HAZARD ASSESSMENT AND INUNDATION MODELING OF MAJURO ATOLL THE REPUBLIC OF MARSHALL ISLANDS

Natalia Sannikova
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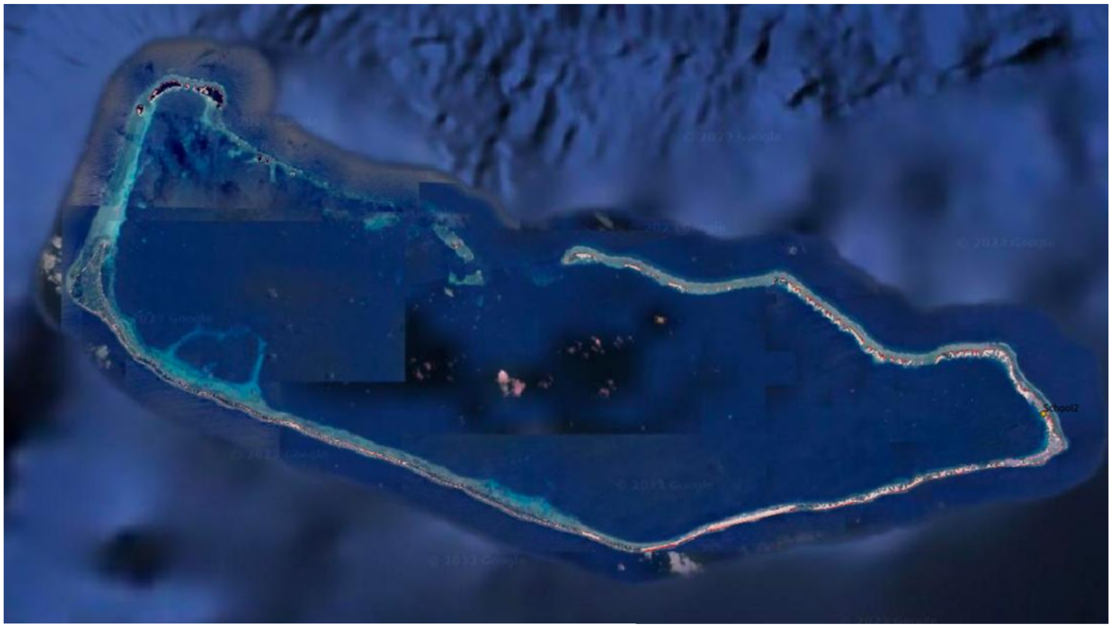

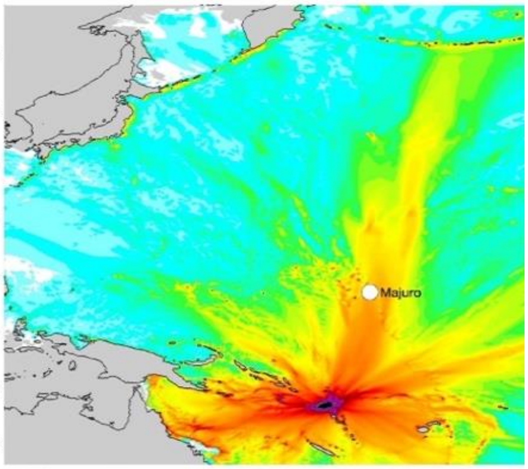

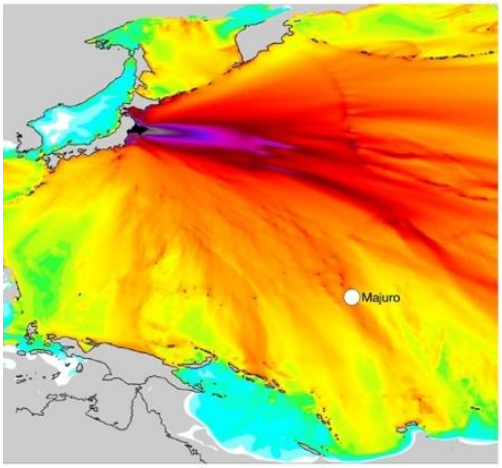

NOAA CENTER FOR TSUNAMI RESEARCH

PACIFIC MARINE AND ENVIRONMENTAL LABORATORY
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May 2023

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Abstract

A tsunami hazard assessment was conducted for Majuro, The Republic of Marshall Islands to establish past tsunami impact and to discern any source location patterns from historical events that impacted the island atoll. Between 2004 and 2011, five large magnitude earthquakes generated tsunami waves that impacted Majuro; 2004 Sumatra, 2005 Sumatra, 2009 Samoa, 2010 Chile, and 2011 Japan. Four of these events stand among the top ten largest instrumentally recorded earthquakes. All four generated tsunamis that caused loss of life and significant damage to homes and critical infrastructure. With these historical events in mind, a sensitivity study was conducted to identify specific source regions with the greatest potential to generate tsunamis most hazardous to Majuro. Tsunami waves originating from 77 discrete earthquake sources along subduction zones throughout the Pacific were modeled using the NOAA Tsunami Forecast Propagation Database. Sources were selected to determine their impact on Majuro by propagating tsunami waves through a high-resolution Digital Elevation Model and calculation grid. The non-linear shallow water wave inundation model tsunami HySEA was used to determine tsunami travel, arrival and duration times, maximum wave amplitudes, wave heights, flow depths, inundation, current speeds and attenuation. Tsunami waves generated along the Manus, South Solomon-New Hebrides, Kuril-Japan-Izu subduction zones were found to pose the greatest threat to Majuro's coastline. Results presented in this report form the basis for tsunami evacuation mapping and planning by Majuro emergency managers and planners in support of Tsunami Ready designation efforts outlined under the UN Decade of Ocean Science for Sustainable Development, Ocean Decade Tsunami

1 Introduction

This report documents the tsunami hazard assessment and subsequent tsunami inundation modeling conducted by the NOAA Pacific Marine Environmental Laboratory for Majuro Atoll, the capital of The Republic of Marshall Islands. Hazard assessment was conducted first by identifying records of historical events that impacted the island in the past and by then investigating the sensitivity of Majuro Atoll to tsunami impact from potential *Mw* 9.1 earthquake-triggered tsunami scenarios. Advancements in tsunami modeling and hardware made it possible to model the entirety of Majuro Atoll using bathymetry resolved to 10m (~1/3 arc-second). The largest credible seismic scenarios of greatest concern to Majuro Atoll were identified and modeled with a fully non-linear shallow water wave model from initial deformation to regional propagation to inundation.

Model results and especially products, including composite plots of maximum inundation and currents, were generated in direct support of outcomes outlined under the UN Decade of Ocean Science and Sustainable Development. Specifically, these products provide the basis for The Republic of Marshall Islands to educate and engage the Majuro Atoll populations in development of evacuation maps and procedures to follow in the event of tsunami generation along one of the subduction zones shown to pose the greatest risk to the island. Collectively, these activities advance Tsunami Ready efforts to mitigate the impact of tsunamis and save lives by preparing individuals and communities.

2. Background

The oceans provide world-wide food security and are the economic driver of economies around the globe. From fisheries to energy production, tourism, and goods transport, millions of people rely on the oceans for their livelihood. The ocean and its inhabitants, however, are under increasing pressure from a warming planet, acidification, pollution, population growth, and diminished life forms that support a fishing stock food chain.

Recognizing the need for action, the United Nations declared 2021-2030 the UN Decade of Ocean Science for Sustainable Development to bring attention and resources to efforts that “turn scientific knowledge and understanding into effective actions supporting improved ocean management, stewardship, and sustainable development” (Reference). Underpinning an ambitious implementation plan is a hierarchy of challenges, programs, projects, actions, and outcomes developed through peer review that together provide a roadmap to the ‘ocean we want’ by the year 2030 (Reference). At the top tier, stakeholders are challenged to identify and take actions that contribute to desired societal outcomes. Actions may take the form of topical programs, standalone projects, or specific activities.

The work presented here directly supports an activity of the ‘The Ocean Decade Tsunami

Programme' to implement the domestically successful Tsunami Ready Program in Pacific Ocean Island countries vulnerable to tsunami waves. Societal outcomes are "A safe ocean" with the goal of protecting communities from ocean hazards and "A transparent and accessible Ocean" aimed at building decision making capacity through the sharing of data, information, and technology. In the broadest sense, this topical program is meeting the Challenge to 'Increase community resilience to ocean hazards' by providing communities with the capacity to develop and implement tsunami mitigation strategies.

2.1 Tsunami History of The Central Pacific Basin

The Central Pacific Basin is a sub-region of the Pacific Ocean that extends from 9.15° S to 20.0º N and 171.8° to 178.0° W. Geographically, the Line Islands and Marshall Islands mark the eastern and western extents of the central basin, respectively. The north extent is delineated by the Mid-Pacific Mountains, located south of the Emperor Seamounts. The southern boundary of the basin extends just south of the equator to the Phoenix and Tokelau Islands. Deep troughs, volcanic mountains and islands are prominent features of the Central basin. Composed of classically dark volcanic mafic basalt, the Central Basin is geologically distinct from other Pacific regions. The imaginary Andesite Line follows the series of high seismicity and volcanically active Aleutian, Kuril, Japan, and Yap trenches and marks the boundary between composite and shield volcanoes.

The United States Geological Survey (USGS, 2009) and the NOAA Center for Environmental Information (NCEI, 2007) each provide a public database of earthquakes recorded worldwide. The databases include information on tsunami generation, fatalities, damage to homes and infrastructure, and runup collected from numerous sources. Information of events prior to 1990 was extracted from the catalogues of Soloviev and Go, 1974, Lander et al., 1993, and Lida,1984. A search result of earthquakes of Mw ≥ 7.5 that impacted the Central Pacific Ocean yields more than 600 events, the first of which dates to June 1768. The earliest recorded event to impact the Marshall Islands was Mw 8.1 that, in November 1952, was recorded on Kwajalein.

2.1.1 Regional Seismicity

Central Pacific Island Countries are encircled by many of the most active subduction zones in the world, both in the near- and far-field. The Yap subduction zone is in close proximity to The Republic of Marshall Islands and thereby poses a high near-field seismic threat. Since the year 2000, thirty-nine earthquakes of moment magnitude (*Mw*) ≥ to Mw 7.5 have been recorded. Of these thirty-nine earthquakes, seven had magnitudes exceeding *Mw* 8.0 (USGS). The complicated tectonics coupled with regionally high seismicity are due mainly to the interaction of four tectonic plates (**Figure 1**); the Pacific, Philippine Sea, Sunda, and

Australia plates. The Philippine Sea plate subducts to the west under the Sunda plate at a rate of approximately 100 mm/year, and the Australia plate subducts to the north beneath the Sunda plate at an estimated rate of 70 – 80 mm/year. The convergence between the Australia and Pacific plates results in a shortening at the subduction plate boundaries along Papua New Guinea, the Solomon Islands, Vanuatu, Fiji and Tonga. The convergence rate is approximately 60 – 70 mm/year along the Tonga trench and on order 100 mm/year along other trenches along the Andesite Line.

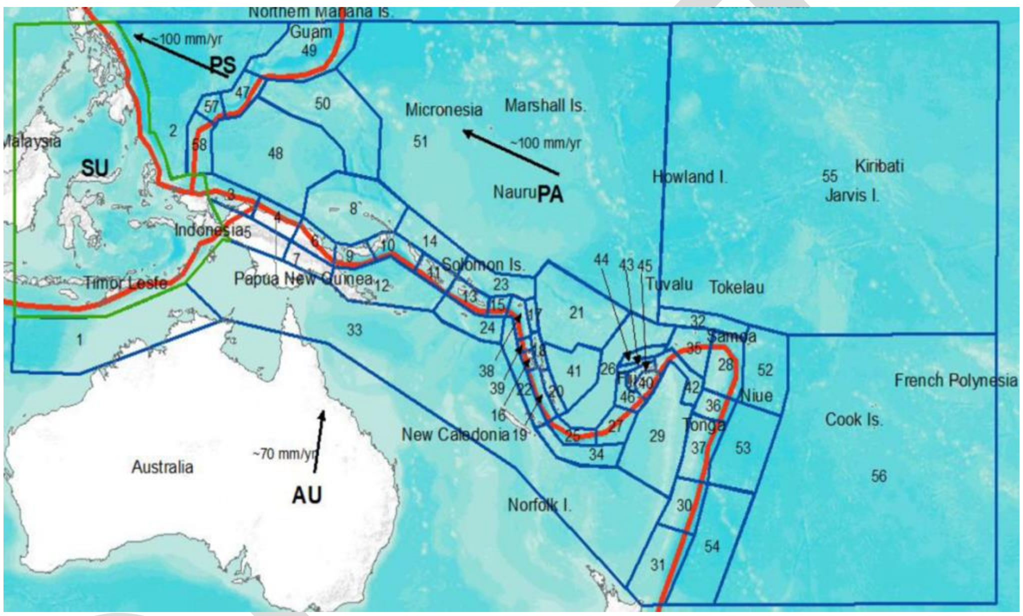


Figure 1: Regional tectonic setting and seismic source zones in the Central Pacific Ocean. Red lines mark boundaries between the four major plates: Pacific (PA), Philippine Sea (PS), Sunda (SU), and Australia (AU) plates. Thick black arrows illustrate the movement of the PA, PS, and AU plates relative to the SU plate (Bird, 2003). The source zones are illustrated by blue polygons, and the numbers are the zone IDs (Rong et al., 2016).

2.1.2 Tsunami Event History of the Marshall Islands

The Republic of Marshall Islands is an island country in the Pacific Ocean's 'Ring of Fire'; a string of volcanoes and high seismic activity, or earthquakes, along coastal margins of the Pacific Ocean. Roughly 90% of worldwide earthquakes occur within the Ring of Fire, dotted with 75% of all active volcanoes on Earth (REFERENCE). The NOAA National Centers for

Environmental Information (NCEI) Global Historical Tsunami Database identifies 32 separate earthquake and submarine landslide generated tsunamis that have historically impacted the Marshall Islands (NCEI, 2022). Thirty-one (31) of these events originated from areas along the Ring of Fire (**Figure 2**). The largest tsunami runups of 66 cm at Kwajalein and 51 cm at Majuro Atolls were measured from the 03/11/2011 Tohoku Tsunami Event.

Table 1 contains information about 32 earthquake or earthquake and slide-generated tsunami that have ever affected Marshall Islands (NCEI, 2022). The majority of them originated from the active subduction zones: South Pacific (Mariana, Yap, Philippines, New Guinea, South Solomon, New Hibrides, Tonga), Kuril-Japan and Aleutian Subduction Zones (**Figure 3**).

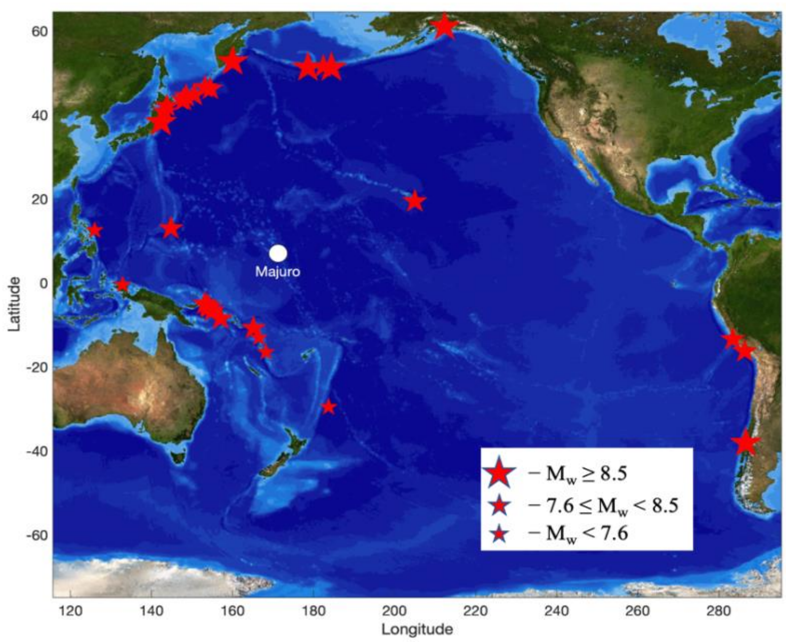


Figure 2: The distribution of earthquake and earthquake generated submarine landslide generated tsunami events from Pacific Ocean subduction zones that have historically impacted the Marshall Islands.

Table 1: Historical tsunami events that affected Marshall Islands.

Date	**Date**	**Source Country**	**Source Longitude**	**Source Latitude**	**M_w**	**Affected Area**	**Runup**

1	2/6/2013	Solomon Islands, Santa Cruz Islands	165.114	-10.766	7.9	Kwajalein, Marshall Islands	12 cm
2	7/6/2011	Kermadec Islands, New Zealand	-176.340	-29.539	7.6	Kwajalein, Marshall Islands	2 cm
3	3/11/2011	Japan, Honshu Island	142.372	38.297	9.1	Kwajalein, Marshall Islands, Majuro, Marshall Islands	66 cm, 51 cm
4	10/7/2009	Vanuatu Islands, Vanuatu	166.510	-13.006	7.6	Majuro, Marshall Islands	2 cm
5	1/3/2009	Indonesia, near North Coast	132.885	-0.414	7.6	Kwajalein, Marshall Islands	3 cm
6	8/15/2007	S. Peru, Peru	-76.603	-13.386	8	Kwajalein, Marshall Islands	4 cm
7	4/1/2007	Solomon Islands, Solomon Islands	157.044	-8.460	8.1	Kwajalein, Marshall Islands	4 cm
8	1/13/2007	Russia, S. Kuril Islands	154.524	46.243	8.1	Kwajalein, Marshall Islands	11 cm
9	11/15/2006	Russia, S. Kuril Islands	153.266	46.592	8.3	Kwajalein, Marshall Islands, Majuro, Marshall Islands	14 cm, 8 cm
10	6/23/2001	S. Peru, Peru	-73.641	-16.265	8.4	Kwajalein, Marshall Islands	5 cm
11	11/26/1999	Vanuatu Islands, Vanuatu	168.214	-16.423	7.5	Kwajalein, Marshall Islands	5 cm
12	6/10/1996	Andreanof Islands, AK, USA	-177.632	51.564	7.9	Kwajalein, Marshall Islands	
13	8/16/1995	Solomon Sea, Papua New Guinea	154.178	-5.799	7.7	Kwajalein, Marshall Islands	6 cm
14	8/8/1993	USA Territory, Guam, Mariana Islands	144.801	12.982	7.8	Kwajalein, Marshall Islands	7 cm
15	11/29/1975	USA, Hawaii	-155.033	19.451	7.7	Kwajalein, Marshall Islands	6 cm
16	10/31/1975	Philippines, Philippine Trench	125.993	12.540	7.6	Kwajalein, Marshall Islands	10 cm
17	7/20/1975	Solomon Sea, Papua New Guinea	155.054	-6.590	7.9	Kwajalein, Marshall Islands	6 cm
18	6/10/1975	Russia, S. Kuril Islands	147.734	43.024	7	Kwajalein, Marshall Islands	12 cm
19	7/26/1971	Papua New Guinea, Solomon Sea	153.2	-4.9	7.9	Kwajalein, Marshall Islands	24 cm

20	7/14/1971	Papua New Guinea, Solomon Sea	153.9	-5.5	7.9	Kwajalein, Marshall Islands	24 cm
21	8/11/1969	Russia, S. Kuril Islands	147.900	43.600	8.2	Kwajalein, Marshall Islands	10 cm
22	5/16/1968	Japan, Off East Coast of Honshu Island	143.2	40.8	8.2	Kwajalein, Marshall Islands	9 cm
23	2/4/1965	Rat Islands, Aleutian Islands, AK, USA	178.550	51.290	8.7	Kwajalein, Marshall Islands	10 cm
24	3/28/1964	USA, Prince William Sound, AK	-147.648	61.017	9.2	Kwajalein, Marshall Islands Enewetak, Marshall Islands	15 cm, 10 cm
25	10/20/1963	Russia, S. Kuril Islands	150.563	44.772	7.9	Kwajalein, Marshall Islands	10 cm
26	5/22/1960	Chile, Southern Chile	-73.407	-38.143	9.5	Kwajalein, Marshall Islands, Enewetak, Marshall Islands	38 cm, 15 cm
27	11/6/1958	Russia, S. Kuril Islands	148.540	44.530	8.3	Kwajalein, Marshall Islands	10 cm
28	3/9/1957	USA, Andreanof Islands, AK	-175.629	51.292	8.6	Kwajalein, Marshall Islands, Enewetak, Marshall Islands	30 cm, 30 cm
29	11/4/1952	Russia, Kamchatka	160.057	52.755	9	Kwajalein, Marshall Islands, Enewetak, Marshall Islands	25 cm, 26 cm
30	3/4/1952	Japan, SE. Hokkaido Island	143.850	42.150	8.1	Kwajalein, Marshall Islands	10 cm
31	7/1/1906	Fed. States of Micronesia, Yap, Caroline Islands				Kwajalein, Marshall Islands	
32	1/15/1899	Papua New Guinea, East Coast, New Ireland	152.0	-3.0		Kwajalein, Marshall Islands	

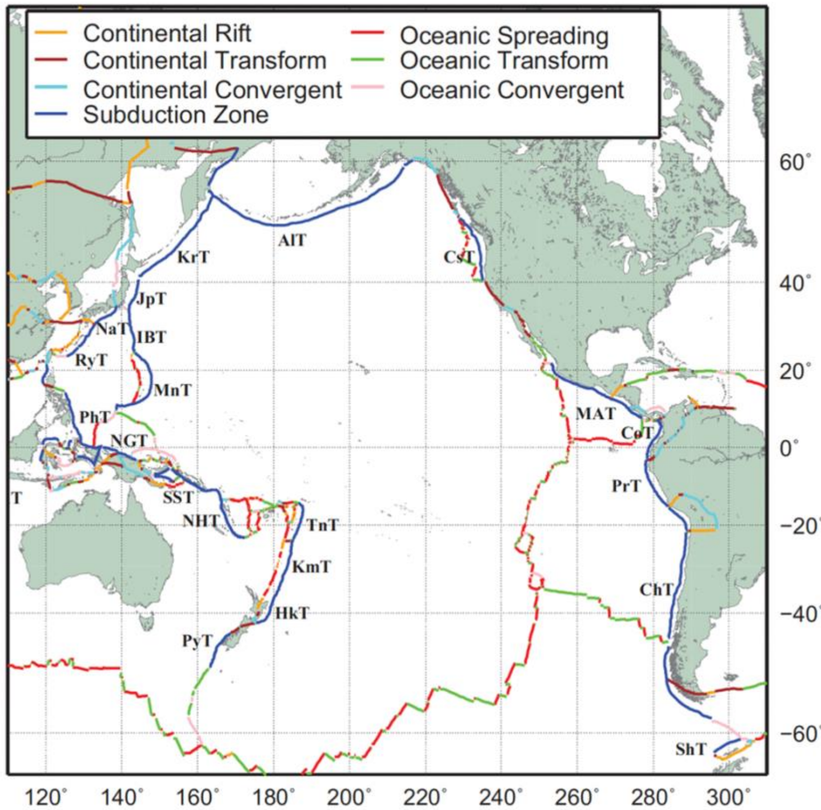


Figure 3: Map of major plate boundaries in the Pacific Ocean with subduction zones shown (in blue) and labeled as follows: AlT-Aleutian Trench, ChT-Chile Trench, CsT-Cascadia Trough, HT-Hikurangi Trough, IBT-Izu-Bonin Trench, JpTJapan Trench, KmT-Kermadec Trench, KrT-Kuril Trench, MT-Mariana Trench, MAT-Middle America Trench, NT-Nankai Trough, NGT-New Guinea Trench, NHT-New Hebrides Trench, PhT-Philippines Trench, PrT-Peru Trench, PyT-Puysegur Trench, RT-Ryukyu Trench, SST-South Solomons Trench, TnT-Tonga Trench (Bird, 2003).

2.2 Study Area

Majuro is the capital and most populated of the 24 inhabited island atolls that make up The Republic of Marshall Islands. Together with another 11 uninhabited atolls, the country landmass spans approximately 180 sq km spread out over more than 1.2 million km of ocean just north of the equator. Inhabited atolls extend from westernmost Enewetak at 11.5˚N 162.33˚E along the Ralik (Sunset) archipelago to easternmost Mili Atoll at 6.13º N 171.9º E along the Ratak (Sunrise) archipelago. Majuro Atoll, population 27,797 (2011 Census), is a coral atoll on the southern Ratak chain that runs north-south and forms the eastern extent of the Marshall Islands. Majuro and the entirety of The Republic of Marshall Islands is surrounded by the seismically active Pacific Ocean 'Ring of Fire'. The country has been affected by historical tsunamis and its location relative to highly active subduction zones points to tsunamigenic potential.

Radiocarbon dating of excavated oven charcoals on Majuro Atoll point to the Marshall Islands being settled by Micronesians between 30 BCE and 50 CE (Kiste, 2013). The islands were known to Spanish explorers in the 1500's and to the British navy in the 1700's but were not colonized and generally overlooked for having no resources of interest. Limited mapping of the Marshall Islands was done by British navy explorers but it was not until Russian expeditions in the early 1800's that the islands were more extensively mapped. Soon after, whaling ships from the United States were routine visitors followed by Christian missionaries in efforts to convert island populations. Foreign presence in the Marshall Islands began with Germany who, under a treaty with island chiefs, established both a coaling station on Jaluit Atoll and a protectorate over the entirety of the Marshall islands (Kiste, 2013). At the start of World War I, Japan drove Germany out of the islands and as a member of the League of Nations, claimed the Marshall Islands as 'Japanese mandated islands'. An American assault of Kwajalein and Enewetak during WWII ended with Japanese defeat and U.S. occupation. The Marshall Islands were made part of the United Nations Trust Territory of the Pacific Islands in 1947 and remained so until the Marshallese voted to separate and approved a constitution in 1979 forming the self-governing Republic of the Marshall Islands. In 1982 the government signed the Compact of Free Association with the United States.

Topographically, Majuro is an elliptically shaped coral reef 40 km long and has a total land area of 10.4 square km (**Figure 4, *a***). It is elongated from east to west and extends from rural Laura in the far west to the highly urbanized Delap-Uliga-Djarrit (DUD) administrative area in the far east (**Figure 4, *b***). Majuro is made up of three contiguous motus, or reef islets. The northern part of the atoll consists of numerous smaller unconnected and mainly uninhabited islets with many reef passes or channels. The main reef pass and entrance into the central lagoon is Calalin Pass located between the islands of Calalin and Eroj (**Figure 5**). The entirety of Majuro Atoll, including the 64 islets open to the Pacific Ocean, was included in the area of study.

The highest elevation on Majuro Atoll, estimated as only 3-meters above sea level, is on the west side of the island at the island community of Laura. The low topographic elevations make Majuro Atoll highly vulnerable to impacts from tsunamis as well as other marine forcing events such as storm surge.

Figure 4: a) Majuro Atoll (Satellite Image), b) Dalap-Uliga-Djarrit (DUD) area of Majuro Atoll.

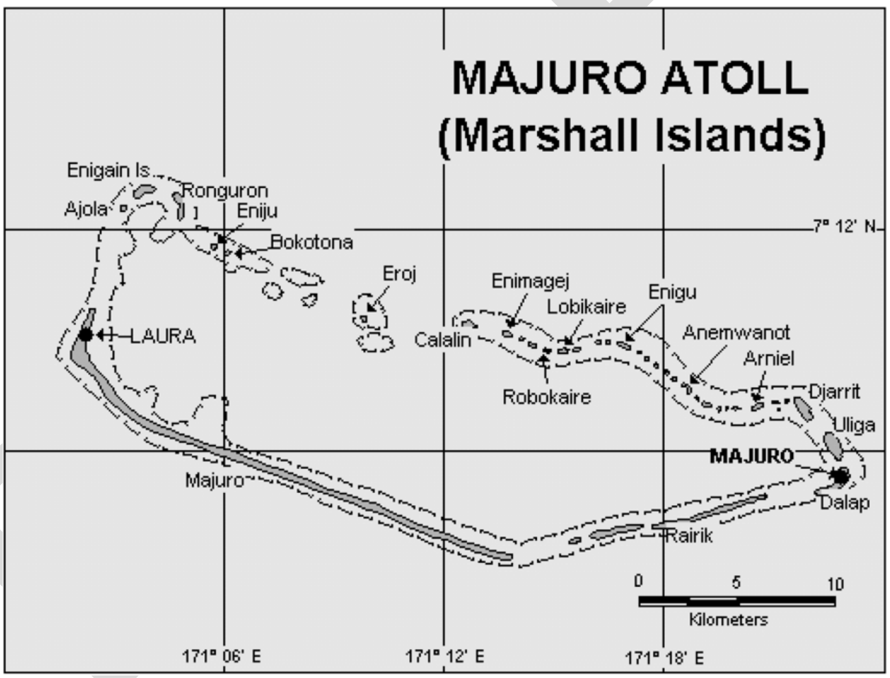


Figure 5: Majuro atoll, showing the shape, size and location of the individual reef islets around the atoll, plus the administrative center Dalap-Uliga-Djarrit (DUD) in the southeast and the rural farming area of Laura in the far west (Terry and Thaman, 2008).

