The 2021 update to New Zealand's National Tsunami Hazard Model

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GNS Science Report 2022/06
April 2022

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BIBLIOGRAPHIC REFERENCE

Power WL, Burbidge DR, Gusman AR. 2022. The 2021 update to New Zealand's National Tsunami Hazard Model. Lower Hutt (NZ): GNS Science. 63 p. (GNS Science report; 2022/06). doi:10.21420/X2XQ-HT52.

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ISSN 2350-3424 (online)
ISBN 978-1-99-101339-2 (online)
http://dx.doi.org/10.21420/X2XQ-HT52

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ABSTRACT

The National Tsunami Hazard Model (NTHM) provides estimates of tsunami heights at the shoreline for return periods of up to 2500 years. It is used as a basis for selecting scenarios used for tsunami inundation modelling, which underpins tsunami evacuation zone design, land-use planning and risk assessments. The original NTHM was completed in 2013, though it built upon a 2005 study focused only on the main coastal cities. Since 2013, there have been improvements in the understanding of tsunami sources and in the techniques of tsunami modelling, and this report describes an incremental update incorporating those improvements. This new revision we refer to as the 2021 NTHM.

One area of improvement is in the definition of earthquake recurrences, and the update uses parameters from the Global Earthquake Model (GEM), which was still in development at the time of the 2013 NTHM.

The 2021 NTHM makes use of a broad catalogue of simulated tsunami events caused by subduction earthquakes from around the Pacific. This catalogue was developed in 2019, initially for the purpose of informing real-time tsunami forecasts. By using this large catalogue of scenarios, and through more sophisticated use of scaling relationships, it is expected that the 2021 NTHM should produce more accurate tsunami hazard estimates.

Modelling of tsunami caused by crustal faults close to New Zealand has also been significantly improved. The 2013 NTHM used simple empirical relationships to estimate tsunami heights, and here those have been replaced by using scaled hydrodynamic models, which should produce significantly more accurate results.

Overall, we find that the 2021 NTHM tends to produce similar or slightly lower estimates of tsunami hazard at the shoreline compared to the 2013 NTHM at most locations and return times. The main exception to this is the east coast of the North Island, for which some areas are estimated to have higher hazard at longer return times. We anticipate that the introduction of improved tsunami height estimates will lead to better choices of scenarios for inundation modelling studies.

KEYWORDS

Tsunami, Hazard Model, Earthquakes, New Zealand

1.0 INTRODUCTION

The National Tsunami Hazard Model (NTHM) is a key science product for reducing the impact of tsunami in New Zealand by providing estimates of tsunami heights at the shoreline for return periods of up to 2500 years. It underpins a variety of other products, such as the evacuation zones used when a tsunami threatens New Zealand, probabilistic tsunami inundation assessments used in land-use planning and probabilistic tsunami risk assessments. The original NTHM was completed in 2013 (Power 2013). Since then, knowledge of tsunami sources and how to model resulting tsunami has improved. We have recently completed an incremental update to the NTHM, and this report outlines the changes that have been made. For the purposes of this report, this new revision will be called NTHM 2021, while the original model will be called NTHM 2013.

Some of the significant changes include:

- Updates to the subduction source earthquake recurrence estimates using the parameters from latest Global Earthquake Model (GEM) global subduction zone model. This is described further in Section 2.1.
- Updates to the scenario database used to estimate the shoreline wave heights of regional and distant source tsunami to make use of the most recent modelling used for producing tsunami threat maps following a large earthquake. Further details are in Section 2.2.
- Revision of the method used to estimate wave heights from local crustal tsunami sources, replacing a very simple empirical modelling approach with scaled hydrodynamical modelling. Further details are in Section 3.

The effects of the changes on estimates of shoreline tsunami hazard around New Zealand are shown at a national scale in Section 3.1, and tsunami hazard curves and deaggregation plots for individual cities are shown in Section 3.2.

2.0 METHOD

The following sections describe the process used to estimate the tsunami hazard around the New Zealand coast. As this report describes an update to the 2013 NTHM (Power 2013), the focus here is on describing the changes made to the 2013 model.

The hazard analysis results in estimates of tsunami hazard along the coast, which, for this purpose, has been divided into a set of coastal zones (Figure 2.1).

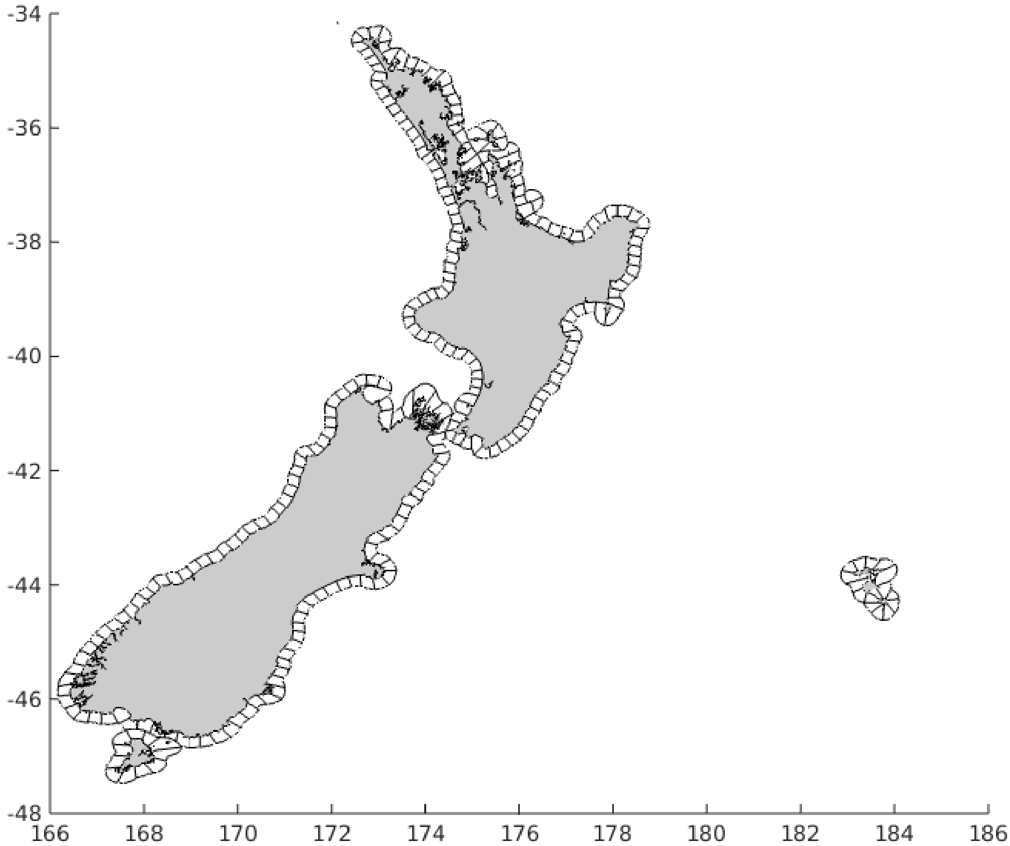


Figure 2.1 Illustration of the 268 coastal zones that are used for defining the tsunami hazard around the coast. Each zone is approximately 20 km in length.

2.1 Revised Subduction Zones Parameters

Since the publication of the 2013 NTHM, further work has been done to better understand and characterise the likelihood of large earthquakes on the world's subduction zones. To update the new NTHM with this new information, we revised the source zones using the GEM (Global Earthquake Model) Faulted Earth Subduction Zone Characterisation Project's 2015 model (Berryman et al. 2015). The aim of that project was to develop a globally consistent characterisation of the world's subduction zone plate boundary faults. The project produced a globally consistent set of earthquake characterisation parameters for all subduction zones in the world. For the NTHM 2021, we updated the NTHM 2013 table of subduction zone parameters with the new information from Berryman et al. (2015), while retaining the subduction zone segmentation assumptions used in NTHM 2013[1], and then used these to calculate the revised shoreline tsunami hazard.

1 Notably, NTHM 2021 continues to assume that the Hikurangi, Kermadec and Tonga subduction zones behave independently.

Most of the subduction zone parameters in NTHM 2021 are quite similar to those used in NTHM 2013. The most significant changes are typically in the b-value assumed for each subduction zone. The b-value is the slope of the magnitude versus frequency distribution for earthquakes following the Gutenberg-Richter equation. Higher b-values correspond to a smaller proportion of high-magnitude earthquakes compared to lower-magnitude ones. In both NTHMs, subduction zone parameters, such as b-value, are randomly selected between a minimum and maximum value using a uniform probability distribution. A particular set of sampled values are then used to create a synthetic catalogue of earthquakes. This process is then repeated using a new set of samples, generating numerous earthquake catalogues and thus estimates of the tsunami hazard. The spread of different hazard curves then reflects the uncertainties in the input parameters. This is explained in greater detail in Section 6 of the NTHM 2013 report (Power 2013). In NTHM 2013, the same range of b-values between 0.5 and 1.0 was used for all subduction zones. Table 2.1 shows the b-values used in NTHM 2021. Most zones now have their own minimum b-value, normally much higher than 0.5. The maximum b-value for most zones is 1.2, up from 1.0 in NTHM 2013.

The maximum magnitude range for each zone is similar in NTHM 2013 and 2021. One exception is the Alaska/Aleutian zone, where the range changes from M_W 9.5 to 9.7 in NTHM 2013 to 9.2 to 9.6 in NTHM 2021 (consistent with Berryman et al. 2015). For all other subduction zones, the maximum magnitude differs by less than 0.1 magnitude unit. The full list of maximum magnitude ranges for each zone is in Berryman et al. (2015). Coupling coefficients, plate velocity rates and directions and subduction zone lengths and widths were also similar or unchanged in both models. The ones used in this revision are those presented in Berryman et al. (2015) and so are not repeated here.

Table 2.1 Table comparing the minimum and maximum b-values used in NTHM 2021. Details of the location of the subduction zones can be found in Power (2013). In NTHM 2013, all zones used the same minimum and maximum b-value (0.5 and 1.0, respectively).

Subduction Zone Name	NTHM 2021 b-Value Minimum	NTHM 2021 b-Value Maximum
Alaska/Aleutians	0.67	1.2
Cascadia	0.7	1.2
Japan/Kurile	0.61	1.2
Kanto	0.7	1.2
Nankai/Ryukyu	0.61	1.2
Japan/Kurile	0.63	1.2
Nankai/Ryukyu	0.61	1.2
Izu-Bonin	0.7	1.2
Marianas	0.68	1.47
North Yap	0.7	1.2
Palau-South Yap	0.7	1.2
Hikurangi	0.7	1.2
Kermadec	0.7	1.21
Tonga	0.7	1.21
Puysegur	0.7	1.2
Hjort	0.7	1.2

Subduction Zone Name	NTHM 2021 b-Value Minimum	NTHM 2021 b-Value Maximum
Northwest Solomons	0.6	1.2
Southeast Solomons	0.6	1.2
New Hebrides (North)	0.6	1.2
New Hebrides (Central)	0.6	1.2
New Hebrides (South)	0.6	1.2
New Hebrides (Matthew Islands)	0.6	1.2
New Britain	0.6	1.2
New Guinea (East)	0.7	1.2
New Guinea (West)	0.7	1.2
Manus (East)	0.7	1.2
Manus (West)	0.7	1.2
South America (Ecuador/Columbia)	0.7	1.2
South America (Peru)	0.53	1.2
South America (North Chile)	0.53	1.2
South America (Central Chile)	0.53	1.2
Patagonia (North)	0.7	1.2
Patagonia (South)	0.7	1.2
Mexico (Jalisc)	0.58	1.2
Mexico (Michoa)	0.58	1.2
Central America (Elsalv)	0.7	1.2
Central America (Costar)	0.69	1.2
Philippine Trench	0.68	1.2
East Luzon Trough	0.7	1.2
Cotabato Trench	0.7	1.2

2.2 Regional and Distant Source Tsunami Heights

The 2013 NTHM used a collection of pre-calculated models of tsunami from a particular regional or distant source to estimate the coefficients in a semi-empirical scaling relationship based on Abe's (1979, 1995) formula:

$$Ht_{ij} = 10^{M_w - B_{ij}} \quad \text{Equation 2.1}$$

where Ht_{ij} is the tsunami height at the coastal zone *j* due to an earthquake of moment magnitude M_W in source region *i* (for distant and regional sources, the 'source regions' are the subduction zones) and B_{ij} is a coefficient specific to tsunami travelling from source region *i* to coastal zone *j*. The B_{ij} coefficients were derived from a catalogue of tsunami scenario models. The catalogue used in 2013 was the 2012 Tsunami Scenario Database (Power, unpublished; an earlier version of the database is described in Power and Gale 2011). This database was initially created to provide GNS Science with a rapid estimate of the tsunami threat level to its coastal warning zones following an earthquake on one of the major subduction zones around the Pacific.

For the 2021 NTHM, a revised and much larger set of scenarios has been used which were developed for an updated Tsunami Scenario Database developed in 2019 (Gusman et al. 2019, 2020). One of the main improvements was a significant increase in the number of scenarios in the new database. Scenarios now exist down to small magnitudes for all of the subduction zones near New Zealand. The number of scenarios increased to 998 (up from 336 scenarios in the 2012 database).[2] For more details about the update, see Gusman et al. (2019, 2020). Analysis of these scenarios indicated that the B_{ij} coefficients were not entirely independent of magnitude. For the current study, the average B_{ij} and their standard deviations were calculated at the specific magnitudes of the scenarios by rearranging Equation 2.1 as:

$$B_{ij}(M_w) = M_w - log_{10}Ht_{ij} \quad \text{Equation 2.2}$$

More specifically, $B_{ij}(M_w)$ was individually calculated for each scenario that occurs in source region *i*, and these were evaluated to produce a mean and standard deviation of $B_{ij}(M_w)$ for the source region *i* as a whole. For each subduction zone, the set of scenarios that arise from that particular source region was found by searching for those scenarios in the database that had rupture centroids within a polygon defining the boundaries of the subduction zone. This is a more flexible approach than that used previously and should make it easier to add more scenarios in future. The Ht_{ij} values were also determined for various percentiles of the tsunami height distribution along each section of coast using the new database, and then these values were used to calculate B_{ij} values for particular percentiles. This gives us the potential to create national-scale tsunami hazard maps for a range of different return periods and percentiles. The results presented here are based on the 99th percentile of the tsunami height distribution within each section of coast.

When used to estimate tsunami heights in the hazard model, interpolation was used to find a $B_{ij}(M_w)$ for the specific magnitude of each event in the synthetic catalogues. To allow for the effects of different locations within the source regions, the standard deviation $\sigma B_{ij}(M_w)$ is also estimated. The tsunami height is then calculated using Equation 2.3, where $\overline{\sigma B_{ij}(M_w)}$ is sampled from a normal distribution with mean zero and standard deviation $\sigma B_{ij}(M_w)$ and the normal distribution is truncated at +/- 2σ.

$$Ht_{ij} = 10^{M_w - \left(B_{ij}(M_w) + \overline{\sigma B_{ij}(M_w)}\right)} \quad \text{Equation 2.3}$$

2.3 Local Subduction Zone Tsunami Height Estimation

For the local subduction zones, that is, those within 1 hour travel time to the New Zealand coast (i.e. the Hikurangi, Puysegur and Kermadec subduction zones), a similar method was developed to that used for the distant and regional sources. However, for these nearby sources, there is greater sensitivity of tsunami heights to the effects of earthquake location, and, rather than treating this sensitivity as a random input (via the standard deviation in B_{ij}), a different approach was used to find a $B_{ij}(M_w)$ that assumed a random position for the earthquake within the subduction zone.

2 There were 723 scenarios in the first round of updates (Gusman et al. 2019) and a further 275 in the second round of updates (Gusman et al. 2020). Not all of these database scenarios were used in the NTHM analysis; in particular, a revised set were used for local subduction zones, see Section 2.3.

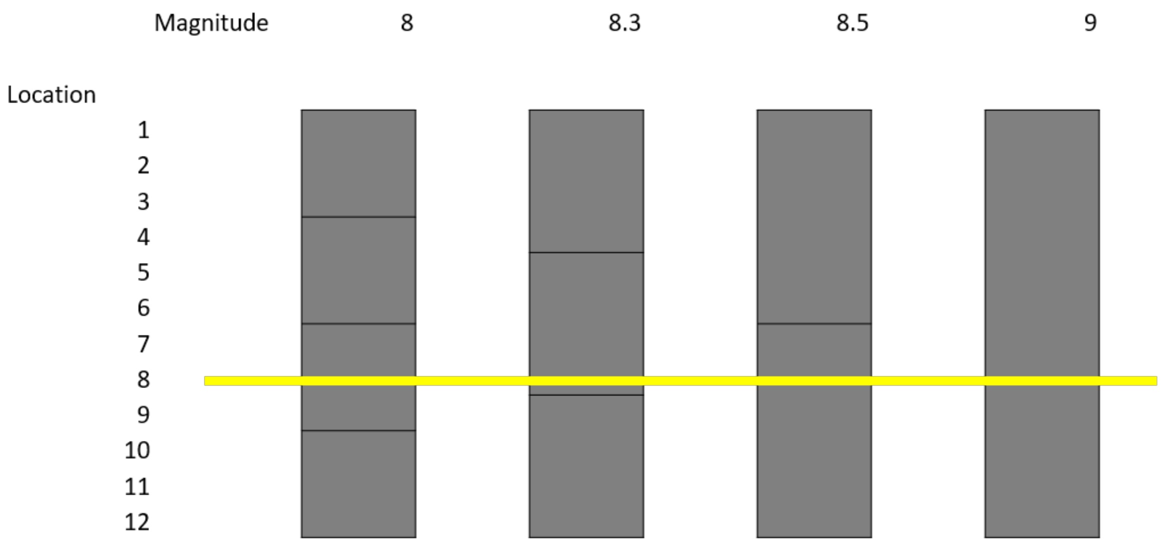


Figure 2.2 Illustration of how scenarios are used to obtain B_{ij} values for the Hikurangi and Puysegur subduction zones (the method for Kermadec Trench is similar but uses different magnitudes and more locations). A random position 1–12 is selected (yellow bar), then B_{ij} values from scenarios whose magnitudes bracket the event magnitude are selected (grey boxes represent scenario rupture areas) and a magnitude dependent $B_{ij}(M_w)$ is calculated from them by interpolation.

The scenarios used for this modelling were similar to those in the 2019 scenario database (Gusman et al. 2019, 2020), except that the scenario magnitudes and locations were chosen such that a whole number of rupture areas would fit within the subduction zones without gaps or overlap (as in Figure 2.2), giving equal coverage to all parts.

2.4 Local Crustal Faults Tsunami Height Estimation

NTHM 2013 used a set of empirical equations based on Abe's (1979, 1995) formula to calculate the amplitude of the tsunami at the coast (*Ht*):

$$Ht = 10^{M_w - \log R + 5.55 + C} \quad \text{Equation 2.4}$$

In this equation, *R* is the distance between the earthquake's epicentre and the coast (in kilometres) and *C* is a constant between 0.0 and 0.2, depending on the location. For NTHM 2013, *C* was assumed to be 0.1 for all coastal zones around New Zealand. Since the above formula becomes large at small *R*, a different formula was used when *R* is small:

$$Ht = 10^{0.5M_w - 3.30 + C} \quad \text{Equation 2.5}$$

Here, *R* is assumed to be small whenever it is less than magnitude specific distance, *r0*, which is given (in kilometres) by:

$$r0 = 10^{0.5\, M_w - 2.25} \quad \text{Equation 2.6}$$

While simple and quick, this method does not take into consideration factors such as bathymetry or source orientation. It is thus subject to considerable uncertainty. This is taken into consideration in an approximate way in the calculation of an 'effective magnitude' M_{eff} in NTHM 2013 (see Section 6.5 of Power [2013]). M_{eff} is an 'effective magnitude' which takes into account a range of different causes of uncertainty as if they had an effect equivalent to increasing or decreasing the earthquake magnitude.

For NTHM 2021, we decided to use hydrodynamic modelling to calculate the heights of tsunami generated by local crustal sources at their characteristic magnitudes and then use the method described in Section 2.2 (i.e. calculating a source and coastal zone specific B_{ij} and standard deviation) to calculate the tsunami shoreline wave heights for other earthquake magnitudes. To do this, we selected local crustal sources that were offshore and capable of producing an earthquake above M_W 6.5 according to the local faults used in Stirling et al. (2012). We also included any onshore local source in that study capable of generating an M_W 7.5 earthquake or greater, or M_W 8.0 if the mechanism was strike-slip. Figure 2.3 shows the location of the 250 local crustal sources used in this study.

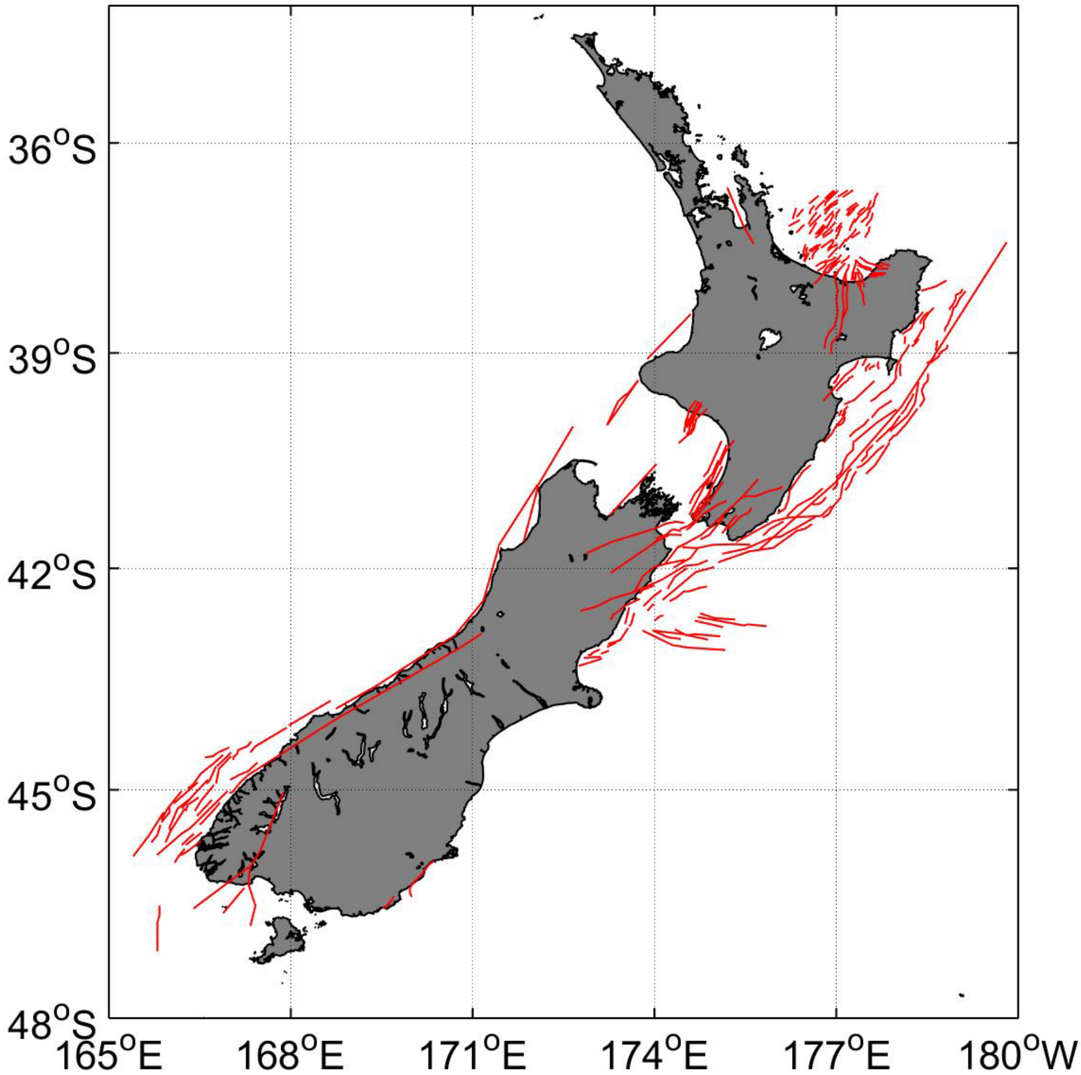


Figure 2.3 Map showing the local crustal sources used in NTHM 2021.

For each local crustal source, we then estimated the tsunami heights by running a COMCOT model using the preferred characteristic magnitude. Details of the magnitudes and recurrence intervals are given in Appendix 1.

Each tsunami scenario was modelled using the COMCOT tsunami simulation model on a series of nested grids (Wang and Power 2011), using the same grid configuration as was used for the tsunami scenario database (Gusman et al. 2019, 2020). The nested grid elevation data and coverages are shown in Figure 2.2. The DEM used to build the modelling grids are the same as those used in Gusman et al. (2019, 2020). The boundaries of the modelling grids are shown in Table 2.2. Each model was run for 10 hours. Vertical wall boundaries are implemented at the

10 cm water-depth contour. The slip amount of each local source scenario was calculated from the earthquake magnitude by assuming a rigidity of 34.3 GPa. Then, the ground surface and seafloor displacement were calculated using the elastic theory documented in Okada (1985).

Table 2.2 Boundaries of the nested grids.

Grid Layer	West	East	South	North
1	150.0000	200.00	-55.0000	-25.0000
2	160.0000	190.0000	-50.0000	-30.0000
3	166.0000	179.0000	-48.0000	-34.0000
4	182.5000	184.5000	-45.0000	-43.0000

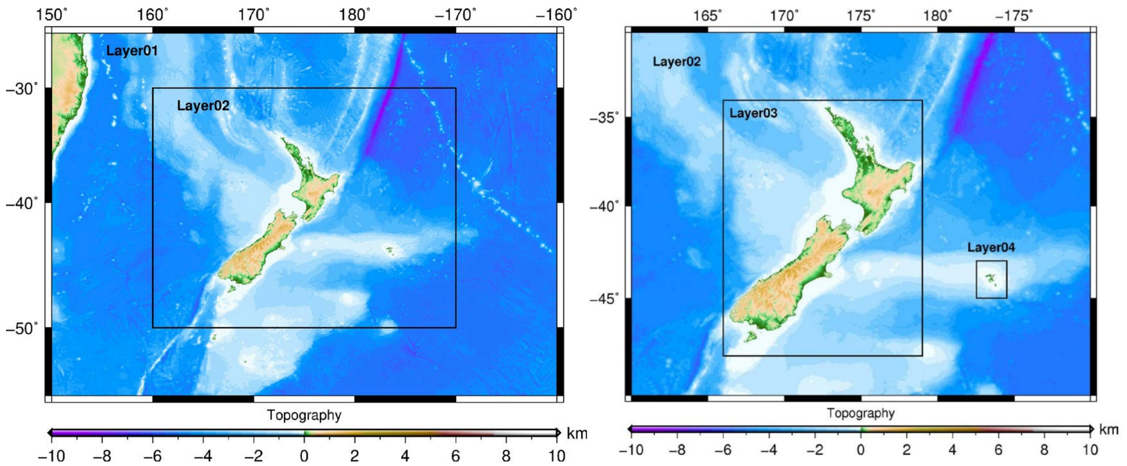


Figure 2.4 Nested grid modelling set-up used for the NTHM 2021 update. See Gusman et al. (2019, 2020) for details.

In total, 250 tsunami scenarios were used to inform the probabilistic model, one for each of the local fault sources. For each scenario *i* (here representing a particular fault), a set of B_{ij} values were calculated using the tsunami heights in each coastal region *j* using Equation 2.2 and the preferred characteristic magnitude for that fault, M_W. For the probabilistic tsunami hazard calculation, the B_{ij} values were used to calculate the shoreline wave heights at each coastal zone for every earthquake in a particular synthetic catalogue.

2.5 Updates to the Tentatively Identified Local Faults

The 2013 NTHM (Power 2013) tentatively identified several sets of local faults that could be tsunamigenic. These fell into three groups: Outer Rise Faults, Taranaki Basin Faults and Offshore West Coast Faults. Since that time, research has changed our understanding of some of these faults, and here we provide details of the updated representations of these faults as used in the 2021 NTHM.

