Tsunami hazard assessment: Lenakel, Tanna, Vanuatu

Geoscience, Energy and Maritime Division of the Pacific Community

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Geoscience, Energy and Maritime Division of the Pacific Community

Pacific Community
Communauté du Pacifique

Suva, Fiji, 2019

Original text: English

Pacific Community Cataloguing-in-publication data

Technical report no. SPC00061

Giblin, Judith

Tsunami hazard assessment: Lenakel, Tanna, Vanuatu / Judith Giblin, Naomi Jackson, Herve Damlamian, Zulfikar Begg, Moritz Wandres, Poate Degei, Salesh Kumar, Tony Kanas, Rodhson Aru and Noel Naki

1. Tsunamis – Risk assessment – Vanuatu.
2. Natural disasters – Risk assessment – Vanuatu.
3. Sea level – Vanuatu.
4. Climatic changes – Vanuatu.
5. Coastal zone management – Vanuatu.
6. Cyclones – Vanuatu.
7. Ocean waves – Vanuatu.

I. Giblin, Judith II. Jackson, Naomi III. Damlamian, Herve IV. Begg, Zulfikar V. Wandres, Moritz
VI. Degei, Poate VII. Kumar, Salesh VIII. Kanas, Tony IX. Aru, Rodhson X. Naki, Noel XI. Title
XII. Pacific Community

551.4637099595 AACR2

ISBN : 978 982 00 1217 2

Prepared for publication at SPC's Suva Regional Office,
Private Mail Bag, Suva, Fiji, 2019
www.spc.int | spc@spc.int

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Tables

GLOSSARY

Amplitude:	Height of the crest of the tsunami wave above mean sea level
Bathymetry:	The measurement of the depth of the ocean floor from the water surface
Hazard curves:	Describes the relationship between the return period and the maximum tsunami amplitude for a particular model output point. The tsunami amplitude given on the y-axis is predicted to be exceeded with the average return period given by the x-axis.
Return period:	The average length of time expected between events exceeding a given amplitude at a given offshore depth
Tsunami:	Wave generated by a sudden disturbance of water. It is fast moving with a small amplitude in deep water but slows down and increases in height as it reached shallow water.
Tsunamigenic:	Earthquake capable of producing a tsunami (commonly along major subduction zone plate boundaries)

ACKNOWLEDGMENTS

This report was prepared under the the SPC Recovery Support for Tropical Cyclone Pam project funded by the KfW Bank Group. The report was prepared with contributions from a large number of people who assisted during field surveys and data processing.

The authors would like to express their appreciation and gratitude to the following organisations and individuals:

- the Vanuatu Land and Surveys Department,
- the Lenakel Town Council,
- GNS Science, MDRR data hosts,
- Judith Giblin, Naomi Jackson, Herve Damlamian, Zulfikar Begg, Moritz Wandres, Poate Degei, Salesh Kumar (Geoscience Energy and Maritime Division, Pacific Community), and
- Tony Kanas, Rodhson Aru, Noel Naki (Department of Lands and Surveys, Vanuatu Government).

EXECUTIVE SUMMARY

Tropical Cyclone (TC) Pam made landfall in Vanuatu on 13 March 2015, causing severe damage to parts of the country. A post-disaster needs assessment (Esler 2015) completed less than a month after the cyclone highlighted the need for multi-hazard mapping of urban areas and for an action plan to identify safe areas for future growth. The report also emphasised the importance of having a sound scientific basis for predicting hazards and a reliable forecasting system.

As part of a recovery and support package commissioned by the *Kreditanstalt für Wiederaufbau* (KfW) Bank Group, a team from the Geoscience, Energy and Maritime Division of the Pacific Community (SPC) undertook a baseline (topography and bathymetry) survey of Lenakel on the island of Tanna in December 2016. The survey utilised unmanned aerial vehicle (UAV) and global navigation satellite system (GNSS) technology, and a single-beam echo-sounder to acquire topography data. The data were used primarily in the preparation of various multi-hazard mapping products to inform improved resilience of coastal communities.

Four key inundation hazards were assessed: tsunami, storm surge, tropical cyclones and swells. This report focuses on outlining the tsunami inundation work that was carried out in support of Lenakel's tsunami evacuation planning.

In this study, the inundation from 16 tsunami scenarios from the World Bank Mainstreaming Disaster Risk Reduction (MDDR) project were investigated. An indicative likelihood was attributed to each scenario, based on the resulting maximum tsunami wave height offshore Lenakel, using the Geoscience Australia new probabilistic tsunami hazard assessment (GA 2018).

As requested by the Government of Vanuatu, the designed worst case scenario, a tsunamigenic earthquake of magnitude 9.4 generated along the New Hebrides Trench, was used during a workshop in Lenakel to plan tsunami evacuation routes. The draft plan was then used to support the first tsunami drill exercise in Lenakel (coordinated by the National Disaster Management Office (NDMO) and Care International), which took place on 18 October 2018.

1 INTRODUCTION

1.1 Background

In December 2015, the Government of the Federal Republic of Germany, through the *Kreditanstalt für Wiederaufbau* (KfW) Bank Group, signed an agreement with SPC for the delivery of a project to support Pacific Islands affected by TC Pam.

The project, SPC Recovery Support for Tropical Cyclone Pam, is implemented through 42 packages that include advisory services, field activities and investments to support the recovery from the cyclone in affected parts of Vanuatu, Tuvalu, Kiribati and Solomon Islands. The project is structured in two phases. The first phase comprised technical capacity support for damage assessments in the immediate aftermath of the cyclone, whilst the second phase, significantly longer, involved implementation of a combination of multi-sector activities targeted at specific recovery needs identified by each country.

1.2 Project objectives and outcomes

Vanuatu is highly vulnerable to natural hazards, both geophysical and hydro-meteorological. The post-disaster need assessment (PDNA) (Esler 2015) report emphasises that a mid- to long-term reconstruction effort needs to be undertaken in order to improve resilience in all sectors.

The PDNA also highlights the need for multi-hazard mapping of urban areas and action plans to identify safe areas for future growth, the importance of having a sound scientific basis for predicting hazards, and a reliable forecasting system.

The Geoscience, Energy and Maritime Division of SPC proposed to assist the multi-hazard mapping effort already under way in Port Vila and Luganville (World Bank MDRR project), by undertaking a similar activity in an appropriate location, namely, Lenakel on Tanna (population about 14,000 people). The study aims to identify the probable risk of coastal inundation from tsunamigenic earthquakes and cyclones, and the co-occurrence of large swells with possible high storm-tide level. The study also investigates the possible exacerbation of the inundation risk inherent from sea-level rise. Community members were engaged to provide information and data, and to participate in the development of response plans.

Through this project, SPC aimed to deliver:

- geospatial baseline data used in cross-sector activities, e.g. topography, bathymetry;
- hazard maps to identify low hazard-prone land suitable for future growth;
- tools and training for the dissemination of the information, both at the central and provincial government level; and
- support response plans for the municipality and adjacent communities.

1.3 Purpose of this report

This report describes the methodology and results of the tsunami hazard assessment computed for Lenakel, Tanna Island, Vanautu. The tsunami modelling was computed using a software package called GeoCLAW, based on earthquake deformation grids provided by the World Bank MDRR project. This report outlines the tsunami software used, the software methodology, and the data processing of the bathymetry grids and earthquake deformation grids.

2 VANUATU TSUNAMI THREAT PROFILE

The archipelago of Vanuatu consists of 83 volcanic islands (65 inhabited) covering a total land area of 12,200 km^2. The islands are home to a population of 253,000 people, distributed among six provinces: Malampa, Penama, Sanma, Shefa, Tafea and Torba. The households in in the rural areas of these provinces primarily engage in subsistence livelihoods (Esler 2015).

Vanuatu's exposure to both geophysical and hydro-meteorological hazards, and limited financial and technical capacity for disaster preparedness and response makes it one of the world's most vulnerable countries. Vanuatu is located along the Pacific Ring of Fire and tropical waters resulting in high exposure to volcanic eruptions, cyclones, earthquakes, tsunamis, storm surges, coastal and river flooding, and landslides (Esler, 2015). The threat of tsunami is faced by a complex mixture of threats from local, regional and distant sources whose effects at any location in the southwest Pacific is highly dependent on variation in seafloor shape between the source and the affected area (Thomas and Burbidge, 2008).

Figure 1: The Pacific ring of fire (National Geographic, 2018)

Vanuatu is situated along the Pacific "ring of fire", which describes tectonic plate boundaries with extremely active seismic zones capable of generating large earthquakes and, in some cases, major tsunamis (Figure 1). In 1999, a magnitude 7.5 earthquake caused extensive damage to Pentecost Island, In addition, a six-metre tsunami wave was generated that completely devastated the village of Baie Martelli (PCRAFI 2011). These events resulted in more than 10 deaths, over 100 injured and millions of dollars' worth of damage. Of the 10 deaths, five were attributed to the tsunami.

PCRAFI (2011) reported that Vanuatu has a 40% chance of experiencing a very strong to severe level of ground-shaking within the next 50 years. This may damage moderate- to well-engineered buildings and compromise structures that are built with less stringent criteria.

Figure 2: The tectonic plates situated near Vanuatu. The New Hebrides Trench is caused by the subduction of the Australian plate below the Pacific plate (Makin 2018).

According to Thomas and Burbidge (2008), Vanuatu has a 4.7 m maximum tsunami amplitude with a one in 2000 year chance from the New Hebrides or Kermadec trench. The closest subduction zone near Vanuatu is the New Hebrides Trench (Figure 2). It lies west of Vanuatu and is a primary source of hazard for the region, as the maximum amplitudes for a 2000-year return period are significantly higher along the western shores, with values of over 4 m on Espiritu Santo, Malakula, Efate, Erromango, Tanna and Aneityum. The eastern shores have lower maximum amplitudes, with 1.9 m near Pentecost. At a 100-year return period, maximum amplitudes of up to 0.6–0.7 m can be expected at some model outputs along Vanuatu (Figure 3).