3 Inundation Modeling

The general methodology followed in this study for modeling tsunami inundation along coastal areas is to reconstruct tsunami events using a linear combination of seismic unit source propagation solutions in deep water. This reconstruction, in turn, provides boundary and initial conditions to computationally propagate tsunami waves through a set of grids that become finer and finer in resolution the closer tsunami waves get to the area and coastline of interest or greatest concern. The finest resolution is the best that can be retained within the smallest of the grids in order to resolve variations in near-shore bathymetry and provide the highest level of detail and most accurate results possible. Model output in the near-shore is directly compared with tide gauge or other site measurements recorded during historical events to validate model performance. The validation process leads to model improvements and lends confidence in modeled wave arrival times, wave amplitude, currents, and simulation of wave inundation.

3.1 Tsunami Model

The tsunami-Hyperbolic Systems and Efficient Algorithms (HySEA) Model finite-volume numerical model was used for modeling tsunami inundation along the Majuro coastline. HySEA has grid-alignment nesting requirements that ensure volume centroids for each grid cell fall exactly on the cell location for superimposed inner grids in the nesting sequence (**Figure 6**). This requirement, along with the desire to maximize computation efficiency and not re-interpolate the baseline field of bathymetry and topography (or digital elevation model) means that the innermost grids are developed first by determining the boundary or extent and then each successive outer grid is developed to ensure that resolutions are integer-multiples of the nested inner grids. Specifics of the digital elevation model (DEM) constructed for modeling inundation along the coast of Majuro is provided in the next section.

Tsunami-HySEA was developed by the University of Malaga, Spain and has been provided to NOAA for tsunami inundation modeling, including hazard assessment and forecasting, through a strong collaboration. Model code was designed and parallelized to solve the non-linear shallow water equations quicky by utilizing Graphics Processing Unit (GPU) cards for computations. Model Stability and rapid computations makes HySEA well suited for modeling the propagation and inundation stages of tsunamis through very large, high-resolution grids

Tsunami-HySEA met the U.S. National Tsunami Hazard Mitigation Program (NTHMP) benchmark criteria following extensive testing against the suite of theoretical, laboratory, and field data that are summarized in Synolakis et al., 2008 and NTHMP, 2017. The model was further validated against the NOAA operational forecast Method of Splitting Tsunami (MOST) model as part of a study conducted for the U.S. Virgin Islands: St. Thomas, St. John, and St. Croix (Moore and Arcas, 2019).

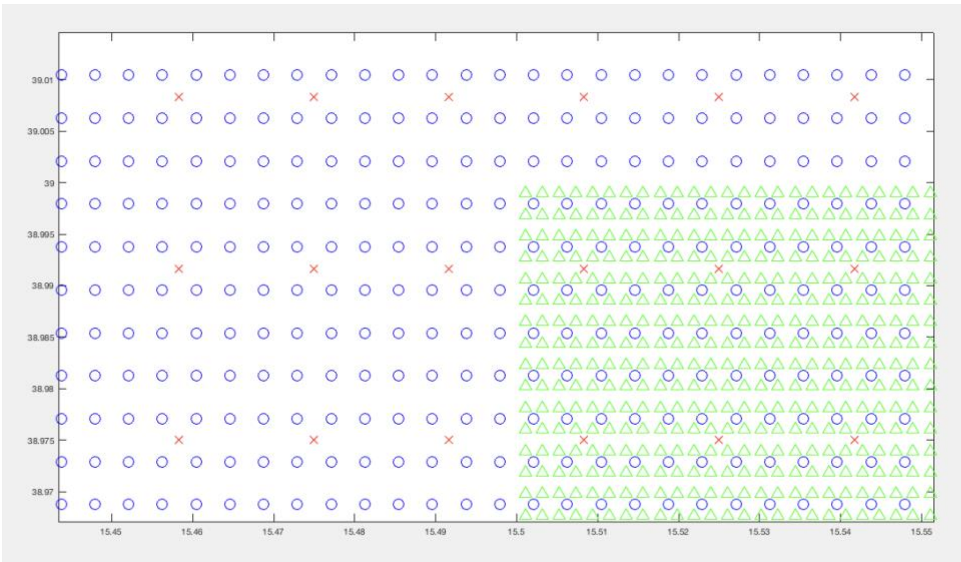


Figure 6: Grid nesting for HySEA showing innermost grid points (green) of twice the resolution of intermediate grid points (blue). Intermediate points have four times the resolution of outermost grid points (red) from Moore and Arcas (2019).

3.2 Digital Elevation Model

Digital Elevation Models (DEM) provide a representation of bathymetry and topography over which waves will pass. Tsunamis are shallow water waves meaning that wave amplitude and travel time are dependent on the depth of the water through which they propagate. As a result, all tsunami models, including HySEA, require a DEM in order to provide credible estimates of wave arrival, tsunami amplitudes, and near-shore currents. With this in mind, a high-resolution Digital Elevation Model was constructed for Majuro. Light Detection and Radar (LiDAR) data at 10 m resolution (1/3 arc-second) were combined with multi-beam and other sourced data that together provided atoll-wide coverage of features off- and on-shore. These highly resolved data ensure accurate representation of bathymetric and topographic features that affect the inundation of tsunami waves on Majuro. It is noted here that bathymetry and topography may change due to natural processes or man-made activities. All data used represent the best available at the time of DEM construction.

3.3 Numerical Grids

Modeling the impact of tsunami waves on Majuro Atoll was accomplished by developing a set of nested grids that telescope down from a larger spatial extent to a grid that finely defines the details of the Majuro Atoll coastline. Full 10 m (1/3 arc-second) resolution DEMs were used for the entirety of Majuro without re-gridding. The ability of HySEA to use full-resolution DEMs provides the highest level of accuracy for each given earthquake as the re-gridding process can introduce errors in model output. The nested grids are implemented in the HySea model keeping the accuracy-speed balance. Three levels of larger grids contain these highest-resolution grid, in increasing size and resolution. The HySEA model requires resolution "jumps" between these nested grids only by factors of 2, 4, 8 or 16.

Extents and resolution of the four nested grids developed for modeling inundation at Majuro Atoll with HySEA appear in **Figure 7**. The magenta-colored grid is the largest in extent, noticeably covering a large expanse of the Pacific Ocean and bordering countries. At 83.418 arc-second, this grid is also the coarsest in terms of DEM resolution. Embedded within this large magenta grid are the barely visible regional (green), intermediate (yellow), and innermost (red) grids. The expanded insert box shows the relationship between the intermediate and innermost grids. Resolution of the regional, intermediate, and the innermost grids are 20.854 arc-second, 2.067 arc-second, and 1/3 arc-second, respectively. The ratios between resolutions are, therefore, 8, 8, and 4, respectively, thus satisfying the HySEA requirement that resolutions be integer-multiples of one another. A separate optimized grid was created for the sensitivity study, described later in this report, with grid resolutions 2.6, 10.4, 41.7 and 166.835 arc-sec correspondingly. The ratios between resolutions are, therefore, 4, 4 and 4, respectively. Majuro LiDAR DEMs were used for the innermost and intermediate grids and the publicly available elevation (including ocean and land) 15 arc-second GEBCO data set was used as the source DEM for regional and outermost grids

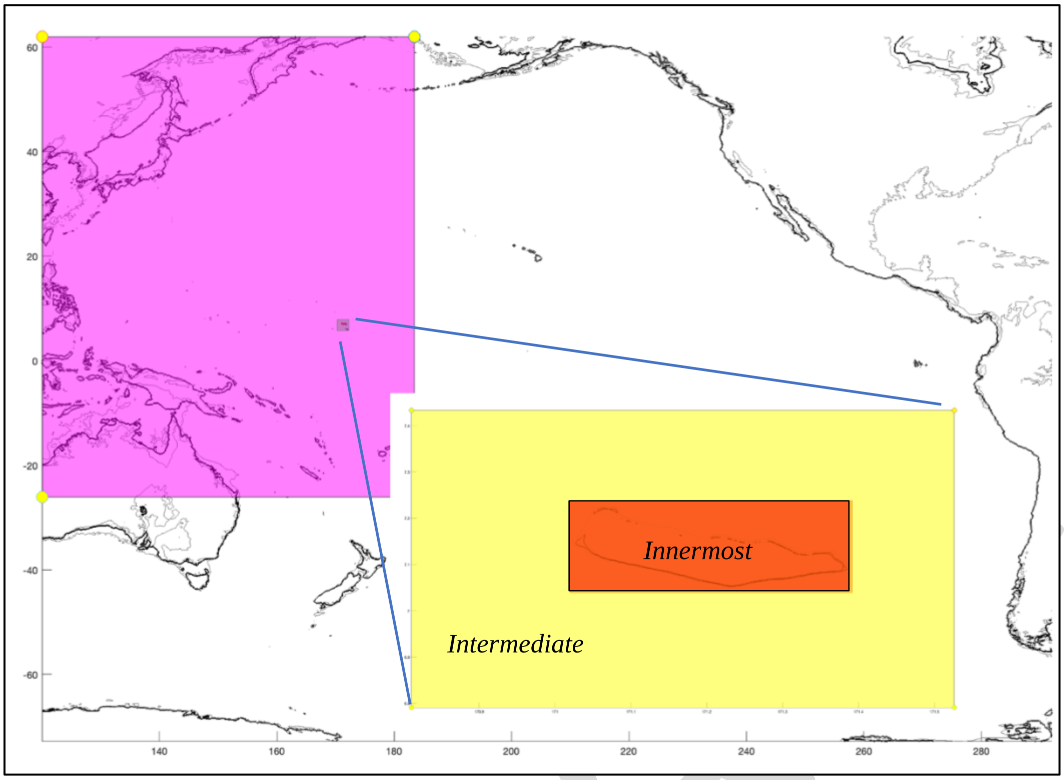


Figure 7: Extents of the grids four grids used for modeling tsunami waves at Majuro. The outermost (magenta) encompasses sources and inner grids, the intermediate (green) includes Majuro, Arno and Mili Atolls and surrounding Pacific Ocean, the intermediate (yellow) includes Majuro and surrounding Pacific Ocean area, and innermost grid (orange) tightly surrounds Majuro Atoll. The expanded insert box shows the relationship between the intermediate and innermost grids**.**

3.4 Propagation Database

A pre-computed propagation database consisting of water level and flow velocities at all grid points for potential seismic unit sources was developed for the world ocean basins by the NOAA Center for Tsunami Research (**Figure 8**) (Gica et al., 2008). Subduction zones were broken up into finite fault segments, or unit sources, each measuring 100 km long by 50 km wide. The propagation database represents a composite from each of these discrete earthquake rupture segments by computing wave propagation throughout the entire Pacific Basin. Currently, there are 403 unit sources from earthquakes of 100 km x 50 km and 1 m, each single unit source equivalent to a moment magnitude of 7.5. Larger events are modeled by combining unit sources. A Mw 9.1 event, therefore, can be successfully modeled as a 600 km × 100 km rupture with a 20 m slip, effectively a combination of 12 Mw 7.5 events scaled up 20 times.

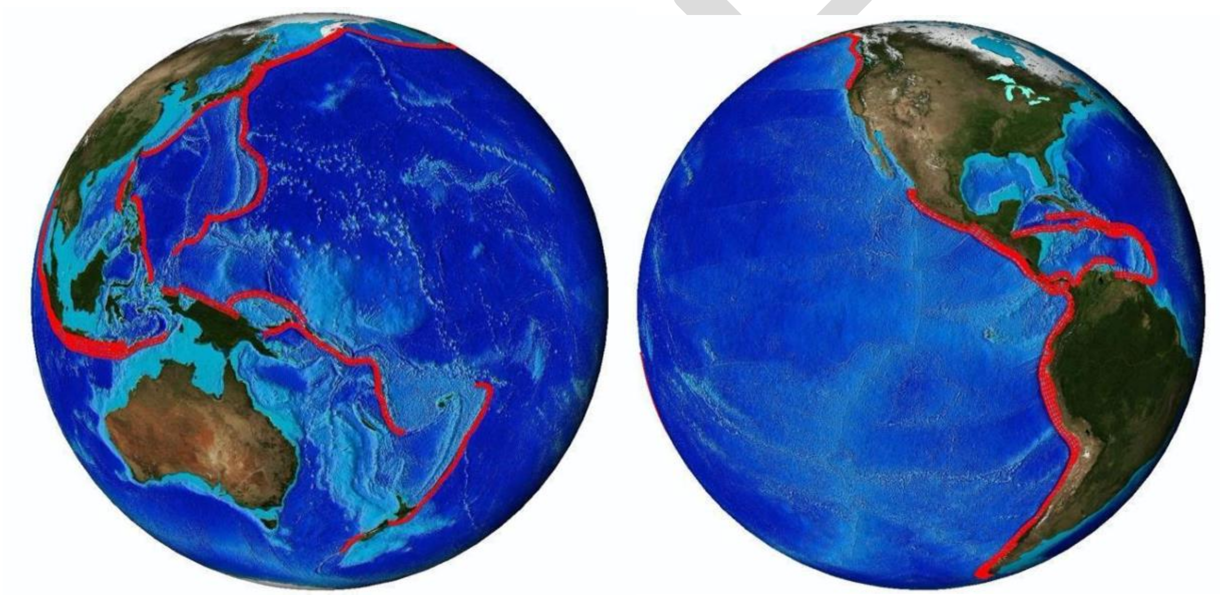


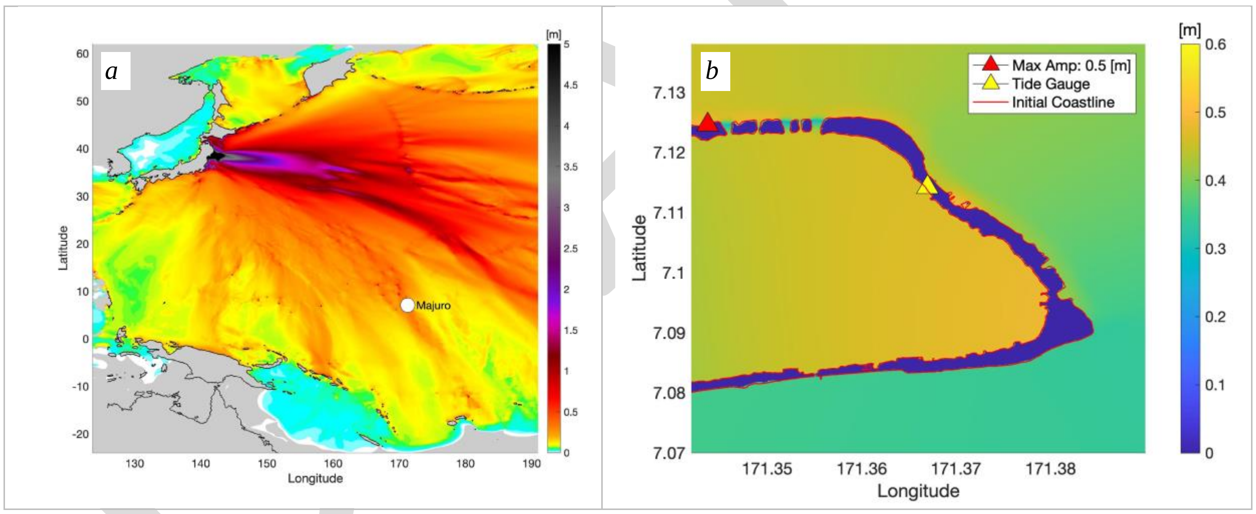
Figure 8: Locations of the unit sources for pre-computed simulated earthquake events in the Propagation Database. These can be combined to provide a very fast forecast during an actual tsunami event.

3.5 Model Validation

Two tsunami records at the Majuro tide gauge are available: from the 10 March 2011 Tohoku and the 7 October 2009 Vanuatu tsunami. **Table 2** provides information on the 2011 and 2009 earthquakes along with the scaling parameters used for the NOAA propagation database. The computed maximum wave heights from the 2009 and 2011 tsunami are shown in **Figure 9**. The comparisons of calculated and observed water level variations are shown in **Figure 10.**

Table 2: Parameters of the 2011 and 2009 earthquakes

Data (UTC)	Time	Location	Epicenter	Mw	Tsunami Source
2011-03-11	05:46:24	Japan	38.322°N 142.369°E	9.0	6.31*ki25a+1.91*ki25b+27.39*ki26a+0.48*ki26b+ 17.5*ki26y+20.99*ki26z+17.01*ki27a+12.43*ki27z+ 4.14*ki28z+9.54*ki29a
2009-10-07	22:03:14	Vanuatu	13.006°S 166.510°E	7.7	1.409*nv24b



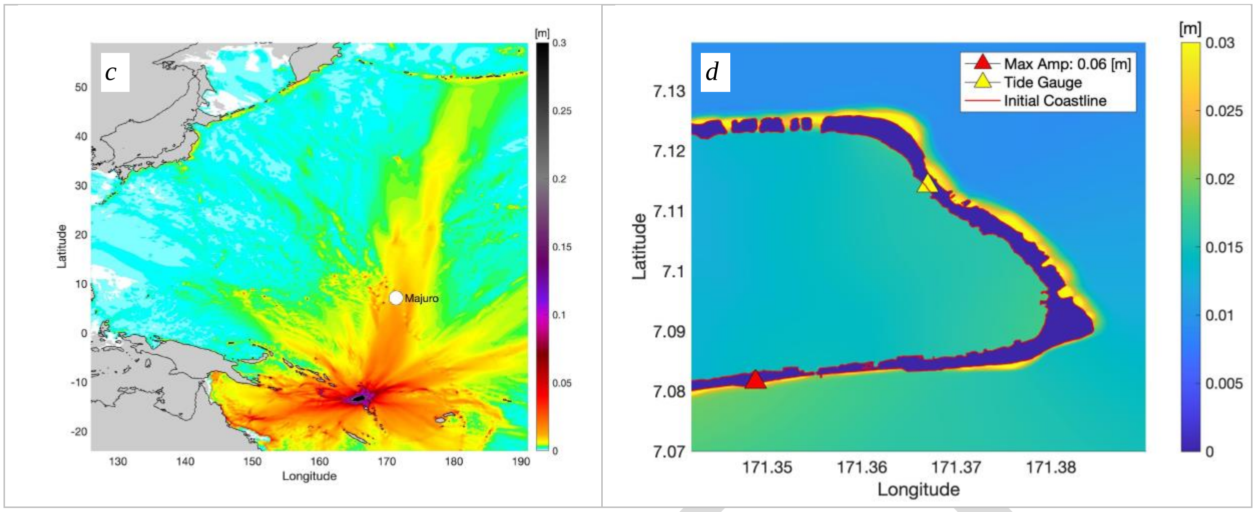


Figure 9: Source location, modeled maximum tsunami wave height in deep ocean (*a*, *c*) and in DUD (*b*, *d*) for the 2011 Tohoku, Japan tsunami (*a*, *b*) and 2009 Vanuatu tsunami (*c*, *d*).

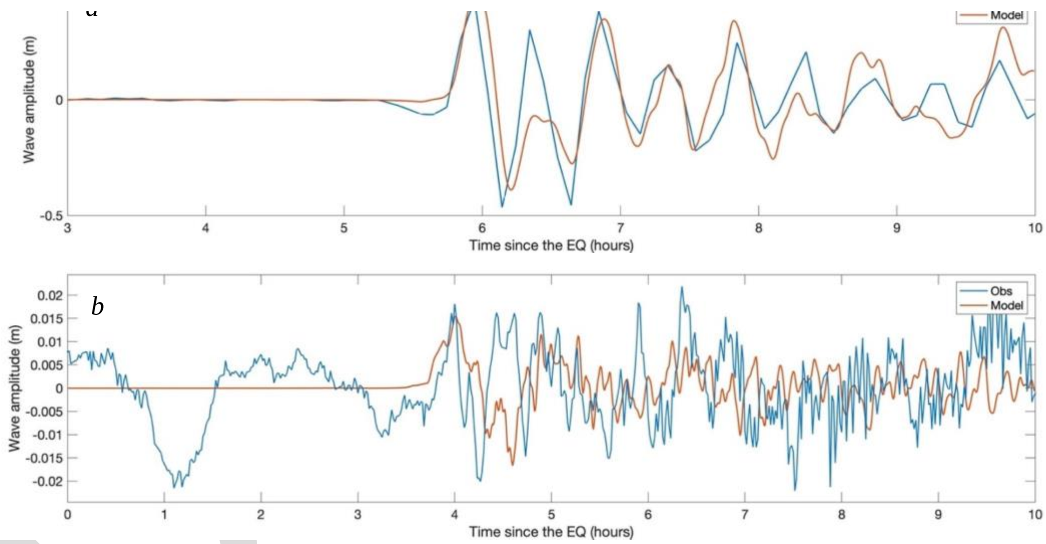


Figure 10: Comparison of numerical results with tide gauge time series recorded at Majuro tide gauge during (a) 2011 Tohoku, Japan tsunami; (b) 2009 Vanuatu tsunami.

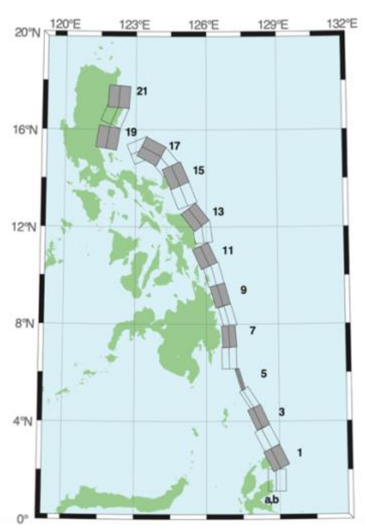
4 Tsunami Sensitivity Study and Testing

4.1 Sensitivity Study

Tsunami energy radiating away from a source is highly directional and depends on source characteristics and bathymetry. Each tsunami event has its specific complex pattern of tsunami amplitudes, arrival times, and frequency decay. Previous studies have shown that tsunamis triggered by similar magnitude earthquakes along different subduction zone sources may have substantially different impacts on the same site (Uslu (2009), Dengler et al. (2008)). With this source dependency in mind, a comprehensive sensitivity study was performed to determine potential earthquake-generated tsunami source regions of greatest concern to Majuro Atoll.

The sensitivity study used computationally optimized grids (nested grids ~ 166.835, 41.7, 10.4 and 2.6 arc-second) to model a total of 77 Mw 9.1 synthetically generated tsunamis. These synthetic tsunamis were generated by combining 6 x 2 consecutive Pacific Basin unit sources contained in the NOAA propagation database described by Gica et al. (2008). Subduction zones that triggered tsunamigenic events that impacted the Marshall Islands in the past were the only sources considered. These sources are along the Andesite Line that follows the tectonically active subduction zones in the western Pacific Ocean. **Appendix B** provides map detail of unit source blocks and source location (longitude and latitude), focal depths, strikes and dips for subduction zones considered in this study.

The 77 source combinations were constructed to be unique with no overlap except in cases where “hanging” unit sources were left as singles not included in previously constructed combinations. Subdivision of the Eastern Philippines SZ into combinations that represent Mw 9.1 is presented as an example (**Figure 11**). The first source from this subduction zone consists of unit sources 0a,b – 5a,b, the second source – 6a,b – 11a,b, the third source – 12a,b – 17a,b. Unit sources 18a,b – 21a,b remain excluded from already created combinations, so an overlapping source was created to capture their contribution in tsunami generation. The source combination 16a,b – 21a,b, then, includes these previously unassigned unit sources. As a result, there were four Mw 9.1 sources considered for the Eastern Philippines SZ. Source combinations from the Eastern Philippines SZ and all other source combinations modeled to generate tsunamis from Mw 9.1 are listed in **Table 3** (notation follows Bird, 2003) and shown in **Figure 12**.



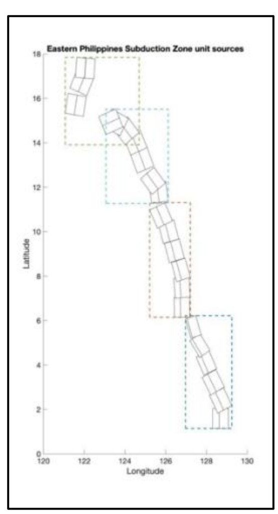


Figure 11: Unit source combinations along the Eastern Philippines Subduction Zone that were used to model tsunami generation from the resulting Mw 9.1 sources.

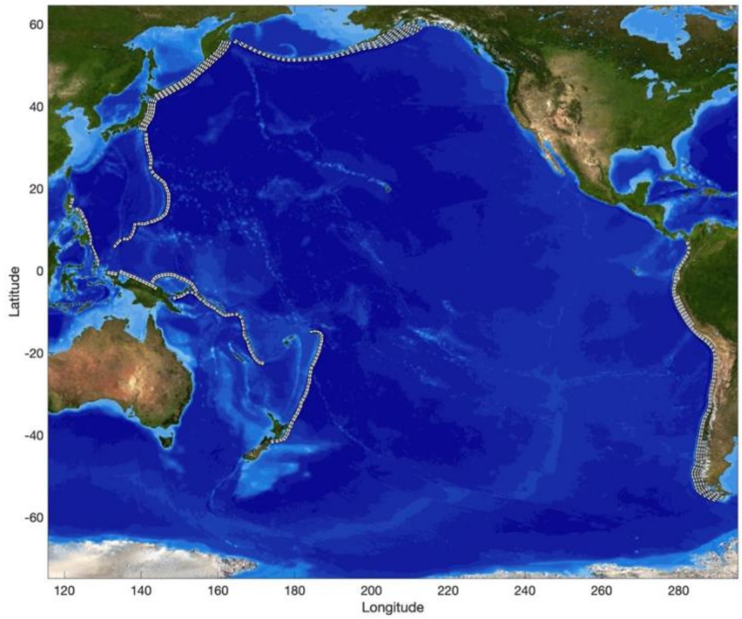


Figure 12: Locations of the unit sources used in the sensitivity study.

Table 3: Unit sources used in the sensitivity study.

Subduction Zone	Unit Sources	Number of Sources
Kamchatka-Kuril-Japan-Izu-Mariana-Yap	ki0a,b – ki75a,b; ki1y,z – ki31y,z	19
Eastern Philippines	ep0a,b – ep21a,b	4
New Guinea	ng1a,b – ng15a,b	3
South Solomon	mo1a,b – mo17a,b	4
New Hebrides	nv1a,b – nv37a,b	7
NewZeland-Kermadec-Hikurangi-Puysegur	nt1a,b – nt39a,b	7
Peru-Chile	cs37a,b – cs115a,b; cs53y,z – cs62y,z; cs96y,z – cs115y,z	20
Aleutian	ac1a,b – ac43a,b; ac24y,z – ac38y,z; ac30x,w – ac36x,w	13

4.2 Sensitivity Testing

A tsunami hazard assessment for Majuro Atoll was conducted first by investigating its sensitivity to tsunami impact from 77 Mw 9.1 earthquake-triggered tsunami scenarios. **Figure 13** shows the sensitivity testing results: maximum tsunami heights at Majuro calculated from all 77 synthetic sources on an optimized grid. From the sources located side by side only those that trigger the larger tsunami are presented to not overload the figure. Model results show that maximum wave amplitudes occur from sources along the Manus, South Solomon-New Hebrides, Kuril-Japan-Izu subduction zones (**Figure 13**). Earthquakes in these regions, therefore, pose the greatest potential tsunami hazard to Marshall Islands, determined by the distance to the source and direction of the most energy released.