2.5.1 Outer Rise Faults

Bathymetric mapping of the seafloor east of the southern Hikurangi Trench has not identified evidence of outer rise faults. It is suspected that, due to the thickness and rigidity of the incoming Hikurangi Plateau, substantial bending of the incoming plate does not occur until after the point at which the incoming plate has started to subduct. In the northern half of the Hikurangi subduction zone, earthquakes caused by normal faulting in the subducting slab are fairly common, and we suggest these are playing the role that is played by Outer Rise faults in other subduction zones (i.e. associated with bending of the incoming plate). If these earthquakes are large enough, they could still cause sufficient deformation to be tsunamigenic. In the southern half of the Hikurangi subduction zone, normal faulting earthquakes in the subducting plate are much less frequently observed. We suggest that this reflects differences in the coupling between plates along the margin – in the north, the coupling is weak and movement of the plates is continuously applying bending forces to the slab, whereas, in the south, the strong interseismic coupling appears to only be released in large infrequent earthquakes, and we may anticipate that the associated normal faulting in the slab tends to occur in the period following one of these large events.

Further research is highly desirable to improve our understanding of these faults and their potential to generate tsunami. For the purposes of the 2021 NTHM, we have adapted the representation of these faults as shown in Figure 2.5 and Table 2.3. For consistency with the 2013 NTHM, we continue to label these as 'Outer Rise Faults', even though they would be more accurately called 'Normal Faults in the Subducting Slab'.

Table 2.3 Assumed Hikurangi Outer Rise fault properties. Type 'nn' implies a normal fault mechanism.

Name	Type	Length (km)	Dip	Dip Direction	Depth of Top (km)	Depth of Bottom (km)	M_W	Recurrence Interval (Years)
Raukumara Outer Rise	nn	150	58°	300°	5	30	8.0	1300
Hawkes Bay Outer Rise	nn	150	58°	300°	5	30	8.0	1460
North Wairarapa Outer Rise	nn	150	58°	308°	5	30	8.0	1640
South Wairarapa Outer Rise	nn	150	58°	315°	5	30	8.0	1900

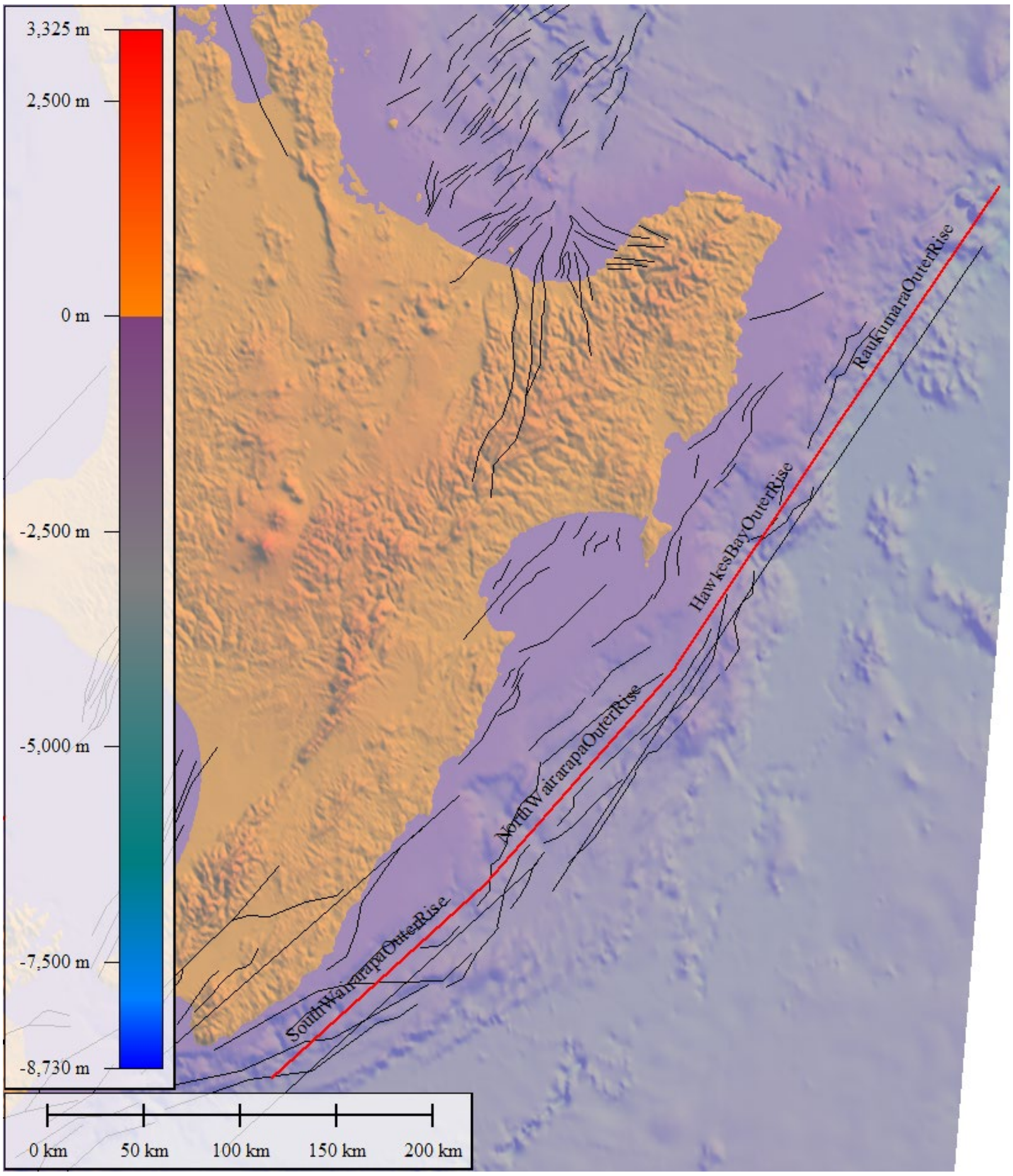


Figure 2.5 Assumed location of Hikurangi 'Outer Rise' faults as used for this study.

2.5.2 Taranaki Basin Faults

Recent research by Seebeck et al. (2021) has improved our understanding of these faults. The revised locations are shown in Figure 2.6, and properties are shown in Table 2.4. What was formerly called the ‘Manaia South Fault’ is now called the ‘Waimea Offshore Fault’ for consistency with the naming used by the Community Fault Model (CFM; Rattenbury 2020). The ‘Manaia North Fault’ in the 2013 NTHM has been removed, as it is regarded as inactive.

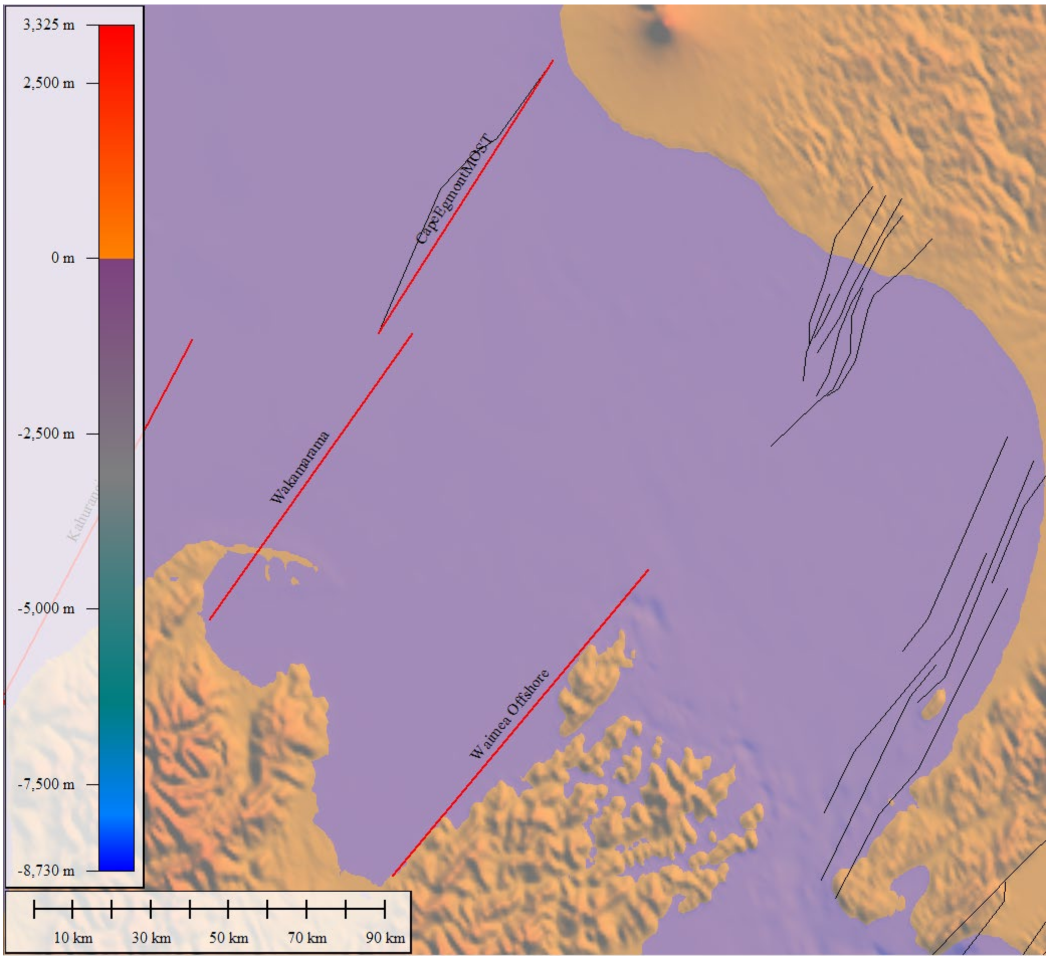


Figure 2.6 Assumed locations of tentatively identified Taranaki Basin faults.

Table 2.4 Assumed Taranaki Basin fault properties. Type ‘nn’ implies a normal fault mechanism, ‘rv’ a reverse mechanism, ‘rs’ a combined reverse and strike-slip.

Name	Type	Length (km)	Dip	Dip Direction	Depth of Top (km)	Depth of Bottom (km)	M_W	Recurrence Interval (Years)
Waimea offshore	rs	102	60°	130°	0	12	7.2	12,000
Wakamarama	rv	90	60°	305°	0	12	7.6	30,000
CapeEgmontMOST	nn	83	60°	122°	0	12	7.6	20,000

2.5.3 Offshore West Coast Faults

The representation of faults offshore of the west coast of the South Island has been revised, largely toward consistency with the CFM. Note in particular the re-numbering of the Cape Foulwind fault segments. The revised locations are shown in Figures 2.7 and 2.8, and properties are shown in Table 2.5.

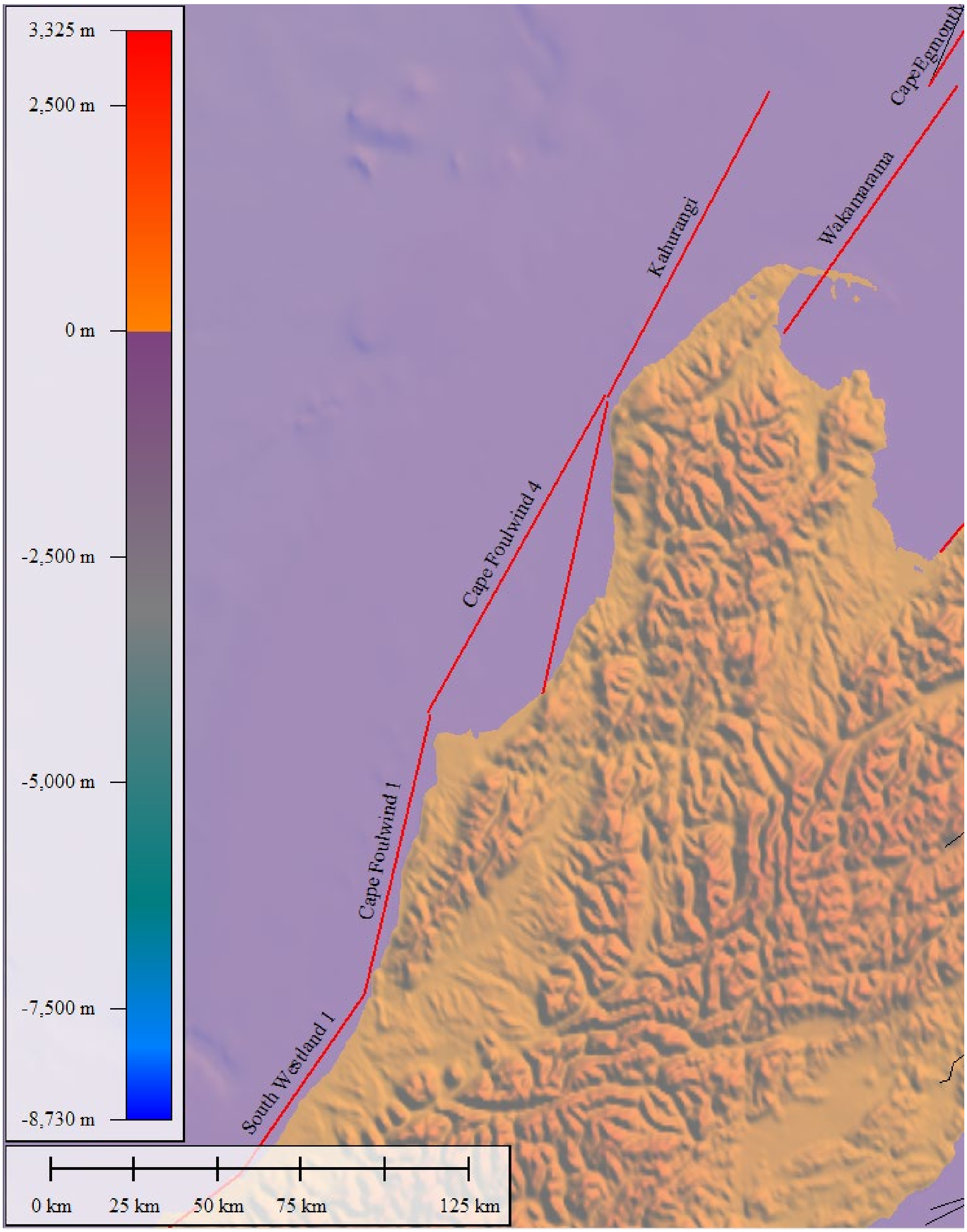


Figure 2.7 Assumed locations of west coast South Island faults (northern view).

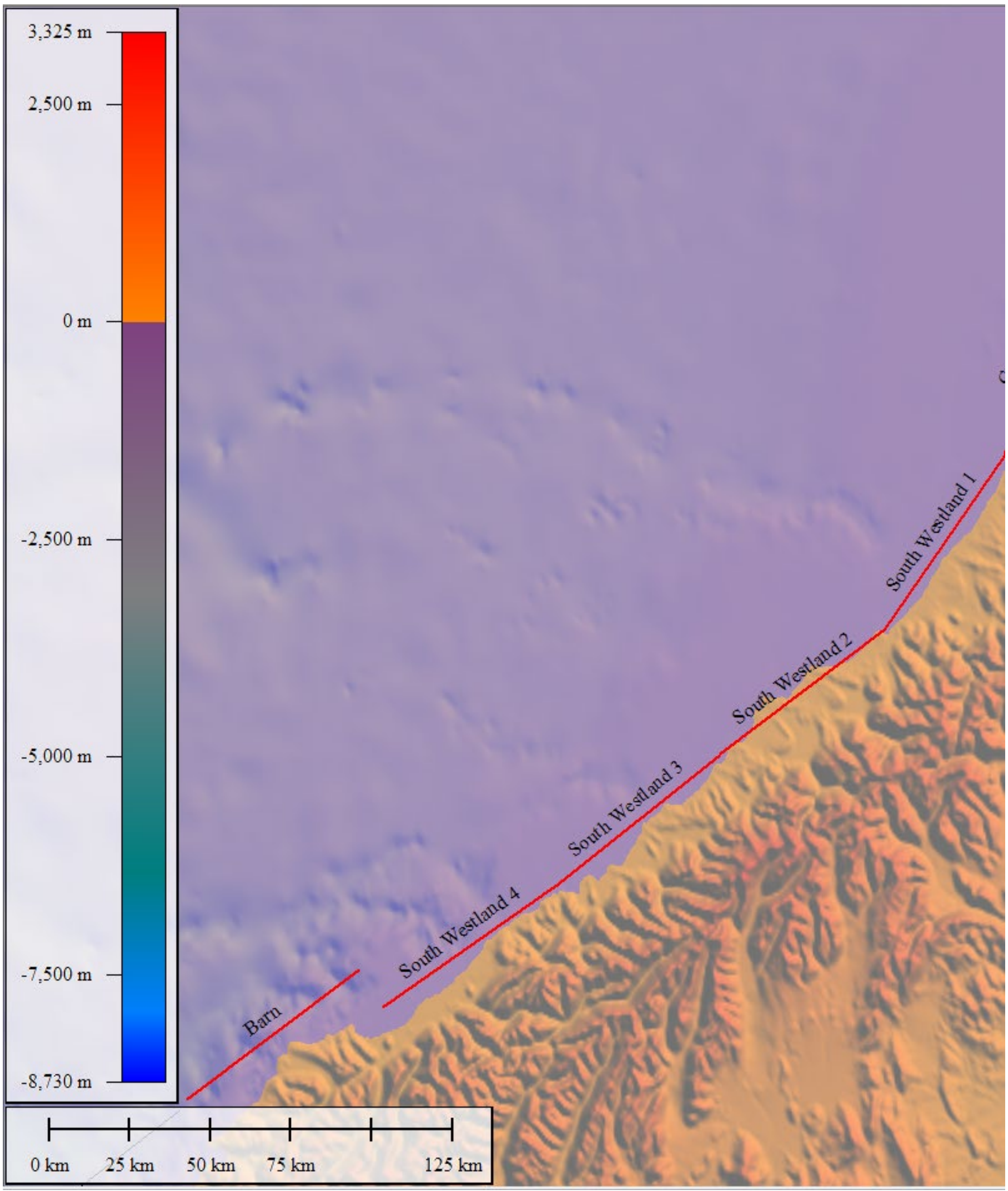


Figure 2.8 Assumed locations of west coast South Island faults (southern view).

Table 2.5 Assumed west coast South Island fault properties. Type ‘rv’ implies a reverse fault mechanism.

Name	Type	Length (km)	Dip	Dip Direction	Depth of Top (km)	Depth of Bottom (km)	M_W	Recurrence Interval (Years)
Barn	rv	67	30°	143°	0	15	7.6	2400
SouthWestland1	rv	65	45°	126°	0	15	7.6	9700
SouthWestland2	rv	65	45°	143°	0	15	7.6	4900
SouthWestland3	rv	65	45°	140°	0	15	7.6	4900
SouthWestland4	rv	65	45°	150°	0	15	7.6	4900
CapeFoulwind4	rv	65	60°	139°	0	15	7.6	9700
CapeFoulwind1	rv	86	60°	105°	0	15	7.6	9700
Kongahu	rv	96	60°	90°	0	15	7.6	15,000
Kahurangi	rv	103	50°	118°	0	15	7.6	15,000

2.6 Other Modifications from National Tsunami Hazard Model 2013

Throughout the tsunami scenario modelling of subduction zone sources, and the probabilistic calculations of the hazard posed by them, a rigidity of 40 Gpa was assumed (in contrast to 50 GPa in NTHM 2013). For the scenario modelling of crustal faults, a rigidity of 34.3 GPa was assumed (Burbidge et al. 2021).

To improve the statistical quality of the estimation of uncertainty, the number of samples of epistemic uncertainty (see Section 6 of Power [2013]) was increased from 300 to 600.

In the deaggregation calculation (see Section 6.8 of Power [2013]), instead of selecting the three closest events from each synthetic catalogue, the 10 closest were selected, this was done to improve the statistical robustness of the deaggregation.

3.0 RESULTS

3.1 National Tsunami Hazard Maps 2021

Figures 3.1–3.4 show the shoreline[3] tsunami hazard in NTHM 2021 with the improvements described in Section 2. Maps show the shoreline hazard at four return periods, 100, 500, 1000 and 2500 years, for the tsunami hazard in each coastal zone. Here, the tsunami hazard level is shown at the 50^{th} (best estimate) and 84^{th} (conservative estimate) percentile of epistemic uncertainty in each coastal section.

Note that, in the following figures, we refer to the 'maximum' tsunami amplitude in each zone. Strictly speaking, this is the 99^{th} percentile of the tsunami maximum amplitude for all coastal points in each hazard zone polygon; this reduces the effect of very localised outliers.

3 The numerical tsunami modelling that underpins the assessment of shoreline tsunami heights has been created using innermost nested modelling grids of 15 arc-second resolution (310–380 m) and assuming vertical-wall boundary conditions at the 10 cm depth contour. 'Shoreline' tsunami heights are approximated by the maximum water levels in the grid cells adjacent to the wall boundary.

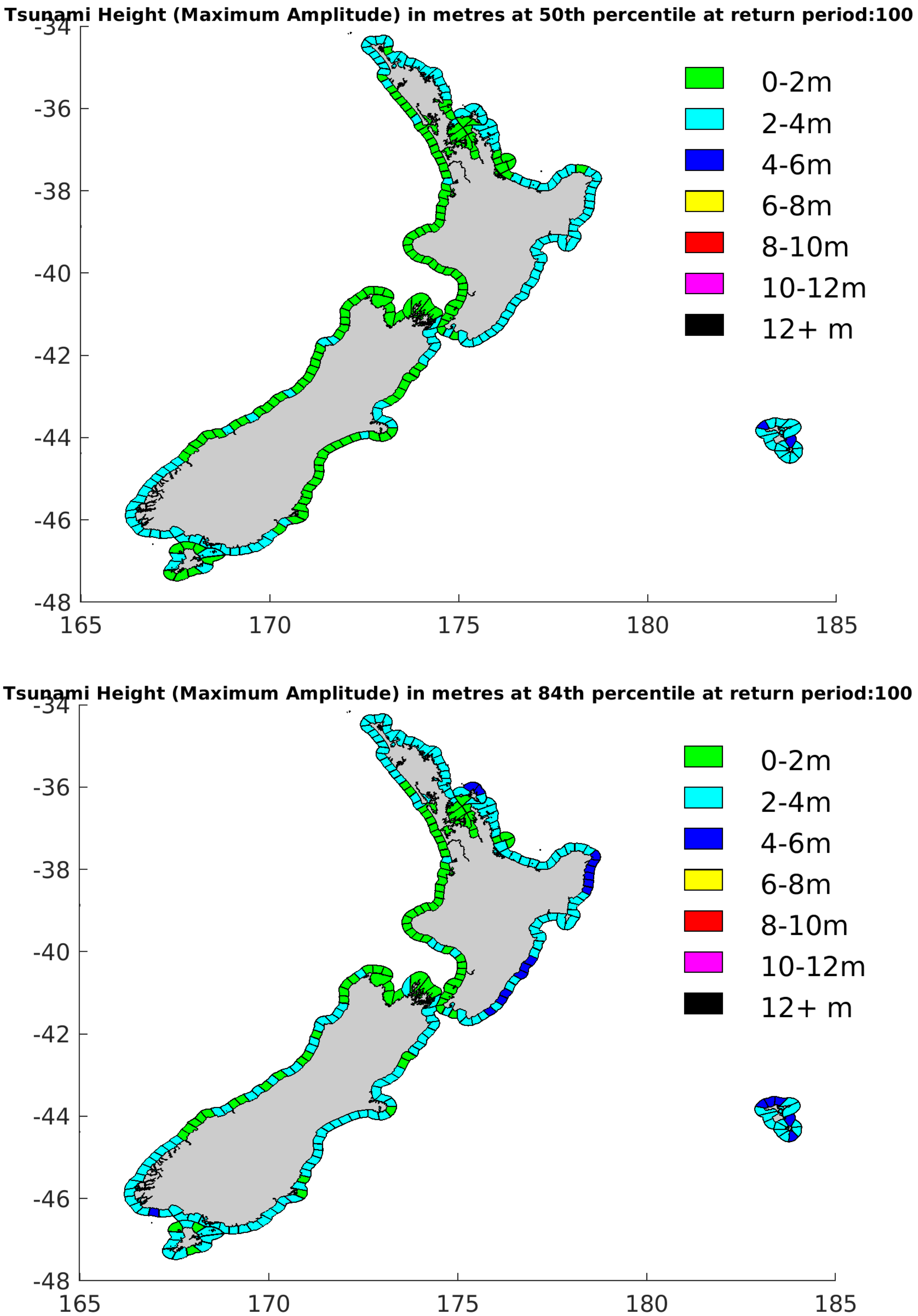
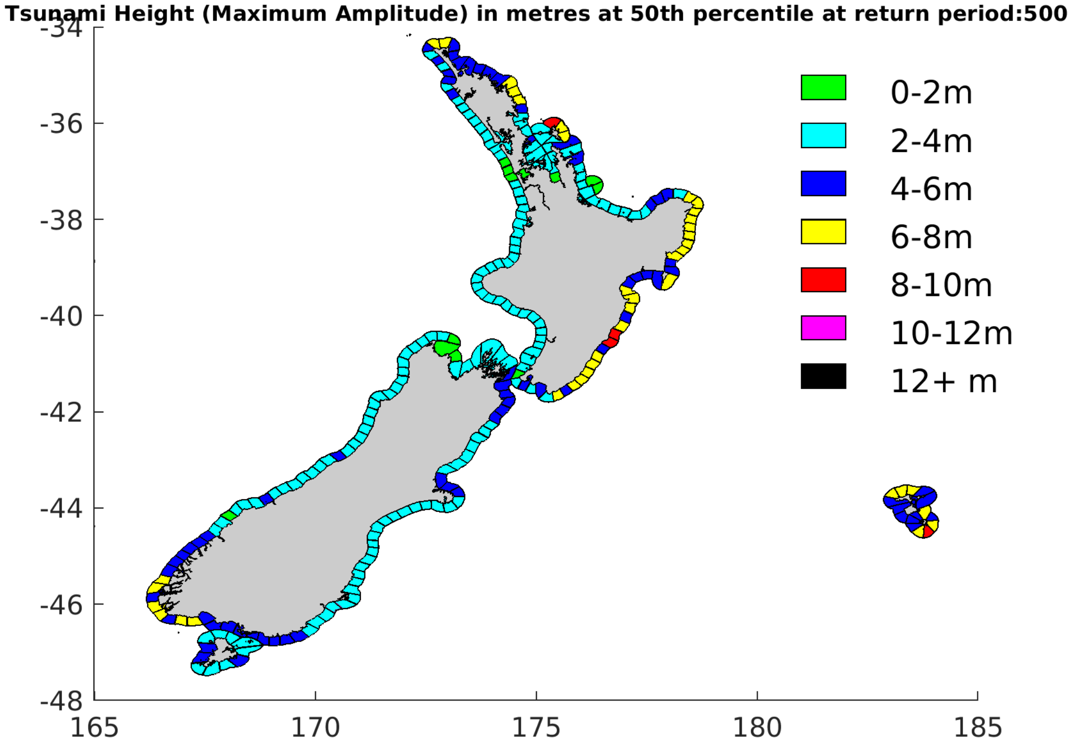


Figure 3.1 Expected maximum tsunami height in metres at the 100-year return period, shown at median (50th) and 84th percentiles of epistemic uncertainty.



