Citation: Malodali, J. S., B. Shibazaki, Y. Fujii (2023), Tsunami propagation and inundation simulations in Fiji based on scenario earthquakes, Synopsis of IISEE-GRIPS Master's Thesis.

TSUNAMI PROPAGATION AND INUNDATION SIMULATIONS IN FIJI BASED ON SCENARIO EARTHQUAKES

Joji MALODALI[1]
MEE22713

Supervisors: Bunichiro SHIBAZAKI[2*], Yushiro FUJII[2]**

ABSTRACT

In this study, tsunami simulations are conducted by assuming an M8.5 earthquake generated along the Tonga Trench, including horizontal deformation effect, and using a depth of five kilometers aligned to the buried faults. We performed numerical tsunami simulations using the Tohoku University's Numerical Analysis Model for Investigation (TUNAMI) code for the linear or non-linear wave equations in a spherical coordinate system. We tested two bathymetry data of GEBCO and ETOPO for single grid computations. We used the GEBCO for bathymetry data and the SRTM data for the topography for the tsunami inundation simulations. We adopted the nesting grid system with four layers including the finer grid merging the GEBCO and SRTM data on the tsunami inundation area. We selected two study areas to focus on the inundation: Suva and Ono-i-Lau. We placed four output points along the Suva coastlines in FDB foreshore, Walu bay, Lami, and Draunibota. The computational result in the Suva study area shows that the maximum inundation height recorded was at Walu Bay, with a height of 3.06 meters, and the earliest wave recorded was at FDB foreshore, with a time of 103.8 minutes. For the second study area in Ono-i-Lau, the four output points are Nukuni, South Nukuni, North Matokana, and Doi. The results show that the maximum inundation height recorded was at South Nukuni, with a height of 1.61 meters, and the earliest wave recorded was also at South Nukuni, with a time of 62.5 minutes.

Keywords: Tonga Trench, Horizontal deformation effect, Buried faults, Tsunami inundation, Tsunami simulations.

1. INTRODUCTION

Fiji, a small island nation in the South Pacific, is vulnerable to natural disasters, including earthquakes and tsunamis. In 1953, a devastating tsunami hit Fiji caused by a submarine landslide allowing significant damage to infrastructure and loss of life (Rahiman et al., 2007).

Understanding the potential impact of tsunamis on Fijis' coastal communities is critical for disaster preparedness and risk reduction. One of the key aspects of this understanding is modeling tsunami inundation, which involves simulating how tsunamis would spread across coastal areas and predicting the extent of flooding and damage that could result.

According to Murata et al. (2018), even with present technologies and knowledge, we still cannot predict the occurrence of earthquakes in advance. Hence it is also impossible to predict the tsunami occurrence. Therefore, providing knowledge and information on tsunami hazard is very important for people living in prone areas to save lives from tsunamis.

[1] Technical Officer, Mineral Resources Department, Fiji Islands.
[2] International Institute of Seismology and Earthquake Engineering, Building Research Institute.
* Chief examiner, ** Examiner

This study aims to model tsunami inundation along the Fiji coastline by merging bathymetry and topography data. This study's results will help authorities inform about coastal hazard assessments and support disaster risk reduction efforts in Fiji.

2. DATA

This study uses the General Bathymetric Chart of the Oceans (GEBCO) as bathymetry data (GEBCO Compilation Group, 2023). We used the current GEBCO_2023 version with the 15 arc-sec interval grid. We also utilized the ETOPO data as bathymetry data. The ETOPO data are available on and downloaded from the (https://www.ncei.noaa.gov/maps/grid-extract/) website. The version used is the ETOPO 2022 with a 15 arc-sec grid interval.

We used the Shuttle Radar Topography Mission (SRTM) for the topography data in this study. It is a one arc-second or about 30 meters (98 feet) sampling that reveals the full resolutions of the original measurements. These data are available on and downloaded from the (https://search.earthdata.nasa.gov/search) website. This SRTM data is then merged with GEBCO data to attain a finer grid to simulate inundation for a selected region within a study area.

