United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental Oceanographic Commission

TSUNAMI GLOSSARY

2013

Technical Series 85

Intergovernmental Oceanographic Commission

TSUNAMI GLOSSARY

2013

Technical Series 85

UNESCO

For bibliographic purposes, this document should be cited as follows:

Intergovernmental Oceanographic Commission. Revised Edition 2013. Tsunami Glossary, 2013. Paris, UNESCO. IOC Technical Series, 85. (English.) (IOC/2008/TS/85rev)

Published by the United Nations Educational, Scientific and Cultural Organization
7 Place de Fontenoy, 75 352 Paris 07 SP, France

Printed by UNESCO/IOC - National Oceanic and Atmospheric Administration (NOAA)
International Tsunami Information Center (ITIC)
737 Bishop St., Ste. 2200, Honolulu, Hawaii 96813, U.S.A.

TABLE OF CONTENTS

1 April 1946 Aleutian Islands tsunami hitting Hilo, Hawaii. Photo courtesy of Bishop Museum Archives

1. TSUNAMI CLASSIFICATION

Characteristics of the Tsunami Phenomena

A tsunami travels outward from the source region as a series of waves. Its speed depends upon the depth of the water, and consequently the waves undergo accelerations or decelerations in passing respectively over an ocean bottom of increasing or decreasing depth. By this process the direction of wave propagation also changes, and the wave energy can become focused or defocused. In the deep ocean, tsunami waves can travel at speeds of 500 to 1,000 kilometres per hour. Near the shore, however, a tsunami slows down to just a few tens of kilometres per hour. The height of a tsunami also depends upon the water depth. A tsunami that is just a metre in height in the deep ocean can grow to tens of metres at the shoreline. Unlike familiar wind-driven ocean waves that are only a disturbance of the sea surface, the tsunami wave energy extends to the ocean bottom. Near the shore, this energy is concentrated in the vertical direction by the reduction in water depth, and in the horizontal direction by a shortening of the wavelength due to the wave slowing down.

Tsunamis have periods (the time for a single wave cycle) that may range from just a few minutes to as much as an hour or exceptionally more. At the shore, a tsunami can have a wide variety of expressions depending on the size and period of the waves, the near-shore bathymetry and shape of the coastline, the state of the tide, and other factors. In some cases a tsunami may only induce a relatively benign flooding of low-lying coastal areas, coming onshore similar to a rapidly rising tide. In other cases it can come onshore as a bore - a vertical wall of turbulent water full of debris that can be very destructive. In most cases there is also a drawdown of sea level preceding crests of the tsunami waves that result in a receding of the waterline, sometimes by a kilometre or more. Strong and unusual ocean currents may also accompany even small tsunamis.

Damage and destruction from tsunamis is the direct result of three factors: inundation, wave impact on structures, and erosion. Deaths occur by drowning and physical impact or other trauma when people are caught in the turbulent, debris-laden tsunami waves. Strong tsunami-induced currents have led to the erosion of foundations and the collapse of bridges and seawalls. Floatation and drag forces have moved houses and overturned railroad cars. Tsunami associated wave forces have demolished frame buildings and other structures. Considerable damage also is caused by floating debris, including boats, cars, and trees that become dangerous projectiles that may crash into buildings, piers, and other vehicles. Ships and port facilities have been damaged by surge action caused by even weak tsunamis. Fires resulting from oil spills or combustion from damaged ships in port, or from ruptured coastal oil storage and refinery facilities, can cause damage greater than that inflicted directly by the tsunami. Other secondary damage can result from sewage and chemical pollution following the destruction. Damage of intake, discharge, and storage facilities also can present dangerous problems. Of increasing concern is the potential effect of tsunami drawdown, when receding waters uncover cooling water intakes associated with nuclear power plants.

Historical tsunami

A tsunami documented to occur through eyewitness or instrumental observation within the historical record.

Local tsunami

A tsunami from a nearby source for which its destructive effects are confined to coasts within about 100 km, or less than 1 hour tsunami travel time from its source. A local tsunami is usually generated by an earthquake, but can also be caused by a landslide or a pyroclastic flow from a volcanic eruption. Over history, 90% of tsunami casualties have been caused by local tsunamis.

Tsunami flow depths exceeding 10 m and flow velocities over 6 m/s overturned and dragged 3-story buildings as much as 50 m during the 11 March 2011 Japan tsunami. Onagawa, Japan. Photo courtesy of ITIC.

Maremoto

Spanish term for tsunami.

Damage caused by the 22 May 1960 Chilean tsunami. Photo courtesy of Ilustre Municipalidad de Maullin, USGS Circular 1187.

Meteorological tsunami (meteotsunami)

Tsunami-like phenomena generated by meteorological or atmospheric disturbances. These waves can be produced by atmospheric gravity waves, pressure jumps, frontal passages, squalls, gales, typhoons, hurricanes and other atmospheric sources. Meteotsunamis have the same temporal and spatial scales as tsunami waves and can similarly devastate coastal areas, especially in bays and inlets with strong amplification and well-defined resonant properties (e.g. Ciutadella Inlet, Baleric Islands; Nagasaki Bay, Japan; Longkou Harbour, China; Vela Luka, Stari Grad and Mali Ston Bays, Croatia). Sometimes referred to as rissaga.

Microtsunami

A tsunami of such small amplitude that it must be observed instrumentally and is not easily detected visually.

Ocean-wide tsunami

A tsunami capable of widespread destruction, not only in the immediate region of its generation but across an entire ocean. All ocean-wide tsunamis have been generated by major earthquakes. Synonym for teletsunami or distant tsunami.

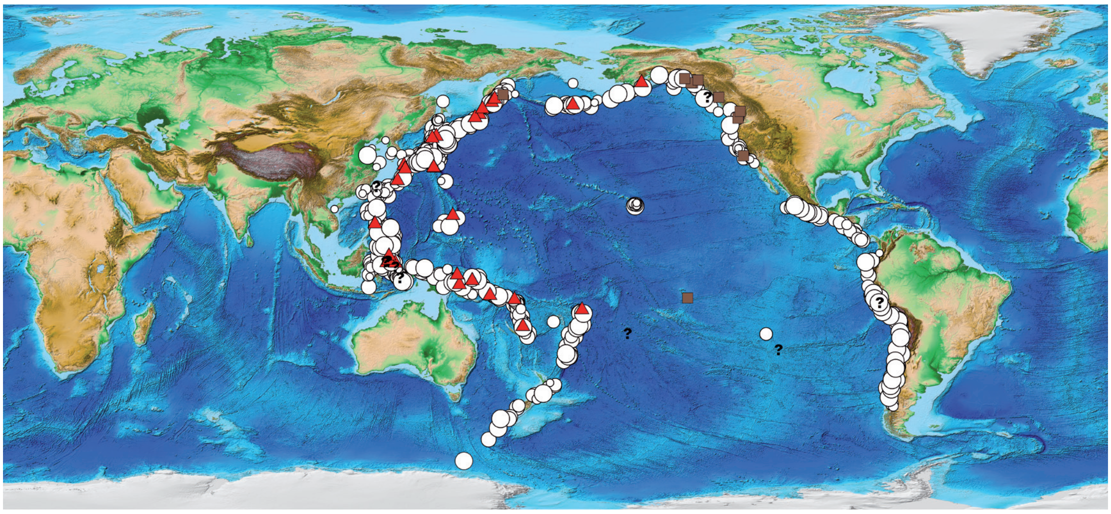
Paleotsunami

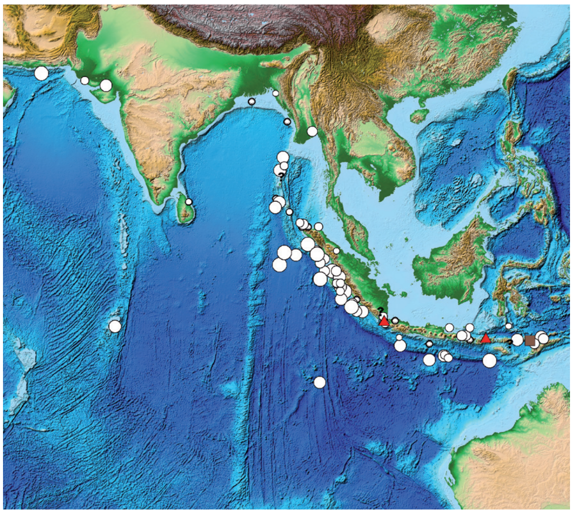
Tsunami occurring prior to the historical record or for which there are no written observations.

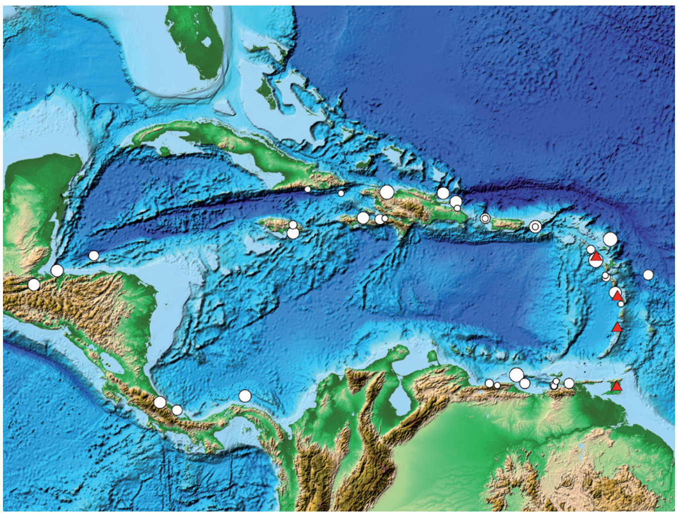
Paleotsunami research is based primarily on the identification, mapping, and dating of tsunami deposits found in coastal areas, and their correlation with similar sediments found elsewhere locally, regionally, or across ocean basins. In one instance, the research has led to a new concern for the possible future occurrence of great earthquakes and tsunamis along the northwest coast of North America. In another instance, the record of tsunamis in the Kuril-Kamchatka region is being extended much further back in time. As work in this field continues it may provide a significant amount of new information about past tsunamis to aid in the assessment of the tsunami hazard.

Regional tsunami

A tsunami capable of destruction in a particular geographic region, generally within 1,000 km or 1-3 hours tsunami travel time from its source. Regional tsunamis also occasionally have very limited and localized effects outside the region.







The four images above show confirmed tsunami source locations in the Pacific Ocean, Indian Ocean, Mediterranean Sea, and Caribbean Sea. The symbols indicate cause of the tsunami: Brown Square is a landslide, Red Triangle is a volcanic eruption, Question Mark is an unknown cause, and White Circle is an earthquake and the size of the circle is graduated to indicate the earthquake magnitude. Source: NGDC / WDS-Geophysics.

Landslide

Volcanic eruption

? *Unknown cause*

Earthquake and the size of the circle is graduated to indicate the earthquake magnitude

Most destructive tsunami can be classified as local or regional. It follows many tsunami related casualties and considerable property damage also comes from these tsunamis. Between 1975 and mid-2012 there were 39 local or regional tsunamis that resulted in 260,000 deaths and billions of dollars in property damage; 26 of these were in the Pacific and adjacent seas.

For example, in the Pacific, a regional tsunami in 1983 in the Sea of Japan or East Sea severely damaged coastal areas of Japan, Korea, and Russia causing more than $800 million in damage, and more than 100 deaths. Then, after nine years with only one event causing one fatality, 10 locally destructive tsunamis occurred in just a seven-year period from 1992 to 1998, resulting in over 2,700 deaths and hundreds of millions of dollars in property damage. In most of these cases, tsunami mitigation efforts in place at the time were unable to prevent significant damage and loss of life. However, losses from future local or regional tsunamis can be reduced if a denser network of warning centres, seismic and water-level reporting stations, and better communications are established to provide a timely warning, and if better programmes of tsunami preparedness and education can be put in place.

