Small threat, but WARNING SOUNDED for *tsunami research*

Mention 'tsunami' and fear washes through coastal settlements in many southern Pacific islands. Australia rarely thinks about tsunamis, yet it has an enormous mainland coastline that is rapidly being populated.

There is an international tsunami warning system for the Pacific Ocean, but none for the Indian Ocean. How vulnerable is Australia to the risk of tsunami, and are we leaving our western coastal communities exposed?

Geoscience Australia has been modelling open-ocean propagation of earthquake-related tsunamis that may affect our western coastline.

Tsunami is a Japanese term that means 'harbour wave'. It is used worldwide to describe a large sea wave generated by sea-floor disturbance. Some spectacular tsunamis such as the 1883 Krakatoa and 1998 Aitape tsunamis were generated by sea-floor disturbances associated with volcanic eruptions or landslides. Subduction zone earthquakes, though, are the most common source of destructive tsunamis.

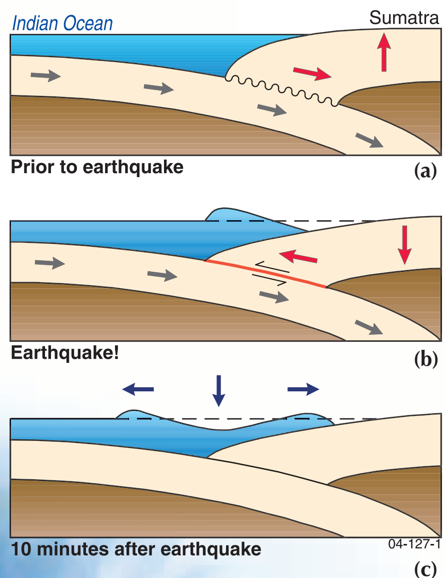


Figure 1. Subduction zone earthquakes are the most common source of destructive tsunamis. They are generated when **(a)** the lower subducting plate drags against the upper plate, causing flexure; **(b)** stress on the plate boundary causes the upper plate to rebound to its initial, un-flexed position, displacing the sea surface; **(c)** the displaced sea surface propagates outward as a tsunami.

The red arrows in **(a)** and **(b)** indicate the direction in which the upper plate is deformed due to drag and release of the lower plate.

Plate convergence

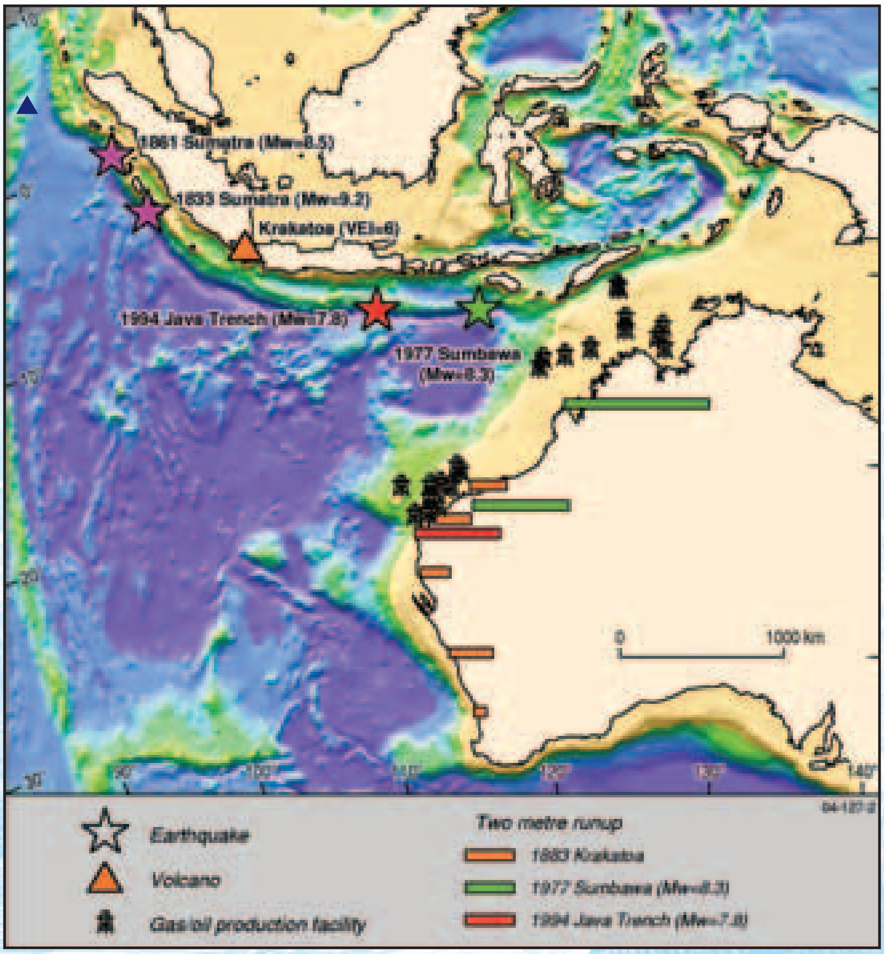
A subduction zone is where two of the Earth's rigid tectonic plates are converging towards one another; and one plate, usually composed of heavier oceanic material, dives beneath the other generally lighter plate of continental material (figure 1). At the boundary where these plates rub past each other, the lower plate drags upon the upper, flexing it slightly downward (figure 1a). When the flexing increases to the point where the stress on the plate boundary exceeds the frictional strength of the interplate contact, the upper plate rebounds to its initial, un-flexed position. This causes sea-floor displacement, which happens so quickly that it is initially reflected on the ocean's surface (figure 1b). This disturbance to the sea surface propagates outward as a tsunami (figure 1c).