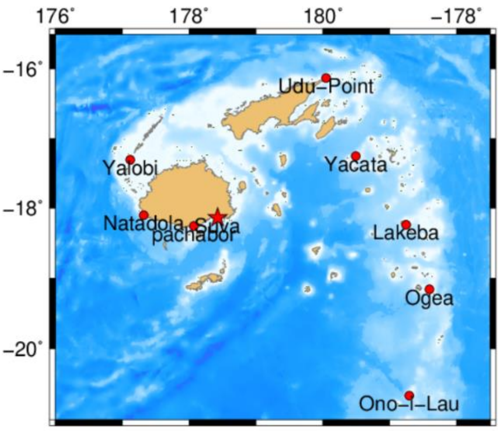


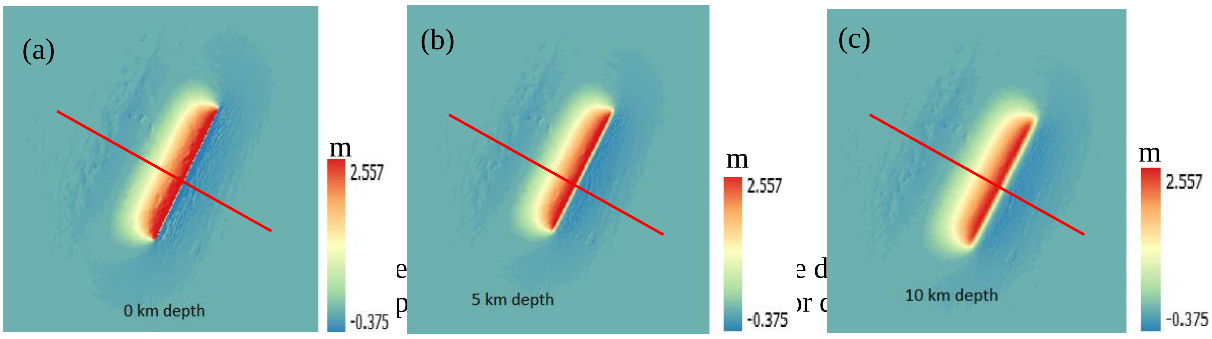
Figure 1. Close-up map of the locations of the nine selected output points in the study region.

This study selected nine output points in high tsunami risk areas identified by Rawaikala (2011). Among the nine output points, we set two study areas. First is Suva the capital city, located in one of Fiji's main islands. The second study area is Ono-i-Lau, an island that is part of the Lau group and one nearest to the Tonga trench. Figure 1 illustrates the different output points and their locations. It identifies Suva with a star indicating that it is an actual tide gauge station. The rest shows assumed tide gauge stations.

3. METHODOLOGY

We calculated the tsunami propagation, travel time, wave height, and inundation through the tsunami simulations. The Tohoku University's Numerical Analysis Model for Investigation (TUNAMI) code (Yanagisawa, 2022-2023) was employed in the tsunami wave propagation simulation in the single grids of 1 arc-min using GEBCO and ETOPO in linear and non-linear. For tsunami inundation, we applied the nesting grids of 1 arc-min, 20 arc-sec, 20/3 arc-esc using GEBCO and SRTM in non-linear.

After conducting a few tests on the results of Rawaikala (2011), we selected the 8.5 magnitude earthquake (source model "B2") along Tonga trench. This earthquake source model is located 186.4˚ east and -21.0˚ south. Added to this study is applying the mentioned effects on the horizontal and buried faults. Figure 2 illustrates the fault deformations with three different depths and horizontal impact.



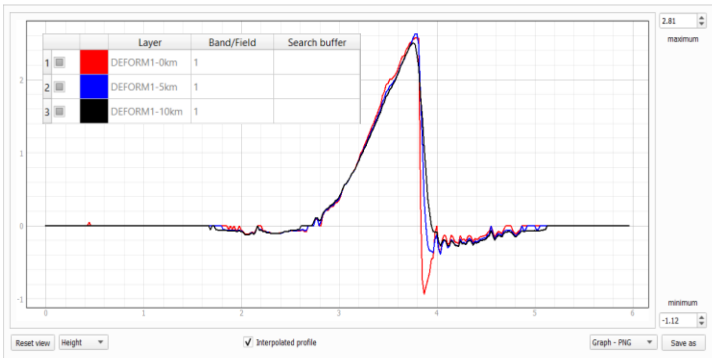


Figure 3. Transect of the vertical deformation by the three faults with different depths of 0, 5, and 10 km.