Regional and local tsunamis causing deaths since 1975

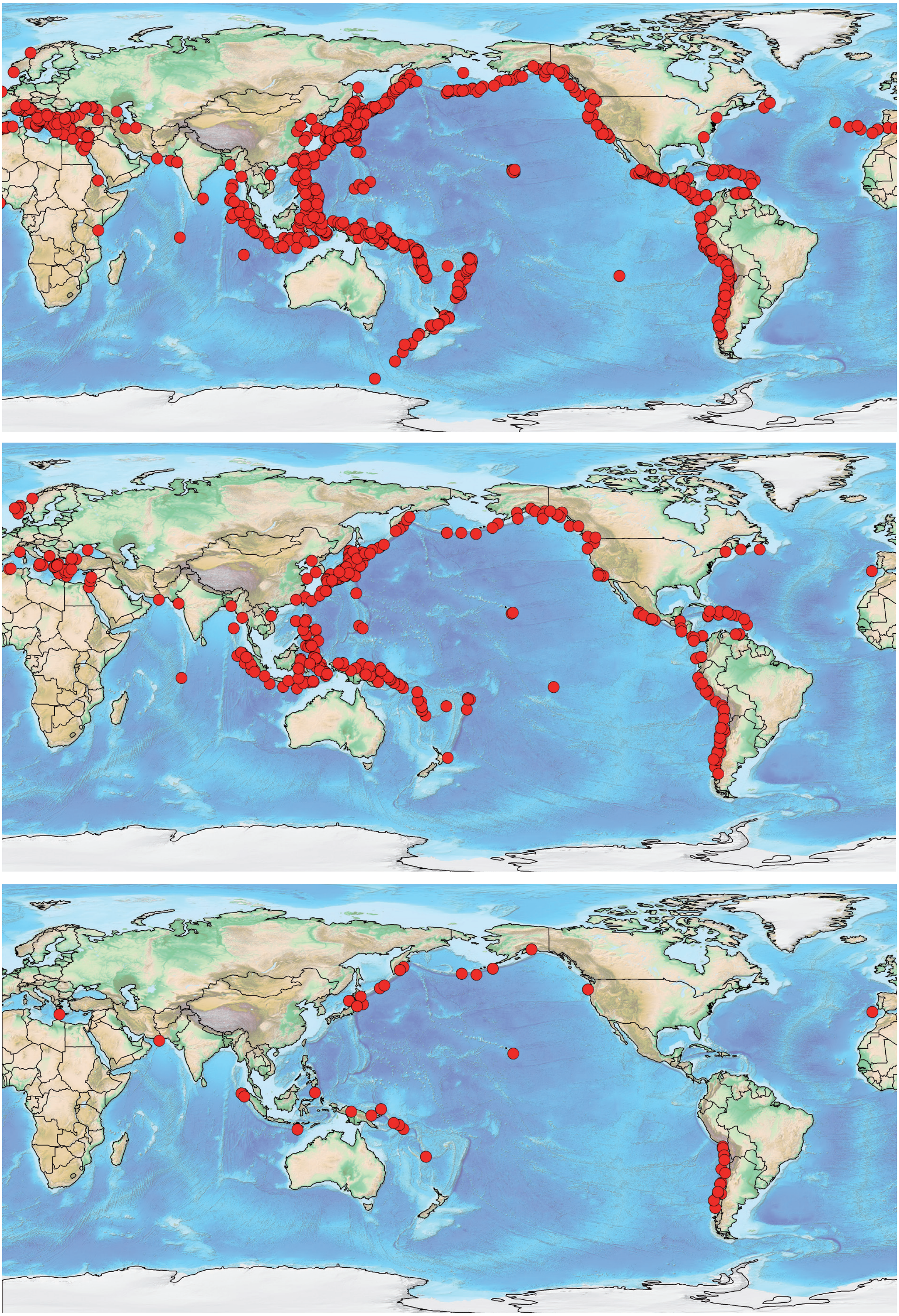
Year	Date Mon	Day	Source Location	Estimated Dead or Missing
1975	10	31	Philippine Trench	1
1975	11	29	Hawaii, USA	2
1976	8	16	Moro Bay, Philippines	4 376
1977	8	19	Sumbawa, Indonesia	189
1979	7	18	Lembata Island, Indonesia **	1 239
1979	9	12	Irian Jaya, Indonesia	100
1979	10	16	French Riviera **	9
1979	12	12	Narino, Colombia	* 600
1981	9	1	Samoa Islands	2
1983	5	26	Noshiro, Japan	100
1988	8	10	Solomon Islands	1
1991	4	22	Limon, Costa Rica	2
1992	9	2	Off coast Nicaragua	170
1992	12	12	Flores Sea, Indonesia	1 169
1993	7	12	Sea of Japan	208
1994	6	2	Java, Indonesia	250
1994	10	8	Halmahera, Indonesia	1
1994	11	4	Skagway Alaska, USA **	1
1994	11	14	Philippine Islands	* 81
1995	5	14	Timor, Indonesia	11
1995	10	9	Manzanillo, Mexico	1
1996	1	1	Sulawesi, Indonesia	9
1996	2	17	Irian Jaya, Indonesia	110
1996	2	21	Northern Peru	12
1998	7	17	Papua New Guinea	2 205
1999	8	17	Izmit Bay, Turkey	155
1999	11	26	Vanuatu Islands	5
2001	6	23	Southern Peru	26
2004	12	26	Banda Aceh, Indonesia	*^ 227 898
2005	3	28	Sumatra, Indonesia	10
2006	3	14	Seram Island, Indonesia	4
2006	7	17	Java, Indonesia	802
2007	4	1	Solomon Islands	* 52
2007	4	21	Southern Chile	10
2009	9	29	Samoa Islands	192
2010	1	12	Haiti	7
2010	2	27	Southern Chile	156
2010	10	25	Mentawai, Indonesia	431
2011	3	11	Tohoku, Japan	*^ 18 717
			Total	259 314

* May include earthquake deaths
** Tsunami generated by landslide
^ Includes dead/missing near and outside source region

Regional and local tsunamis causing 2,000 or more deaths

Year	Date Mon	Day	Source Location	Estimated Dead or Missing
365	7	21	Crete, Greece	5 700
887	8	2	Niigata, Japan	2 000
1341	10	31	Aomori Prefecture, Japan	2 600
1498	9	20	Enshunada Sea, Japan	31 000
1570	2	8	Central Chile	2 000
1586	1	18	Ise Bay, Japan	* 8 000
1605	2	3	Nankaido, Japan	5 000
1611	12	2	Sanriku, Japan	5 000
1674	2	17	Banda Sea, Indonesia	2 244
1687	10	20	Southern Peru	* 5 000
1692	6	7	Port Royal, Jamaica	2 000
1703	12	30	Boso Peninsula, Japan	* 5 233
1707	10	28	Enshunada Sea, Japan	2 000
1707	10	28	Nankaido, Japan	* 5 000
1746	10	29	Central Peru	4 800
1751	5	20	Northwest Honshu, Japan	2 100
1755	11	1	Lisbon, Portugal	* 50 000
1771	4	24	Ryukyu Islands, Japan	13 486
1792	5	21	Kyushu Island, Japan **	5 443
1854	12	24	Nankaido, Japan	* 3 000
1868	8	13	Northern Chile*	25 000
1883	8	27	Krakatau, Indonesia **	36 000
1896	6	15	Sanriku, Japan	* 27 122
1899	9	29	Banda Sea, Indonesia	* 2 460
1923	9	1	Sagami Bay, Japan	2 144
1933	3	2	Sanriku, Japan	3 022
1945	11	27	Makran Coast, Pakistan	* 4 000
1952	11	4	Kamchatka, Russia	4 000
1976	8	16	Moro Gulf, Philippines	4 376
1998	7	17	Papua New Guinea	2 205
2004	12	26	Banda Aceh, Indonesia	*^ 227 898
2011	3	11	Tohoku, Japan	*^ 18 717
			Total	518 550

* May include earthquake deaths
** Tsunami generated by volcanic eruption
^ Includes dead/missing near and outside source region



More than 80% of the world's tsunamis were caused by earthquakes and over 70% of these were observed in the Pacific where large earthquakes occur as tectonic plates are subducted along the Pacific Ring of Fire. Top: Epicentre of all tsunamigenic earthquakes tsunamis have caused damage locally in all ocean basins. Middle: Locations of earthquakes, volcanic eruptions, and landslides generating tsunamis that caused damage or casualties locally. Although the majority of tsunamis that were observed more than 1,000 km away (teletsunamis) were generated by earthquakes in the Pacific, teletsunamis have also caused damage and casualties in the Indian and Atlantic oceans. Bottom: Source locations of teletsunamis generated by earthquakes or volcanic eruptions causing damage or casualties. These data are based on historical records. Source: NGDC / WDS-Geophysics.

Teletsunami or Distant Tsunami

A tsunami originating from a far away source, generally more than 1,000 km or more than 3 hours tsunami travel time from its source.

Less frequent, but more hazardous than regional tsunamis, are ocean-wide or distant tsunamis. Usually starting as a local tsunami that causes extensive destruction near the source, these waves continue to travel across an entire ocean basin with sufficient energy to cause additional casualties and destruction on shores more than a 1,000 kilometres from the source. In the last 200 years, there have been at least 28 destructive ocean-wide tsunamis and 14 have caused fatalities more than 1,000 kilometres from the source.

The most destructive Pacific-wide tsunami of recent history was generated by a massive earthquake off the coast of Chile on 22 May 1960. All Chilean coastal towns between the 36th and 44th parallels were either destroyed or heavily damaged by the action of the tsunami and the earthquake. The combined tsunami and earthquake toll included 2,000 killed, 3,000 injured, two million homeless, and $550 million damage. Off the coast of Corral, Chile, the waves were estimated to be 20 metres (67 feet) high. The tsunami caused 61 deaths in Hawaii, 20 in the Philippines, and 139 in Japan. Estimated damages were $50 million in Japan, $24 million in Hawaii and several millions of dollars along the west coast of the United States and Canada. Distant wave heights varied from slight oscillations in some areas to 12 metres (40 feet) at Pitcairn Island, 11 metres (37 feet) at Hilo, Hawaii, and 6 metres (20 feet) at some places in Japan.

The tsunami of 26 December 2004 destroyed the nearby city of Bandas Aceh, Indonesia, leaving only a few structures standing. Photo courtesy of Yuichi Nishimura, Hokkaido University.

The worst tsunami catastrophe in history occurred in the Indian Ocean on 26 December 2004, when a M9.3 earthquake off of the northwest coast of Sumatra, Indonesia, produced an ocean-wide tsunami that hit Thailand and Malaysia to the east, and Sri Lanka, India, the Maldives, and Africa to the west as it traversed across the Indian Ocean. Nearly 228,000 people lost their lives and more than a million people were displaced, losing their homes, property, and their livelihoods. The magnitude of death and destructiveness caused immediate response by the world's leaders and led to the development of the Indian Ocean Tsunami Warning and Mitigation System in 2005. The event also raised awareness of tsunami hazards globally, and new systems were established in the Caribbean, the Mediterranean and Atlantic.

