2024 Tsunami Guide for QUEENSLAND

Queensland Government

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Foreword

Disaster events impact the lives of all Queenslanders and have a substantial effect on the economy and the environment. Whether they arise from natural causes or human actions, disasters are becoming more extreme and intricate, amplified by the interconnectedness of our global economies.

This update to the Tsunami Guide for Queensland incorporates learnings which have occurred since the first release of the Guide in 2019. The 2022 Hunga Tonga-Hunga Ha'apai eruption was a reminder that tsunami do pose a very real threat, with evacuations at Lord Howe Island and further tsunami warnings triggered along Australia's east coast as a result of this event. Acknowledging the possibility of such an event occurring is crucial for Queensland's ongoing preparedness. While tsunamis are rare, they pose a constant risk to communities along the coastal regions of Queensland, with the potential for catastrophic consequences that would be felt throughout the entire State.

Recognising disaster risk and effectively communicating relevant risk information across the three tiers of Queensland's Disaster Management Arrangements (QDMA): local, district, and state, is a crucial step towards building a resilient state and communities.

Nikki Boyd MP

Minister for Fire and Disaster Recovery and Minister for Corrective Services

Steve Smith AFSM

Commissioner, Queensland Fire and Emergency Services

This aligns with the global emphasis on understanding risk as a priority of the Sendai Framework 2015-2030. Starting at the local level, consistent communication of risk information across each tier of QDMA can aid communities, government agencies, emergency services, and all emergency management partners in making well informed decisions.

The information provided in this hazard guide is valuable for stakeholders within government and practitioners in the emergency management sector. It signifies a growing capability to inform the creation of risk-based plans throughout Queensland's disaster management arrangements. Risk-based planning is a fundamental facilitator for Queensland communities to enhance our ability to prevent, prepare for, respond to and recover from natural disasters.

As the Minister for Fire and Disaster Recovery and the Commissioner of Queensland Fire and Emergency Services, we express our gratitude to all stakeholders, particularly Geoscience Australia, the Department of Environment, Science and Innovation, and the University of Newcastle, for their contributions to this guide and their ongoing dedication to building safer and more resilient communities.

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INTRODUCTION

Purpose and intended audience

We cannot predict where and when a tsunami will occur, but we can understand the hazard and risk to inform effective disaster risk management and be better prepared for events. Although unlikely for Queensland, tsunami have the potential to impact broad areas of coastline with devastating consequences.

The tsunami triggered from the Hunga Tonga-Hunga Ha'apai volcanic eruption in January 2022 was a timely reminder of the dangers that tsunamis pose to Queensland. This event was not the first time that Australia has been impacted by a tsunami triggered by a volcanic eruption, and it is not the first time that tsunami has been observed in Queensland.

Due to where the major sources for tsunami are located, there should be some time for communities to respond before impact, and it is crucial to know what to do and where to go. It is also crucial to know the natural warning signs of tsunami for anyone in areas that cannot receive warnings. Given the low probability of tsunami, the general level of awareness of tsunami is very low, presenting risks to community safety.

This 2024 Tsunami Guide for Queensland (TGQ) has been updated in conjunction with the 2024 State Earthquake Risk Assessment (SERA). These are intended as overarching assessments of earthquake and tsunami risk, for use by all levels of Queensland's Disaster Management Arrangements (QDMA) to inform the development of risk-based disaster management plans. Both reports are an update to the 2019 versions, utilising new data and information which has become available since the initial release.

The TGQ provides general advice and information for consideration at the local, district and state level, increasing the understanding of tsunami in Queensland and dispelling myths surrounding offshore islands and reefs.

As with the 2019 Tsunami Guide for Queensland, QFES has collaborated with Geoscience Australia (GA), Queensland Department of Environment, Science and Innovation and the University of Newcastle for this 2024 update.

How to use this guide in local and district disaster risk assessments

Although widespread destruction due to tsunami (as observed in countries such as Indonesia) is highly unlikely within Queensland, the consequences of these events can be devastating and have significant and prolonged impacts on the community. Advice for the implementation of this guide at a local or district level is to distil the information contained within this document by applying a scenario-based approach.

A scenario could be developed based on the information described in Appendix A. Such a scenario would need to be developed with high resolution near-shore elevation data for the onshore and offshore environment. Developing tsunami scenarios is resource intensive and there are currently only a limited number of scenarios which have been developed for Queensland. In the interim, the tsunami evacuation mapping for Queensland can be used as a conservative guide, however, there is uncertainty on where this mapping may be an overestimate or underestimate of the extent of potential tsunami inundation. The mapping provides an extent only and doesn't provide any indication of water depth or speed which are major drivers of damage.

Conducting a local or district tsunami risk assessment using this scenario-based approach allows the understanding of which elements of the community may be exposed and how vulnerable they would be to a tsunami, allowing risk reduction activities to be prioritised and implemented.

Understanding the hazard

Definition

Tsunami (pronounced ‘soo-nar-me’) is a Japanese word comprising ‘tsu’ meaning harbour and ‘nami’ meaning wave. Tsunami are waves caused by the sudden movement of the ocean surface due to earthquakes, sea floor (or ‘submarine’) landslides, land slumping into the ocean, large volcanic eruptions, near earth objects (asteroids, comets, meteorites) making impact in or above the ocean, or meteorological instances. Figure 1 shows the current record of tsunami and the generation sources across the globe.

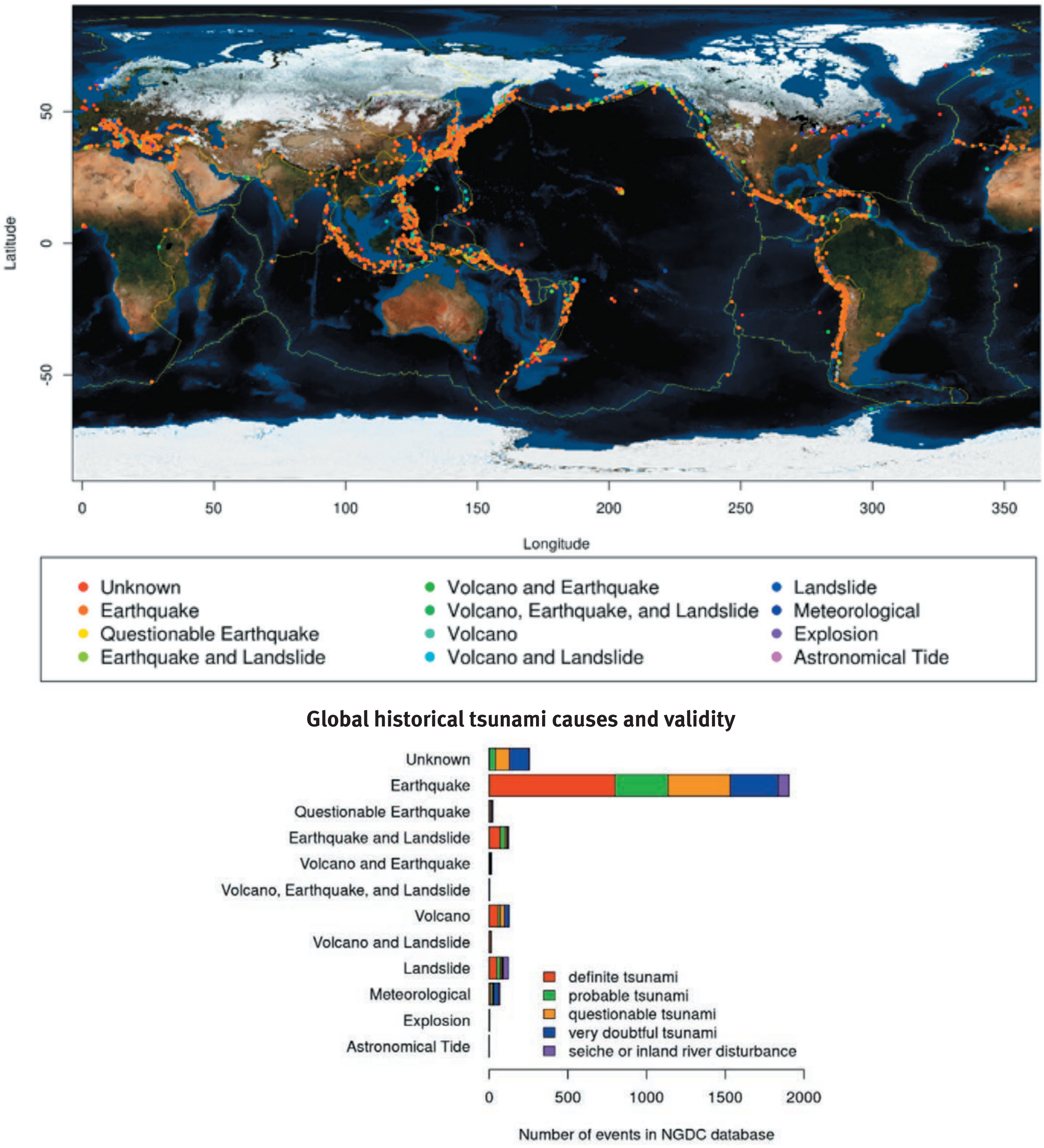


Figure 1: Record of event-driven tsunami across earth and global historical causes and validity. Source: Geoscience Australia

Until recently, tsunami were often called tidal waves. This term is now generally discouraged because tsunami generation has nothing to do with tides, which are driven by the gravity of the earth, moon and sun. Although some tsunami may appear like a rapidly rising or falling tide at the coast, in other situations they can also feature one or more turbulent breaking waves.[1]

Impacts to coastlines from tsunami vary on the scale of the tsunami. Small, non-destructive tsunami may appear as a strong, fast-moving tide however will have limited to no impacts on coastal areas. Larger tsunami can have devastating impacts on coastal areas with lives lost and destruction of coastal communities. Volatile flooding will also be experienced as taller tsunami impact as forceful walls of water.

How does a tsunami occur?

Tsunami are generated by the displacement of a water column over a large area, typically in the ocean. A range of geophysical mechanisms can achieve this including earthquakes, landslides, volcanic activity, asteroid impacts, and meteorological processes. For more information, refer to Tsunami: The Ultimate Guide, or animations available at the Australian Institute of Disaster Resilience website.[2]

The main source of tsunami (75%) are submarine earthquakes along the subduction zones within the circum-Pacific seismic belt, also known as the Ring of Fire. This belt is a collection of oceanic trenches, volcanoes, and plate movements along the rim of the Pacific Ocean and is responsible for about 70% of the world's tsunami. The main subduction zones that generate tsunami which could impact the Queensland coast are the Kermadec-Tonga, New Hebrides, and Solomon trenches, shown in Figure 2, and the South America trenches along the west coast of South America.

A simple example to demonstrate how tsunami act is by dropping a pebble into a pond: the pebble generates a deformation of the water surface which in turn creates a wave or series of waves that radiate from the source of disruption in concentric circles of increasing size, as shown in Figure 3 and 4.

Accordingly, the specific characteristics of the earthquake generation process can have a significant impact on tsunami magnitude and characteristics.

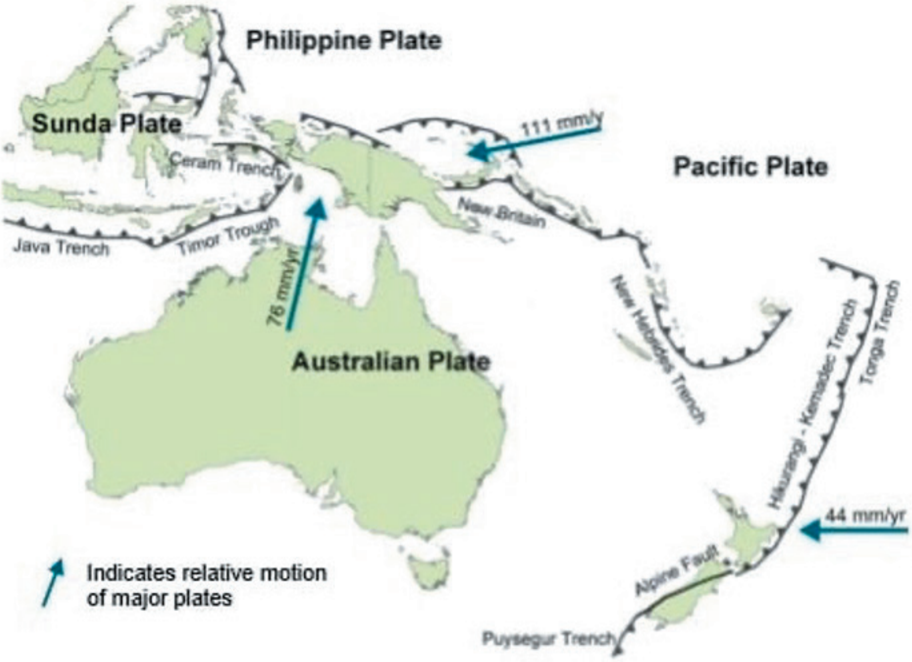


Figure 2: Tectonic context of Australia, showing key subduction zones. Source: Verisk 2020

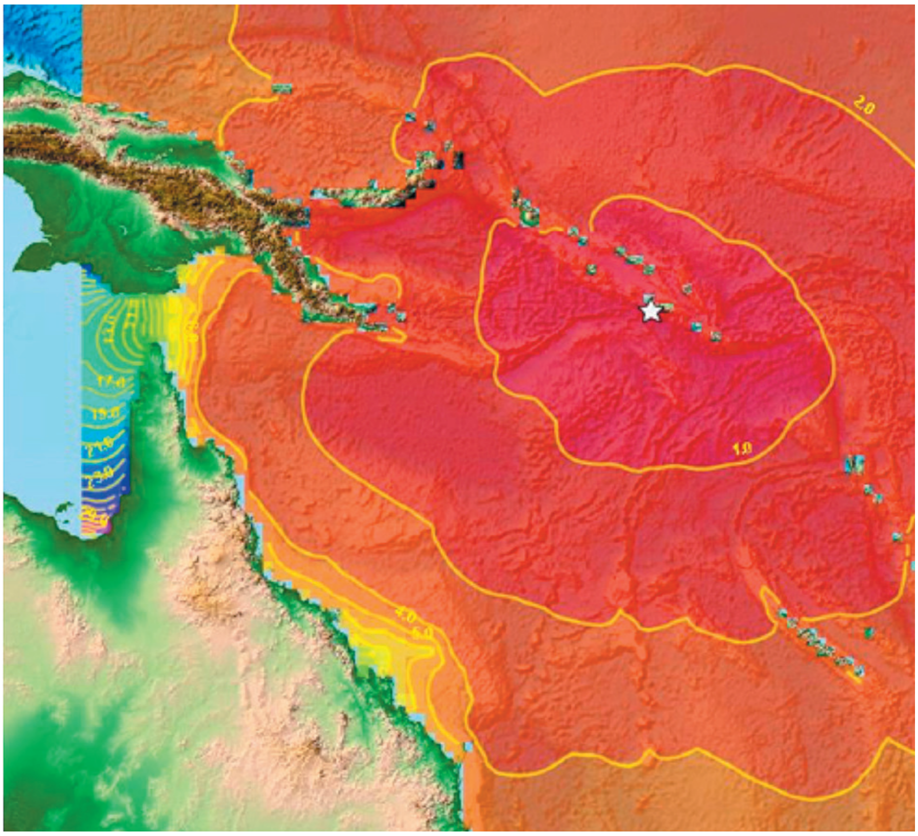


Figure 3: Tsunami model showing the movement of waves generated from the 2007 Solomon Islands earthquake. Source: Yushiro Fujii, International Institute of Seismology and Earthquake Engineering

