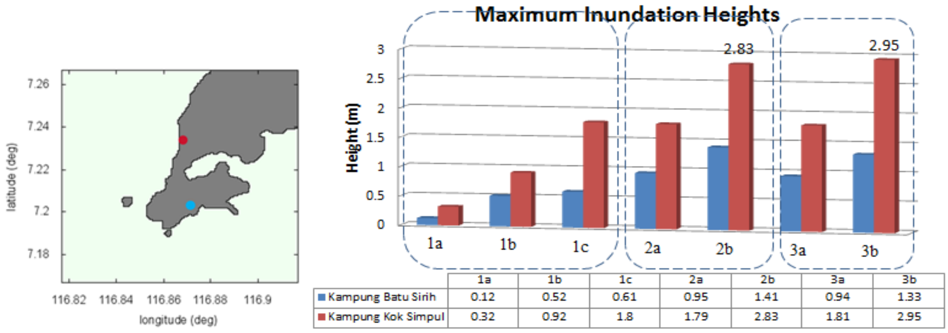

Figure 7. Same as Figure 7, but in R4b. Red and blue corresponds to Kampung Kok Simpul and Kampung Batu Sirih, respectively.

4.3.3 Region 4c – Banggi Island

Figure 9 shows the location of the selected area Molbog village. For the worst case Scenario 3b, Molbog village reaches the highest inundation height to 1.68 m. Molbog Village is another selected place located close to the Philippines at open coast, in which direct tsunami waves may approach the coast.

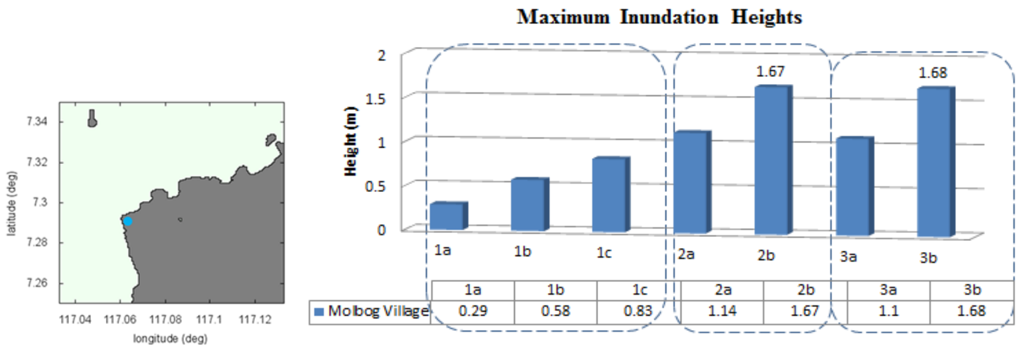

Figure 8. Same as Figure 7, but in R4c. Blue corresponds to Molbog Village, respectively.

5. CONCLUSIONS

We found that the slip on the segment MT1 is not sensitive for the tsunami height to the coastal area of northwest Sabah. We also found that the most significant tsunami is expected from MT4, as well as MT3 and MT2 cause larger tsunamis. The result shows that under the worst case scenario, target points Kampung Air, Tanjung Kapor and Kudat Airport located in Kudat Peninsula of Region 4a are affected by the tsunami inundation with height of approximately 1 m or more. In Region 4b most areas along Balambangan Island are significantly inundated with height of more than 1.3 m for the catastrophic event of Mw 9.1. Balambangan Island located closest to the Philippines is the first affected area with target point Kampung Kok Simpul, and is directly approached by tsunami waves. Kampung Batu Sirih is affected with greater inundation height as its shoreline shape has bay along the coast. Based on the result of tsunami simulation, the maximum inundation height more than 1.5 m was calculated in target area Region 4c for the worst case scenario Mw 9.1. Molbog Village located at the northern part of Banggi Island is hit with direct tsunami waves as it is located at open coast.

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