Tsunamis causing deaths greater than 1,000 km from the source location

Date				Estimated Dead or Missing		
Year	Mon.	Day	Source Location	Local and Regional	Distant	Distant locations that reported casualties
1837	11	7	Southern Chile	0	16	USA (Hawaii)
1868	8	13	Northern Chile **	* 25 000	7	New Zealand, Samoa, Southern Chile
1877	5	10	Northern Chile	Hundreds	Thousands	Fiji, Japan, Peru, USA (Hawaii)
1883	8	27	Krakatau, Indonesia	36 000	1	Sri Lanka
1899	1	15	Papua New Guinea	0	Hundreds	Caroline Islands, Solomon Islands
1901	8	9	Loyalty Islands, New Caledonia	0	Several	Santa Cruz Islands
1923	2	3	Kamchatka, Russia	2	1	USA (Hawaii)
1945	11	27	Makran coast, Pakistan	* 4 000	Some	India
1946	4	1	Unimak Island, Alaska, USA	5	159	USA (California, Hawaii)
1960	5	22	Central Chile	1 000	222	Japan, Philippines, USA (California, Hawaii)
1964	3	28	Prince William Sound, Alaska, USA	106	18	USA (California, Oregon)
2004	12	26	Banda Aceh, Indonesia ***	* 175 827	52 071	Bangladesh, India, Kenya, Maldives, Myanmar, Seychelles, Somalia, South Africa, Sri Lanka, Tanzania, Yemen
2005	3	28	Sumatra, Indonesia	0	10	Sri Lanka (deaths during evacuation)
2011	3	11	Tohoku, Japan ****	* 18 715	2	Indonesia, USA (California)

* May include earthquake deaths ** Local and regional deaths in Chile and Peru *** Local and regional deaths in Indonesia, Malaysia, and Thailand **** Local and regional deaths in Japan

Tsunami

Destruction along the waterfront of Hilo, Hawaii, from the Pacific-wide tsunami generated off the coast of Unimak Island, Aleutian Island, USA on 1 April 1946.

Japanese term meaning wave ("nami") in a harbour ("tsu"). A series of travelling waves of extremely long length and period, usually generated by disturbances associated with earthquakes occurring below or near the ocean floor. (Also called seismic sea wave and, incorrectly, tidal wave). Volcanic eruptions, submarine landslides, and coastal rock falls can also generate tsunamis, as can a large meteorite impacting the ocean. These waves may reach enormous dimensions and travel across entire ocean basins with little loss of energy. They proceed as ordinary gravity waves with a typical period between 10 and 60 minutes. Tsunamis steepen and increase in height on approaching shallow water, inundating low-lying areas, and where local submarine topography causes the waves to steepen, they may break and cause great damage. Tsunamis have no connection with tides; the popular name, tidal wave, is entirely misleading.

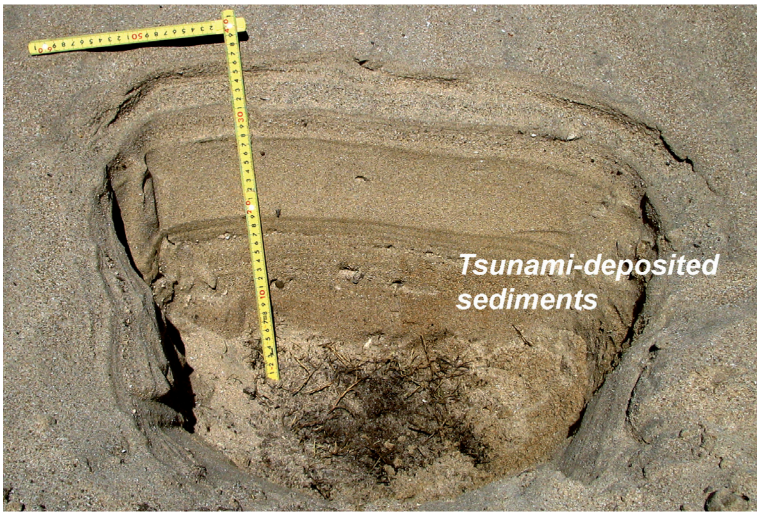
Tsunami generated by 26 May 1983, Japan Sea earthquake approaching Okushiri Island, Japan. Photo courtesy of Tokai University.

Tsunami earthquake

An earthquake that produces an unusually large tsunami relative to the earthquake magnitude (Kanamori, 1972). Typical characteristics of tsunami earthquakes include long rupture durations for the magnitude of the earthquake, rupture on the very shallow part of the plate interface (inferred from a location near the trench and a low-angle thrust mechanism), and high energy release at low frequencies. They are also slow earthquakes, with slippage along their faults occurring more slowly than would occur in normal earthquakes. The last events of this type were in 1992 (Nicaragua), 1996 (Chimbote, Peru), and in Indonesia in 1994 (Java), 2006 (Java), and 2010 (Mentawai).

Tsunami sediments

Sediments deposited by a tsunami. The finding of tsunami sediment deposits within the stratigraphic soil layers provides information on the occurrence of historical and paleotsunamis. The discovery of similarly-dated deposits at different locations, sometimes across ocean basins and far from the tsunami source, can be used to map and infer the distribution of tsunami inundation and impact.



Sediment layers deposited from successive waves of 26 December 2004 Indian Ocean tsunami, as observed in Banda Aceh, Indonesia. Photo courtesy of Yuichi Nishimura, Hokkaido University.

2. GENERAL TSUNAMI TERMS

This section contains general terms used in tsunami mitigation and in tsunami generation and modelling

Breaker

A sea-surface wave that has become so steep (wave steepness of 1/7) that the crest outraces the body of the wave and it collapses into a turbulent mass on shore or over a reef. Breaking usually occurs when the water depth is less than 1.28 times the wave height. Roughly, three kinds of breakers can be distinguished, depending primarily on the gradient of the bottom: a) spilling breakers (over nearly flat bottoms) which form a foamy patch at the crest and break gradually over a considerable distance; b) plunging breakers (over fairly steep bottom gradients) which peak up, curl over with a tremendous overhanging mass and then break with a crash; c) surging breakers (over very steep bottom gradients) which do not spill or plunge but surge up the beach face. Waves also break in deep water if they build too high while being generated by the wind, but these are usually short-crested and are termed whitecaps.

Water gate used to protect against tsunami waves on Okushiri Island, Japan. The gate begins to automatically close within seconds after earthquake shaking triggers its seismic sensors. Photo courtesy of ITIC.

Breakwater

An offshore or onshore structure, such as a wall, water gate, or other in-water wave-dissipating object that is used to protect a harbour or beach from the force of waves.

Sea wall with stairway evacuation route used to protect a coastal town against tsunami inundation in Japan. Photo courtesy of River Bureau, Ministry of Land, Infrastructure and Transport, Japan.

Eddy

By analogy with a molecule, a "glob" of fluid within the fluid mass that has a certain integrity and life history of its own; the activities of the bulk fluid being the net result of the motion of the eddies.

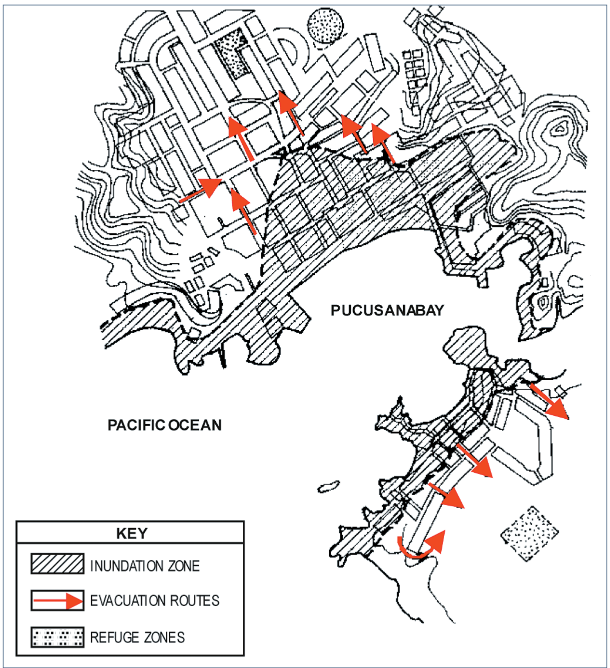
Eddies generated by the interactions of tsunami waves as they hit the coast of Sri Lanka, 26 December 2004. Photo courtesy of Digital Globe.

Estimated time of arrival (ETA)

Time of tsunami arrival at some fixed location, as estimated from modelling the speed and refraction of the tsunami waves as they travel from the source. ETA is estimated with very good precision if the bathymetry and source are well known (less than a couple of minutes). The first wave is not necessarily the largest, but it is usually one of the first five waves.

Evacuation map

A drawing or representation that outlines danger zones and designates limits beyond which people must be evacuated to avoid harm from tsunami waves. Evacuation routes are sometimes designated to ensure the efficient movement of people out of the evacuation zone to evacuation shelters.



Inundation and Evacuation Map created for the coastal town of Pucusana, Peru.

Elevated platform used for tsunami evacuation that also serves as a high-elevation scenic vista point for tourist. Okushiri Island, Japan. Photo courtesy of ITIC.

Emergency shelter building that also acts as community centre and Museum for Disaster Prevention. Kisei, Mie Prefecture, Japan. The building is 22 m high, has five floors covering 320 m², and holds 500 persons. Info courtesy of http://www.pref.mie.lg.jp/ENGLISH/

Historical tsunami data

Historical data are available in many forms and at many locations. These forms include published and unpublished catalogs of tsunami occurrences, personal narratives, marigraphs, tsunami amplitude, runup and inundation zone measurements, field investigation reports, newspaper accounts, film, or video records.

Probabilistic Tsunami Hazard Assessment (PTHA)

An assessment of the probability that a tsunami will reach, or exceed, a given size within a specified interval of time at a particular location. The tsunami size may be measured in various ways, such as: run-up height, flow depth, or tsunami height at the coast. Usually a PTHA would provide probabilities for a range of different time spans, for example from 50 to 2500 years. The assessment may cover a single location, a stretch of coastline, or an area of land (if inundation is included). See also 'Tsunami Hazard Assessment' which provides information on some of the techniques that may be used to make a PTHA.

Seiche

A seiche may be initiated by a standing wave oscillating in a partially or fully enclosed body of water. It may be initiated by long period seismic waves (an earthquake), wind and water waves, or a tsunami.

Seismic sea wave

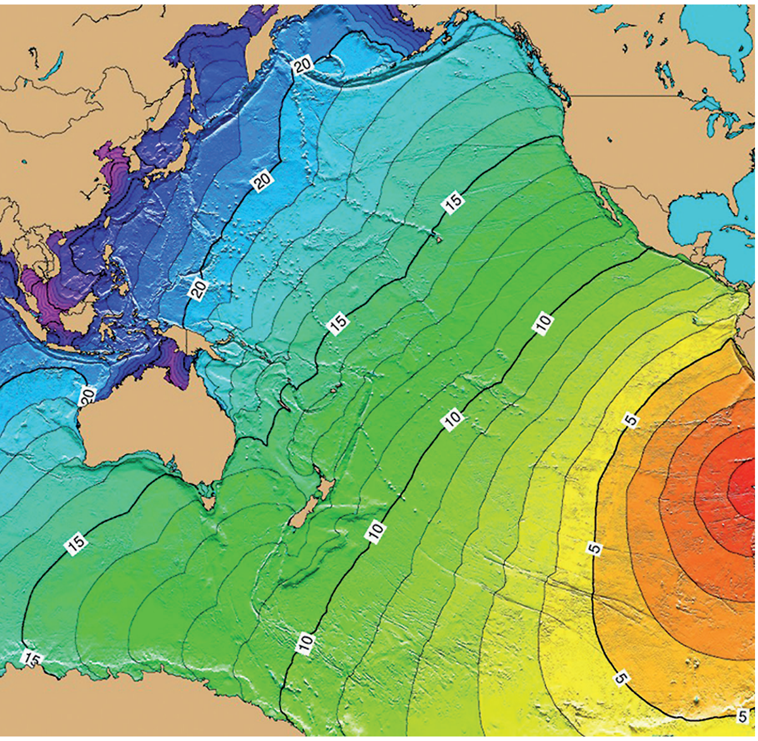
Tsunamis are sometimes referred to as seismic sea waves because they are most often generated by earthquakes.

