TSUNAMI PROPAGATION AND INUNDATION MODELINGS ALONG SOUTH-EAST COAST OF PAPUA NEW GUINEA

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ABSTRACT

This study covers tsunami generation, propagation and inundation using eight earthquake scenarios along the New Britain Trench and Ramu-Markham Fault zone in the south-eastern region of Papua New Guinea. The tsunami propagation and inundation modeling, based on the TUNAMI-N2 hydrodynamic computational model, was used in this study. The computational domain ranges from 141^o to 158^o longitude and negative 1^o to negative 12^o latitude. The GEBCO 30 arc-second data and coastal topography data from SRTM were utilized in the computation of tsunami waves and the inundation study in the target areas. Eight earthquake scenarios comprising of two Mw8.6 segments, an Mw8.7 segment, and five Mw8.1 magnitudes were selected along the Ramu-Markham Fault zone and the New Britain Trench for computing tsunami height, travel time and inundation of the target areas. Geographically assuming tidal gauge stations at desired coastal points within the computational domain, tsunami heights and travel time to these coastal points were computed and results obtained. The earthquake scenarios, Mw8.6 segment_1 and Mw8.1 segment_A, with the highest tsunami height to the target areas were selected as computational model for tsunami inundation study. The tsunami travel time from fault segments covering both the sea and the land produced 0 min to 20 min travel time. The maximum tsunami heights of 3 to 4 m were recorded for Mw8.6 segment_1 and Mw8.7 segment_2 in Woodlark Island, Kiriwina Island, and Finch coastal points. The inundation study reveals Lae City observing negligible inundation, while Salamaua Coast was inundated with tsunami inundation height of 3 m.

Keywords: Tsunami Waveforms, Tsunami Heights, Tsunami Travel Time, Inundation

1. INTRODUCTION

The complex seismic zone, active and frequent seismic activities in the region of Papua New Guinea has significantly put the country at risk of seismic induced tsunami. In 17th July 1998, seismic induced submarine slump caused tsunami off the coast of Aitape claiming more than 2,200 lives and left more than 10,000 homeless. Several tsunamigenic earthquakes following the year caused recorded tsunami heights as far as 3 m along the coast and the coastal islands of Papua New Guinea. The high seismicity observed along New Britain Trench axis and Ramu-Markham Fault zone, where Solomon Sea and Australian Plates subduct South Bismarck and Pacific Plates, are potential tsunami source areas. In this study, tsunami heights and travel time of earthquake scenarios placed along the Ramu-Markham and New Britain Trench were assessed along the south-east coast of Papua New Guinea. Lae City and Salamaua coast in Morobe Province were selected as the target areas of tsunami inundation.

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2. THEORETICAL CONSIDERATION

2.1 Shallow Water Equations

The theory considers trans-oceanic tsunami of long wavelength against shallow water depth. The governing equations in spherical coordinates system are as follows.

$$\frac{\partial \eta}{\partial t} + \frac{1}{R\cos\theta}\left(\frac{\partial M}{\partial \lambda} + \frac{\partial}{\partial \theta}(N\cos\theta)\right) = 0 \tag{1}$$

$$\frac{\partial M}{\partial t} + \frac{gD}{R\cos\theta}\frac{\partial \eta}{\partial \lambda} + \frac{1}{R\cos\theta}\frac{\partial}{\partial \lambda}\left(\frac{M^2}{D}\right) + \frac{1}{R\cos\theta}\frac{\partial}{\partial \theta}\left(\cos\theta\ \frac{MN}{D}\right) + \frac{\tau_x}{\rho} = 0 \tag{2}$$

$$\frac{\partial N}{\partial t} + \frac{gD}{R\cos\theta}\frac{\partial}{\partial \theta}(\cos\theta\eta) + \frac{1}{R\cos\theta}\frac{\partial}{\lambda}\left(\cos\theta\ \frac{N^2}{D}\right) + \frac{1}{R\cos\theta}\frac{\partial}{\partial \lambda}\left(\frac{MN}{D}\right) + \frac{\tau_y}{\rho} = 0 \tag{3}$$

where θ and λ denote longitude and latitude respectively, η denotes elevation of water surface, D is the total water depth ($h+\eta$), h is the still water depth, t is time, R is the earth's rotational axis, ρ is density, M and N are flux (discharge) along the θ longitude and λ latitude while τ_x/ρ and τ_y/ρ are bottom friction terms. The fundamental continuity and momentum equations expressed in a Cartesian coordinate system are as follows (Koshimura, 2013).