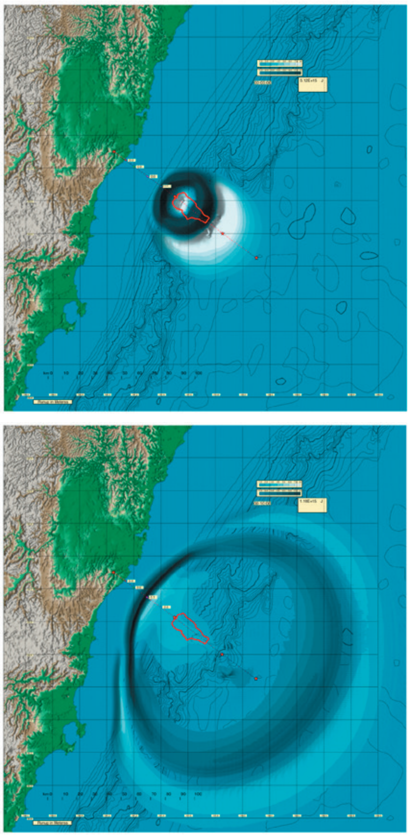


Figure 4: Tsunami modelling showing the outwards movement of the wave generated from a point source. Source: Associate Professor Hannah Power, University of Newcastle

Earthquake-generated tsunami

Of tsunami recorded, around 75% have been caused by significant earthquakes on the sea floor where large slabs of rock, separated by a fault plane move suddenly past each other, resulting in rapid movement of the above water.[1]

Tsunami generated by submarine earthquakes do not emanate from a single point but rather a broad region near the earthquake, affected by a complex pattern of seabed movements.

The exact nature of the waves is affected by how the earthquake occurred. An earthquake rupture is very complex spatially (with lengths from less than 100 kilometres to more than 1000 kilometres) and may last for minutes. As the tsunami travels across the deep ocean, it will be directed, scattered, and reflected by the shape of the seafloor and any land masses in its way (Figure 5).

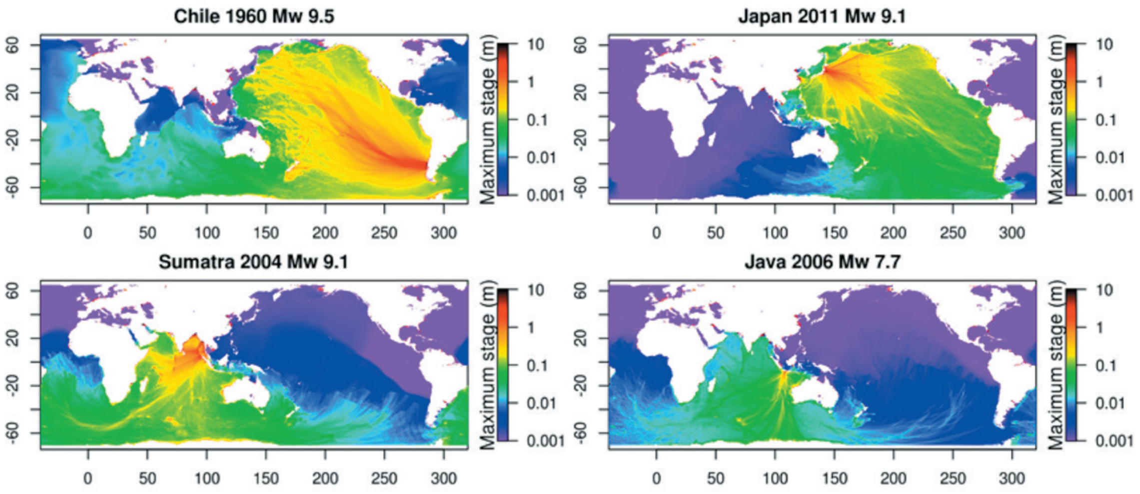


Figure 5: Demonstrated tsunami directionality from historical events. Source: Geoscience Australia

Submarine landslide-generated tsunami

Submarine landslides are a gravity driven mass movement of seafloor material that occur in a range of geological settings, including on the continental slopes of passive margins such as the east Australian margin. When these underwater landslides occur (potentially post-earthquake) a large mass of sediment can move down slope, which draws down the overlying ocean water resulting in a tsunami potentially being formed and travelling across the ocean.[1]

Submarine landslides have caused tsunami that have led to the destruction of property and significant loss of life, including the 1998 Papua New Guinea event. Earthquakes are the most probable external trigger for submarine landslides, however, the generation of a large tsunami from these events depends on multiple key factors including:

- the size of the slide
- the depth of the slide
- the unstable sediment moving as one solid mass
- a significant slip rate of the landslide
- friction from the underlying seafloor not acting to reduce the slip rate.

According to the National Geophysical Data Centre (NGDC) database, submarine landslides are more likely to occur near tectonic plate boundaries where destabilisation has occurred due to factors such as proximity to earthquake shaking, erosion, and oversteepening of slope sediments.

Volcanic eruption-generated tsunami

Tsunami caused by volcanic eruptions are less common and can occur in a variety of ways:

- Collapse of coastal, island and underwater volcanoes which can result in massive landslides
- Pyroclastic flows (a mixture of hot blocks, pumice, ash and gas) moving down volcanic slopes into the ocean and pushing water outwards.
- Underwater explosion
- Resonance of the ocean with an atmospheric pressure wave caused by a volcanic explosion (i.e. a volcano-generated meteotsunami)
- A caldera volcano collapsing after an eruption causing water to drop suddenly.[3]

Meteotsunami

Meteotsunami are lesser known, however they have previously impacted Queensland. Meteotsunami are commonly caused by a change in atmospheric pressure and can be generated when there are changes in air pressure of 5hPa over a period of 10 minutes. Meteotsunami have been associated with squalls, thunderstorms, frontal passages, tropical and extratropical cyclones (east coast lows), and atmospheric gravity waves.[4]

Meteotsunami have the potential to significantly impact coastal regions. Flooding, damaging waves and strong currents lasting from several hours to 24 hours may occur and impacts to people and property may be felt.[5] Boothbay Harbour in Maine, USA experienced a significant meteotsunami in 2008 where waves emptied and flooded the harbour three times in 15 minutes.[6]

Meteotsunami have also occurred in Australia, common across the Western Australia coastline due to thunderstorms and low-pressure systems.[7] New South Wales and Queensland have also recorded meteotsunami, in 2016 coastal regions of Queensland experienced a tsunami-like wave that was captured on several storm tide gauges over a 10-hour period.[5] Fortunately, there was no damage caused by this event.

Volcanic eruptions, such as the Hunga Tonga-Hunga Ha'pai eruption in 2022, are also known to create meteotsunami from a change in atmospheric pressure. This eruption caused waves to arrive two hours earlier than predicted in Japan.[8]

Why is there more than one wave?

Even if you make disturbance in your bathtub, you will see that a series of waves are generated. This is a fundamental property of water waves. Because of gravity, water will be accelerated away from uplifted areas (and towards low areas). Once the waves are initiated, they will keep propagating around the ocean until they slowly dissipate due to friction.

A tsunami comprises a series of very long waves and each wave generally lasts between five and 90 minutes. The first wave may not be the largest and the tsunami may still be evident up to 24 to 48 hours after the first wave. Even if a tsunami does not impact land, dangerous rips and currents can result. Therefore, water activities should cease until the hazard advisory is lifted.

Is the first wave the largest wave?

Offshore, the Probabilistic Tsunami Hazard Assessment (PTHA18) suggests that the largest waves may not be the first wave. Irrespective of whether the first wave is the largest offshore, as the waves approach the coast, other factors influence the wave train such as reflections, shelf trapped waves and coastal trapped waves. These processes can result in the largest wave occurring several hours after the first wave. Measured tsunami waves during the Solomon Island event in 2007 showed that for some sites the first wave was the largest, but most sites had the largest wave several hours after the arrival of the first wave. It is important to heed the warnings provided as there is no guarantee when the largest wave will occur.

How fast do tsunami travel?

Tsunami speed is directly related to the water depth:

$$\sqrt{}(\mathit{Gravity\ x\ Depth})$$

This means a tsunami will travel fast in deep water and will slow down as the water depth becomes shallower. Tsunami can travel as fast as an aircraft, around 600 kilometres to 800 kilometres per hour, in very deep water.

For volcano-generated meteotsunamis, the tsunami arrival time can appear shorter than would be expected from this theory. That is because the atmospheric disturbance travels near the speed of sound, which is faster than $\sqrt{}$ (GRAVITY x DEPTH) in most of the ocean. The atmospheric disturbance will generate tsunamis wherever it crosses the ocean at depths close to resonance, and so there is potential for waves to arrive more rapidly than would be possible if they had propagated from the source through the ocean.

How long does a tsunami last?

This will vary widely depending on the event and the characteristics of the nearshore environment. A tsunami may be evident for just a few hours to several days after initial impact.

How are tsunami different from wind waves?

Both kind of waves are influenced by similar processes of refraction, diffraction, reflection and trapping, but tsunami waves occur at a much larger scale than wind waves. Tsunami do not tend to dissipate over significant distances, whereas wind waves will.

Wind waves will tend to break and dissipate on the beach, whereas tsunami typically do not break (as shown in Figure 6). The momentum of a tsunami can push water further inland than wind waves, with the current too strong for a person to stand or remain stable.

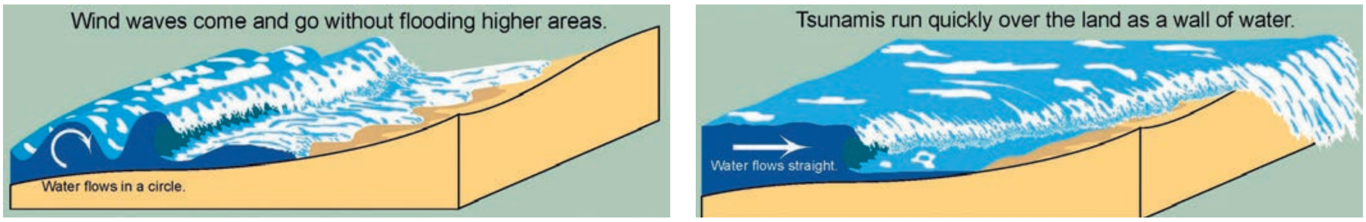


Figure 6: Differences between wind waves and tsunami at the coast. Source: AIDR Tsunami Emergency Planning in Australia Handbook

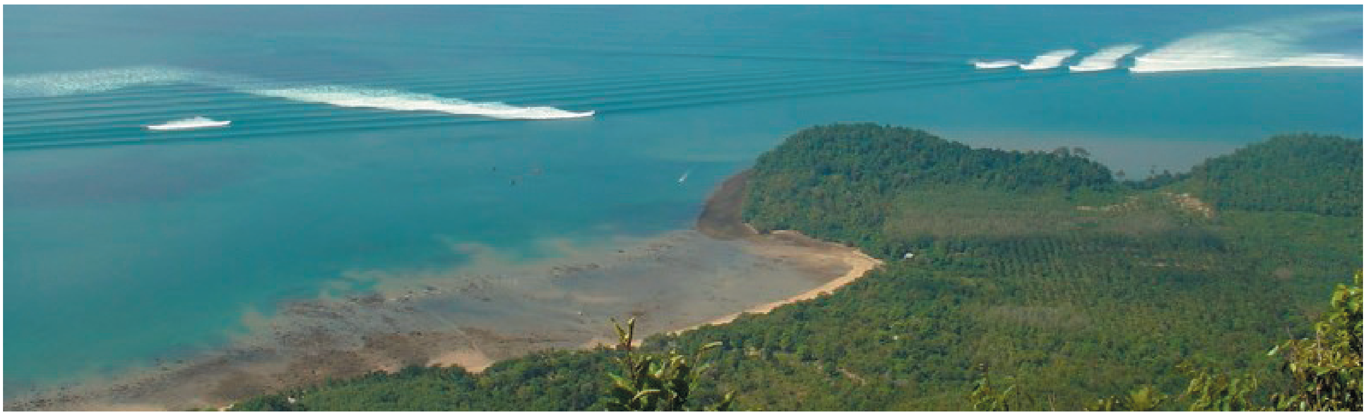


Figure 7: The 26 December 2004 Indian Ocean tsunami approaching the North Beach of the island Koh Jum, off the coast of Thailand. The waves present in the photo, taken from the top of Mount Pu, are shorter period waves riding on top of the tsunami, which is not obvious with the naked eye.
Source: Anders Grawin, reproduced with permission

Will the water from the coastline recede before the arrival of a tsunami?

The nature of subduction zones and how an earthquake was generated would indicate whether water will recede from a beach. At subduction zones, one tectonic plate slides underneath another, and for the most common kind of large earthquakes (known as ‘thrust’), the tsunami will have a leading peak on the ‘sinking plate side’ (often called the oceanic plate) and a leading trough on the ‘overlying plate site’ (often called the continental plate).

Communities will experience a leading peak or trough, depending on which side of the subduction zone they are on. Queensland is located on the oceanic plate side of some subduction zones and the continental plate side of others so could have either a leading peak or trough.

For a submarine landslide generated tsunami, modelling has shown that some areas of the coastline will experience a leading trough while others will experience a leading peak, depending on proximity and orientation from the source location.

How does the coastline affect tsunami?

The shape of the sea floor plays a major role in how much the tsunami will grow in height (shoaling) or lose height. This is illustrated in Figure 8. Tsunami slow down and increase in size (shoal) as they travel over the continental shelf. Low-lying areas are likely to be more vulnerable, but this is also highly dependent on where the tsunami was generated.