Travel time

Time required for the first tsunami wave to propagate from its source to a given point on a coastline.

Travel time map

Map showing isochrons or lines of equal tsunami travel time calculated from the source outwards toward terminal points on distant coastlines.



Travel times (in hours) for the 22 May 1960 Chile tsunami crossing the Pacific basin. This tsunami was extremely destructive along the nearby coast of Chile, and the tsunami also caused significant destruction and casualties as far away as Hawaii and Japan. The awareness and concern raised by this Pacific-wide tsunami ultimately led to the formation of the PTWS.

Tsunami bore

A steep, turbulent, rapidly moving tsunami wave front typically occurring in a river mouth or estuary.

Tsunami bore entering Wailua River, Hawaii, during the 1946 Aleutian Island tsunami. Photo courtesy of Pacific Tsunami Museum.

Tsunami damage

Loss or harm caused by a destructive tsunami. More specifically, the damage caused directly by tsunamis can be summarized into the following: 1) Deaths and injuries; 2) houses destroyed, partially destroyed, inundated, flooded, or burned; 3) other property damage and loss; 4) boats washed away, damaged or destroyed; 5) lumber washed away; 6) marine installations destroyed, and; 7) damage to public utilities such as railroads, roads, bridges, power plants, water or fuel storage tanks, or wastewater facilities, etc. Indirect secondary tsunami damage can be: 1) Damage by fire of houses, boats, oil tanks, gas stations, and other facilities; 2) environmental pollution or health hazards caused by drifting materials, oil, and hazardous waste spillages; 3) outbreak of disease of epidemic proportions, which could be serious in densely populated areas.

Tall reinforced concrete buildings served as vertical evacuation refuges during the 11 March 2011 Japan tsunami, saving many lives. Minami Sanriku, Japan. Photo courtesy of ITIC.

The 11 March 2011 tsunami leveled the town of Ofunato, Japan. Photo courtesy of ITIC.

Tsunami dispersion

Redistribution of tsunami energy, particularly as a function of its period, as it travels across a body of water.

Tsunami edge wave

Wave generated by a tsunami that travels along the coast.

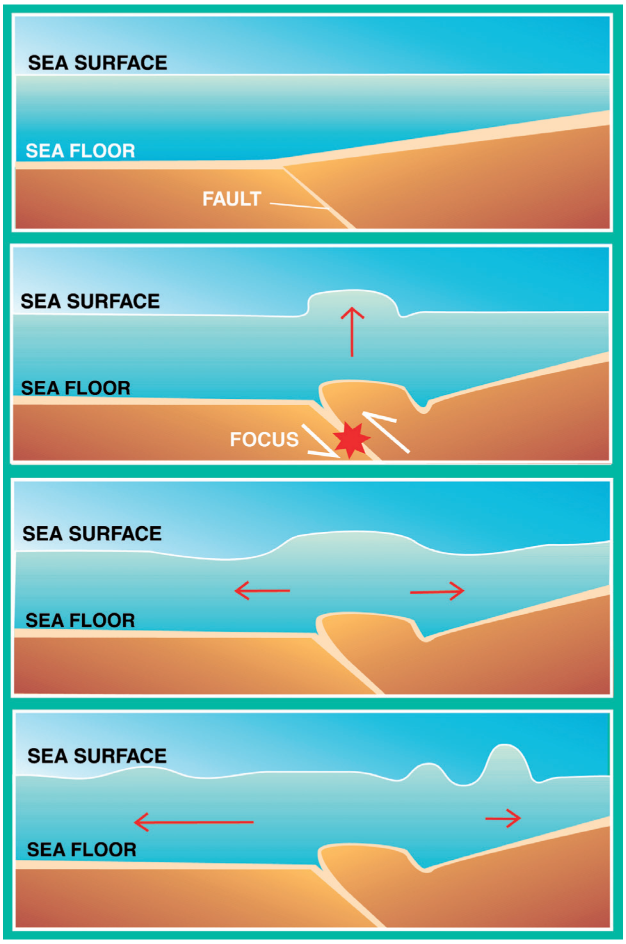
Tsunami forerunner

A series of oscillations of the water level preceding the arrival of the main tsunami waves, mainly due to the resonance in bays and shelves that could occur before the arrival of the main tsunami.

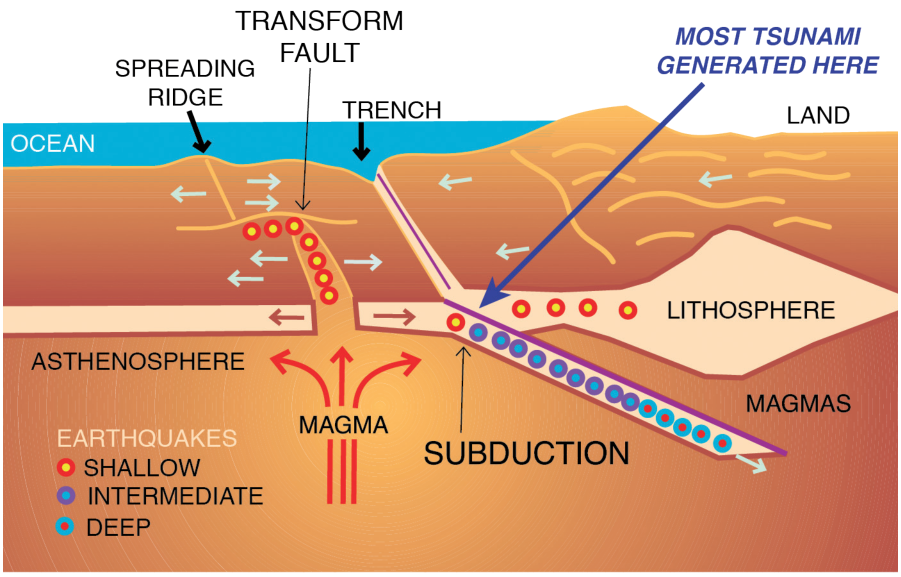
Tsunami generation

Tsunamis are most frequently caused by earthquakes, but can also result from landslides, volcanic eruptions, and very infrequently by meteorites or other impacts upon the ocean surface. Tsunamis are generated primarily by tectonic dislocations under the sea which are caused by shallow focus earthquakes along areas of subduction. The upthrusted and downthrusted crustal blocks impart potential energy into the overlying water mass with drastic changes in the sea level over the affected region. The energy imparted into the water mass results in tsunami generation, i.e. energy radiating away from the source region in the form of long period waves.

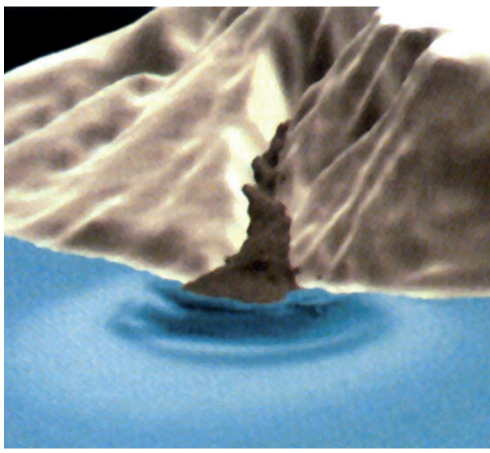
Tsunamis can be generated by submarine landslides, or by subaerial landslides that enter the water. Courtesy of LDG, France.



Tsunamis are most often generated by shallow earthquakes



Most tsunamis are generated by large, shallow, thrust earthquakes that occur as a tectonic plate is subducted. Shallow earthquakes also occur along spreading ridges, but these are not large enough to cause tsunamis. Large, shallow earthquakes also occur along transform faults, but there is only minor vertical motion during the faulting so no tsunamis are generated.



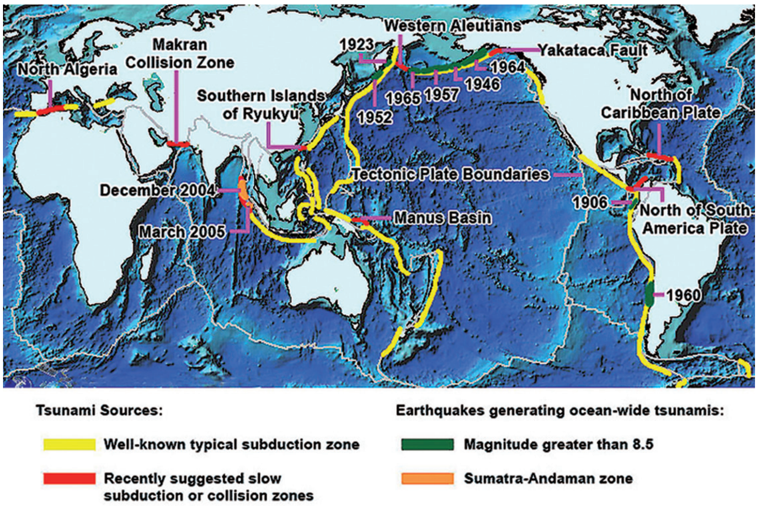
Tsunamis can be generated by pyroclastic flows associated with volcanic eruptions. Courtesy of LDG, France.

Tsunami generation theory

The theoretical problem of generation of the gravity wave (tsunami) in the layer of elastic liquid (an ocean) occurring on the surface of elastic solid half-space (the crust) in the gravity field can be studied with methods developed in the dynamic theory of elasticity. The source representing an earthquake focus is a discontinuity in the tangent component of the displacement on some element of area within the crust. For conditions representative of the Earth's oceans, the solution of the problem differs very little from the joint solution of two more simple problems: The problem of generation of the displacement field by the given source in the solid elastic half-space with the free boundary (the bottom) considered quasi-static; and the problem of the propagation of gravity wave in the layer of heavy incompressible liquid generated by the known (from the solution of the previous problem) motion of the solid bottom. There is the theoretical dependence of the gravity wave parameters on the source parameters (depth and orientation). One can roughly estimate the quantity of energy transferred to the gravity wave by the source. In general, it corresponds to the estimates obtained with empirical data. Also, tsunamis can be generated by other different mechanisms such as volcanic or nuclear explosions, landslides, rock falls, and submarine slumps.

Tsunami hazard

The probability that a tsunami of a particular size will strike a particular section of coast.



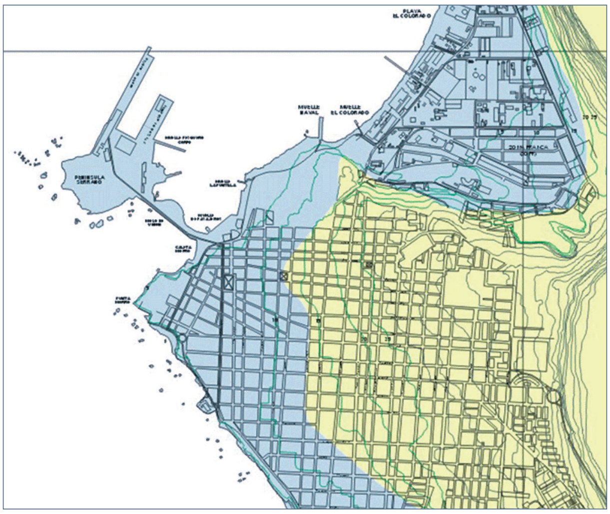
Global tsunami source zones. Tsunami hazards exist in all oceans and basins, but occur most frequently in the Pacific Ocean. Tsunamis can occur anywhere and at any time because earthquakes cannot be accurately predicted. Courtesy of LDG, France.