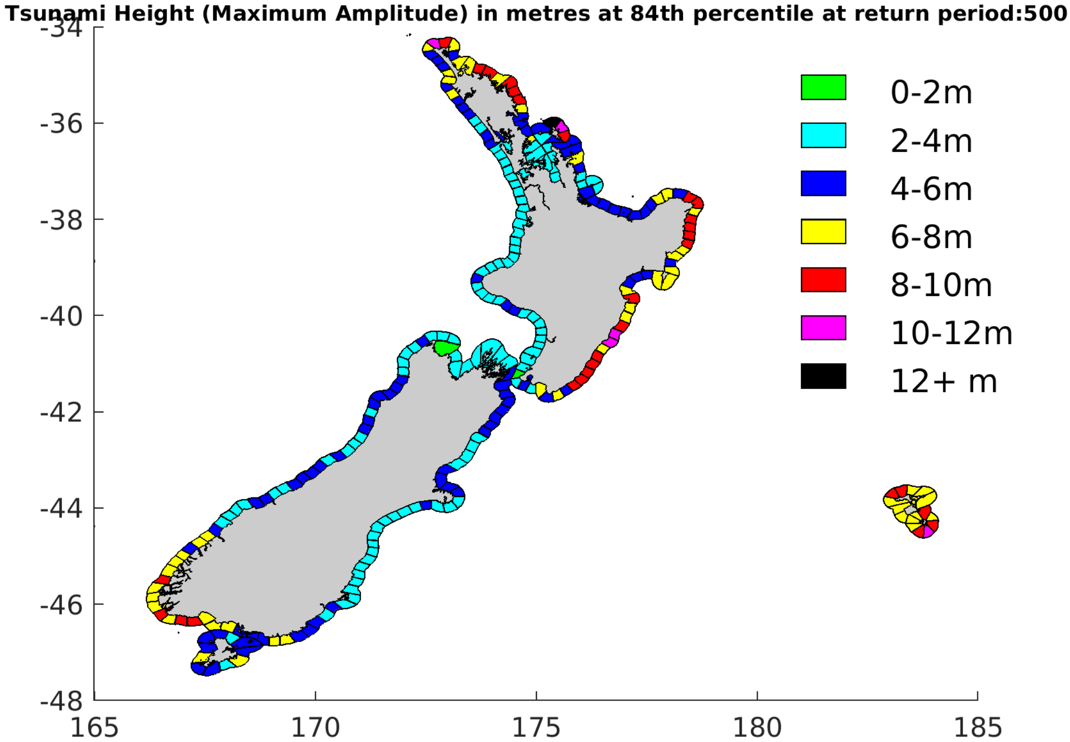


Figure 3.2 Expected maximum tsunami height in metres at the 500-year return period, shown at median (50th) and 84th percentiles of epistemic uncertainty.

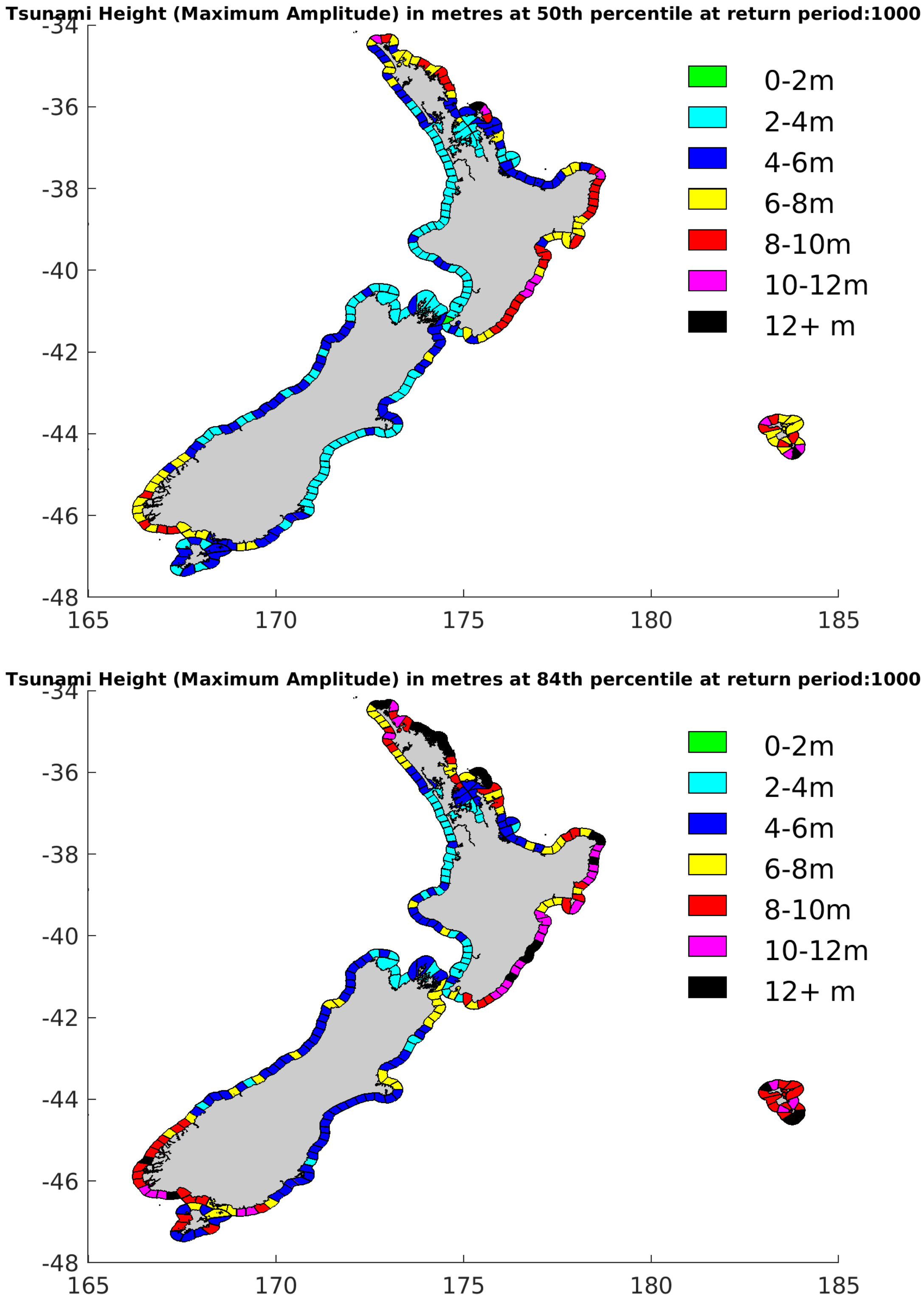


Figure 3.3 Expected maximum tsunami height in metres at the 1000-year return period, shown at median (50th) and 84th percentiles of epistemic uncertainty.

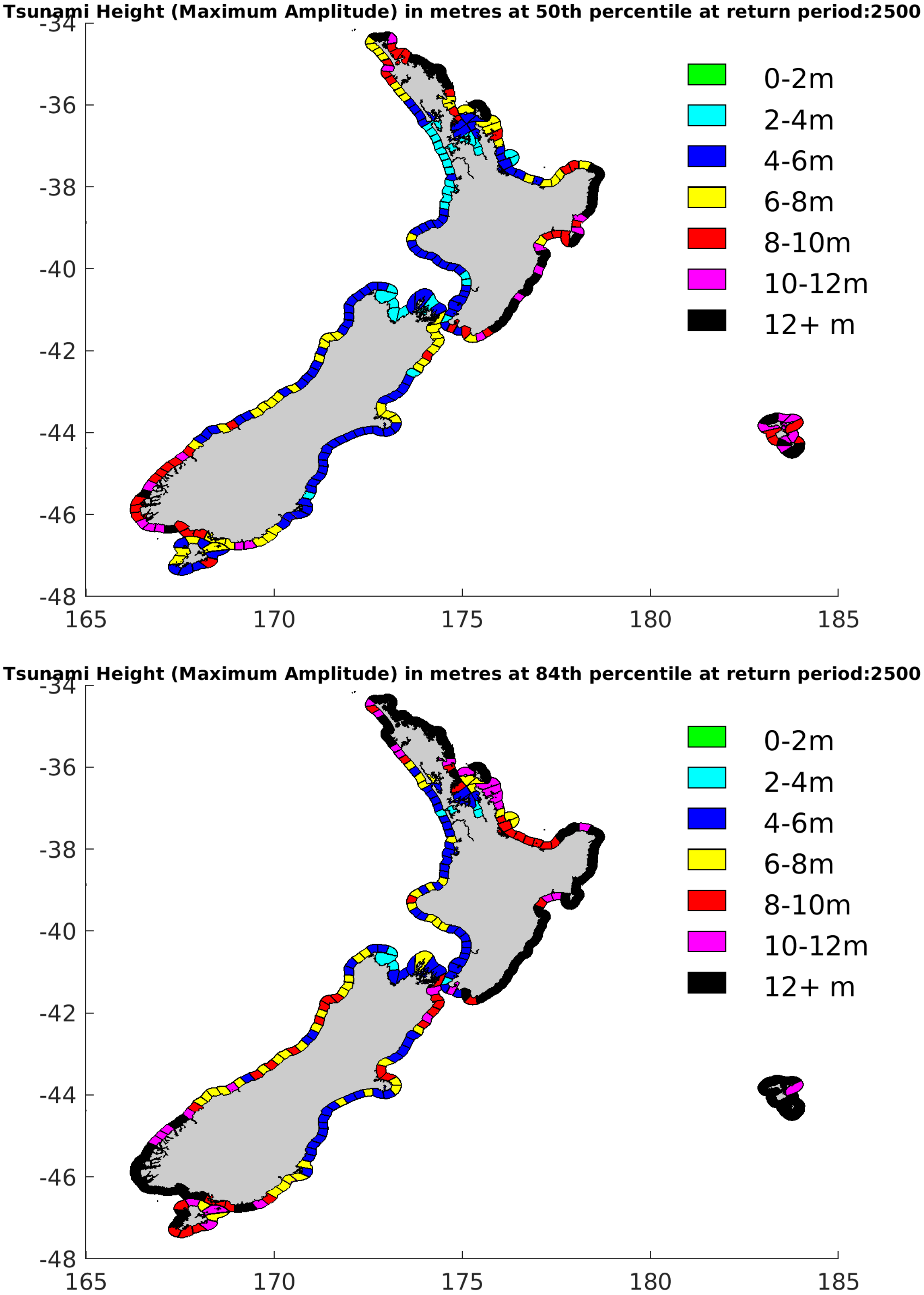


Figure 3.4 Expected maximum tsunami height in metres at the 2500-year return period, shown at median (50^{th}) and 84^{th} percentiles of epistemic uncertainty.

Maps showing the difference between NTHM 2021 and NTHM 2013 at the 500-year return period (50% level of confidence) are shown in Figure 3.5. At this return period, the estimated tsunami hazard is mostly lower in the 2021 study, which we interpret as being mostly due to the more accurate modelling of distant tsunami sources in the revised model.

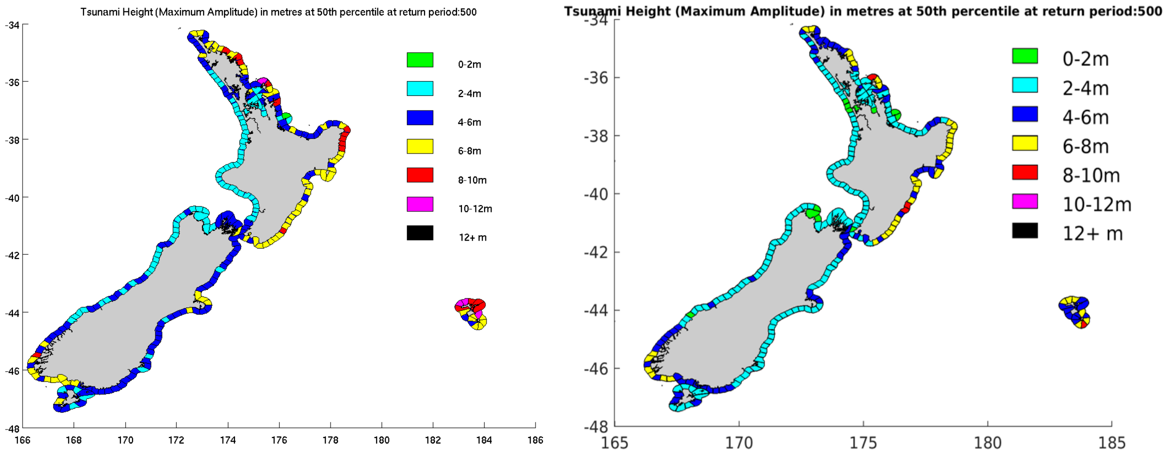


Figure 3.5 Comparison of the 500-year tsunami hazard (at the 50% level of confidence) in the 2013 (left) and 2021 (right) tsunami hazard models.

At the 2500-year return period (50% level of confidence) shown in Figure 3.6, we see a reduction in the estimated hazard along the west coast of the South Island and in the Bay of Plenty but an increase in the estimated hazard along the east coast of the North Island. The increased hazard along the east coast of the North Island we interpret as being related to the more accurate modelling applied to the 'Outer Rise' sources (see Section 2.5.1).

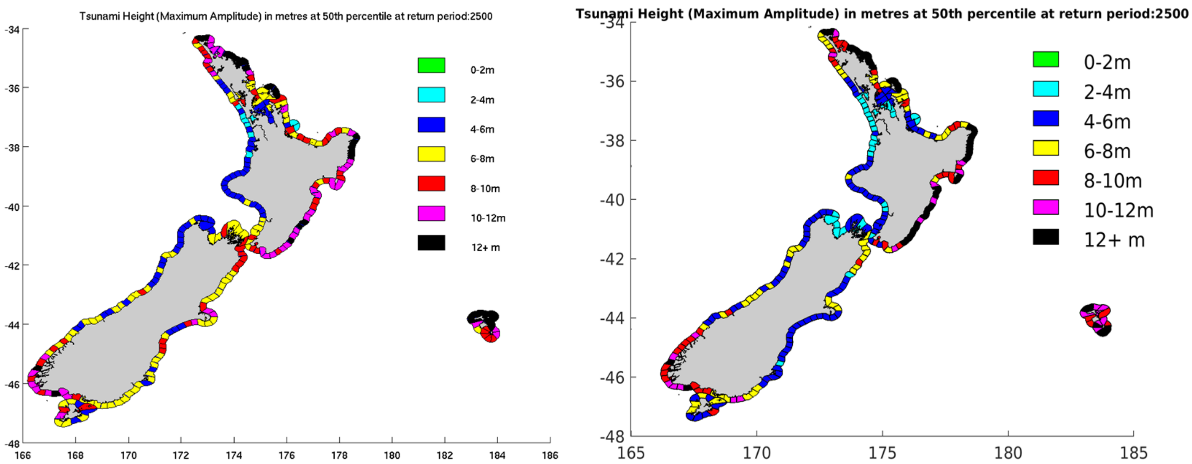
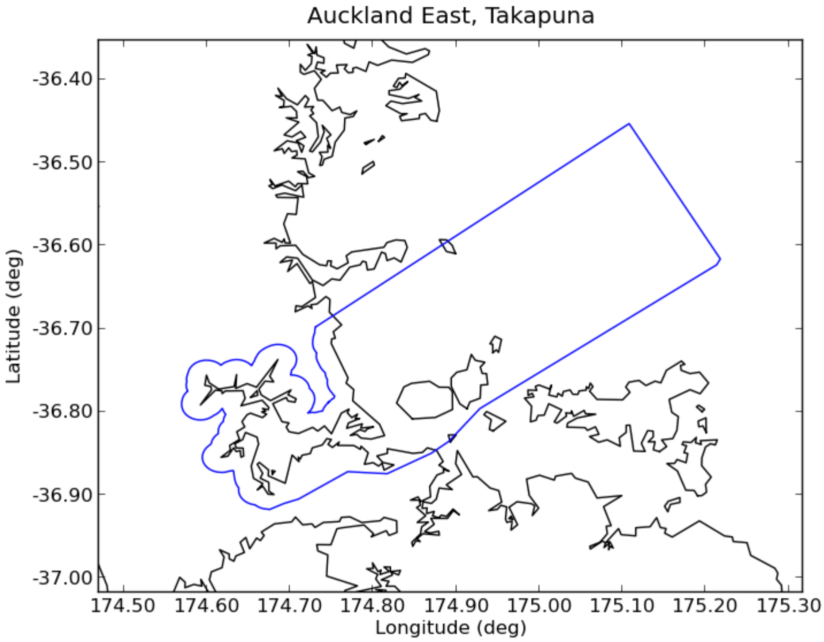


Figure 3.6 Comparison of the 2500-year tsunami hazard (at the 50% level of confidence) in the 2013 (left) and 2021 (right) tsunami hazard models.

3.2 Tsunami Hazard Curves and Hazard Deaggregation for Major Cities

In this section, we show the outline of the coastal section, the tsunami hazard curves for return periods between 100 and 2500 years, the deaggregation of the tsunami hazard at the 500-year return period and the deaggregation of the hazard at the 2500-year return period for each of the major coastal cities. The fault name codes used in the deaggregation plots are given in Appendix 1.

Auckland East Coast



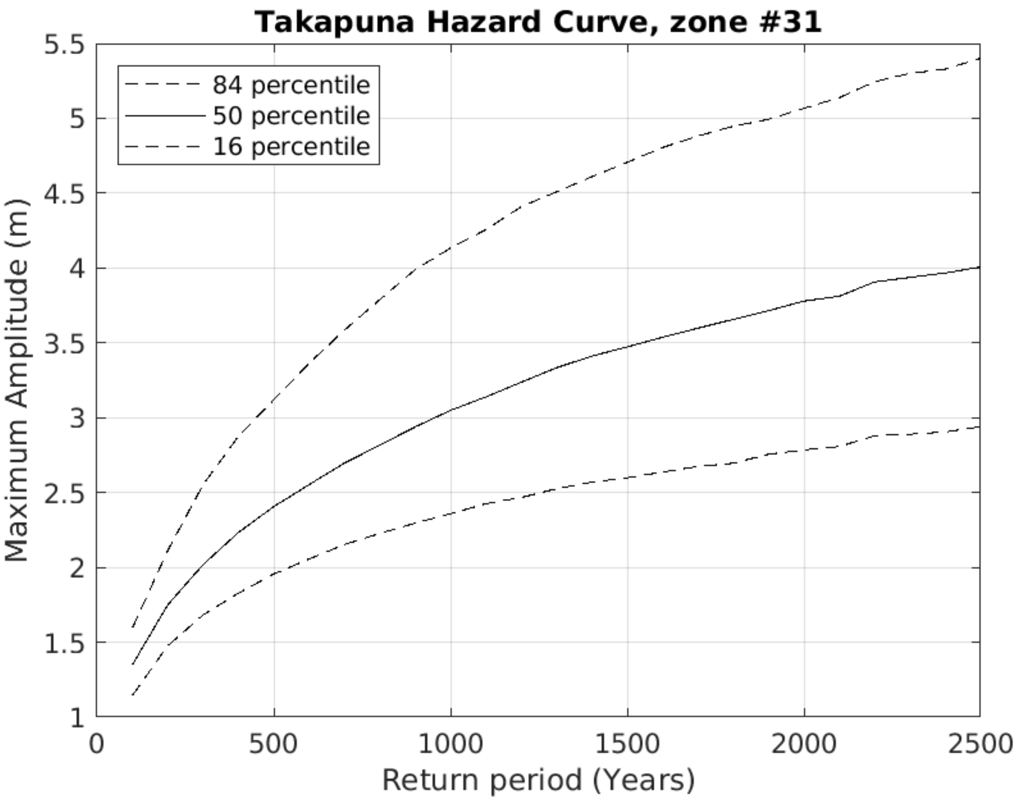
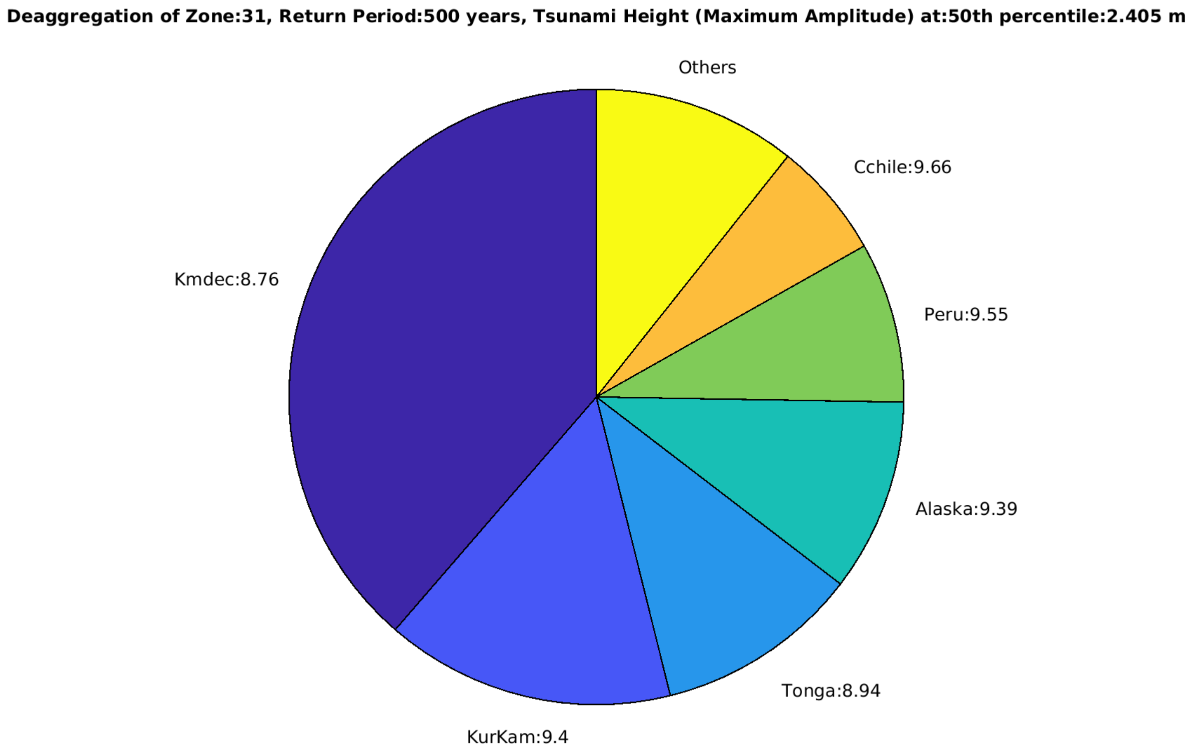


Figure 3.7 Area map and tsunami hazard curve for Auckland East.



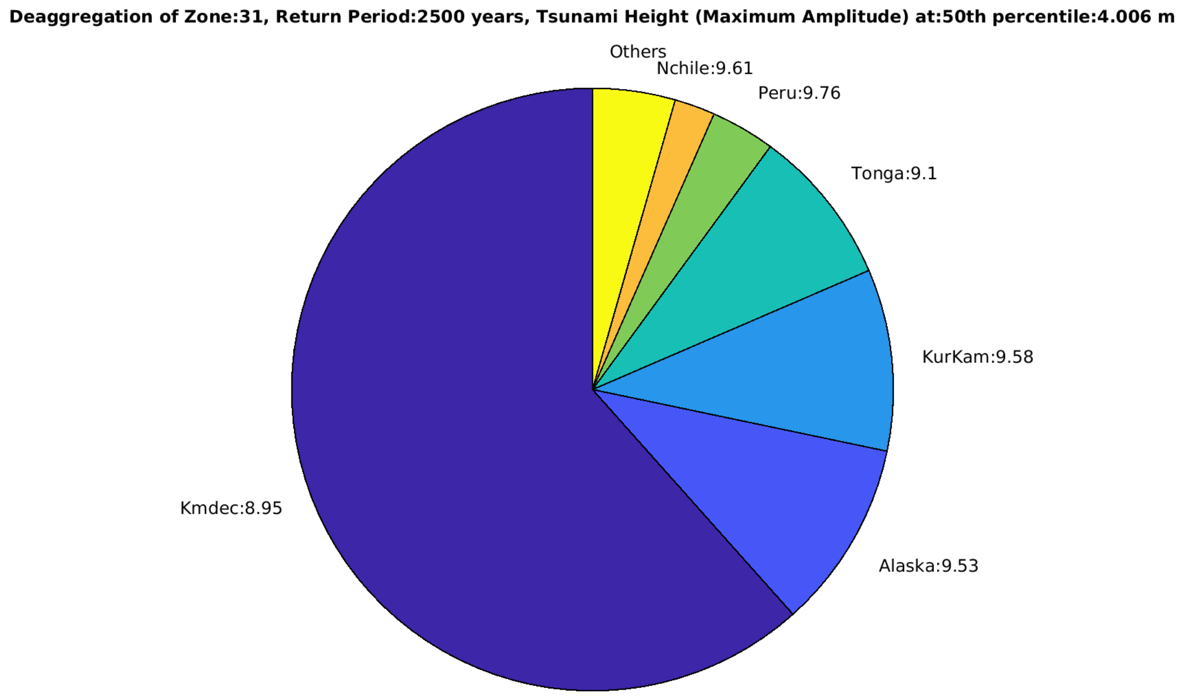
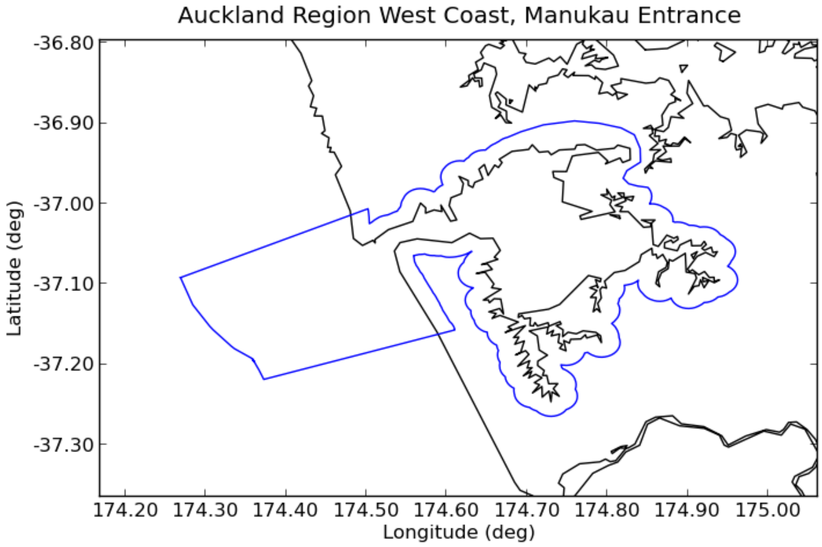


Figure 3.8 Deaggregation of tsunami sources for Auckland East Coast at the 500-year (top) and 2500-year (bottom) return periods.

Auckland West Coast



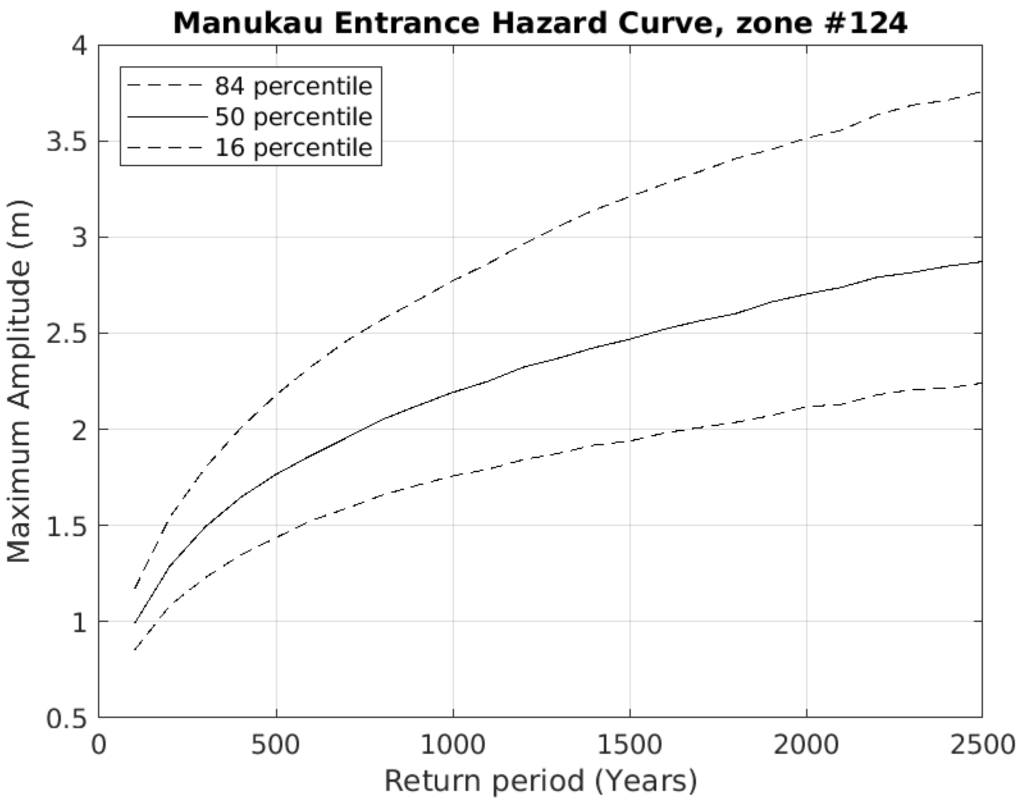
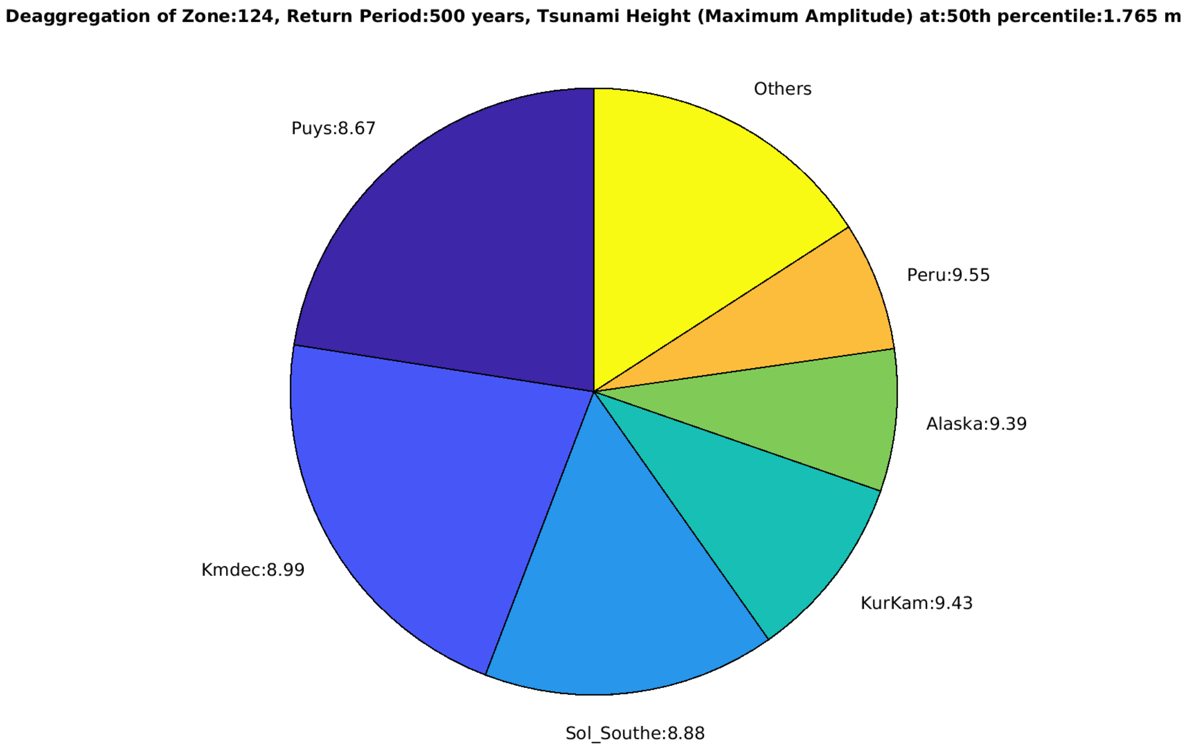


Figure 3.9 Area map and tsunami hazard curve for Auckland West.