In the deep ocean this wave travels at speeds of 300–500 kilometres/hour and may be only a few tens of centimetres to a metre or so in height. As it approaches shallow water, the wave speed slows dramatically and the height may increase to 10 metres or more.

Australian region

The Pacific Tsunami Warning Centre was established because several earthquake zones around the Pacific Rim generate earthquakes so massive that the associated tsunamis can affect the entire Pacific basin. Even the 1960 Chilean earthquake caused a one-metre high tsunami in Sydney. Australia, though, is not thought to be at high risk from tsunamis because most accounts relate to trans-Pacific tsunamis such as the Chilean event.

The most direct threat to Australia is to the north-west off Indonesia, where the Australian plate subducts beneath the Eurasian plate. This subduction zone is called the Sunda Arc.



Earthquakes off Java have caused large tsunamis which reached heights of four to six metres on Australia's north-west coast (the 1994 Java and 1977 Sumbawa earthquakes, respectively, see figure 2). These events caused little damage in Australia and no lives were lost. But population increases in north-western Australia and the substantial investment in oil and gas infrastructure along the Northwest Shelf (figure 2) suggest that the potential risk of tsunami merits further consideration.

Western Australia's economy would feel the impact if a tsunami affected Northwest Shelf oil and gas production.

Sunda Arc

There are two distinct zones for earthquake activity in the Sunda Arc. The 1977 and 1994 events mentioned above occurred in the eastern part of the arc, where relatively old (approximately 100 million years) oceanic lithosphere subducts offshore Java. Very few of the classical subduction zone earthquakes illustrated in figure 1 occur in this part of the arc—1994 being the only confirmed event of this type. The largest earthquake-generated tsunamis in the eastern Sunda Arc are actually normal faulting events in the Australian plate, in the 'outer rise' where the subducting plate bends prior to diving beneath Indonesia.

Figure 2. Tsunami-generated events off West Australia are colour-coded to match run-up observations. Mw is a logarithmic measure of earthquake size, similar to the Richter scale. VEI is the Volcanic Explosivity Index; Krakatoa with a score of six is one of the largest in recorded history. There are no recorded observations in Australia of the tsunami events of 1833 and 1861. Important areas of oil and gas production along the Northwest Shelf are shown.