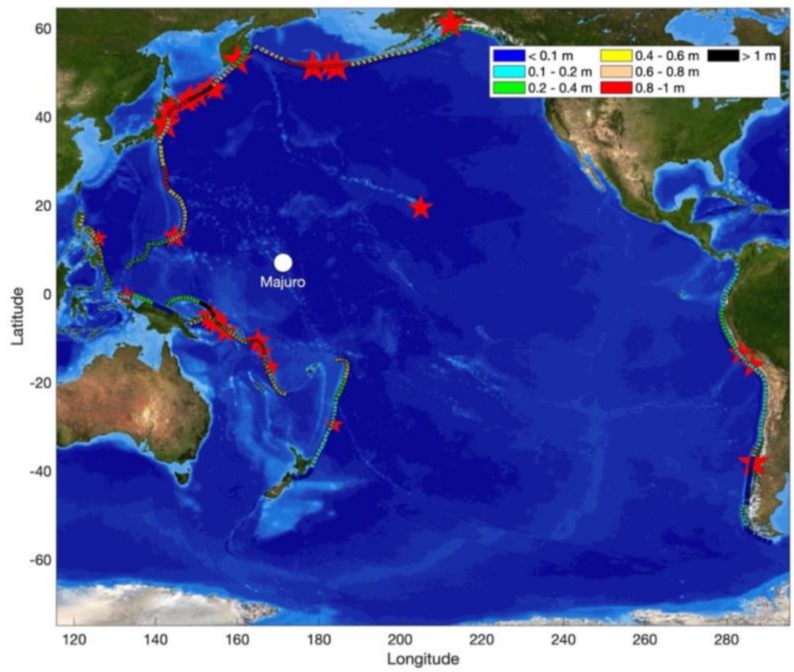


Figure 13: Maximum tsunami heights computed for Majuro from tsunamis triggered by synthetic Mw 9.1 earthquakes along Pacific Basin subduction zones. The optimized tsunami forecast model was used for all model runs.

Subsequent to the sensitivity study, five earthquake scenarios along the most hazardous source segments as identified in the sensitivity analysis were selected and modeled at the highest possible resolution of 10 m. **Table 4** provides the scaling parameters used for the NOAA propagation database for these five sources.

Table 4: Unit sources forming the most hazardous sources.

Source Nickname and Subduction Zone Origin	Unit Sources
Manus	20*mo1a+20*mo1b+20*mo2a+20*mo2b+20*mo3a+ 20*mo3b+20*mo4a+20*mo4b+20*mo5a+20*mo5b+ 20*mo6a+20*mo6b
Kuril	20*ki12a+20*ki12b+20*ki13a+20*ki14b+20*ki15a+ 20*ki15b+20*ki16a+20*ki16b+20*ki17a+20*ki17b+ 20*ki18a+20*ki18b
South Solomon-New Hebrides	20*nv19a+20*nv19b+20*nv20a+20*nv20b+20*nv21a+ 20*nv21b+20*nv22a+20*nv22b+20*nv23a+20*nv23b +20*nv24a+20*nv24b
Kuril-Japan	20*ki19a+20*ki19b+20*ki20a+20*ki20b+20*ki21a+ 20*ki21b+20*ki22a+20*ki22b+20*ki23a+20*ki23b+ 20*ki24a+20*ki24b
Izu-Bonin	20*ki37a+20*ki37b+20*ki38a+20*ki38b+20*ki38a+ 20*ki38b+20*ki39a+20*ki39b+20*ki40a+20*ki40b+ 20*ki41a+20*ki41b

Results

Numerical tsunami model HySEA was run for each of the five scenarios identified as potential worst-case for impact to Majuro. The outputs of HySEA included tsunami travel time (arrival time), maximum amplitude (tsunami height), flow depth, current speed and current attenuation. Travel time and maximum amplitude were output by the model as tsunami waves propagated through the deep ocean. Within the highest resolution Majuro grid, travel time, tsunami height, flow depth, inundation, current speeds and current attenuation were output.

Wave amplitude is the maximum vertical rise or drop of a column of seawater as measured from wave crest (peak) or trough to a mean water level state referenced to a stated datum. Maximum amplitude in the context of this study is the greatest of all individual maximum wave amplitudes in a time series or across cells within the boundaries of a model grid. All maximum amplitudes presented and discussed here were referenced to mean high water. Maximum wave amplitudes for the entire model simulation were saved every 60 seconds at every grid point to produce inundation maps. Tsunami heights and current speeds were saved at population centers and in areas with critical infrastructure. Wave amplitudes were also saved every 60 seconds for the first five hours of the simulation at every grid point for a Manus source scenario in order to track tsunami wave dynamics.

Tsunami Propagation

Figure 14 shows the source location, arrival times (travel time isochrones), and maximum wave amplitudes in the deep ocean in the propagation phase for the five sources modeled. In these figures, it is also possible to appreciate the directionality of the modeled tsunamis. **Figure 14 *a, b*** highlights the sources Manus and Kuril that cause the largest amplitudes at Majuro. Sources South Solomon-New Hebrides and Manus have earlier arrival times near Majuro than the more distant sources $\approx 2.5 - 3$ hours (**Figure 14 *a, c***).

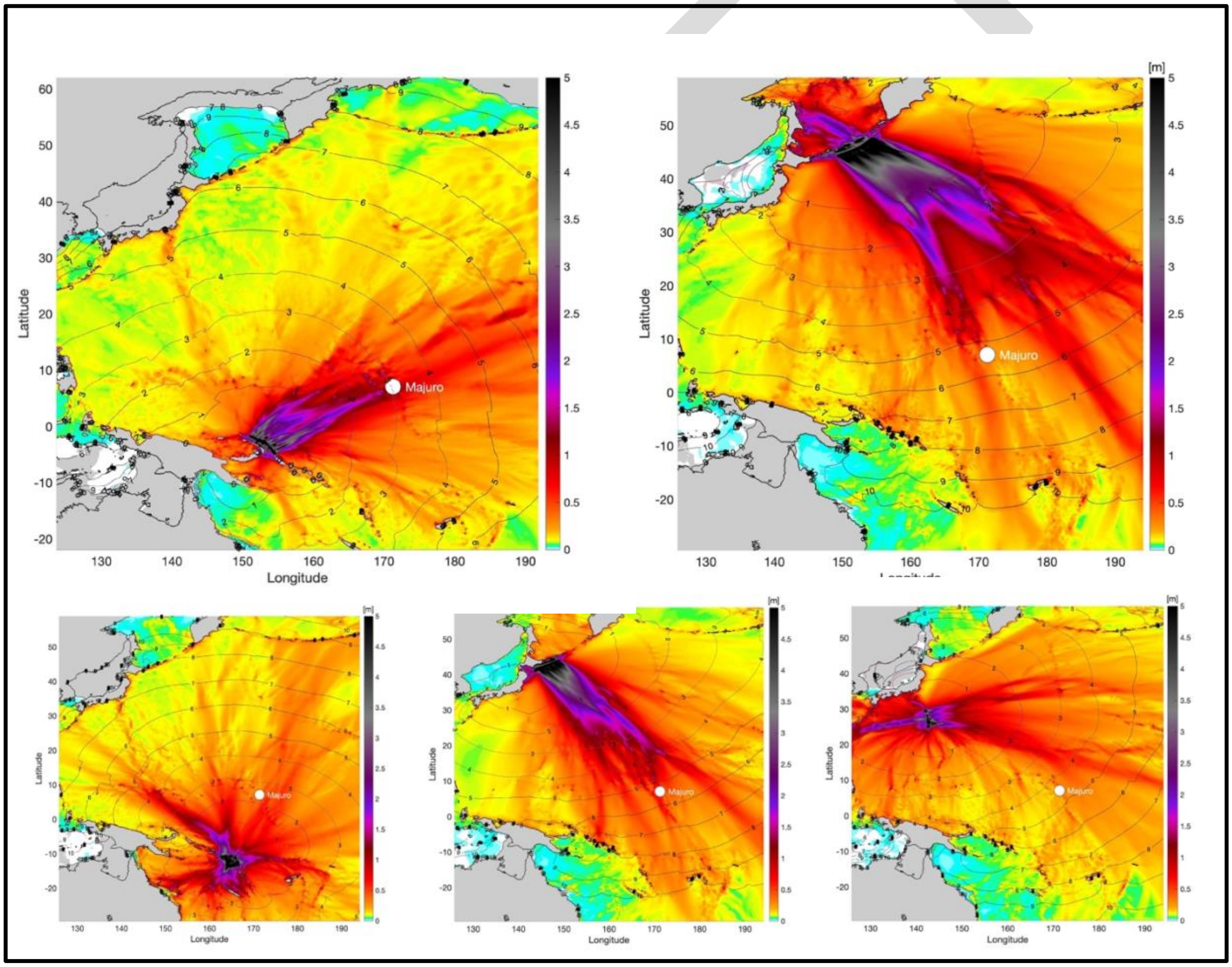


Figure 14: Source location, arrival times, and maximum wave amplitudes in deep ocean for the largest sources: a) Manus, b) Kuril, c) South Solomon-New Hebrides, d) Kuril-Japan, e) Izu-Bonin.

Tsunami Inundation

Tsunami inundation is the inland extent or reach of tsunami waves. Inundation is a function of tsunami height or the elevation of water above sea level (analogous to wave crest amplitude in the open ocean). Inundation occurs when tsunami height is larger than the elevation of normally dry land. An area of inundation is the composite of all modeled grid cells where the tsunami height is larger than ground elevation. The maximum tsunami height may be located anywhere in the inundation area. Run-up is the ground elevation at the limit or extent of tsunami inundation. In some cases, the location of run-up and inundation coincide with one another. Flow depth is the height of the tsunami above the ground elevation, or the depth of water a person, building or object in the flood zone experiences. The distinction and relationship between these terms is graphically shown in **Figure 15**.

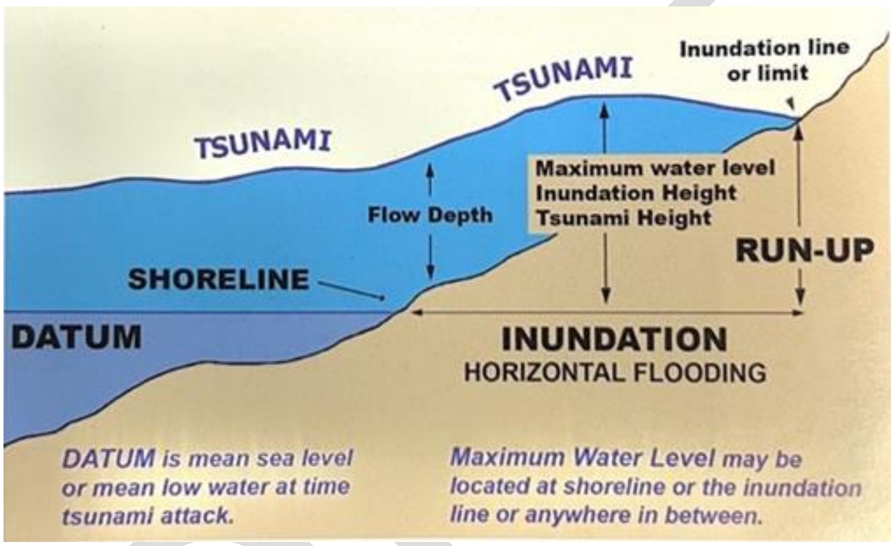


Figure 15: Tsunami inundation terms (Intergovernmental Oceanographic Commission, 2019).

Modeling of tsunami waves impacting Majuro was conducted in three phases; generation, propagation, and inundation. Once modeling of tsunami generation from a seismic source segment and tsunami propagation through the deep ocean phases completed, inundation of Majuro and offshore currents were modeled. Maximum current speed for the duration of the simulation was saved at every grid point every 120 seconds and every 60 seconds for the first five hours of the simulation at every grid point for the most hazardous source for Majuro – Manus. **Figure 16** illustrates maximum wave amplitudes and tsunami heights, as well as currents (black vectors) at different times from the most dangerous source for Majuro, Manus.

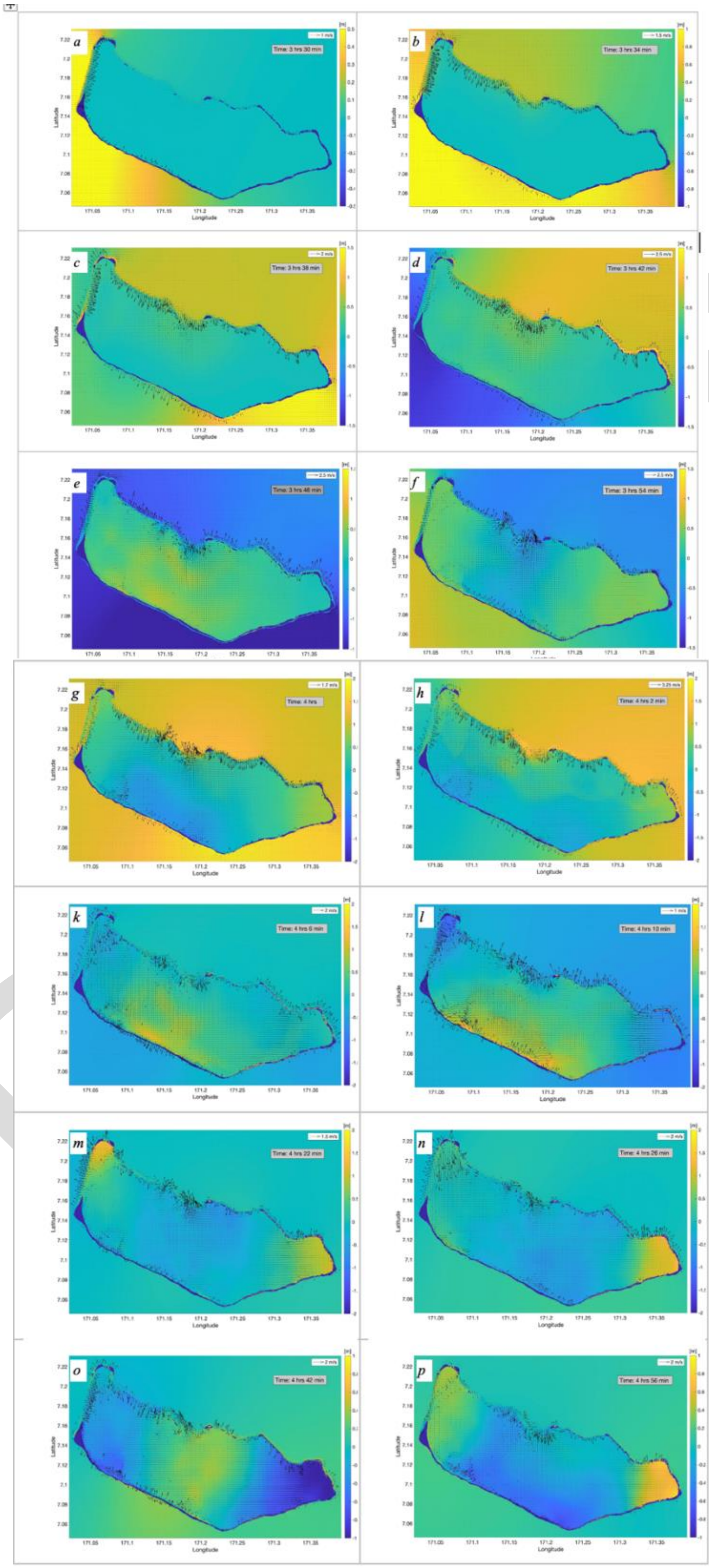


Figure 16: The wave amplitudes (offshore) and tsunami heights (onshore) and currents (black vectors, note scale in upper right corner of figures) at different time intervals after earthquake (shown on the figure) from the Manus source, the most dangerous for Majuro.

7.1. Wave Arrival

Figure 16 also shows the tsunami in Majuro at different times from earthquake origin for the Manus source which is the most dangerous for the island. The wave arrives from the south-west starting with the rise of water (runup) and reaches its maximum tsunami height at Laura in 3 hours 35 minutes after the earthquake and about 4 minutes later at DUD (Figure 16 *a* – *c*). The velocity vectors show the wave refracts around the island and enters the lagoon center at the north through the Calalin Pass and other smaller passes (**Figure 16 *d*, *e***). 20 minutes later after the first wave arrives, the second bigger wave hits Majuro (Figure 16 *f*, *g*). The velocity vectors show the wave refracts around the island exceeding the current velocities of 9 knots at the north of the atoll (Figure 16 *h*). The second order seiches form in the lagoon with a period of 30 min that continue many hours and attenuate slowly (Figure 16 *k* – *p*). The maximum tsunami heights around the island mostly vary within the range of 1.5 – 2.5 m exceeding these values at some points on the back side of the atoll (in respect to the source location) next to Ronguron, Arniel and Djarrit islands (**Figure 17**). This occurs given the wave interference caused by the collision of the waves propagating around the atoll from the place where the tsunami hits first (Liu et al., 1995, Briggs et al. 1995, Kanoglu, 1998), by the bathymetry specificities and coastline geometry.

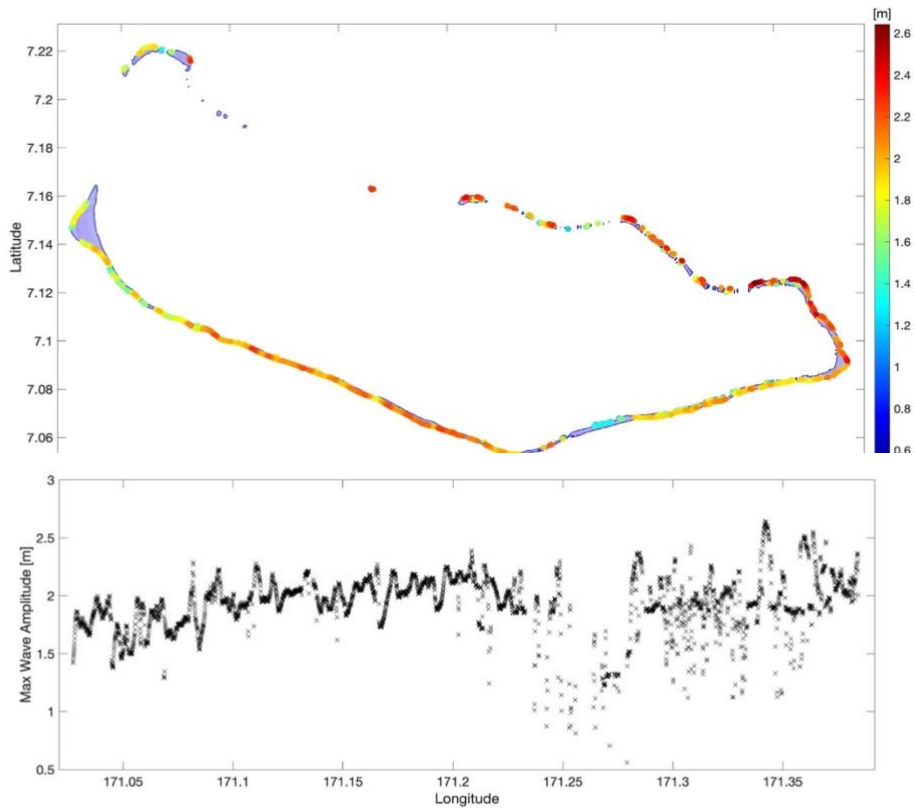


Figure 17: Maximum wave heights distribution along the coastline (a) and along the longitude (b) for the most hazardous source for Majuro – Manus.

7.2 Maximum Tsunami Height, Inundation, Runup, and Flow Depth

Maximum tsunami height, inundation, runup and flow depth were determined for all of Majuro. **Figure 18** illustrates the maximum tsunami height for the two most hazardous sources for Majuro, Manus (**Figure 18, *a***), Kuril (**Figure 18, *b***). The largest values for maximum tsunami height are 2.6 m and 1.97 m respectively. The location of these overall maximums is on the north part of Majuro in Arniel and Calalin islands, respectively. The inundation for the Manus event is extensive. The low-lying south-eastern (Rairik with Amata Kabua International Airport) and north-eastern (islands between Djarrit and Calalin) parts of the atoll are almost fully inundated, the DUD areas between Djarrit-Uliga and Uliga-Delap are also significantly inundated. In the major part of the Laura area only 20 – 30 m of the coast facing the open ocean and 10 m of the coast facing the lagoon are inundated.

The inundations are less with the similar areas of concern for South Solomon-New Hebrides, Kuril-Japan and Izu-Bonin sources (**Figure 19**). The largest values for maximum tsunami height are 1.39 m, 1.19 m and 1.05 m respectively.

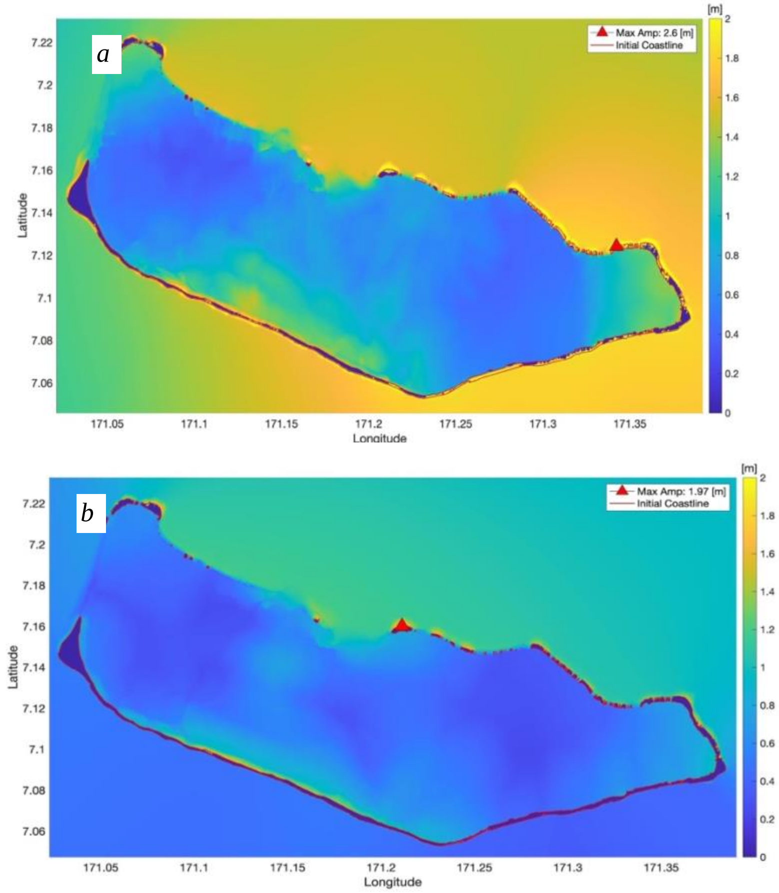
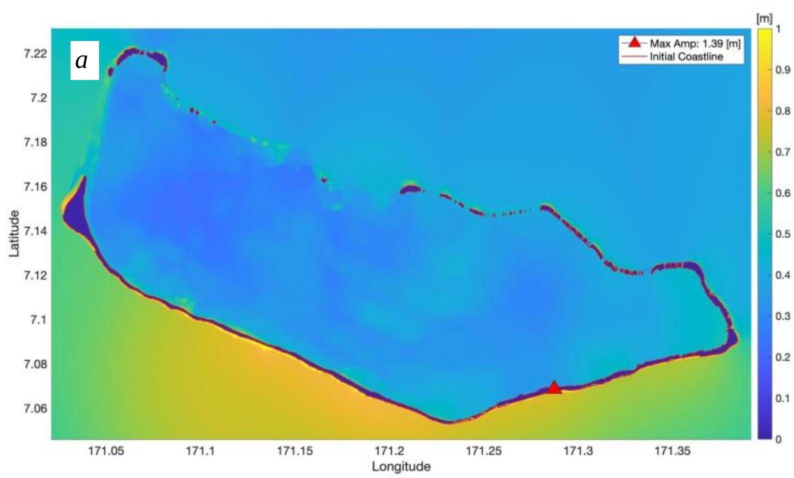


Figure 18: Maximum tsunami height and inundation for the a) Manus and b) Kuril sources. Red triangle marks the position of the overall grid maximum.



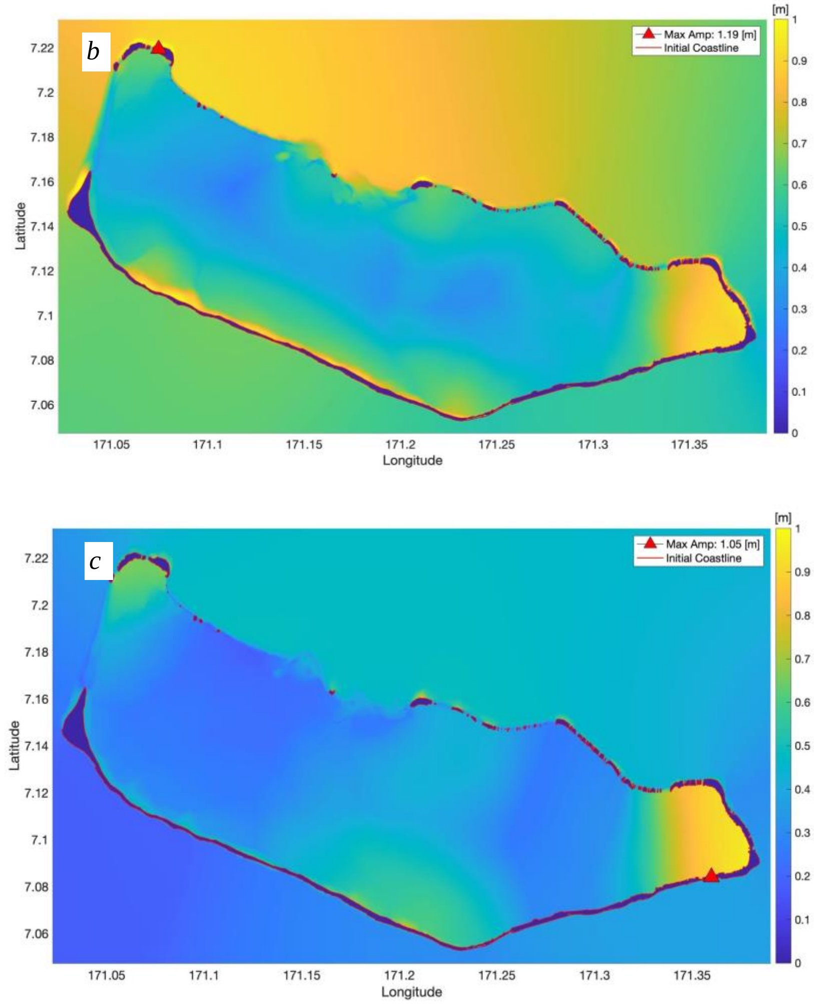


Figure 19: Maximum tsunami height and inundation for the a) South Solomon-New Hebrides, b) Kuril-Japan and e) Izu-Bonin sources. Red triangle marks the position of the overall grid maximum.