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \tag{4}$$

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} + \frac{\tau_x}{\rho} = 0 \tag{5}$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} + \frac{\tau_y}{\rho} = 0 \tag{6}$$

The discharge flux M and N are given in Eq. (7) and (8).

$$M = \int_{-h}^{\eta} u\,dz = u(h+\eta) = uD \tag{7}$$

$$N = \int_{-h}^{\eta} v\,dz = v(h+\eta) = vD \tag{8}$$

where u and v are water particle velocities in direction x and y respectively.

3. DATA AND METHODOLOGY

The Tohoku University's Numerical Analysis Model for Investigation of Near-field Tsunami (TUNAMI-N2), the simulation code by Koshimura (2013) and Fujii (2013) was used for computing tsunami heights and travel times, while inundation code by Yanagisawa (2013) was used for tsunami inundation study. The bathymetry data from GEBCO 30 arc-second and SRTM 3 arc-second were utilized for the computation. The computational domain at 141° to 158° longitude and 1° to 12° latitude was set as region 1 of the study with the grid size of 1020 x 660. In the computation of tsunami heights and travel times, GEBCO 30 arc-second data with 1 arc-minute spatial grid size was used for region 1. In the inundation study of the target area, region 2, 3 and 4, the grid sizes are 390 x 300, 270 x 225 and 459 x 243, respectively. The region 2 and 3 used GEBCO bathymetry data, while SRTM 3 arc-second data was used as coastal topographic data in region 4. Figure 2 shows the location of the existing and assumed tidal gauge stations.

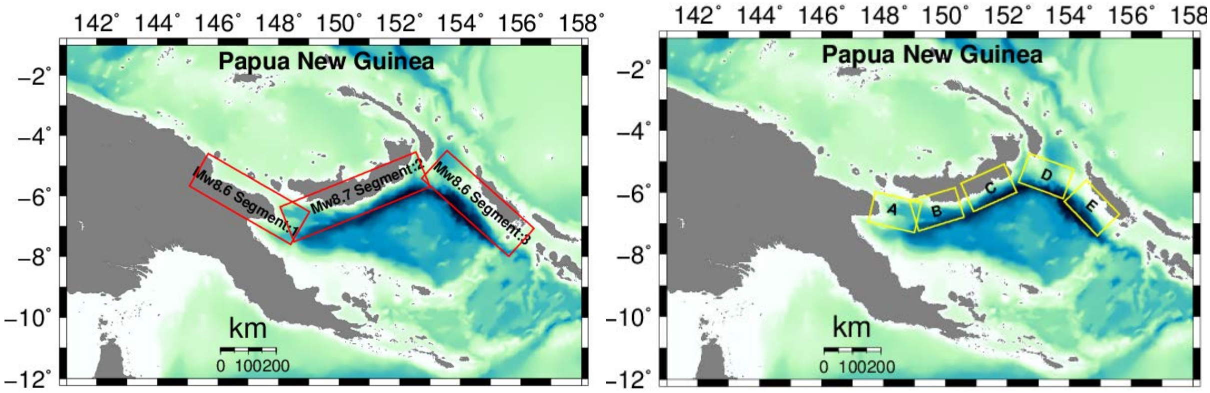

Figure 1. Location of earthquake scenarios. Left: mega scenarios, right: Mw8.1 scenarios.