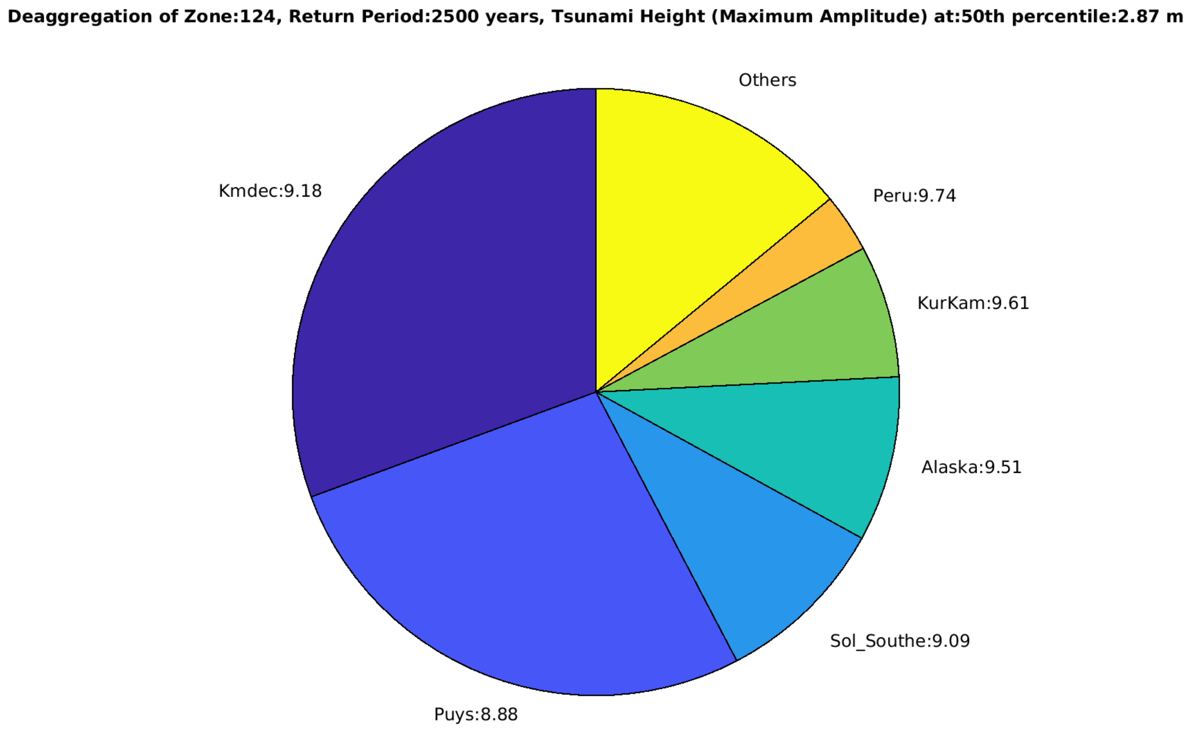
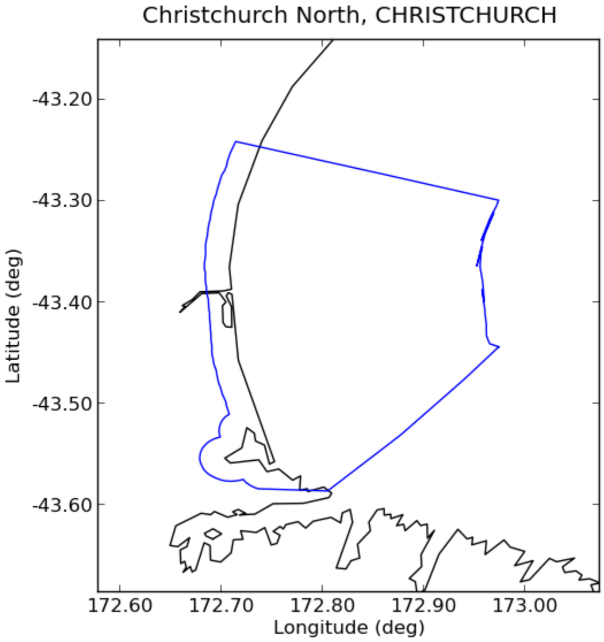


Figure 3.10 Deaggregation of tsunami sources for Auckland West Coast at the 500-year (top) and 2500-year (bottom) return periods.

Christchurch



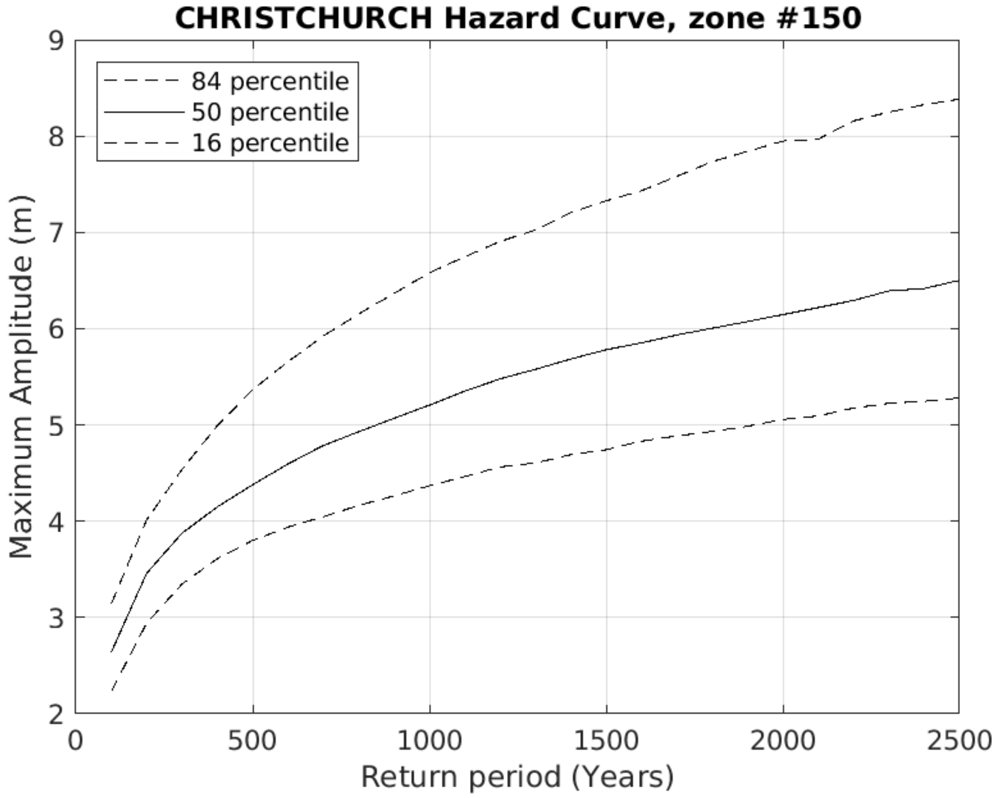


Figure 3.11 Area map and tsunami hazard curve for Christchurch.

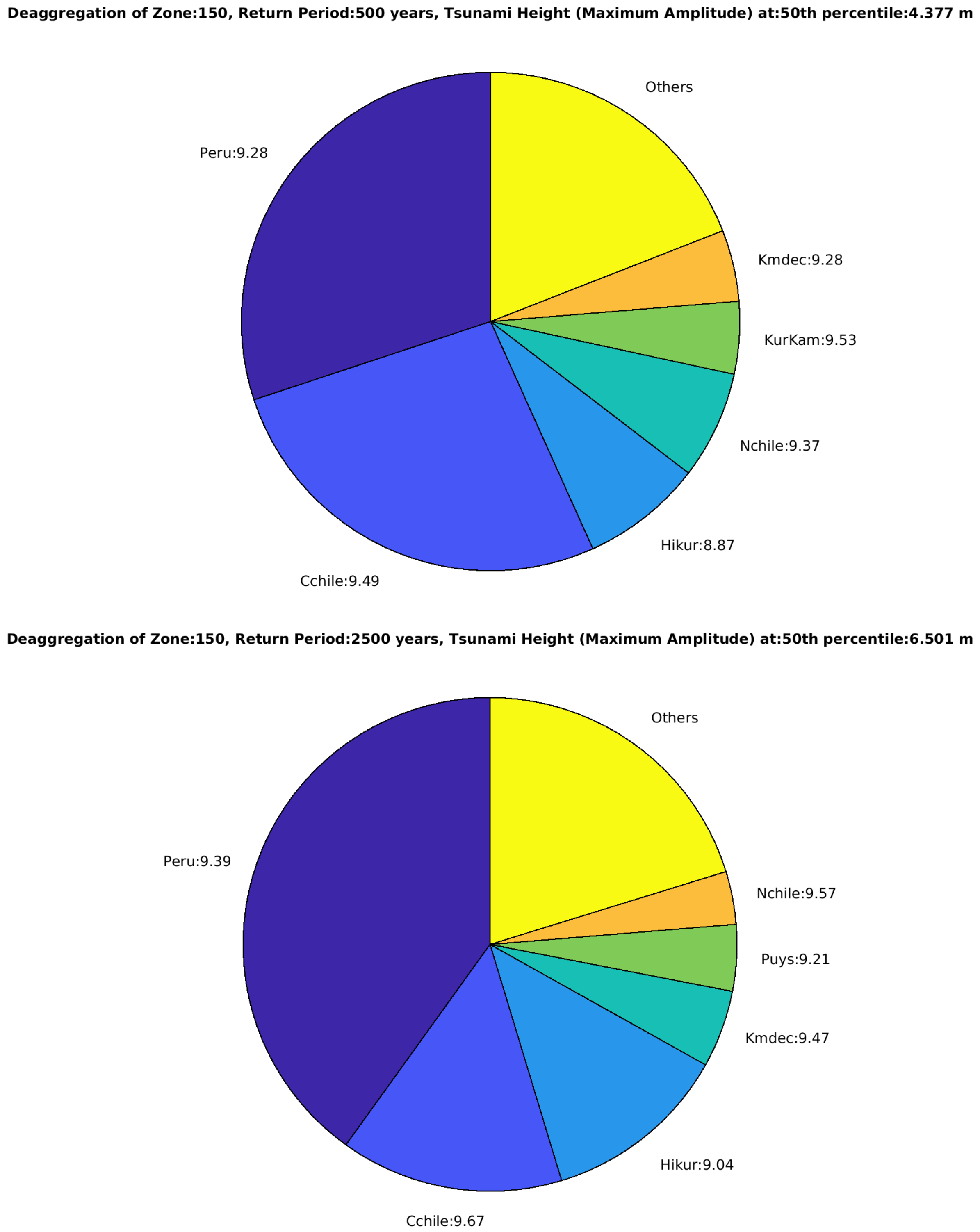


Figure 3.12 Deaggregation of tsunami sources for Christchurch at the 500-year (top) and 2500-year (bottom) return periods.

Dunedin

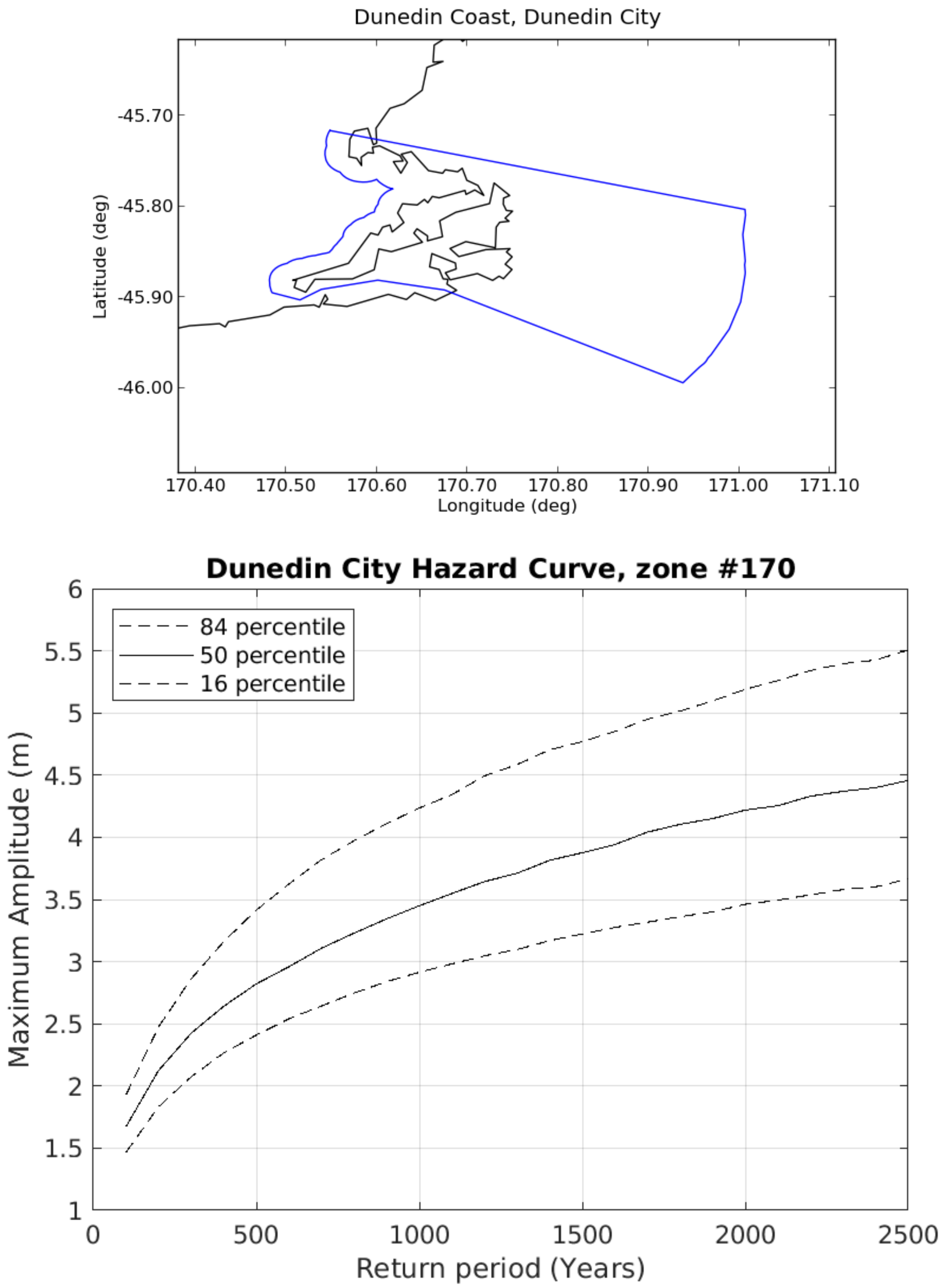
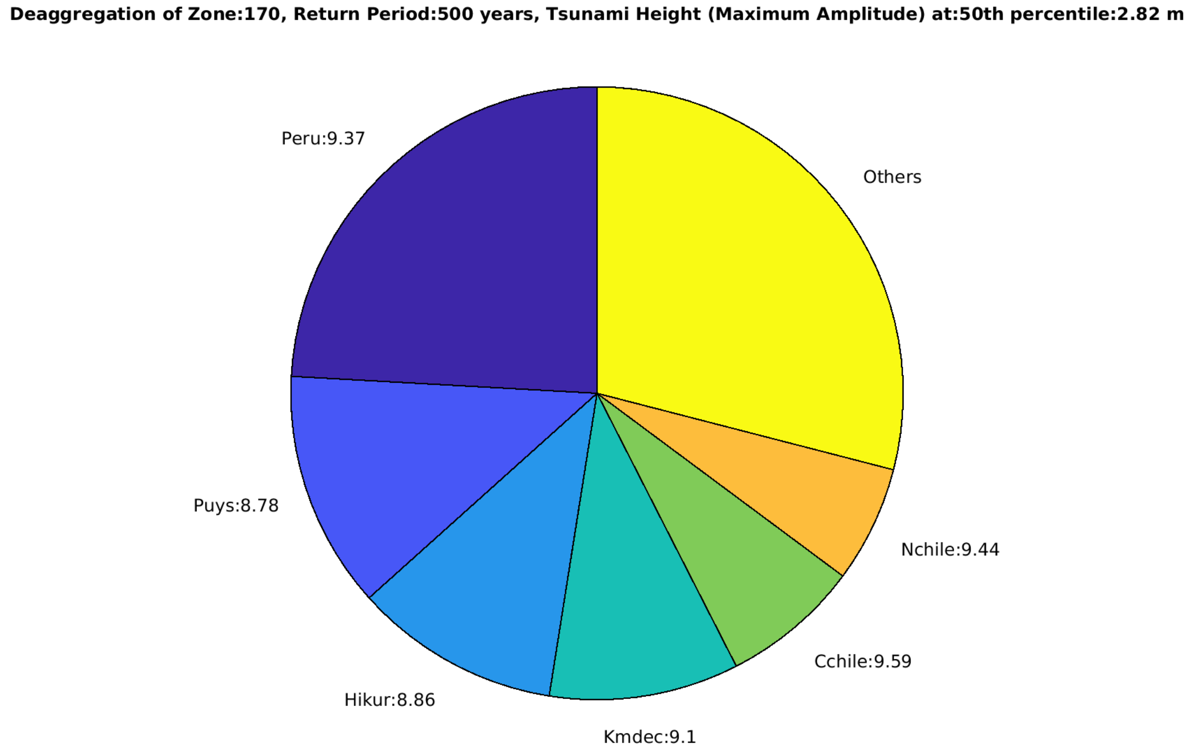


Figure 3.13 Area map and tsunami hazard curve for Dunedin.



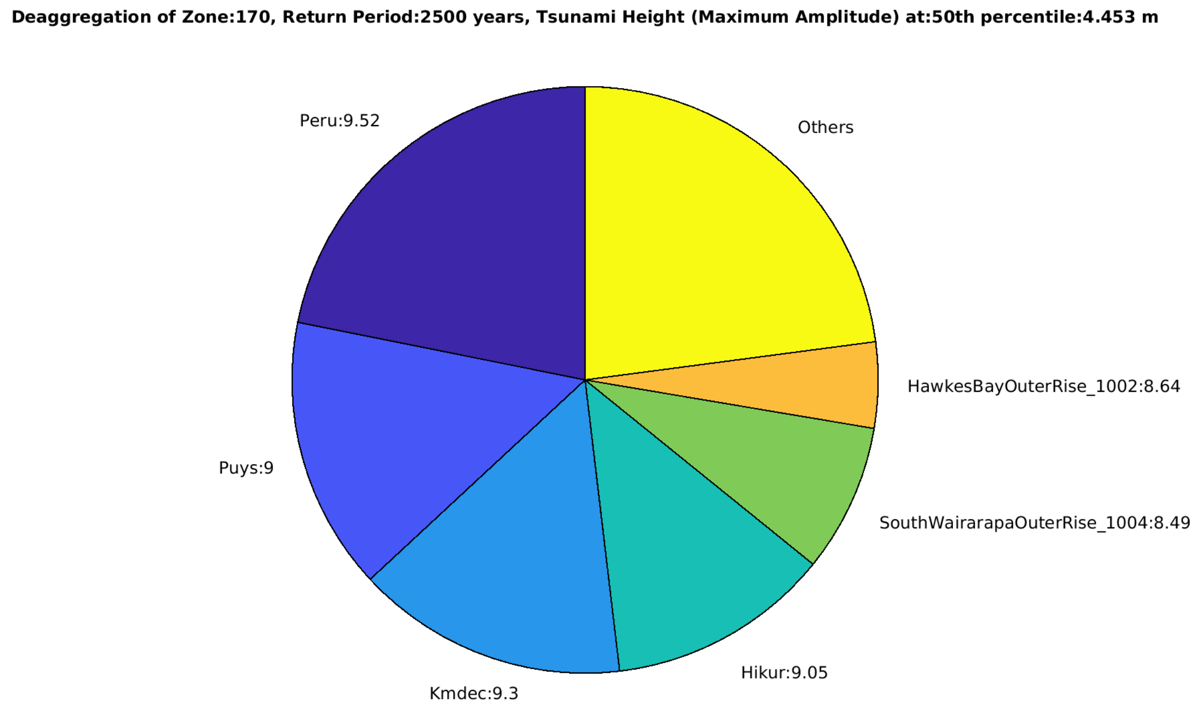
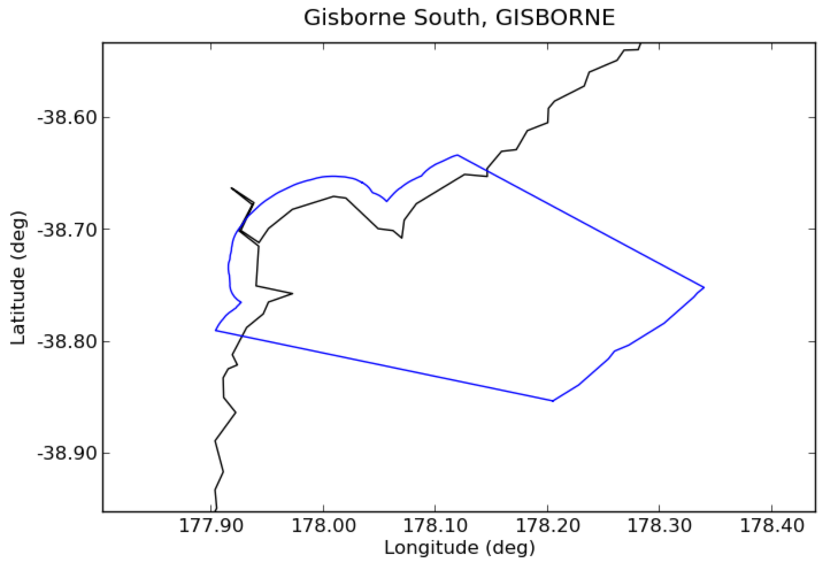


Figure 3.14 Deaggregation of tsunami sources for Dunedin at the 500-year (top) and 2500-year (bottom) return periods.

Gisborne



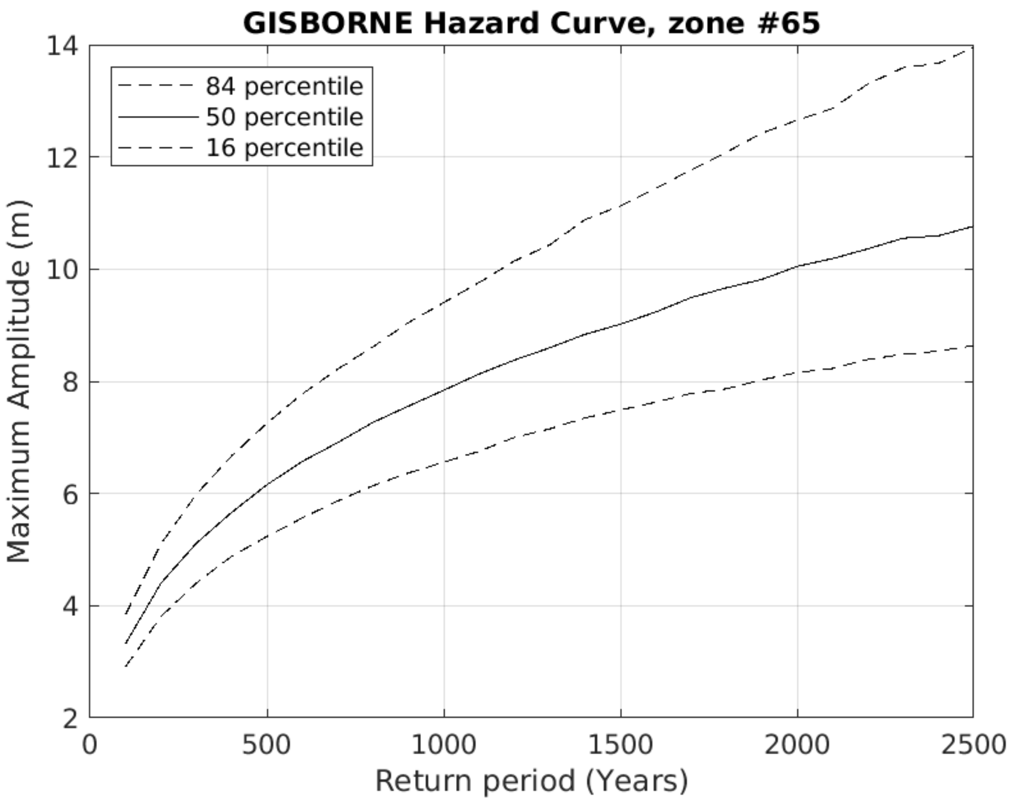
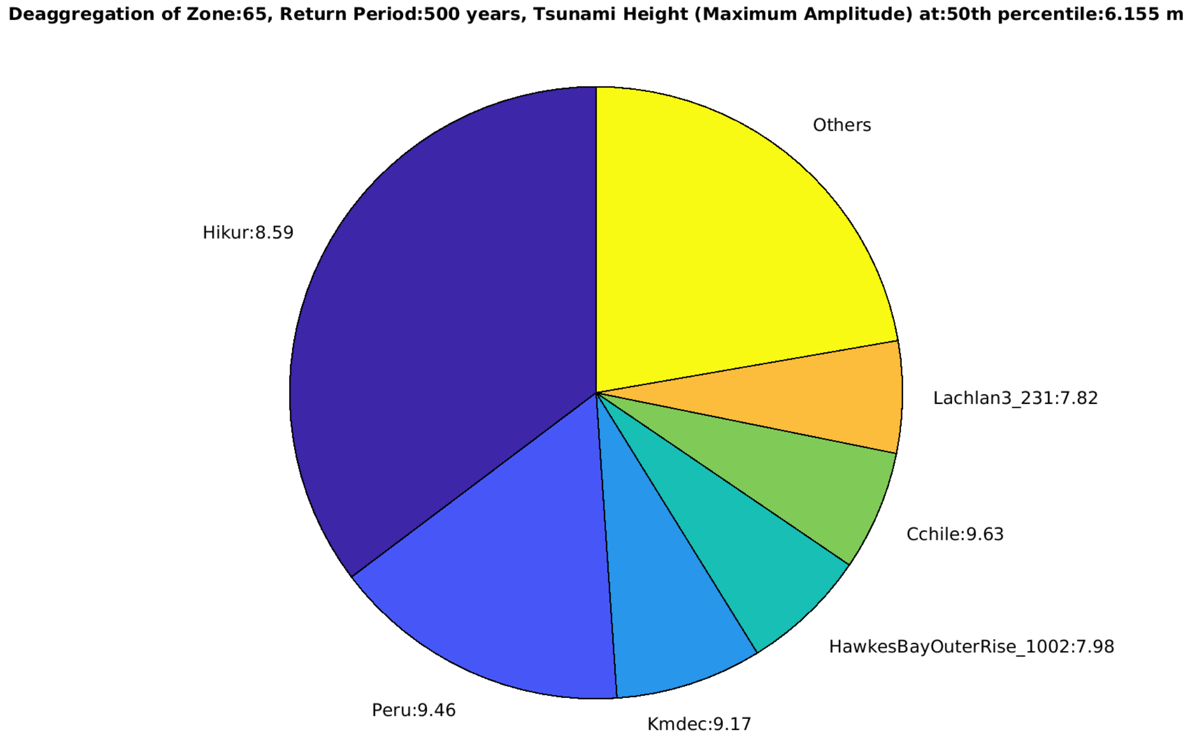


Figure 3.15 Area map and tsunami hazard curve for Gisborne.