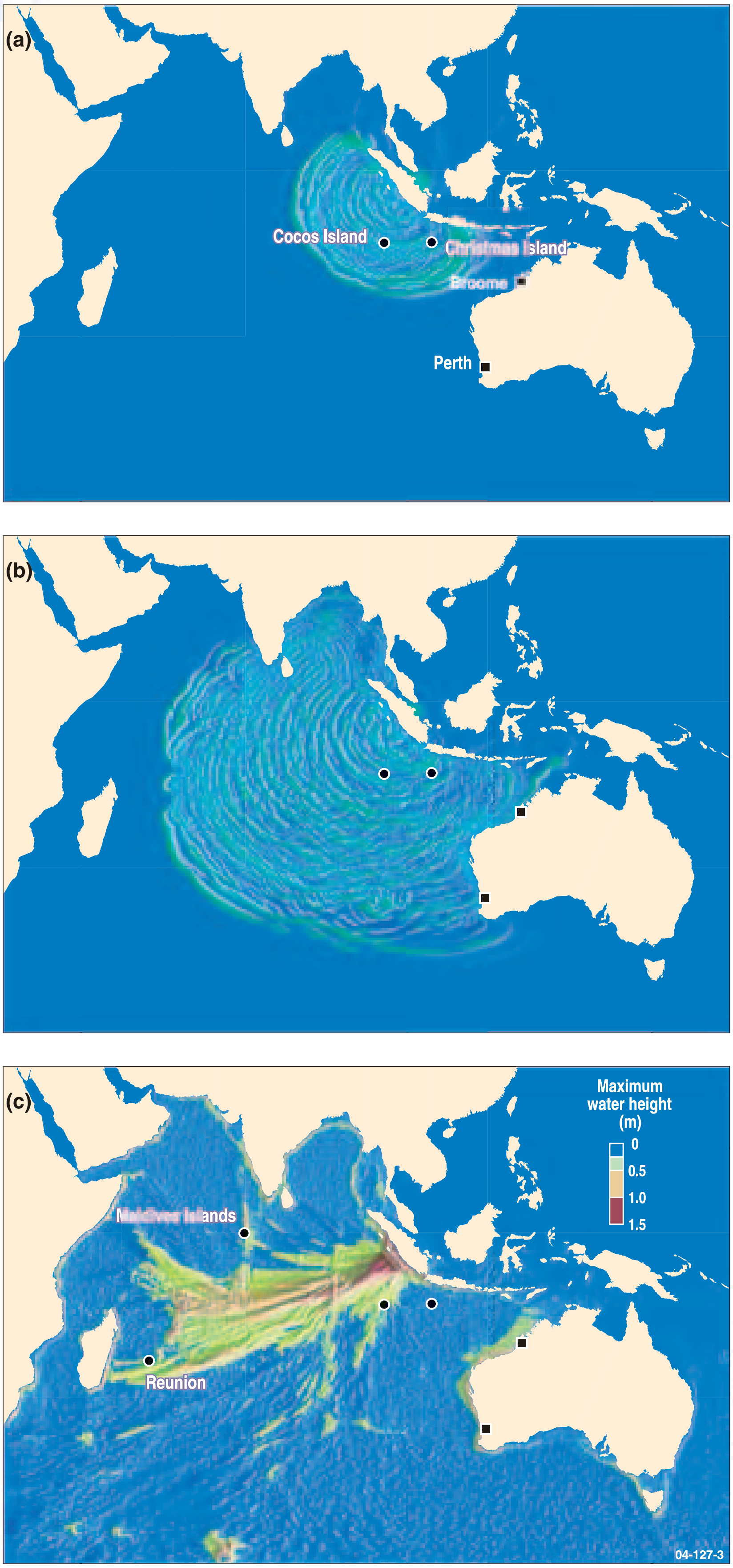


Figure 3. Results of numerical modelling of the open-ocean propagation of the tsunami associated with the 1833 Sumatra earthquake: **(a)** illustrates the tsunami's propagation in the Indian Ocean after two hours, and **(b)** after five hours; **(c)** shows the distribution of maximum tsunami wave height throughout the Indian Ocean.

Farther to the north-west in the Sunda Arc, relatively young (40 million years) oceanic lithosphere subducts offshore Sumatra. The subduction of such young oceanic lithosphere in the Pacific Ocean is associated with most of the massive earthquakes that generate the huge tsunamis that pose a threat to the entire Pacific basin. Although there are no Australian observations on record of tsunamis excited by earthquakes off Sumatra, great thrust earthquakes occurred there in historic times. The most recent occurred in 1833 before widespread European settlement in Western Australia.