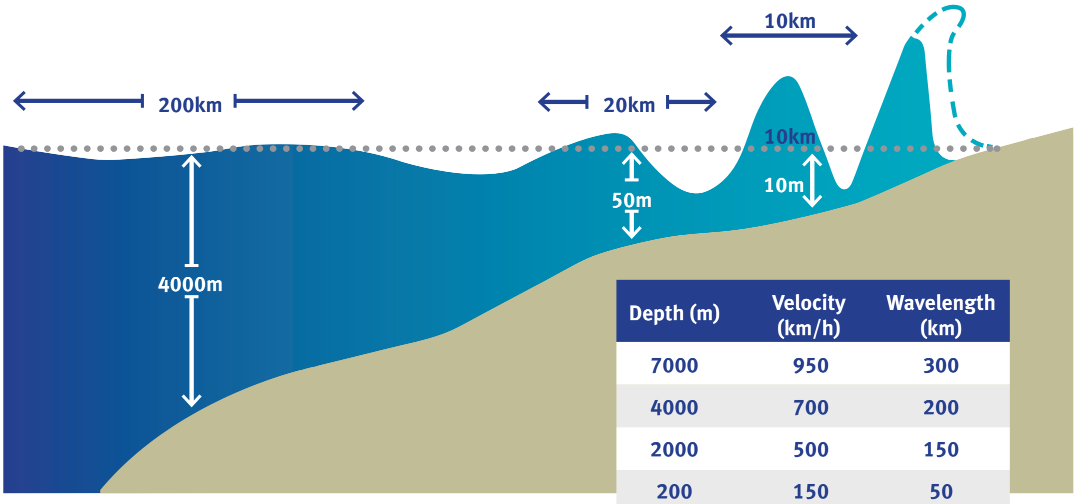


Figure 8: Wave characteristics in the open ocean and near shore. Source: Adapted from the AIDR

Depth (m)	Velocity (km/h)	Wavelength (km)
7000	950	300
4000	700	200
2000	500	150
200	150	50
50	80	20
10	40	10

Further, as the tsunami approaches the coastline, it is influenced by coastal features and nearshore bathymetry in the following ways:

- Refraction can focus energy on particular features, such as prominent headlands.
- Complex bathymetry may cause crossing of waves, generating localised amplification.
- The tsunami can also be reflected off the coastline, generating a longer and more complicated wave train.

Tsunami will therefore differ along the coast, as illustrated in Figure 9. Geoscience Australia has created several video guides about tsunami behaviour which are useful for disaster management and community education and can be found at Geoscience Australia’s YouTube channel.[9]

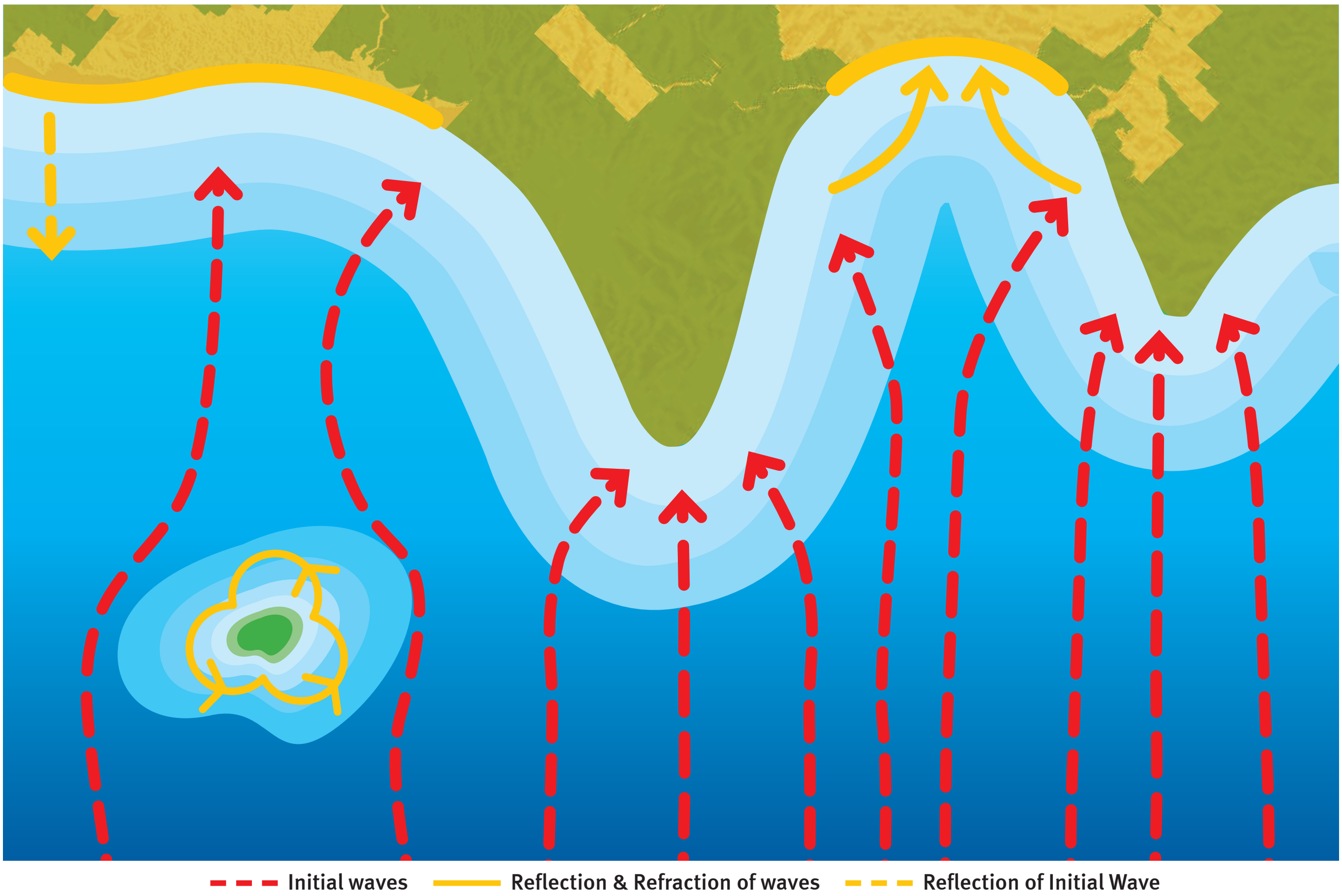


Figure 9: Refraction and reflection of tsunami waves. Source: Coastal Unit, DESI

How do islands and breakwaters affect tsunami?

While areas in the lee of islands and breakwaters can be sheltered from ocean wind waves, this is not the case for tsunami. The wavelength of tsunami are tens of kilometres, even in relatively shallow water, whereas small islands and breakwaters are around hundreds of metres in size. Documented cases in other parts of the world show tsunami have wrapped around an island and even amplified in the lee.

Figures 10 and 11 show the effect of the offshore breakwater at Redcliffe for a hypothetical tsunami by modelling with and without the structure. Although a slight reduction in amplitudes occurs with the structure in place, current speeds around the structure significantly increases.

Advice to the public should always be to heed warnings and move to higher ground. Structures or features that provide shelter from wind waves should never be assumed to provide the same protection from tsunami.

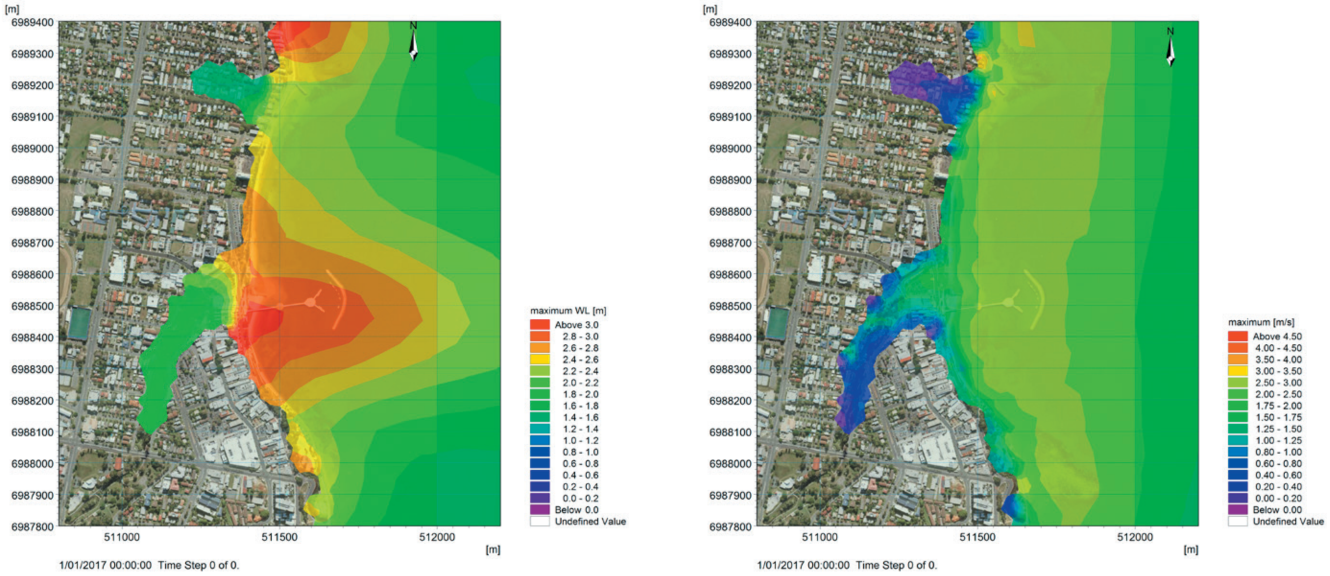


Figure 10: Maximum water level (left) and maximum current speed (right) for modelled tsunami scenario with Redcliffe breakwater omitted.
Source: Coastal Unit, DESI

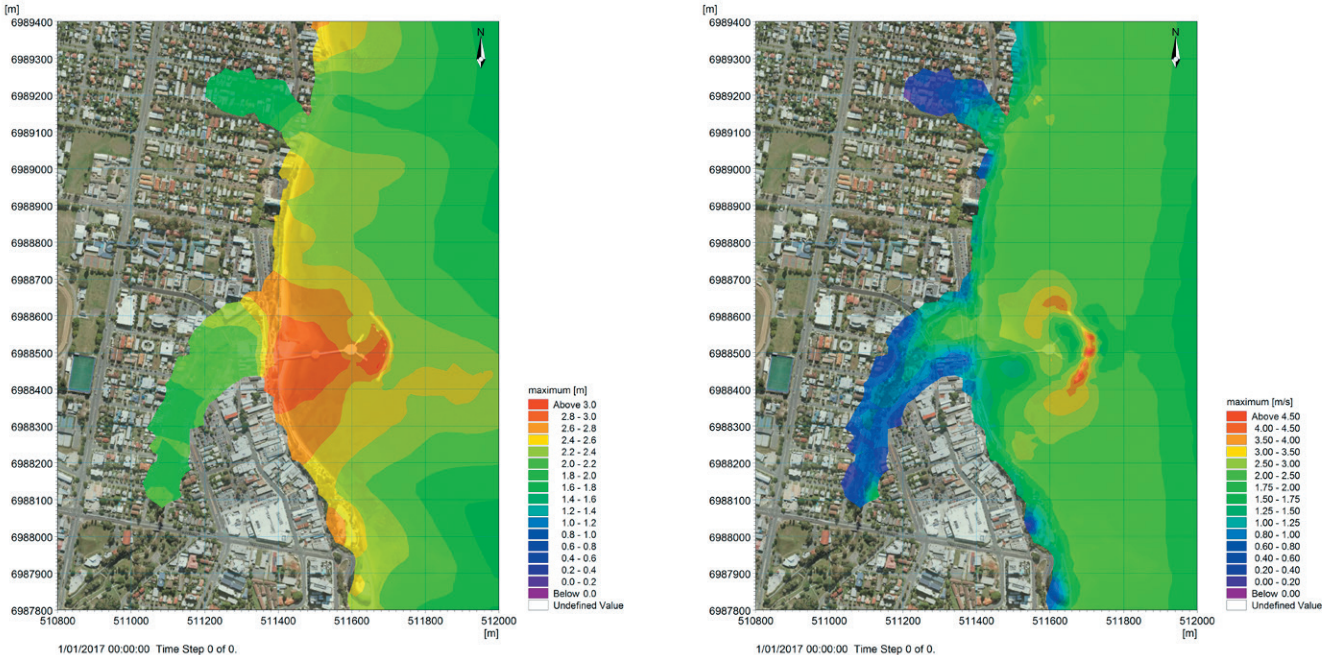


Figure 11: Maximum water level (left) and maximum current speed (right) for modelled tsunami scenario with Redcliffe breakwater included.
Source: Coastal Unit, DESI

The Australian context

Dozens of tsunami have been observed historically in Australia and have generated marine hazards and locally significant inundation. Detailed tsunami inundation studies have shown the potential for greater impacts than what has been observed to date.

Australia's historical tsunami record is not a reliable guide to our tsunami hazard as the written history is short compared with the estimated frequency of damaging tsunami. Geological records suggest energetic marine inundation has occurred at some sites in the last few thousand years, however, it is very difficult to determine with any certainty whether these deposits represent tsunami or storm surges.[10]

Oral stories of Australia's First Nations people are believed to date back further than almost anywhere else in the world. Ingrained in a culture of storytelling, information and wisdom has been passed orally across almost 400 generations, depicting memories of events that have shaped the country. Submergence stories are of particular significance, recalling sea levels following the last ice age, to volcanic eruptions and tsunami events. To date, more than 30 submergence stories across the county's coastline portray a vastly different Australia - helping us to understand not only the past, but also the future.[11]

The average return intervals (frequency and likelihood) of large tsunami are very uncertain, due to constraints of observational data and limitations in our understanding of key tsunami sources, such as earthquakes and landslides. As a result, modelled tsunami average return intervals in hazard studies should generally be interpreted as 'nominal' or 'indicative', rather than an accurate measure.

Probabilistic Tsunami Hazard Assessment

In 2018, Geoscience Australia released an updated offshore Probabilistic Tsunami Hazard Assessment - the PTHA18.[12] The PTHA18 was a significant update to the 2008 version and included advances in the understanding of earthquakes and the resulting tsunami and provided hazard information for all Australian offshore territories for the first time. Compared with the previous iterations of the PTHA, the PTHA18 included a more comprehensive treatment of the natural variability of earthquake size and slip. This has an important impact on the predicted tsunami wave heights and hazard.

The PTHA18 models the frequency with which tsunami of any given size occur around the entire Australian coast due to subduction earthquakes in the Indian and Pacific Oceans. The PTHA18 also provides modelled tsunami data for hundreds of thousands of earthquake-tsunami scenarios around Australia. The PTHA18 provides vital information to emergency managers for planning and reducing the risk of tsunami on the Australian coast, and for the insurance industry to understand the tsunami risk as an input to pricing insurance premiums.