Earthquake scenarios with fault segments shown in Figure 1 were used for computation for tsunami waves and inundation. The fault parameters are shown in Table 1. The fault segments were placed along the subduction trench, and subducting plates based on Wallace *et al*., (2004). The earthquake scenarios were two Mw8.6 segments (S1 and S3), an Mw8.7 segment (S2), and five Mw8.1 segments (SA, SB, SC, SD, SE). Dip angles were obtained from USGS Slab 1 Interactive Map data.

Table 1. Fault parameters for each earthquake scenario.

Scenario	*Mw*	*Lon. (deg.)*	*Lat (deg.)*	*Length, L (km)*	*Width, W (km)*	*Strike, θ (deg.)*	*Dip, δ (deg.)*	*Rake, λ (deg.)*	*Slip, u (m)*
1	8.6	148.4	-7.6	426	146	300	20	90	3.6
2	8.7	153.0	-5.7	536	146	248	20	90	4.0
3	8.6	155.6	-8.0	426	146	312	20	90	3.6
A	8.1	149.0	-7.3	169	117	283	20	90	2.0
B	8.1	150.6	-6.8	169	117	253	20	90	2.0
C	8.1	152.3	-6.0	169	117	246	20	90	2.0
D	8.1	153.8	-6.2	169	117	290	20	90	2.0
E	8.1	154.9	-7.4	169	117	316	20	90	2.0

The scaling law by Moritani *at al*. (2013) and the equations that follows were utilized for the computation of the fault parameters.

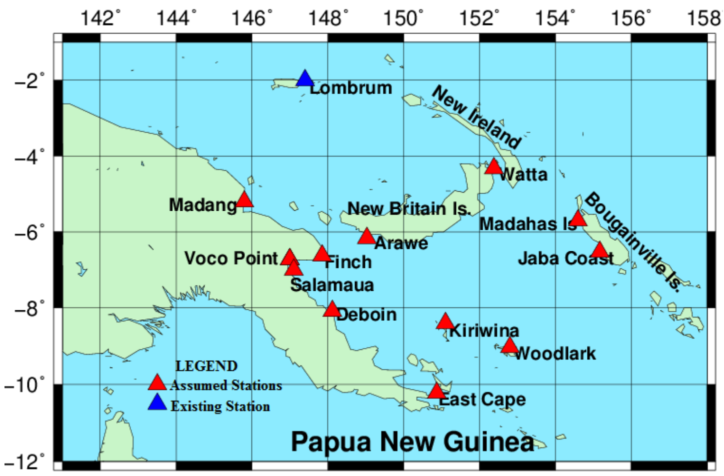

Figure 2. Location of tidal gauge stations.

$$W = \frac{bottom\ depth - top\ depth}{Sin\ (\delta)} \tag{9}$$

$$Mo = \frac{10^{(1.5Mw+16.1)}}{10^{7}} \tag{10}$$

$$u = 1.66 * 10^{-7} Mo^{2/3} \tag{11}$$

$$S = 1.34 * 10^{-10} Mo^{2/3} \tag{12}$$

$$L = \frac{S}{W} \tag{13}$$

where W is the width area of the fault, Mo is the seismic moment, u is the average slip, S is the fault area and L is the length of the fault segment.

4. RESULTS AND DISCUSSION

Figure 3 shows the tsunami waveforms obtained from earthquake scenario Mw8.1 S1 for all coastal points located around the Ramu-Markham and New Guinea Trench. The Finch and Voco Point coastal points observed the first wave of 1 m amplitude at initial time of 0 min. Madang coastal point showed similar phenomenon. Arawe coastal point, however, received negative waves at the initial time of 0 min. The other coastal points observed tsunami waves after the initial time. These waveform characteristics were observed in all earthquake scenarios.

Relating to Figure 3, tidal gauge stations located within the fault areas and uplift regions observed waveforms characteristic similar to Finch, while those located outside fault area but within subsidence observed waveforms similar to Arawe. Positive wave was read from tidal gauge within the uplift region at the initial time, while negative wave was read at initial time for tidal gauge stations located within subsidence region.

