

All About Tsunamis: The Science Behind Tsunamis

Tsunamis, also known as seismic sea waves (mistakenly called “tidal waves”), are a series of enormous waves created by an underwater disturbance such as an earthquake, landslide, volcanic eruption, or meteorite. A tsunami can move hundreds of miles per hour in the open ocean and smash into land with waves as high as 100 feet or more.

Tsunami is a Japanese word with the English translation: "harbour wave". In the past, tsunamis have been referred to as "tidal waves" or "seismic sea waves". The term "tidal wave" is misleading; even though a tsunami's impact upon a coastline is dependent upon the tidal level at the time a tsunami strikes, tsunamis are unrelated to the tides. (Tides result from the gravitational influences of the moon, sun, and planets.) The term "seismic sea wave" is also misleading. "Seismic" implies an earthquake-related generation mechanism, but a tsunami can also be caused by a non-seismic event, such as a landslide or meteorite impact.

From the area where the tsunami originates, waves travel outward in all directions. Once the wave approaches the shore, it builds in height. The topography of the coastline and the ocean floor will influence the size of the wave. There may be more than one wave and the succeeding one may be larger than the one before. That is why a small tsunami at one beach can be a giant wave a few miles away.

All tsunamis are potentially dangerous, even though they may not damage every coastline they strike. A tsunami can strike anywhere along most of the U.S. coastline. The most destructive tsunamis have occurred along the coasts of California, Oregon, Washington, Alaska and Hawaii.

Earthquake-induced movement of the ocean floor most often generates tsunamis. If a major earthquake or landslide occurs close to shore, the first wave in a series could reach the beach in a few minutes, even before a warning is issued. Areas are at greater risk if they are less than 25 feet above sea level and within a mile of the shoreline. Drowning is the most common cause of death associated with a tsunami. Tsunami waves and the receding water are very destructive to structures in the run-up zone. Other hazards include flooding, contamination of drinking water, and fires from gas lines or ruptured tanks.

The physics of a Tsunami

Tsunamis can have wavelengths ranging from 10 to 500 km and wave periods of up to an hour. As a result of their long wavelengths, tsunamis act as shallow-water waves. A wave becomes a shallow-water wave when the wavelength is very large compared to the water depth. Shallow-water waves move at a speed, c , that is dependent upon the water depth and is given by the

formula: $c = \sqrt{gH}$ where g is the acceleration due to gravity ($= 9.8 \text{ m/s}^2$) and H is the depth of water.

In the deep ocean, the typical water depth is around 4000 m, so a tsunami will therefore travel at around 200 m/s, or more than 700 km/h.

For tsunamis that are generated by underwater earthquakes, the amplitude (i.e wave height) of the tsunami is determined by the amount by which the sea-floor is displaced. Similarly, the wavelength and period of the tsunami are determined by the size and shape of the underwater disturbance.

As well as travelling at high speeds, tsunamis can also travel large distances with limited energy losses. As the tsunami propagates across the ocean, the wave crests can undergo refraction (bending), which is caused by segments of the wave moving at different speeds as the water depth along the wave crest varies.

What happens to a tsunami as it approaches land?

As a tsunami leaves the deep water of the open-ocean and travels into the shallower water near the coast, it transforms. If you read the "The physics of a tsunami" section, you will know that a tsunami travels at a speed that is related to the water depth - hence, as the water depth decreases, the tsunami slows. The tsunami's energy flux, which is dependent on both its wave speed and wave height, remains nearly constant. Consequently, as the tsunami's speed diminishes, its height grows. This is called shoaling. Because of this shoaling effect, a tsunami that is unnoticeable at sea, may grow to be several metres or more in height near the coast.

The increase of the tsunami's waveheight as it enters shallow water is given by:

$$\frac{h_s}{h_d} = \left(\frac{H_d}{H_s} \right)^{\frac{1}{4}}$$

where h_s and h_d are waveheights in shallow and deep water and H_s and H_d are the depths of the shallow and deep water. So a tsunami with a height of 1 m in the open ocean where the water depth is 4000m would have a waveheight of 4 to 5 m in water of depth 10 m.