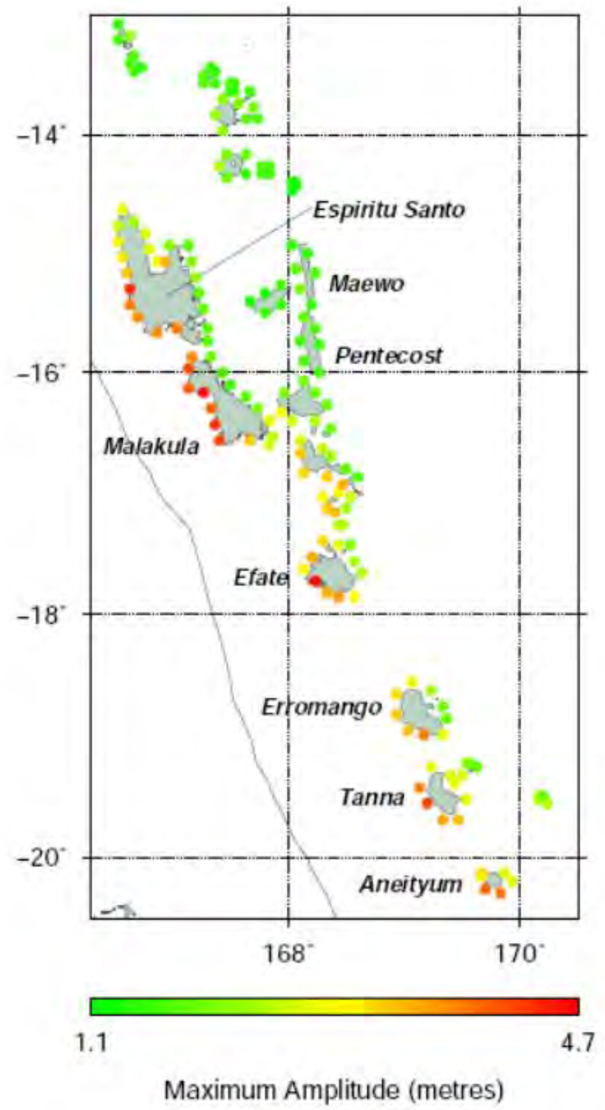

Figure 3: Maximum amplitude at a 2000-year return period for all model output points (Thomas and Burbidge 2008)

3 TSUNAMI MODELLING SOFTWARE – GEOCLAW

To assess the tsunami hazard, the SPC team used the tsunami model Clawpack (version 5). Clawpack (Conservation Laws Package) is a collection of finite volume methods for linear and non-linear hyperbolic systems of conservations laws (Clawpack Development Team, 2018). It is an open source software (http://www.clawpack.org/) and is well maintained by the development team.

The key feature of the model is the adaptive mesh refinement that is included in a specialised version, GeoClaw, that is well tested for geophysical flow problems and focuses on two-dimensional, depth-averaged, shallow-water equations for flow over varying bathymetry (Clawpack Development Team 2018).

3.1 GeoCLAW parameters – staying conservative

While simulating the tsunamis using GeoClaw, a primary concern was ensuring that the model was set up and run conservatively. This was done because of the lack of historical data, which limited the ability to accurately validate and adjust the model to Lenakel. Model parameters, such as friction coefficient, were set conservatively to allow for a safety margin.

3.2 Model validation

The tsunami model settings were validated against tide gauge observations of the 2017 magnitude 6.9 tsunamigenic earthquake that occurred 226 km southwest of Nadi, Fiji on 3 January 2017 at 21:52:30 (UTC) (Figure 4). The focal mechanism indicates a normal fault at a depth of 15.5 km, following the direction of the ridges (35° strike), with the block on the southeast earthquake side sliding down the fault plane (49° dip) and a −74° rake angle (Kumar and Bosserelle 2017; USGS 2018).

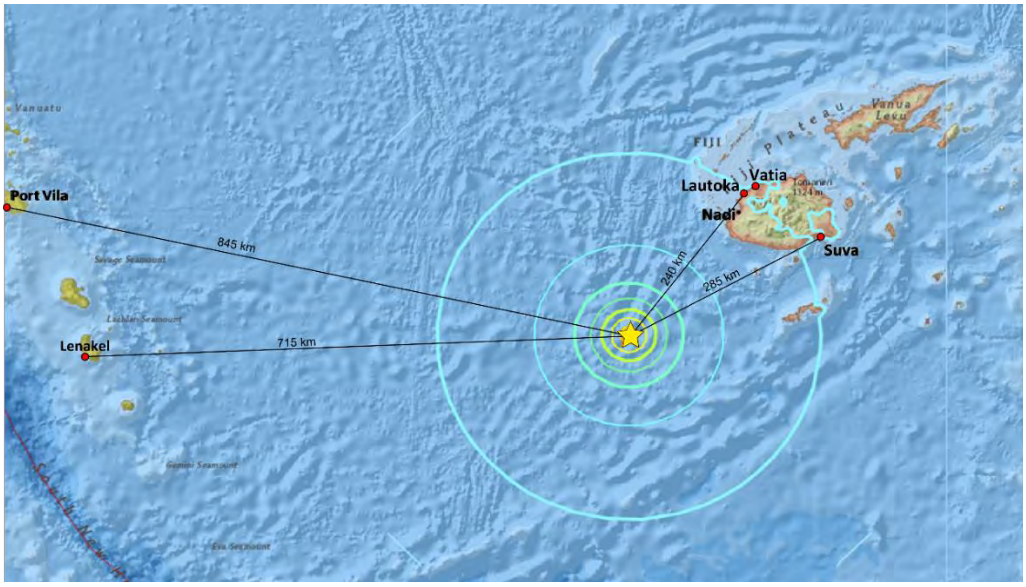

Figure 4: Earthquake and tide gauge locations, adapted from the USGS earthquake hazards website (Kumar and Bosserelle 2017)

Tide gauges located in Suva and Lautoka on Viti Levu, Fiji, recorded very small tsunami wave heights (<0.02 m) but the tide gauges in Port Vila and Lenakel in Vanuatu, recorded larger waves of 0.05 m and 0.26 m, respectively. The leading wave reached the Lenakel tide gauge 50 minutes after the earthquake (Kumar and Bosserelle 2017).

Figure 5 illustrates the comparison between the waves recorded by the Lenakel tide gauge (blue) and the simulated waves (orange). The dashed lines show the confidence level of 0.065 m (6.5 cm) above and below the Lenakel tide gauge.

Figure 5 indicates that the signals are in phase, even though the simulated model amplitude is much higher. This discrepancy is mainly attributed to the tsunami having a short period (~ five minutes). Furthermore, it shares similar harmonics with the natural oscillation of the bay. The interaction between the harmonics complicates separating the tsunami wave signal from the Lenakel bay oscillation. In addition, the earthquake is not well constrained, leading to uncertainties in source data and earthquake mechanism.

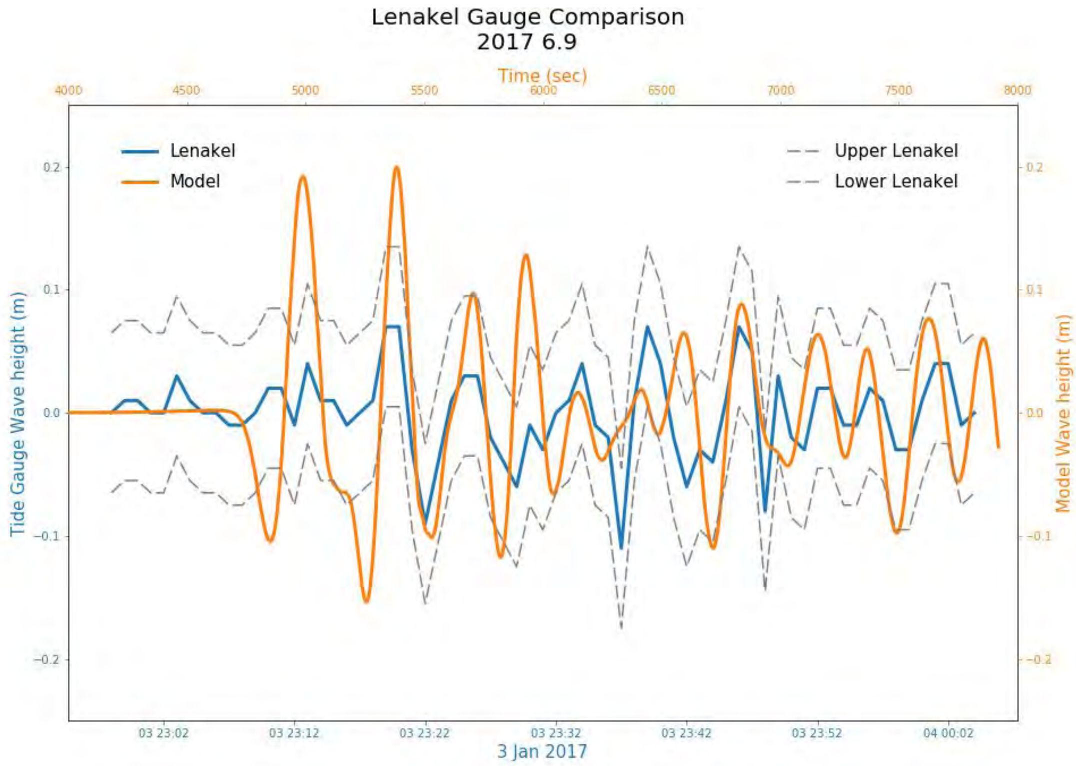

Figure 5: Comparison of Lenakel tide gauge and the computed tsunami model sea height data

The validation displayed some uncertainty, however, as the parameterisation was chosen conservatively and wave amplitudes were over-predicted. This resulted in a margin of safety, as larger than expected wave heights resulted in more conservative evacuation routes and centres.

3.3 Sensitivity analysis

The sensitivity of the grid resolution was evaluated by comparing the results of simulations with different grid resolutions. The analysis reviewed the resolution at 30 km, 20 km and 10 km grids. As shown in Figure 6, the results varied slightly with different grid sizes. The SPC team therefore implemented a 10 km grid resolution to allow for the highest accuracy in the simulation, despite increased computational costs.