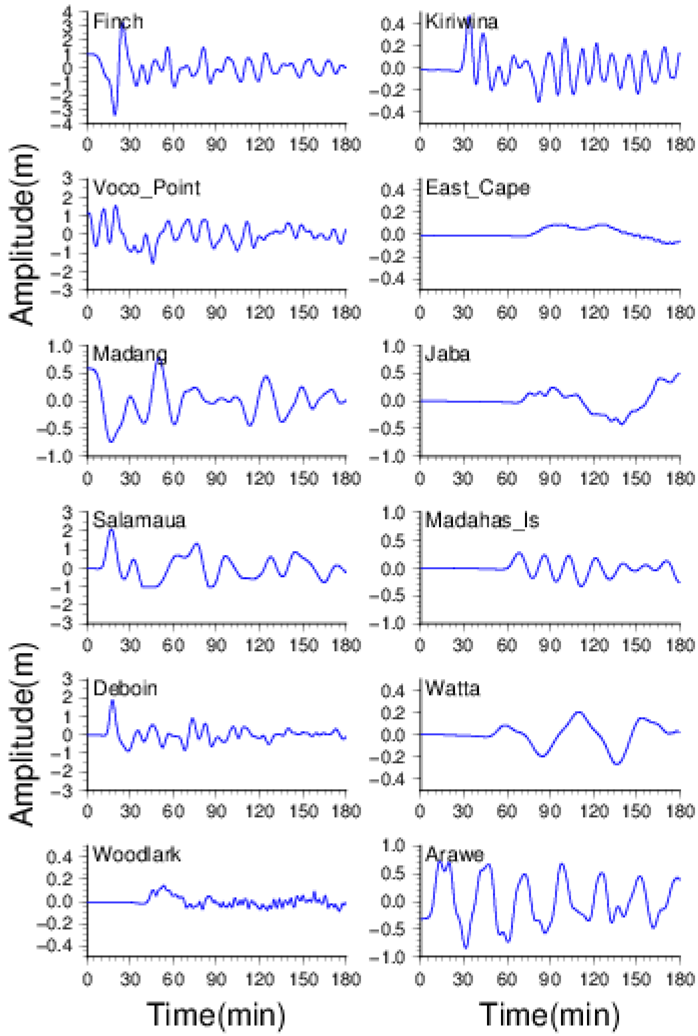

Figure 3. Calculated tsunami waveforms for each coastal point for the earthquake scenario Mw8.6 S1.

Figure 4, the maximum tsunami heights observed for the mega earthquake scenarios, Mw8.6 S1 and Mw8.7 S2, were more than 3 m at Finch, Woodlark Island and Kiriwina Island coastal points. Maximum tsunami height observed from earthquake scenarios Mw8.1 was from SA. The maximum tsunami height at Voco Point and Salamaua coastal points, were obtained from Mw8.6 S1 and Mw8.1 SA computation. Accordingly, these two scenarios were used for the inundation study of the target area.

In Figure 5, tsunami travel time less than 10 min for earthquake scenario Mw8.6 S1 was observed at Finch, Voco Point and Madang coastal points. For earthquake scenario Mw8.7 S2, the tsunami travel time within 10 min was observed at Finch, Watta and Arawe coastal points. The tsunami travel time less than 10 min for Mw8.1 SA was observed at Finch and Voco Point coastal points. For Mw8.1 SB, tsunami travel time less than 10 min was observed at Arawe coastal point, while Mw8.1 SC was observed at Watta coastal point. The tsunami travel time less than 10 min for earthquake scenario Mw8.1 SD was observed at Madahas Island and Watta coastal points. For earthquake scenario Mw8.1 SE, tsunami travel time less than 10 min was observed at Jaba and Madahas Island coastal points.

The inundation study in Figures 6 and 7 revealed negligible inundation in Lae City, while inundation in Salamaua was observed with a height of 3 m from Mw8.6 S1. For Mw8.1 SA, only Salamaua coast was inundated at 1.2 m height. Bathymetry and coastal topography of Lae City and Salamaua was responsible for the inundation pattern observed in the two target areas.