Just like other water waves, tsunamis begin to lose energy as they rush onshore - part of the wave energy is reflected offshore, while the shoreward-propagating wave energy is dissipated through bottom friction and turbulence. Despite these losses, tsunamis still reach the coast with tremendous amounts of energy. Depending on whether the first part of the tsunami to reach the shore is a crest or a trough, it may appear as a rapidly rising or falling tide. Local bathymetry may also cause the tsunami to appear as a series of breaking waves.

Tsunamis have great erosion potential, stripping beaches of sand that may have taken years to accumulate and undermining trees and other coastal vegetation. Capable of inundating, or flooding, hundreds of metres inland past the typical high-water level, the fast-moving water associated with the inundating tsunami can crush homes and other coastal structures. Tsunamis may reach a maximum vertical height onshore above sea level, often called a run-up height, of tens of metres.

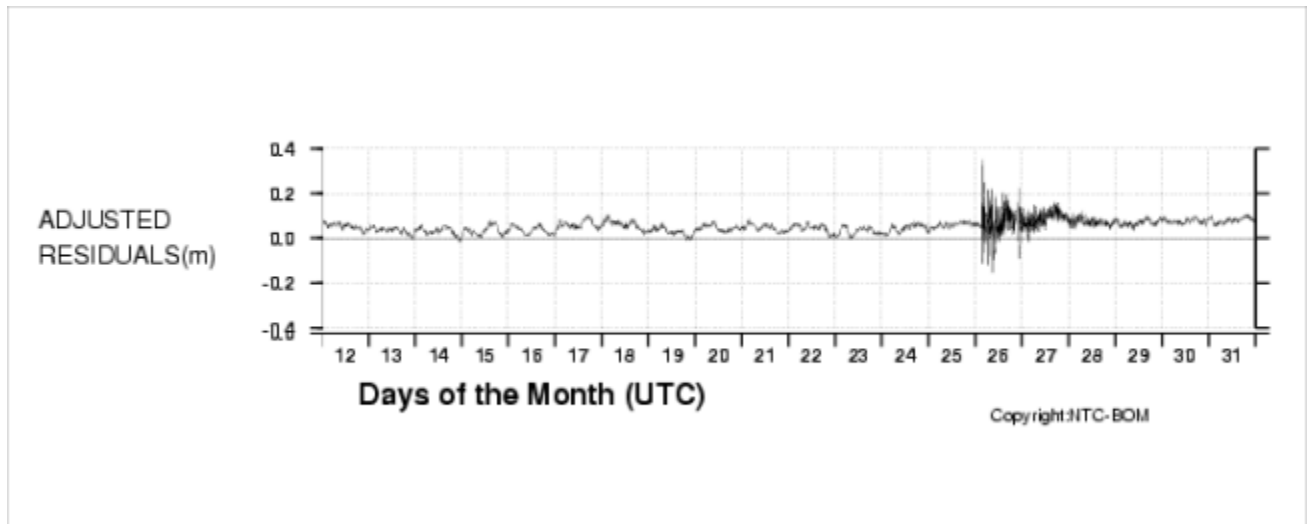
How are tsunamis measured or observed?

In the deep ocean, a tsunami has a small amplitude (less than 1 metre) but very long wavelength (hundreds of kilometres). This means that the slope, or steepness of the wave is very small, so it is practically undetectable to the human eye. However, there are ocean observing instruments that are able to detect tsunamis.

Tide Gauges

Tide gauges measure the height of the sea-surface and are primarily used for measuring tide levels. Most of the tide gauges operated by the Bureau of Meteorology's National Tidal Centre are SEAFRAME stations (Sea Level Fine Resolution Acoustic Measuring Equipment). These consist of an acoustic sensor connected to a vertical tube open at the lower end which is in the water. The acoustic sensor emits a sound pulse which travels from the top of the tube down to the water surface, and is then reflected back up the tube. The distance to the water level can then be calculated using the travel time of the pulse. This system filters out small-scale effects like wind-waves and has the capacity to measure sea-level changes within 1mm accuracy.