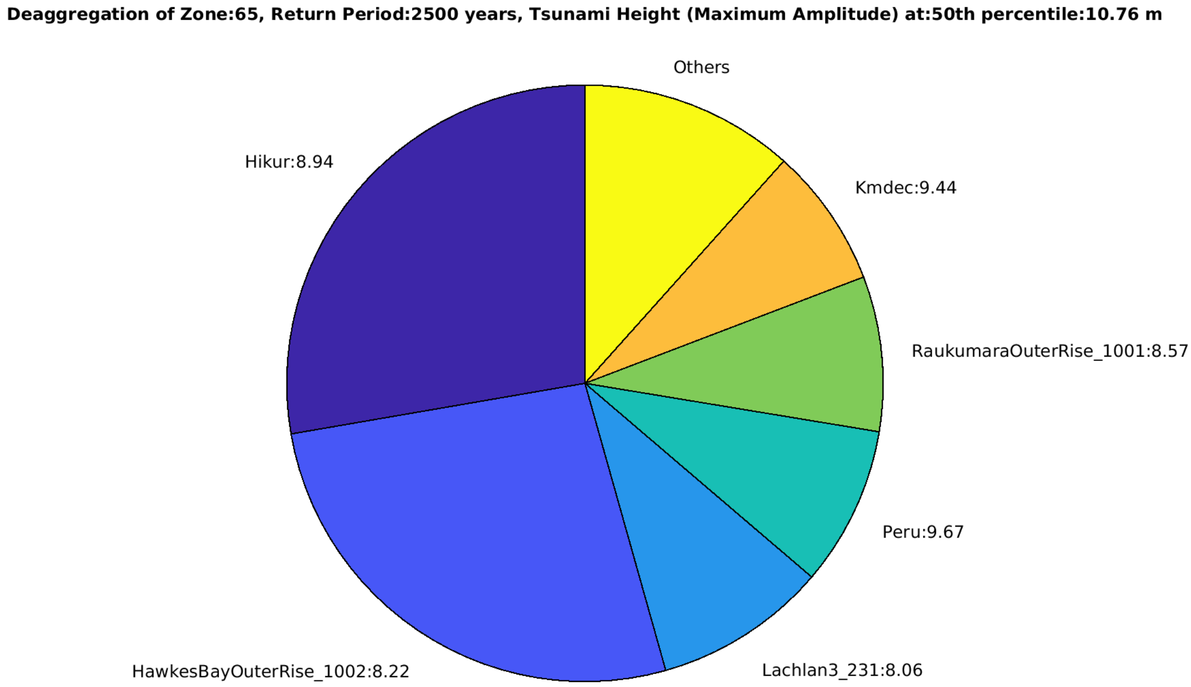


Figure 3.16 Deaggregation of tsunami sources for Gisborne at the 500-year (top) and 2500-year (bottom) return periods.

Invercargill

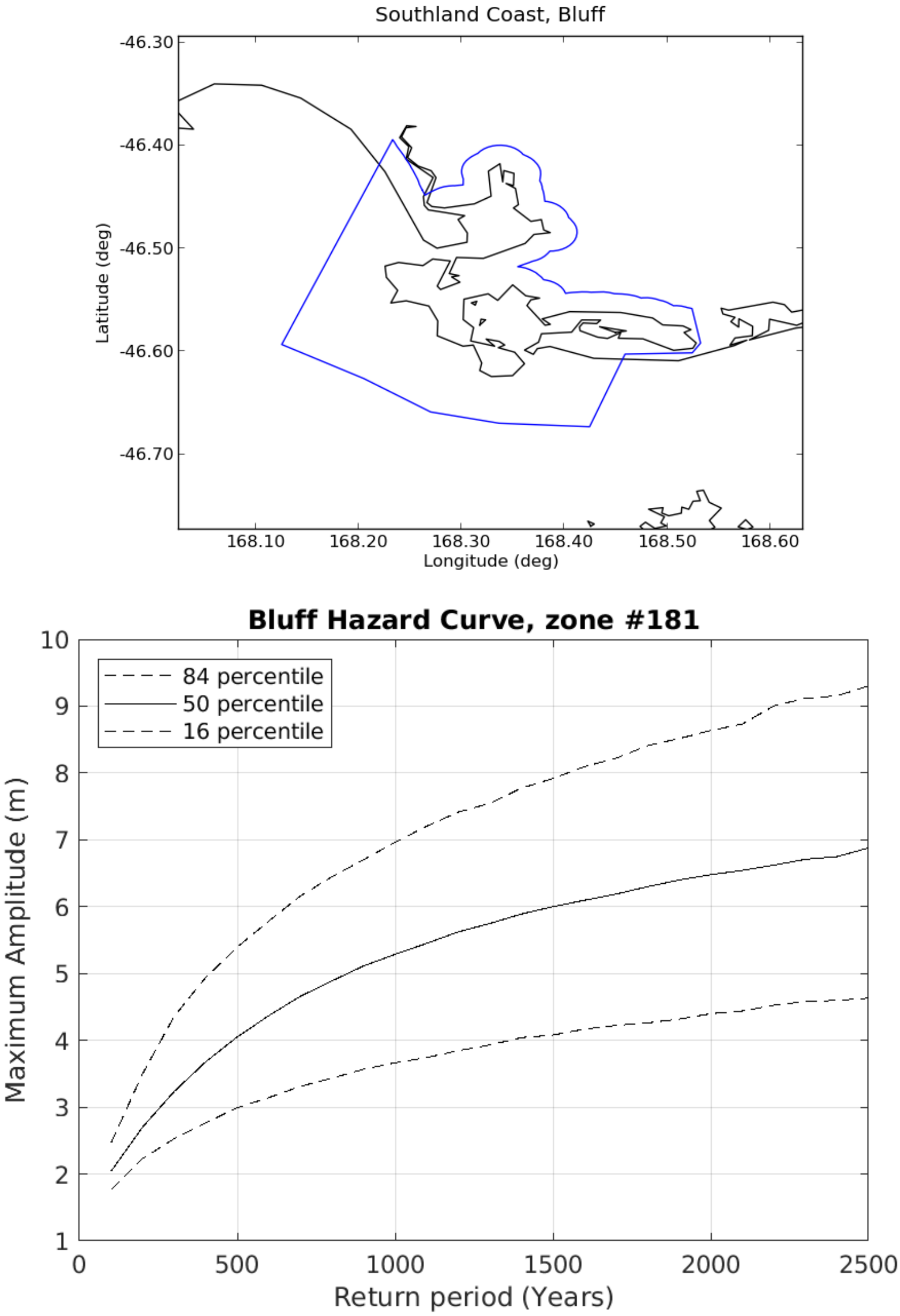


Figure 3.17 Area map and tsunami hazard curve for Invercargill.

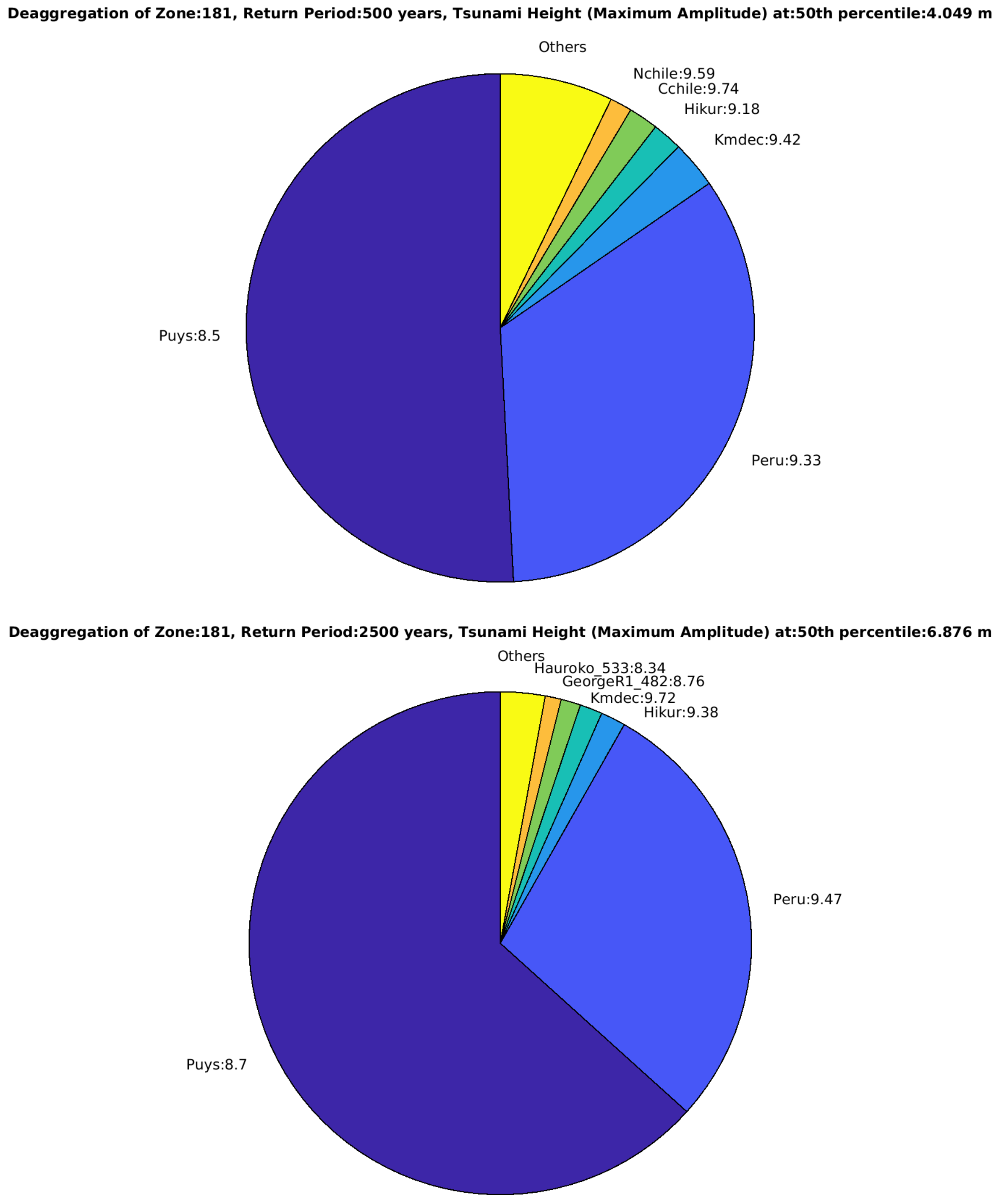


Figure 3.18 Deaggregation of tsunami sources for Invercargill at the 500-year (top) and 2500-year (bottom) return periods.

Kāpiti Coast

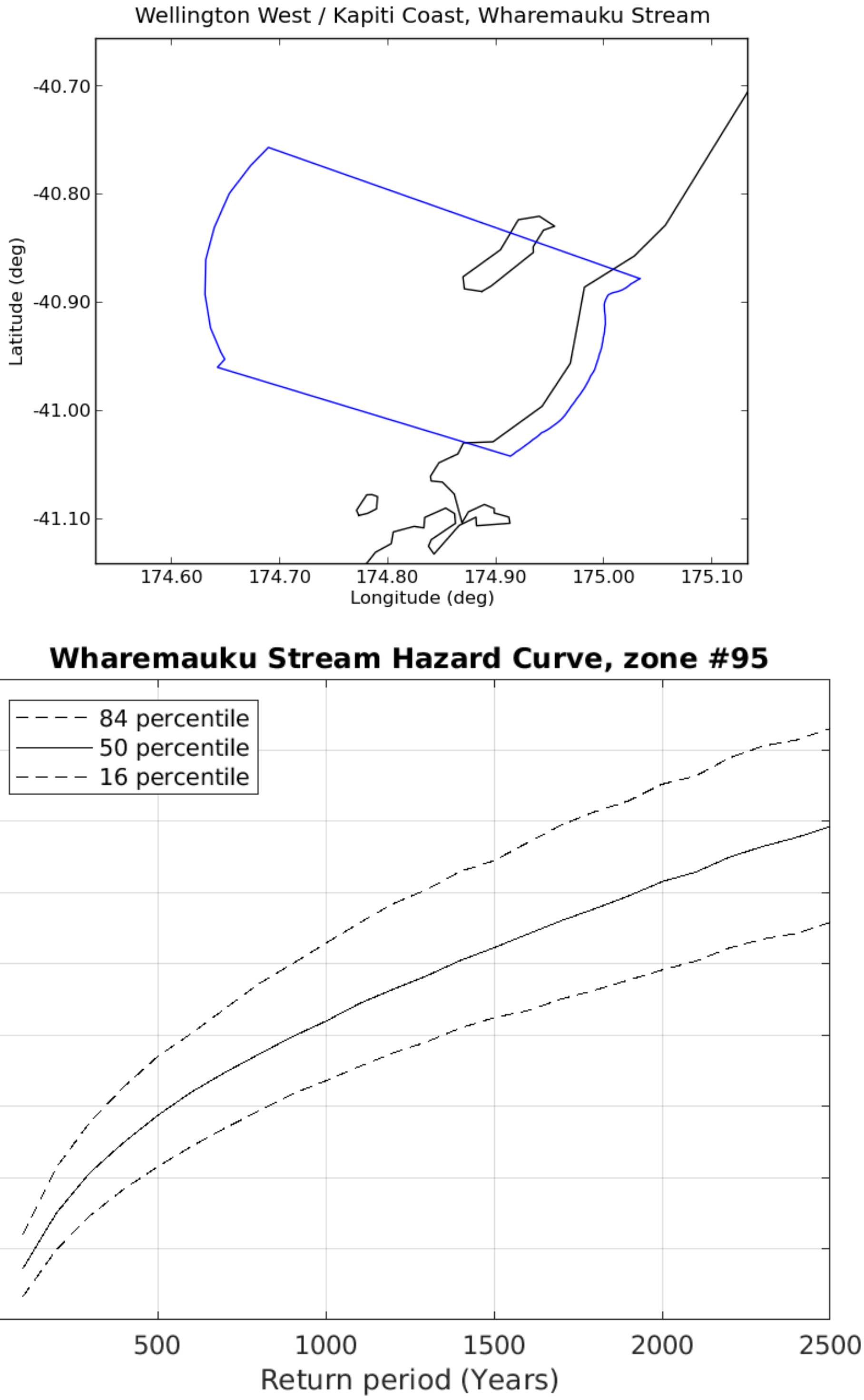


Figure 3.19 Area map and tsunami hazard curve for Kāpiti Coast.

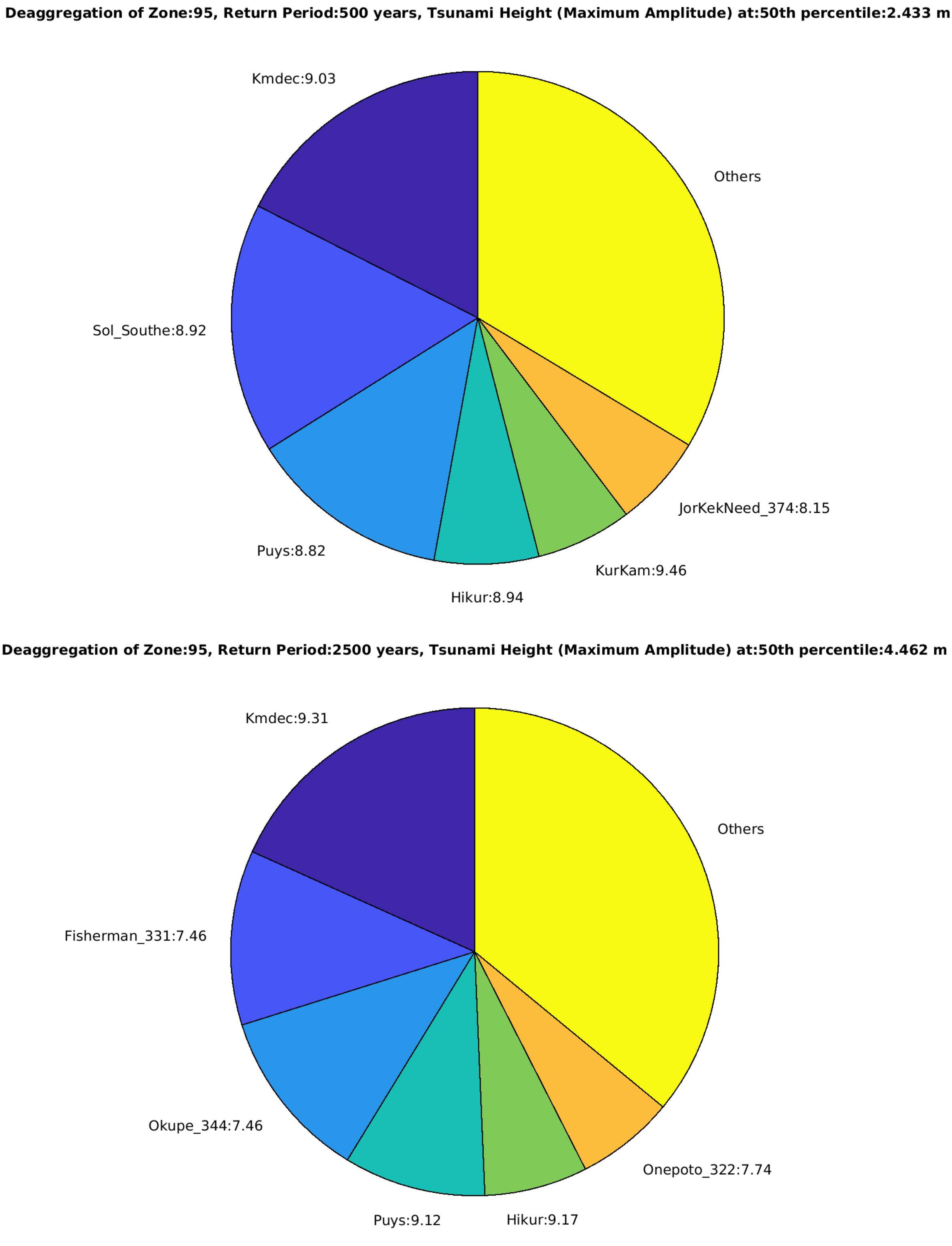


Figure 3.20 Deaggregation of tsunami sources for Kāpiti Coast at the 500-year (top) and 2500-year (bottom) return periods.

Napier

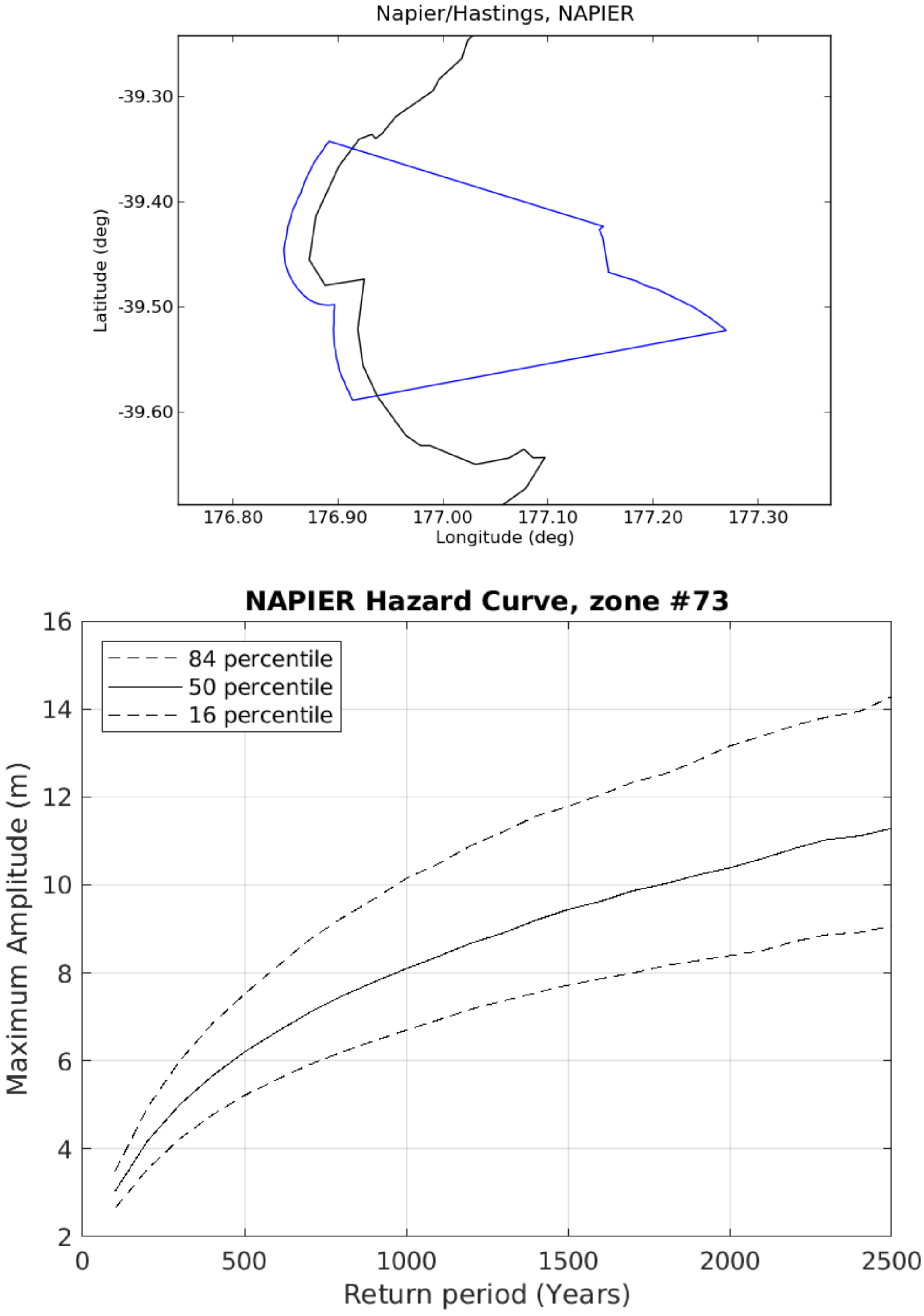
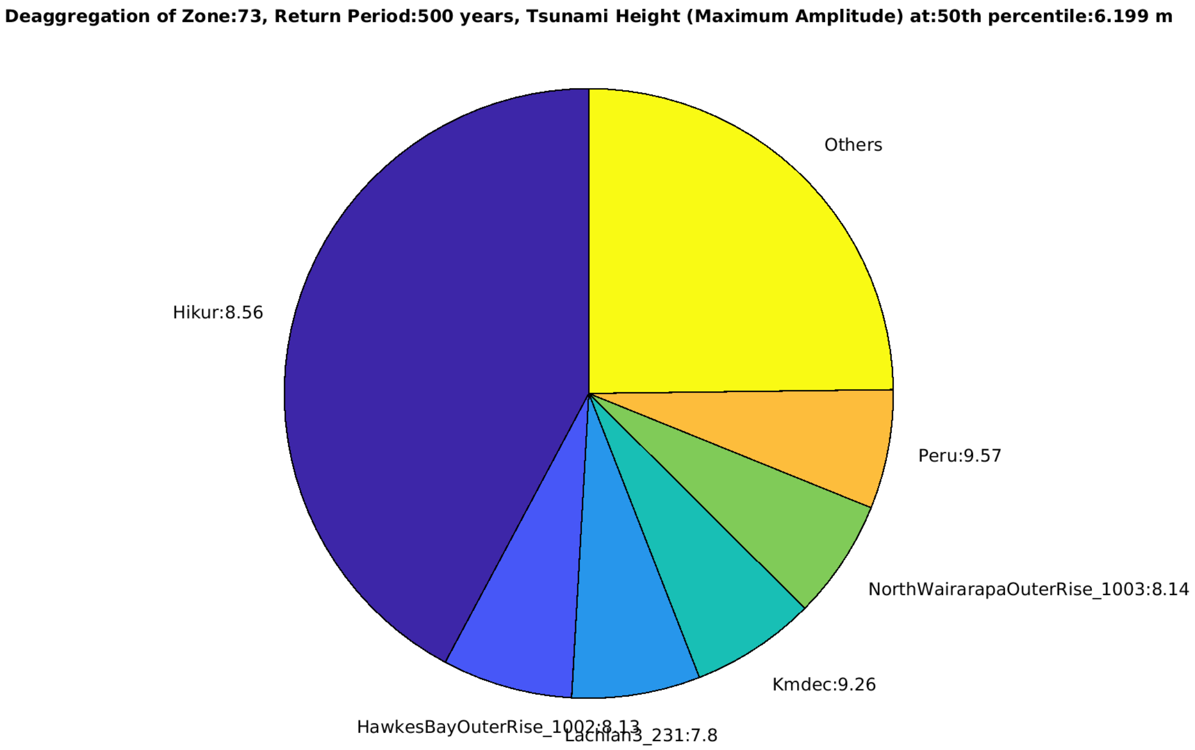


Figure 3.21 Area map and tsunami hazard curve for Napier.