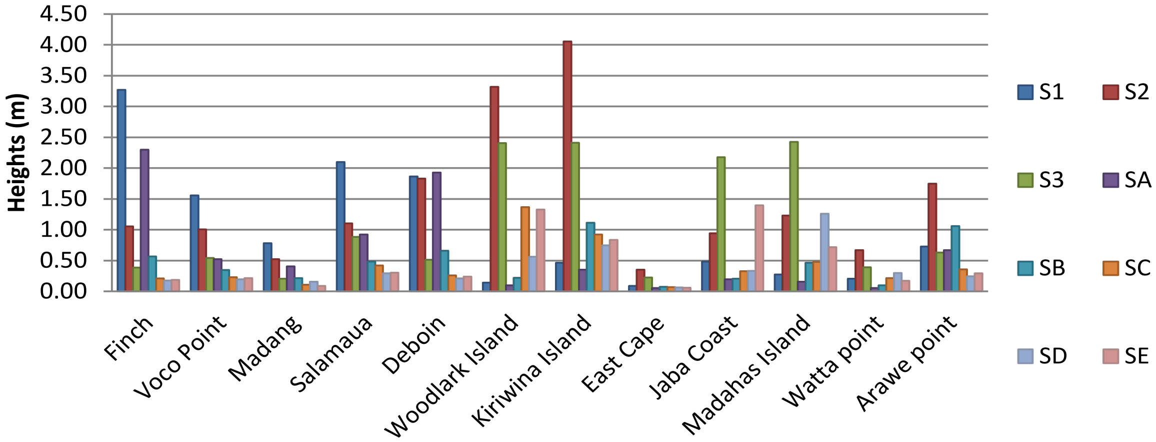

Figure 4. Tsunami heights for each coastal point from the computation of the earthquake scenarios.

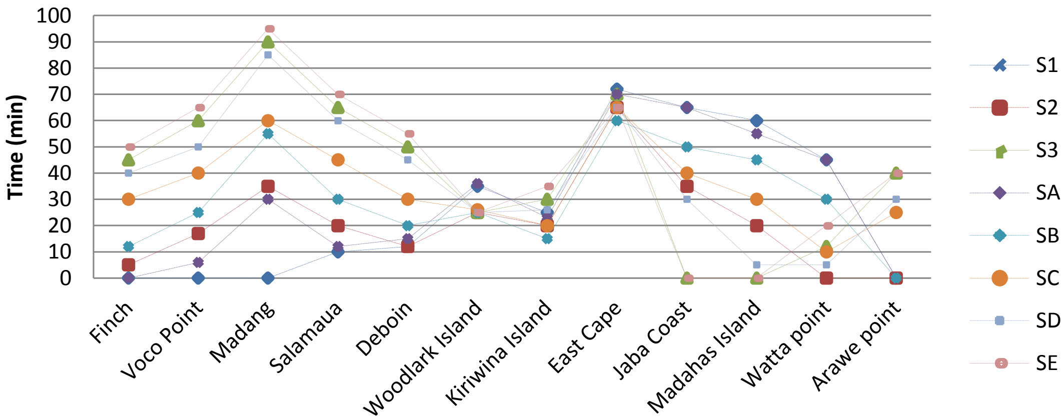

Figure 5. Tsunami travel time to various coastal points from respective earthquake scenario source area.