The PTHA18 also provides a nationally consistent basis for understanding tsunami inundation hazards in Australia. Importantly, the PTHA18 does not define the onshore tsunami impacts, or the effect of tsunami on communities.

However, understanding the frequency of tsunami offshore, as provided by the PTHA18, is a valuable input for developing local tsunami inundation models, in conjunction with additional high-resolution bathymetry (the study and mapping of the sea floor) and elevation data.

This in turn allows the derivation of evidence-based evacuation plans to improve community safety. Further, high risk areas can be identified and prioritised for further analysis or to conduct scenarios to improve risk mitigation and community safety at a local, regional and national level.

Currently the PTHA18 does not include non-earthquake sources that can cause a tsunami such as landslides, volcanic activity, asteroids and meteorological events. Methods for assessing tsunami hazards for these sources are much less well established than for earthquakes both internationally as well as in Australia. Further research is required to underpin a nationally consistent treatment for these tsunami sources.

The Australian Tsunami Warning System

The Australian Tsunami Warning System (ATWS) is an end-to-end tsunami warning and emergency response system. The ATWS involves key national, state and territory partners and agencies in earthquake detection, tsunami assessment and warning, and emergency response and recovery. The ATWS includes:

- The Joint Australian Tsunami Warning Centre, operated by Geoscience Australia (GA) and the Bureau of Meteorology (BoM), which provides emergency managers and the Australian public with at least 90 minutes warning (where possible).
- The Australian Tsunami Advisory Group (ATAG), which provides national leadership in the coordination of programs and projects relating to tsunami capability development, promoting research, information, knowledge management and education in Australia. ATAG is an expert advisory group for the Australia-New Zealand Emergency Management Committee (ANZEMC) and its sub-committees. ATAG members are drawn from each Australian state and territory, including offshore territories, Surf Life Saving Australia, New Zealand and the Australian Government. For more information about ATAG visit the Australia Institute for Disaster Resilience website.[13] Additional national resources are provided at the end of this guide.

The Queensland context

What is the history of tsunami in Queensland?

As our historical records are short, and damaging tsunami are relatively rare in this region, it is uncertain how often they might occur in Queensland. Unfortunately, scientists still do not have a good understanding of the frequency of key tsunami generating processes such as large earthquakes and volcanic eruptions.

Since the 2004 Indian Ocean tsunami, the Department of Environment, Science and Innovation's Coastal Unit has upgraded the state-wide storm tide monitoring network to measure water levels at one-minute intervals, capturing multiple tsunami events within Queensland, including those from the Solomon Islands 2007, Japan 2011, and the 2022 Hunga Tonga-Hunga Ha'apai eruption, some of which are shown in Table 1. To date, the largest tsunami wave captured by the Coastal Unit's storm tide monitoring network was a 0.82m wave at the Gold Coast, resulting from the Hunga Tonga-Hunga Ha'pai eruption in January 2022.[14]

Through a process of digitising historic data, a potential meteotsunami that occurred along the Queensland coastline in 1917 was uncovered.[15] Other events have also been uncovered with observations reportedly associated with the 1883 Krakatoa eruption made along the Moreton Bay area, describing a tsunami that caused potential loss of life due to people thrown overboard off boats, and significant damage to the region. Anecdotal observations were also made of a tsunami associated with the June 1918 earthquake offshore K'gari.

In 2016 South East Queensland (predominantly the Gold Coast) experienced a meteotsunami as a result of a storm event, which occurred over a 10-hour period. The tsunami waves came early in the morning around low tide, recorded at 0.41m in height (recorded at West Crab Island, North Channel). Had this occurred at high tide, the potential for property damage through inundation would have increased significantly. This meteotsunami event consisted of a 10 to 15 wave train with one wave being double the height.[15] Information obtained from this event will assist in establishing a meteotsunami early warning system for southeast Queensland regions.[16] Similarly, data that was obtained from the 2022 Hunga Tonga-Hunga Ha'apai event supports future analysis of meteotsunami, and model verification.[17]

Table 1: Queensland's recorded history of tsunami [18]

Date	Impact Region	Source Region	Comments
15 August, 1868	NSW, QLD, SA, TAS, WA	North Chile	The ebbing tide reversed and waters returned to Sydney Harbour with great force. Ships swung at anchor and boats washed ashore in Newcastle. The jetty washed away in Long Bay Tasmania.
5 May, 1877	NSW, QLD	North Chile	A series of waves recorded at Fort Denison, Sydney Harbour.
23 May, 1960	NSW, QLD, SA, TAS, VIC	Central Chile	Slight to moderate damage to boats in harbours at Evans Head, Newcastle, Sydney and Eden.
26 July, 1971	QLD, NSW	Bismark Sea	
20 April, 1977	NSW, QLD	Solomon Islands	
21 April, 1977	QLD	Solomon Islands	Strongest recorded earthquake in the Solomon Islands region.
26 December, 2004	NSW, QLD, SA, TAS, VIC, WA	Sumatra	Major Indian Ocean tsunami. 35 people rescued from rip currents, boats damaged in marinas (especially in WA, but also including as far as Tasmania), some limited and localised inundation of immediate foreshores in a small number of WA coastal towns.
3 May, 2006	NSW, QLD, TAS, VIC	Tonga	
2 April, 2007	QLD	Solomon Islands	Tsunami alert and warnings for dangerous waves and currents for the east coast of Australia, including Tasmania. Beaches closed. Low lying areas in Yeppoon evacuated. Cairns Hospitals evacuated first floors. Schools closed. 13% of Cairns residents evacuated causing a mass gridlock – highlighting concerns for future evacuations. It was recommended early warning buoys be installed for better response, with the first buoys installed in the southeast Tasman Sea on 15 April 2007.

Date	Impact Region	Source Region	Comments
28 February, 2010	NSW, QLD, TAS	Chile	50cm wave at Norfolk Island, 42cm wave at Gold Coast QLD, 29cm wave at Port Kembla NSW, and a 28cm wave at Southport TAS.
11 March, 2011	QLD	Japan	
15 January, 2022	QLD	Tonga	Minor waves generated at the Gold Coast – a max amplitude of 0.48m was measured at the Gold Coast Seaway.[19]
30 December, 2023	QLD	Japan	Earthquake in Japan produced a max wave height of 0.9m at Rosslyn Bay (near Yeppoon).

What areas of Queensland are more exposed?

The PTHA18 shows us that the entire Queensland coast (including within the Gulf of Carpentaria) could experience a tsunami, with the southern parts of Queensland having a higher level of hazard (i.e. wave height) than other parts of the coastline because of the narrower and gradual sloping continental shelf and the location of the predominant source zones.

The PTHA18 provides the projected offshore tsunami wave heights for a range of different annual exceedance probabilities (the chances of the event occurring once in a year, expressed as a percentage) from earthquake sources only. It identifies parts of the coastline which may be more vulnerable than others but does not address the potential impacts on the land. The PTHA18 can provide scenarios for input into further inundation studies.

The Coastal Unit examined the nearshore hazard along the east Queensland coast by using the original 2008 PTHA to determine amplification factors from 100 metres depth to 10 metres depth. The results suggest the hazard is greatest for southeast Queensland as well as for some areas within the Great Barrier Reef lagoon. However, a full assessment of the hazard requires detailed inundation modelling as further shoaling would likely occur landwards of the 10-metre depth contour.

The following regions have been identified as having the highest tsunami risk from earthquake sources along the Queensland coast:[20]

- Gold Coast
- Ocean side of Bribie, Moreton and Stradbroke Islands.
- Sunshine Coast
- K'gari
- Bundaberg
- Flying Fish Point
- Along the Capricorn Coast
- Agnes Water
- Hervey Bay

If an earthquake-triggered tsunami were to occur, where in Queensland might it be observed?

The most likely sources for an earthquake-triggered tsunami for the Queensland coast are the Kermadec-Tonga trench (north of New Zealand), the New Hebrides trench (near Vanuatu and New Caledonia) and the Solomon trench (near the Solomon Islands and eastern Papua New Guinea). Tsunami generated from earthquakes on the west coast of South America could also impact the Queensland coast. Tsunami generated from these sources would impact the entire east Queensland coastline to varying degrees. Further, the Gulf of Carpentaria could experience a tsunami from earthquakes generated in the Banda Sea but this region is relatively sheltered compared with the east coast.

An earthquake does not need to occur close to Australia or Queensland for it to have an impact either. The 1960 Chile earthquake, the largest recorded earthquake in history, produced waves that travelled over 11,000 kilometres to Australia – generating waves up to four metres in some estuarine areas.[21]

Where are the volcanic sources which could threaten the Queensland coast?

The Queensland coast faces the Pacific Ring of Fire, an area with numerous active volcanic regions, as shown in Figure 12, these include the Tonga Islands, Solomon Islands, Vanuatu, Papua New Guinea, and Indonesia.[22] These regions have multiple active volcanos and are listed as high-risk sources.

Volcanic sources, although only accounting for around 5% of all tsunamis, do not need to be within the immediate area to have an impact and still pose a risk to the Queensland coast. Following the Hunga Tonga-Hunga Ha'apai eruption in January 2022, a tsunami warning was issued for the entire east coast of Australia with 1 metre waves reaching the coast. [23] Warnings were also issued for New Zealand, Canada, Japan, and the United States. Waves over a metre high reached Japan, prompting 230,000 residents to evacuate. In Vanuatu, waves reached up to two-and-a-half metres high and caused widespread damage. [23]

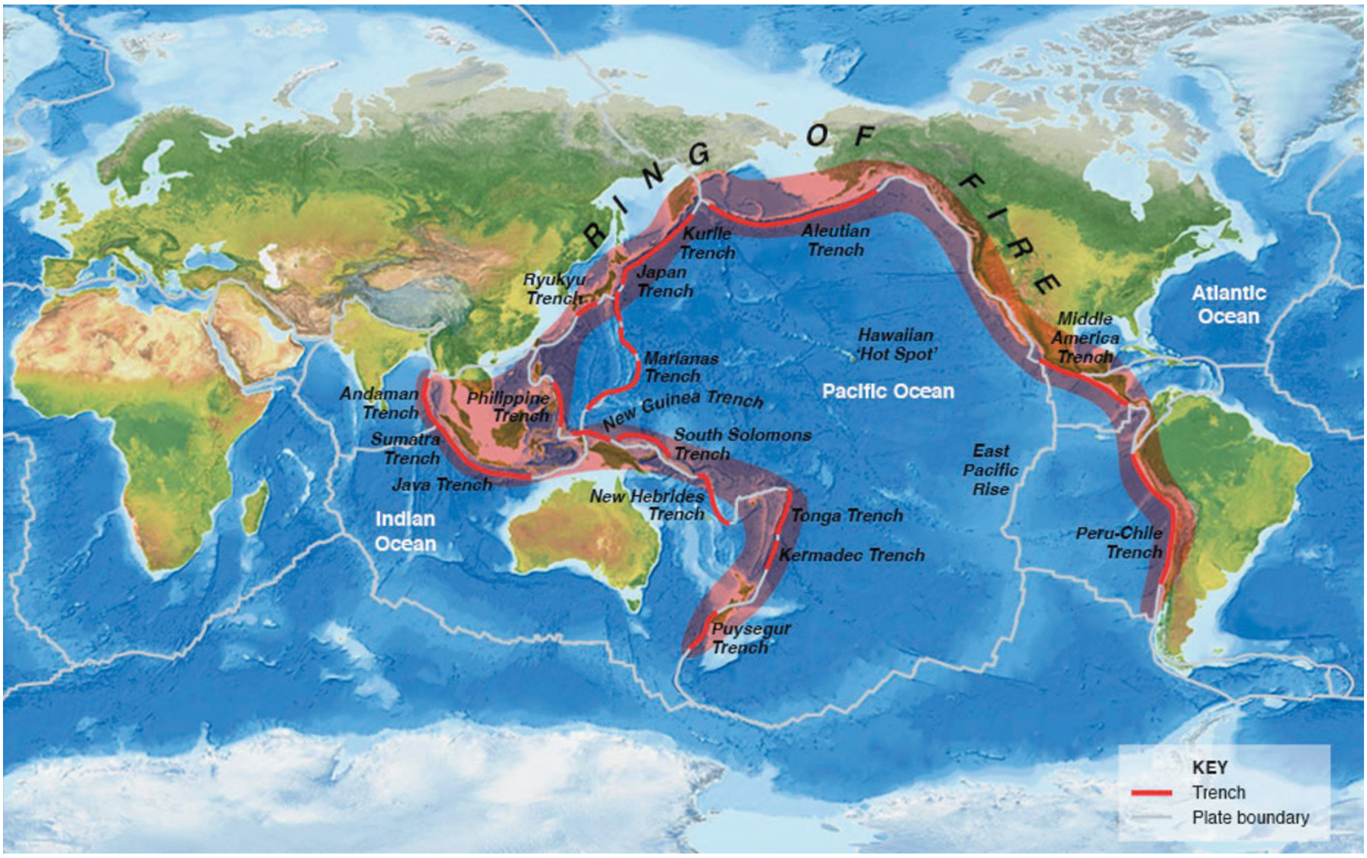


Figure 12: Pacific Ring of Fire, showing potential source zones for a tsunami generated by a volcanic eruption. Source: AIDR

Another notable event was the 1883 Krakatoa eruption in Indonesia, the eruption generated a 37m high tsunami wave in the Sunda Strait killing 36,000 people. In 1927 Krakatoa erupted again as an underwater volcano, killing 437 people and injuring 32,000. Both the Krakatoa and the Hunga Tonga-Hunga Ha'apai eruptions were volatile and difficult to predict through tsunami warning systems, as the eruptions generated meteotsunami in addition to a seismic tsunami.[24, 25, 26]

Available data indicates that many volcanoes in the region have the potential to generate tsunami events, perhaps even meteotsunami.[27] However, information is limited and there is not a clear understanding of the potential for impact to Australia. Based on previous events, there is strong precedence to conduct further research in order to increase awareness and inform decision making and planning.

What is the history of tsunami from submarine landslides?

Historic submarine landslides are evident off the Queensland coast and research groups have identified areas where future landslides may be possible (as shown in Figure 13). A 2018 University of Newcastle report suggests estimates of return intervals for submarine landslide generated tsunami along the east coast region are between 1,500 to 15,000 years.[28]

It is likely that such an event would be triggered from a large undersea earthquake. However, the chance of such a large earthquake occurring within Queensland is very small. For example, there is less than 1% chance per year of a magnitude 6.0 earthquake occurring within any 100 x 100km area near the K'gari region.

There have been large earthquakes recorded in the vicinity of the Queensland coast, did they cause a tsunami?