Tsunami hazard assessment

Documentation of tsunami hazards for a coastal community is needed to identify populations and assets at risk, and the level of that risk. This assessment requires knowledge of probable tsunami sources (such as earthquakes, landslides, and volcanic eruptions), their likelihood of occurrence, and the characteristics of tsunamis from those sources at different places along the coast. For those communities, data of earlier (historical and paleotsunamis) tsunamis may help quantify these factors. For most communities, however, only very limited or no past data exist. For these coasts, numerical models of tsunami inundation can provide estimates of areas that will be flooded in the event of a local or distant tsunamigenic earthquake or a local landslide.

Tsunami impact

Although infrequent, tsunamis are among the most terrifying and complex physical phenomena and have been responsible for great loss of life and extensive damage. Because of their destructiveness, tsunamis have important impacts on the human, social, and economic sectors of societies. Over the past 3500 years, there have been 279 fatal tsunamis and more than 600,000 deaths. The worst catastrophe in history was the 26 December 2004 Sumatra, Indonesia tsunami that killed 228,000 people in 12 Indian Ocean countries and caused $10 billion in damage. The Pacific Ocean, however, is where 75% of the world's tsunamis occur. 99% of the deaths were caused by local tsunamis, which are those hit in less than 1 hour tsunami travel time. Since 80% of the tsunamis are generated by shallow great earthquakes, shaking and damage from the earthquake is the 1st hazard to address before the tsunami arrives.



Estimated tsunami inundation at Iquique, Chile, based on numerical model results. Courtesy of SHOA, Chile.

In Japan, which has one of the most populated coastal regions in the world and a long history of earthquake activity, tsunamis have destroyed entire coastal populations. There is also a history of severe tsunami destruction in Alaska, the Hawaiian Islands, Indonesia, and South

America.The last major Pacific-wide tsunami was the 11 March 2011 Japan tsunami which killed more than 18,000 in Japan and 2 persons in the far field.

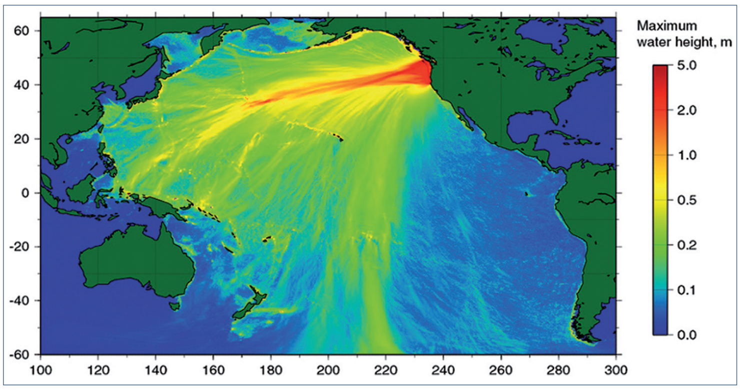
Tsunami numerical modelling

Mathematical descriptions that seek to describe the observed tsunami and its effects.

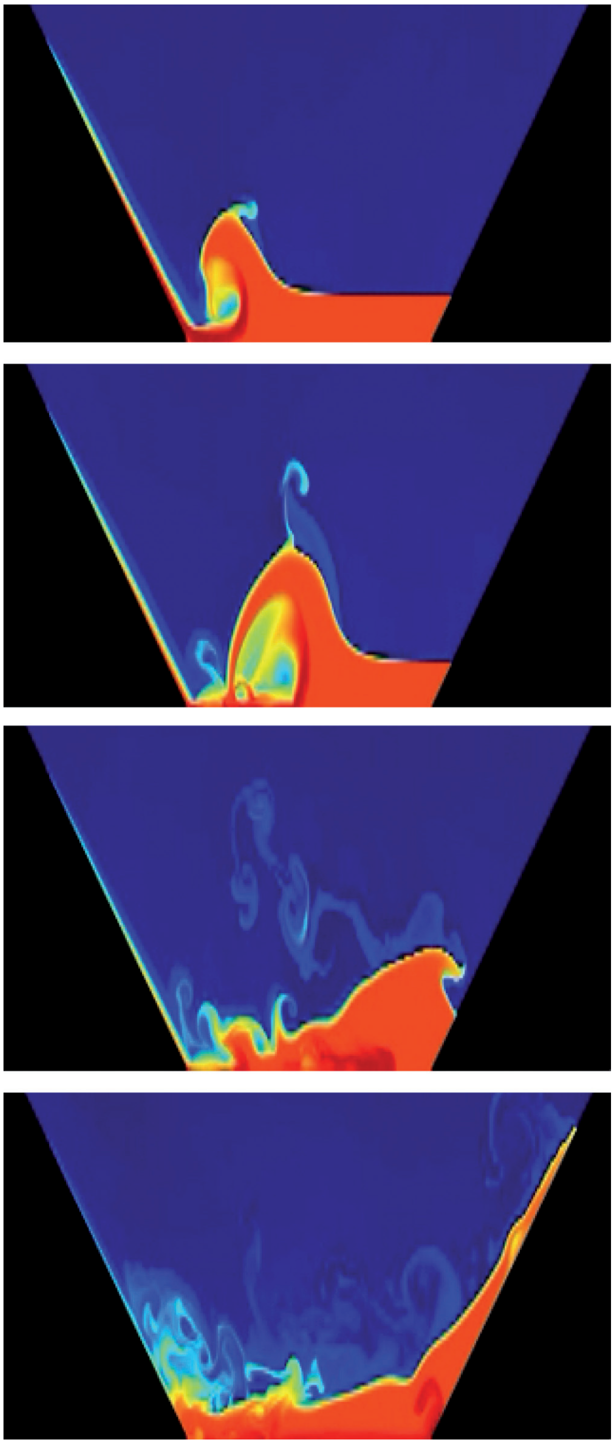
Often the only way to determine the potential runups and inundation from a local or distant tsunami is to use numerical modelling since data from past tsunamis is usually insufficient. Models can be initialized with potential worst case scenarios for the tsunami sources or for the waves just offshore to determine corresponding worst case scenarios for runup and inundation. Models can also be initialized with smaller sources to understand the severity of the hazard for the less extreme but more frequent events. This information is then the basis for creating tsunami evacuation maps and procedures. At present, such modelling has only been carried out for a small fraction of the coastal areas at risk. Sufficiently accurate modelling techniques have only been available in recent years, and these models require training to understand and use correctly, as well as input of detailed bathymetric and topographic data in the area being modelled.

Numerical models have been used in recent years to simulate tsunami propagation and interaction with land masses. Such models usually solve similar equations but often employ different numerical techniques and are applied to different segments of the total problem of tsunami propagation from generation regions to distant areas of runup. For example, several numerical models have been used to simulate the interaction of tsunamis with islands. These models have used finite difference, finite element, and boundary integral methods to solve the linear long wave equations. These models solve these relatively simple equations and provide reasonable simulations of tsunamis for engineering purposes.

Tsunami warning centres use numerical models to forecast expected wave arrival times, directions of maximum tsunami energy, strength of near-shore water currents, and coastal wave height. This important information helps emergency response officials to plan and focus relief on where the impact is expected to be the greatest.



Calculated maximum tsunami wave heights for a M9.0 Cascadia subduction zone earthquake. The model was calculated after tsunami deposits found in Japan and elsewhere suggested that a repeat of the 1700 Cascadia great earthquake would generate a destructive teletsunami. Courtesy of Kenji Satake, Geological Survey of Japan.



Complex numerical model calculated to match the 1958 Lituya Bay, Alaska landslide-generated local tsunami which caused the largest runup ever recorded (525 m). The complex model matches very closely the detail of the second order eddies and splash effects that laboratory experiments showed. Courtesy of Galen Gisler, Los Alamos National Laboratory.

Tsunami observation

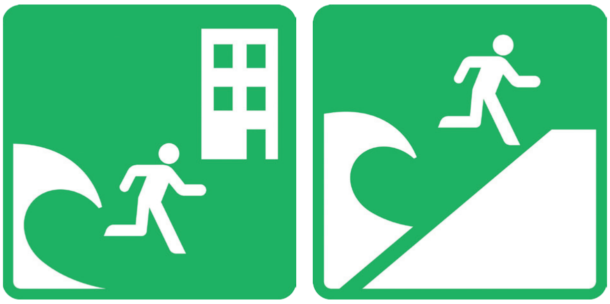
Noticeable, observation or measurement of sea level fluctuation at a particular point in time caused by the incidence of a tsunami on a specific point.

1946 Aleutian Islands tsunami rushing ashore in Hilo, Hawaii. Photo courtesy of Pacific Tsunami Museum.

Tsunami preparedness

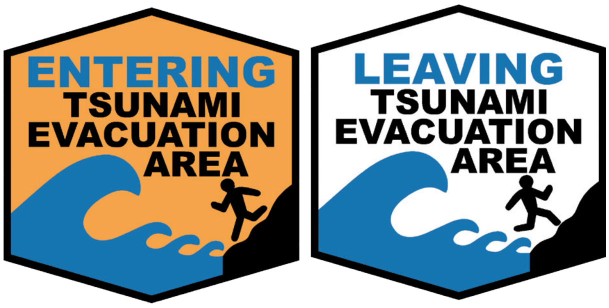
Readiness of plans, methods, procedures, and actions taken by government officials and the general public for the purpose of minimizing potential risk and mitigating the effects of future tsunamis. The appropriate preparedness for a warning of impending danger from a tsunami requires knowledge of areas that could be flooded (tsunami inundation maps) and knowledge of the warning system to know when to evacuate and when it is safe to return.

Tsunami evacuation route sign, Chile



Tsunami evacuation building and safe place signs in Japan approved by ISO.

Tsunami hazard sign approved by International Standards Organization (ISO) in 2008.

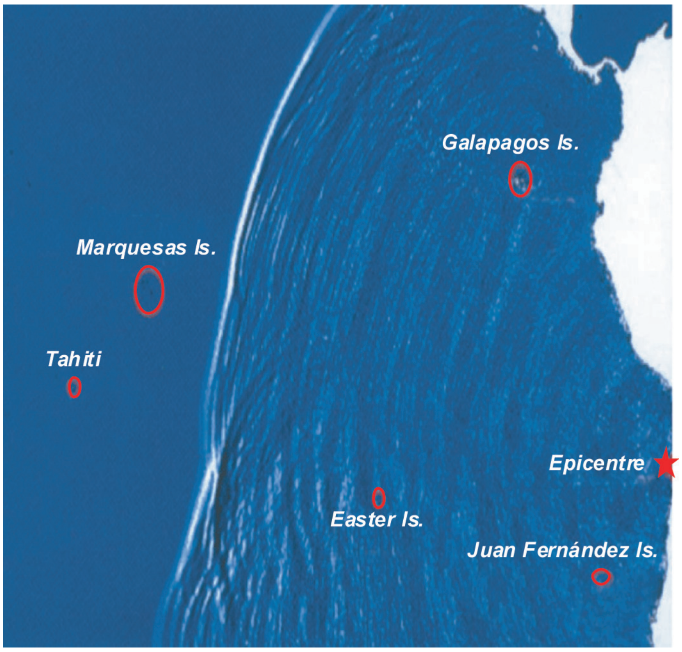


Tsunami evacuation area signs, Hawaii, USA

Tsunami hazard zone sign, Washington, USA

Tsunami propagation

Tsunamis travel outward in all directions from the generating area, with the direction of the main energy propagation generally being orthogonal to the direction of the earthquake fracture zone. Their speed depends on the depth of water, so that the waves undergo accelerations and decelerations in passing over an ocean bottom of varying depth. In the deep and open ocean, they travel at speeds of 500 to 1,000 km per hour (300 to 600 miles per hour). The distance between successive crests can be as much as 500 to 650 km (300 to 400 miles). However, in the open ocean, the height of the waves is generally less than a meter (3 feet) even for the most destructive teletsunamis, and the waves pass unnoticed. Variations in tsunami propagation result when the propagation impulse is stronger in one direction than in others because of the orientation or dimensions of the generating area and where regional bathymetric and topographic features modify both the waveform and rate of advance. Specifically, tsunami waves undergo a process of wave refraction and reflection throughout their travel. Tsunamis are unique in that the energy extends through the entire water column from sea surface to the ocean bottom. It is this characteristic that accounts for the great amount of energy propagated by a tsunami.