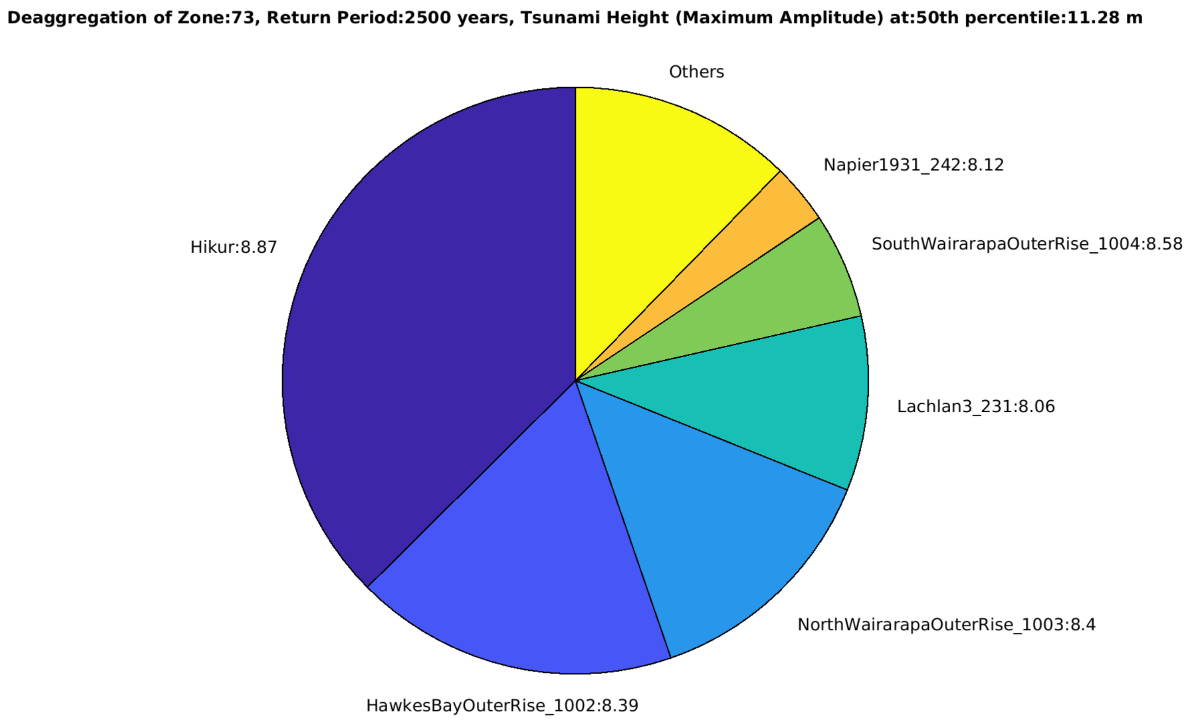
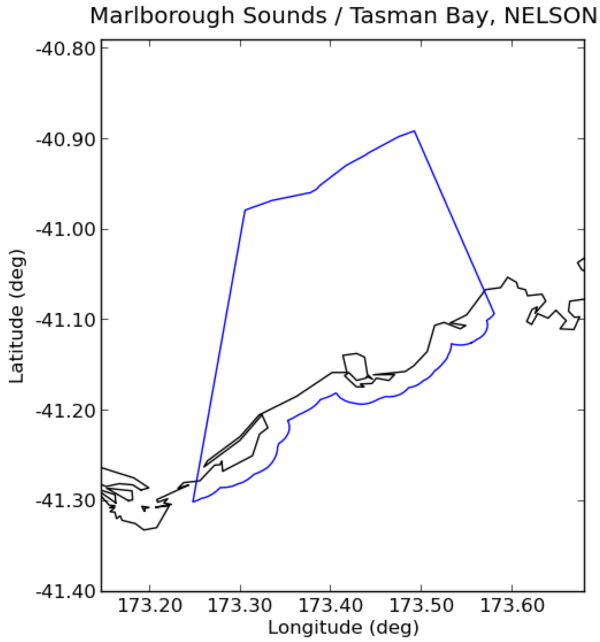


Figure 3.22 Deaggregation of tsunami sources for Napier at the 500-year (top) and 2500-year (bottom) return periods.

Nelson



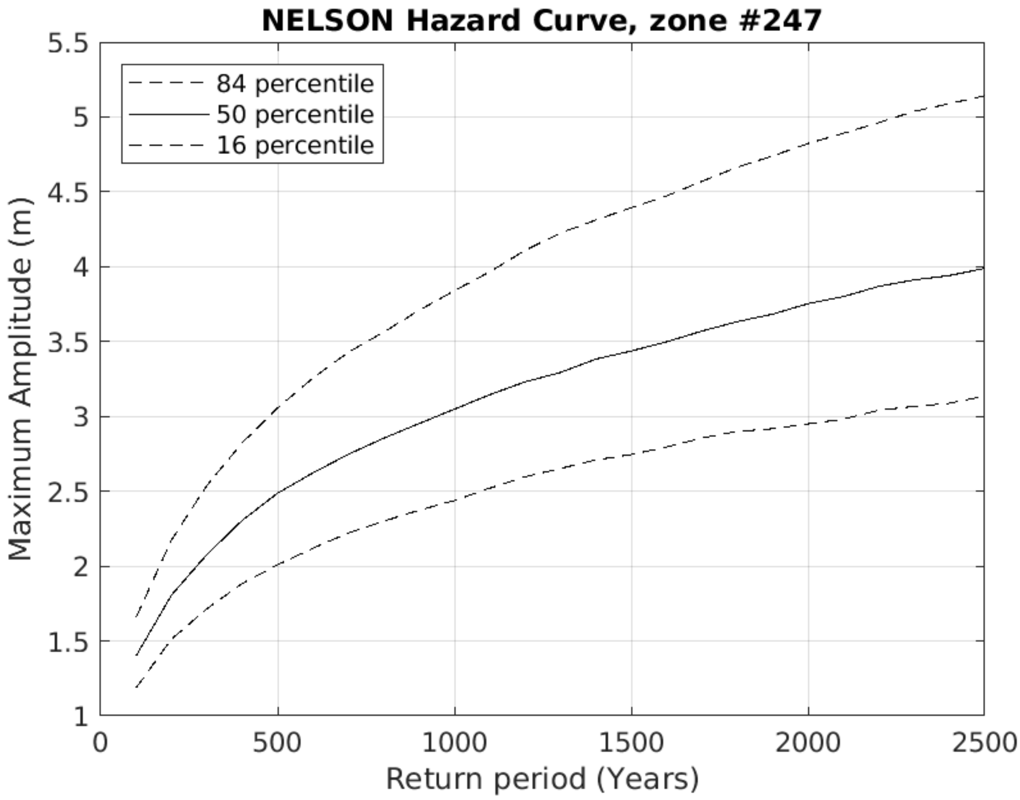


Figure 3.23 Area map and tsunami hazard curve for Nelson.

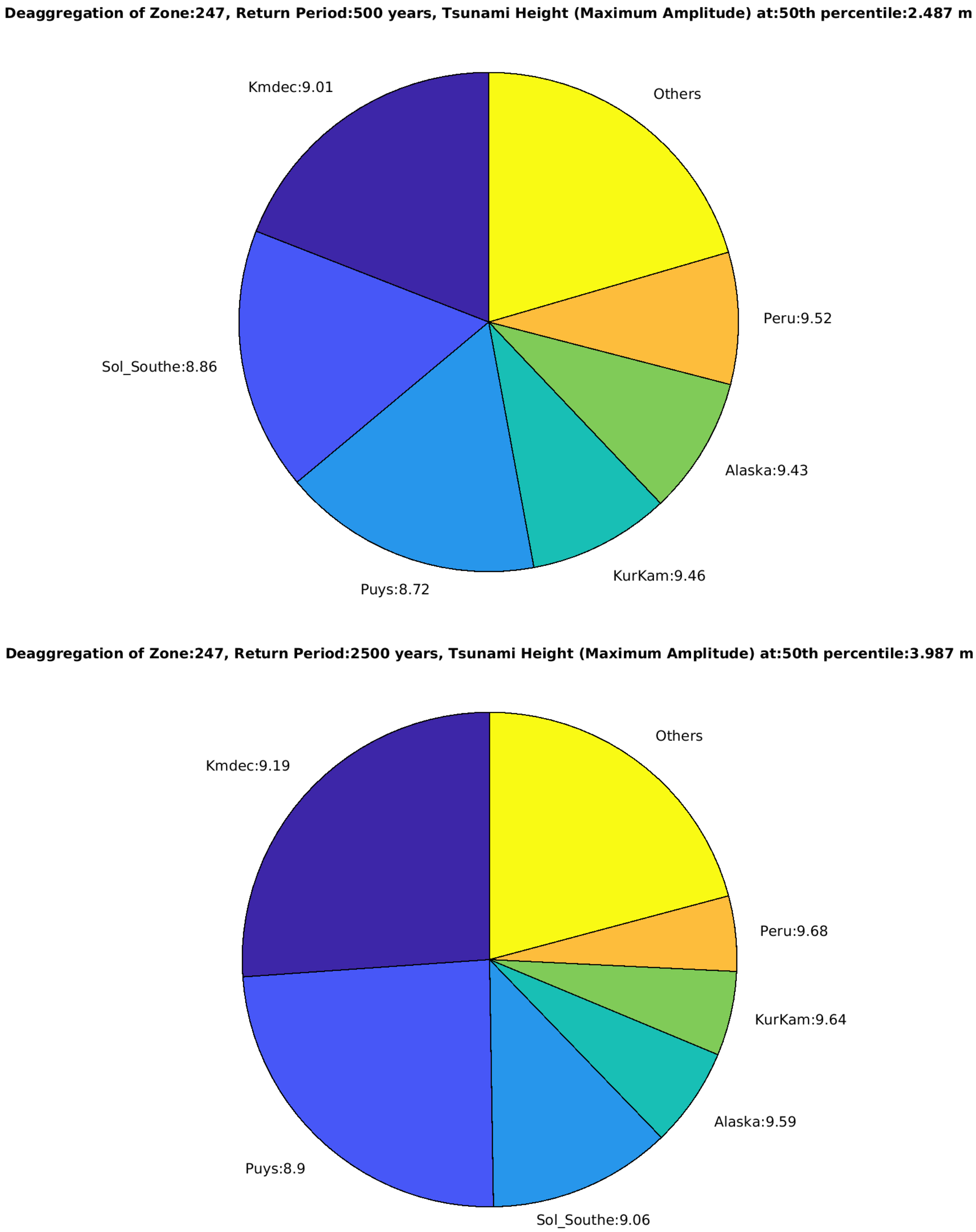
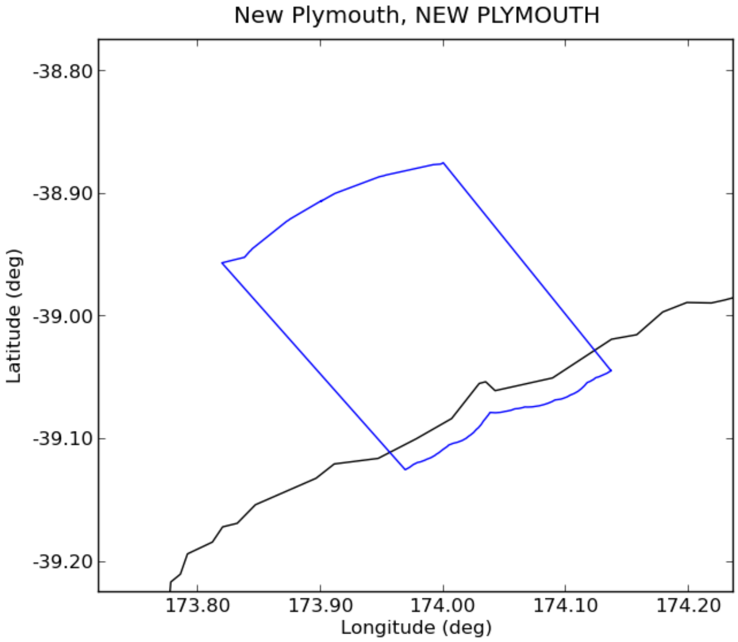


Figure 3.24 Deaggregation of tsunami sources for Nelson at the 500-year (top) and 2500-year (bottom) return periods.

New Plymouth



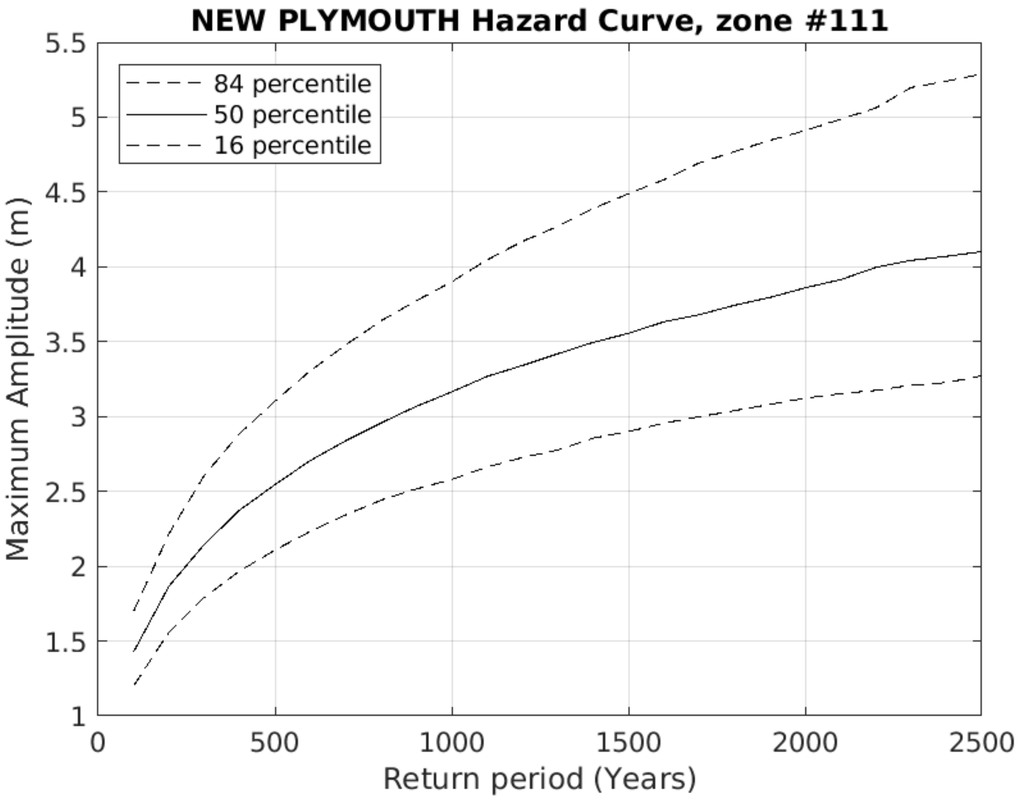


Figure 3.25 Area map and tsunami hazard curve for New Plymouth.

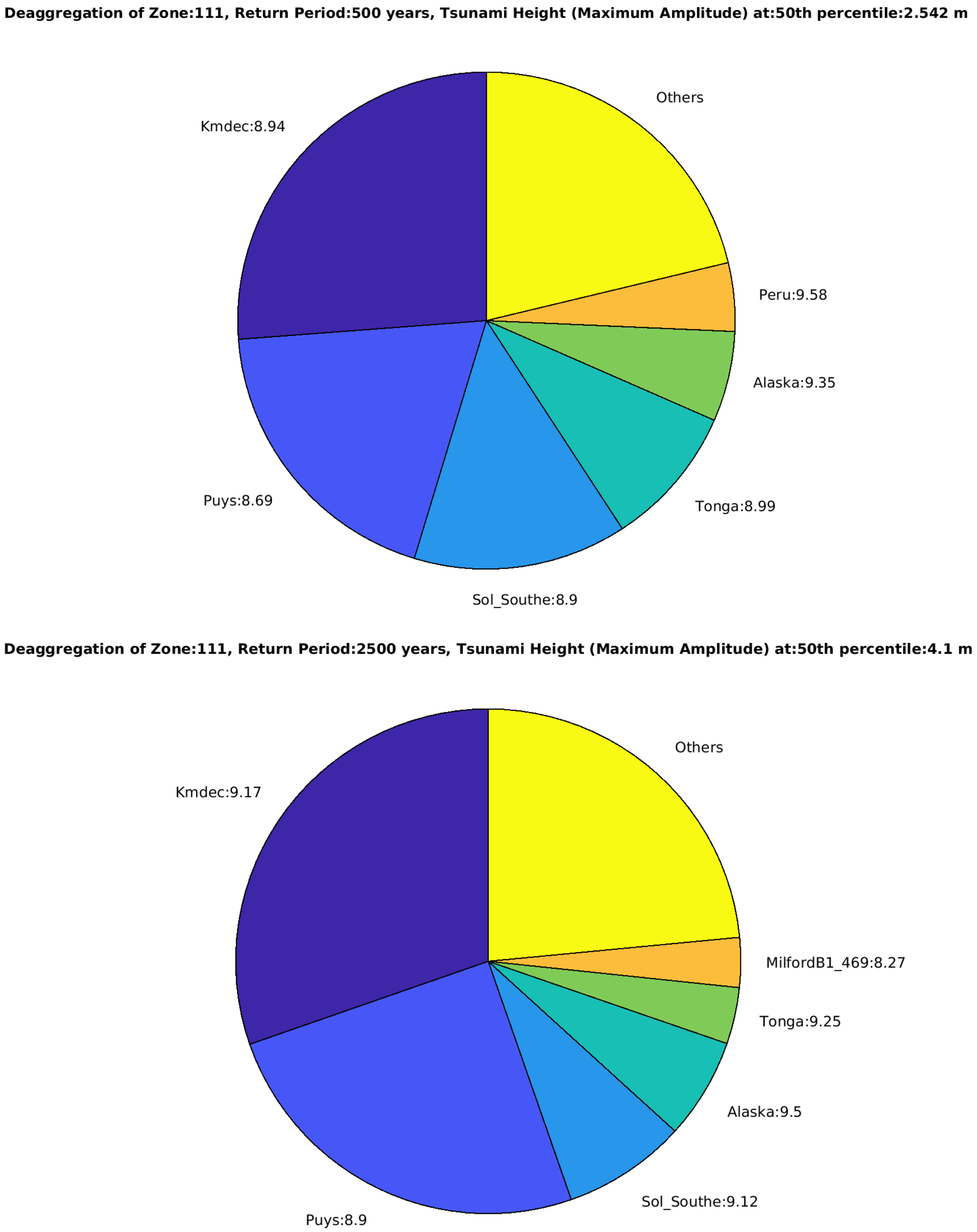
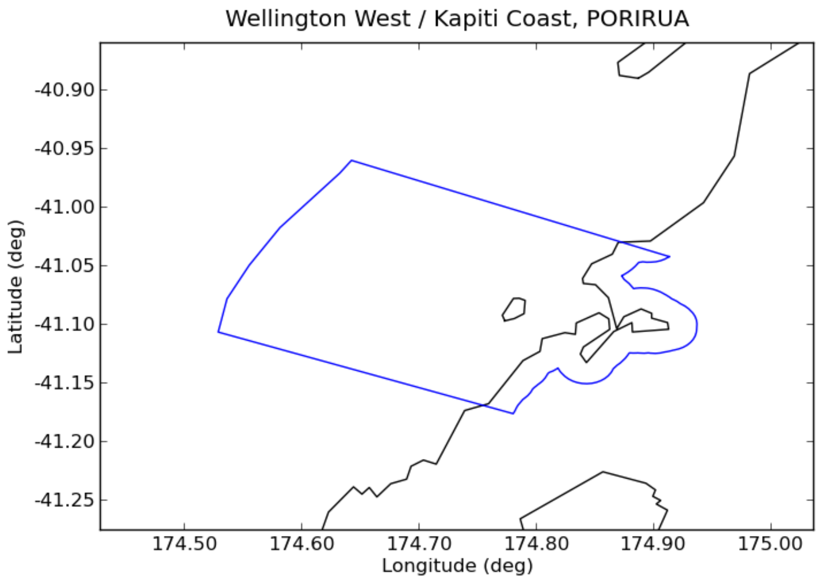


Figure 3.26 Deaggregation of tsunami sources for New Plymouth at the 500-year (top) and 2500-year (bottom) return periods.

Porirua



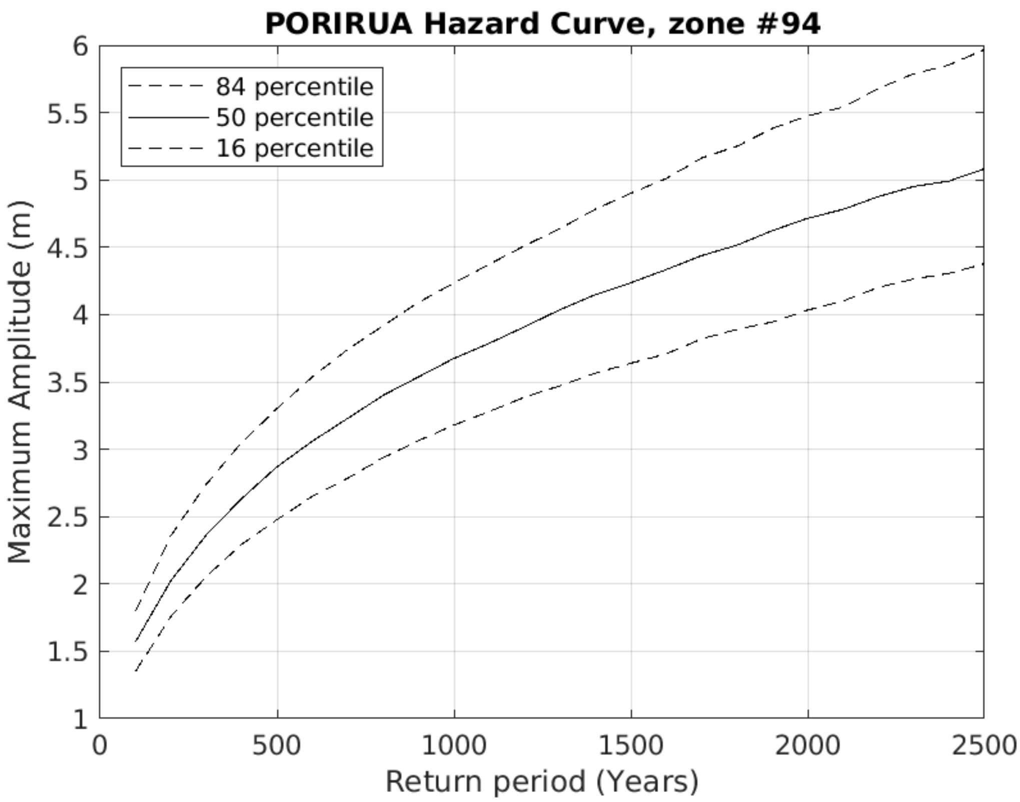


Figure 3.27 Area map and tsunami hazard curve for Porirua.

Figure 3.28 Deaggregation of tsunami sources for Porirua at the 500-year (top) and 2500-year (bottom) return periods.

Tauranga

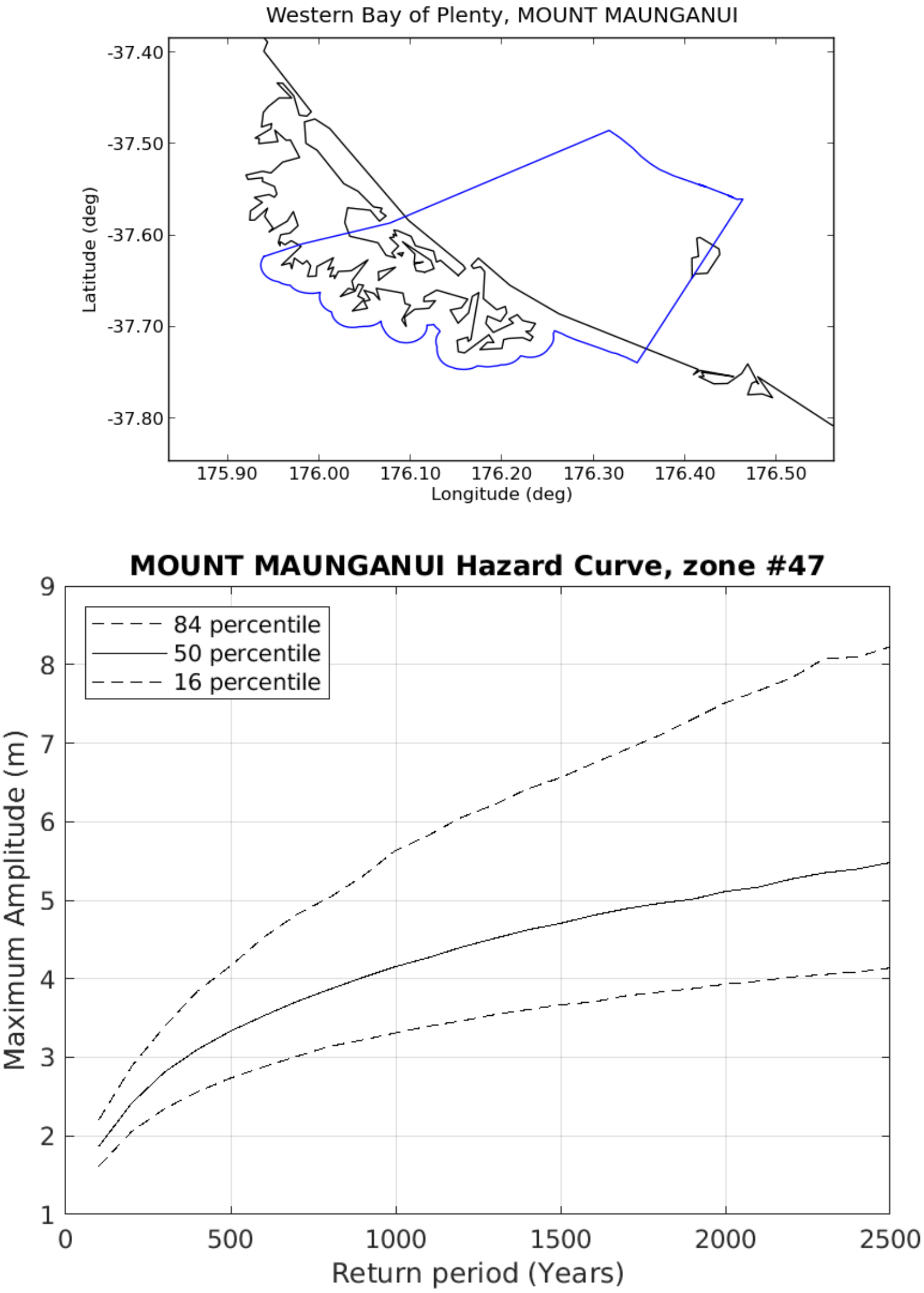
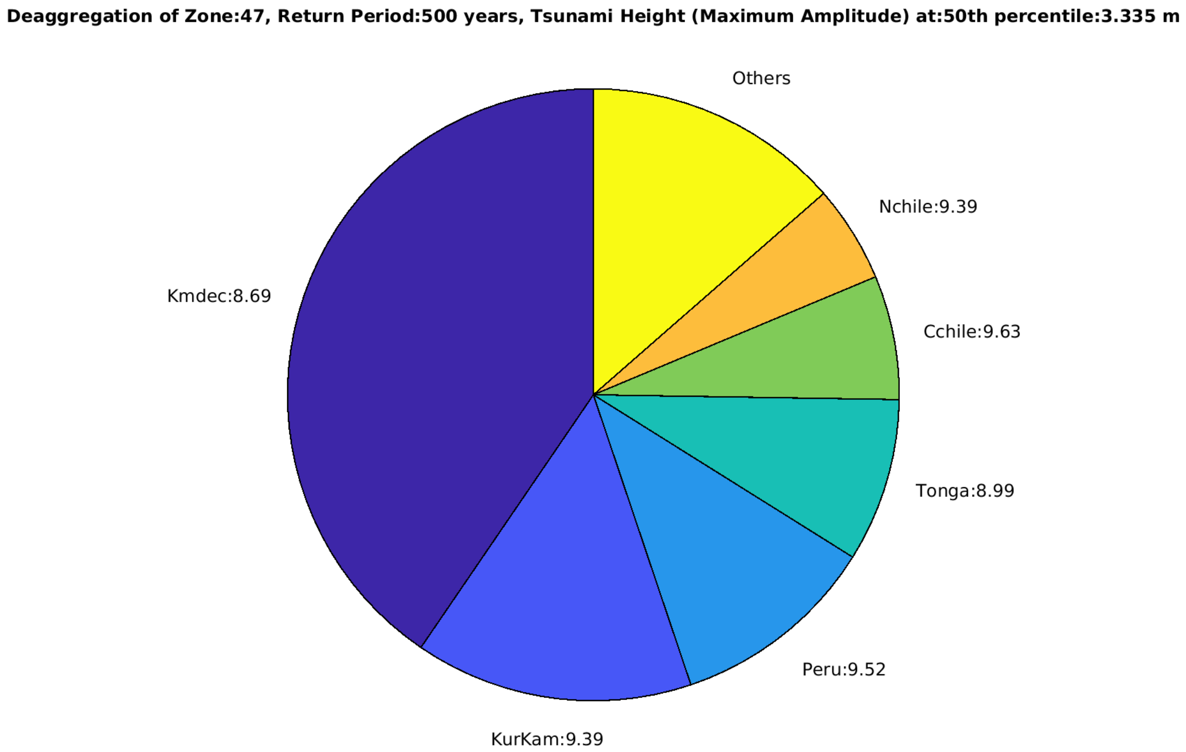


Figure 3.29 Area map and tsunami hazard curve for Tauranga.