At the time of the offshore Bowen earthquakes in 2016 and K'gari in 2015 there was public interest in the potential of a tsunami. Whilst these events are significant by Australian standards and have the potential to cause major damage if they were to occur near a populated area, no tsunami was generated. If you feel an earthquake near the Queensland coast, and it lasts longer than a minute, or is strong enough to knock you off your feet, move immediately to higher ground or as far inland as you can.

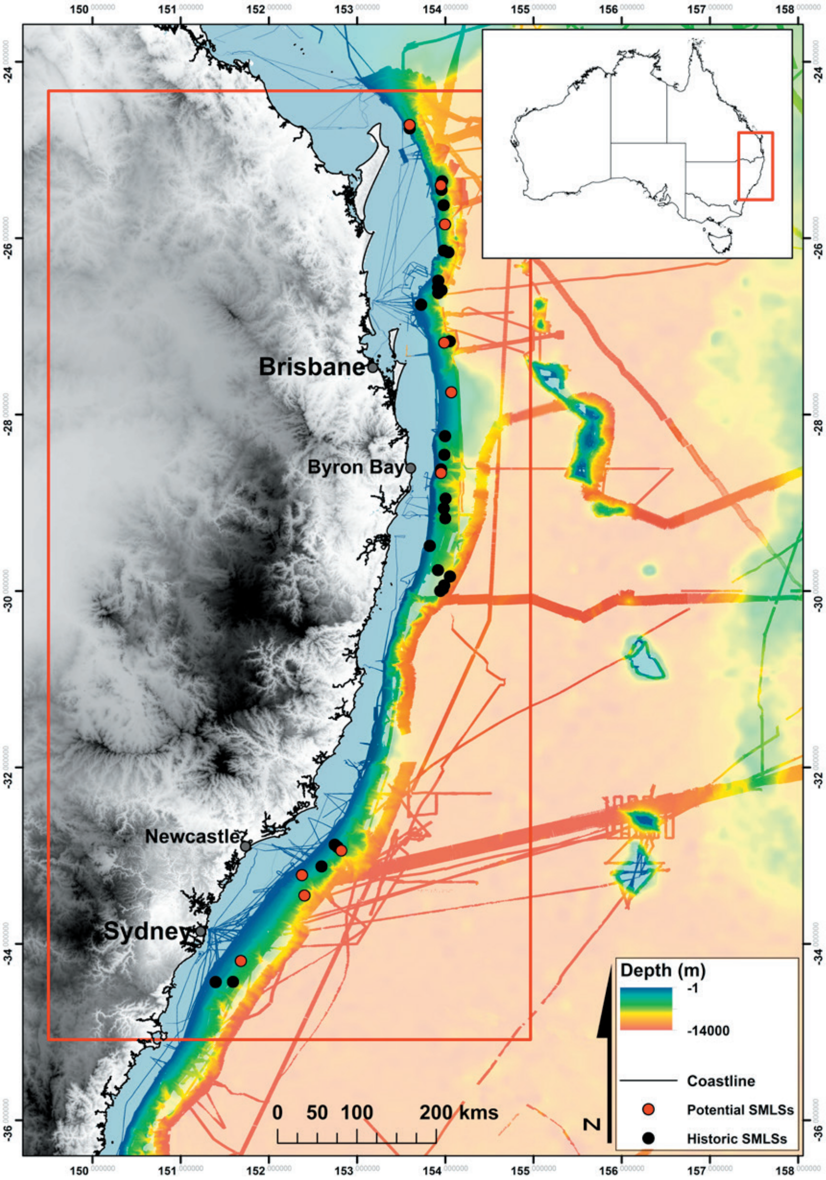


Figure 13: This illustration shows the location of historic submarine landslides with tsunamigenic potential (black dots) and potential future submarine landslides sites (red dots). The red box outlines the region containing submarine landslides with tsunamigenic potential. Slides with tsunamigenic potential were defined as those with dimensions of 50-250mm thick, 1km to >10km wide and in depths of 500-2500m. Source: Clarke et al. (2019) Eastern Australia's submarine landslides: implications for tsunami hazard between Jervis Bay and Fraser Island. Landslides.

Can tsunamis affect Moreton Bay or Hervey Bay?

Modelling by the Coastal Unit suggests that tsunami can propagate into these bays. The tsunami hazard is greater on the ocean side of the islands and the northern regions of the bays, with low lying areas vulnerable to tsunami. More information can be found at the Coastal assessment studies page of the Queensland Government website.[29]

Can tsunamis affect the Gulf of Carpentaria?

Tsunami generated outside the Gulf of Carpentaria can propagate into the Gulf, just as they can propagate throughout the ocean. However, the PTHA18 suggests that the Gulf has low exposure to earthquake generated tsunami compared with the rest of Australia. Broadly speaking, the shallow bathymetry around northern Australia makes it harder for tsunami energy to reach the Gulf coast.

Does the Great Barrier Reef protect Queensland from tsunamis?

Modelling suggests that small amplitude tsunami, such as that recorded by the Queensland Department of Environment, Science and Innovation's storm tide monitoring network during the 2007 Solomon Island event, can propagate over the reef. According to modelling of this event, the coral reefs delayed the tsunami arrival time by 5–10 minutes, decreased the amplitude of the first tsunami pulse to half or less, and lengthened the period of the tsunami.[30]

For larger amplitude events, some dissipation over the reef can occur but the tsunami can regain this energy through shoaling as it approaches the beach. The complex geometry and gaps between the many reefs within the Great Barrier Reef can also focus energy on particular stretches of coastline. Further information can be found at the Coastal assessment studies page of the Queensland Government website.[29]

What is the annual risk to Queensland's coastline from a tsunamis?

Any estimate about the annual risk to Queensland will be very uncertain, mainly because scientists do not have a precise understanding of how often large earthquakes, or other source events, occur in key locations of relevance to Queensland. Fundamentally, these difficulties stem from the fact that large tsunamis are rare on most coastlines, compared with the length of reliable historical records and instrumental measurements.

The assessment of the risk requires the development of tsunami inundation models. The hazard exposure will vary along the coast due to nearshore and coastline characteristics. Tsunami inundation modelling has been undertaken for the Sunshine Coast, Moreton Bay and Hervey Bay by the Department of Environment, Science and Innovation with the reports available at the Coastal assessment studies page of the Queensland Government website.[29]

However, these studies do not answer the question of what annual exceedance probability will result in a land risk as this will vary along the coast, depending on the nearshore characteristics that have transformed the waves, the topographic features that restrict wave run-up and the tidal cycle. There is also uncertainty associated with the offshore probabilistic hazard assessments.

Appendix A provides the earthquake sources that are considered to produce the most likely and credible worst-case scenarios for several locations at the 100-metre depth contour along the Queensland coast.

Could Queensland experience a tsunami at the scale of the 2004 Indian Ocean tsunami?

Tsunami are most often very damaging near the earthquake source. The 2004 Indian Ocean tsunami was so devastating in the Aceh province in northern Sumatra because this area is very close to a major subduction zone in southern Indonesia. However, tsunami can also be very damaging at intermediate and far distances from the source, depending on tsunami directionality.

For example, during the 2004 event, the tsunami still reached heights of around five to 10 metres in Somalia (about 5000 kilometres from the earthquake source), which led to around 300 deaths. Despite its distance from the source, the tsunami was well suited to direct energy to this region.

Historically there are multiple instances where tsunami directionality has led to large impacts far from the earthquake source. For example, Hawaii has repeatedly suffered damaging tsunami due to earthquakes in South America and the Aleutian Islands in the northern Pacific.

Although Queensland is not located very close to major earthquake sources (the nearest being around 1500 kilometres away), it may still be vulnerable to a 'well directed' tsunami. Tsunami modelling undertaken by Coastal Unit showed maximum water levels of up to 10 metres could occur on the ocean side of Moreton and North Stradbroke Islands during very extreme events (10,000-year Average Recurrence Interval).

We have not seen in modern times an event in the southwest Pacific of a similar magnitude, but it may be possible. We do not know what the impacts would be until further studies are undertaken.

Could a tsunami propagate up rivers and waterways?

Modelling undertaken by Coastal Unit indicates that tsunami can travel up rivers and waterways for considerable distance but the waves reduce as they enter the waterway and continue to reduce as they travel upstream. This has been supported by measurements of actual events such as the storm tide gauge at Mooloolaba in the Mooloolah River that measured tsunami waves during the Solomon Island event in 2007. Although the waves reduce, waterways are susceptible to inundation in low lying areas. Modelling suggests that wave penetration into rivers and waterways is affected by the period of the waves, with longer period waves like those originating in South America penetrating further inland with less reduction in wave height.

Risk considerations

Are ports and marinas vulnerable to tsunami?

Coastal infrastructure, such as ports, harbours and marinas, may be affected during a tsunami. Strong currents can develop within ports and harbours, even if there is no land risk, damaging vessels and facilities, and causing substantial erosion. Abnormal tides may occur also leading to damage or sinking of moored vessels, which can in turn damage marine infrastructure. Resonance or seiches can also form in enclosed harbours and marinas, exacerbating the effect.

As an example, the 1960 Chile event generated a tsunami that impacted parts of the New South Wales coastline. The tsunami was observed at the Fort Denison tide gauge within Sydney Harbour, with damage to leisure craft in the Sydney area and evidence of erosion within the harbour. [31]

Impacts were observed in Geraldton Harbour, Western Australia following the 2004 Indian Ocean tsunami and large container ships in the Oman port – some 6000 kilometres from the earthquake event itself – were impacted. Further, the 2011 Japan tsunami caused damage to vessels and port facilities within California.

More recently, significant damage from the tsunami generated by the Hunga Tonga-Hunga Ha'apai eruption resulted in 50 vessels being damaged in Tonga with many sinking, and berths becoming detached.

What other impacts to infrastructure are likely?

Anything located within the impact area has the potential to be damaged, depending on the severity of the event.

Roads and transport infrastructure (including runways) may experience scouring and damage from inundation, cutting off access which is important for repairs, access and resupply operations. The movement of debris (such as boats, cars, trees, etc.) can occur as the tsunami pushes water inland, creating further hazards for the community during and after the event. Waste, wastewater, and chemicals could be spread over a large area, putting people's health and safety at risk and causing significant damage to the environment.

How much warning time will there be?

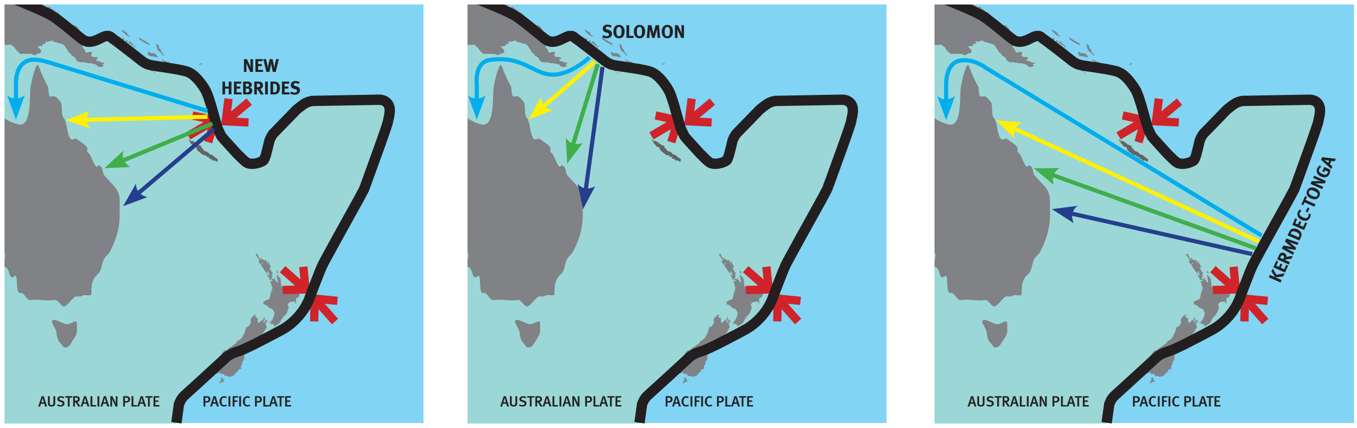
The Joint Australian Tsunami Warning Centre, or JAWTC, is jointly operated by Geoscience Australia and the BoM. Geoscience Australia detects earthquakes, determines the potential for these earthquakes to generate tsunami and then advises BoM within 10 minutes of the earthquake occurring. BoM then uses its network of sea level monitoring equipment to confirm the existence of a tsunami and uses tsunami models to estimate the risk level at the Australian coast. BoM issues the relevant tsunami warnings and bulletins to emergency management agencies and the public, giving 90 minutes' notice (when possible) to move away from the coast and travel to higher ground.

There may not be time for a warning for a tsunami generated by a submarine landslide. Travel time is expected to be generally less than 30 mins for submarine landslides off the Queensland coast. If there are at least 5 public reports of a earthquake being felt, the JATWC will issue a warning.

In the case of a tsunami generated by a volcanic eruption, the JATWC will monitor the sea level monitoring network and provide advice accordingly.

The time for a tsunami to travel from source to shore depends on the depth of the ocean, the nearshore environment and the travel distance. More specifically:

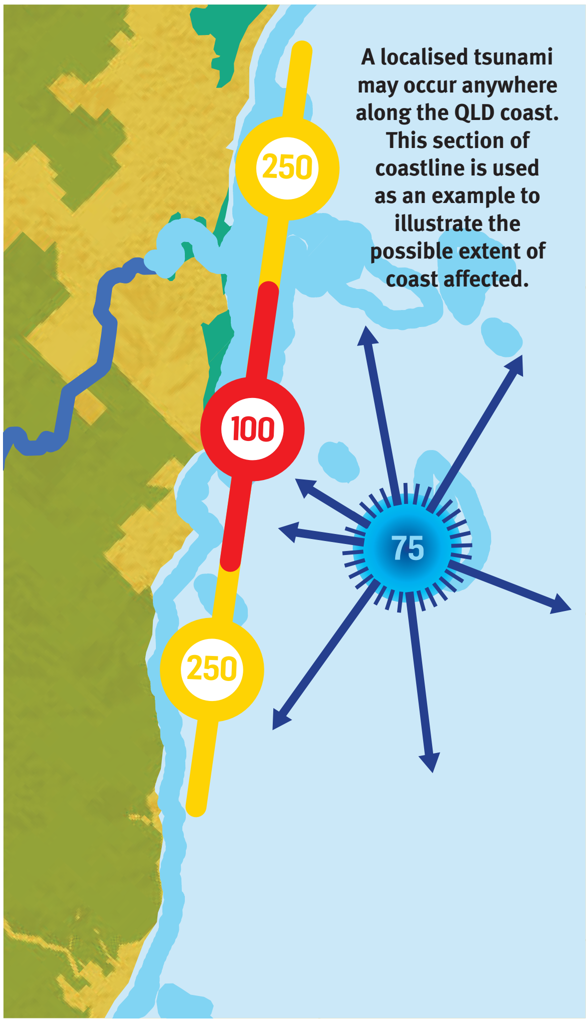
- The nearest subduction zone to Queensland is the New Hebrides and Solomon Islands with travel times of three to four hours. The Kermadec-Tonga Trench travel times are between four and six hours and tsunami from Chile can take 14 hours or more.[21]
- Tsunami generated from submarine landslides will have much shorter arrival times due to their proximity to the coast. As an example, if a submarine landslide tsunami had been generated by the August 2016 magnitude 5.8 earthquake about 60 kilometres off the Bowen coastline, it would have taken around 30 minutes to impact the shoreline.
- If a volcanic event generated a meteotsunami, travel times may be much faster, particularly as waves approach a shallow continental shelf or closed body of water.[6] This was observed for the Hunga Tonga-Hunga Ha'apai eruption, where tsunami waves were expected to impact Japan at 10:30pm local time but were picked up by advanced early warning systems at 8:20pm.[24]
- Figures 14 and 15 illustrate the difference in travel time from a regional earthquake-tsunami and a local submarine landslide-tsunami.