Model of tsunami propagation in the southeast Pacific, nine hours after generation. Source: Antofagasta, Chile (30 July 1995). Courtesy of LDG, France.

Tsunami resonance

The continued reflection and interference of tsunami waves from the edge of a harbour or narrow bay that can cause amplification of the wave heights, and extend the duration of wave activity from a tsunami.

Tsunami risk

The probability of a particular coastline being struck by a tsunami multiplied by the likely destructive effects of the tsunami and by the number of potential victims. In general terms, risk is the hazard multiplied by the exposure.

Tsunami simulation

Numerical model of tsunami generation, propagation, and inundation.

Tsunami source

Point or area of tsunami origin, usually the site of an earthquake, volcanic eruption, or landslide that caused large-scale rapid displacement of the water to initiate the tsunami waves.

Tsunami velocity or shallow water velocity

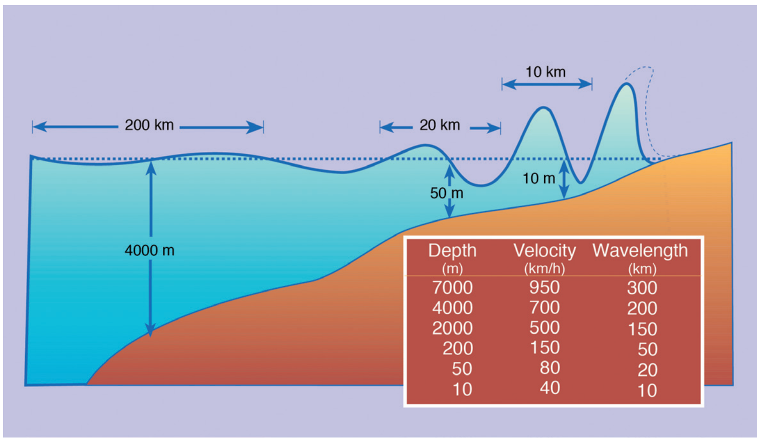
The velocity of an ocean wave whose length is sufficiently large compared to the water depth (i.e., 25 or more times the depth) can be approximated by the following expression:

$$c = \sqrt{(gh)}$$

Where:
c: is the wave velocity
g: the acceleration due to gravity
h: the water depth.

Thus, the velocity of shallow-water waves is independent of wavelength L. In water depths between ½ L and 1/25 L it is necessary to use a more precise expression:

$$c = \sqrt{((gL/2\pi)[\tanh(2\pi h/L)])}$$



Wave height and water depth. In the open ocean, a tsunami is often only a tens of centimetres high, but its wave height grows rapidly in shallow water. Tsunami wave energy extends from the surface to the bottom in the deepest waters.
As the tsunami attacks the coastline, the wave energy is compressed into a much shorter distance creating destructive, life-threatening waves.

Tsunami zonation (tsunami zoning)

Designation of distinctive zones along coastal areas with varying degrees of tsunami risk and vulnerability for the purpose of disaster preparedness, planning, construction codes, or public evacuation.

Tsunamigenic

Capable of generating a tsunami. For example: a tsunamigenic earthquake, a tsunamigenic landslide.

Destruction of Hilo Harbor, Hawaii, 1 April 1946. The tsunami generated off the coast of Unimak Island, Aleutian Islands, raced across the Pacific, coming ashore in Hawaii less than five hours later. Photo courtesy of NOAA.

3

3. SURVEYS AND MEASUREMENTS

This section contains terms used to measure and describe tsunami waves on mareographs and in the field during a survey, and terms used to describe the size of the tsunami

Arrival time

Time of the first maximum of the tsunami waves.

Crest length

The length of a wave along its crest. Sometimes called crest width.

Drop

The downward change or depression in sea level associated with a tsunami, a tide, or some long-term climatic effect.

Elapsed time

Time between the maximum level arrival time and the arrival time of the first wave.

Flow depth

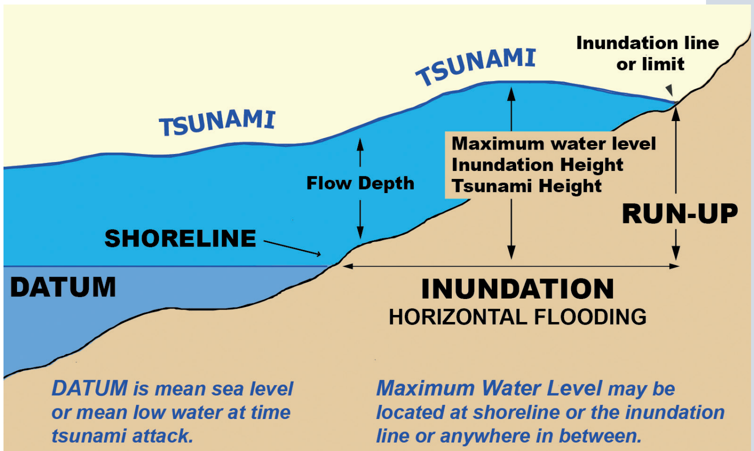
Depth, or height of the tsunami above the ground, at a specific location as indicated by flow markers such as piles of debris, impact scars on tree trunks, dead vegetation on trees or electric wires, or mud marks on building walls. The inundation height is the sum of the flow depth and local topographic height.

Initial rise

Time of the first minimum of the tsunami waves.

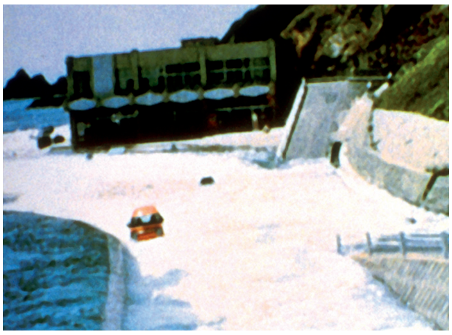
Intensity

The measure of strength, force, or energy.



Inundation or Inundation-distance

The horizontal distance inland that a tsunami penetrates, generally measured perpendicularly to the shoreline.



Tsunami inundation generated by the earthquake of 26 May 1983, at Oga aquarium in Japan. Photo courtesy of Takaaki Uda, Public Works Research Institute, Japan.

Inundation (maximum)

Maximum horizontal penetration of the tsunami from the shoreline. A maximum inundation is measured for each different coast or harbour affected by the tsunami.

Inundation area

Area flooded with water by the tsunami.

Dark area shows inundation area from the 1964 Alaska tsunami. Photo courtesy of NGDC/WDS-Geophysics.

Inundation height

Elevation reached by seawater measured relative to a stated datum such as mean sea level or the sea level at the time of tsunami arrival, at a specified inundation distance. Inundation height is the sum of the flow depth and the local topographic height. Sometimes referred to as tsunami height.

Inundation line

Inland limit of wetting, measured horizontally from the mean sea level (MSL) line. The line between living and dead vegetation is sometimes used as a reference. In tsunami science, the landward limit of tsunami runup.

Leading wave

First arriving wave of a tsunami. In some cases, the leading wave produces an initial depression or drop in sea level, and in other cases, an elevation or rise in sea level. When a drop in sea level occurs, sea level recession is observed.

Magnitude

A number assigned to the properties of an event such that the event can be compared with other events of the same class.

Mean height

Average height of a tsunami measured from the trough to the crest after removing the tidal variation.

Modified Sieberg sea-wave intensity scale

1. Very light. Wave so weak as to be perceptible only on tide-gauge records.

2. Light. Wave noticed by those living along the shore and familiar with the sea. On very flat shores generally noticed.

3. Rather strong. Generally noticed. Flooding of gently sloping coasts. Light sailing vessels or small boats carried away on shore. Slight damage to light structures situated near the coast. In estuaries reversal of the river flow some distance upstream.

4. Strong. Flooding of the shore to some depth. Light scouring on man-made ground. Embankments and dikes damaged. Light structures near the coasts damaged. Solid structures on the coast injured. Big sailing vessels and small ships carried inland or out to sea. Coasts littered with floating debris.

5. Very strong. General flooding of the shore to some depth. Breakwater walls and solid structures near the sea damaged. Light structures destroyed. Severe scouring of cultivated land and littering of the coast with floating items and sea animals. With the exception of big ships, all other type of vessels carried inland or out to sea. Big bores in estuary rivers. Harbour works damaged. People drowned. Wave accompanied by strong roar.

6. Disastrous. Partial or complete destruction of man-made structures for some distance from the shore. Flooding of coasts to great depths. Big ships severely damaged. Trees uprooted or broken. Many casualties.

Overflow

A flowing over; inundation.

Post-tsunami survey

Tsunamis are relatively rare events and most of their evidence is perishable. Therefore, it is very important that reconnaissance surveys be organized and carried out quickly and thoroughly after each tsunami occurs, to collect detailed data valuable for hazard assessment, model validation, and other aspects of tsunami mitigation.

Since the early 1990s, post-tsunami reconnaissance surveys have been organized following each major destructive tsunami to make measurements of runups and inundation limits, to collect associated data from eyewitnesses such as the number of waves, arrival time of waves, and which wave was the largest, and to assess human response to tsunami danger. The surveys have been organized on an ad-hoc basis, facilitated and coordinated by the IOC and ITIC working with the affected country, and conducted by international academic tsunami researchers (International Tsunami Survey Team, ITST). The IOC Post-tsunami survey field guide (Manual and Guides 37, 1998, revised 2012, SC.98/WS/24) has been prepared to guide surveys, identify methods, measurements, and observations to be taken, and to standardize data collections. The Tsunami Bulletin Board e-mail service has been used for quickly organizing ITST surveys and for sharing of the observations from impacted areas.

After a major tsunami, physical oceanographers, social scientists and engineers conduct post-tsunami surveys to collect information. These data, including runup, flow depth, and inundation, deformation, scour, building and structural impact, wave arrival descriptions, and social impact, are important for designing better mitigation to reduce the impacts of tsunami on life and property. Photo courtesy of Philip Liu, Cornell University.

ITST measuring tsunami runup using laser rangefinder in El Salvador, 2012. Photo courtesy of ITIC

Recession

Drawdown of sea level prior to tsunami flooding. The shoreline moves seaward, sometimes by a kilometre or more, exposing the sea bottom, rocks, and fish. The recession of the sea is a natural warning sign that a tsunami is approaching.

North Shore, Oahu, Hawaii. During the 9 March 1957 Aleutian Island tsunami, people foolishly explored the exposed reef, unaware that tsunami waves would return in minutes to inundate the shoreline. Photo by A. Yamauchi, courtesy of Honolulu Star-Bulletin.

Rise

The upward change or elevation in sea level associated with a tsunami, a tropical cyclone, storm surge, the tide, or other long term climatic effect.

Runup

1. Difference between the elevation of maximum tsunami penetration (inundation line) and the sea level at the time of the tsunami. In practical terms, runup is only measured where there is a clear evidence of the inundation limit on the shore.