Cross-section view of vertical deformation can be crucial in estimating fault displacements. Figure 3 illustrates the cross-section view of the vertical deformation of the three faults with different depths corresponding to those in Figure 2. The red line indicates the 0 km fault depth. The blue line denotes the 5 km fault depth. Lastly, the black line indicates the 10 km fault depth. In Figure 3, the 5 km depth was recorded as the highest comparing the other two models.

4. RESULTS AND DISCUSSION

Tsunami heights vary due to various reasons. Bathymetry and topography are contributing factors. Figure 4 shows the waveforms calculated through a non-linear computation between GEBCO and ETOPO with 5 km depth and the horizontal deformation effect obtained from the tsunami simulation at the nine output points placed along the Fiji coastlines. The result contributed to the selection of which bathymetry data to be used for tsunami inundation simulations in this study.

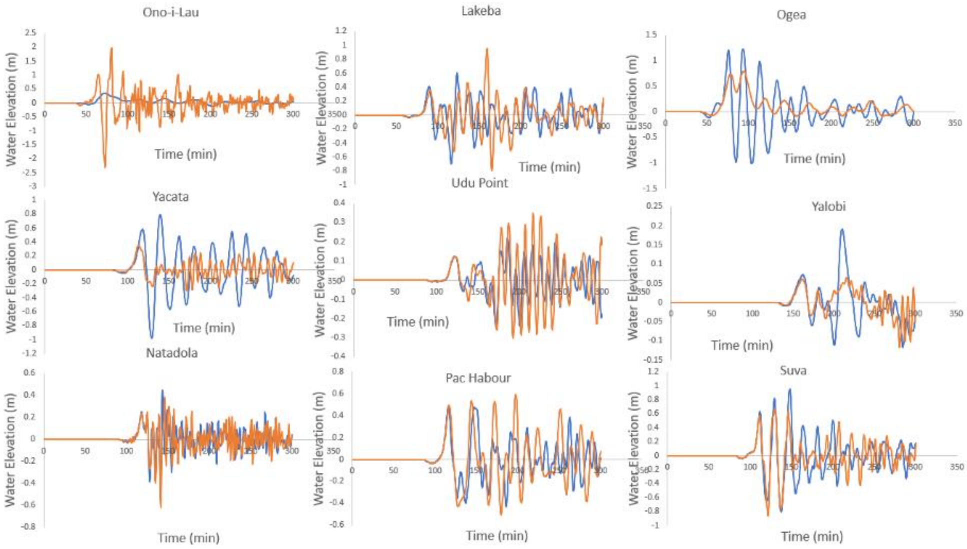


Figure 4. Comparison of the non-linear computations between GEBCO (blue waveforms) and ETOPO (orange waveforms) at the nine output points.

For the tsunami inundation modeling, the tsunami run-up and inundated area are the crucial elements or outputs contributing to the tsunami hazard assessment and disaster mitigation planning. We measured the inundation height from the mean sea level (MSL) to the tsunami inundation limit (Yanagisawa, 2022-2023). The tsunami inundation modeling focused on Suva, which is the capital of Fiji and located in Viti Levu, and Ono-i-Lau, which is an island in the Lau region, closest to the Tonga region. Figure 5 illustrate the nesting grid system with four regions. Region 4 provided finer details of the determined inundated areas in the two study areas by merging the bathymetry and topography data.