	● GOLD COAST	● YEPPOON	● CAIRNS	● MORNINGTON ISLAND
NEW HEBRIDES	› 2.1-3.5 hrs	› 4.8-6.5 hrs	› 3.3-4.9 hrs	› 17.2-19.2 hrs
SOLOMON	› 2.7-4.2 hrs	› 3.9-5.3 hrs	› 1-3 hrs	› 14.3-17.1 hrs
KERMADEC-TONGA	› 3.3-6.3 hrs	› 7.3-10.1 hrs	› 5.7-8.6 hrs	› 20.1-23.1 hrs

› = *Initial tsunami wave will arrive during this time.*

Figure 14: Travel times for regional earthquake-tsunami from the Solomon, New Hebrides and Kermadec-Tonga trenches. Note: These travel times are derived from models and are based on the initial tsunami arrival offshore. They do not consider the time required for the tsunami to propagate close to shore, or the fact that the tsunami may consist of multiple waves lasting for hours or days. Therefore, these travel times are not suitable when determining when the largest waves will arrive, or when the tsunami risk has passed. Source: Produced by QFES with assistance from Geoscience Australia



A localised tsunami may inundate the coastline within **18-60 minutes** of landslide collapse that would vary with distance from the slide

100 Up to 100km of the coastline may experience current speeds in excess of **4-10m/s** and wave amplitudes of in excess of **4-10m**

250 250+ km of coastline may experience currents speeds greater than **2m/s** and wave amplitudes of over **1m**

Inundation and high current speeds could occur in low-lying areas

75 An area of ocean, centred on the continental slope above the tsunami source with a radius in excess of **75km** would be extremely hazardous for vessels

A leading negative amplitude wave may cause ocean drawback, providing a 4-5min warning before inundation. Some areas may have a leading positive wave with no prior ocean drawback

Figure 15: Indicative diagram representing the travel times and possible impacts from a localised submarine landslide generated tsunami event on the Queensland coast. Produced with assistance from Associate Professor Hannah Power, University of Newcastle

What will a warning look like? What do the warning levels mean?

The Australian Tsunami Warning System (ATWS) has three levels of tsunami warning for Australia.

Table 2: Tsunami warnings and definitions

Watch	A tsunami watch is to advise people that a tsunami threat may exist, and updates should be monitored in case the situation changes.
Marine Warning	Warning of potentially dangerous rips, waves, and strong ocean currents within the marine environment. Included in a marine warning is the possibility of some localised overflow onto immediate foreshores in affected areas.
Land Warning:	Warning for low lying areas along the coastline for major land inundation and flooding. Dangerous rips, waves, and strong ocean currents.

Figure 16: Example of a tsunami warning from the Australian Tsunami Warning System, published in response to the Hunga Tonga-Hunga Ha'apai volcanic eruption in January 2022. Source: Bureau of Meteorology

What are other warning signs of a tsunami?

It is important to pay attention to any tsunami alerts or marine warnings issued for an area. In addition, some natural warning signs to be aware of include:

- Receding water near the coastline before returning.
- A roaring sound may precede the arrival of a tsunami.
- Abnormal tides and currents.
- Increased boat movement may be evident in ports and marinas.
- Long and strong earthquakes.
- Abnormally large initial waves.

Which areas do we expect to be impacted?

There is limited information to understand the extent and likelihood of tsunami inundation around Australia. Since tsunami inundation is so dependent on the nature of the nearshore environment, it is difficult to estimate the extent of tsunami inundation. The Australian Tsunami Warning System provides general advice in the absence of detailed modelling which is based on the rule of thumb of 1km inland and 10m elevation.

The Queensland tsunami evacuation mapping has been developed using this general advice and incorporates detailed inundation modelling where it is available. As more detailed inundation modelling is completed, this mapping will be updated. The mapping identifies broad areas for evacuation in the event of a tsunami warning, to support community warnings and risk-informed planning. This mapping does not include any information relating to the tsunami depth or speed, or the likelihood. Until more detailed modelling is available, it is uncertain to whether this mapping is an overestimate or underestimate.

Unlike the New Zealand tsunami evacuation mapping[32], the Queensland tsunami evacuation mapping is not aligned to size of a tsunami. There is national recognition that the general advice would result in a significant evacuation challenge for a land inundation warning. As a result, efforts are underway to develop an evidence-based approach to refine the evacuation zones.

What can local and state governments do?

Understanding the local tsunami hazard is an important first step in managing tsunami. As noted previously, the PTHA18 provides an indication of what the offshore wave height might be for a range of different annual exceedance probabilities and this information can be used as input into detailed studies to understand the tsunami hazard onshore.

High quality onshore and nearshore elevation data is required to model tsunami inundation and nearshore behaviour with accuracy. Lower resolution global datasets are generally only suitable for modelling oceanic scale tsunami propagation. If good quality elevation data is unavailable, then advanced tsunami models may be of little benefit compared with crude geometric models such as the bathtub, or attenuation rules of thumb.

If local governments wish to pursue modelling within their area, the Department of Environment, Science and Innovation’s Coastal Unit can provide technical advice as they do for other coastal hazards, such as storm tide. Local governments should also refer to the Tsunami Hazard Modelling Guidelines.[7]

What can be done to protect the coast from tsunami?

There have been numerous nature-based and man-made solutions implemented globally to safeguard coastlines from flooding caused by rising sea levels, storm surges, and tsunami. Typical protection measures used to protect coastal areas from inundation usually involve grey infrastructure, such as sea walls and breakwaters. After the 2011 Tohoku earthquake and tsunami, there has been significant investment in constructing sea walls along the Sendai coast as a response.

Nature-based solutions encompass the use of mangroves, seagrasses, and the restoration of coastal dunes. Healthy ecosystems act as a natural barrier, with dense mangrove and scrub forest responsible for saving many lives and properties in Sri Lanka during the 2004 Indian Ocean tsunami.[33] In a similar manner, after Typhoon Haiyan in 2013, the Philippine Government initiated a significant project to replant a large portion of the impacted coastal area with mangroves.[34] This initiative aimed to establish a robust natural barrier against storms, flooding, coastal erosion, and powerful waves. Offshore reefs can also act as natural barriers and have a significant role in reducing impact on the community, as shown during the 2007 Solomon Islands event. The United Nations Office for Disaster Risk Reduction has produced a guideline dedicated to nature-based solutions, acknowledging them as crucial and effective measures to reducing risk.[35] These solutions are often easy to implement, cost-effective, and can engage local communities.

What can the public do?

Tsunami causing events are unpredictable and highly variable, and warning systems depend on timely and accurate information. In the 2011 Great Tohoku earthquake and tsunami approximately 100 tsunami shelters were affected by the tsunami, putting the community at risk.[36] This section highlights actions and mitigation strategies the public can take to prevent, prepare, respond, and recover in the event of a tsunami.

Prevent

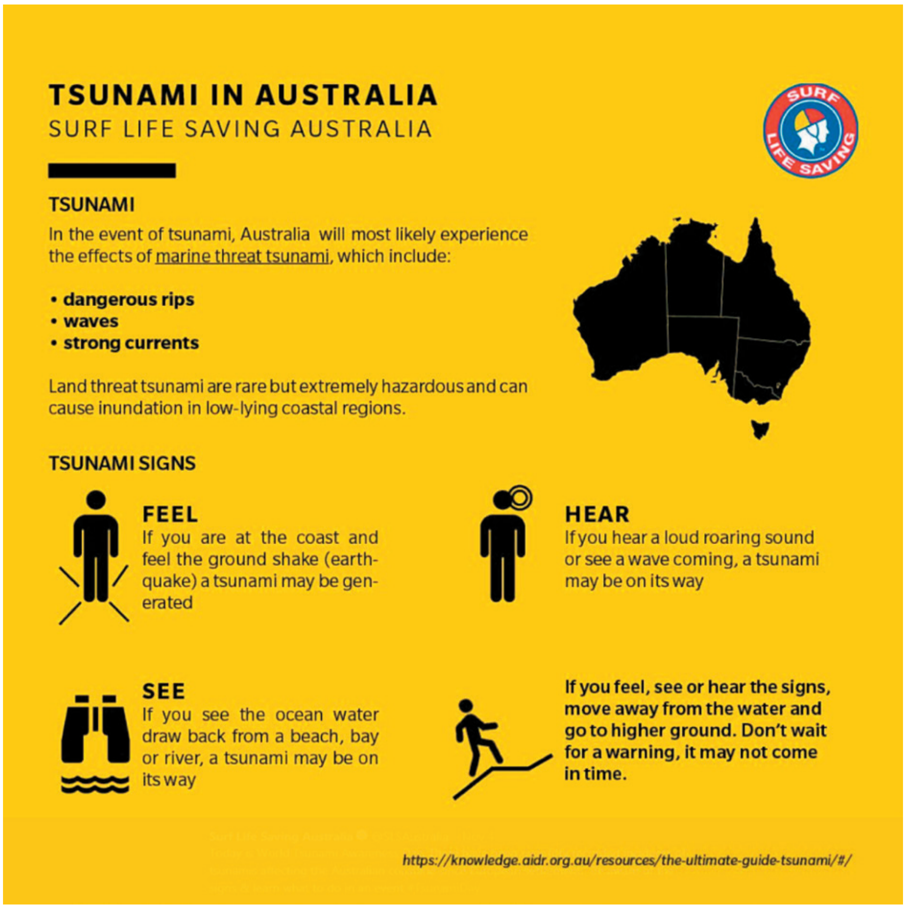
Community education and awareness is key to preventing significant impacts from a tsunami. During the 2004 Indian Ocean tsunami in Thailand, 10-year-old Tilly saved hundreds of lives after she was able to recognise and warn of the signs of a tsunami after being taught about tsunamis at school.[2] Involvement in local land-care and restoration groups is another example of risk prevention, which aids in restoring natural tsunami barriers such as coral reefs, sand dunes, and mangroves which have been destroyed.

Several websites, tools, and factsheets exist for the public to gain an understanding and awareness of tsunamis:

- Get Ready Queensland keeps a host of information readily available to the public which can assist in their education.
- Geoscience Australia's YouTube channel is a valuable resource for tsunami and earthquake education. YouTube is also an excellent resource to watch past tsunami footage to understand how fast and severe a tsunami event can occur.
- Council disaster dashboards may contain information to assist the community in understanding their risk at a local level.
- Local libraries and councils may have additional information, tsunami history, and plans available.

Prepare

In the event of a tsunami no warning may be given and there may be little time to respond. It is important to be prepared. The below Surf Life Saving Australia's Tsunami in Australia factsheet (Figure 17) provides key information on what to do if you suspect a tsunami may occur. The Queensland Government also provides important and clear messaging on how to prepare for and respond to tsunami which is available on the Queensland Government's 'Preparing for Disasters' website.[37]



TSUNAMI IN AUSTRALIA
SURF LIFE SAVING AUSTRALIA

TSUNAMI

In the event of tsunami, Australia will most likely experience the effects of marine threat tsunami, which include:

- **dangerous rips**
- **waves**
- **strong currents**

Land threat tsunami are rare but extremely hazardous and can cause inundation in low-lying coastal regions.

TSUNAMI SIGNS

FEEL
If you are at the coast and feel the ground shake (earthquake) a tsunami may be generated

HEAR
If you hear a loud roaring sound or see a wave coming, a tsunami may be on its way

SEE
If you see the ocean water draw back from a beach, bay or river, a tsunami may be on its way

If you feel, see or hear the signs, move away from the water and go to higher ground. Don't wait for a warning, it may not come in time.

https://knowledge.aidr.org.au/resources/the-ultimate-guide-tsunami/#/

Figure 17: Surf Life Saving Australia Tsunami factsheet

Other key actions to take include:

- Check with local councils about local warning systems, evacuation process and nominated evacuation routes:
    - The Joint Australian Tsunami Warning Centre (JATWC) warnings page can be found at http://www.bom.gov.au/tsunami/index.shtml. This webpage also contains warning statuses for countries surrounding the Indian Ocean
    - The Queensland Government has developed an evacuation map for the states coastline and identifies broad areas of evacuation: www.qfes.qld.gov.au/prepare/tsunami/evacuation-areas.
    - Local disaster management dashboards may contain further information on alerts and beach conditions.
- If living in a flood-prone area or evacuation zone, consider making arrangements to stay with friends on higher ground in the event of a tsunami.
- Ask about emergency and evacuation plans at workplaces, schools, and childcare providers. Check if they need details of individual household emergency contacts.
- Develop personal evacuation plans, have an emergency kit ready, and discuss emergency plans with family and friends, especially those with vulnerabilities (for example, accessibility, age, physical or mental health, language skills).