2. Elevation reached by seawater measured relative to some stated datum such as mean sea level, mean low water, sea level at the time of the tsunami attack, etc., and measured ideally at a point that is a local maximum of the horizontal inundation. Where the elevation is not measured at the maximum of horizontal inundation, this is often referred to as the inundation-height.

Tsunami stripped forested hills of vegetation leaving clear marker of tsunami runup, Banda Aceh, 26 December 2004 Sumatra tsunami. Photo courtesy of Yuichi Nishimura, Hokkaido University.

Runup can often be inferred from the vertical extent of dead vegetation, from debris normally found at ground level that are observed stuck on electric wires, in trees, or at other heights, and from water line marks left on building walls. In extreme cases, cars, boats, and other heavy objects have been lifted and deposited atop buildings. Banda Aceh, Indonesia, 26 December 2004. Photo courtesy of C. Courtney, Tetra Tech EMI.

Runup distribution

Set of tsunami runup values measured or observed along a coastline.

Sieberg tsunami intensity scale

A descriptive tsunami intensity scale, which was later modified into the Sieberg-Ambraseys tsunami intensity scale (Ambraseys, 1962) described in page 20.

Significant wave height

The average height of the one-third highest waves of a given wave group. Note that the composition of the highest waves depends upon the extent to which the lower waves are considered. In wave record analysis, the average height of the highest one-third of a selected number of waves, this number being determined by dividing the time of record by the significant period. Also called characteristic wave height.

Spreading

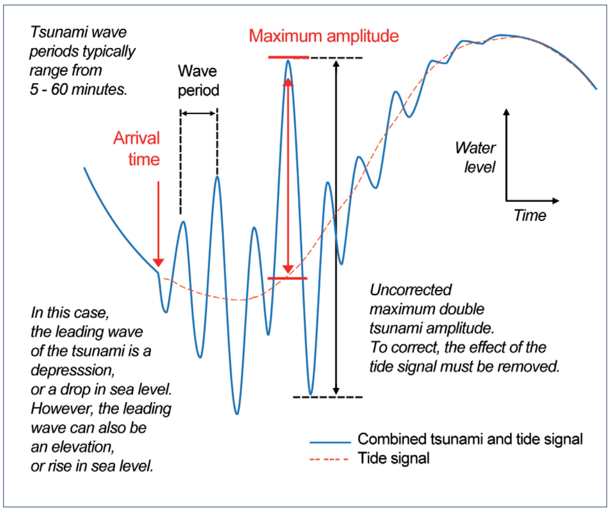
When referring to tsunami waves, it is the spreading of the wave energy over a wider geographical area as the waves propagate away from the source region. The reason for this geographical spreading and reduction of wave energy with distance travelled, is the sphericity of the earth. The tsunami energy will begin converging again at a distance of 90 degrees from the source. Tsunami waves propagating across a large ocean undergo other changes in configuration primarily due to refraction, but geographical spreading is also very important depending upon the orientation, dimensions, and geometry of the tsunami source.

Subsidence (uplift)

The permanent movement of land down (subsidence) or up (uplift) due to geologic processes, such as during an earthquake.

Tsunami amplitude

Usually measured on a sea level record, it is 1) the absolute value of the difference between a particular peak or trough of the tsunami and the undisturbed sea level at the time, 2) half the difference between an adjacent peak and trough, corrected for the change of tide between that peak and trough. It is intended to represent the true amplitude of the tsunami wave at some point in the ocean. However, it is often an amplitude modified in some way by the tide gauge response.



Mareogram (sea level) record of a tsunami

3

The 26 December 2004 earthquake resulted in 1.2 m of land subsidence in the Car Nicobar, Nicobar Islands, India, leaving houses that were once above sea level now permanently submerged. Photo courtesy of ICMAM, Chennai, DOD, India.

Tsunami intensity

Size of a tsunami based on the macroscopic observation of a tsunami's effect on humans, objects including various sizes of marine vessels, and buildings.

The original scale for tsunamis was published by Sieberg (1923), and later modified by Ambraseys (1962) to create a six-category scale. Papadopoulus and Imamura (2001) proposed a new 12-grade intensity scale which is independent of the need to measure physical parameters like wave amplitude, sensitive to the small differences in tsunami effects, and detailed enough for each grade to cover the many possible types of tsunami impact on the human and natural environment. The scale has 12 categories, similar to the Modified Mercalli Intensity Scale used for macroseismic descriptions of earthquake intensity.

Tsunami magnitude

Size of a tsunami based on the measurement of the tsunami wave on sea level gauges and other instruments.

The scale, originally descriptive and more similar to an intensity, quantifies the size by using measurements of wave height or tsunami runup. Lida et al. (1972) described the magnitude (m) as dependent in logarithmic base 2 on the maximum wave height measured in the field, and corresponding to a magnitude range from -1 to 4:

$$m = \log_2 H_{max}$$

Hatori (1979) subsequently extended this so-called Imamura-lida scale for far-field tsunamis by including distance in the formulation. Soloviev (1970) suggested that the mean tsunami height may be another good indicator of tsunami size, and the maximum intensity would be that measured nearest to the tsunami source. A variation on this is the Imamura-Soloviev intensity scale I (Soloviev, 1972). Shuto (1993) has suggested the measurement of H as the height where specific types of impact or damage occur, thus proposing a scale which can be used as a predictive quantitative tool for macroscopic effects.

Tsunami magnitudes have also been proposed that are similar in form to those used to calculate earthquake magnitudes. These include the original formula proposed by Abe (1979) for tsunami magnitude, M_t:

$$M_t = \log H + B$$

where H is the maximum single crest or trough amplitude of the tsunami waves (in metres) and B is a constant, and the far-field application proposed by Hatori (1986) which adds a distance factor into the calculation.

Tsunami period

Amount of time that a tsunami wave takes to complete a cycle, or one wavelength. Tsunami periods typically range from 5-60 minutes. Tsunami period is often measured as the difference between the arrival time of the highest peak and the next one measured on a water level record.

Tsunami wavelength

The horizontal distance between similar points on two successive waves measured perpendicular to the crest. The wavelength and the tsunami period give information on the tsunami source. For tsunamis generated by earthquakes, the typical wavelength ranges from 20 to 300 km. For tsunamis generated by landslides, the wavelength is much shorter, ranging from 100s of metres to 10s of kilometres.

Water level (maximum)

Difference between the elevation of the highest local water mark and the elevation of the sea level at the time of the tsunami. This is different from maximum runup because the water mark is often not observed at the inundation line, but maybe halfway up the side of a building or on a tree trunk. Also referred to as inundation or tsunami height.

Wave crest

1. The highest part of a wave.
2. That part of the wave above still water level.

Wave trough

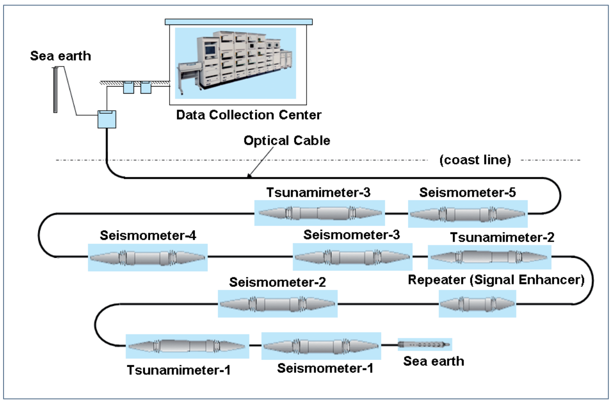
The lowest part of a wave.

4. TIDE, MAREOGRAPH, SEA LEVEL

This section contains terms to describe sea level and the instruments used to measure tsunamis

Cabled ocean bottom instrument

An instrument at the ocean bottom connected to the land by a cable that provides power for the measurement and transmission of data from the seafloor to the coast. Cables can extend for tens of kilometres offshore and across oceans. They enable real-time, multi-sensor seafloor observatories to be deployed for long-term monitoring. Examples of sensors on cabled systems are seismometers to measure earthquakes, sensitive pressure gauges to measure tsunamis, geodetic sensors to measure seafloor deformation, and cameras. Japan operates several cable systems.



Schematic diagram of cabled ocean system for monitoring earthquakes and tsunamis. Courtesy of JMA.

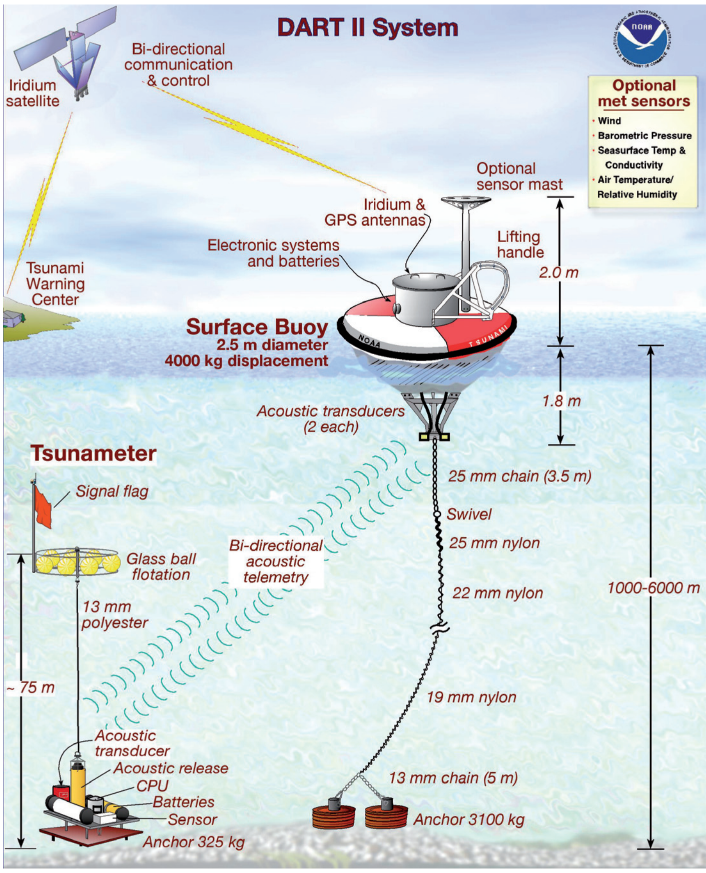
Cotidal

Indicating equality with the tides or a coincidence with the time of high or low tide.

Deep-ocean Assessment and Reporting of Tsunamis (DART®)

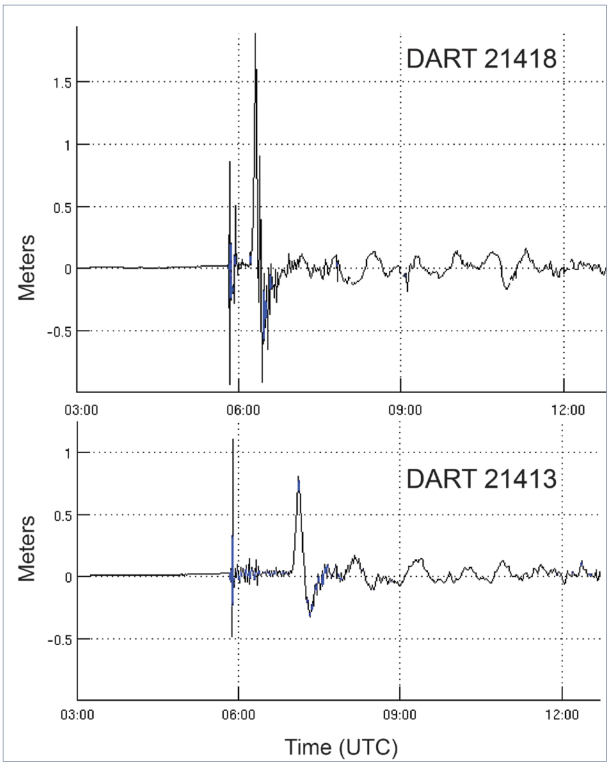
An instrument for the early detection, measurement, and real-time reporting of tsunamis in the open ocean.