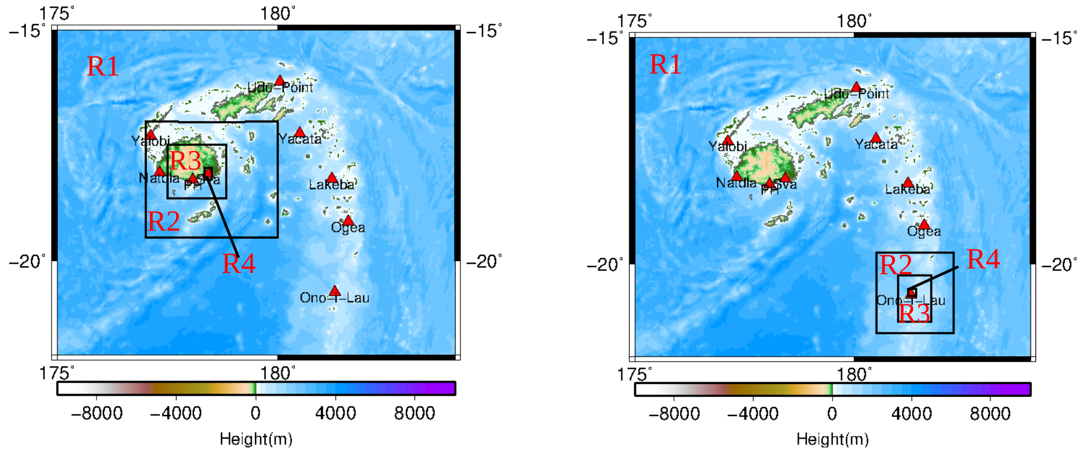


Figure 5. Nesting grids for the Suva (left) and Ono-i-Lau (right) study area with an indication of the four regions.

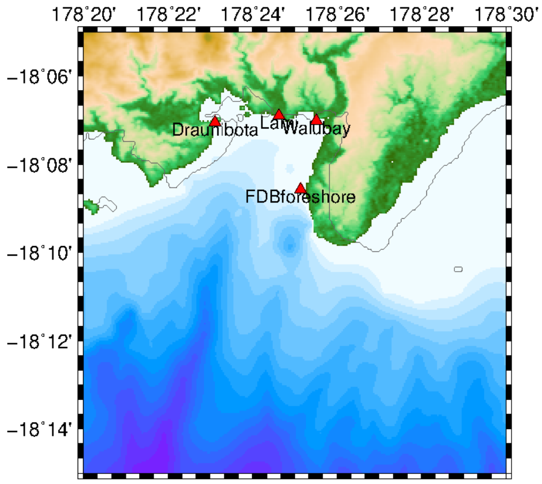


Figure 6. Merged topography and bathymetry grid data with the four assumed output points around Suva harbor. This region is denoted as R4 in Figure 5.

Suva is the capital city of Fiji and a major commercial center for other Pacific islands. Figure 6 shows the merged topography and bathymetry data around the Suva peninsula, and shows the four assumed output points, namely FDB foreshore, Walubay, Lami, and Draunibota, from which the tsunami inundation waves were recorded. Figure 7 shows the tsunami waveforms at the four output points in the Suva coastline. Also, Figure 8 shows the areas affected by the tsunami waves.

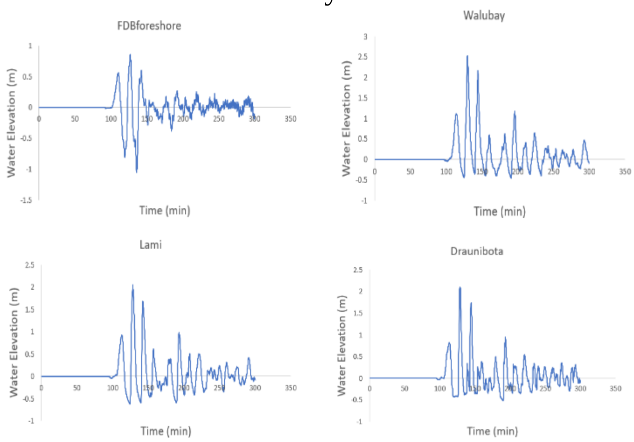


Figure 7. Tsunami simulation waveforms recorded at the four output points along the Suva coastline.

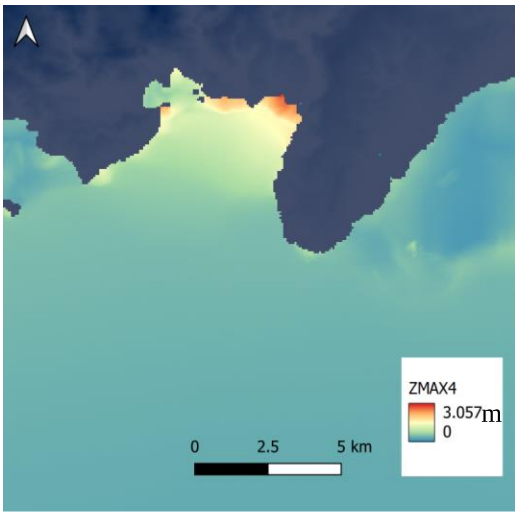


Figure 8. Inundated areas around Suva with the maximum inundation height.