Respond

- Key messaging indicates that if you feel the ground move, see the water draw back, hear a loud rumbling, or hear sirens you should relocate to higher ground immediately and listen to the local radio station for further messaging, warning, and advice.[2]
- The New Zealand National Emergency Management Agency has developed the communication message of ‘Long or Strong: Get Gone” which provides an excellent overview for personal protection. More information is available at New Zealand Get Ready website.[32]
- If members of the public are unable to evacuate in time, prior to waves making impact, the messaging explains to seek shelter in the upper story of a brick or concrete building. These buildings traditionally have a much higher impact tolerance compared to timber dwellings. The general rule of thumb for tsunami is 1km inland or 10m in height.
- The Queensland Government webpage provides more information on how to respond should you be in or on the water, or at work : https://www.qld.gov.au/emergency/dealing-disasters/disaster-types/tsunami

Recover

- Heed all warnings and do not return to an area until told to do so.
- Continue to listen to the local radio station and heed all warnings and advice.
- Follow all instructions from emergency services and authorities.
- Beware of any secondary effects such as contaminated water, damaged or flooded buildings, and lighting matches or appliances for gas leaks or flammable liquids.
- Only make calls if you require emergency services.
- Remember more waves may follow the first wave, and the largest wave may not be the first wave.[38]

Sources of additional information

Much of the information supplied in this tsunami guide comes from Geoscience Australia and tsunami modelling reports prepared by the Queensland Department of Environment, Science and Innovation, available from:

- https://www.qld.gov.au/environment/coasts-waterways/beach/studies-tsunami

State and National Resources

- Tsunami: Get Ready Queensland - https://getready.qld.gov.au/natural-disasters/tsunami/
- Queensland Tsunami Notification Manual - https://www.disaster.qld.gov.au/dmg/st/Documents/M1183-Queensland-Tsunami-Manual.pdf
- AIDR Tsunami Emergency Planning in Australia Handbook and companion document – https://knowledge.aidr.org.au/resources/tsunami-planning-handbook
- Tsunami: The Ultimate Guide – https://knowledge.aidr.org.au/tsunami-the-ultimate-guide
- Tsunami Hazard Modelling Guidelines – https://knowledge.aidr.org.au/resources/tsunami-planning-handbook
- Australian Tsunami Advisory Group (ATAG) – https://knowledge.aidr.org.au/resources/australian-tsunami-advisory-group
- The 2018 Probabilistic Tsunami Hazard Assessment – www.ga.gov.au/ptha
- Geoscience Australia tsunami page – http://www.ga.gov.au/scientific-topics/hazards/tsunami
- Geoscience Australia tsunami videos – https://www.youtube.com/watch?v=ILlyfwDwJVs&feature=youtu.be
- Bureau of Meteorology tsunami page – http://www.bom.gov.au/tsunami
- Tsunami evacuation areas for Queensland - https://www.qfes.qld.gov.au/prepare/tsunami/evacuation-areas

International resources

- UNDRR World Tsunami Awareness Day 5 Nov – https://www.unisdr.org/tsunamiday
- UNDRR International Day for Disaster Risk Reduction 13 October – https://www.unisdr.org/we/campaign/iddr
- NOAA National Centre for Environmental Information – Tsunami Data and Information – https://www.ngdc.noaa.gov/hazard/tsu.shtml
- IOC Tsunami Programme IOC – http://www.ioc-tsunami.org/index.php
- Tsunami: The Tsunami Story – https://www.tsunami.noaa.gov/tsunami_story.html
- International Tsunami Information Center – http://itic.ioc-unesco.org/index.php
- Tsunami: Produced by the COMET Program – http://www.torbenespersen.dk/Publish/tsunami/index.htm

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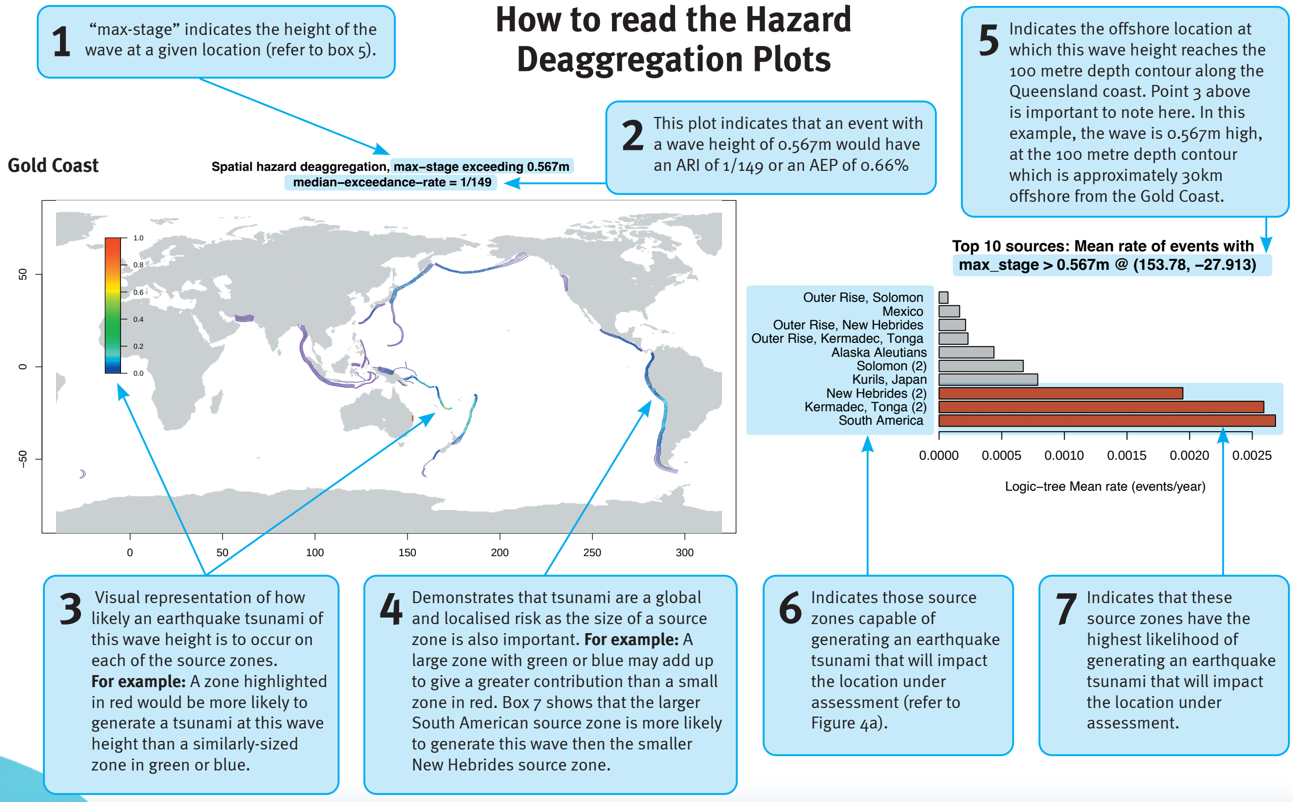
Appendices

Appendix A: Applying the PTHA18 in Queensland

How to understand and interpret the plots:

1. These plots depict the subduction zones most likely to generate an earthquake-tsunami affecting the given locations in Queensland.
2. These de-aggregation maps (depicting a most likely and credible worst-case scenario for each location) reflect a combination of two factors:
   a) How likely a large earthquake is to occur on each source-zone; and
   b) How well placed that source-zone is to direct tsunami waves to the site of interest.
3. We cannot directly go from information in these plots to an understanding of the onshore impact without undertaking nearshore and inundation modelling such as that undertaken by the Coastal Unit, Department of Environment, Science and Innovation. Although there will be some correlation between the 'maximum stage' and the onshore impacts, it is far from precise because other aspects of the wave train also affect inundation.
4. There are two primary approaches to undertaking tsunami inundation modelling. The first approach is to model a select number of events representing the main source zones that contribute to the hazard at a given location as well as several probabilities of occurrence. The second approach is to model thousands of events that contribute to the hazard at the site to develop probabilistic inundation mapping. There are advantages and disadvantages to each approach. The first approach is less computationally demanding, and it allows the modeller to examine key characteristics of events from a given source zone. For example, the Gold Coast study undertaken by the Coastal Unit of the Department of Environment, Science and Innovation found that the long period waves from South America were similar to the shelf resonance period of the study area, resulting in increased tsunami heights with subsequent waves. It also showed that longer period waves penetrate further into waterways, increasing the inundation of low-lying areas. The second approach provides a better indication of probabilistic inundation but requires more computational power. For further information on these two approaches, refer to Giblin et al. (2022).[39] Inundation models should include areas offshore of the shelf to allow for coastal process including shelf trapped waves.
5. In general, the exposure of Queensland to offshore tsunami is "moderate" by Australian standards, at least for these distant earthquake sources. There is a general decrease in the offshore wave heights for fixed return period and depth heading north along the Queensland coast.



How to read the Hazard Deaggregation Plots

1 "max-stage" indicates the height of the wave at a given location (refer to box 5).

2 This plot indicates that an event with a wave height of 0.567m would have an ARI of 1/149 or an AEP of 0.66%

5 Indicates the offshore location at which this wave height reaches the 100 metre depth contour along the Queensland coast. Point 3 above is important to note here. In this example, the wave is 0.567m high, at the 100 metre depth contour which is approximately 30km offshore from the Gold Coast.

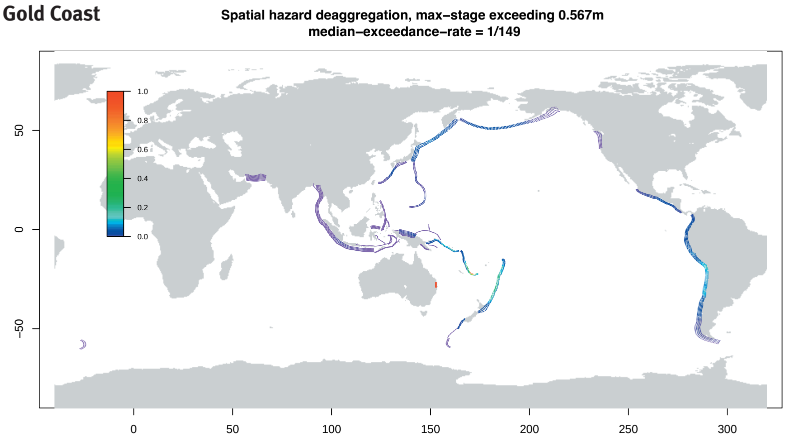
3 Visual representation of how likely an earthquake tsunami of this wave height is to occur on each of the source zones. **For example:** A zone highlighted in red would be more likely to generate a tsunami at this wave height than a similarly-sized zone in green or blue.

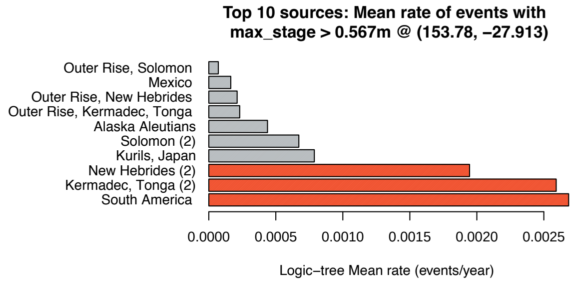
4 Demonstrates that tsunami are a global and localised risk as the size of a source zone is also important. **For example:** A large zone with green or blue may add up to give a greater contribution than a small zone in red. Box 7 shows that the larger South American source zone is more likely to generate this wave then the smaller New Hebrides source zone.

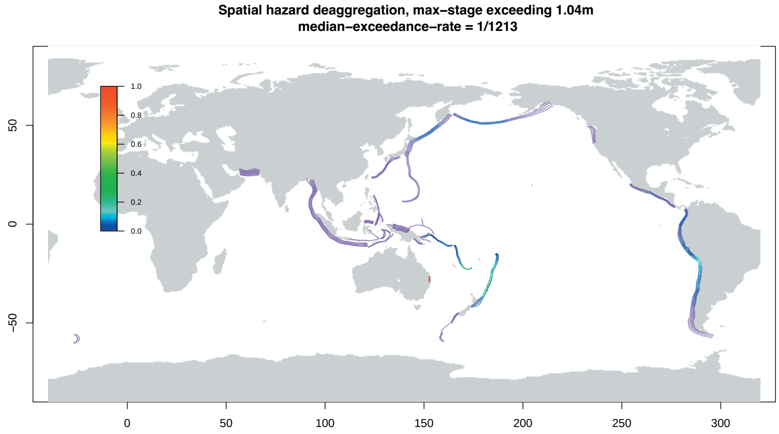
6 Indicates those source zones capable of generating an earthquake tsunami that will impact the location under assessment (refer to Figure 4a).

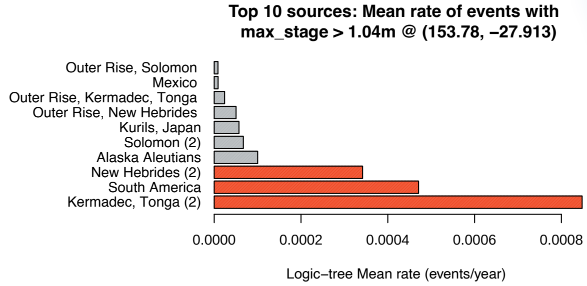
7 Indicates that these source zones have the highest likelihood of generating an earthquake tsunami that will impact the location under assessment.