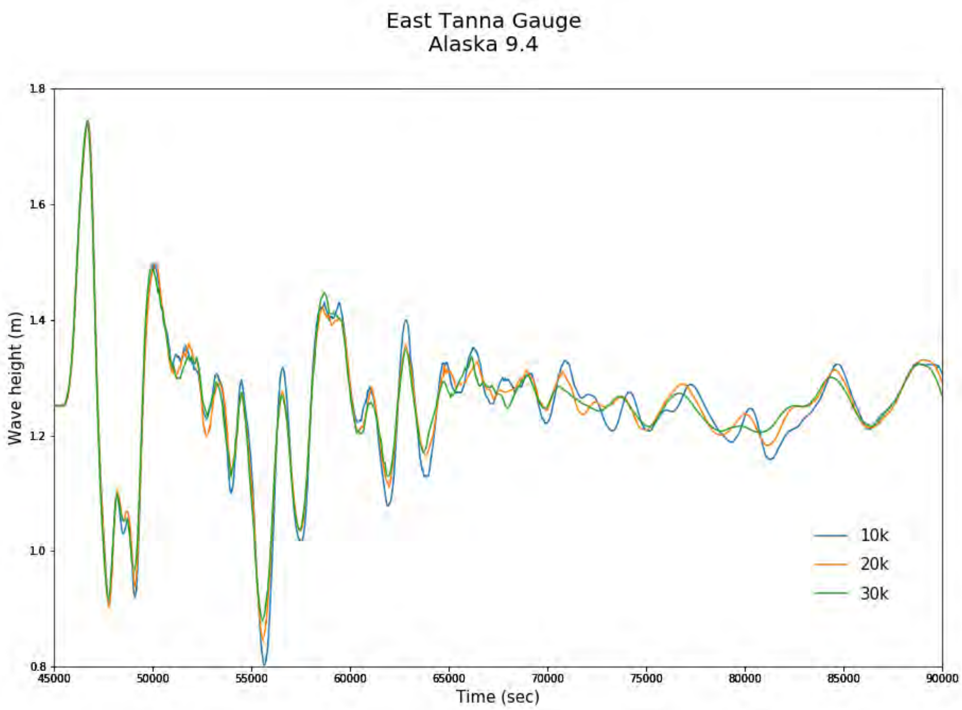

Figure 6: Comparison of the sensitivity analysis carried out on 30 km, 20 km and 10 km resolution grids

4 METHODOLOGY

The tsunami hazard assessment for Lenakel was based on a numerical model study, using the tsunami model GeoClaw, a component of the Clawpack package (http://www.clawpack.org/geoclaw.html). Information on how to run GeoClaw and set up topography and earthquake deformation grids can be obtained from the website. The topography grids used in this computation were collected using unmanned aerial vehicles and bathymetry data were collected using multi-beam echo-sounders. A detailed account of this process is available in Report.

The earthquake deformation grids were collected from the Mainstreaming Disaster and Risk Reduction (MDRR) project implemented by the Vanuatu Meteorology and Geohazards Department. The custodian for the grids was GNS Science, which provided the tsunamigenic earthquake hazard deformation grids that were used to assemble hazard data for Port Vila and Luganville under the MDRR project.

4.1 MDRR scenarios

An aspect of the MDRR project was the development of tsunami evacuation maps using numerical modelling of 15 tsunamigenic earthquake scenarios that included local, regional and distant events. The seismic events were intended to represent plausible worst case scenarios. However, there is significant uncertainty about the mean return period of some of the seismic scenarios modelled (Heron and Lukovic 2015).

Table 1 shows the earthquake source scenarios that were simulated under the MDRR project with their corresponding magnitude. These scenarios were used to map tsunami evacuation maps for Port Vila and Luganville in Vanuatu. To ensure consistency, the SPC team used the same earthquake deformation grids (provided by GNS Science) to simulate tsunami inundation for Lenakel. Figure 7 illustrates the mapped locations of the scenarios.

Table 1: Tsunamigenic earthquake source scenarios simulated under the MDRR project and used for this Lenakel tsunami modelling

No	Source	Magnitude (Mw)
1	Alaska	9.4
2	Aleutian	9.4
3	Chile	9.4
4	East Philippine	9.4
5	Kuril Islands	9.4
6	Marianas	9.4
7	Mexico	9.4
8	Nankai	9.4
9	Peru	9.4
10	New Hebrides Trench	9.0
11	New Hebrides Trench	9.4
12	New Hebrides Back-Arc	8.2
13	Tonga Trench	9.0
14	Northern Tonga Trench	8.2
15	Tonga Trench near Niuatoputapu	8.5

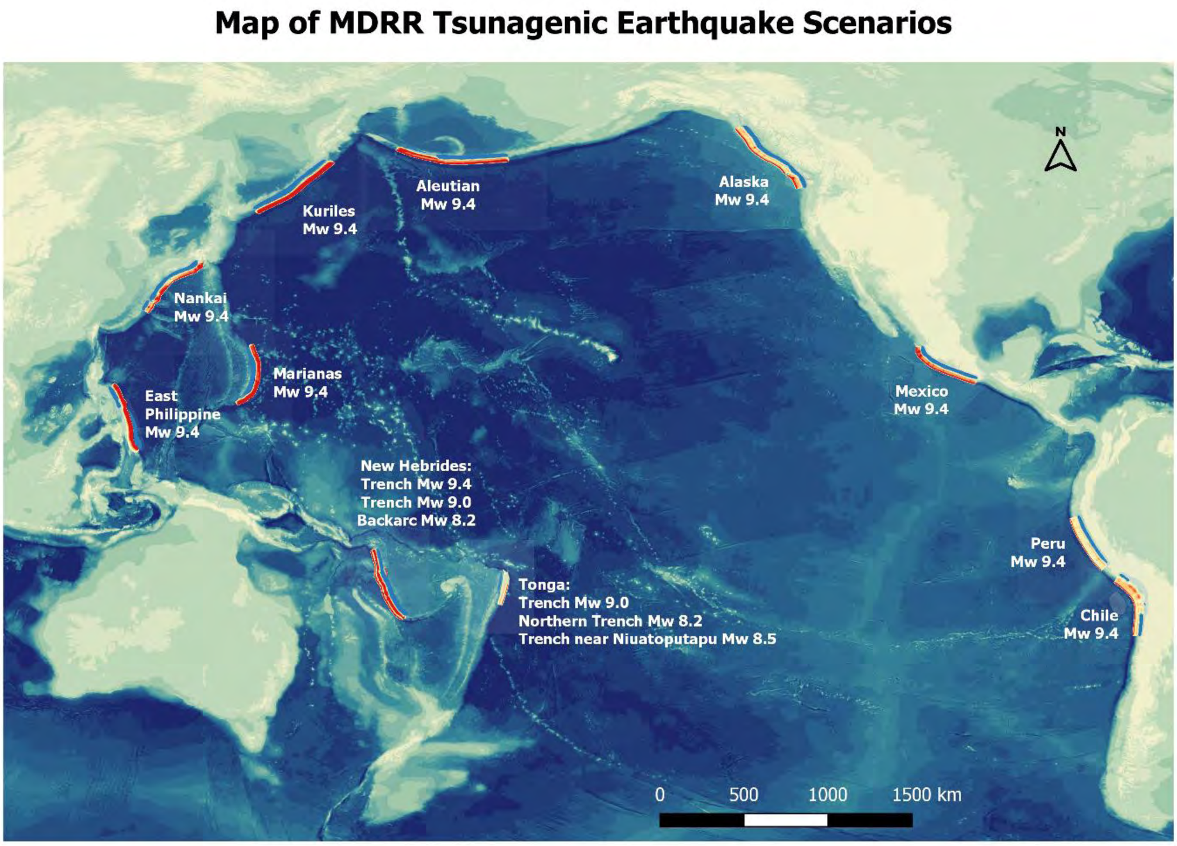

Figure 7: Map of the MDRR tsunamigenic earthquake scenario locations

4.2 Historical tsunami

In addition, historical tsunamigenic earthquakes were investigated. Over the past 150 years, two large tsunamis were triggered by major earthquakes on 28 March 1875 and 20 September 1920 (Ioualalen et al. 2017). Historical tsunami observations (mostly from testimonials in missionary reports), earthquake scenarios and tsunami modelling were used to derive the magnitudes of these historical tsunamigenic earthquakes.

In this study we chose the 28 March 1875 Mw 8.3 scenario. The earthquake deformation grid was obtained from the Okada model and used in GeoClaw.

4.3 Sea-level rise inclusion scenarios

In addition to the 15 MDRR scenarios and an 1875 historical scenario, sea-level rise (SLR) was considered in this assessment to ensure that flood risk of the potential evacuation zones remains low in the decades to come. The SLR component was added to each of the 16 scenarios, resulting in a total of 32 scenarios.

The SLR projections for Vanuatu were retrieved from the Australian Bureau of Meteorology and CSIRO (2014). Continuing the approach of being conservative, the worst case 2090 RCP 8.5 scenario was chosen. Under this scenario, the projected relative sea-level change near Vanuatu is 42–89 cm (Figure 8). For this research, an SLR of 0.64 cm was selected.

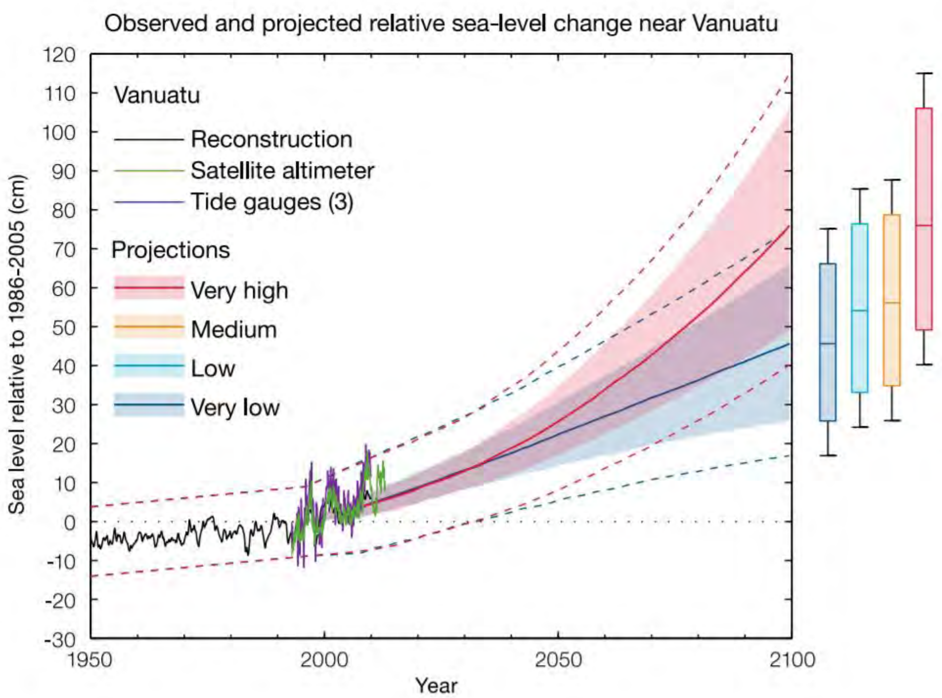

Figure 8: Tide gauge records (purple) of relative sea-level and satellite record (green) since 1993. Reconstructed sea-level data at Vanuatu (black) since 1950. Also, 1995–2100 multi-model mean projections for very high (red solid line), and very low (blue solid line) emission scenarios, with 5–95% uncertainty range in shaded red and blue regions. Range of projections for the four emission scenarios by 2100 are show by the bars on the right (Australian Bureau of Meteorology and CSIRO 2014).