For output point FDB foreshore, the first tsunami arrival time is 103.8 min, with an inundation depth of 0.66 m and an inundation height of 0.98 m. For the output point in Walu Bay, the first tsunami arrival time is 108.6 min, with an inundation depth of 2.38 m and the 3.06 m inundation height. In Lami, the first tsunami arrival time is 107.6 min, with an inundation depth of 2.05 m and the 2.44 m inundation height. Lastly, for the output point in Draunibota, the first tsunami arrival time is 108 min, with an inundation depth of 2.23 m and the 2.44 m inundation height. The maximum inundation height of 3.06 m was recorded at Walu Bay, and the earliest wave was recorded at the FDB foreshore, with a time of 103.8 min.

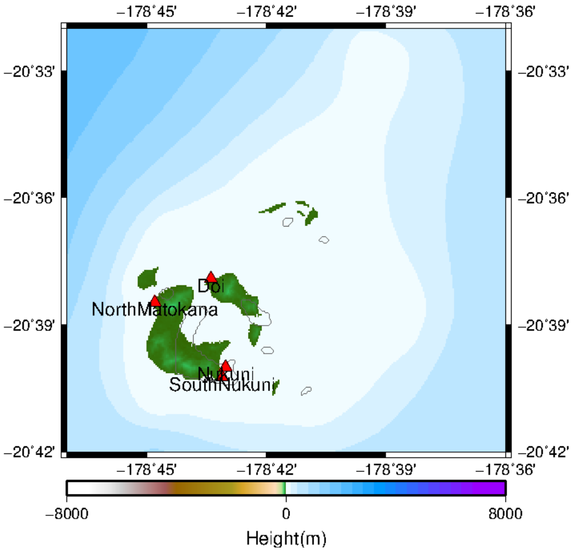


Figure 9. Merged topography and bathymetry grid data with the four assumed output points around Ono-i-Lau Island. This region is denoted as R4 in Figure 5.

Ono-i-Lau is an island located 400 km from Suva and 350 km from Tongatapu Island. According to Clark (2009), it has three main islands and several islets with a total land area of 7.9 km^2 within an 80 km^2 reef system. Figure 9 shows the merged topography and bathymetry data around Ono-i-Lau Island and the four assumed output points, of Nukuni, South Nukuni, North Matokana, and Doi, where the tsunami inundation were simulated. Figure 10 shows the tsunami waveforms at the four output points in the Ono-i-Lau coastline. Also, Figure 11 shows the areas affected by the tsunami waves.

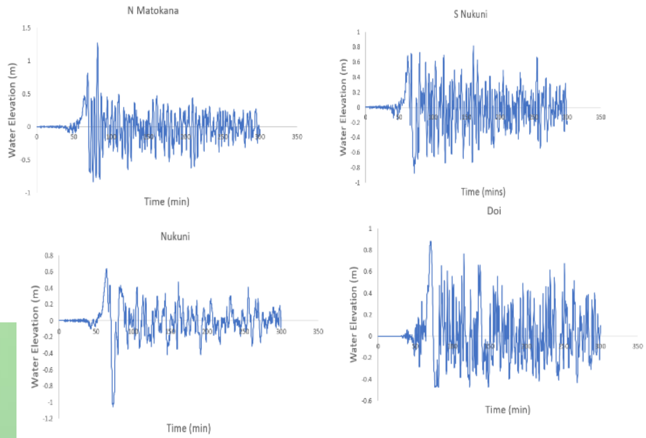


Figure 10. Tsunami simulation waveforms recorded at the four output points along the Ono-i-Lau coastline.

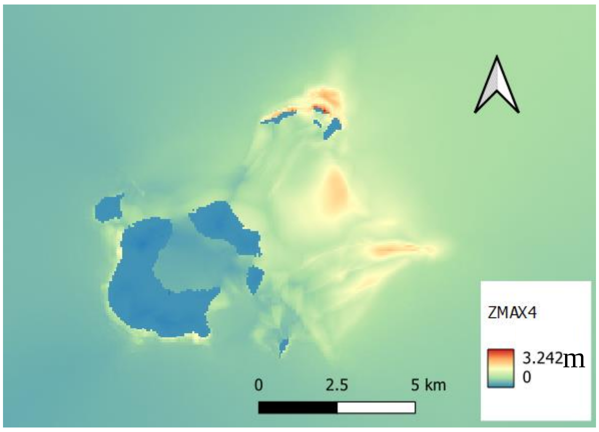


Figure 11. Inundated areas around Ono-i-Lau with the maximum inundation height.