The maximum tsunami height plots show the wave pattern, focusing, and run-up elevation. But oftentimes the flow depth is a more intuitive and critical quantity. Flow depth is the wave amplitude minus ground elevation, or the depth of water a person in the flood zone sees. Flow depths greater than .5 m are considered to be dangerous. With this in mind, we provide the maximum flow depth for the most hazardous for the atoll – Manus source (**Figure 20**).

b

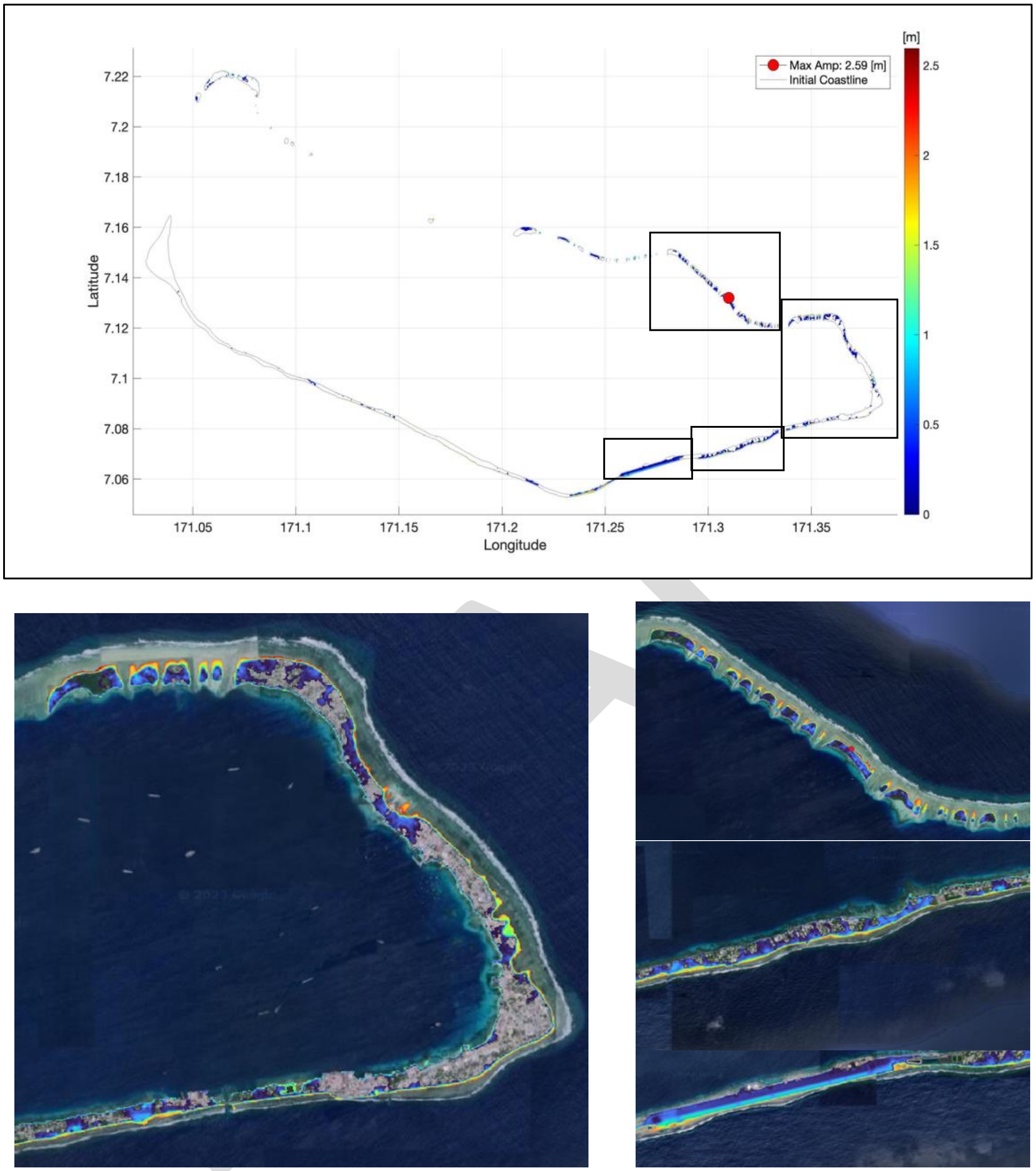


Figure 20: Maximum flow depth for the Manus source with the areas of major concern highlighted: *a* – DUD, *b* – from Arniel to Enigu islands, *c* – Rairik island, *d* – Amata Kabua International Airport.

7.3 Coastal Time Series at Specific Locations

Saving all variables at every time step for the whole simulation is not possible, but the model allows saving chosen locations at every time step and generating a time series. The time series includes the tsunami arrival time, wave amplitude and current speed. For the time series, the tsunami amplitude is the absolute value of the difference between a particular peak or trough of the tsunami and the undisturbed sea level at the time (**Figure 21**). It is intended to represent the true amplitude of the tsunami wave at some point along the coast. Tsunami heights and current speeds were saved at the most populated locations, locations with important infrastructure and at Calalin Pass – the main reef pass into the central lagoon (**Figure 22**, **Table 5**).

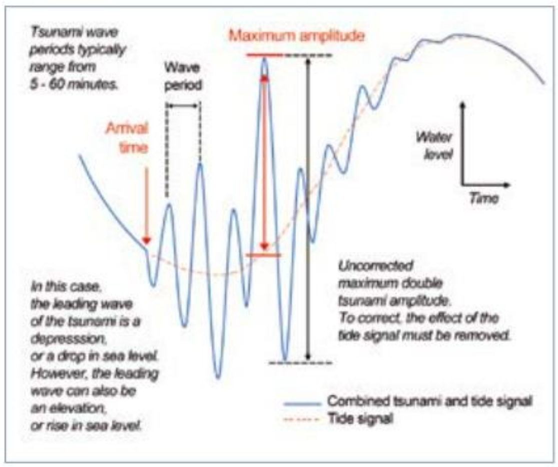


Figure 21. Terms used in the analysis of coastal time series.

Majuro coastal wave amplitudes forced by the most hazardous source for Majuro vary between 0.8 to 2 meters in the considered coastal locations (**Figure 22**, **Table 5**). The maximum amplitude is almost 2 meters at #1, #2, #6 – #9, #11, #12. The wave arrival starts with the rise of water (runup) water recession at the closest to the source locations (#12 Laura) 3 hours 26 minutes after the earthquake strikes and at the furthest locations of the ocean faced part of the atoll (#10 Private Island Boutique Resort) in 3 hours 34 minutes. The wave enters the lagoon 3 hours 31 min after the earthquake (#11 Calalin Pass) and reaches the farthest point of it in 3 hours 42 minutes (#5 Marshall Island Resort). After water recession another bigger rise of water elevation starts in 3 hours 52 minutes after the earthquake at the closest locations (#12 Laura) and in 3 hours 59 minutes at the furthest locations (#10 Private Island Boutique Resort). The second order seiches form in the lagoon with period of 30 min that continue many hours and attenuate slowly (**Figure 22**, #3 – #5).

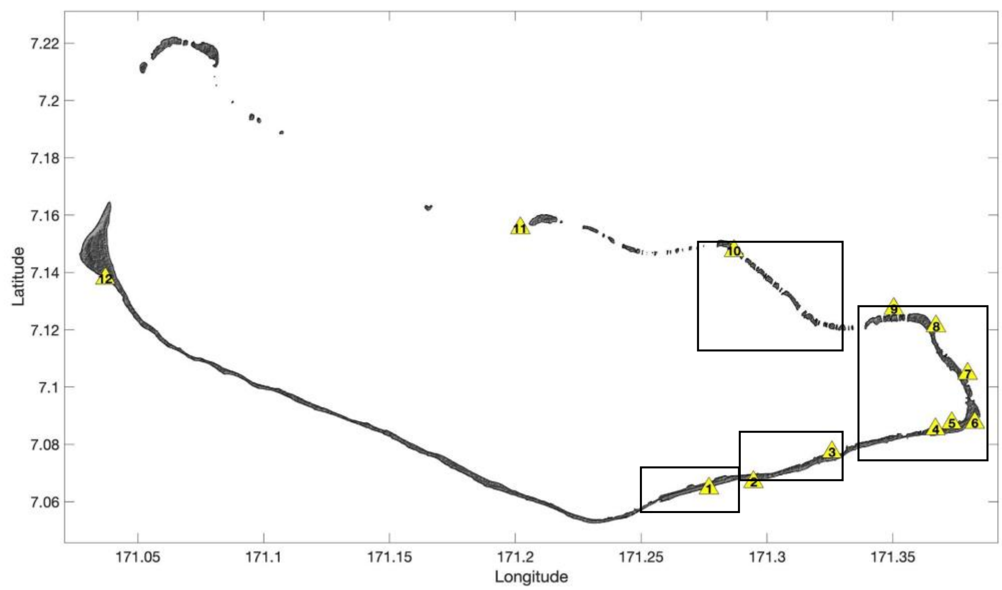


Figure 22: Locations of the synthetic tide gauges

Tsunami currents are an obviously important and damaging component of tsunami dynamics, in many cases causing significant hazard to maritime assets. The effects of tsunami currents in nearshore areas have been reported from many locations with docks being destroyed (Dengler, et al., 2008, Wilson, et al., 2013) and large ships breaking free from mooring lines and drifting uncontrolled through their respective ports (Lynett, et al., 2012, Lynett, et al., 2014). Tsunami currents usually accompany large inundations but can happen without them (Lynett, et al., 2014). Therefore, we present here both the time series of wave amplitudes and currents speeds at considered locations.

We highlight here the 3-knot (1.54 meters/second) current speed as the threshold value for currents causing moderate dock/boat damage following tsunami-induced current impacts metrics proposed by Lynett et al., 2014 (**Figure 23**).

Maximum current speeds and 3-knot current attenuation times (time between wave arrival and when currents drop below 3 knots) are sensitive to the bathymetry, harbor geometry as well as distance to source and source location. Due to the reef bordering the atoll the current speed attenuates significantly on the approach to the coastline. The maximum current speed does not exceed 0.05 m/s (0.1 knots) at the locations #1 – #9. Calalin Pass (#11) shows the largest consistent currents overall reaching 4 m/s (7.8 knots), and the 3-knots attenuation time of 3 hours is the longest of the time series records. All the locations except Calalin do not reach 3-knots current attenuation. The 3-knot attenuation time for them is listed as "NaN" in **Table 5**. A Scatter plot of observed damage indices and their corresponding tsunami-induced current with potential damage is shown in **Figure 24**.

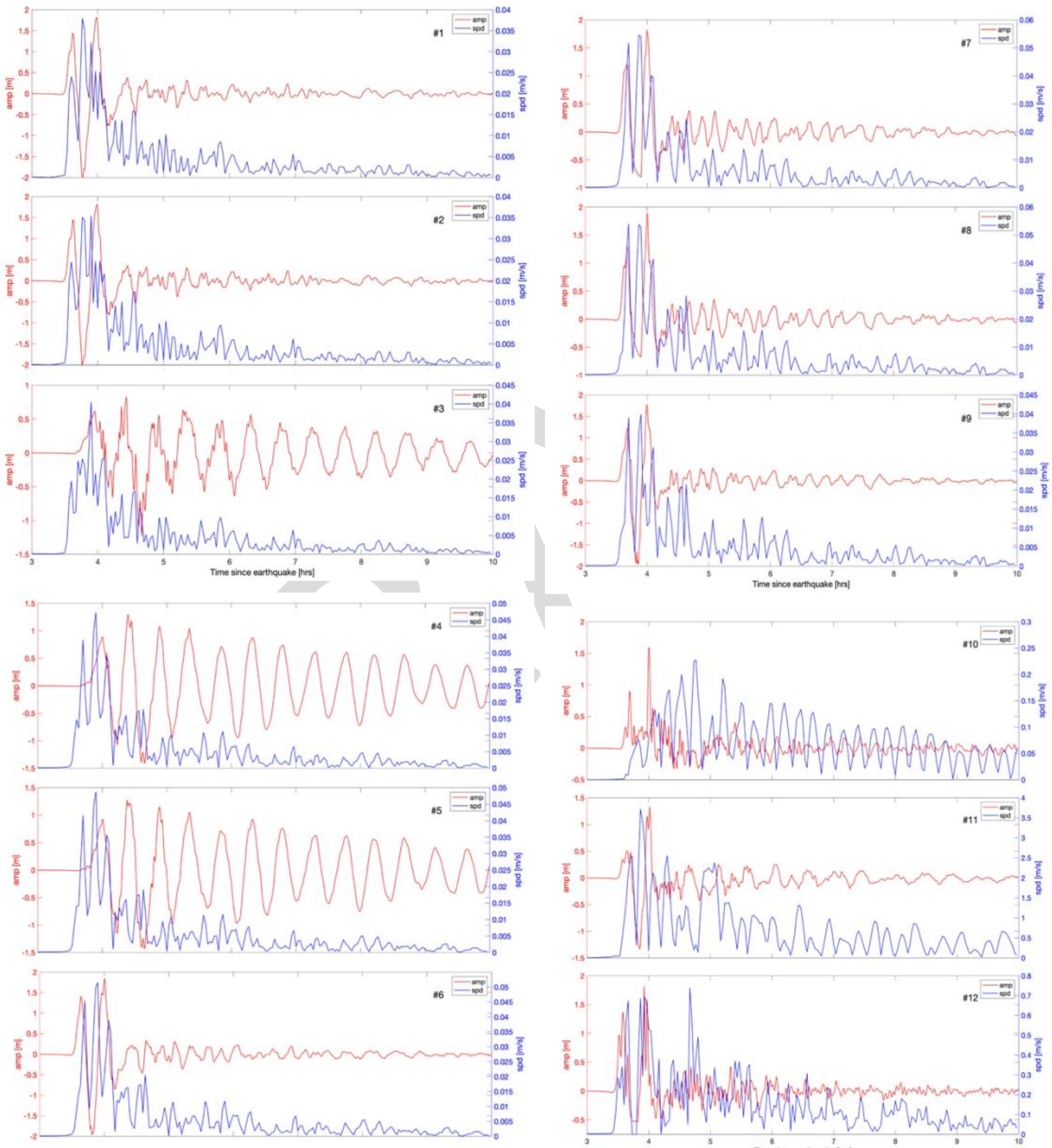


Figure 23: Time series of wave amplitude (red) and current speed (blue) forced with the Manus source at twelve synthetic tide gauges.

Table 5: Statistics for Majuro time series points due to the Manus source.

Gauge #	Close by Locations	Lon	Lat	Depth [m]	Min. Amp. [m]	Max. Amp. [m]	First Run-up Arr. Time	Drawdown Arr. Time	Second Run-up Arr. Time	Max Speed [m/s]	3-knot Atten.
1	Amata Kabua International Airport	171.2769	7.0647	-3.26	-1.99	1.82	3 h 38 min	3 h 46 min	3h 59 min	0.04	NaN
2	US Embassy in the RMI and Majuro National Weather Service	171.2946	7.0669	-2.85	-2.01	1.82	3 h 38 min	3 h 46 min	4 h	0.04	NaN
3	USP MI Campus and Office of the Attorney General	171.3258	7.0773	-2.04	-1.22	0.83	3 h 58 min	4 h 14 min	4 h 26 min	0.04	NaN
4	Port of Delap Dock, Majuro Power Plant, RMI Sea Patrol, MI Marine Resources Authority	171.367	7.0853	-2.93	-1.41	1.3	4 h	4 h 14 min	4 h 24 min	0.05	NaN
5	Marshall Island Resort, Government Office, Ministry of Finance	171.3734	7.0874	-1.59	-1.43	1.27	4 h 1 min	4 h 14 min	4 h 23 min	0.05	NaN
6	Office of the President and Cabinet, Capitol Building, Majuro Hospital	171.3825	7.0876	-2.74	-1.96	1.84	3h 39 min	3h 49 min	4h 1 min	0.05	NaN
7	College of the MI	171.3797	7.1047	-0.92	-0.81	1.82	3 h 41 min	3h 54 min	4 h	0.05	NaN
8	MI High School and Majuro Middle School	171.3671	7.1212	-0.91	-0.68	1.88	3 h 41 min	3h 54 min	4 h	0.05	NaN
9	Ejit Elementary School and Ejit Hospital	171.3504	7.1273	-1.24	-1.95	1.77	3 h 41 min	3h 49 min	4 h	0.04	NaN
10	Private Island Boutique Resort Bikendrik Island	171.2869	7.1476	-0.96	-0.33	1.59	3h 42 min	3h 47 min	4 h	0.23	NaN
11	Calalin Pass	171.202	7.1555	-46.73	-1.96	1.84	3h 39 min	3 h 49 min	4 h 1 min	3.71	2 h 46 min
12	Laura Public High School	171.0371	7.1379	-0.53	-0.53	1.81	3h 35 min	3h 44 min	3 h 56 min	0.74	NaN

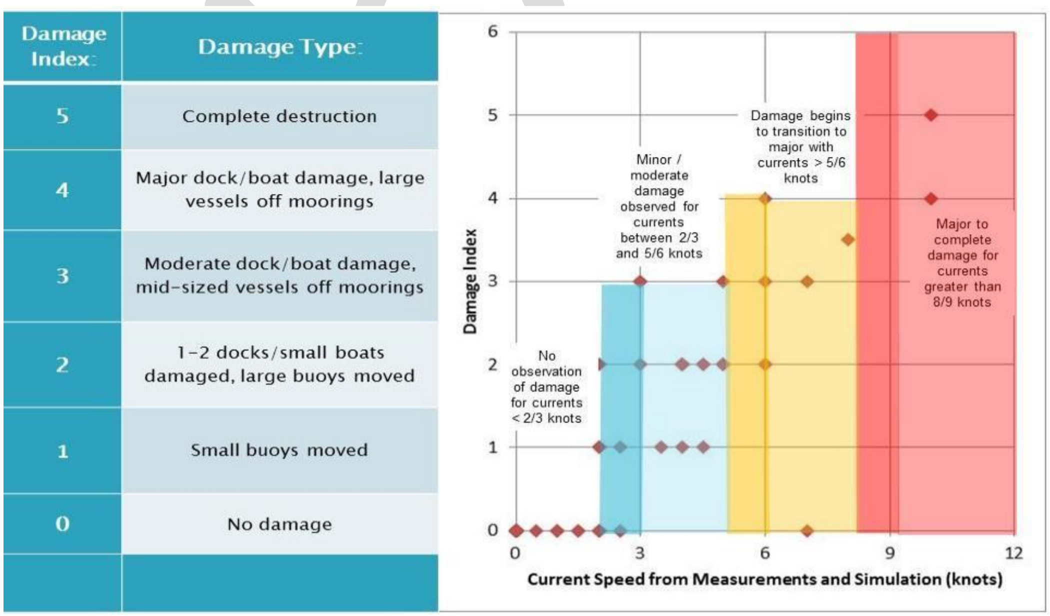


Figure 24: Scatter plot of observed damage indices and their corresponding tsunami-induced current with potential damage description (https://calema.maps.arcgis.com/apps/MapSeries/index.html?appid=baea43e6453b49ff9ae3f967eb6935be modified from Lynett et al., 2014).

7.4 Maximum Currents and Duration

In this section we provide overall maximum current speed and duration information as two-dimensional map plots. Maximum current plots are shown in knots as a three-dimensional surface plot (**Figure 25**) to show the specificities of the current speed behavior and as a color-filled contours (**Figure 26**) binning current speed into four bins: 0-3 knots (blue), 3-6 knots (cyan), 6-9 knots (yellow) and above 9 knots (red), as recommended by the proceedings of the NTHP Tsunami Current Modeling Workshop (NTHMP, 2017).

The maximum currents occur in areas where a constriction occurs: between islands or at the mouth of a bay, but the attenuation time (time it takes for currents to fall below the 3-knot cutoff) depends on many factors including harbor resonance.

The outer reef serves as a barrier to the approaching tsunami: part of the wave reflects from the fore reef, the rest of it slows down while moving along the reef flat toward the shore. This behavior can be seen well at the east, south and west parts of the atoll (**Figure 26**). The maximum currents are getting bigger at the north part of the atoll (where there are a lot of narrow passes) and exceed the 6-knot threshold between island and 9-knot threshold at the Calalin Pass and next to it between Eroj and Bokotana Islands (Figure 25).

The 3-knot current attenuation times are the longest at the central pass to the lagoon – Calalin Pass and exceed two hours (**Figure 26**).

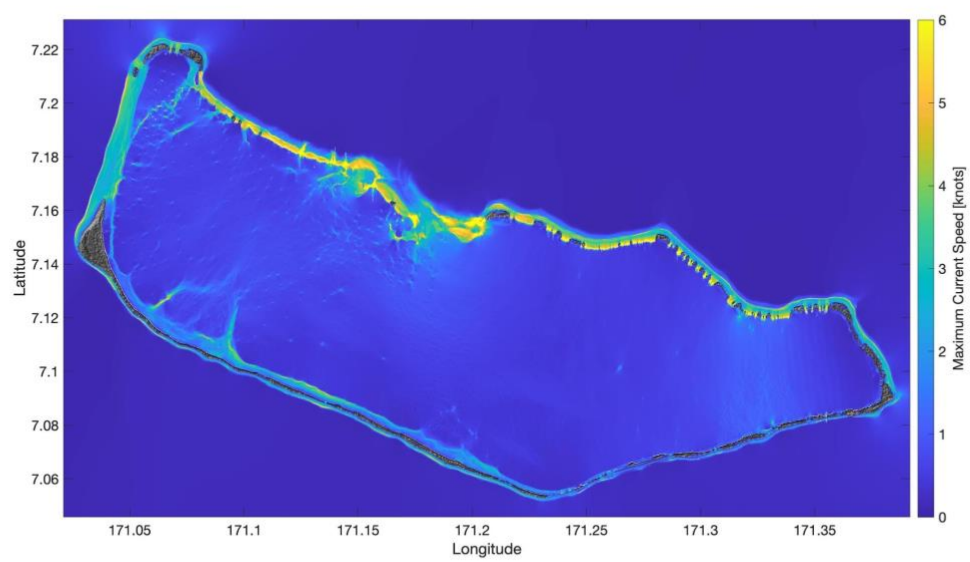


Figure 25: Maximum current speeds in Majuro for the Manus source.

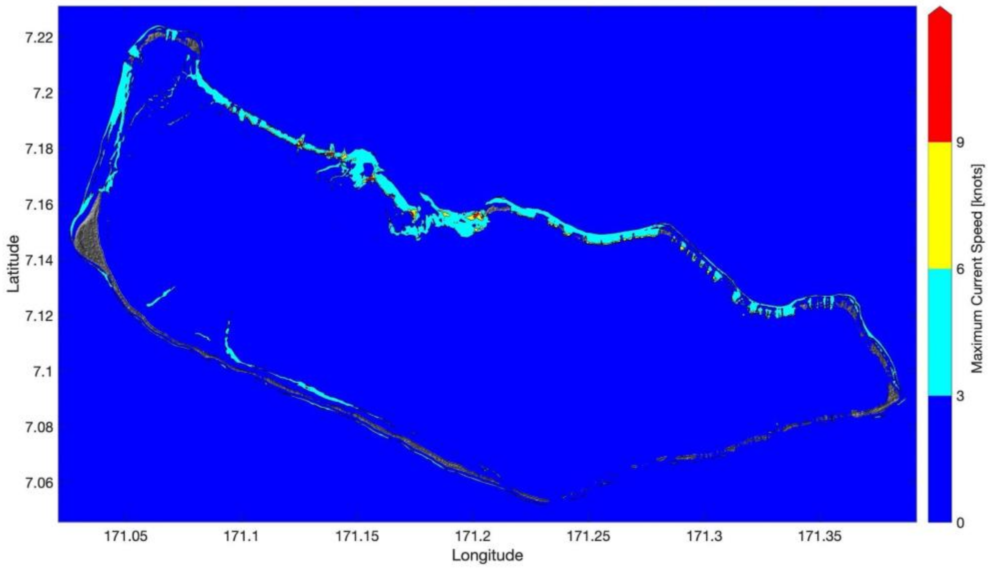


Figure 26: Maximum current speeds in Majuro for the Manus source.

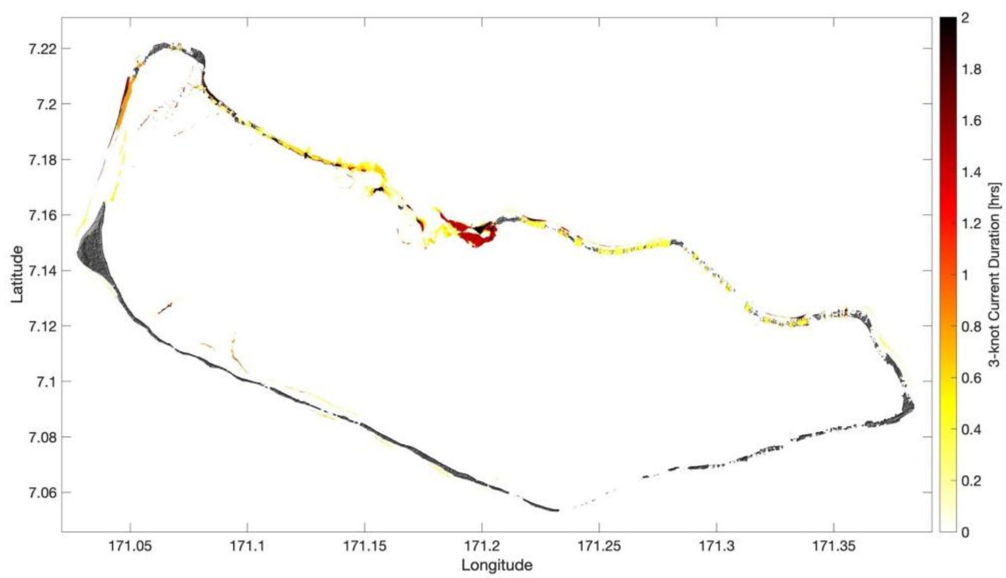


Figure 27: 3-knot current attenuation time in Majuro for the Manus source.

7.5 Composite Results

This project has identified five sources with potential significant impact on Majuro, and has focused so far on the most hazardous as they provide the largest inundation. But it is possible that smaller events inundate an area that a larger source has not, either because the incident direction of wave fronts from the two sources come from different directions, or because the dynamics of the wave as it shoals causes a focusing specific to a certain source. For this reason, we create a composite maximum by taking the envelope of maximum output from each source (e.g., the maximum of the maximums) (**Figure 28**). This composite looks very much like the most hazardous source (Figure 18, *a*) shown in section 7.2.

Patterns for Barbados inundation are typical for those seen in most islands: low-lying beach areas experience the worst inundation especially in the areas where "island back side" waves collision happens. Coral reefs serve as a protecting barrier from tsunami and tend to mitigate inundation, significantly reduce the velocity of a wave approaching the shore and in general lower the potential tsunami impact.

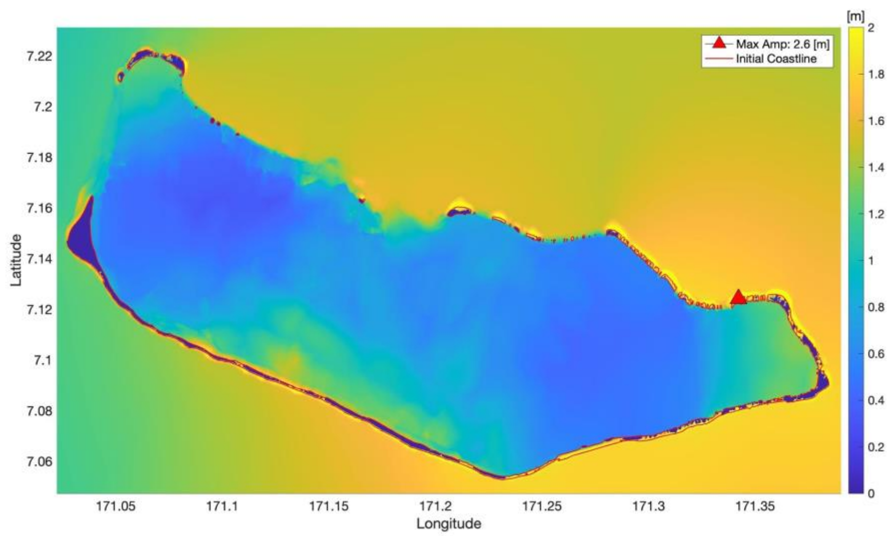


Figure 27: Composite maximum tsunami height.

Conclusion

The aim of this project was to conduct thorough scenario-based tsunami inundation study using the worst-case scenarios to identify the possible tsunami impact to Majuro. The Republic of Marshall Islands is surrounded by the Pacific Ocean "Ring of Fire" – extremely active seismic zones, which align with the boundaries of the tectonic plates. The sensitivity study using the NOAA Tsunami Forecast Propagation Database conducted to model tsunami impact along the coastline of Majuro from tsunami originating from 77 discrete earthquake sources located all around the Pacific helped to identify five the most potentially hazardous sources from Manus, South Solomon-New Hebrides, Kuril-Japan-Izu subduction zones. Arrival times for waves from the most hazardous source range from 3 hours 26 minutes at Laura to 3 hours 42 minutes at Marshall Island Resort in the lagoon. The overall maximum tsunami height of 2.6 m is reached at the north part of Majuro in Arniel island. Due to the tsunami the second order seiches form in the lagoon with a period of 30 min that continue many hours and attenuate slowly. The inundation from this source is extensive. The low-lying south-eastern (Rairik with Amata Kabua International Airport) and north-eastern (islands between Djarrit and Calalin) parts of the atoll are almost fully inundated, the DUD areas between Djarrit-Uliga and Uliga-Delap are also significantly inundated, so education, planning, preparedness and mitigation are fundamentally necessary.

The large consistent currents exceeding the threshold of 9 knots form in the Calalin Pass – the main reef pass and entrance into the central lagoon due to the tsunami from the most hazardous source. The 3-knots attenuation time here is more than 3 hours.

Patterns for Majuro inundation are those seen in most islands: low-lying beach areas experience the worst inundation especially in the areas where "island back side" wave collision happens and also the areas where location bathymetry creates a focusing effect. Coral reefs serve as a protecting barrier from tsunami and tend to mitigate inundation, significantly reduce the velocity of a wave approaching the shore and in general lower the potential tsunami impact.