5 RESULTS

The maximum simulated inundation for all 32 scenarios was calculated and inundation maps were generated and provided to the Government of Vanuatu .

Table 2 lists 12 scenarios with the largest inundation, along with the corresponding earthquake magnitudes. The table also lists the corresponding inundation maps for each scenario (Figures 9–20).

Table 2: List of tsunamigenic earthquake scenarios that revealed the most inundation heights out of the 32 scenarios tested that were recorded on the Lenakel coastline from the tsunami simulation. Also provided is the range of inundation heights and arrival time recorded with the corresponding 3D plot figure number.

No.	Scenario	Magnitude (Mw)	Inundation heights (m)	Arrival time	Figure No.
1	Historical Tsunami 1875	8.3	3.6 – 7.2	1 min	Figure 9
2	Historical Tsunami 1875 with SLR (2090)	8.3	4.1 – 7.9	1 min	Figure 10
3	Alaska	9.4	0.0 – 1.9	11 hrs 13 min	Figure 11
4	Alaska with SLR (2090)	9.4	0.0 – 2.6	12 hrs 54 min	Figure 12
5	Aleutian	9.4	0.0 – 2.5	11 hrs	Figure 13
6	Aleutian with SLR (2090)	9.4	0.5 – 3.1	11 hrs	Figure 14
7	New Hebrides Trench	9.0	2.4 – 4.7	1 min	Figure 15
8	New Hebrides Trench with SLR (2090)	9.0	3.0 – 5.5	1 min	Figure 16
9	New Hebrides Trench	9.4	17 - 20	1 min	Figure 17
10	New Hebrides Trench with SLR (2090)	9.4	18 - 20	1 min	Figure 18
11	Tonga Trench	9.0	0.0 – 1.7	3 hrs 22 min	Figure 19
12	Tonga Trench with SLR (2090)	9.0	0.0 – 2.4	3 hrs 22 min	Figure 20

Figure 21 Tsunami inundation map of the historical tsunami in 1875, gives a template of one the maps created for the Government of Vanuatu that was provided to them during our workshops. It is also available at SPC upon request.

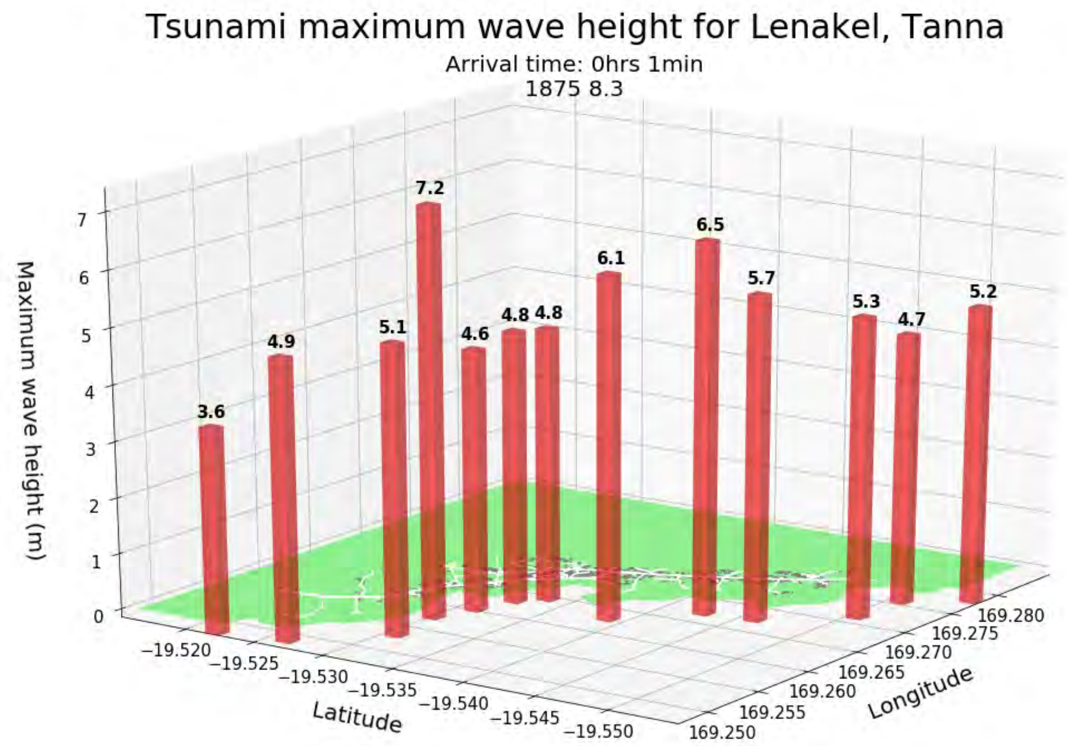

Figure 9: Plot-3D of the historical tsunami 1875 inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of one minute

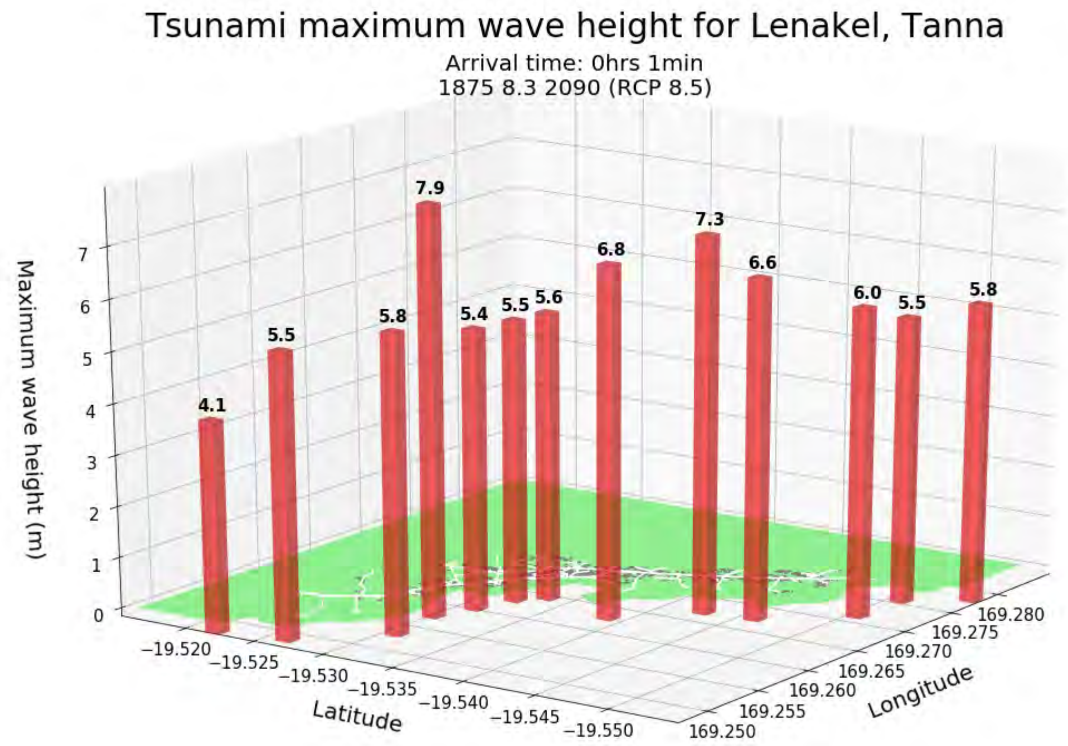

Figure 10: Plot-3D of the historical tsunami 1875 (with 2090 sea-level rise) inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of one minute

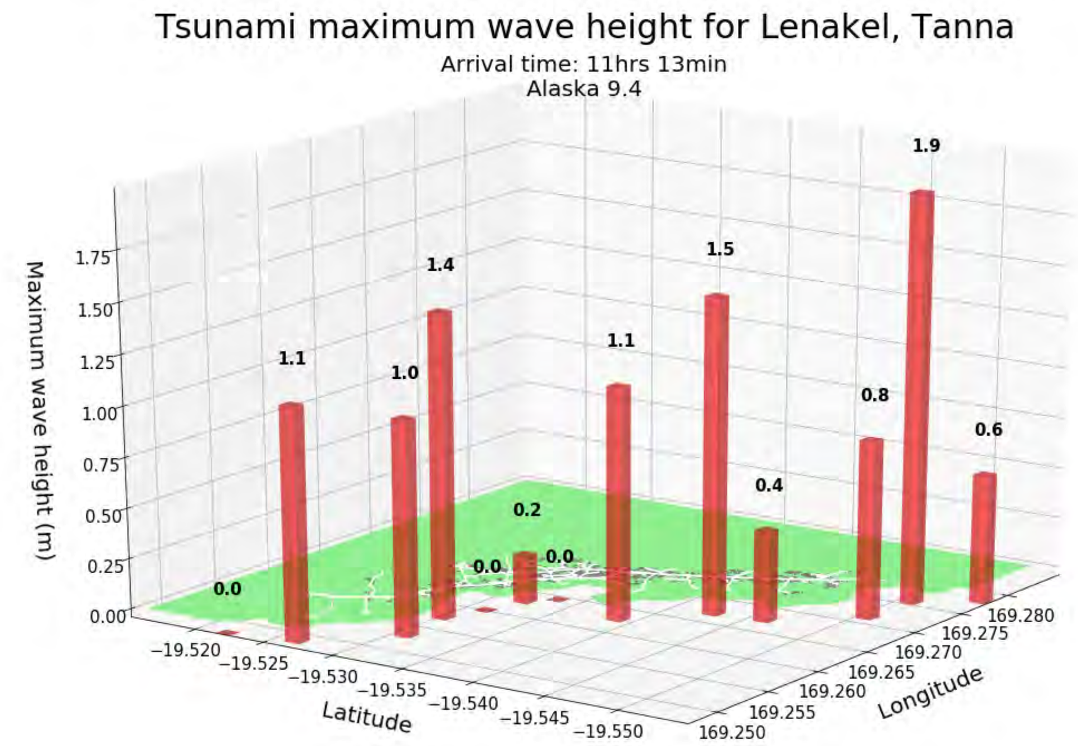

Figure 11: Plot-3D of the Alaska Mw 9.4 tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of 11 hours and 13 minutes