The moment magnitude of the earthquake in 1833 is estimated to be 8.7–8.8, and 8.3–8.5 for the one in 1861.[1] However, the magnitude of the 1833 earthquake may have been as high as 9.2 based on a recent study that used the growth ring record of coral micro-atolls to estimate the uplift.[2] This massive earthquake would probably have affected the entire Indian Ocean basin, and the whole Western Australian coastline.

Tsunami modelling

Geoscience Australia has been modelling the open-ocean propagation of the tsunami associated with the 1833 Sumatra earthquake (figure 3). This modelling is accurate only for tsunami propagation in deep water, and does not account for shoreline run-up, where the amplitude will usually increase several fold.

The numerical simulation shows that although the waves are large enough to affect the entire Indian Ocean basin, most of the tsunami energy radiates out into the Indian Ocean and not towards Australia. Even though Western Australia is spared the largest tsunami waves generated by the earthquake, open-ocean tsunami wave heights all along the western coast are 15–25 centimetres, and the run-up from these may be one metre or more.

Tsunami alert

Geoscience Australia is involved in negotiations with the Bureau of Meteorology and Emergency Management Australia to establish an Australian Tsunami Alert Service.

One well-established method to warn the public about impending tsunamis is to rapidly locate and estimate the size of earthquakes which occur in a region, and estimate whether the detected event has the potential to produce a tsunami. However, the size of tsunamis often cannot be estimated with complete confidence based on earthquake data, because some of the details of the faulting mechanism are not easily resolved using seismic data alone.

Direct observations of the tsunami are necessary to establish with confidence whether or not a large tsunami has been excited by an earthquake or other event. This information is available from tide gauges.

In the Australian region, tide gauges on Cocos Island and Christmas Island will provide an early, direct indication of whether a tsunami has been excited off the Indonesian coast (figure 4). Tide gauges on these islands will record the tsunami just 15 and 40 minutes, respectively, after an earthquake. This could provide a tsunami warning three to four hours before it has an impact on the Australian coast (figure 4).

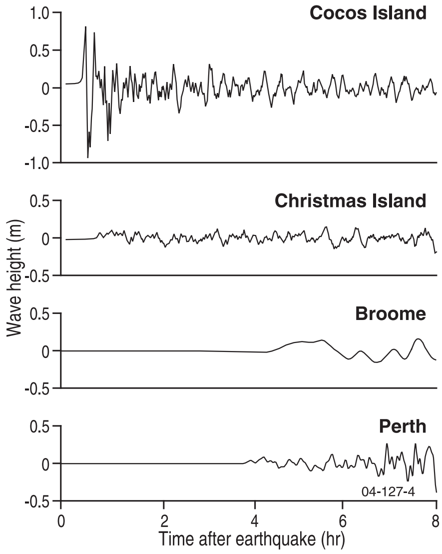


Figure 4. Waveforms computed at hypothetical tide gauges in deep water off Christmas Island, Cocos Island, Broome and Perth. The tsunami's early arrival at the two islands may provide a basis for warning more distant areas. The tsunami reaches Broome at almost the same time as that travelling a much longer path to Perth, due to the shallow ocean between Indonesia and north-west Australia.

Research needs

The tsunami hazard for Australia is probably highest along the north-west coast. But the tsunami hazard along the coast near Perth may be higher than historical experience suggests because there were very few settlers in Western Australia prior to 1840 to make observations.

Historical accounts of tsunamis in the region need to be collated. Although Australian accounts of the massive 1833 earthquake are lacking, there are many Indonesian ones, and there should be evidence in historical documents from elsewhere in the Indian Ocean. Further research into tsunami hazard for the Western Australian coast should also include a systematic study that distinguishes between tsunami and storm deposits.[3]

More accurate tsunami run-up calculations are also needed, to identify places along the coast where tsunami energy may be focused (this would also be useful to narrow down the search for tsunami deposits). Finally, a warning capability should be established, using tide gauges on Cocos Island and Christmas Island to provide several hours' advance warning of a tsunami generated off Sumatra.

Image courtesy of National Information Service for Earthquake Engineering, University of California, Berkeley. Engraving by Edouard Riou, 1833-1900

References

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For more information phone Phil Cummins on +61 2 6249 9632 or e-mail phil.cummins@ga.gov.au