This study provides a good first step toward assessing the effect of tsunamigenic earthquakes on Majuro. However, this study does not consider tsunami generating volcanic eruptions and tsunamigenic landslides that may occur due to earthquakes or volcanic activity.

While this report highlights the biggest events, the composite results were also included because it is possible that smaller events inundate an area that a larger source has not due to a particular source direction or focusing effects. This composite looks very much like the most hazardous source.

Model output products are provided (in GIS-readable TIFF format). They include the maximum wave amplitudes, the maximum flow depths as well as composite over all sources for maximum wave amplitude/tsunami height and flow depth.

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Appendix A

Propagation Database: Pacific Ocean Unit Sources

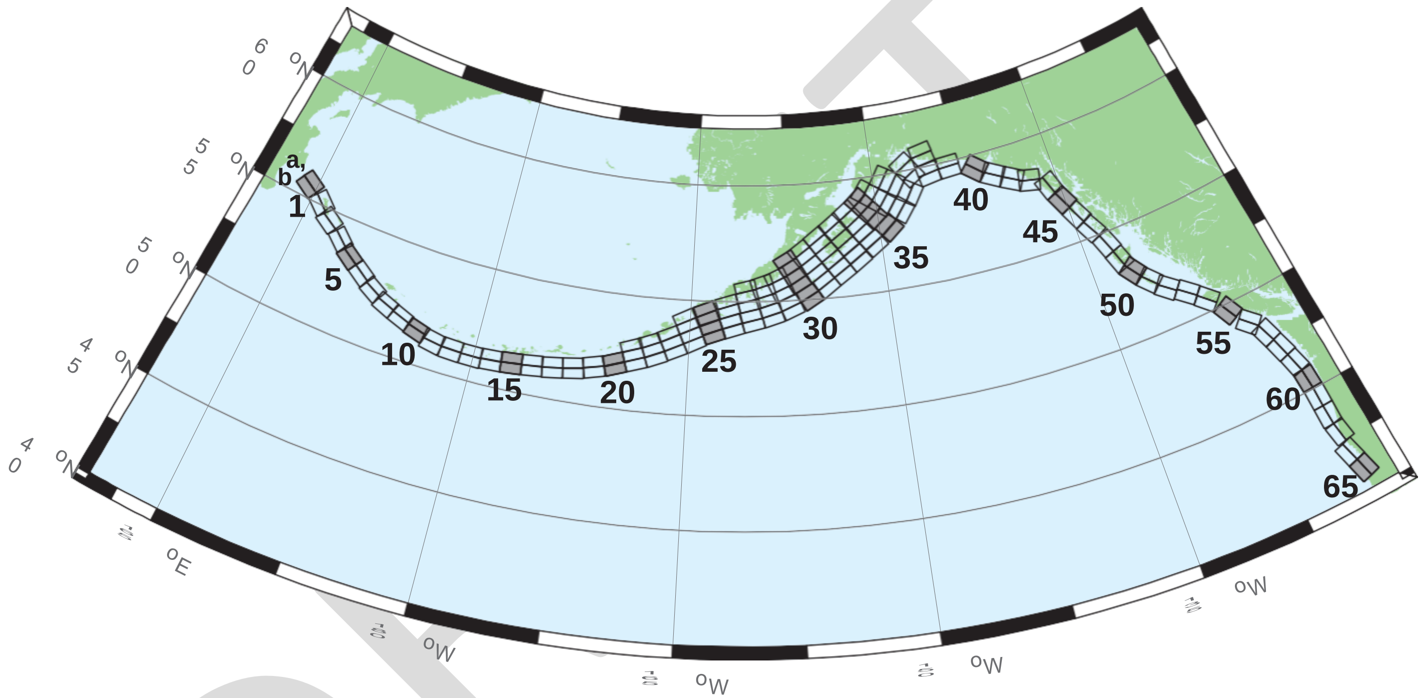

Figure A.1: Aleutian–Alaska–Cascadia Subduction Zone unit sources.

Table A.1: Earthquake parameters for Aleutian–Alaska–Cascadia Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz–1a	Aleutian–Alaska–Cascadia	164.7994	55.9606	299	17	19.61
acsz–1b	Aleutian–Alaska–Cascadia	164.4310	55.5849	299	17	5
acsz–2a	Aleutian–Alaska–Cascadia	166.3418	55.4016	310.2	17	19.61
acsz–2b	Aleutian–Alaska–Cascadia	165.8578	55.0734	310.2	17	5
acsz–3a	Aleutian–Alaska–Cascadia	167.2939	54.8919	300.2	23.36	24.82
acsz–3b	Aleutian–Alaska–Cascadia	166.9362	54.5356	300.2	23.36	5
acsz–4a	Aleutian–Alaska–Cascadia	168.7131	54.2852	310.2	38.51	25.33
acsz–4b	Aleutian–Alaska–Cascadia	168.3269	54.0168	310.2	24	5
acsz–5a	Aleutian–Alaska–Cascadia	169.7447	53.7808	302.8	37.02	23.54
acsz–5b	Aleutian–Alaska–Cascadia	169.4185	53.4793	302.8	21.77	5
acsz–6a	Aleutian–Alaska–Cascadia	171.0144	53.3054	303.2	35.31	22.92
acsz–6b	Aleutian–Alaska–Cascadia	170.6813	52.9986	303.2	21	5
acsz–7a	Aleutian–Alaska–Cascadia	172.1500	52.8528	298.2	35.56	20.16
acsz–7b	Aleutian–Alaska–Cascadia	171.8665	52.5307	298.2	17.65	5
acsz–8a	Aleutian–Alaska–Cascadia	173.2726	52.4579	290.8	37.92	20.35
acsz–8b	Aleutian–Alaska–Cascadia	173.0681	52.1266	290.8	17.88	5
acsz–9a	Aleutian–Alaska–Cascadia	174.5866	52.1434	289	39.09	21.05
acsz–9b	Aleutian–Alaska–Cascadia	174.4027	51.8138	289	18.73	5
acsz–10a	Aleutian–Alaska–Cascadia	175.8784	51.8526	286.1	40.51	20.87
acsz–10b	Aleutian–Alaska–Cascadia	175.7265	51.5245	286.1	18.51	5
acsz–11a	Aleutian–Alaska–Cascadia	177.1140	51.6488	280	15	17.94
acsz–11b	Aleutian–Alaska–Cascadia	176.9937	51.2215	280	15	5
acsz–12a	Aleutian–Alaska–Cascadia	178.4500	51.5690	273	15	17.94
acsz–12b	Aleutian–Alaska–Cascadia	178.4130	51.1200	273	15	5
acsz–13a	Aleutian–Alaska–Cascadia	179.8550	51.5340	271	15	17.94
acsz–13b	Aleutian–Alaska–Cascadia	179.8420	51.0850	271	15	5
acsz–14a	Aleutian–Alaska–Cascadia	181.2340	51.5780	267	15	17.94
acsz–14b	Aleutian–Alaska–Cascadia	181.2720	51.1290	267	15	5
acsz–15a	Aleutian–Alaska–Cascadia	182.6380	51.6470	265	15	17.94
acsz–15b	Aleutian–Alaska–Cascadia	182.7000	51.2000	265	15	5
acsz–16a	Aleutian–Alaska–Cascadia	184.0550	51.7250	264	15	17.94
acsz–16b	Aleutian–Alaska–Cascadia	184.1280	51.2780	264	15	5
acsz–17a	Aleutian–Alaska–Cascadia	185.4560	51.8170	262	15	17.94
acsz–17b	Aleutian–Alaska–Cascadia	185.5560	51.3720	262	15	5
acsz–18a	Aleutian–Alaska–Cascadia	186.8680	51.9410	261	15	17.94
acsz–18b	Aleutian–Alaska–Cascadia	186.9810	51.4970	261	15	5
acsz–19a	Aleutian–Alaska–Cascadia	188.2430	52.1280	257	15	17.94
acsz–19b	Aleutian–Alaska–Cascadia	188.4060	51.6900	257	15	5
acsz–20a	Aleutian–Alaska–Cascadia	189.5810	52.3550	251	15	17.94
acsz–20b	Aleutian–Alaska–Cascadia	189.8180	51.9300	251	15	5
acsz–21a	Aleutian–Alaska–Cascadia	190.9570	52.6470	251	15	17.94
acsz–21b	Aleutian–Alaska–Cascadia	191.1960	52.2220	251	15	5
acsz–21z	Aleutian–Alaska–Cascadia	190.7399	53.0443	250.8	15	30.88
acsz–22a	Aleutian–Alaska–Cascadia	192.2940	52.9430	247	15	17.94
acsz–22b	Aleutian–Alaska–Cascadia	192.5820	52.5300	247	15	5
acsz–22z	Aleutian–Alaska–Cascadia	192.0074	53.3347	247.8	15	30.88
acsz–23a	Aleutian–Alaska–Cascadia	193.6270	53.3070	245	15	17.94
acsz–23b	Aleutian–Alaska–Cascadia	193.9410	52.9000	245	15	5
acsz–23z	Aleutian–Alaska–Cascadia	193.2991	53.6768	244.6	15	30.88
acsz–24a	Aleutian–Alaska–Cascadia	194.9740	53.6870	245	15	17.94
acsz–24b	Aleutian–Alaska–Cascadia	195.2910	53.2800	245	15	5
acsz–24y	Aleutian–Alaska–Cascadia	194.3645	54.4604	244.4	15	43.82
acsz–24z	Aleutian–Alaska–Cascadia	194.6793	54.0674	244.6	15	30.88

Table A.1 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz–25a	Aleutian–Alaska–Cascadia	196.4340	54.0760	250	15	17.94
acsz–25b	Aleutian–Alaska–Cascadia	196.6930	53.6543	250	15	5
acsz–25y	Aleutian–Alaska–Cascadia	195.9009	54.8572	247.9	15	43.82
acsz–25z	Aleutian–Alaska–Cascadia	196.1761	54.4536	248.1	15	30.88
acsz–26a	Aleutian–Alaska–Cascadia	197.8970	54.3600	253	15	17.94
acsz–26b	Aleutian–Alaska–Cascadia	198.1200	53.9300	253	15	5
acsz–26y	Aleutian–Alaska–Cascadia	197.5498	55.1934	253.1	15	43.82
acsz–26z	Aleutian–Alaska–Cascadia	197.7620	54.7770	253.3	15	30.88
acsz–27a	Aleutian–Alaska–Cascadia	199.4340	54.5960	256	15	17.94
acsz–27b	Aleutian–Alaska–Cascadia	199.6200	54.1600	256	15	5
acsz–27x	Aleutian–Alaska–Cascadia	198.9736	55.8631	256.5	15	56.24
acsz–27y	Aleutian–Alaska–Cascadia	199.1454	55.4401	256.6	15	43.82
acsz–27z	Aleutian–Alaska–Cascadia	199.3135	55.0170	256.8	15	30.88
acsz–28a	Aleutian–Alaska–Cascadia	200.8820	54.8300	253	15	17.94
acsz–28b	Aleutian–Alaska–Cascadia	201.1080	54.4000	253	15	5
acsz–28x	Aleutian–Alaska–Cascadia	200.1929	56.0559	252.5	15	56.24
acsz–28y	Aleutian–Alaska–Cascadia	200.4167	55.6406	252.7	15	43.82
acsz–28z	Aleutian–Alaska–Cascadia	200.6360	55.2249	252.9	15	30.88
acsz–29a	Aleutian–Alaska–Cascadia	202.2610	55.1330	247	15	17.94
acsz–29b	Aleutian–Alaska–Cascadia	202.5650	54.7200	247	15	5
acsz–29x	Aleutian–Alaska–Cascadia	201.2606	56.2861	245.7	15	56.24
acsz–29y	Aleutian–Alaska–Cascadia	201.5733	55.8888	246	15	43.82
acsz–29z	Aleutian–Alaska–Cascadia	201.8797	55.4908	246.2	15	30.88
acsz–30a	Aleutian–Alaska–Cascadia	203.6040	55.5090	240	15	17.94
acsz–30b	Aleutian–Alaska–Cascadia	203.9970	55.1200	240	15	5
acsz–30w	Aleutian–Alaska–Cascadia	201.9901	56.9855	239.5	15	69.12
acsz–30x	Aleutian–Alaska–Cascadia	202.3851	56.6094	239.8	15	56.24
acsz–30y	Aleutian–Alaska–Cascadia	202.7724	56.2320	240.2	15	43.82
acsz–30z	Aleutian–Alaska–Cascadia	203.1521	55.8534	240.5	15	30.88
acsz–31a	Aleutian–Alaska–Cascadia	204.8950	55.9700	236	15	17.94
acsz–31b	Aleutian–Alaska–Cascadia	205.3400	55.5980	236	15	5
acsz–31w	Aleutian–Alaska–Cascadia	203.0825	57.3740	234.5	15	69.12
acsz–31x	Aleutian–Alaska–Cascadia	203.5408	57.0182	234.9	15	56.24
acsz–31y	Aleutian–Alaska–Cascadia	203.9904	56.6607	235.3	15	43.82
acsz–31z	Aleutian–Alaska–Cascadia	204.4315	56.3016	235.7	15	30.88
acsz–32a	Aleutian–Alaska–Cascadia	206.2080	56.4730	236	15	17.94
acsz–32b	Aleutian–Alaska–Cascadia	206.6580	56.1000	236	15	5
acsz–32w	Aleutian–Alaska–Cascadia	204.4129	57.8908	234.3	15	69.12
acsz–32x	Aleutian–Alaska–Cascadia	204.8802	57.5358	234.7	15	56.24
acsz–32y	Aleutian–Alaska–Cascadia	205.3385	57.1792	235.1	15	43.82
acsz–32z	Aleutian–Alaska–Cascadia	205.7880	56.8210	235.5	15	30.88
acsz–33a	Aleutian–Alaska–Cascadia	207.5370	56.9750	236	15	17.94
acsz–33b	Aleutian–Alaska–Cascadia	207.9930	56.6030	236	15	5
acsz–33w	Aleutian–Alaska–Cascadia	205.7126	58.3917	234.2	15	69.12
acsz–33x	Aleutian–Alaska–Cascadia	206.1873	58.0371	234.6	15	56.24
acsz–33y	Aleutian–Alaska–Cascadia	206.6527	57.6808	235	15	43.82
acsz–33z	Aleutian–Alaska–Cascadia	207.1091	57.3227	235.4	15	30.88
acsz–34a	Aleutian–Alaska–Cascadia	208.9371	57.5124	236	15	17.94
acsz–34b	Aleutian–Alaska–Cascadia	209.4000	57.1400	236	15	5
acsz–34w	Aleutian–Alaska–Cascadia	206.9772	58.8804	233.5	15	69.12
acsz–34x	Aleutian–Alaska–Cascadia	207.4677	58.5291	233.9	15	56.24
acsz–34y	Aleutian–Alaska–Cascadia	207.9485	58.1760	234.3	15	43.82
acsz–34z	Aleutian–Alaska–Cascadia	208.4198	57.8213	234.7	15	30.88
acsz–35a	Aleutian–Alaska–Cascadia	210.2597	58.0441	230	15	17.94
acsz–35b	Aleutian–Alaska–Cascadia	210.8000	57.7000	230	15	5

Table A.1 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz–35w	Aleutian–Alaska–Cascadia	208.0204	59.3199	228.8	15	69.12
acsz–35x	Aleutian–Alaska–Cascadia	208.5715	58.9906	229.3	15	56.24
acsz–35y	Aleutian–Alaska–Cascadia	209.1122	58.6590	229.7	15	43.82
acsz–35z	Aleutian–Alaska–Cascadia	209.6425	58.3252	230.2	15	30.88
acsz–36a	Aleutian–Alaska–Cascadia	211.3249	58.6565	218	15	17.94
acsz–36b	Aleutian–Alaska–Cascadia	212.0000	58.3800	218	15	5
acsz–36w	Aleutian–Alaska–Cascadia	208.5003	59.5894	215.6	15	69.12
acsz–36x	Aleutian–Alaska–Cascadia	209.1909	59.3342	216.2	15	56.24
acsz–36y	Aleutian–Alaska–Cascadia	209.8711	59.0753	216.8	15	43.82
acsz–36z	Aleutian–Alaska–Cascadia	210.5412	58.8129	217.3	15	30.88
acsz–37a	Aleutian–Alaska–Cascadia	212.2505	59.2720	213.7	15	17.94
acsz–37b	Aleutian–Alaska–Cascadia	212.9519	59.0312	213.7	15	5
acsz–37x	Aleutian–Alaska–Cascadia	210.1726	60.0644	213	15	56.24
acsz–37y	Aleutian–Alaska–Cascadia	210.8955	59.8251	213.7	15	43.82
acsz–37z	Aleutian–Alaska–Cascadia	211.6079	59.5820	214.3	15	30.88
acsz–38a	Aleutian–Alaska–Cascadia	214.6555	60.1351	260.1	0	15
acsz–38b	Aleutian–Alaska–Cascadia	214.8088	59.6927	260.1	0	15
acsz–38y	Aleutian–Alaska–Cascadia	214.3737	60.9838	259	0	15
acsz–38z	Aleutian–Alaska–Cascadia	214.5362	60.5429	259	0	15
acsz–39a	Aleutian–Alaska–Cascadia	216.5607	60.2480	267	0	15
acsz–39b	Aleutian–Alaska–Cascadia	216.6068	59.7994	267	0	15
acsz–40a	Aleutian–Alaska–Cascadia	219.3069	59.7574	310.9	0	15
acsz–40b	Aleutian–Alaska–Cascadia	218.7288	59.4180	310.9	0	15
acsz–41a	Aleutian–Alaska–Cascadia	220.4832	59.3390	300.7	0	15
acsz–41b	Aleutian–Alaska–Cascadia	220.0382	58.9529	300.7	0	15
acsz–42a	Aleutian–Alaska–Cascadia	221.8835	58.9310	298.9	0	15
acsz–42b	Aleutian–Alaska–Cascadia	221.4671	58.5379	298.9	0	15
acsz–43a	Aleutian–Alaska–Cascadia	222.9711	58.6934	282.3	0	15
acsz–43b	Aleutian–Alaska–Cascadia	222.7887	58.2546	282.3	0	15
acsz–44a	Aleutian–Alaska–Cascadia	224.9379	57.9054	340.9	12	11.09
acsz–44b	Aleutian–Alaska–Cascadia	224.1596	57.7617	340.9	7	5
acsz–45a	Aleutian–Alaska–Cascadia	225.4994	57.1634	334.1	12	11.09
acsz–45b	Aleutian–Alaska–Cascadia	224.7740	56.9718	334.1	7	5
acsz–46a	Aleutian–Alaska–Cascadia	226.1459	56.3552	334.1	12	11.09
acsz–46b	Aleutian–Alaska–Cascadia	225.4358	56.1636	334.1	7	5
acsz–47a	Aleutian–Alaska–Cascadia	226.7731	55.5830	332.3	12	11.09
acsz–47b	Aleutian–Alaska–Cascadia	226.0887	55.3785	332.3	7	5
acsz–48a	Aleutian–Alaska–Cascadia	227.4799	54.6763	339.4	12	11.09
acsz–48b	Aleutian–Alaska–Cascadia	226.7713	54.5217	339.4	7	5
acsz–49a	Aleutian–Alaska–Cascadia	227.9482	53.8155	341.2	12	11.09
acsz–49b	Aleutian–Alaska–Cascadia	227.2462	53.6737	341.2	7	5
acsz–50a	Aleutian–Alaska–Cascadia	228.3970	53.2509	324.5	12	11.09
acsz–50b	Aleutian–Alaska–Cascadia	227.8027	52.9958	324.5	7	5
acsz–51a	Aleutian–Alaska–Cascadia	229.1844	52.6297	318.4	12	11.09
acsz–51b	Aleutian–Alaska–Cascadia	228.6470	52.3378	318.4	7	5
acsz–52a	Aleutian–Alaska–Cascadia	230.0306	52.0768	310.9	12	11.09
acsz–52b	Aleutian–Alaska–Cascadia	229.5665	51.7445	310.9	7	5
acsz–53a	Aleutian–Alaska–Cascadia	231.1735	51.5258	310.9	12	11.09
acsz–53b	Aleutian–Alaska–Cascadia	230.7150	51.1935	310.9	7	5
acsz–54a	Aleutian–Alaska–Cascadia	232.2453	50.8809	314.1	12	11.09
acsz–54b	Aleutian–Alaska–Cascadia	231.7639	50.5655	314.1	7	5
acsz–55a	Aleutian–Alaska–Cascadia	233.3066	49.9032	333.7	12	11.09
acsz–55b	Aleutian–Alaska–Cascadia	232.6975	49.7086	333.7	7	5
acsz–56a	Aleutian–Alaska–Cascadia	234.0588	49.1702	315	11	12.82
acsz–56b	Aleutian–Alaska–Cascadia	233.5849	48.8584	315	9	5

Table A.1 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
acsz–57a	Aleutian–Alaska–Cascadia	234.9041	48.2596	341	11	12.82
acsz–57b	Aleutian–Alaska–Cascadia	234.2797	48.1161	341	9	5
acsz–58a	Aleutian–Alaska–Cascadia	235.3021	47.3812	344	11	12.82
acsz–58b	Aleutian–Alaska–Cascadia	234.6776	47.2597	344	9	5
acsz–59a	Aleutian–Alaska–Cascadia	235.6432	46.5082	345	11	12.82
acsz–59b	Aleutian–Alaska–Cascadia	235.0257	46.3941	345	9	5
acsz–60a	Aleutian–Alaska–Cascadia	235.8640	45.5429	356	11	12.82
acsz–60b	Aleutian–Alaska–Cascadia	235.2363	45.5121	356	9	5
acsz–61a	Aleutian–Alaska–Cascadia	235.9106	44.6227	359	11	12.82
acsz–61b	Aleutian–Alaska–Cascadia	235.2913	44.6150	359	9	5
acsz–62a	Aleutian–Alaska–Cascadia	235.9229	43.7245	359	11	12.82
acsz–62b	Aleutian–Alaska–Cascadia	235.3130	43.7168	359	9	5
acsz–63a	Aleutian–Alaska–Cascadia	236.0220	42.9020	350	11	12.82
acsz–63b	Aleutian–Alaska–Cascadia	235.4300	42.8254	350	9	5
acsz–64a	Aleutian–Alaska–Cascadia	235.9638	41.9818	345	11	12.82
acsz–64b	Aleutian–Alaska–Cascadia	235.3919	41.8677	345	9	5
acsz–65a	Aleutian–Alaska–Cascadia	236.2643	41.1141	345	11	12.82
acsz–65b	Aleutian–Alaska–Cascadia	235.7000	41.0000	345	9	5
acsz–238a	Aleutian–Alaska–Cascadia	213.2878	59.8406	236.8	15	17.94
acsz–238y	Aleutian–Alaska–Cascadia	212.3424	60.5664	236.8	15	43.82
acsz–238z	Aleutian–Alaska–Cascadia	212.8119	60.2035	236.8	15	30.88

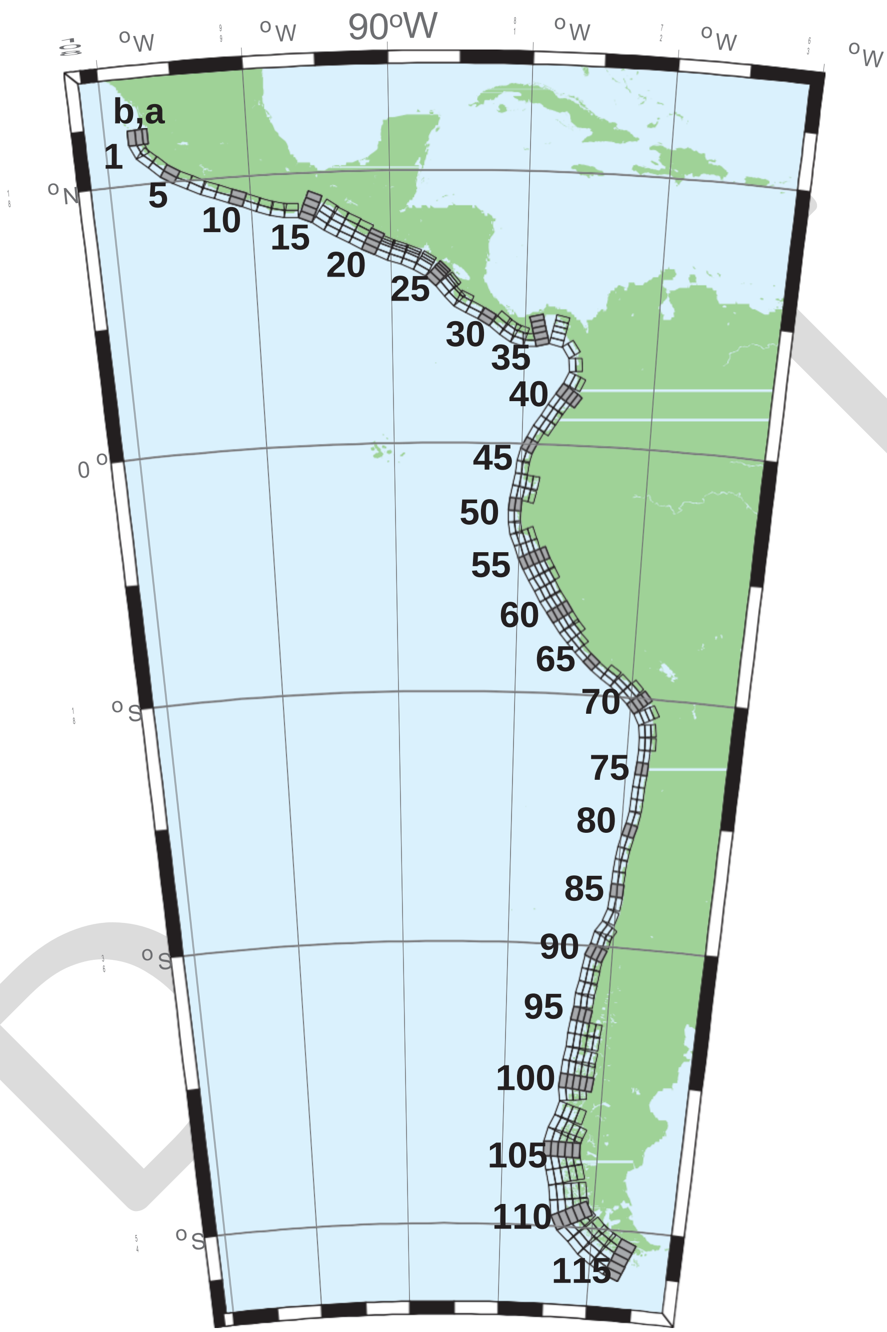

Figure A.2: Central and South America Subduction Zone unit sources.