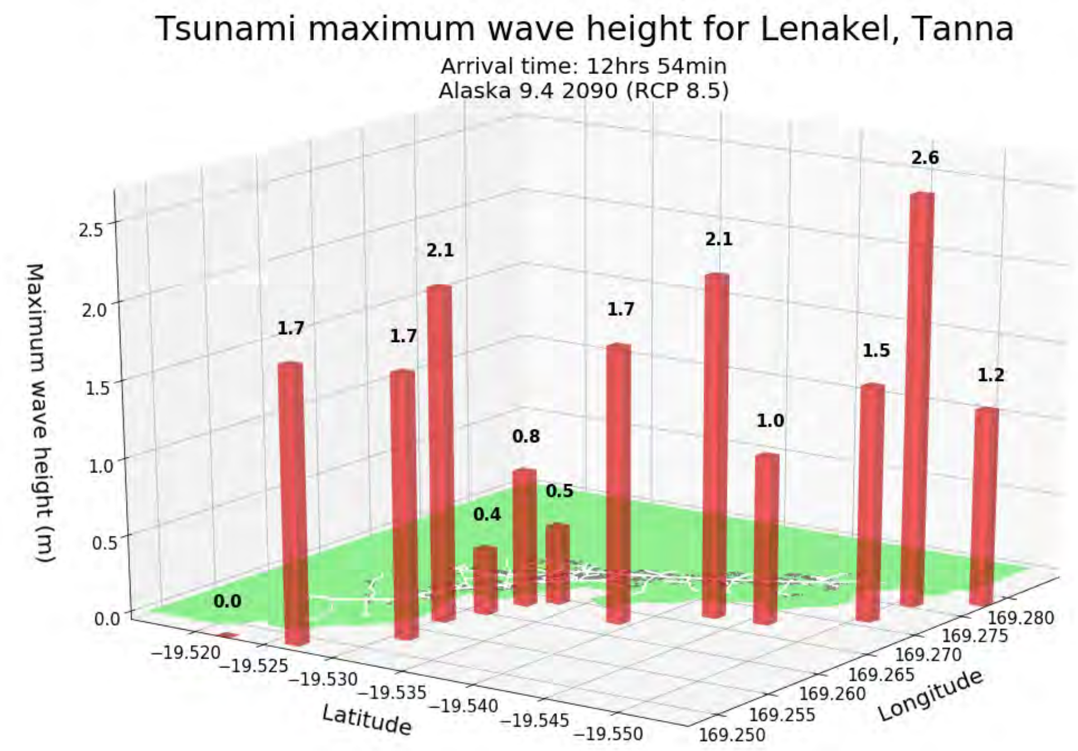

Figure 12 Plot-3D of the Alaska Mw 9.4 (with 2090 sea-level rise) tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of 12 hours and 54 minutes

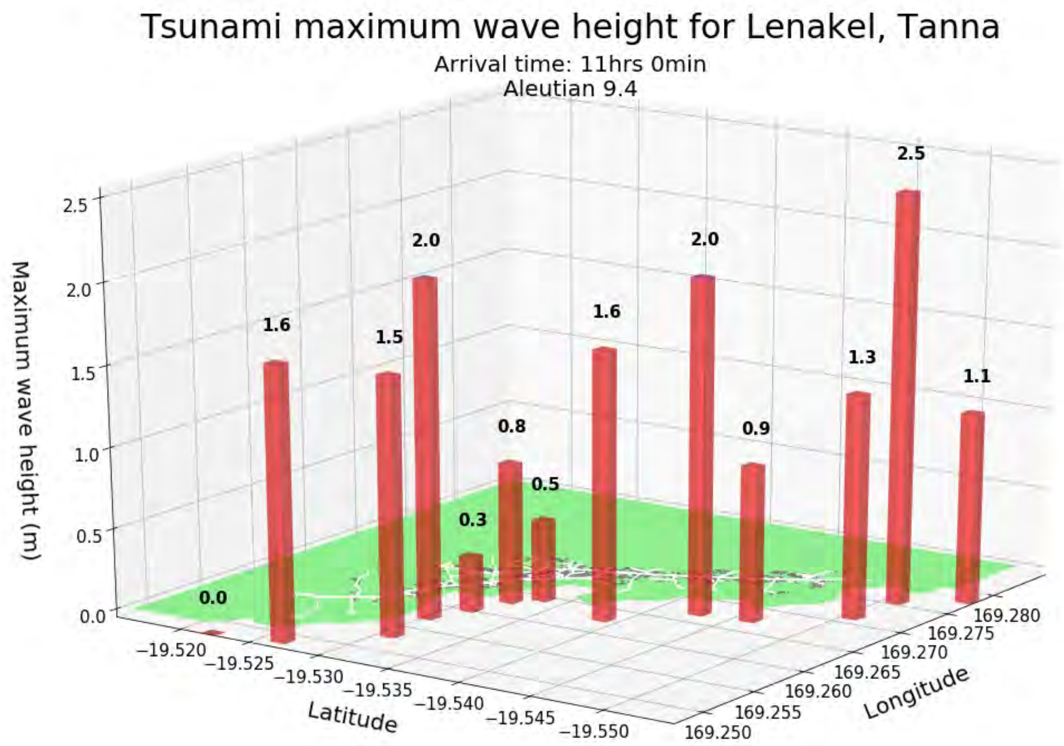

Figure 13: Plot-3D of the Aleutian Mw 9.4 tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of 11 hours

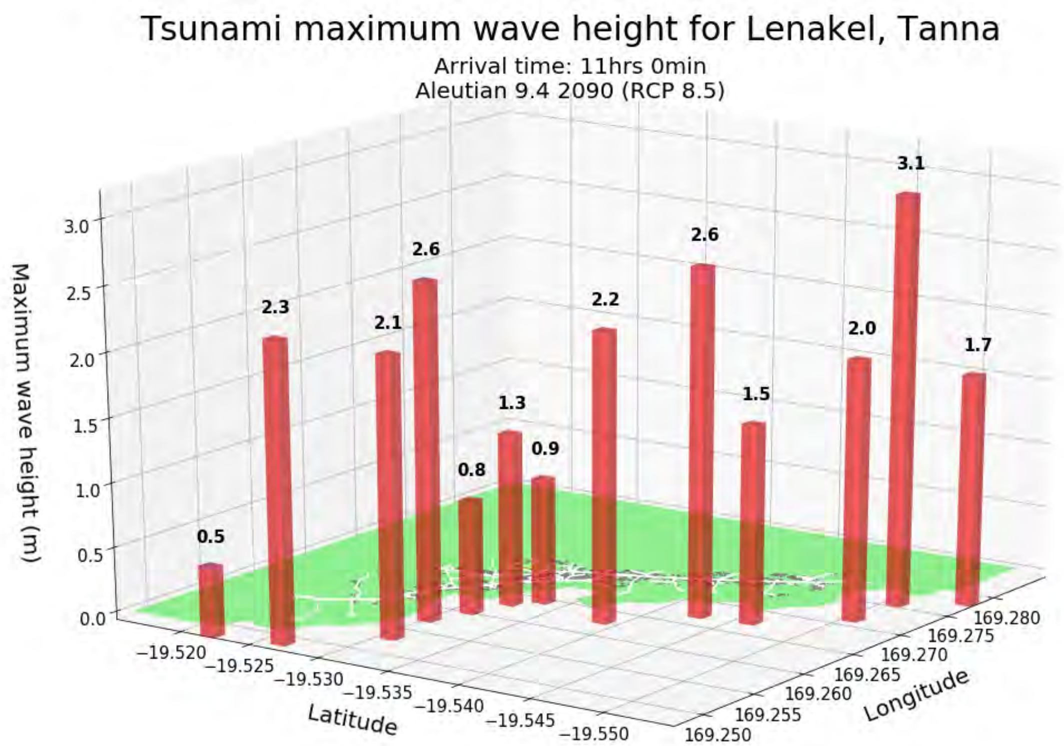

Figure 14: Plot-3D of the Aleutian Mw 9.4 (with 2090 sea-level rise) tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of 11 hours

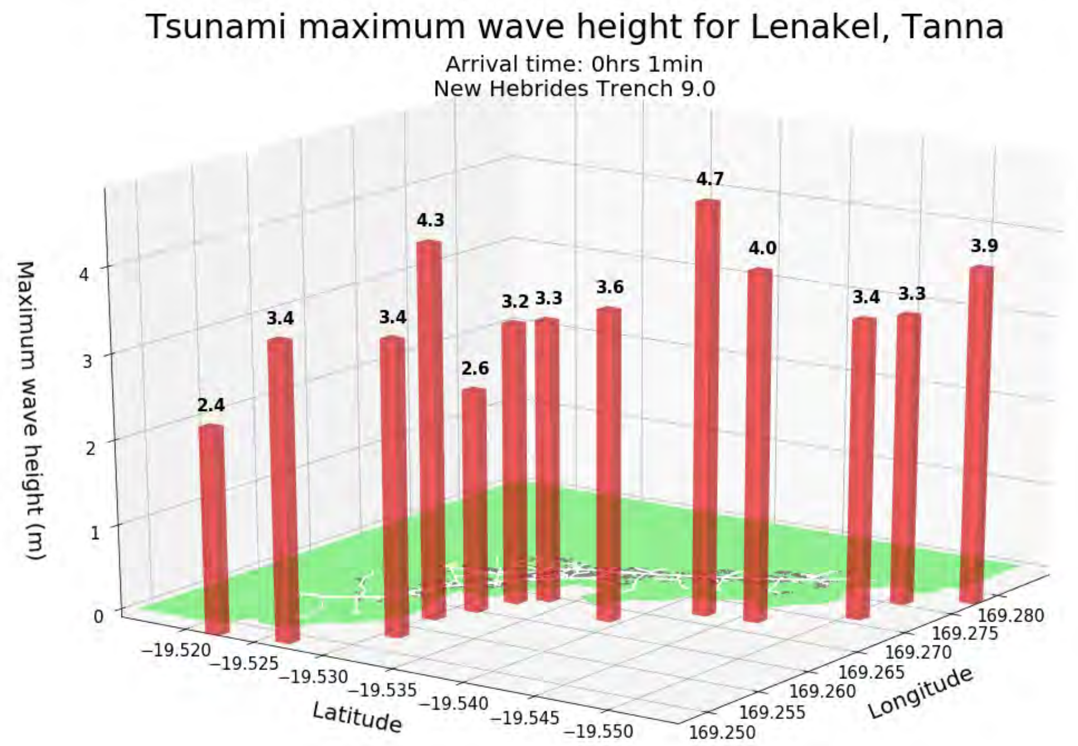

Figure 15: Plot-3D of the New Hebrides Trench Mw 9.0 tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of one minute