Gold Coast

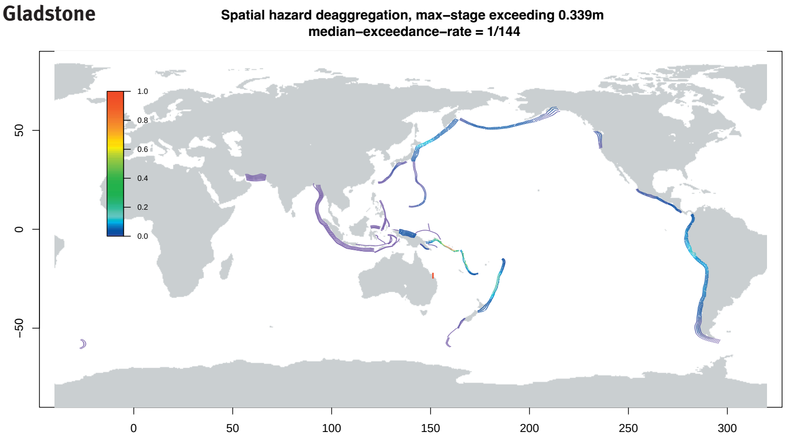


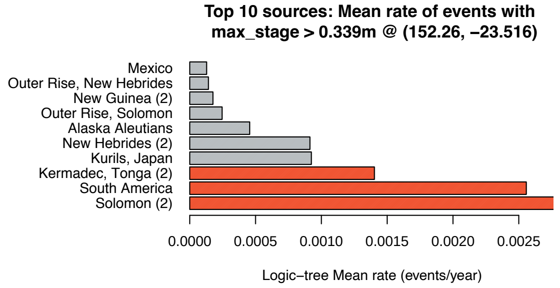


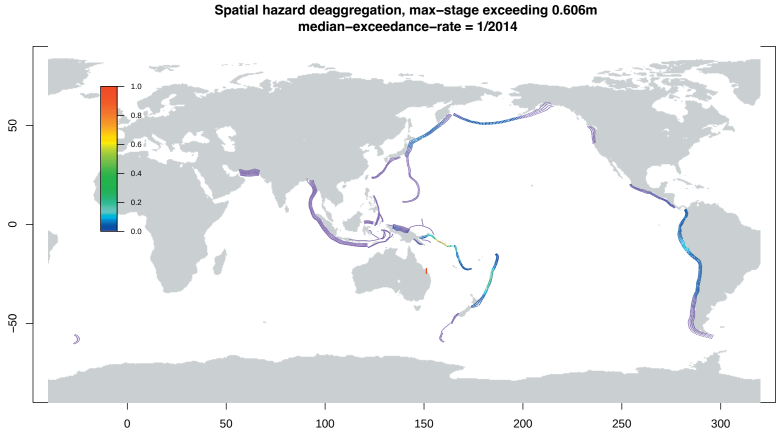


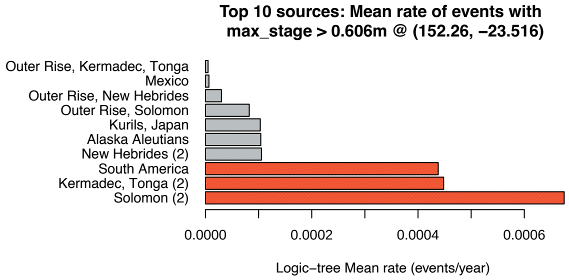


Gladstone



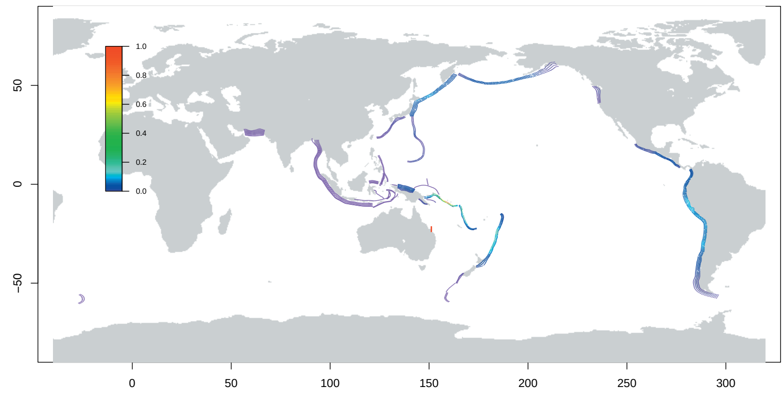




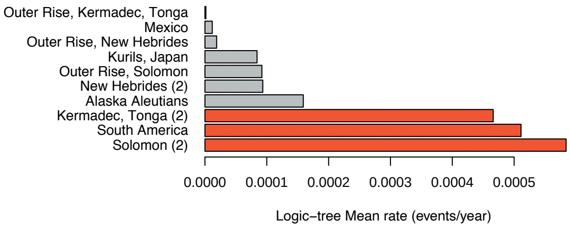


Yeppoon

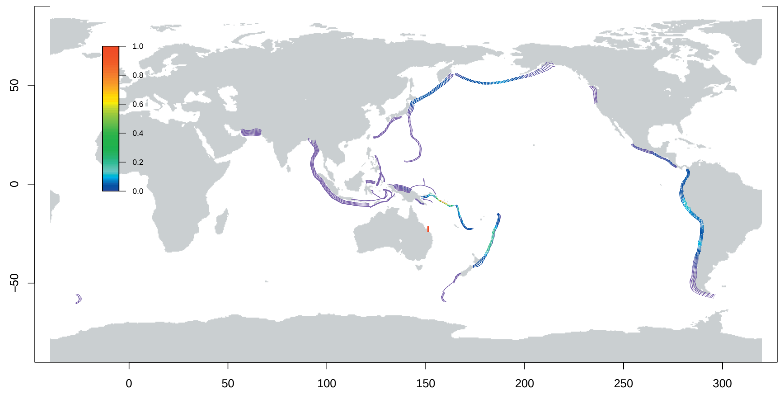
Spatial hazard deaggregation, max–stage exceeding 0.446m
median–exceedance–rate = 1/141



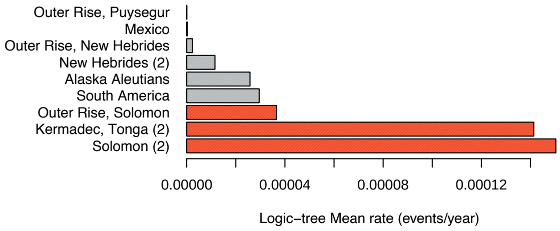
Top 10 sources: Mean rate of events with max_stage > 0.82m @ (152.193, −22.748)



Spatial hazard deaggregation, max–stage exceeding 0.82m
median–exceedance–rate = 1/1798

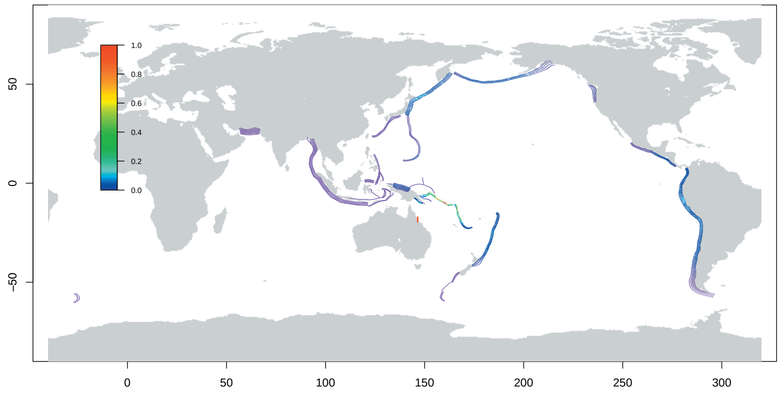


Top 9 sources: Mean rate of events with max_stage > 1.26m @ (152.193, −22.748)

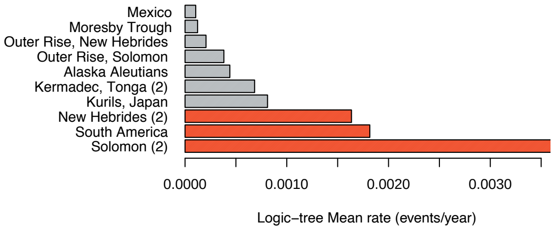


Townsville

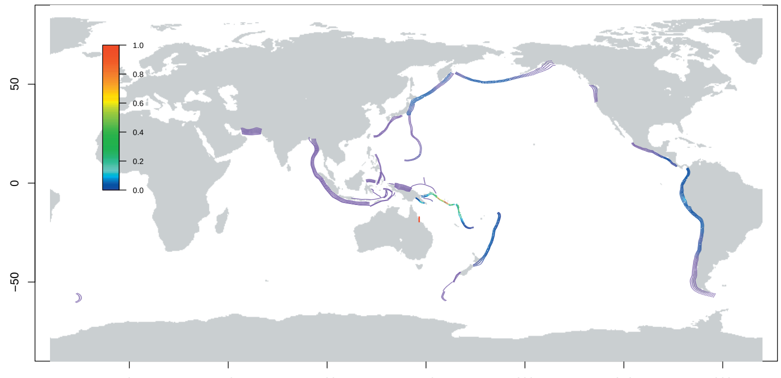
Spatial hazard deaggregation, max–stage exceeding 0.312m
median–exceedance–rate = 1/150



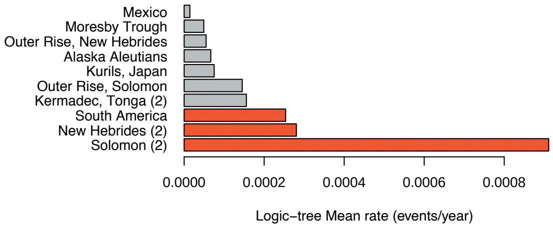
Top 10 sources: Mean rate of events with max_stage > 0.312m @ (147.566, −18.37)



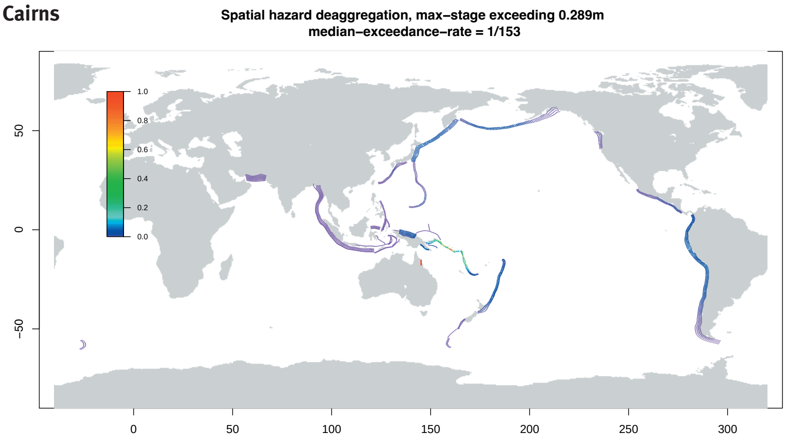
Spatial hazard deaggregation, max–stage exceeding 0.548m
median–exceedance–rate = 1/1964

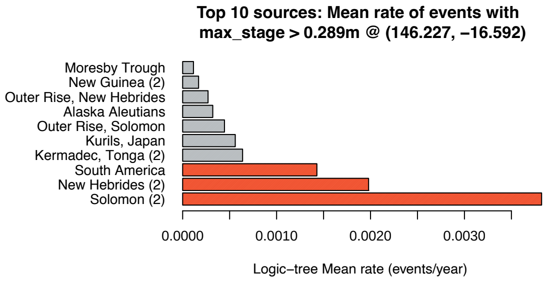


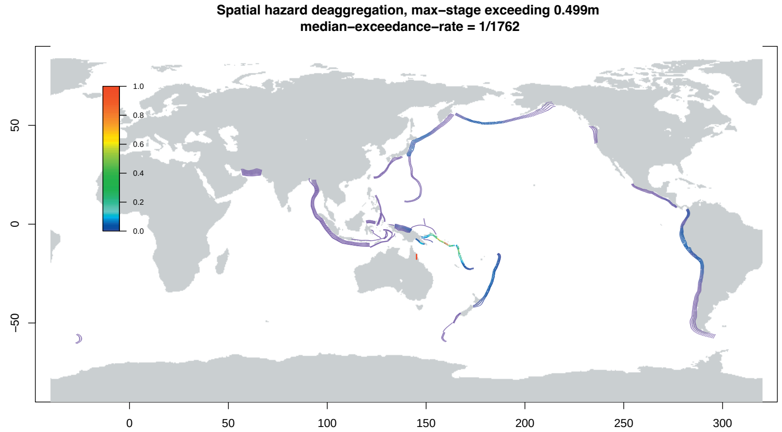
Top 10 sources: Mean rate of events with max_stage > 0.548m @ (147.566, −18.37)

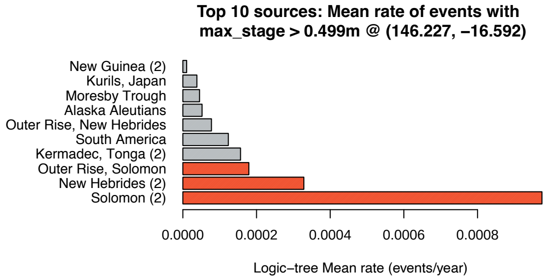


Cairns

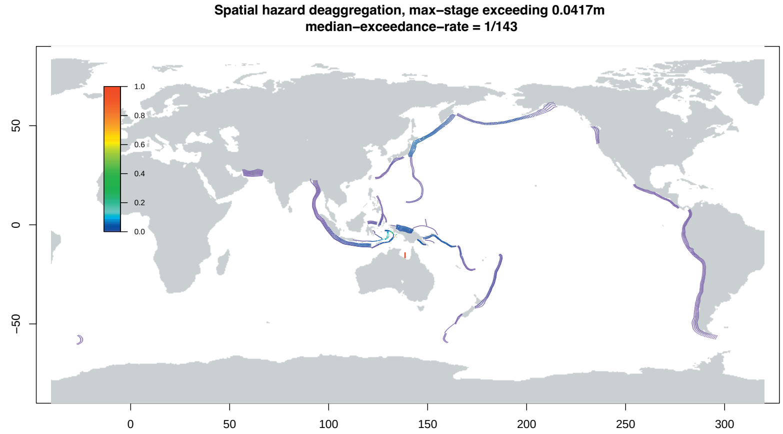


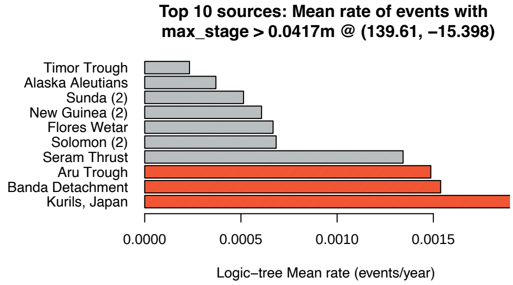


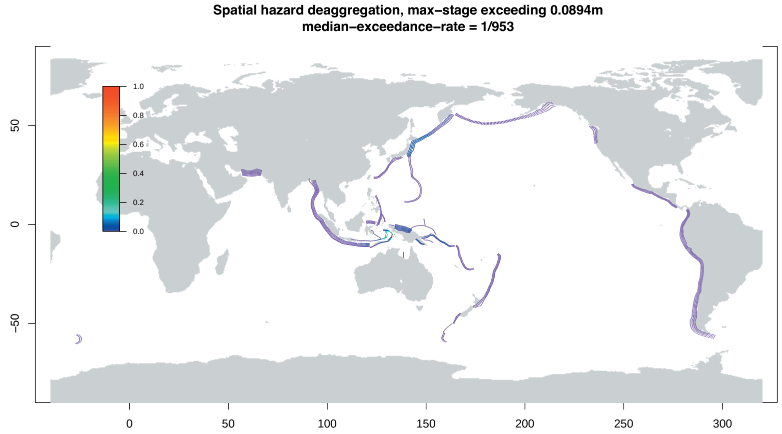


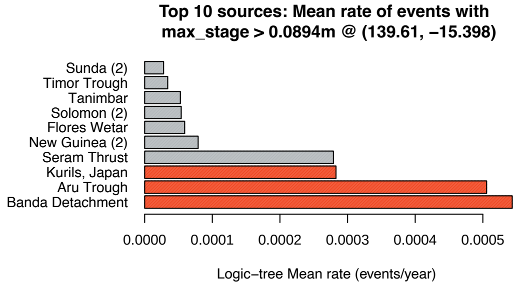


Karumba and Mornington Island









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