Table A.2: Earthquake parameters for Central and South America Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz–1a	Central and South America	254.4573	20.8170	359	19	15.4
cssz–1b	Central and South America	254.0035	20.8094	359	12	5
cssz–1z	Central and South America	254.7664	20.8222	359	50	31.67
cssz–2a	Central and South America	254.5765	20.2806	336.8	19	15.4
cssz–2b	Central and South America	254.1607	20.1130	336.8	12	5
cssz–3a	Central and South America	254.8789	19.8923	310.6	18.31	15.27
cssz–3b	Central and South America	254.5841	19.5685	310.6	11.85	5
cssz–4a	Central and South America	255.6167	19.2649	313.4	17.62	15.12
cssz–4b	Central and South America	255.3056	18.9537	313.4	11.68	5
cssz–5a	Central and South America	256.2240	18.8148	302.7	16.92	15
cssz–5b	Central and South America	255.9790	18.4532	302.7	11.54	5
cssz–6a	Central and South America	256.9425	18.4383	295.1	16.23	14.87
cssz–6b	Central and South America	256.7495	18.0479	295.1	11.38	5
cssz–7a	Central and South America	257.8137	18.0339	296.9	15.54	14.74
cssz–7b	Central and South America	257.6079	17.6480	296.9	11.23	5
cssz–8a	Central and South America	258.5779	17.7151	290.4	14.85	14.61
cssz–8b	Central and South America	258.4191	17.3082	290.4	11.08	5
cssz–9a	Central and South America	259.4578	17.4024	290.5	14.15	14.47
cssz–9b	Central and South America	259.2983	16.9944	290.5	10.92	5
cssz–10a	Central and South America	260.3385	17.0861	290.8	13.46	14.34
cssz–10b	Central and South America	260.1768	16.6776	290.8	10.77	5
cssz–11a	Central and South America	261.2255	16.7554	291.8	12.77	14.21
cssz–11b	Central and South America	261.0556	16.3487	291.8	10.62	5
cssz–12a	Central and South America	262.0561	16.4603	288.9	12.08	14.08
cssz–12b	Central and South America	261.9082	16.0447	288.9	10.46	5
cssz–13a	Central and South America	262.8638	16.2381	283.2	11.38	13.95
cssz–13b	Central and South America	262.7593	15.8094	283.2	10.31	5
cssz–14a	Central and South America	263.6066	16.1435	272.1	10.69	13.81
cssz–14b	Central and South America	263.5901	15.7024	272.1	10.15	5
cssz–15a	Central and South America	264.8259	15.8829	293	10	13.68
cssz–15b	Central and South America	264.6462	15.4758	293	10	5
cssz–15y	Central and South America	265.1865	16.6971	293	10	31.05
cssz–15z	Central and South America	265.0060	16.2900	293	10	22.36
cssz–16a	Central and South America	265.7928	15.3507	304.9	15	15.82
cssz–16b	Central and South America	265.5353	14.9951	304.9	12.5	5
cssz–16y	Central and South America	266.3092	16.0619	304.9	15	41.7
cssz–16z	Central and South America	266.0508	15.7063	304.9	15	28.76
cssz–17a	Central and South America	266.4947	14.9019	299.5	20	17.94
cssz–17b	Central and South America	266.2797	14.5346	299.5	15	5
cssz–17y	Central and South America	266.9259	15.6365	299.5	20	52.14
cssz–17z	Central and South America	266.7101	15.2692	299.5	20	35.04
cssz–18a	Central and South America	267.2827	14.4768	298	21.5	17.94
cssz–18b	Central and South America	267.0802	14.1078	298	15	5
cssz–18y	Central and South America	267.6888	15.2148	298	21.5	54.59
cssz–18z	Central and South America	267.4856	14.8458	298	21.5	36.27
cssz–19a	Central and South America	268.0919	14.0560	297.6	23	17.94
cssz–19b	Central and South America	267.8943	13.6897	297.6	15	5
cssz–19y	Central and South America	268.4880	14.7886	297.6	23	57.01
cssz–19z	Central and South America	268.2898	14.4223	297.6	23	37.48
cssz–20a	Central and South America	268.8929	13.6558	296.2	24	17.94
cssz–20b	Central and South America	268.7064	13.2877	296.2	15	5
cssz–20y	Central and South America	269.1796	14.2206	296.2	45.5	73.94
cssz–20z	Central and South America	269.0362	13.9382	296.2	45.5	38.28

Table A.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz–21a	Central and South America	269.6797	13.3031	292.6	25	17.94
cssz–21b	Central and South America	269.5187	12.9274	292.6	15	5
cssz–21x	Central and South America	269.8797	13.7690	292.6	68	131.8
cssz–21y	Central and South America	269.8130	13.6137	292.6	68	85.43
cssz–21z	Central and South America	269.7463	13.4584	292.6	68	39.07
cssz–22a	Central and South America	270.4823	13.0079	288.6	25	17.94
cssz–22b	Central and South America	270.3492	12.6221	288.6	15	5
cssz–22x	Central and South America	270.6476	13.4864	288.6	68	131.8
cssz–22y	Central and South America	270.5925	13.3269	288.6	68	85.43
cssz–22z	Central and South America	270.5374	13.1674	288.6	68	39.07
cssz–23a	Central and South America	271.3961	12.6734	292.4	25	17.94
cssz–23b	Central and South America	271.2369	12.2972	292.4	15	5
cssz–23x	Central and South America	271.5938	13.1399	292.4	68	131.8
cssz–23y	Central and South America	271.5279	12.9844	292.4	68	85.43
cssz–23z	Central and South America	271.4620	12.8289	292.4	68	39.07
cssz–24a	Central and South America	272.3203	12.2251	300.2	25	17.94
cssz–24b	Central and South America	272.1107	11.8734	300.2	15	5
cssz–24x	Central and South America	272.5917	12.6799	300.2	67	131.1
cssz–24y	Central and South America	272.5012	12.5283	300.2	67	85.1
cssz–24z	Central and South America	272.4107	12.3767	300.2	67	39.07
cssz–25a	Central and South America	273.2075	11.5684	313.8	25	17.94
cssz–25b	Central and South America	272.9200	11.2746	313.8	15	5
cssz–25x	Central and South America	273.5950	11.9641	313.8	66	130.4
cssz–25y	Central and South America	273.4658	11.8322	313.8	66	84.75
cssz–25z	Central and South America	273.3366	11.7003	313.8	66	39.07
cssz–26a	Central and South America	273.8943	10.8402	320.4	25	17.94
cssz–26b	Central and South America	273.5750	10.5808	320.4	15	5
cssz–26x	Central and South America	274.3246	11.1894	320.4	66	130.4
cssz–26y	Central and South America	274.1811	11.0730	320.4	66	84.75
cssz–26z	Central and South America	274.0377	10.9566	320.4	66	39.07
cssz–27a	Central and South America	274.4569	10.2177	316.1	25	17.94
cssz–27b	Central and South America	274.1590	9.9354	316.1	15	5
cssz–27z	Central and South America	274.5907	10.3444	316.1	66	39.07
cssz–28a	Central and South America	274.9586	9.8695	297.1	22	14.54
cssz–28b	Central and South America	274.7661	9.4988	297.1	11	5
cssz–28z	Central and South America	275.1118	10.1643	297.1	42.5	33.27
cssz–29a	Central and South America	275.7686	9.4789	296.6	19	11.09
cssz–29b	Central and South America	275.5759	9.0992	296.6	7	5
cssz–30a	Central and South America	276.6346	8.9973	302.2	19	9.36
cssz–30b	Central and South America	276.4053	8.6381	302.2	5	5
cssz–31a	Central and South America	277.4554	8.4152	309.1	19	7.62
cssz–31b	Central and South America	277.1851	8.0854	309.1	3	5
cssz–31z	Central and South America	277.7260	8.7450	309.1	19	23.9
cssz–32a	Central and South America	278.1112	7.9425	303	18.67	8.49
cssz–32b	Central and South America	277.8775	7.5855	303	4	5
cssz–32z	Central and South America	278.3407	8.2927	303	21.67	24.49
cssz–33a	Central and South America	278.7082	7.6620	287.6	18.33	10.23
cssz–33b	Central and South America	278.5785	7.2555	287.6	6	5
cssz–33z	Central and South America	278.8328	8.0522	287.6	24.33	25.95
cssz–34a	Central and South America	279.3184	7.5592	269.5	18	17.94
cssz–34b	Central and South America	279.3223	7.1320	269.5	15	5
cssz–35a	Central and South America	280.0039	7.6543	255.9	17.67	14.54
cssz–35b	Central and South America	280.1090	7.2392	255.9	11	5
cssz–35x	Central and South America	279.7156	8.7898	255.9	29.67	79.22
cssz–35y	Central and South America	279.8118	8.4113	255.9	29.67	54.47

Table A.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz–35z	Central and South America	279.9079	8.0328	255.9	29.67	29.72
cssz–36a	Central and South America	281.2882	7.6778	282.5	17.33	11.09
cssz–36b	Central and South America	281.1948	7.2592	282.5	7	5
cssz–36x	Central and South America	281.5368	8.7896	282.5	32.33	79.47
cssz–36y	Central and South America	281.4539	8.4190	282.5	32.33	52.73
cssz–36z	Central and South America	281.3710	8.0484	282.5	32.33	25.99
cssz–37a	Central and South America	282.5252	6.8289	326.9	17	10.23
cssz–37b	Central and South America	282.1629	6.5944	326.9	6	5
cssz–38a	Central and South America	282.9469	5.5973	355.4	17	10.23
cssz–38b	Central and South America	282.5167	5.5626	355.4	6	5
cssz–39a	Central and South America	282.7236	4.3108	24.13	17	10.23
cssz–39b	Central and South America	282.3305	4.4864	24.13	6	5
cssz–39z	Central and South America	283.0603	4.1604	24.13	35	24.85
cssz–40a	Central and South America	282.1940	3.3863	35.28	17	10.23
cssz–40b	Central and South America	281.8427	3.6344	35.28	6	5
cssz–40y	Central and South America	282.7956	2.9613	35.28	35	53.52
cssz–40z	Central and South America	282.4948	3.1738	35.28	35	24.85
cssz–41a	Central and South America	281.6890	2.6611	34.27	17	10.23
cssz–41b	Central and South America	281.3336	2.9030	34.27	6	5
cssz–41z	Central and South America	281.9933	2.4539	34.27	35	24.85
cssz–42a	Central and South America	281.2266	1.9444	31.29	17	10.23
cssz–42b	Central and South America	280.8593	2.1675	31.29	6	5
cssz–42z	Central and South America	281.5411	1.7533	31.29	35	24.85
cssz–43a	Central and South America	280.7297	1.1593	33.3	17	10.23
cssz–43b	Central and South America	280.3706	1.3951	33.3	6	5
cssz–43z	Central and South America	281.0373	0.9573	33.3	35	24.85
cssz–44a	Central and South America	280.3018	0.4491	28.8	17	10.23
cssz–44b	Central and South America	279.9254	0.6560	28.8	6	5
cssz–45a	Central and South America	279.9083	-0.3259	26.91	10	8.49
cssz–45b	Central and South America	279.5139	-0.1257	26.91	4	5
cssz–46a	Central and South America	279.6461	-0.9975	15.76	10	8.49
cssz–46b	Central and South America	279.2203	-0.8774	15.76	4	5
cssz–47a	Central and South America	279.4972	-1.7407	6.9	10	8.49
cssz–47b	Central and South America	279.0579	-1.6876	6.9	4	5
cssz–48a	Central and South America	279.3695	-2.6622	8.96	10	8.49
cssz–48b	Central and South America	278.9321	-2.5933	8.96	4	5
cssz–48y	Central and South America	280.2444	-2.8000	8.96	10	25.85
cssz–48z	Central and South America	279.8070	-2.7311	8.96	10	17.17
cssz–49a	Central and South America	279.1852	-3.6070	13.15	10	8.49
cssz–49b	Central and South America	278.7536	-3.5064	13.15	4	5
cssz–49y	Central and South America	280.0486	-3.8082	13.15	10	25.85
cssz–49z	Central and South America	279.6169	-3.7076	13.15	10	17.17
cssz–50a	Central and South America	279.0652	-4.3635	4.78	10.33	9.64
cssz–50b	Central and South America	278.6235	-4.3267	4.78	5.33	5
cssz–51a	Central and South America	279.0349	-5.1773	359.4	10.67	10.81
cssz–51b	Central and South America	278.5915	-5.1817	359.4	6.67	5
cssz–52a	Central and South America	279.1047	-5.9196	349.8	11	11.96
cssz–52b	Central and South America	278.6685	-5.9981	349.8	8	5
cssz–53a	Central and South America	279.3044	-6.6242	339.2	10.25	11.74
cssz–53b	Central and South America	278.8884	-6.7811	339.2	7.75	5
cssz–53y	Central and South America	280.1024	-6.3232	339.2	19.25	37.12
cssz–53z	Central and South America	279.7035	-6.4737	339.2	19.25	20.64
cssz–54a	Central and South America	279.6256	-7.4907	340.8	9.5	11.53
cssz–54b	Central and South America	279.2036	-7.6365	340.8	7.5	5
cssz–54y	Central and South America	280.4267	-7.2137	340.8	20.5	37.29

Table A.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz–54z	Central and South America	280.0262	-7.3522	340.8	20.5	19.78
cssz–55a	Central and South America	279.9348	-8.2452	335.4	8.75	11.74
cssz–55b	Central and South America	279.5269	-8.4301	335.4	7.75	5
cssz–55x	Central and South America	281.0837	-7.7238	335.4	21.75	56.4
cssz–55y	Central and South America	280.7009	-7.8976	335.4	21.75	37.88
cssz–55z	Central and South America	280.3180	-8.0714	335.4	21.75	19.35
cssz–56a	Central and South America	280.3172	-8.9958	331.6	8	11.09
cssz–56b	Central and South America	279.9209	-9.2072	331.6	7	5
cssz–56x	Central and South America	281.4212	-8.4063	331.6	23	57.13
cssz–56y	Central and South America	281.0534	-8.6028	331.6	23	37.59
cssz–56z	Central and South America	280.6854	-8.7993	331.6	23	18.05
cssz–57a	Central and South America	280.7492	-9.7356	328.7	8.6	10.75
cssz–57b	Central and South America	280.3640	-9.9663	328.7	6.6	5
cssz–57x	Central and South America	281.8205	-9.0933	328.7	23.4	57.94
cssz–57y	Central and South America	281.4636	-9.3074	328.7	23.4	38.08
cssz–57z	Central and South America	281.1065	-9.5215	328.7	23.4	18.22
cssz–58a	Central and South America	281.2275	-10.5350	330.5	9.2	10.4
cssz–58b	Central and South America	280.8348	-10.7532	330.5	6.2	5
cssz–58y	Central and South America	281.9548	-10.1306	330.5	23.8	38.57
cssz–58z	Central and South America	281.5913	-10.3328	330.5	23.8	18.39
cssz–59a	Central and South America	281.6735	-11.2430	326.2	9.8	10.05
cssz–59b	Central and South America	281.2982	-11.4890	326.2	5.8	5
cssz–59y	Central and South America	282.3675	-10.7876	326.2	24.2	39.06
cssz–59z	Central and South America	282.0206	-11.0153	326.2	24.2	18.56
cssz–60a	Central and South America	282.1864	-11.9946	326.5	10.4	9.71
cssz–60b	Central and South America	281.8096	-12.2384	326.5	5.4	5
cssz–60y	Central and South America	282.8821	-11.5438	326.5	24.6	39.55
cssz–60z	Central and South America	282.5344	-11.7692	326.5	24.6	18.73
cssz–61a	Central and South America	282.6944	-12.7263	325.5	11	9.36
cssz–61b	Central and South America	282.3218	-12.9762	325.5	5	5
cssz–61y	Central and South America	283.3814	-12.2649	325.5	25	40.03
cssz–61z	Central and South America	283.0381	-12.4956	325.5	25	18.9
cssz–62a	Central and South America	283.1980	-13.3556	319	11	9.79
cssz–62b	Central and South America	282.8560	-13.6451	319	5.5	5
cssz–62y	Central and South America	283.8178	-12.8300	319	27	42.03
cssz–62z	Central and South America	283.5081	-13.0928	319	27	19.33
cssz–63a	Central and South America	283.8032	-14.0147	317.9	11	10.23
cssz–63b	Central and South America	283.4661	-14.3106	317.9	6	5
cssz–63z	Central and South America	284.1032	-13.7511	317.9	29	19.77
cssz–64a	Central and South America	284.4144	-14.6482	315.7	13	11.96
cssz–64b	Central and South America	284.0905	-14.9540	315.7	8	5
cssz–65a	Central and South America	285.0493	-15.2554	313.2	15	13.68
cssz–65b	Central and South America	284.7411	-15.5715	313.2	10	5
cssz–66a	Central and South America	285.6954	-15.7816	307.7	14.5	13.68
cssz–66b	Central and South America	285.4190	-16.1258	307.7	10	5
cssz–67a	Central and South America	286.4127	-16.2781	304.3	14	13.68
cssz–67b	Central and South America	286.1566	-16.6381	304.3	10	5
cssz–67z	Central and South America	286.6552	-15.9365	304.3	23	25.78
cssz–68a	Central and South America	287.2481	-16.9016	311.8	14	13.68
cssz–68b	Central and South America	286.9442	-17.2264	311.8	10	5
cssz–68z	Central and South America	287.5291	-16.6007	311.8	26	25.78
cssz–69a	Central and South America	287.9724	-17.5502	314.9	14	13.68
cssz–69b	Central and South America	287.6496	-17.8590	314.9	10	5
cssz–69y	Central and South America	288.5530	-16.9934	314.9	29	50.02
cssz–69z	Central and South America	288.2629	-17.2718	314.9	29	25.78

Table A.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz–70a	Central and South America	288.6731	-18.2747	320.4	14	13.25
cssz–70b	Central and South America	288.3193	-18.5527	320.4	9.5	5
cssz–70y	Central and South America	289.3032	-17.7785	320.4	30	50.35
cssz–70z	Central and South America	288.9884	-18.0266	320.4	30	25.35
cssz–71a	Central and South America	289.3089	-19.1854	333.2	14	12.82
cssz–71b	Central and South America	288.8968	-19.3820	333.2	9	5
cssz–71y	Central and South America	290.0357	-18.8382	333.2	31	50.67
cssz–71z	Central and South America	289.6725	-19.0118	333.2	31	24.92
cssz–72a	Central and South America	289.6857	-20.3117	352.4	14	12.54
cssz–72b	Central and South America	289.2250	-20.3694	352.4	8.67	5
cssz–72z	Central and South America	290.0882	-20.2613	352.4	32	24.63
cssz–73a	Central and South America	289.7731	-21.3061	358.9	14	12.24
cssz–73b	Central and South America	289.3053	-21.3142	358.9	8.33	5
cssz–73z	Central and South America	290.1768	-21.2991	358.9	33	24.34
cssz–74a	Central and South America	289.7610	-22.2671	3.06	14	11.96
cssz–74b	Central and South America	289.2909	-22.2438	3.06	8	5
cssz–75a	Central and South America	289.6982	-23.1903	4.83	14.09	11.96
cssz–75b	Central and South America	289.2261	-23.1536	4.83	8	5
cssz–76a	Central and South America	289.6237	-24.0831	4.67	14.18	11.96
cssz–76b	Central and South America	289.1484	-24.0476	4.67	8	5
cssz–77a	Central and South America	289.5538	-24.9729	4.3	14.27	11.96
cssz–77b	Central and South America	289.0750	-24.9403	4.3	8	5
cssz–78a	Central and South America	289.4904	-25.8621	3.86	14.36	11.96
cssz–78b	Central and South America	289.0081	-25.8328	3.86	8	5
cssz–79a	Central and South America	289.3491	-26.8644	11.34	14.45	11.96
cssz–79b	Central and South America	288.8712	-26.7789	11.34	8	5
cssz–80a	Central and South America	289.1231	-27.7826	14.16	14.54	11.96
cssz–80b	Central and South America	288.6469	-27.6762	14.16	8	5
cssz–81a	Central and South America	288.8943	-28.6409	13.19	14.63	11.96
cssz–81b	Central and South America	288.4124	-28.5417	13.19	8	5
cssz–82a	Central and South America	288.7113	-29.4680	9.68	14.72	11.96
cssz–82b	Central and South America	288.2196	-29.3950	9.68	8	5
cssz–83a	Central and South America	288.5944	-30.2923	5.36	14.81	11.96
cssz–83b	Central and South America	288.0938	-30.2517	5.36	8	5
cssz–84a	Central and South America	288.5223	-31.1639	3.8	14.9	11.96
cssz–84b	Central and South America	288.0163	-31.1351	3.8	8	5
cssz–85a	Central and South America	288.4748	-32.0416	2.55	15	11.96
cssz–85b	Central and South America	287.9635	-32.0223	2.55	8	5
cssz–86a	Central and South America	288.3901	-33.0041	7.01	15	11.96
cssz–86b	Central and South America	287.8768	-32.9512	7.01	8	5
cssz–87a	Central and South America	288.1050	-34.0583	19.4	15	11.96
cssz–87b	Central and South America	287.6115	-33.9142	19.4	8	5
cssz–88a	Central and South America	287.5309	-35.0437	32.81	15	11.96
cssz–88b	Central and South America	287.0862	-34.8086	32.81	8	5
cssz–88z	Central and South America	287.9308	-35.2545	32.81	30	24.9
cssz–89a	Central and South America	287.2380	-35.5993	14.52	16.67	11.96
cssz–89b	Central and South America	286.7261	-35.4914	14.52	8	5
cssz–89z	Central and South America	287.7014	-35.6968	14.52	30	26.3
cssz–90a	Central and South America	286.8442	-36.5645	22.64	18.33	11.96
cssz–90b	Central and South America	286.3548	-36.4004	22.64	8	5
cssz–90z	Central and South America	287.2916	-36.7142	22.64	30	27.68
cssz–91a	Central and South America	286.5925	-37.2488	10.9	20	11.96
cssz–91b	Central and South America	286.0721	-37.1690	10.9	8	5
cssz–91z	Central and South America	287.0726	-37.3224	10.9	30	29.06
cssz–92a	Central and South America	286.4254	-38.0945	8.23	20	11.96

Table A.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz–92b	Central and South America	285.8948	-38.0341	8.23	8	5
cssz–92z	Central and South America	286.9303	-38.1520	8.23	26.67	29.06
cssz–93a	Central and South America	286.2047	-39.0535	13.46	20	11.96
cssz–93b	Central and South America	285.6765	-38.9553	13.46	8	5
cssz–93z	Central and South America	286.7216	-39.1495	13.46	23.33	29.06
cssz–94a	Central and South America	286.0772	-39.7883	3.4	20	11.96
cssz–94b	Central and South America	285.5290	-39.7633	3.4	8	5
cssz–94z	Central and South America	286.6255	-39.8133	3.4	20	29.06
cssz–95a	Central and South America	285.9426	-40.7760	9.84	20	11.96
cssz–95b	Central and South America	285.3937	-40.7039	9.84	8	5
cssz–95z	Central and South America	286.4921	-40.8481	9.84	20	29.06
cssz–96a	Central and South America	285.7839	-41.6303	7.6	20	11.96
cssz–96b	Central and South America	285.2245	-41.5745	7.6	8	5
cssz–96x	Central and South America	287.4652	-41.7977	7.6	20	63.26
cssz–96y	Central and South America	286.9043	-41.7419	7.6	20	46.16
cssz–96z	Central and South America	286.3439	-41.6861	7.6	20	29.06
cssz–97a	Central and South America	285.6695	-42.4882	5.3	20	11.96
cssz–97b	Central and South America	285.0998	-42.4492	5.3	8	5
cssz–97x	Central and South America	287.3809	-42.6052	5.3	20	63.26
cssz–97y	Central and South America	286.8101	-42.5662	5.3	20	46.16
cssz–97z	Central and South America	286.2396	-42.5272	5.3	20	29.06
cssz–98a	Central and South America	285.5035	-43.4553	10.53	20	11.96
cssz–98b	Central and South America	284.9322	-43.3782	10.53	8	5
cssz–98x	Central and South America	287.2218	-43.6866	10.53	20	63.26
cssz–98y	Central and South America	286.6483	-43.6095	10.53	20	46.16
cssz–98z	Central and South America	286.0755	-43.5324	10.53	20	29.06
cssz–99a	Central and South America	285.3700	-44.2595	4.86	20	11.96
cssz–99b	Central and South America	284.7830	-44.2237	4.86	8	5
cssz–99x	Central and South America	287.1332	-44.3669	4.86	20	63.26
cssz–99y	Central and South America	286.5451	-44.3311	4.86	20	46.16
cssz–99z	Central and South America	285.9574	-44.2953	4.86	20	29.06
cssz–100a	Central and South America	285.2713	-45.1664	5.68	20	11.96
cssz–100b	Central and South America	284.6758	-45.1246	5.68	8	5
cssz–100x	Central and South America	287.0603	-45.2918	5.68	20	63.26
cssz–100y	Central and South America	286.4635	-45.2500	5.68	20	46.16
cssz–100z	Central and South America	285.8672	-45.2082	5.68	20	29.06
cssz–101a	Central and South America	285.3080	-45.8607	352.6	20	9.36
cssz–101b	Central and South America	284.7067	-45.9152	352.6	5	5
cssz–101y	Central and South America	286.5089	-45.7517	352.6	20	43.56
cssz–101z	Central and South America	285.9088	-45.8062	352.6	20	26.46
cssz–102a	Central and South America	285.2028	-47.1185	17.72	5	9.36
cssz–102b	Central and South America	284.5772	-46.9823	17.72	5	5
cssz–102y	Central and South America	286.4588	-47.3909	17.72	5	18.07
cssz–102z	Central and South America	285.8300	-47.2547	17.72	5	13.72
cssz–103a	Central and South America	284.7075	-48.0396	23.37	7.5	11.53
cssz–103b	Central and South America	284.0972	-47.8630	23.37	7.5	5
cssz–103x	Central and South America	286.5511	-48.5694	23.37	7.5	31.11
cssz–103y	Central and South America	285.9344	-48.3928	23.37	7.5	24.58
cssz–103z	Central and South America	285.3199	-48.2162	23.37	7.5	18.05
cssz–104a	Central and South America	284.3440	-48.7597	14.87	10	13.68
cssz–104b	Central and South America	283.6962	-48.6462	14.87	10	5
cssz–104x	Central and South America	286.2962	-49.1002	14.87	10	39.73
cssz–104y	Central and South America	285.6440	-48.9867	14.87	10	31.05
cssz–104z	Central and South America	284.9933	-48.8732	14.87	10	22.36
cssz–105a	Central and South America	284.2312	-49.4198	0.25	9.67	13.4

Table A.2 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
cssz–105b	Central and South America	283.5518	-49.4179	0.25	9.67	5
cssz–105x	Central and South America	286.2718	-49.4255	0.25	9.67	38.59
cssz–105y	Central and South America	285.5908	-49.4236	0.25	9.67	30.2
cssz–105z	Central and South America	284.9114	-49.4217	0.25	9.67	21.8
cssz–106a	Central and South America	284.3730	-50.1117	347.5	9.25	13.04
cssz–106b	Central and South America	283.6974	-50.2077	347.5	9.25	5
cssz–106x	Central and South America	286.3916	-49.8238	347.5	9.25	37.15
cssz–106y	Central and South America	285.7201	-49.9198	347.5	9.25	29.11
cssz–106z	Central and South America	285.0472	-50.0157	347.5	9.25	21.07
cssz–107a	Central and South America	284.7130	-50.9714	346.5	9	12.82
cssz–107b	Central and South America	284.0273	-51.0751	346.5	9	5
cssz–107x	Central and South America	286.7611	-50.6603	346.5	9	36.29
cssz–107y	Central and South America	286.0799	-50.7640	346.5	9	28.47
cssz–107z	Central and South America	285.3972	-50.8677	346.5	9	20.64
cssz–108a	Central and South America	285.0378	-51.9370	352	8.67	12.54
cssz–108b	Central and South America	284.3241	-51.9987	352	8.67	5
cssz–108x	Central and South America	287.1729	-51.7519	352	8.67	35.15
cssz–108y	Central and South America	286.4622	-51.8136	352	8.67	27.61
cssz–108z	Central and South America	285.7505	-51.8753	352	8.67	20.07
cssz–109a	Central and South America	285.2635	-52.8439	353.1	8.33	12.24
cssz–109b	Central and South America	284.5326	-52.8974	353.1	8.33	5
cssz–109x	Central and South America	287.4508	-52.6834	353.1	8.33	33.97
cssz–109y	Central and South America	286.7226	-52.7369	353.1	8.33	26.73
cssz–109z	Central and South America	285.9935	-52.7904	353.1	8.33	19.49
cssz–110a	Central and South America	285.5705	-53.4139	334.2	8	11.96
cssz–110b	Central and South America	284.8972	-53.6076	334.2	8	5
cssz–110x	Central and South America	287.5724	-52.8328	334.2	8	32.83
cssz–110y	Central and South America	286.9081	-53.0265	334.2	8	25.88
cssz–110z	Central and South America	286.2408	-53.2202	334.2	8	18.92
cssz–111a	Central and South America	286.1627	-53.8749	313.8	8	11.96
cssz–111b	Central and South America	285.6382	-54.1958	313.8	8	5
cssz–111x	Central and South America	287.7124	-52.9122	313.8	8	32.83
cssz–111y	Central and South America	287.1997	-53.2331	313.8	8	25.88
cssz–111z	Central and South America	286.6832	-53.5540	313.8	8	18.92
cssz–112a	Central and South America	287.3287	-54.5394	316.4	8	11.96
cssz–112b	Central and South America	286.7715	-54.8462	316.4	8	5
cssz–112x	Central and South America	288.9756	-53.6190	316.4	8	32.83
cssz–112y	Central and South America	288.4307	-53.9258	316.4	8	25.88
cssz–112z	Central and South America	287.8817	-54.2326	316.4	8	18.92
cssz–113a	Central and South America	288.3409	-55.0480	307.6	8	11.96
cssz–113b	Central and South America	287.8647	-55.4002	307.6	8	5
cssz–113x	Central and South America	289.7450	-53.9914	307.6	8	32.83
cssz–113y	Central and South America	289.2810	-54.3436	307.6	8	25.88
cssz–113z	Central and South America	288.8130	-54.6958	307.6	8	18.92
cssz–114a	Central and South America	289.5342	-55.5026	301.5	8	11.96
cssz–114b	Central and South America	289.1221	-55.8819	301.5	8	5
cssz–114x	Central and South America	290.7472	-54.3647	301.5	8	32.83
cssz–114y	Central and South America	290.3467	-54.7440	301.5	8	25.88
cssz–114z	Central and South America	289.9424	-55.1233	301.5	8	18.92
cssz–115a	Central and South America	290.7682	-55.8485	292.7	8	11.96
cssz–115b	Central and South America	290.4608	-56.2588	292.7	8	5
cssz–115x	Central and South America	291.6714	-54.6176	292.7	8	32.83
cssz–115y	Central and South America	291.3734	-55.0279	292.7	8	25.88
cssz–115z	Central and South America	291.0724	-55.4382	292.7	8	18.92