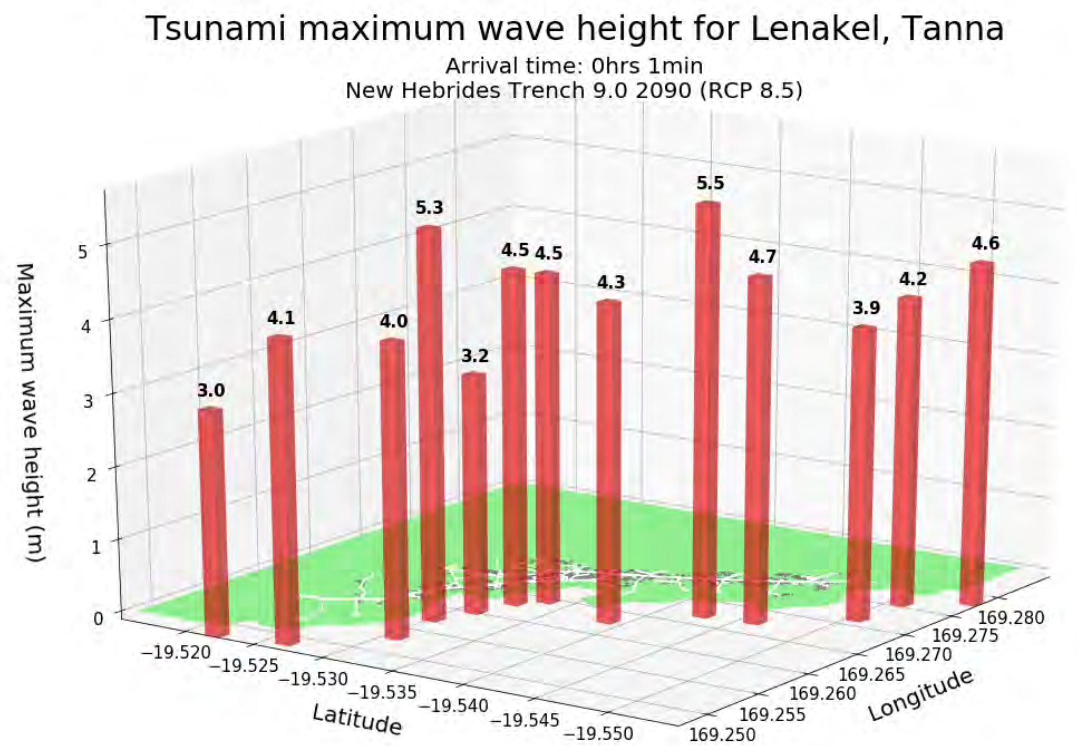

Figure 16: Plot-3D of the New Hebrides Trench Mw 9.0 (with 2090 sea-level rise) tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of one minute

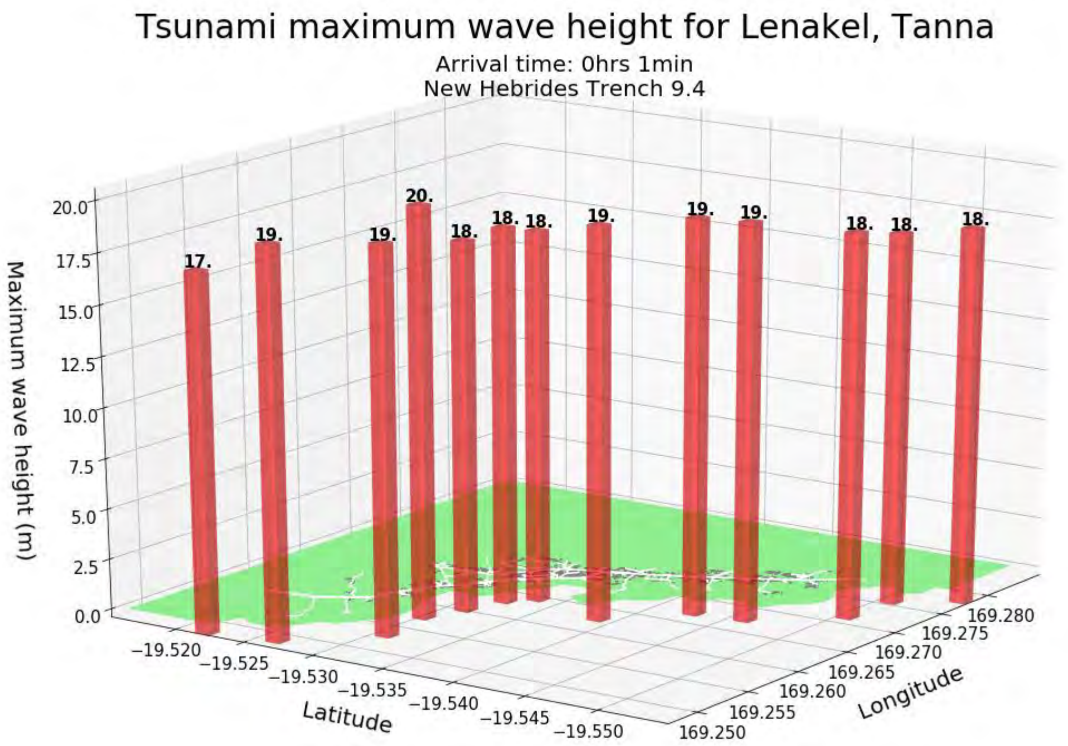

Figure 17: Plot-3D of the New Hebrides Trench Mw 9.4 tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of one minute

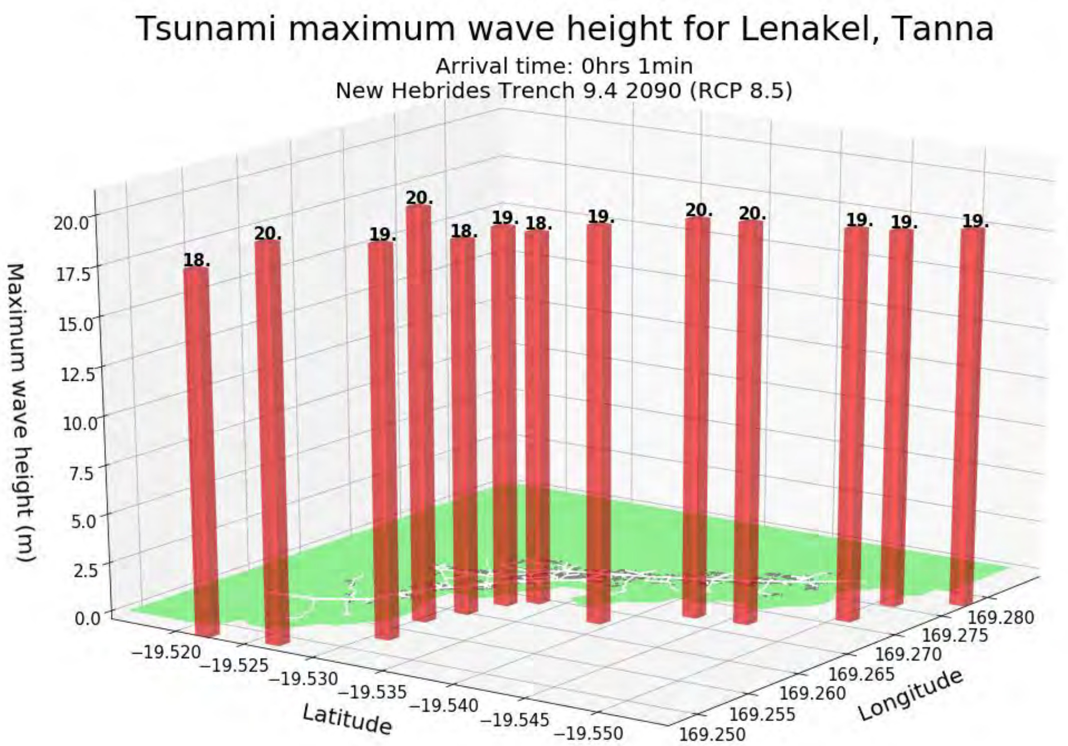

Figure 18: Plot-3D of the New Hebrides Trench Mw 9.4 (with 2090 sea-level rise) tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of one minute