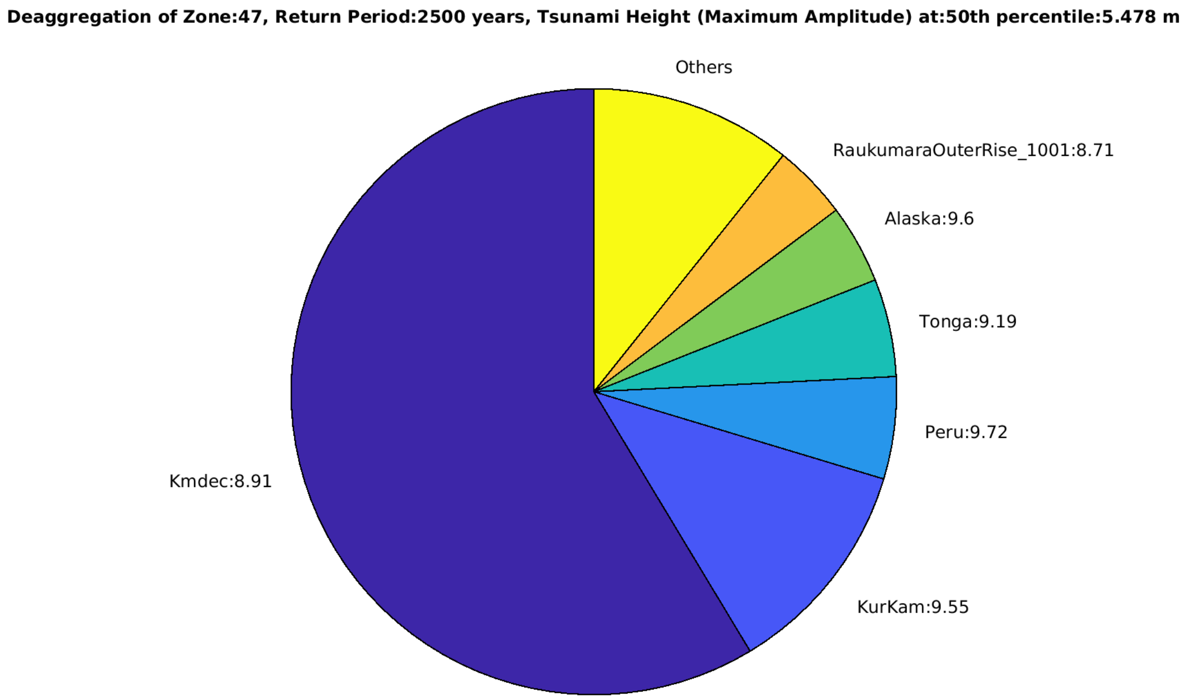


Figure 3.30 Deaggregation of tsunami sources for Tauranga at the 500-year (top) and 2500-year (bottom) return periods.

Timaru

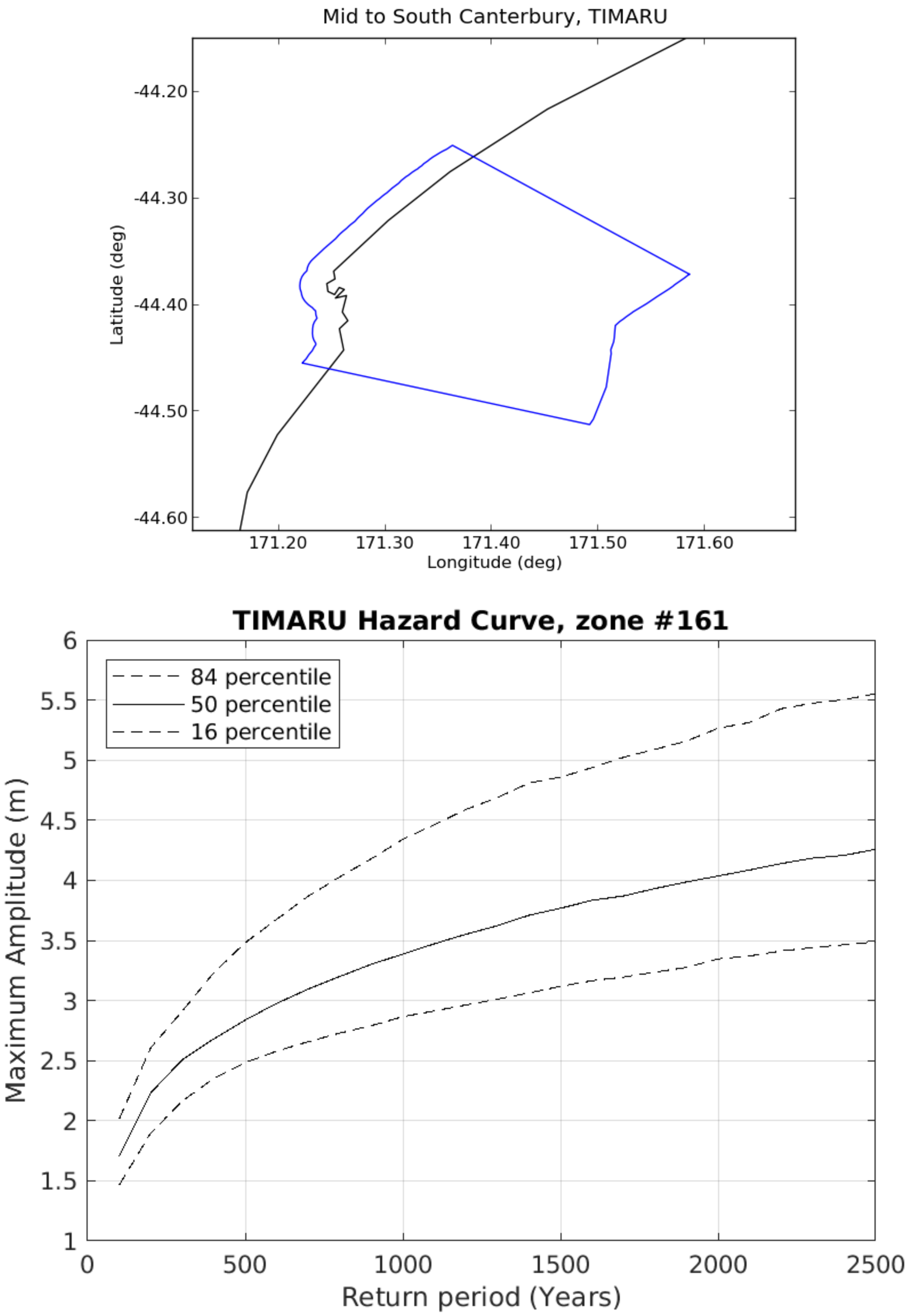


Figure 3.31 Area map and tsunami hazard curve for Timaru.

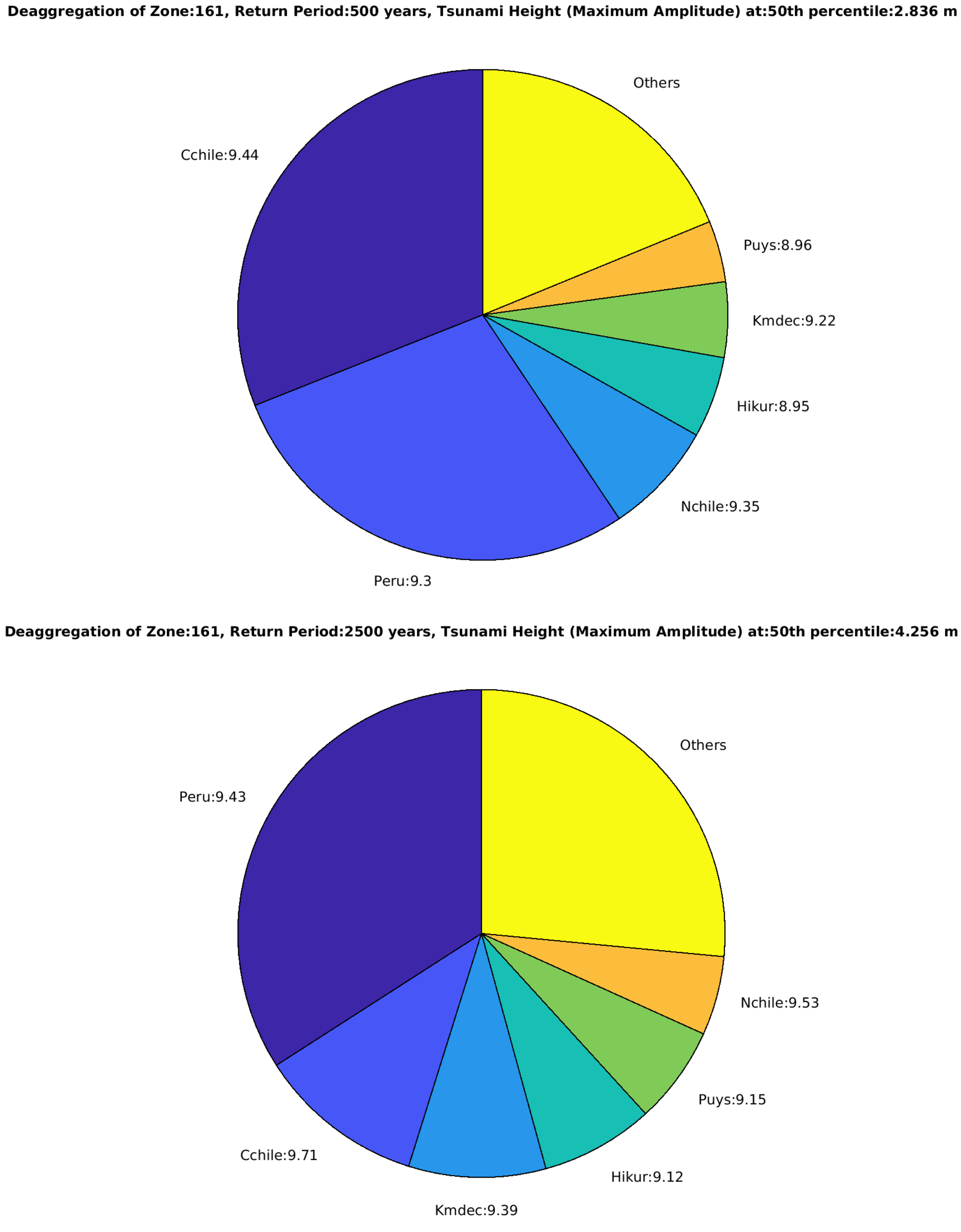
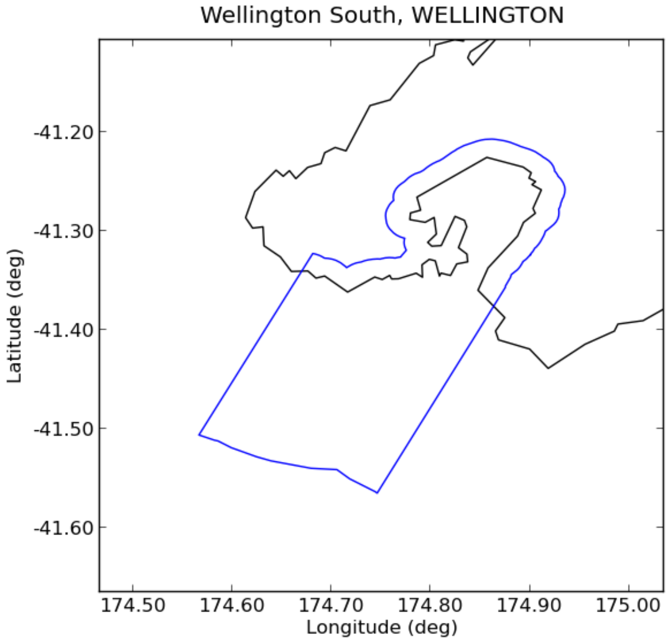


Figure 3.32 Deaggregation of tsunami sources for Timaru at the 500-year (top) and 2500-year (bottom) return periods.

Wellington



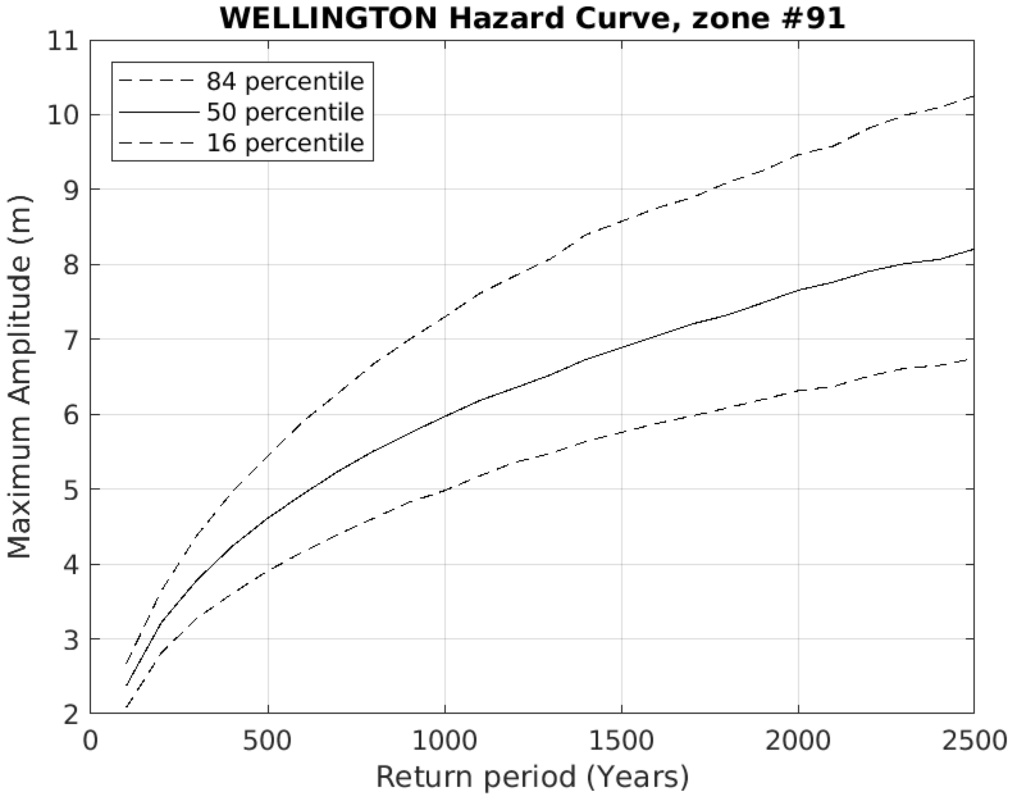


Figure 3.33 Area map and tsunami hazard curve for Wellington.

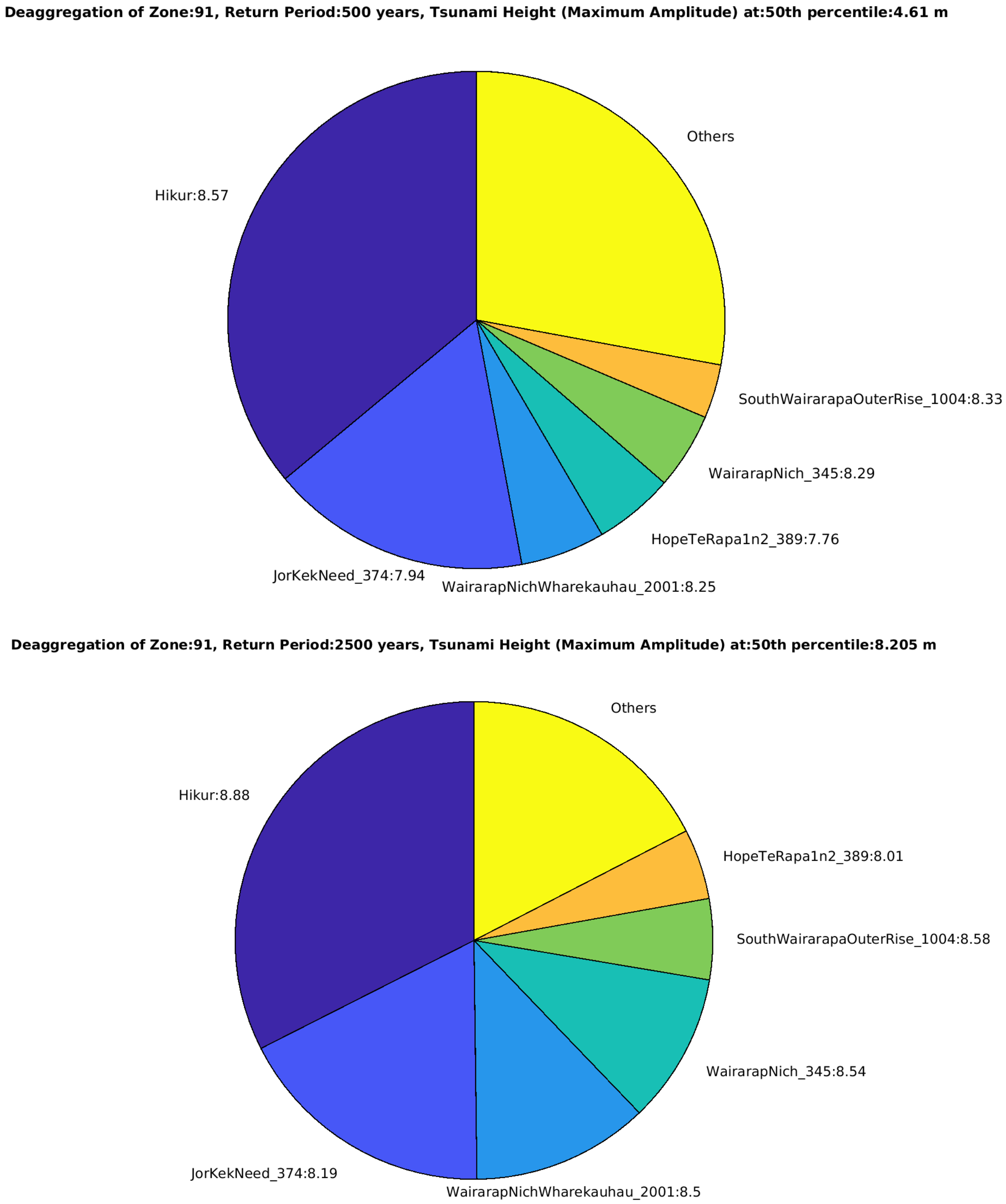


Figure 3.34 Deaggregation of tsunami sources for Wellington at the 500-year (top) and 2500-year (bottom) return periods.

Whakatāne

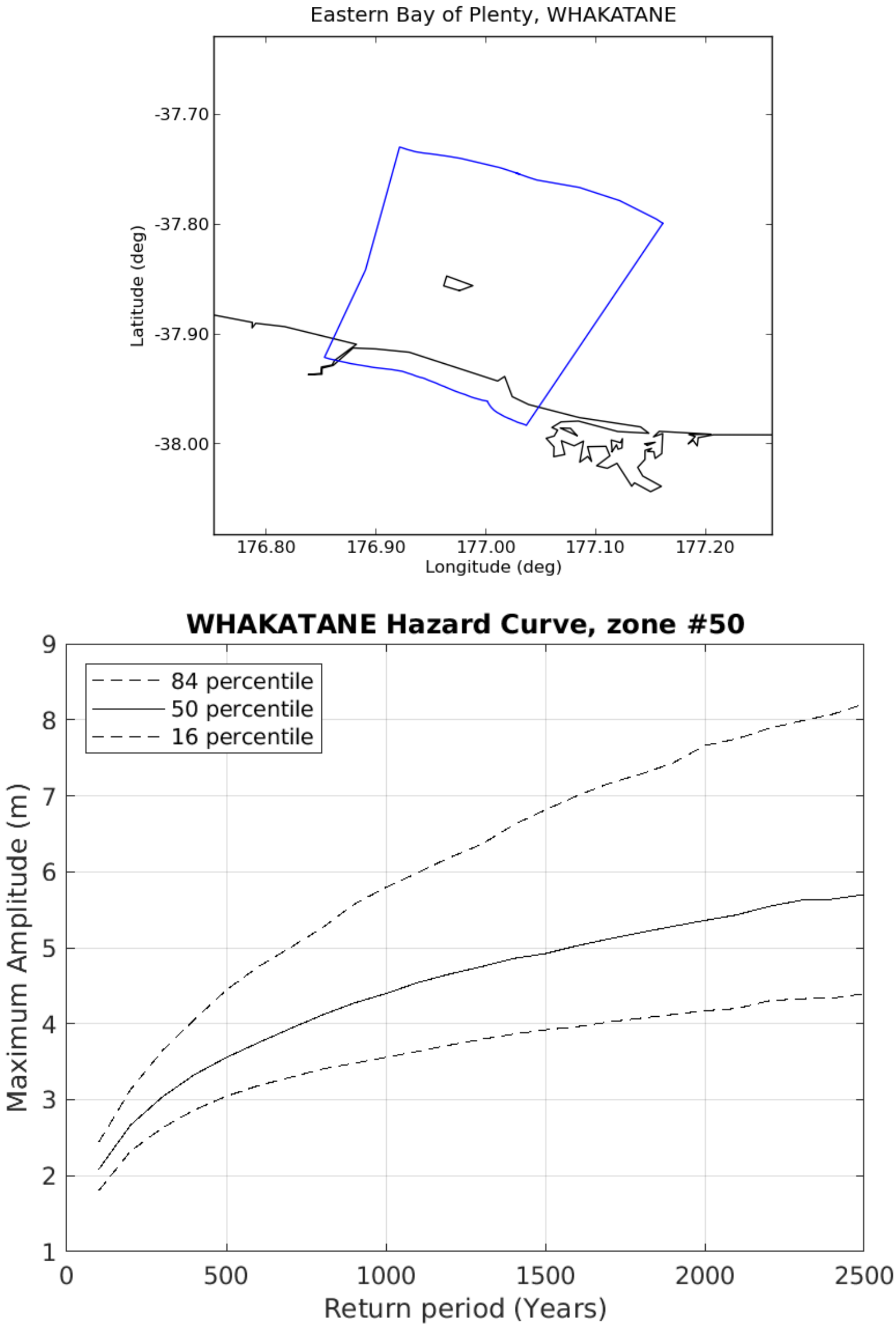
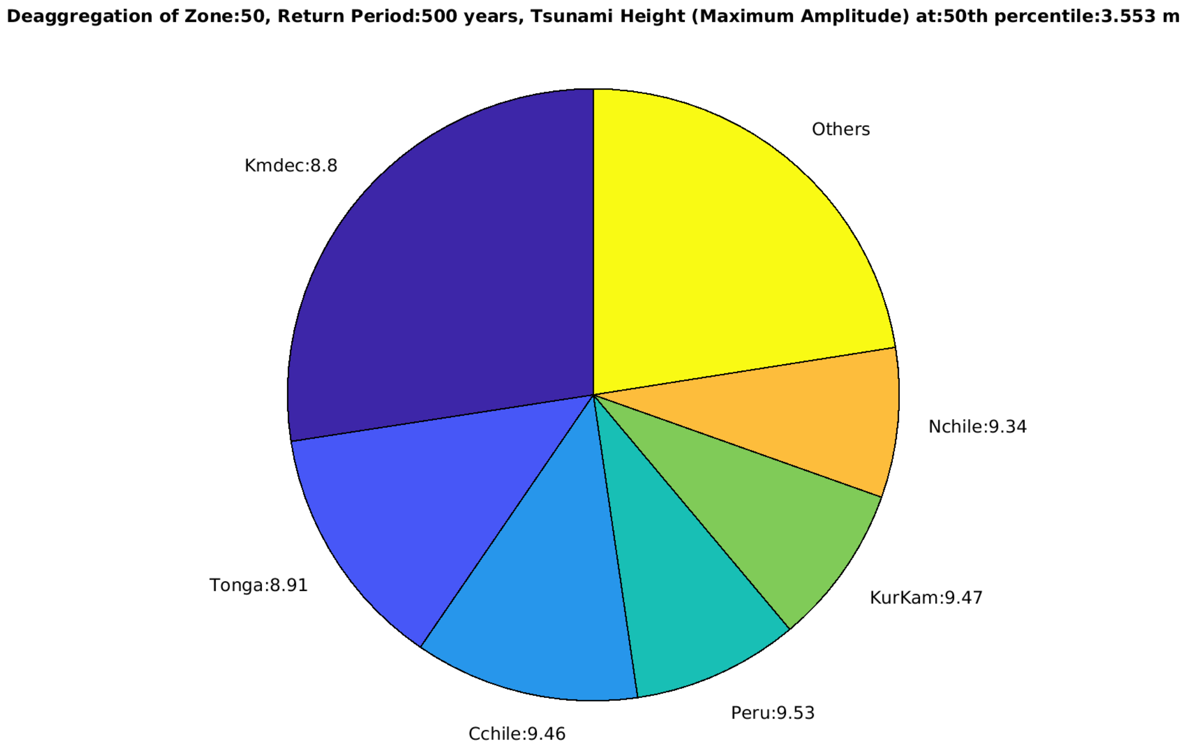


Figure 3.35 Area map and tsunami hazard curve for Whakatāne.



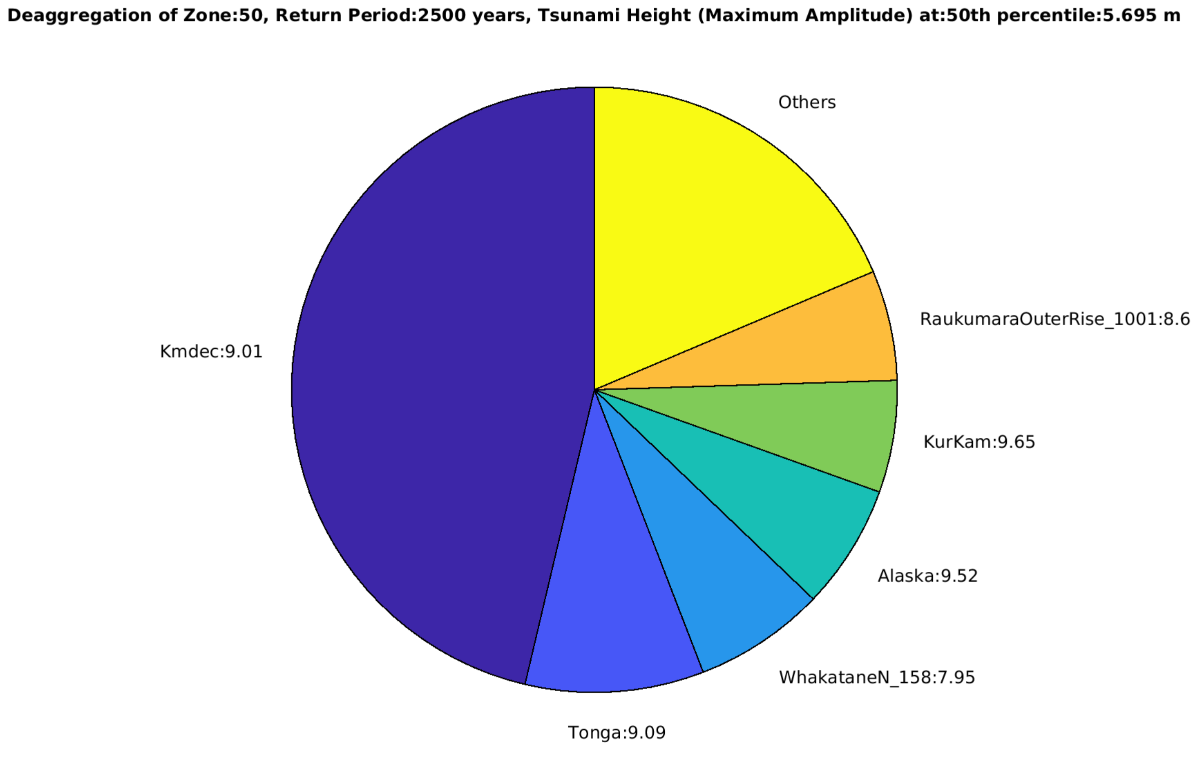


Figure 3.36 Deaggregation of tsunami sources for Whakatāne at the 500-year (top) and 2500-year (bottom) return periods.