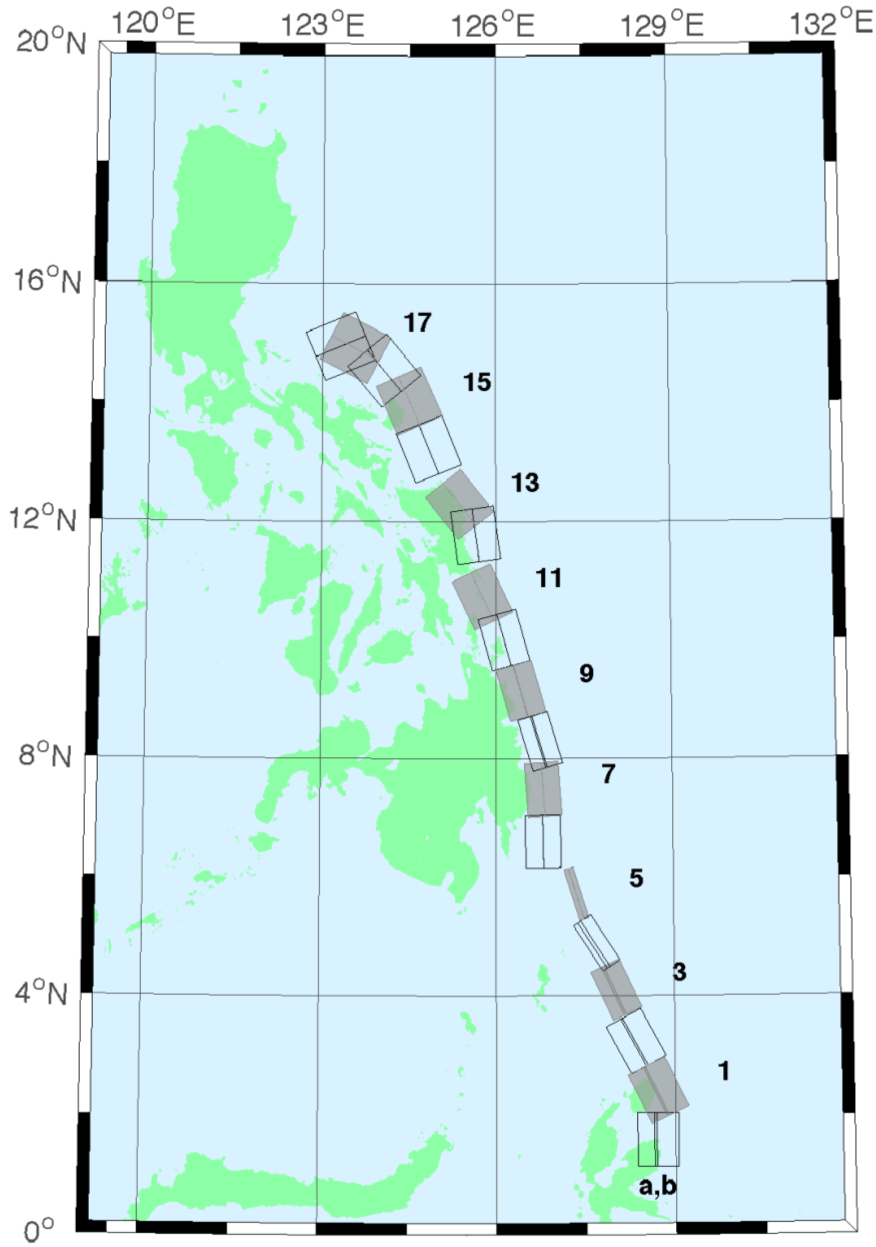

Figure A.3: Eastern Philippines Subduction Zone unit sources.

Table A.3: Earthquake parameters for Eastern Philippines Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
epsz–0a	Eastern Philippines	128.5264	1.5930	180	44	26.92
epsz–0b	Eastern Philippines	128.8496	1.5930	180	26	5
epsz–1a	Eastern Philippines	128.5521	2.3289	153.6	44.2	27.62
epsz–1b	Eastern Philippines	128.8408	2.4720	153.6	26.9	5
epsz–2a	Eastern Philippines	128.1943	3.1508	151.9	45.9	32.44
epsz–2b	Eastern Philippines	128.4706	3.2979	151.9	32.8	5.35
epsz–3a	Eastern Philippines	127.8899	4.0428	155.2	57.3	40.22
epsz–3b	Eastern Philippines	128.1108	4.1445	155.2	42.7	6.31
epsz–4a	Eastern Philippines	127.6120	4.8371	146.8	71.4	48.25
epsz–4b	Eastern Philippines	127.7324	4.9155	146.8	54.8	7.39
epsz–5a	Eastern Philippines	127.3173	5.7040	162.9	79.9	57.4
epsz–5b	Eastern Philippines	127.3930	5.7272	162.9	79.4	8.25
epsz–6a	Eastern Philippines	126.6488	6.6027	178.9	48.6	45.09
epsz–6b	Eastern Philippines	126.9478	6.6085	178.9	48.6	7.58
epsz–7a	Eastern Philippines	126.6578	7.4711	175.8	50.7	45.52
epsz–7b	Eastern Philippines	126.9439	7.4921	175.8	50.7	6.83
epsz–8a	Eastern Philippines	126.6227	8.2456	163.3	56.7	45.6
epsz–8b	Eastern Philippines	126.8614	8.3164	163.3	48.9	7.92
epsz–9a	Eastern Philippines	126.2751	9.0961	164.1	47	43.59
epsz–9b	Eastern Philippines	126.5735	9.1801	164.1	44.9	8.3
epsz–10a	Eastern Philippines	125.9798	9.9559	164.5	43.1	42.25
epsz–10b	Eastern Philippines	126.3007	10.0438	164.5	43.1	8.09
epsz–11a	Eastern Philippines	125.6079	10.6557	155	37.8	38.29
epsz–11b	Eastern Philippines	125.9353	10.8059	155	37.8	7.64
epsz–12a	Eastern Philippines	125.4697	11.7452	172.1	36	37.01
epsz–12b	Eastern Philippines	125.8374	11.7949	172.1	36	7.62
epsz–13a	Eastern Philippines	125.2238	12.1670	141.5	32.4	33.87
epsz–13b	Eastern Philippines	125.5278	12.4029	141.5	32.4	7.08
epsz–14a	Eastern Philippines	124.6476	13.1365	158.2	23	25.92
epsz–14b	Eastern Philippines	125.0421	13.2898	158.2	23	6.38
epsz–15a	Eastern Philippines	124.3107	13.9453	156.1	24.1	26.51
epsz–15b	Eastern Philippines	124.6973	14.1113	156.1	24.1	6.09
epsz–16a	Eastern Philippines	123.8998	14.4025	140.3	19.5	21.69
epsz–16b	Eastern Philippines	124.2366	14.6728	140.3	19.5	5
epsz–17a	Eastern Philippines	123.4604	14.7222	117.6	15.3	18.19
epsz–17b	Eastern Philippines	123.6682	15.1062	117.6	15.3	5
epsz–18a	Eastern Philippines	123.3946	14.7462	67.4	15	17.94
epsz–18b	Eastern Philippines	123.2219	15.1467	67.4	15	5

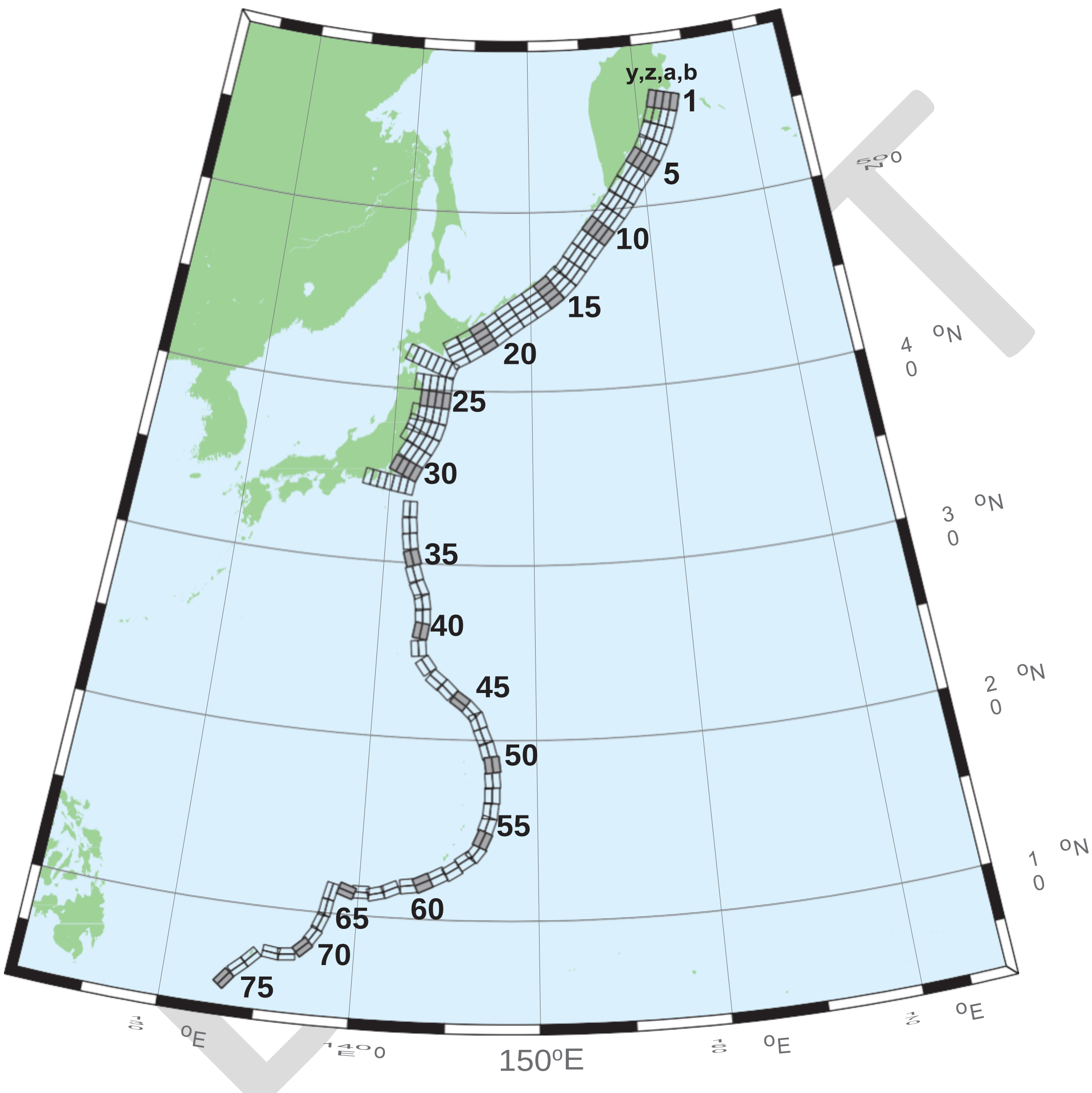

Figure A.4: Kamchatka-Kuril-Japan-Izu-Mariana-Yap Subduction Zone unit sources.

Table A.4: Earthquake parameters for Kamchatka-Kuril-Japan-Izu-Mariana-Yap Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
kisz–1a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	128.5521	2.3289	153.6	44.2	27.62
kisz–1b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	128.8408	2.4720	153.6	26.9	5
kisz–2a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	128.1943	3.1508	151.9	45.9	32.44
kisz–2b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	128.4706	3.2979	151.9	32.8	5.35
kisz–3a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	127.8899	4.0428	155.2	57.3	40.22
kisz–3b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	128.1108	4.1445	155.2	42.7	6.31
kisz–4a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	127.6120	4.8371	146.8	71.4	48.25
kisz–4b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	127.7324	4.9155	146.8	54.8	7.39
kisz–5a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	127.3173	5.7040	162.9	79.9	57.4
kisz–5b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	127.3930	5.7272	162.9	79.4	8.25
kisz–6a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.6488	6.6027	178.9	48.6	45.09
kisz–6b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.9478	6.6085	178.9	48.6	7.58
kisz–7a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.6578	7.4711	175.8	50.7	45.52
kisz–7b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.9439	7.4921	175.8	50.7	6.83
kisz–8a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.6227	8.2456	163.3	56.7	45.6
kisz–8b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.8614	8.3164	163.3	48.9	7.92
kisz–9a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.2751	9.0961	164.1	47	43.59
kisz–9b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.5735	9.1801	164.1	44.9	8.3
kisz–10a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.9798	9.9559	164.5	43.1	42.25
kisz–10b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	126.3007	10.0438	164.5	43.1	8.09
kisz–11a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.6079	10.6557	155	37.8	38.29
kisz–11b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.9353	10.8059	155	37.8	7.64
kisz–12a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.4697	11.7452	172.1	36	37.01
kisz–12b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.8374	11.7949	172.1	36	7.62
kisz–13a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.2238	12.1670	141.5	32.4	33.87
kisz–13b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.5278	12.4029	141.5	32.4	7.08
kisz–14a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	124.6476	13.1365	158.2	23	25.92
kisz–14b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	125.0421	13.2898	158.2	23	6.38
kisz–15a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	124.3107	13.9453	156.1	24.1	26.51
kisz–15b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	124.6973	14.1113	156.1	24.1	6.09
kisz–16a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	123.8998	14.4025	140.3	19.5	21.69
kisz–16b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	124.2366	14.6728	140.3	19.5	5
kisz–17a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	123.4604	14.7222	117.6	15.3	18.19
kisz–17b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	123.6682	15.1062	117.6	15.3	5
kisz–18a	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	123.3946	14.7462	67.4	15	17.94
kisz–18b	Kamchatka-Kuril-Japan-Izu-Mariana-Yap	123.2219	15.1467	67.4	15	5

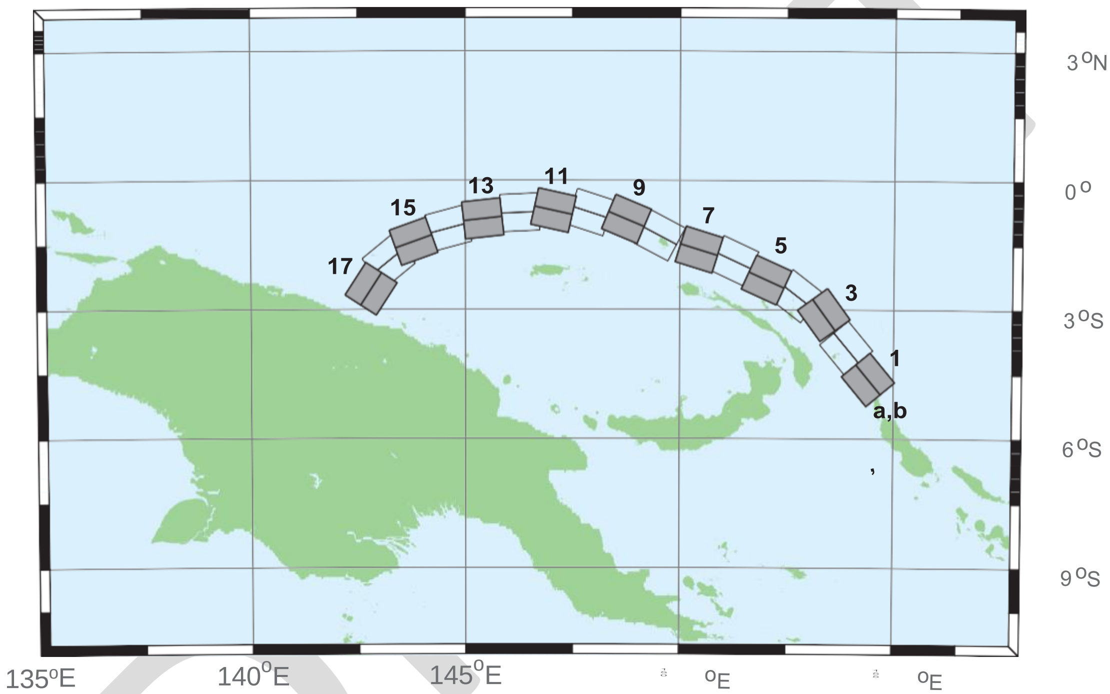

Figure A.5: Manus–Oceanic Convergent Boundary Subduction Zone unit sources.

Table A.5: Earthquake parameters for Manus–Oceanic Convergent Boundary Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
mosz–1a	Manus–Oceanic Convergent Boundary	154.0737	-4.8960	140.2	15	15.88
mosz–1b	Manus–Oceanic Convergent Boundary	154.4082	-4.6185	140.2	15	5
mosz–2a	Manus–Oceanic Convergent Boundary	153.5589	-4.1575	140.2	15	15.91
mosz–2b	Manus–Oceanic Convergent Boundary	153.8931	-3.8800	140.2	15	5.35
mosz–3a	Manus–Oceanic Convergent Boundary	153.0151	-3.3716	143.9	15	16.64
mosz–3b	Manus–Oceanic Convergent Boundary	153.3662	-3.1160	143.9	15	6.31
mosz–4a	Manus–Oceanic Convergent Boundary	152.4667	-3.0241	127.7	15	17.32
mosz–4b	Manus–Oceanic Convergent Boundary	152.7321	-2.6806	127.7	15	7.39
mosz–5a	Manus–Oceanic Convergent Boundary	151.8447	-2.7066	114.3	15	17.57
mosz–5b	Manus–Oceanic Convergent Boundary	152.0235	-2.3112	114.3	15	8.25
mosz–6a	Manus–Oceanic Convergent Boundary	151.0679	-2.2550	115	15	17.66
mosz–6b	Manus–Oceanic Convergent Boundary	151.2513	-1.8618	115	15	7.58
mosz–7a	Manus–Oceanic Convergent Boundary	150.3210	-2.0236	107.2	15	17.73
mosz–7b	Manus–Oceanic Convergent Boundary	150.4493	-1.6092	107.2	15	6.83
mosz–8a	Manus–Oceanic Convergent Boundary	149.3226	-1.6666	117.8	15	17.83
mosz–8b	Manus–Oceanic Convergent Boundary	149.5251	-1.2829	117.8	15	7.92
mosz–9a	Manus–Oceanic Convergent Boundary	148.5865	-1.3017	112.7	15	17.84
mosz–9b	Manus–Oceanic Convergent Boundary	148.7540	-0.9015	112.7	15	8.3
mosz–10a	Manus–Oceanic Convergent Boundary	147.7760	-1.1560	108	15	17.78
mosz–10b	Manus–Oceanic Convergent Boundary	147.9102	-0.7434	108	15	8.09
mosz–11a	Manus–Oceanic Convergent Boundary	146.9596	-1.1226	102.5	15	17.54
mosz–11b	Manus–Oceanic Convergent Boundary	147.0531	-0.6990	102.5	15	7.64
mosz–12a	Manus–Oceanic Convergent Boundary	146.2858	-1.1820	87.48	15	17.29
mosz–12b	Manus–Oceanic Convergent Boundary	146.2667	-0.7486	87.48	15	7.62
mosz–13a	Manus–Oceanic Convergent Boundary	145.4540	-1.3214	83.75	15	17.34
mosz–13b	Manus–Oceanic Convergent Boundary	145.4068	-0.8901	83.75	15	7.08
mosz–14a	Manus–Oceanic Convergent Boundary	144.7151	-1.5346	75.09	15	17.21
mosz–14b	Manus–Oceanic Convergent Boundary	144.6035	-1.1154	75.09	15	6.38
mosz–15a	Manus–Oceanic Convergent Boundary	143.9394	-1.8278	70.43	15	16.52
mosz–15b	Manus–Oceanic Convergent Boundary	143.7940	-1.4190	70.43	15	6.09
mosz–16a	Manus–Oceanic Convergent Boundary	143.4850	-2.2118	50.79	15	15.86
mosz–16b	Manus–Oceanic Convergent Boundary	143.2106	-1.8756	50.79	15	5
mosz–17a	Manus–Oceanic Convergent Boundary	143.1655	-2.7580	33	15	16.64
mosz–17b	Manus–Oceanic Convergent Boundary	142.8013	-2.5217	33	15	5

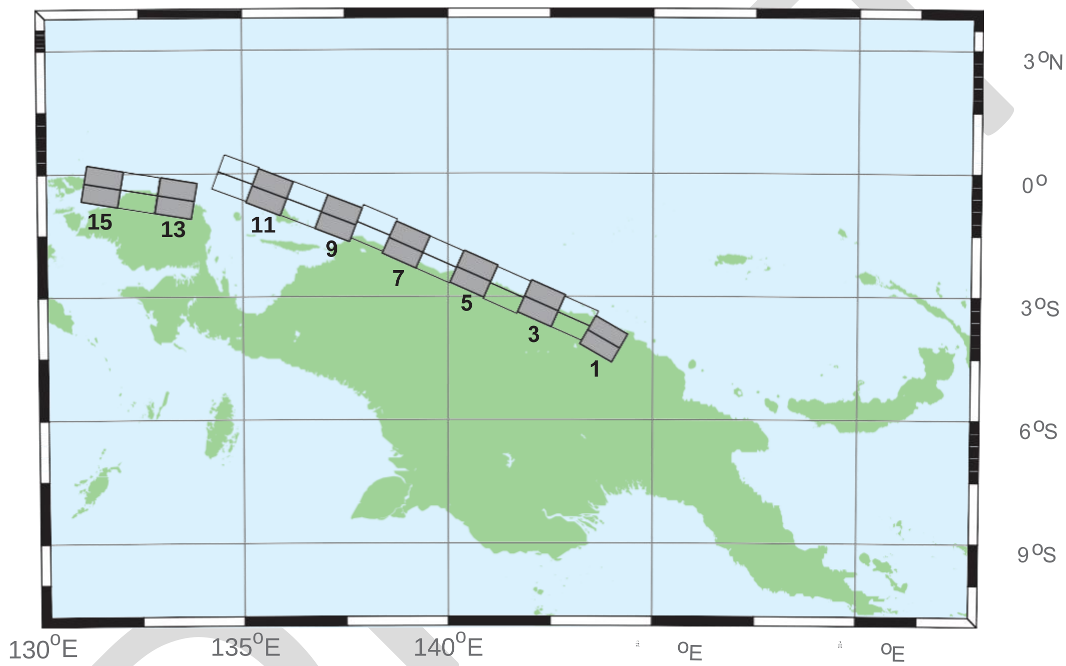

Figure A.6: New Guinea Subduction Zone unit sources.

Table A.6: Earthquake parameters for New Guinea Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
ngsz–1a	New Guinea	143.6063	-4.3804	120	29	25.64
ngsz–1b	New Guinea	143.8032	-4.0402	120	29	1.4
ngsz–2a	New Guinea	142.9310	-3.9263	114	27.63	20.1
ngsz–2b	New Guinea	143.0932	-3.5628	114	21.72	1.6
ngsz–3a	New Guinea	142.1076	-3.5632	114	20.06	18.73
ngsz–3b	New Guinea	142.2795	-3.1778	114	15.94	5
ngsz–4a	New Guinea	141.2681	-3.2376	114	21	17.76
ngsz–4b	New Guinea	141.4389	-2.8545	114	14.79	5
ngsz–5a	New Guinea	140.4592	-2.8429	114	21.26	16.14
ngsz–5b	New Guinea	140.6296	-2.4605	114	12.87	5
ngsz–6a	New Guinea	139.6288	-2.4960	114	22.72	15.4
ngsz–6b	New Guinea	139.7974	-2.1175	114	12	5
ngsz–7a	New Guinea	138.8074	-2.1312	114	21.39	15.4
ngsz–7b	New Guinea	138.9776	-1.7491	114	12	5
ngsz–8a	New Guinea	138.0185	-1.7353	113.1	18.79	15.14
ngsz–8b	New Guinea	138.1853	-1.3441	113.1	11.7	5
ngsz–9a	New Guinea	137.1805	-1.5037	111	15.24	13.23
ngsz–9b	New Guinea	137.3358	-1.0991	111	9.47	5
ngsz–10a	New Guinea	136.3418	-1.1774	111	13.51	11.09
ngsz–10b	New Guinea	136.4983	-0.7697	111	7	5
ngsz–11a	New Guinea	135.4984	-0.8641	111	11.38	12.49
ngsz–11b	New Guinea	135.6562	-0.4530	111	8.62	5
ngsz–12a	New Guinea	134.6759	-0.5216	110.5	10	13.68
ngsz–12b	New Guinea	134.8307	-0.1072	110.5	10	5
ngsz–13a	New Guinea	133.3065	-1.0298	99.5	10	13.68
ngsz–13b	New Guinea	133.3795	-0.5935	99.5	10	5
ngsz–14a	New Guinea	132.4048	-0.8816	99.5	10	13.68
ngsz–14b	New Guinea	132.4778	-0.4453	99.5	10	5
ngsz–15a	New Guinea	131.5141	-0.7353	99.5	10	13.68
ngsz–15b	New Guinea	131.5871	-0.2990	99.5	10	5

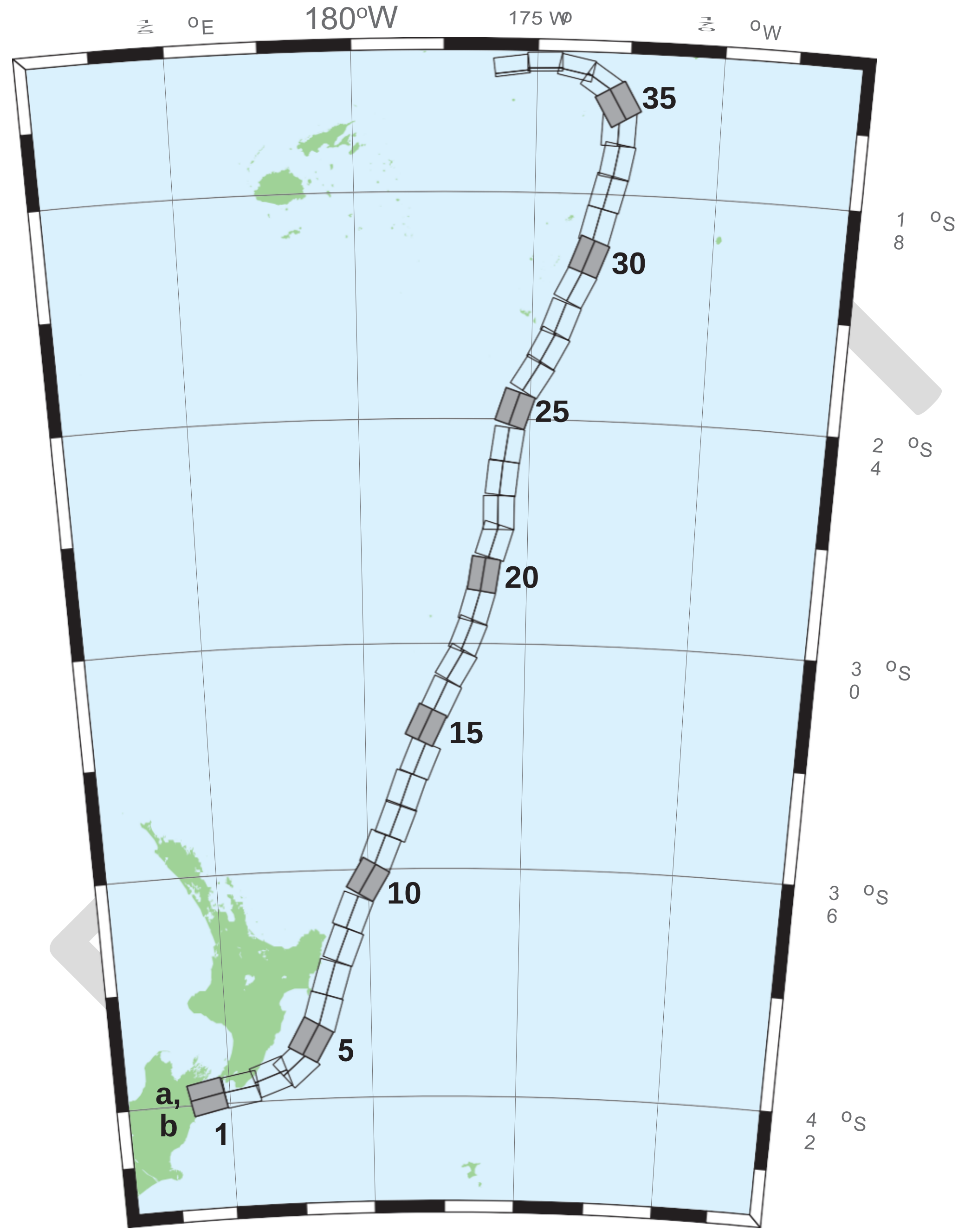

Figure A.7: New Zealand–Keradec–Tonga Subduction Zone unit sources.