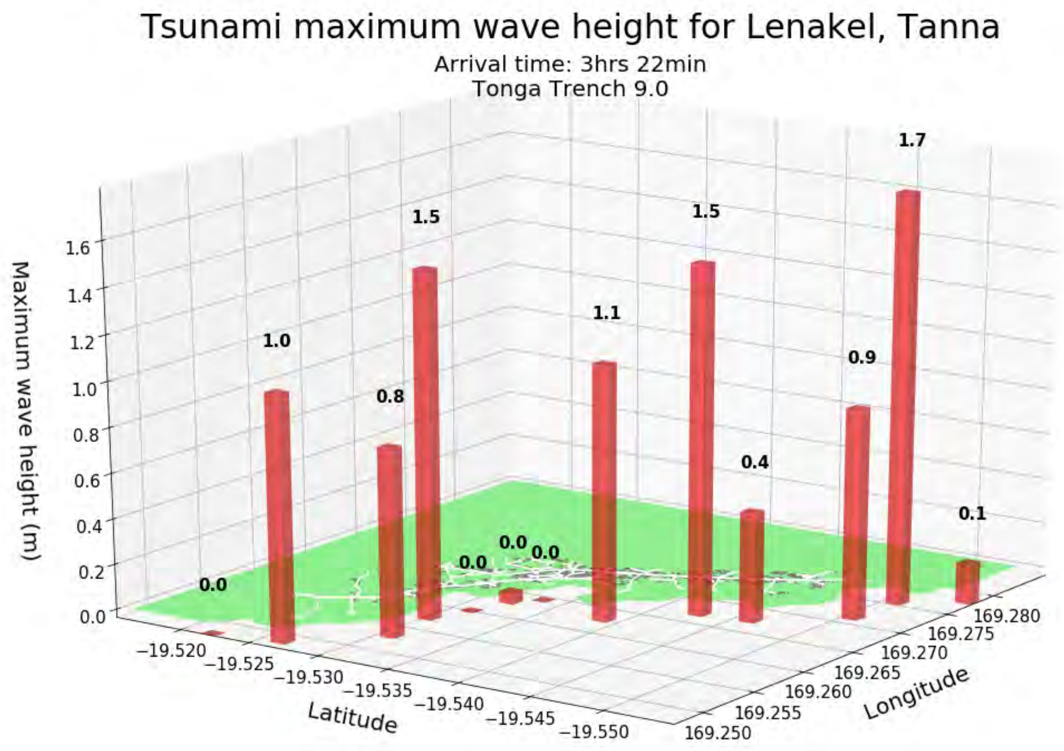

Figure 19: Plot-3D of the Tonga Trench Mw 9.0 tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of 3 hours 22 minutes

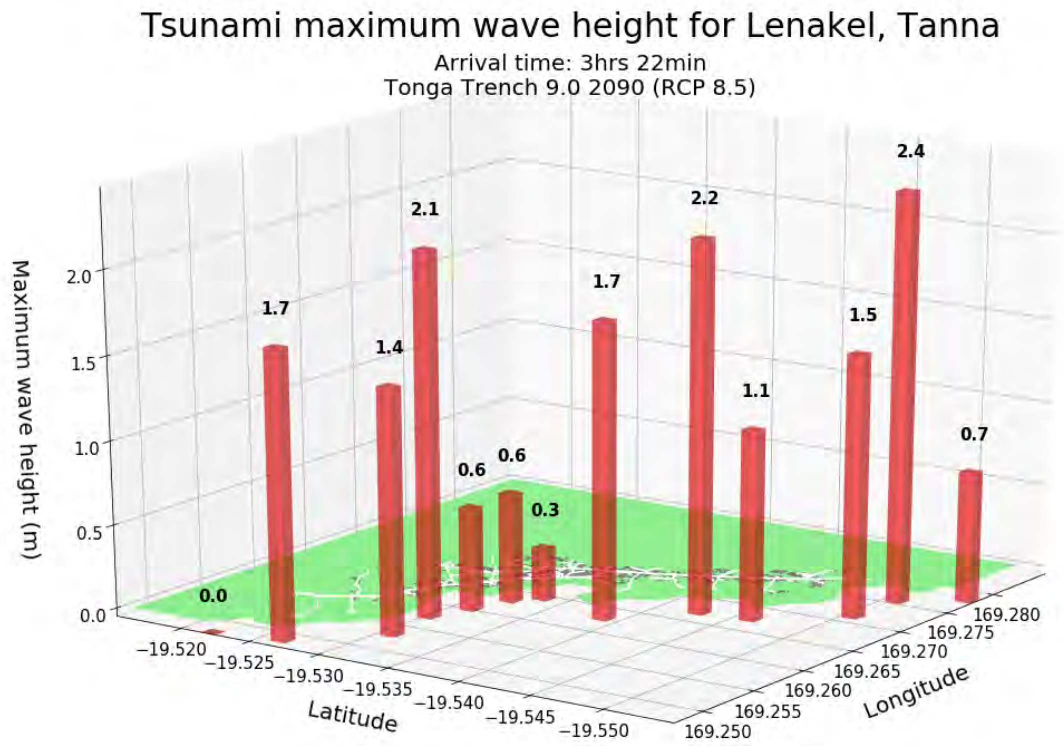

Figure 20: Plot-3D of the Tonga Trench Mw 9.0 (with 2090 sea-level rise) tsunami inundation heights along the Lenakel coastline with the depth (m) noted on top of the bars with the arrival time of 3 hours 22 minutes

Tsunami Inundation Map
Lenakel, Tanna Island - Vanuatu

Legend

Max - Inundation depth (m)

- <= 0.587
- 0.587 - 1.17
- 1.17 - 1.74
- 1.74 - 2.32
- 2.32 - 2.9
- 2.9 - 3.48
- 3.48 - 4.06
- 4.06 - 4.64
- 4.64 - 5.22
- 5.22 - 5.8
- > 5.8

Earthquake Scenarios *(From Ioualalen et al., 2017)*
Historical event 1875 - Mw - (8.3)

Sea level rise scenario:
SLR: 0m (Present day)

Projection:
Coordinate system: GCS WGS 1984 (zone 59 South)

Other data sources:
Orthophoto 2007
Orthophoto 2016 (from UAV survey)
Building layer & Roads digitised from UAV orthophoto acquired from the UAV survey 2016

Scale:1:10,000 @ A2

0 100 200 300 400 500 m

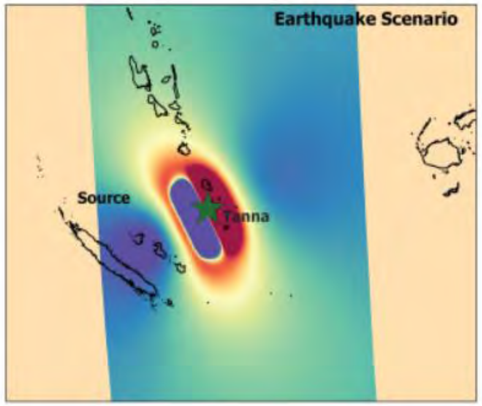

Figure 21 Tsunami inundation map of the historical tsunami in 1875

6 DISCUSSION

Of the 32 scenarios, the 12 scenarios listed in Table 2 provided the largest simulated inundation heights along the Lenakel coastline.

The largest inundation due to tsunamis generated from local earthquake zones occurred from:

- Historical 1875 Mw 8.3,
- Historical 1875 Mw 8.3 with SLR (2090),
- New Hebrides Trench Mw 9.0,
- New Hebrides Trench Mw 9.0 with SLR (2090),
- New Hebrides Trench Mw 9.4, and
- New Hebrides Trench Mw 9.4 (SLR).

The regional earthquake scenarios and zones resulting in the tsunamis with the largest inundation were:

- Tonga Trench Mw 9.0, and
- Tonga Trench Mw 9.0 with SLR (2090).

The distant earthquake zones were:

- Alaska Mw 9.4,
- Alaska Mw 9.4 with SLR (2090),
- Aleutian Mw 9.4, and
- Aleutian Mw 9.4 with SLR (2090).

The highest tsunami inundation resulted from the New Hebrides Trench Mw 9.4 earthquake (both present and 2090 SLR scenarios). The 2090 SLR scenario had slightly higher inundation heights of more than one metre in some locations along the coastline when compared to the present sea level New Hebrides Trench Mw 9.4 scenario. However, the maximum heights for both scenarios ranged around 18–20 m.

The highest inundation heights were observed at three locations. Figure 22 illustrates the locations of these three points along the Lenakel coastline. The location (19.529° S, 169.260° E) had the highest inundation for tsunamigenic earthquakes that originated within local earthquake zones (apart from the New Hebrides Mw 9.0). The third highest inundation height location (−19.549° S, 169.277° E) was most prominent in regional and distant tsunamigenic earthquake sources. Each of these locations has buildings approximately 250 m from the coastline and are at high risk from the tsunami run-up.

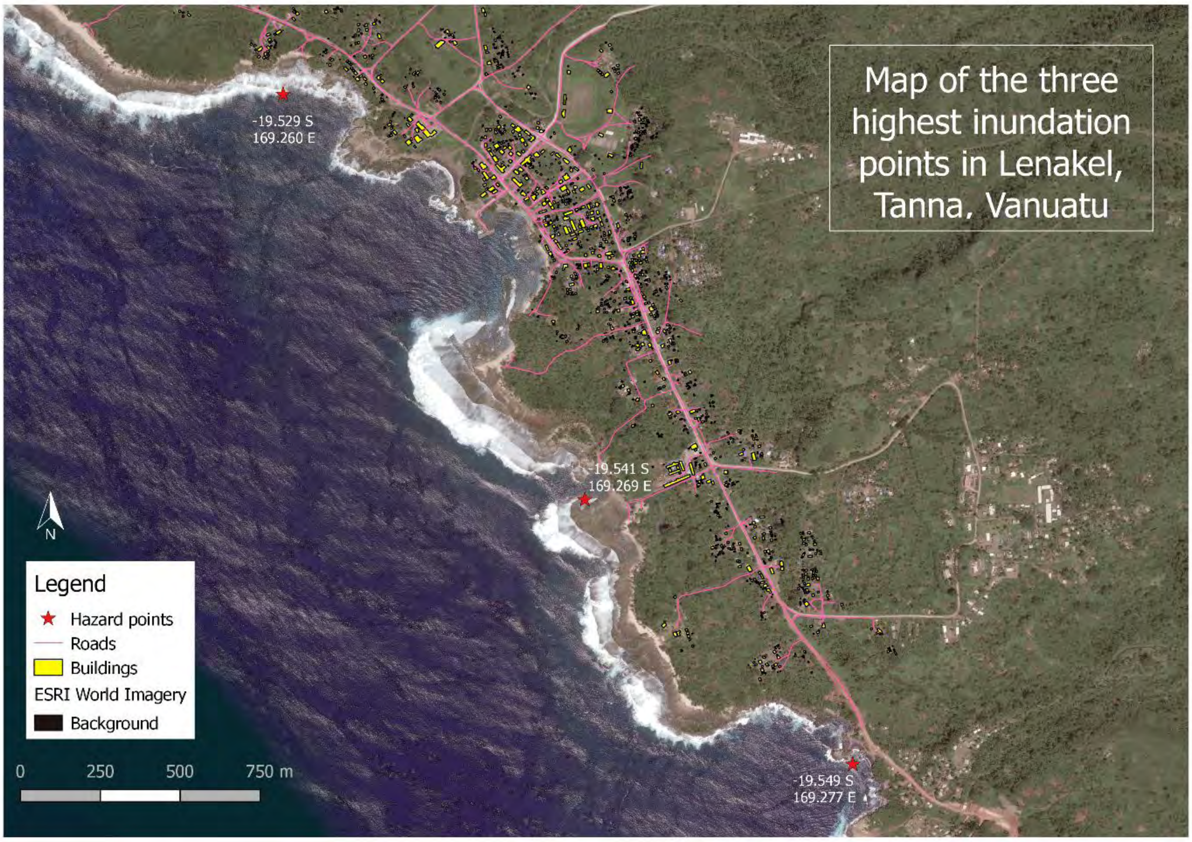

Figure 22: Map of the three hazardous points with the highest inundation locations for a majority of the tsunami scenarios (red stars). The buildings (yellow) and roads (pink lines) are overlaid on a satellite imagery of Lenakel, Tanna.