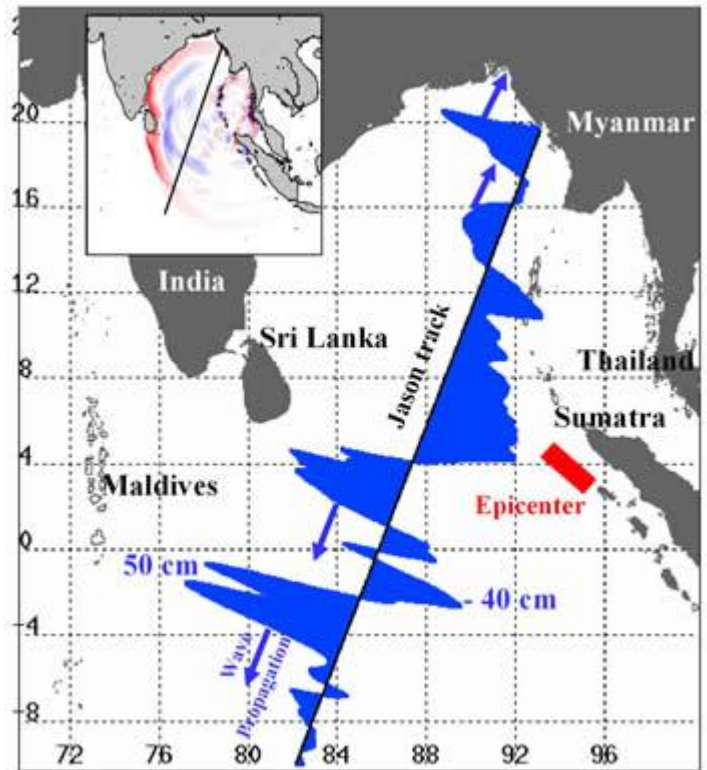
The tide gauge at Cocos Island observed the tsunami on December 26th 2004 as it passed by the island, as shown in these observations made during December.



Satellites

Satellite altimeters measure the height of the ocean surface directly by the use of electromagnetic pulses. These are sent down to the ocean surface from the satellite and the height of the ocean surface can be determined by knowing the speed of the pulse, the location of the satellite and measuring the time that the pulse takes to return to the satellite. One problem with this kind of satellite data is that it can be very sparse - some satellites only pass over a particular location about once a month, so you would be lucky to spot a tsunami since they travel so quickly. However, during the Indian Ocean tsunami of December 26th 2004, the Jason satellite altimeter happened to be in the right place at the right time.

The picture below shows the height of the sea surface (in blue) measured by the Jason satellite two hours after the initial earthquake hit the region southeast of Sumatra (shown in red) on December 26, 2004. The data were taken by a radar altimeter on board the satellite along a track traversing the Indian Ocean when the tsunami waves had just filled the entire Bay of Bengal. The data shown are the differences in sea surface height from previous observations made along the same track 20-30 days before the earthquake, showing the signals of the tsunami.



The DART System

In 1995 the National Oceanic and Atmospheric Administration (NOAA) began developing the Deep-ocean Assessment and Reporting of Tsunamis (DART) system. An array of stations is currently deployed in the Pacific Ocean. These stations give detailed information about tsunamis while they are still far off shore. Each station consists of a sea-bed bottom pressure recorder which detects the passage of a tsunami. (The pressure of the water column is related to the height of the sea-surface). The data is then transmitted to a surface buoy via sonar. The surface buoy then radios the information to the Pacific Tsunami Warning Center (PTWC) via satellite. The bottom pressure recorder lasts for two years while the surface buoy is replaced every year. The system has considerably improved the forecasting and warning of tsunamis in the Pacific.

The Indian Ocean tsunami of 26th December 2004

An undersea earthquake in the Indian Ocean on 26th December 2004 produced a tsunami that caused one of the biggest natural disasters in modern history. Over 200,000 people are known to have lost their lives.

The waves devastated the shores of parts of Indonesia, Sri Lanka, India, Thailand and other countries with waves reported up to 15 m high, reaching as far as Somalia on the east coast of Africa, 4500 km west of the epicentre. Refraction and diffraction of the waves meant that the impact of the tsunami was noticed around the world and sea-level monitoring stations in places such as Brazil and Queensland also felt the effect of the tsunami.

The earthquake took place at about 1am UTC (8am local time) in the Indian Ocean off the western coast of northern Sumatra. With a



magnitude of 9.0 on the Richter scale, it was the largest since the 1964 earthquake off Alaska and equal fourth largest since 1900, when accurate global seismographic record-keeping began.