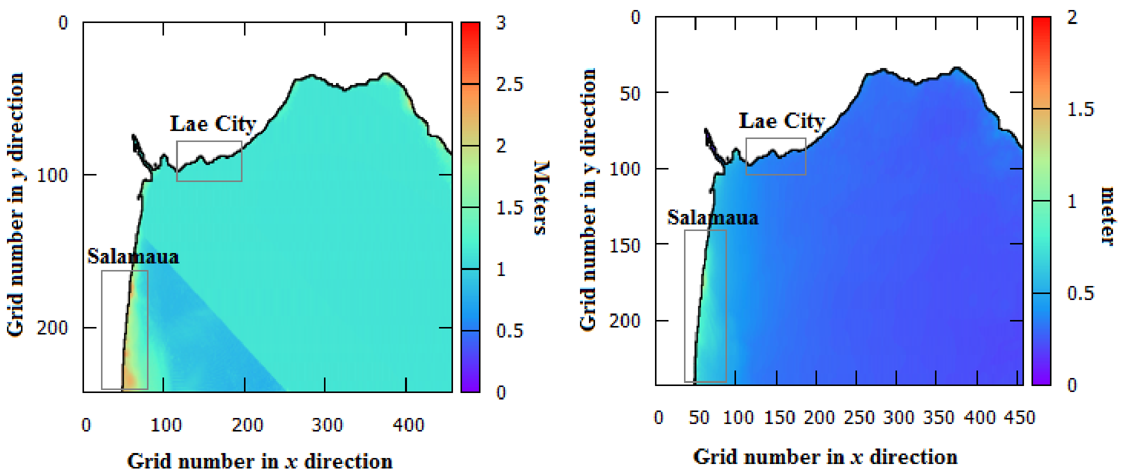

Figure 6. Calculated tsunami inundation of the region 4 from earthquake scenarios Mw8.6 S1 (left) and Mw8.1 SA (right).

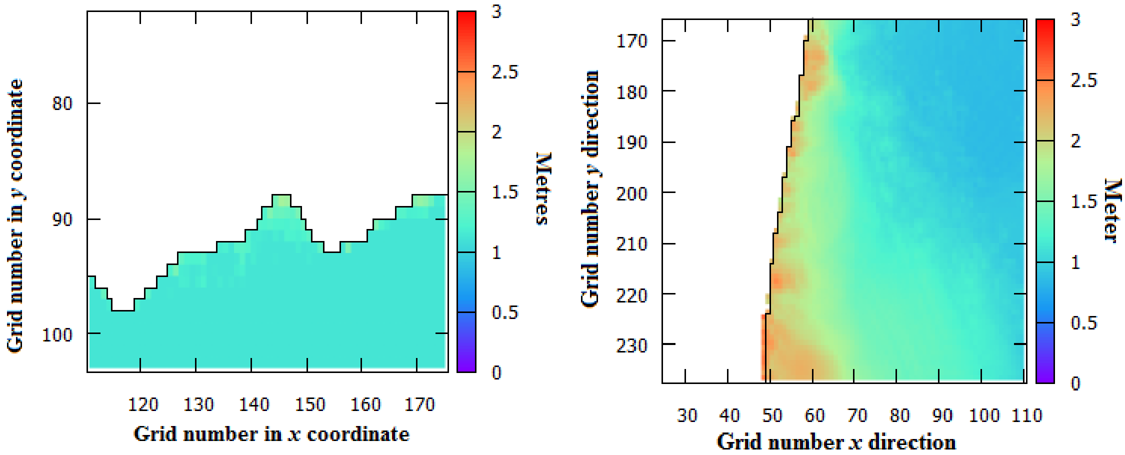

Figure 7. Magnified maps of rectangular areas in Figure 6. The left figure shows negligible inundation in Lae City, while right figure shows inundation in Salamaua.

5. CONCLUSION

The study covers simulations of tsunami propagation and inundation performed from earthquake scenarios along the New Britain Trench and the Ramu-Makharm Fault zone. Utilizing the GEBCO bathymetry data and SRTM coastal topographic data, tsunami travel time for each scenario and tsunami inundation study of Lae City and Salamaua were investigated. The tsunami heights exceeded 3 m were observed from earthquake scenarios Mw8.6 S1 and Mw8.7 S2 at Finch, Kiriwina Island and Woodlark Island coastal points. Coastal points within the fault area, the uplift region and subsidence region recorded tsunami travel time within 10 min. The inundation study of Lae City and Salamaua revealed negligible inundation observed in Lae, while 3 m height tsunami inundation was observed at Salamaua. Similar studies are needed for coastal towns and cities in Papua New Guinea. To carry out such study, the Department of Works must have tsunami disaster management policy as prerequisite to utilizing government resources (manpower and finance).

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