6.1 Possible evacuation routes from the maps

In addition to these tsunami hazard maps from the 32 scenarios, possible evacuation zones may be determined and proposed to the Lenakel Town Council to ensure that evacuation procedures are in place for possible future tsunamis.

6.2 Probabilistic tsunami hazard assessment

At the end of 2018, Geoscience Australia (2019) released a new probabilistic tsunami hazard assessment (PTHA), providing free and open access to a database of tsunamigenic earthquakes, including thousands of sources around the ring of fire. Furthermore, deep-water tsunami wave propagation was computed for all scenarios and its maximum stage recorded at key locations, named hazard points, around the Pacific region. For each hazard point, the study also attempts to estimate the return period of the offshore tsunami wave height.

Figure 23 illustrates the hazard curve obtained from a hazard point located off Lenakel from the PTHA18 database. The hazard curve is shown in the diagram as an orange line with the confidence interval marked as dashed lines. It is important to note that the estimated return period of tsunami wave height has a high uncertainty, so it should be used only as indicative information. The maximum stage for each MDRR scenario (red crosses), as well as for the 1875 tsunami event, is plotted against the hazard curve to provide some context. Most of the MDRR scenarios have a high likelihood with a return period less than 25 years. The worst case scenario, a magnitude 9.4 earthquake along the New Hebrides Trench, could have an estimated return period significantly higher than 10,000 years. Interestingly, the return period of the 1875 tsunami event is estimated at about 2,500 years.

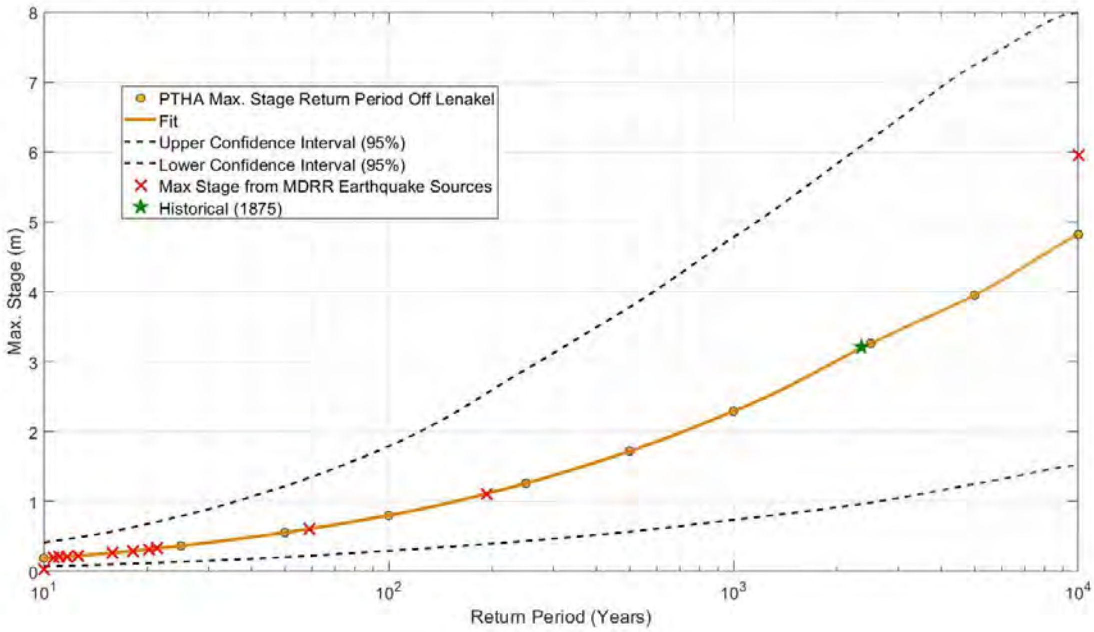

Figure 23: Hazard curve of the PTHA18 database with the maximum stage of the MDRR scenarios (red crosses) overlaid on the curve (orange line). The historical scenario is labelled using a green star.

7 EVACUATION PLANNING

In October 2018, SPC, in partnership with local authorities, the Vanuatu Meteorology and Geohazards Departments and the Tafea Provincial Office organised a two-day workshop in Lenakel to showcase information developed as part of the project and to support the tsunami drill exercise for Lenakel led by CARE International and the National Disaster Management Office.

Participants at the two-day workshop, including representatives from vulnerable groups (disabled people, women, children) school teachers, NGOs, and provincial and central government personnel, were guided toward designing Lenakel's evacuation routes and locating evacuation zones.

SPC, guided by the Government of Vanuatu, used the worst case scenario (New Hebrides Trench magnitude 9.4 scenario) as a baseline for this mapping exercise. In groups, participants discussed the various route options and drew on transparent papers overlayed onto the tsunami inundation map.

After each group had reported back, a consensus was found on the first draft of Lenakel's tsunami evacuation map (Figure 24).

Finally, the draft evacuation map was presented by a government representative to community leaders on the Community Provincial Disaster and Climate Change Committees across Tanna to support the tsunami drill exercise that was successfully carried out on 18 October 2018.

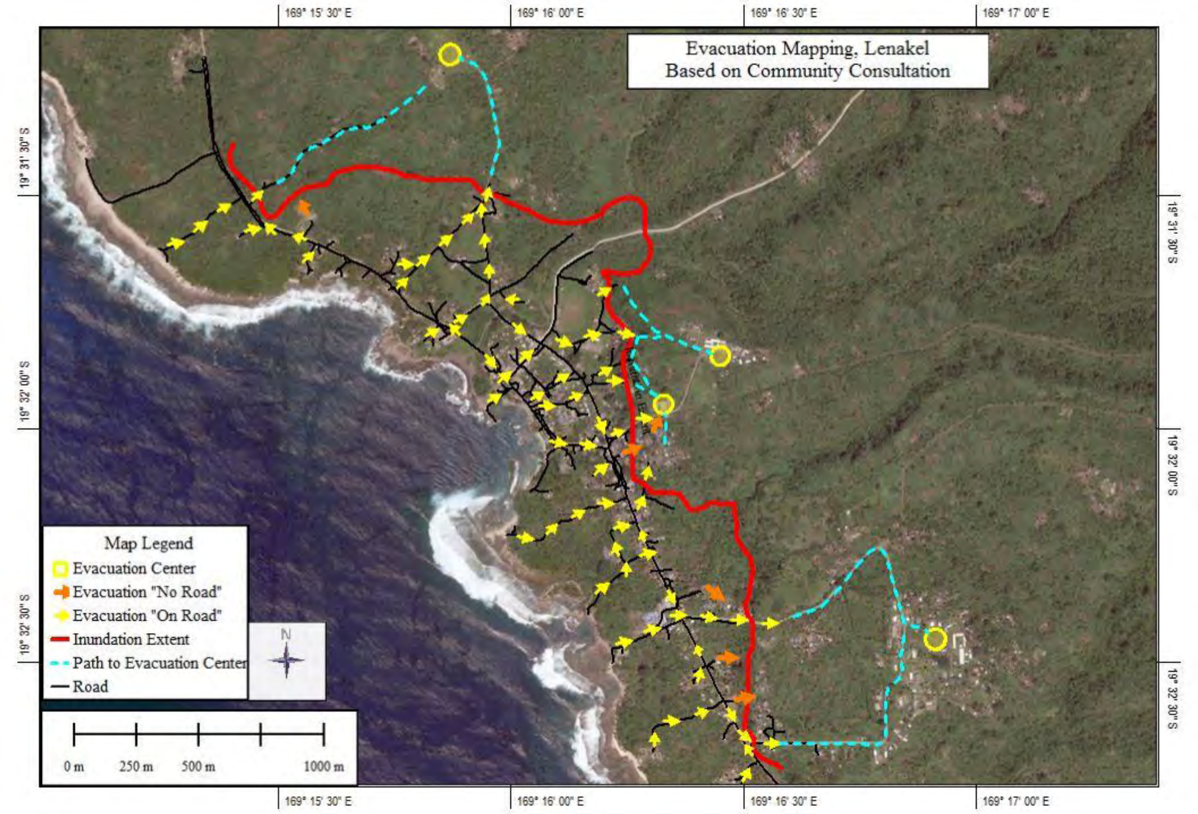

Figure 24: Draft Lenakel tsunami evacuation map

8 CONCLUSION

A tsunami inundation hazard assessment was carried out on Lenakel, Tanna. This assessment was part of a multi-hazard mapping component of the KfW project. The output of this assessment was the 32 tsunami inundation hazard maps produced for Lenakel Town Council and relevant government departments. The 32 tsunamigenic earthquake scenarios were based on the MDRR project, inclusive of the 2090 SLR (RCP 8.5) projection. These scenarios were simulated, using the tsunami model GeoClaw to produce the heights of the inundation.

Furthermore, a probabilistic tsunami hazard curve was obtained from the PTHA database for Lenakel. Indicative return periods were given to each MDRR scenario in relation to the maximum wave height generated offshore Lenakel.

The hazard assessment was used to provide detailed inundation maps and to identify low-risk areas for evacuation routes and centre planning. A workshop was organised, in collaboration with the central and provincial government, to support the design of evacuation routes. The draft evacuation routes were used as part of the tsunami evacuation drill exercise that was successfully carried out in Lenakel on 18 October 2018.

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ANNEX A: Tsunami Evacuation Planning Workshop, participant list

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