Table A.7: Earthquake parameters for New Zealand–Keradec–Tonga Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
ntsz–1a	New Zealand–Keradec–Tonga	174.0985	-41.3951	258.6	24	25.34
ntsz–1b	New Zealand–Keradec–Tonga	174.2076	-41.7973	258.6	24	5
ntsz–2a	New Zealand–Keradec–Tonga	175.3289	-41.2592	260.6	29.38	23.17
ntsz–2b	New Zealand–Keradec–Tonga	175.4142	-41.6454	260.6	21.31	5
ntsz–3a	New Zealand–Keradec–Tonga	176.2855	-40.9950	250.7	29.54	21.74
ntsz–3b	New Zealand–Keradec–Tonga	176.4580	-41.3637	250.7	19.56	5
ntsz–4a	New Zealand–Keradec–Tonga	177.0023	-40.7679	229.4	24.43	18.87
ntsz–4b	New Zealand–Keradec–Tonga	177.3552	-41.0785	229.4	16.1	5
ntsz–5a	New Zealand–Keradec–Tonga	177.4114	-40.2396	210	18.8	19.29
ntsz–5b	New Zealand–Keradec–Tonga	177.8951	-40.4525	210	16.61	5
ntsz–6a	New Zealand–Keradec–Tonga	177.8036	-39.6085	196.7	18.17	15.8
ntsz–6b	New Zealand–Keradec–Tonga	178.3352	-39.7310	196.7	12.48	5
ntsz–7a	New Zealand–Keradec–Tonga	178.1676	-38.7480	197	28.1	17.85
ntsz–7b	New Zealand–Keradec–Tonga	178.6541	-38.8640	197	14.89	5
ntsz–8a	New Zealand–Keradec–Tonga	178.6263	-37.8501	201.4	31.47	18.78
ntsz–8b	New Zealand–Keradec–Tonga	179.0788	-37.9899	201.4	16	5
ntsz–9a	New Zealand–Keradec–Tonga	178.9833	-36.9770	202.2	29.58	20.02
ntsz–9b	New Zealand–Keradec–Tonga	179.4369	-37.1245	202.2	17.48	5
ntsz–10a	New Zealand–Keradec–Tonga	179.5534	-36.0655	210.6	32.1	20.72
ntsz–10b	New Zealand–Keradec–Tonga	179.9595	-36.2593	210.6	18.32	5
ntsz–11a	New Zealand–Keradec–Tonga	179.9267	-35.3538	201.7	25	16.09
ntsz–11b	New Zealand–Keradec–Tonga	180.3915	-35.5040	201.7	12.81	5
ntsz–12a	New Zealand–Keradec–Tonga	180.4433	-34.5759	201.2	25	15.46
ntsz–12b	New Zealand–Keradec–Tonga	180.9051	-34.7230	201.2	12.08	5
ntsz–13a	New Zealand–Keradec–Tonga	180.7990	-33.7707	199.8	25.87	19.06
ntsz–13b	New Zealand–Keradec–Tonga	181.2573	-33.9073	199.8	16.33	5
ntsz–14a	New Zealand–Keradec–Tonga	181.2828	-32.9288	202.4	31.28	22.73
ntsz–14b	New Zealand–Keradec–Tonga	181.7063	-33.0751	202.4	20.77	5
ntsz–15a	New Zealand–Keradec–Tonga	181.4918	-32.0035	205.4	32.33	22.64
ntsz–15b	New Zealand–Keradec–Tonga	181.8967	-32.1665	205.4	20.66	5
ntsz–16a	New Zealand–Keradec–Tonga	181.9781	-31.2535	205.5	34.29	23.59
ntsz–16b	New Zealand–Keradec–Tonga	182.3706	-31.4131	205.5	21.83	5
ntsz–17a	New Zealand–Keradec–Tonga	182.4819	-30.3859	210.3	37.6	25.58
ntsz–17b	New Zealand–Keradec–Tonga	182.8387	-30.5655	210.3	24.3	5
ntsz–18a	New Zealand–Keradec–Tonga	182.8176	-29.6545	201.6	37.65	26.13
ntsz–18b	New Zealand–Keradec–Tonga	183.1985	-29.7856	201.6	25	5
ntsz–19a	New Zealand–Keradec–Tonga	183.0622	-28.8739	195.7	34.41	26.13
ntsz–19b	New Zealand–Keradec–Tonga	183.4700	-28.9742	195.7	25	5
ntsz–20a	New Zealand–Keradec–Tonga	183.2724	-28.0967	188.8	38	26.13
ntsz–20b	New Zealand–Keradec–Tonga	183.6691	-28.1508	188.8	25	5
ntsz–21a	New Zealand–Keradec–Tonga	183.5747	-27.1402	197.1	32.29	24.83
ntsz–21b	New Zealand–Keradec–Tonga	183.9829	-27.2518	197.1	23.37	5
ntsz–22a	New Zealand–Keradec–Tonga	183.6608	-26.4975	180	29.56	18.63
ntsz–22b	New Zealand–Keradec–Tonga	184.0974	-26.4975	180	15.82	5
ntsz–23a	New Zealand–Keradec–Tonga	183.7599	-25.5371	185.8	32.42	20.56
ntsz–23b	New Zealand–Keradec–Tonga	184.1781	-25.5752	185.8	18.13	5
ntsz–24a	New Zealand–Keradec–Tonga	183.9139	-24.6201	188.2	33.31	23.73
ntsz–24b	New Zealand–Keradec–Tonga	184.3228	-24.6734	188.2	22	5
ntsz–25a	New Zealand–Keradec–Tonga	184.1266	-23.5922	198.5	29.34	19.64
ntsz–25b	New Zealand–Keradec–Tonga	184.5322	-23.7163	198.5	17.03	5
ntsz–26a	New Zealand–Keradec–Tonga	184.6613	-22.6460	211.7	30.26	19.43
ntsz–26b	New Zealand–Keradec–Tonga	185.0196	-22.8497	211.7	16.78	5
ntsz–27a	New Zealand–Keradec–Tonga	185.0879	-21.9139	207.9	31.73	20.67

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Table A.7 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
ntsz–27b	New Zealand–Keradec–Tonga	185.4522	-22.0928	207.9	18.27	5
ntsz–28a	New Zealand–Keradec–Tonga	185.4037	-21.1758	200.5	32.44	21.76
ntsz–28b	New Zealand–Keradec–Tonga	185.7849	-21.3084	200.5	19.58	5
ntsz–29a	New Zealand–Keradec–Tonga	185.8087	-20.2629	206.4	32.47	20.4
ntsz–29b	New Zealand–Keradec–Tonga	186.1710	-20.4312	206.4	17.94	5
ntsz–30a	New Zealand–Keradec–Tonga	186.1499	-19.5087	200.9	32.98	22.46
ntsz–30b	New Zealand–Keradec–Tonga	186.5236	-19.6432	200.9	20.44	5
ntsz–31a	New Zealand–Keradec–Tonga	186.3538	-18.7332	193.9	34.41	21.19
ntsz–31b	New Zealand–Keradec–Tonga	186.7339	-18.8221	193.9	18.89	5
ntsz–32a	New Zealand–Keradec–Tonga	186.5949	-17.8587	194.1	30	19.12
ntsz–32b	New Zealand–Keradec–Tonga	186.9914	-17.9536	194.1	16.4	5
ntsz–33a	New Zealand–Keradec–Tonga	186.8172	-17.0581	190	33.15	23.34
ntsz–33b	New Zealand–Keradec–Tonga	187.2047	-17.1237	190	21.52	5
ntsz–34a	New Zealand–Keradec–Tonga	186.7814	-16.2598	182.1	15	13.41
ntsz–34b	New Zealand–Keradec–Tonga	187.2330	-16.2759	182.1	9.68	5
ntsz–35a	New Zealand–Keradec–Tonga	186.8000	-15.8563	149.8	15	12.17
ntsz–35b	New Zealand–Keradec–Tonga	187.1896	-15.6384	149.8	8.24	5
ntsz–36a	New Zealand–Keradec–Tonga	186.5406	-15.3862	123.9	40.44	36.72
ntsz–36b	New Zealand–Keradec–Tonga	186.7381	-15.1025	123.9	39.38	5
ntsz–37a	New Zealand–Keradec–Tonga	185.9883	-14.9861	102	68.94	30.99
ntsz–37b	New Zealand–Keradec–Tonga	186.0229	-14.8282	102	31.32	5
ntsz–38a	New Zealand–Keradec–Tonga	185.2067	-14.8259	88.4	80	26.13
ntsz–38b	New Zealand–Keradec–Tonga	185.2044	-14.7479	88.4	25	5
ntsz–39a	New Zealand–Keradec–Tonga	184.3412	-14.9409	82.55	80	26.13
ntsz–39b	New Zealand–Keradec–Tonga	184.3307	-14.8636	82.55	25	5

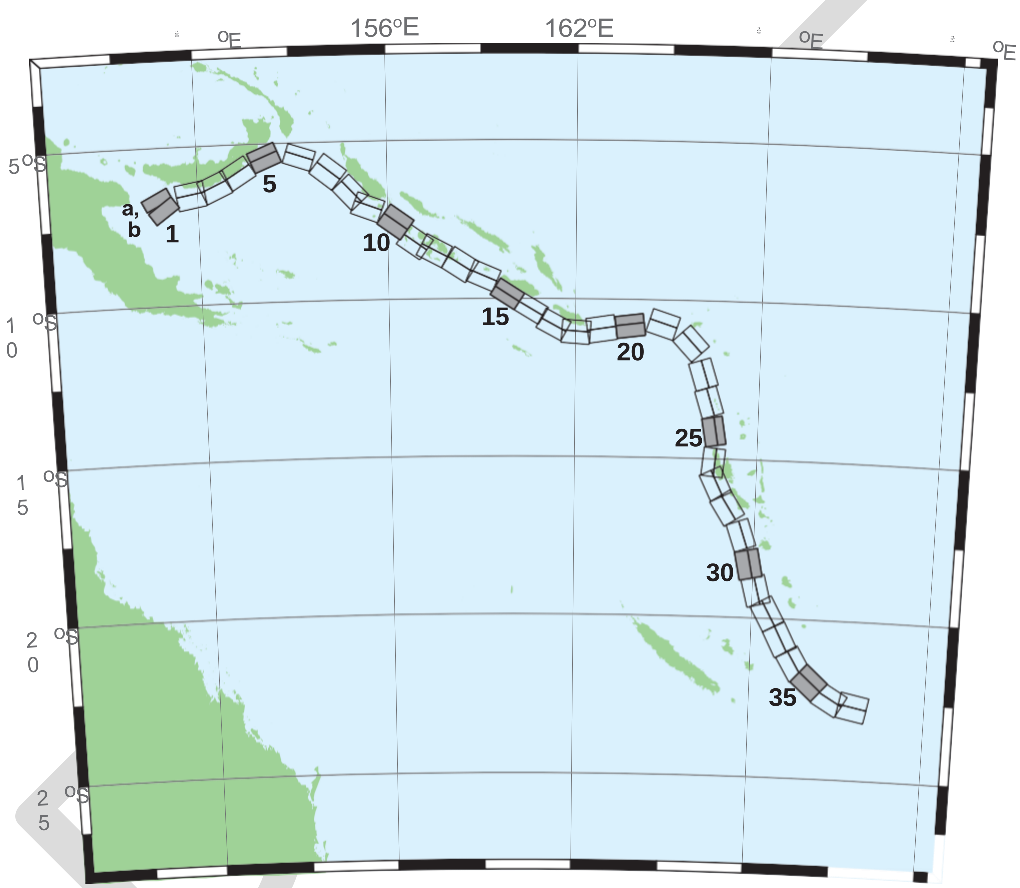

Figure A.8: New Britain–Solomons–Vanuatu Zone unit sources.

Table A.8: Earthquake parameters for New Britain–Solomons–Vanuatu Subduction Zone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
nvsz–1a	New Britain–Solomons–Vanuatu	148.6217	-6.4616	243.2	32.34	15.69
nvsz–1b	New Britain–Solomons–Vanuatu	148.7943	-6.8002	234.2	12.34	5
nvsz–2a	New Britain–Solomons–Vanuatu	149.7218	-6.1459	260.1	35.1	16.36
nvsz–2b	New Britain–Solomons–Vanuatu	149.7856	-6.5079	260.1	13.13	5
nvsz–3a	New Britain–Solomons–Vanuatu	150.4075	-5.9659	245.7	42.35	18.59
nvsz–3b	New Britain–Solomons–Vanuatu	150.5450	-6.2684	245.7	15.77	5
nvsz–4a	New Britain–Solomons–Vanuatu	151.1095	-5.5820	238.2	42.41	23.63
nvsz–4b	New Britain–Solomons–Vanuatu	151.2851	-5.8639	238.2	21.88	5
nvsz–5a	New Britain–Solomons–Vanuatu	152.0205	-5.1305	247.7	49.22	32.39
nvsz–5b	New Britain–Solomons–Vanuatu	152.1322	-5.4020	247.7	33.22	5
nvsz–6a	New Britain–Solomons–Vanuatu	153.3450	-5.1558	288.6	53.53	33.59
nvsz–6b	New Britain–Solomons–Vanuatu	153.2595	-5.4089	288.6	34.87	5
nvsz–7a	New Britain–Solomons–Vanuatu	154.3814	-5.6308	308.3	39.72	19.18
nvsz–7b	New Britain–Solomons–Vanuatu	154.1658	-5.9017	308.3	16.48	5
nvsz–8a	New Britain–Solomons–Vanuatu	155.1097	-6.3511	317.2	45.33	22.92
nvsz–8b	New Britain–Solomons–Vanuatu	154.8764	-6.5656	317.2	21	5
nvsz–9a	New Britain–Solomons–Vanuatu	155.5027	-6.7430	290.5	48.75	22.92
nvsz–9b	New Britain–Solomons–Vanuatu	155.3981	-7.0204	290.5	21	5
nvsz–10a	New Britain–Solomons–Vanuatu	156.4742	-7.2515	305.9	36.88	27.62
nvsz–10b	New Britain–Solomons–Vanuatu	156.2619	-7.5427	305.9	26.9	5
nvsz–11a	New Britain–Solomons–Vanuatu	157.0830	-7.8830	305.4	32.97	29.72
nvsz–11b	New Britain–Solomons–Vanuatu	156.8627	-8.1903	305.4	29.63	5
nvsz–12a	New Britain–Solomons–Vanuatu	157.6537	-8.1483	297.9	37.53	28.57
nvsz–12b	New Britain–Solomons–Vanuatu	157.4850	-8.4630	297.9	28.13	5
nvsz–13a	New Britain–Solomons–Vanuatu	158.5089	-8.5953	302.7	33.62	23.02
nvsz–13b	New Britain–Solomons–Vanuatu	158.3042	-8.9099	302.7	21.12	5
nvsz–14a	New Britain–Solomons–Vanuatu	159.1872	-8.9516	293.3	38.44	34.06
nvsz–14b	New Britain–Solomons–Vanuatu	159.0461	-9.2747	293.3	35.54	5
nvsz–15a	New Britain–Solomons–Vanuatu	159.9736	-9.5993	302.8	46.69	41.38
nvsz–15b	New Britain–Solomons–Vanuatu	159.8044	-9.8584	302.8	46.69	5
nvsz–16a	New Britain–Solomons–Vanuatu	160.7343	-10.0574	301	46.05	41
nvsz–16b	New Britain–Solomons–Vanuatu	160.5712	-10.3246	301	46.05	5
nvsz–17a	New Britain–Solomons–Vanuatu	161.4562	-10.5241	298.4	40.12	37.22
nvsz–17b	New Britain–Solomons–Vanuatu	161.2900	-10.8263	298.4	40.12	5
nvsz–18a	New Britain–Solomons–Vanuatu	162.0467	-10.6823	274.1	40.33	29.03
nvsz–18b	New Britain–Solomons–Vanuatu	162.0219	-11.0238	274.1	28.72	5
nvsz–19a	New Britain–Solomons–Vanuatu	162.7818	-10.5645	261.3	34.25	24.14
nvsz–19b	New Britain–Solomons–Vanuatu	162.8392	-10.9315	261.3	22.51	5
nvsz–20a	New Britain–Solomons–Vanuatu	163.7222	-10.5014	262.9	50.35	26.3
nvsz–20b	New Britain–Solomons–Vanuatu	163.7581	-10.7858	262.9	25.22	5
nvsz–21a	New Britain–Solomons–Vanuatu	164.9445	-10.4183	287.9	40.31	23.3
nvsz–21b	New Britain–Solomons–Vanuatu	164.8374	-10.7442	287.9	21.47	5
nvsz–22a	New Britain–Solomons–Vanuatu	166.0261	-11.1069	317.1	42.39	20.78
nvsz–22b	New Britain–Solomons–Vanuatu	165.7783	-11.3328	317.1	18.4	5
nvsz–23a	New Britain–Solomons–Vanuatu	166.5179	-12.2260	342.4	47.95	22.43
nvsz–23b	New Britain–Solomons–Vanuatu	166.2244	-12.3171	342.4	20.4	5
nvsz–24a	New Britain–Solomons–Vanuatu	166.7236	-13.1065	342.6	47.13	28.52
nvsz–24b	New Britain–Solomons–Vanuatu	166.4241	-13.1979	342.6	28.06	5
nvsz–25a	New Britain–Solomons–Vanuatu	166.8914	-14.0785	350.3	54.1	31.16
nvsz–25b	New Britain–Solomons–Vanuatu	166.6237	-14.1230	350.3	31.55	5
nvsz–26a	New Britain–Solomons–Vanuatu	166.9200	-15.1450	365.6	50.46	29.05
nvsz–26b	New Britain–Solomons–Vanuatu	166.6252	-15.1170	365.6	28.75	5
nvsz–27a	New Britain–Solomons–Vanuatu	167.0053	-15.6308	334.2	44.74	25.46

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Table A.8 – continued

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
nvsz–27b	New Britain–Solomons–Vanuatu	166.7068	-15.7695	334.2	24.15	5
nvsz–28a	New Britain–Solomons–Vanuatu	167.4074	-16.3455	327.5	41.53	22.44
nvsz–28b	New Britain–Solomons–Vanuatu	167.1117	-16.5264	327.5	20.42	5
nvsz–29a	New Britain–Solomons–Vanuatu	167.9145	-17.2807	341.2	49.1	24.12
nvsz–29b	New Britain–Solomons–Vanuatu	167.6229	-17.3757	341.2	22.48	5
nvsz–30a	New Britain–Solomons–Vanuatu	168.2220	-18.2353	348.6	44.19	23.99
nvsz–30b	New Britain–Solomons–Vanuatu	167.8895	-18.2991	348.6	22.32	5
nvsz–31a	New Britain–Solomons–Vanuatu	168.5022	-19.0510	345.6	42.2	22.26
nvsz–31b	New Britain–Solomons–Vanuatu	168.1611	-19.1338	345.6	20.2	5
nvsz–32a	New Britain–Solomons–Vanuatu	168.8775	-19.6724	331.1	42.03	21.68
nvsz–32b	New Britain–Solomons–Vanuatu	168.5671	-19.8338	331.1	19.49	5
nvsz–33a	New Britain–Solomons–Vanuatu	169.3422	-20.4892	332.9	40.25	22.4
nvsz–33b	New Britain–Solomons–Vanuatu	169.0161	-20.6453	332.9	20.37	5
nvsz–34a	New Britain–Solomons–Vanuatu	169.8304	-21.2121	329.1	39	22.73
nvsz–34b	New Britain–Solomons–Vanuatu	169.5086	-21.3911	329.1	20.77	5
nvsz–35a	New Britain–Solomons–Vanuatu	170.3119	-21.6945	311.9	39	22.13
nvsz–35b	New Britain–Solomons–Vanuatu	170.0606	-21.9543	311.9	20.03	5
nvsz–36a	New Britain–Solomons–Vanuatu	170.9487	-22.1585	300.4	39.42	23.5
nvsz–36b	New Britain–Solomons–Vanuatu	170.7585	-22.4577	300.4	21.71	5
nvsz–37a	New Britain–Solomons–Vanuatu	171.6335	-22.3087	281.3	30	22.1
nvsz–37b	New Britain–Solomons–Vanuatu	171.5512	-22.6902	281.3	20	5

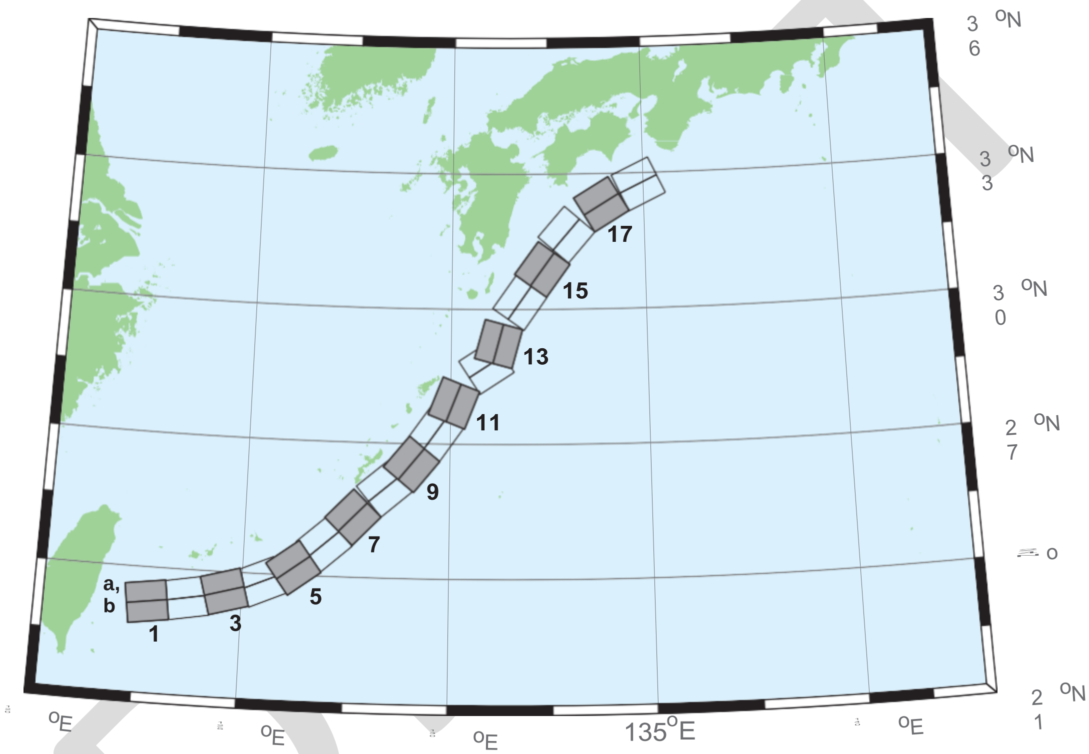

Figure A.9: Ryukyu–Kyushu–Nankai Zone unit sources.

Table A.9: Earthquake parameters for Ryukyu–Kyushu–Nankai SubductionZone unit sources.

Segment	Description	Longitude(°E)	Latitude(°N)	Strike(°)	Dip(°)	Depth (km)
rnsz–1a	Ryukyu–Kyushu–Nankai	122.6672	23.6696	262	14	11.88
rnsz–1b	Ryukyu–Kyushu–Nankai	122.7332	23.2380	262	10	3.2
rnsz–2a	Ryukyu–Kyushu–Nankai	123.5939	23.7929	259.9	18.11	12.28
rnsz–2b	Ryukyu–Kyushu–Nankai	123.6751	23.3725	259.9	10	3.6
rnsz–3a	Ryukyu–Kyushu–Nankai	124.4604	23.9777	254.6	19.27	14.65
rnsz–3b	Ryukyu–Kyushu–Nankai	124.5830	23.5689	254.6	12.18	4.1
rnsz–4a	Ryukyu–Kyushu–Nankai	125.2720	24.2102	246.8	18	20.38
rnsz–4b	Ryukyu–Kyushu–Nankai	125.4563	23.8177	246.8	16	6.6
rnsz–5a	Ryukyu–Kyushu–Nankai	125.9465	24.5085	233.6	18	20.21
rnsz–5b	Ryukyu–Kyushu–Nankai	126.2241	24.1645	233.6	16	6.43
rnsz–6a	Ryukyu–Kyushu–Nankai	126.6349	25.0402	228.7	17.16	19.55
rnsz–6b	Ryukyu–Kyushu–Nankai	126.9465	24.7176	228.7	15.16	6.47
rnsz–7a	Ryukyu–Kyushu–Nankai	127.2867	25.6343	224	15.85	17.98
rnsz–7b	Ryukyu–Kyushu–Nankai	127.6303	25.3339	224	13.56	6.26
rnsz–8a	Ryukyu–Kyushu–Nankai	128.0725	26.3146	229.7	14.55	14.31
rnsz–8b	Ryukyu–Kyushu–Nankai	128.3854	25.9831	229.7	9.64	5.94
rnsz–9a	Ryukyu–Kyushu–Nankai	128.6642	26.8177	219.2	15.4	12.62
rnsz–9b	Ryukyu–Kyushu–Nankai	129.0391	26.5438	219.2	8	5.66
rnsz–10a	Ryukyu–Kyushu–Nankai	129.2286	27.4879	215.2	17	12.55
rnsz–10b	Ryukyu–Kyushu–Nankai	129.6233	27.2402	215.2	8.16	5.45
rnsz–11a	Ryukyu–Kyushu–Nankai	129.6169	28.0741	201.3	17	12.91
rnsz–11b	Ryukyu–Kyushu–Nankai	130.0698	27.9181	201.3	8.8	5.26
rnsz–12a	Ryukyu–Kyushu–Nankai	130.6175	29.0900	236.7	16.42	13.05
rnsz–12b	Ryukyu–Kyushu–Nankai	130.8873	28.7299	236.7	9.57	4.74
rnsz–13a	Ryukyu–Kyushu–Nankai	130.7223	29.3465	195.2	20.25	15.89
rnsz–13b	Ryukyu–Kyushu–Nankai	131.1884	29.2362	195.2	12.98	4.66
rnsz–14a	Ryukyu–Kyushu–Nankai	131.3467	30.3899	215.1	22.16	19.73
rnsz–14b	Ryukyu–Kyushu–Nankai	131.7402	30.1507	215.1	17.48	4.71
rnsz–15a	Ryukyu–Kyushu–Nankai	131.9149	31.1450	216	15.11	16.12
rnsz–15b	Ryukyu–Kyushu–Nankai	132.3235	30.8899	216	13.46	4.48
rnsz–16a	Ryukyu–Kyushu–Nankai	132.5628	31.9468	220.9	10.81	10.88
rnsz–16b	Ryukyu–Kyushu–Nankai	132.9546	31.6579	220.9	7.19	4.62
rnsz–17a	Ryukyu–Kyushu–Nankai	133.6125	32.6956	239	10.14	12.01
rnsz–17b	Ryukyu–Kyushu–Nankai	133.8823	32.3168	239	8.41	4.7
rnsz–18a	Ryukyu–Kyushu–Nankai	134.6416	33.1488	244.7	10.99	14.21
rnsz–18b	Ryukyu–Kyushu–Nankai	134.8656	32.7502	244.5	10.97	4.7