Whangārei

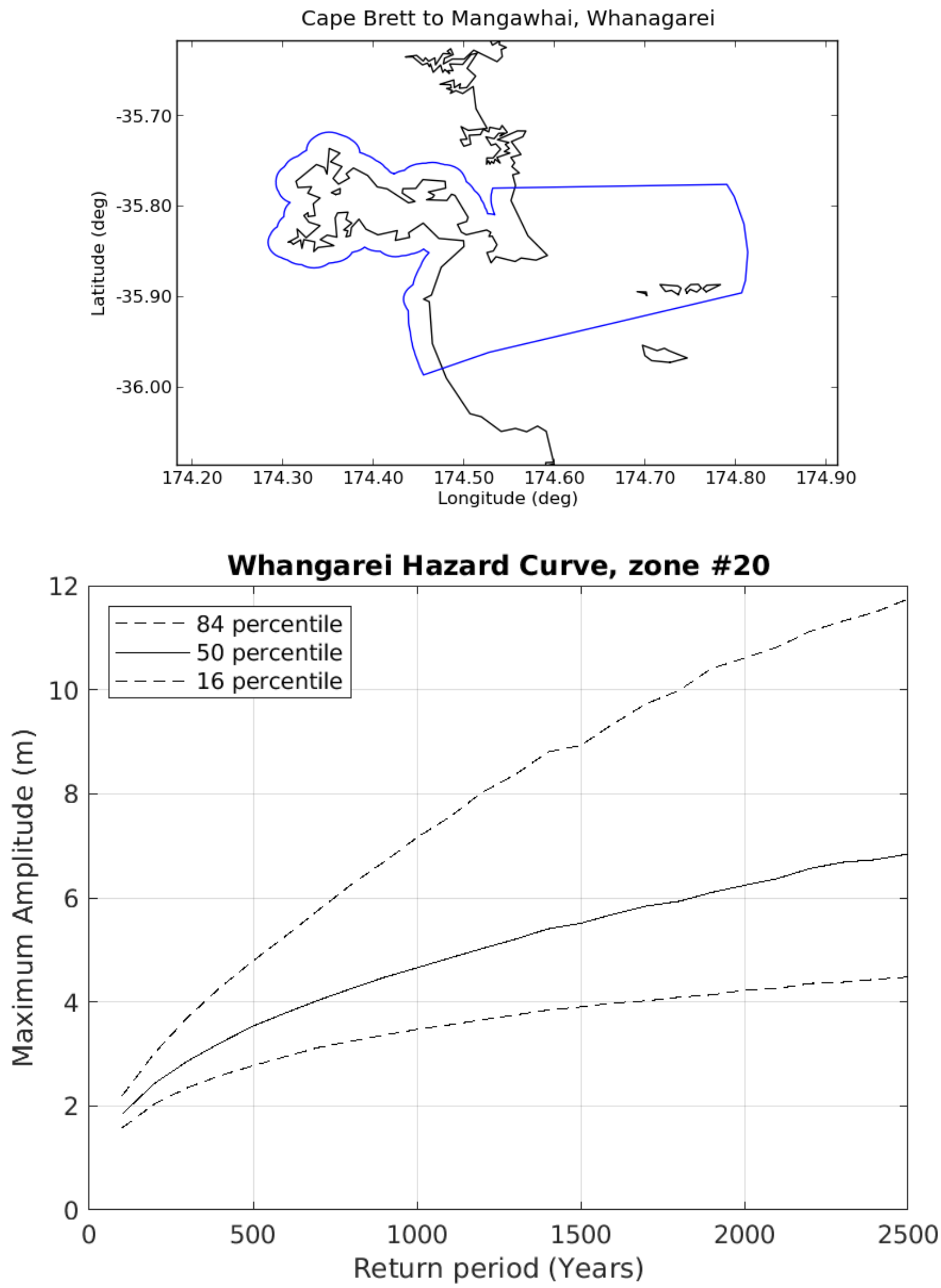
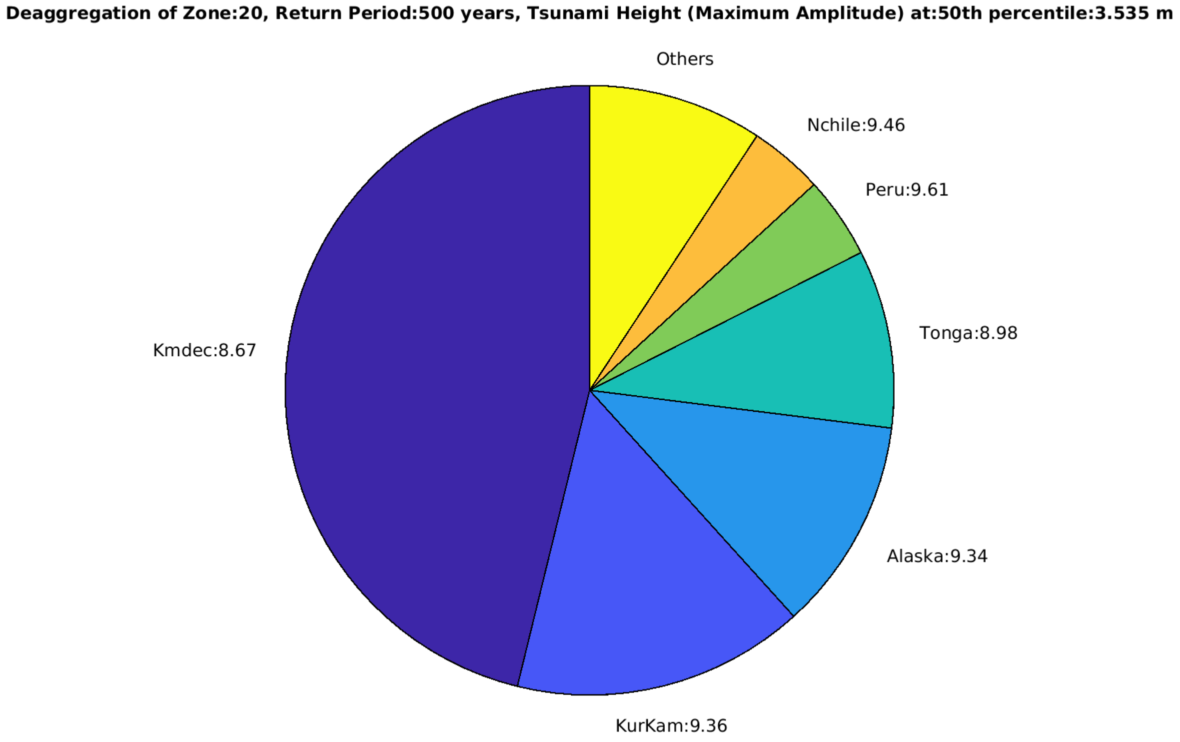


Figure 3.37 Area map and tsunami hazard curve for Whangārei.



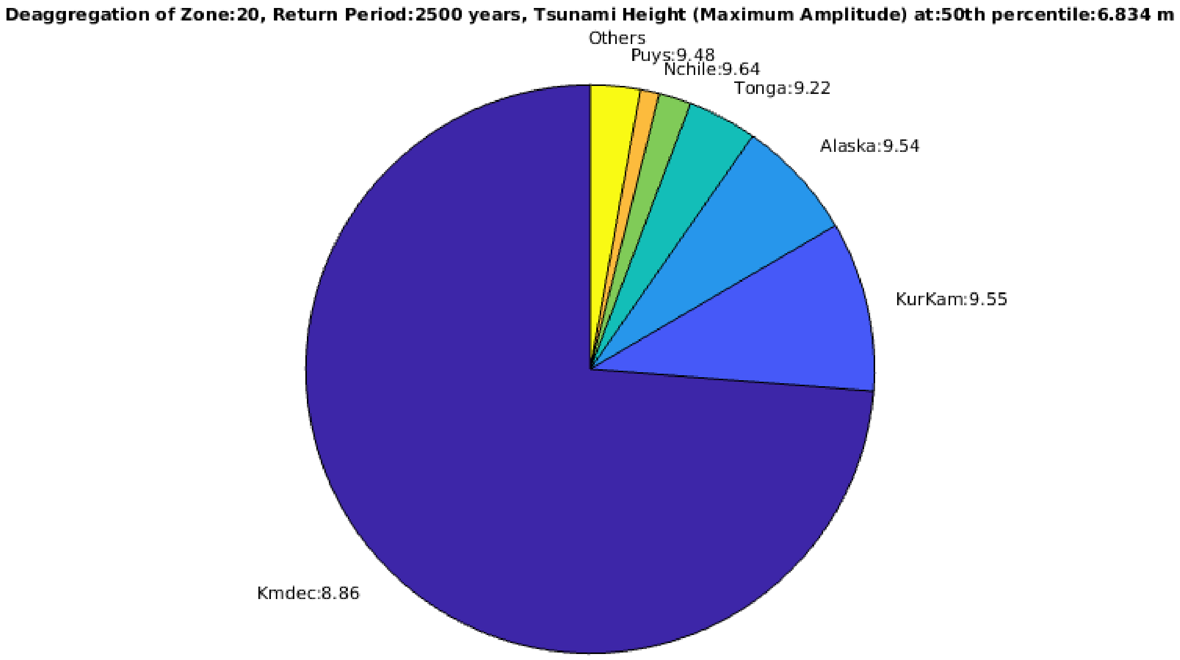


Figure 3.38 Deaggregation of tsunami sources for Whangārei at the 500-year (top) and 2500-year (bottom) return periods.

4.0 DISCUSSION AND LIMITATIONS

The 2021 updates to the NTHM should significantly improve the accuracy of the hazard estimates, primarily because of the improved accuracy with which the tsunami heights have been estimated for the events in our synthetic catalogue of earthquakes.

For the most part, the hazard estimates appear to have been revised lower, although they remain broadly consistent with our knowledge of historical and paleo-tsunami (for instance, when compared with Section 3 of Power [2013]). Where hazard curves are now lower, the modelling improvements will also lead to better selection of scenarios for deaggregation, with the net effect that estimates of inundation extents (where these have previously been made using deaggregations of the 2013 NTHM) will not necessarily decrease, as the scenarios selected by the improved deaggregation may still be able to inundate further inland when modelled from source through to inundation.

The 2021 model does show increased estimates of hazard for the east coast of the North Island at long return periods. We interpret this as being due to better estimation of tsunami heights caused by earthquakes in the subducting slab (these are also referred to as 'outer rise' earthquakes for consistency with the naming used in the 2013 study). As these faults are not at all well characterised, and not even proven to exist along the southern part of the Hikurangi margin, we see this as an important area of uncertainty in our results and would like to encourage study of the potential for large earthquakes in the slab as a research topic for the coming years.

As with the 2013 study, the 2021 probabilistic tsunami hazard model represents the best endeavours of the report authors at the time it was created. Scientific understanding of input parameters will continue to evolve, and improved methods for calculating the hazard will be developed. The programs used to perform the calculations are complicated, and programming errors may be found and corrected. Hence, the results in this report represent only a snapshot of the estimated tsunami hazard as determined at the time of its construction.

5.0 ACKNOWLEDGMENTS

We would like to acknowledge Christof Mueller and Xiaoming Wang for reviewing this report. This work has been funded by GNS Science Strategic Science Investment Fund (SSIF).

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APPENDICES

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APPENDIX 1 CRUSTAL FAULT PARAMETERS, AS USED IN THE 2021 NATIONAL TSUNAMI HAZARD MODEL

Table A1.1 Crustal fault properties. Fault Name and NZSHM_Number are as used in the National Seismic Hazard Model (Stirling et al. 2012). NZSHM_Number can be used to identify fault locations using the figures in Stirling et al. (2012). MWMN, MW, MWMX are minimum, preferred and maximum moment magnitudes. RECINTMN, RECINT and RECINTMX are minimum, preferred and maximum recurrence intervals (in years).

Fault Name	NZSHM_ NUMBER	MWMN	MW	MWMX	RECINTMN	RECINT	RECINTMX
Wairaka02	2	6.6	6.6	6.7	936	906	990
KerepehiO	3	7.2	7.2	7.3	18954	19860	22903
NgatoroS03	4	6.1	6.5	6.6	241	434	474
NgatoroS05	6	6.3	6.5	6.5	376	522	571
Ohena04	7	5.9	6.5	6.5	202	499	546
Ohena02	8	6.7	6.8	6.9	530	653	714
Ohena03	9	6.2	6.5	6.6	307	518	567
Wairaka05	13	6.4	6.8	6.9	626	1173	1283
AldermanE06	17	6.3	6.5	6.6	2177	2859	3014
Astrolabe07	24	6	6.7	6.8	234	693	730
Ohena01	27	6	6.6	6.6	1243	3467	3791
OtaraEast03	28	6.5	6.7	6.8	708	1026	1121
Astrolabe05	31	6.2	6.7	6.8	292	687	724
TaurTrE03	32	6	6.5	6.6	251	562	614
TaurTrE02	37	6.2	6.7	6.7	246	530	580
TuhuaN03	38	6.2	6.4	6.5	1277	1745	1840
TaurTrE01	40	6.2	6.5	6.6	238	388	424
OtaraEast04	41	6.4	6.4	6.5	853	825	902
AldermanW01	43	6.1	6.5	6.5	5960	10967	11563
Tuakana11	48	6.1	6.4	6.5	536	860	941
AldermanE02	49	6.1	6.4	6.5	1905	2996	3159
Tuakana10	54	6.1	6.6	6.6	514	1034	1131
TuhuaN01	55	6.3	6.6	6.7	1282	2162	2279
Wairaka01	56	6.6	6.6	6.7	3769	3647	3987
Tuakana05	58	6	6.7	6.7	381	1302	1423
OtaraEast02	61	6.4	6.4	6.5	317	307	336
Astrolabe02	62	6.1	6.7	6.7	795	1786	1884
OtaraWest02	68	5.9	6.6	6.6	188	517	565
AldermanE07	69	6.1	6.5	6.6	1890	4122	5704
Matatara04	72	6.1	6.8	6.8	892	2766	3025
Astrolabe01	73	6.1	6.6	6.6	941	2027	2138

Fault Name	NZSHM_ NUMBER	MWMN	MW	MWMX	RECINTMN	RECINT	RECINTMX
MaungatiW02	74	6	6.5	6.5	646	1346	1471
Tuakana04	76	6.1	6.5	6.6	720	1547	1692
TuhuaS02	77	6.1	6.4	6.5	2072	3473	3662
Tuakana03	78	6.2	6.5	6.5	924	1310	1433
MaungatiW01	80	6.6	6.6	6.7	518	714	978
Tuakana02	81	6.3	6.6	6.7	754	1209	1321
WhiteIsN01	82	6.5	6.5	6.6	9182	8884	9714
Volkner04	86	6.1	6.7	6.7	124	351	384
Matatara03	87	6.1	6.5	6.6	520	992	1084
TeArawa03	88	6.4	6.4	6.5	222	268	367
Volkner03	96	6.1	6.5	6.6	230	459	502
Tauranga05	98	6.1	6.6	6.7	491	1123	1227
Tumokemoke02	99	6.4	6.5	6.5	773	842	921
Maketu02	106	5.9	6.5	6.6	592	1756	2286
Okurei02	107	6	6.7	6.7	1895	5466	5586
Tumokemoke01	108	6.2	6.5	6.6	527	886	969
Maketu03	110	6.1	6.4	6.5	2805	4335	4430
Okurei01	112	6.5	6.6	6.7	2361	2868	2932
Volkner01	113	6.6	6.6	6.6	865	837	915
Tauranga03	114	6.3	6.6	6.6	718	1000	1006
Maketu01	120	6.4	6.4	6.5	1284	1285	1318
Pokare02	126	6.1	6.5	6.6	473	1207	1881
Nukuhou01	127	6.1	6.5	6.5	649	1104	1056
RaukumaraF22	129	7	7.2	7.3	24445	27161	59754
Tarawera05	130	6	6.5	6.6	785	1865	1911
Ohae01	135	6.9	7	7.1	19760	26347	43472
Opotiki03	136	6.6	7	7.1	2582	7773	25650
Tarawera03	137	6.2	6.5	6.6	1434	2351	2410
Moutoki02	139	6.3	6.6	6.6	1681	2571	3163
Tokata01	140	6	6.4	6.5	418	1014	1974
Pokare01	145	6	6.6	6.6	445	1273	1984
WhiteIs01	146	6.6	6.7	6.8	602	879	1262
Tarawera01	147	6.3	6.5	6.6	975	1314	1346
Moutoki01	149	6.2	6.6	6.6	1413	2589	3184
Wkm-1	150	6.6	6.6	6.7	423	454	766
Ohae02	151	6.8	6.9	7	16892	22522	37162
RaukumaraF15	155	6.9	7	7.2	9500	10000	10500

Fault Name	NZSHM_ NUMBER	MWMN	MW	MWMX	RECINTMN	RECINT	RECINTMX
WhakataneN	158	7.4	7.5	7.6	1516	2374	4420
Opotiki02	161	5.9	6.5	6.6	810	3372	11127
Urewera3	162	7.2	7.3	7.4	4925	7661	14045
Matata	163	6.6	6.7	6.8	497	812	829
RaukumaraF13	164	6.7	6.8	7	3134	3482	19152
Waikaremoana	165	7.4	7.5	7.6	6716	10446	19152
WaimanaN	166	7.4	7.5	7.6	6805	10586	19407
Houtunui	175	7.1	7.2	7.4	1671	2786	6129
RuatoriaS2	180	6.7	7	7.2	1003	1857	6129
RuatoriaS1	182	7	7.3	7.5	1805	3343	11031
ArielBank	202	7.3	7.4	7.6	449	723	1087
GableEnd	206	7.1	7.2	7.4	386	763	1502
ArielNorth	207	6.7	6.8	7	766	1641	4304
TuriN	208	6.7	6.8	6.8	3698	3154	10518
TuriC	224	6.8	6.8	6.9	4189	3573	11913
PovertyBay	225	6.4	6.5	6.7	150	358	1408
ArielEast	227	6.4	6.6	6.8	334	716	1878
TuaheniR	228	6.2	6.5	6.7	710	1184	2605
TuriS	230	6.7	6.8	6.8	3698	3154	10518
Lachlan3	231	7.3	7.5	7.7	665	1068	2114
ParituW	238	6.2	6.5	6.7	710	1184	2605
HawkeBay4	241	6.5	6.6	6.8	2037	3018	9959
Napier1931	242	7.4	7.6	7.7	1692	2821	6205
HawkeBay7	245	6.4	6.5	6.7	3761	8357	9193
ParituR	247	6.6	6.9	7.1	815	1358	2988
HawkeBay5&11	248	6.5	6.7	6.9	2350	3482	5746
Mahia2	249	6.5	6.7	6.9	1985	3308	7278
HawkeBay6&12	250	6.4	6.6	6.7	3761	8357	9193
RitchieR	257	6.9	7.1	7.3	1429	2646	8733
HawkeBay1	258	6.6	6.7	6.9	1332	2368	6512
HawkeBay2	260	7	7.1	7.3	1639	2960	8682
CEgmontN	262	6.7	6.8	6.9	1577	1682	1869
KidnappersR	263	7.3	7.4	7.6	1755	2600	4290
RitchieW1	266	7.3	7.5	7.7	3761	6268	13789
Lachlan1&2	269	7	7.2	7.4	752	1170	2145
RitchieW2	277	6.8	7	7.2	903	1671	5516
CEgmontC	278	6.7	6.8	6.8	1479	1577	1753

Fault Name	NZSHM_ NUMBER	MWMN	MW	MWMX	RECINTMN	RECINT	RECINTMX
WaverOkaia1	281	6.9	7	7.1	29755	40988	73293
MotuokuraN	282	7	7.1	7.3	1630	2716	5975
MoumahOkaia4	284	6.9	6.9	7	8565	7866	26724
RidgeROkaia2	285	6.9	7	7.1	59509	81977	146586
Waitot1011	288	7	7.1	7.1	8088	9285	23718
Waimarama3&4	289	6.6	6.8	6.9	752	1254	2758
PaoanuiRN	291	7.1	7.3	7.5	2800	4666	10265
NukWaitot1to6	292	7	7.1	7.1	15251	26011	162788
MotuokuraE	293	7.3	7.5	7.7	1609	2681	5899
Waimarama1&2	294	6.3	6.5	6.6	460	766	1685
KairakauN	295	6.8	6.9	7.1	1003	1671	3677
CegmontS	296	6.5	6.6	6.6	7244	9267	15450
Kairakau2	297	6.7	6.8	7	878	1463	3218
Waitot8to9	298	7	7	7.1	2466	3798	9072
Okaia5	300	6.6	6.6	6.7	18593	29825	85484
KairakauS	303	7	7.1	7.3	533	789	1302
MotuokuraR	312	7	7.1	7.3	1222	1811	2988
Rangioffsh	315	7.1	7.2	7.3	2758	3830	8427
Madden	316	7.5	7.6	7.8	1540	2396	4392
Mascarin	317	7.3	7.4	7.5	1110	1439	3166
OmakereR	318	7	7.2	7.4	2215	3691	8120
PoranagR	320	7.1	7.2	7.4	2424	4039	8886
Onepoto	322	7.3	7.4	7.5	3604	4805	8810
OmakereS	323	6.8	7	7.1	2865	4457	8171
PaoanuiRS	325	7	7.2	7.4	2173	3621	7967
Fisherman	331	7.4	7.5	7.6	4126	5502	10087
Mataikona	335	7.2	7.3	7.5	614	853	1251
Manaota	336	7.5	7.6	7.7	14259	21125	34856
PoranagW1	338	7	7.2	7.4	1922	3204	7048
PoranagW2	339	6.8	7	7.1	852	1579	5209
Okupe	344	7.3	7.4	7.5	3886	5397	11874
WairarapNich	345	7.9	8.2	8.3	1570	2398	3702
Riversdale	351	7.1	7.2	7.4	527	731	1073
UrutiE	354	6.9	7.1	7.3	1755	2925	6435
UrutiN	356	6.7	6.9	7.1	1003	1671	3677
KekNeed	360	7.3	7.4	7.6	1463	2438	5363
UrutiR2	363	6.5	6.7	6.9	439	731	1609

Fault Name	NZSHM_ NUMBER	MWMN	MW	MWMX	RECINTMN	RECINT	RECINTMX
Wharekauhau[4]	367	7.2	7.3	7.5			
Otaraia	368	7	7.1	7.2	10969	16250	26813
UrutiBasin	369	7.1	7.2	7.3	558	853	1502
WhareamaBank	370	7.3	7.5	7.7	1655	3064	10112
OpouaweUruti	371	7.7	7.8	8	3560	6593	21757
PalliserKai	372	7.5	7.6	7.8	716	1114	2043
JorKekCha	373	7.4	7.6	7.8	1410	2089	3447
JorKekNeed	374	7.4	7.6	7.8	313	389	455
Honeycomb	375	7	7.1	7.3	1504	2507	5516
Pahaua	377	7.7	7.9	8	3660	6779	22369
AwatNEVerCl	379	7.6	7.7	7.8	2528	4213	9270
AwatNEVer	380	7.6	7.7	7.8	2486	4604	9116
WharaToCampB	385	7	7.2	7.4	655	1091	1964
HopeTeRapa1n2	389	7.3	7.4	7.6	802	1254	2006
KekerenguBF	390	7.4	7.6	7.8	3265	6122	14692
UpperSlope	391	7	7.2	7.4	1553	2911	6987
MS05	399	6.7	6.8	7	5571	13393	208930
MS04	400	7.1	7.3	7.5	6351	13232	47636
MS01	402	6.8	7	7.2	3789	9471	28414427
Hundalee	405	7.1	7.3	7.4	1444	3076	10150
MS02	406	6.3	6.5	6.6	527	1163	5934
NorthCant13	408	6.7	6.9	7.1	2953	7382	2214654
NorthCant10	412	6.6	6.8	7	403	756	1814
NMFZM	413	7.1	7.3	7.5	13642	27283	81850
MS09	415	6.4	6.5	6.7	1683	3756	25239
NMFZK1	416	7.2	7.4	7.6	10188	20731	66857
NMFZ1819	418	6.9	7.1	7.3	14597	34212	328437
NMFZK2	423	6.8	7	7.2	4776	9718	31339
NorthCant8	426	6.9	7.1	7.3	5376	10753	32259
NMFZF1	427	6.8	7	7.2	4776	9286	25072
NMFZB0	429	7	7.2	7.4	25796	32245	55277
NMFZ4647	430	7	7.2	7.4	7540	17672	169651
NMFZE1	431	7	7.2	7.4	4569	10982	171322

4 The Wharekauhau Fault is assumed in the 2021 National Tsunami Hazard Model to not rupture independently of the Wairarapa Fault; instead, 50% of Wairarapa Fault ruptures are assumed to also include rupture of the Wharekauhau Fault.

Fault Name	NZSHM_ NUMBER	MWMN	MW	MWMX	RECINTMN	RECINT	RECINTMX
NMFZE2	433	6.9	7.1	7.3	3900	9375	146251
NMFZF2	434	6.9	7.1	7.2	5412	10524	28414
NorthCant11	438	6.4	6.5	6.7	1560	3250	11700
NMFZB1	439	6.6	6.8	7	11477	14347	24594
NMFZB2	443	7.1	7.3	7.5	27913	34891	59814
NorthCant2	444	6.5	6.7	6.9	5321	9501	19953
NorthCant4	445	6.2	6.4	6.6	4364	8183	19639
NorthCant1	448	6.6	6.8	7	6407	12814	38443
Pegasus1nw	449	6.8	7	7.2	6110	9165	13748
MilfordB1	469	7.4	7.6	7.8	765	1416	4673
Swedge6to10	474	7.1	7.3	7.6	529	882	1941
MilB5GeoR2	475	7.8	7.9	8	15461	25768	56690
CaswellH8	476	7	7.1	7.2	2051	3582	9193
CaswellH10	480	6.8	6.9	7	1302	2350	6895
CaswellH9	481	6.6	6.8	6.9	998	1802	5286
GeorgeR1	482	7.9	8.1	8.4	3836	7104	23442
FiordMar1&2	489	7.1	7.2	7.3	56411	62679	68947
CaswellH67	490	7.1	7.2	7.4	2300	4152	12181
Cwedge123	491	7	7.2	7.4	3029	5049	11108
Swedge5	492	7.5	7.7	7.9	1017	1695	3728
Cw4Swedge411	497	7.3	7.5	7.8	752	1254	2758
Caswell5	498	7.1	7.2	7.3	3064	6129	33707
Swedge2	499	7.2	7.4	7.7	577	1068	3524
Caswell4	503	7.1	7.3	7.4	2849	4975	12768
Swedge3	508	7	7.1	7.4	390	650	1430
Swedge1	510	7	7.2	7.4	2159	4318	23748
SFiordMg13	511	7	7.1	7.2	878	1463	3218
Caswell3	513	6.7	6.9	7	1425	2487	6384
Caswell1	517	7.4	7.5	7.6	4331	7561	19407
Caswell211	521	6.8	7	7.1	1652	2885	7405
Chalky4to8	522	6.8	6.9	7	1170	1950	4290
SFiordMg1to9	523	6.6	6.6	6.7	1033	1762	8157
FiveFingers	526	6.9	7	7.1	4137	7661	25280
Chalky1to3	530	6.7	6.8	7	3009	5571	18386
Akatore	531	7.3	7.4	7.6	1852	3482	7114
HumpR	532	7.5	7.6	7.7	37942	63236	139119
Hauroko	533	7.5	7.6	7.7	1943	3238	7124

Fault Name	NZSHM_ NUMBER	MWMN	MW	MWMX	RECINTMN	RECINT	RECINTMX
Solander	534	7.1	7.2	7.3	19096	31827	70019
Settlement	535	6.7	6.8	7	2403	4004	8810
CBalleny	536	7.3	7.4	7.5	699	932	1281
WairarapNich Wharekauhau	345	7.9	8.2	8.3	1570	2398	3702
BooBooALL	383	7.4	7.6	7.7	581	933	1568
AlpineR	504	7.7	7.8	7.9	249	295	359
OhariuC	346	7.1	7.2	7.3	1379	2043	3371
PukeShep	349	7.2	7.3	7.4	3917	6964	12768
OhariuS	362	7.3	7.4	7.5	1661	2461	4060
WellWHV	359	7.4	7.5	7.6	594	836	1103
AwatereNE	357	7.5	7.6	7.7	2110	3197	7737
HopeConwayOS	396	7.6	7.7	7.8	1264	1685	2317
Wairau	376	7.7	7.8	7.9	1793	2490	5477
AlpineF2K	432	7.9	8.1	8.3	199	341	607
KerepehiN	83	6.7	6.8	6.8	8521	8928	10296
RaukumaraF23	142	6.5	6.6	6.7	124000	125000	126000
RaukumaraF21	156	6.5	6.6	6.7	28205	41786	13789354
RaukumaraF19	167	6.6	6.7	6.8	31339	46429	15321505
RaukumaraF18	168	6.6	6.7	6.8	10000	67500	125000
RaukumaraF17	170	6.3	6.4	6.5	10000	67500	125000
DryHuang	366	7.1	7.3	7.4	2946	4676	9001
WhiteCk	352	7.5	7.8	8	22286	41786	100286

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