For the output point in Nukuni, the first tsunami arrival time is 64 min, with 0.55 m inundation depth and 0.81 m inundation height. For the output point in South Nukuni, the first tsunami arrival time is 62.5 min, with 1.20 m inundation depth and 1.61 m inundation height. In North Matokana, the first tsunami arrival time is 68.4 min, with 1.49 m inundation depth and 1.60 m inundation height. Lastly, for the output point in Doi, the first tsunami arrival time is 70.7 min, with 0.66 m inundation depth and 1.01 m inundation height. The maximum inundation height of 1.61 m recorded at South Nukuni, along with the earliest wave with a time of 62.5 min.

5. CONCLUSIONS

In this study, we conducted tsunami propagation and inundation simulations along the Tonga trench with a source model earthquake of 8.5 magnitude. Along with the fault parameters, the horizontal deformation effect and buried faults of 5 km depth are also applied to examine and investigate the impact of tsunami simulations on Fiji coastlines. Also, we conducted single grid computations with the bathymetry data between GEBCO and ETOPO to compare results and to see the differences. We adopted the TUNAMI code to simulate the tsunami propagation and inundation together with the nested grid system, where for the fourth layer we merged GEBCO and SRTM data to get finer detailing of inundation simulations in Suva and Ono-i-Lau. Around Suva and Ono-i-Lau, we placed four output points to assess important parameters such as tsunami arrival times and tsunami inundation heights. For Suva, the output points were FDB foreshore, Walu bay, Lami, and Draunibota. While in Ono-i-Lau, they were Nukuni, South Nukuni, North Matokana and Doi.

Tsunami simulation results showed that assuming fault parameters and the effects. The computational result in the Suva study area showed that the maximum inundation height recorded was at Walu Bay, with a height of 3.06 meters, and the earliest wave recorded was at FDB foreshore, with a time of 103.8 minutes. As for the second study area in Ono-i-Lau, the results showed that the maximum inundation height recorded was at South Nukuni, with a height of 1.61 meters, and the earliest wave recorded was also at South Nukuni, with a time of 62.5 minutes.

The tsunami simulation results generally indicate that tsunami travel times for Suva and Ono-i-Lau are about an hour and a half, respectively. At the same time, the inundation height is more than 1.5 meters for both. Given these simulation results, the residents in these high-risk areas will know their vulnerability and give them time to move regarding future disasters like tsunamis.

ACKNOWLEDGEMENTS

This research was conducted during the individual study period of the training course “Seismology, Earthquake Engineering and Tsunami Disaster Mitigation” by the Building Research Institute, JICA, and GRIPS. I would like to express my sincere gratitude to my supervisor Dr. Bunichiro Shibazaki for his valuable support and experience which helped me to complete my research successfully, and to Dr. Yushiro Fujii for his guidance and constructive comments during my individual study.

REFERENCES

Clark, G. (2009). Early ceramic sites in southern Lau, Fiji. *Archaeology in New Zealand*, *62*, 81-89.

GEBCO Compilation Group (2023). GEBCO 2023 Grid (doi:10.5285/f98b053b-0cbc-6c23-e053-6c86abc0af7b)

Murata, S., Imamura, F., Katoh, K., Kawata, Y., Takahashi, S., & Takayama, T. (2018). *Tsunami: to survive from tsunami*. World Scientific.

Rahiman, T. I., Pettinga, J. R., & Watts, P. (2007). The source mechanism and numerical modelling of the 1953 Suva tsunami, Fiji. *Marine Geology*, *237*(1-2), 55-70.

Rawaikala, U. R. (2011). TSUNAMI SIMULATION AND HAZARD ASSESSMENT ALONG THE COASTS OF FIJI. *Bulletin of the International Institute of Seismology and Earthquake Engineering*, *45*, 103-108.

Yanagisawa, H. (2022-2023). *Lecture note on Numerical simulation of Tsunami inundation and its application*.