The epicentre of the earthquake was located about 250 km south-southeast of the Indonesian city of Banda Aceh. It was a rare megathrust earthquake and occurred on the interface of the India and Burma tectonic plates. This was caused by the release of stresses that develop as the India plate subducts beneath the overriding Burma plate. A megathrust earthquake is where one tectonic plate slips beneath another, causing vertical motion of the plates. This large vertical displacement of the sea-floor generated the devastating tsunami, which caused damage over such a large area around the Indian Ocean.

The earthquake was also unusually large in geographical extent. An estimated 1200 km of faultline slipped about 15 m along the subduction zone over a period of several minutes. Because the 1,200 km of faultline affected by the quake was in a nearly north-south orientation, the greatest strength of the waves was in an east-west direction. Bangladesh, which lies at the northern end of the Bay of Bengal, had very few casualties despite being a populous low-lying country.

Due to the distances involved, the tsunami took anywhere from fifteen minutes to seven hours (for Somalia) to reach the various coastlines. The northern regions of the Indonesian island of Sumatra were hit very quickly, while Sri Lanka and the east coast of India were hit roughly two hours later. Thailand was also struck about two hours later, despite being closer to the epicentre, because the tsunami travelled more slowly in the shallow Andaman Sea off its western coast.

On its arrival on shore, the height of the tsunami varied greatly, depending on its distance and direction from the epicentre and other factors such as the local bathymetry. Reports have the height ranging from 2-3 m at the African coast (Kenya) up to 10-15 m at Sumatra, the region closest to the epicentre.

Characteristics of a Tsunami

Tsunamis are different from normal waves

Tsunami waves involve the movement of water all the way to the sea floor. The effects of wind-driven ocean waves are seen only near the surface of the ocean.

Tsunamis have long wavelengths

In the deep ocean tsunami waves have extremely long wavelengths. In comparison to wind-driven waves, tsunami waves may have wavelengths up to hundreds of kilometres between wave crests. Tsunamis are therefore much more destructive than normal waves because the huge flooding body of water can continue to rush onto land for an extended period of time. This may be anything from a few minutes up to an hour, compared to seconds for wind-driven waves.

As a tsunami approaches land, the size increases

The speed and size of a tsunami is controlled by water depth. In the deep ocean tsunami waves may be unnoticed by ships or from the air. As the wave approaches land it reaches shallow water and slows down. Relative to the front of the wave, the rear is still in slightly deeper water (so it is going slightly faster) and catches up. The result is that the wave quickly 'bunches up', the

wavelength becomes shorter and the body of water becomes much higher. This is called shoaling.

Tsunamis are fast

In the deep ocean, a tsunami can travel at more than 900 kilometres per hour, close to the speed of a jumbo jet, and in shallow water, it can be described as roughly the speed of a fast cyclist.

Tsunamis retain their energy

As well as travelling at high speeds, tsunamis can also travel large distances with limited energy losses. Tsunamis can therefore have sufficient energy to travel across entire oceans.

Tsunami waves move outwards, away from their source

The path of a tsunami is never symmetrical and is determined by a number of factors including the bathymetry of the sea floor. Bathymetry is the measurement of the depth of the ocean floor from the water surface and is the oceanic equivalent of topography. Tsunamis move outwards at right angles to the subduction trench where the earthquake has occurred. A tsunami travels faster through deep water and slower through shallow water. This directs the wave along undersea valleys. The magnitude of the earthquake, the shape of the earthquake and the orientation of the subduction zone that ruptures are also influencing factors.

A tsunami is a 'series' of waves

A tsunami generally consists of a series of waves. The amount of time between successive waves is known as the wave period. Waves can be a few minutes or over two hours apart. In most cases, the first tsunami wave is not the largest. Subsequent waves, sometimes the fifth or sixth, can be many times larger.

Tsunamis can vary in size and severity

The impact of a tsunami can vary widely. A small tsunami may result in unusual tides or currents that can be dangerous to swimmers or cause damage to berthed boats. A large tsunami can cause widespread flooding and destruction such as that seen off the west coast of Northern Sumatra on 26 December 2004. The south Java tsunami (17 July 2006) was caused by a relatively small earthquake (magnitude 7.7) that generated a 0.5 metre tsunami. This tsunami inundated the coast with run-up heights of four meters in some places, killing over 600 people. Large tsunamis cause strong rips and currents in oceans around the world for up to a few days after the initiating earthquake.

All About Tsunamis: Utah Tsunamis

**There is no known record of a tsunami ever having occurred in Utah history.