Developed by the US NOAA Pacific Marine Environmental Laboratory, the DART® system consists of a seafloor bottom pressure recording system capable of detecting tsunamis as small as one centimetre, and a moored surface buoy for real-time communications. An acoustic link is used to transmit data from the seafloor to the surface buoy. The data are then relayed via a satellite link to ground stations, which demodulate the signals for immediate dissemination to the NOAA tsunami warnings centres. The DART® data, along with state-of-the-art numerical modelling technology, are part of a tsunami forecasting system package that will provide site-specific predictions of tsunami impact on the coast.

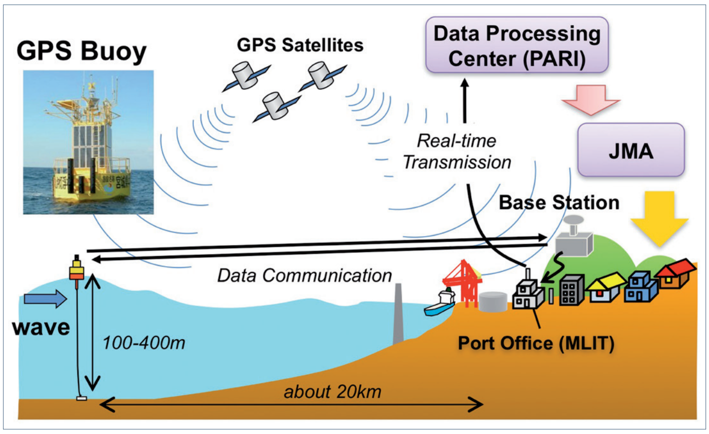


GPS wave gauge

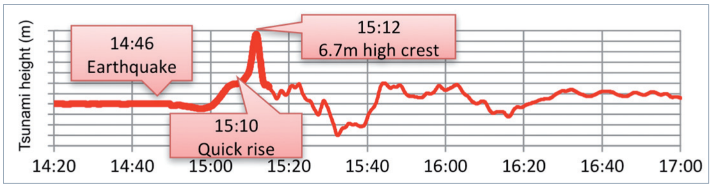
A surface buoy with a Global Positioning System (GPS) antenna moored about 20 km from coast to monitor sea level changes using real time kinematic (RTK) GPS technique with a land-based station. The GPS buoy is used as a wave gauge to detect tsunami before its arrival to the coast. In Japan, the system has been in operation since 2008, and in 2012, 15 GPS buoys were in operation by Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT). GPS data are transmitted to land, processed in real time by PARI (Port and Airport Research Institute), and then sent to JMA who is responsible for tsunami monitoring and warnings. During the 2011 Tohoku tsunami, the JMA detected the tsunami offshore and upgraded its tsunami warning for Japan.



The 11 March 2011 tsunami recorded on DART® #21418 located 450 nautical miles northeast of Tokyo. The maximum wave amplitude was 1.8 m measured at 33 min after the earthquake. The 1st arrival on the record is from the earthquake shaking. Data courtesy of NOAA.



GPS buoy system was introduced at 15 sites around Japan by MLIT for wave monitoring



The GPS buoy at 204 m in water depth off Kamaishi Port, Japan, recorded the first wave crest exceeded 6 m in the 2011 Tohoku-oki earthquake tsunami event. Profile acquired by Ports and Harbours Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan and processed by PARI.

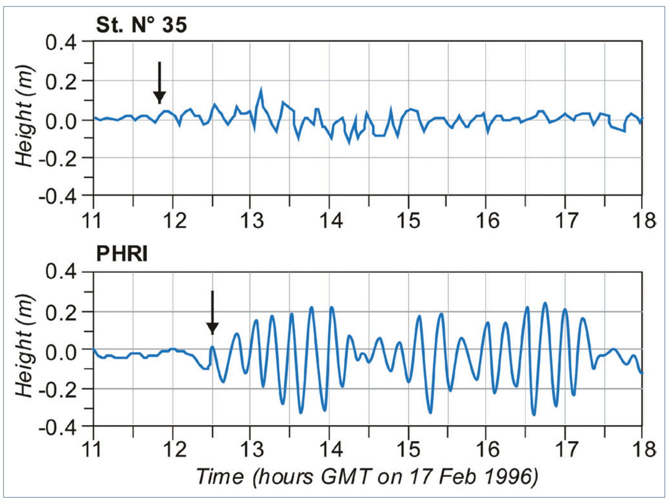
Low water

The lowest water level reached during a tide cycle. The accepted popular term is low tide.

Mareogram or Marigram

1. Record made by a mareograph.

2. Any graphic representation of the rise and fall of the sea level, with time as abscissa and height as ordinate, usually used to measure tides, may also show tsunamis.



Mareograms of tsunami signals measured by an underwater gauge located 50 km outside the entrance to Tokyo Bay in about 50 m of water (upper trace), and another gauge located at the shore (lower trace). The tsunami is detected on the outside gauge about 40 minutes before it reaches shore (arrows). The offshore cabled ocean bottom pressure sensor was developed by Japan's Port and Harbours Research Institute, and used by JMA.

Mareograph

A recording sea level gauge. Also known as a marigraph or tide gauge.

Mean sea level

The arithmetic mean of hourly heights of tide height on the open coast, or in adjacent waters which have free access to the sea, observed over some specified time period; often used as a datum for geodetic surveys. In the United States, mean sea level is defined as the average height of the surface of the sea for all stages of the tide over a 19-year period.

Probable maximum water level

A hypothetical water level (exclusive of wave runup from normal wind-generated waves) that might result from the most severe combination of hydrometeorological, geoseismic and other geophysical factors that is considered reasonably possible in the region involved, with each of these factors considered as affecting the locality in a maximum manner. This level represents the physical response of a body of water to maximum applied phenomena such as hurricanes, moving squall lines, other cyclonic meteorological events, tsunamis, and astronomical tide combined with maximum probable ambient hydrological conditions such as wave level with virtually no risk of being exceeded.

Reference sea level

The observed elevation differences between geodetic benchmarks are processed through least-squares adjustments to determine orthometric heights referred to a common vertical reference surface, which is the reference sea level. In this way, height values of all benchmarks in the vertical control portion of a surveying agency are made consistent and can be compared directly to determine differences of elevation between benchmarks in a geodetic reference system that may not be directly connected by lines of geodetic levelling. This important vertical geodetic control system is made possible by a universally accepted, reference sea level.

Refraction diagrams

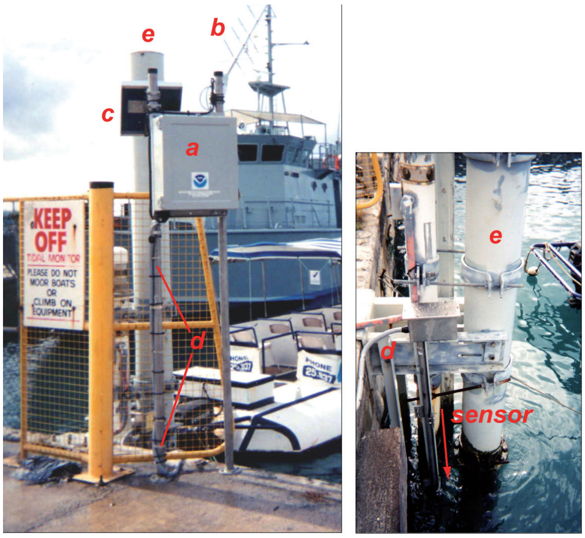
Models using water depths, direction of wave, separation angle, and ray separation between two adjacent rays as input, produce the path of wave orthogonals, refraction coefficients, wave heights, and travel times.

Sea level

The height of the sea at a given time measured relative to some datum, such as mean sea level.

Sea level station

A system consisting of a device such as a tide gauge for measuring the height of sea level, a data collection platform (DCP) for acquiring, digitizing, and archiving the sea level information digitally, and often a transmission system for delivering the data from the field station to a central data collection centre. The specific requirements of data sampling and data transmission are dependent on the application. The GLOSS programme maintains a core network of sea level stations. For local tsunami monitoring, one-second sampled data streams available in real time are required. For distant tsunamis, warning centres may be able to provide adequate warnings using data acquired in near-real time (one-minute sampled data transmitted every 15 minutes or better). Sea level stations are also used for monitoring long-term sea level change and climate change studies, where an important requirement is for the very accurate location of the station as acquired through surveying techniques.

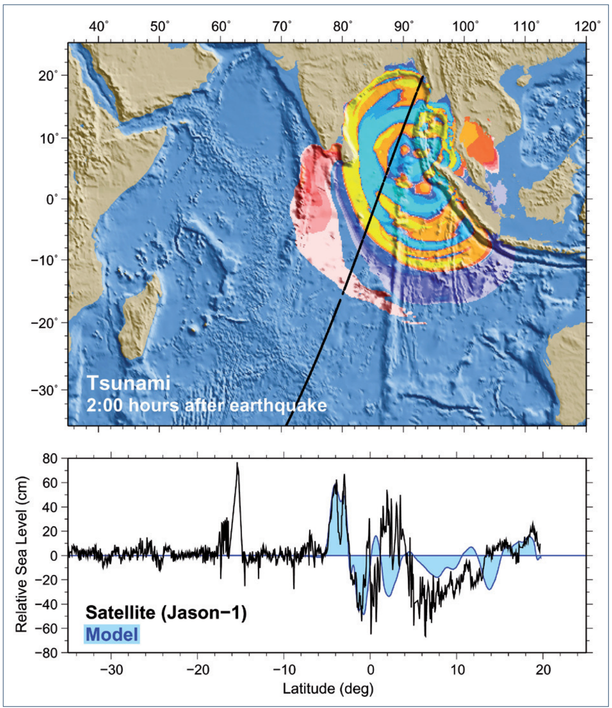


Rarotonga sea level station, Avarua Harbor, Cook Islands. The fiberglass electronics package (a), antenna (b), solar panel (c) were installed on a pier. Conduit (d) containing cables connecting the sensor, located at a depth of five feet below low-tide water level, to the data collection platform containing the electronics above, was externally attached to the tube containing the sensor (e).

GLOSS sea level stations employ a number of instruments to measure sea level, including down-looking radars to measure sea level. Port Louis, Mauritius. Photo courtesy of University of Hawaii Sea Level Center.

Sea Surface Height

Satellite altimeters monitor Sea Surface Height (SSH), and can record a snapshot of the propagating tsunami if the satellite orbit is located above the tsunami. During the 2004 Indian Ocean tsunami and 2011 Tohoku tsunami, several satellites captured the tsunami as it propagated across the Indian and Pacific Ocean, respectively.



Radar altimeters aboard the Jason-1 satellite recorded the 26 December 2004 Indian Ocean tsunami in a snapshot taken two hours after the earthquake. Bottom profile superimposing MOST model calculations on the satellite data shows a maximum wave amplitude of about 60 cm. Image courtesy of NOAA.

Tidal wave

1) The wave motion of the tides.

2) Often incorrectly used to describe a tsunami, storm surge, or other unusually high and therefore destructive water levels along a shore that are unrelated to the tides.

Tide

The rhythmic, alternate rise and fall of the surface (or water level) of the ocean, and of bodies of water connected with the ocean such as estuaries and gulfs, occurring twice a day over most of the Earth and resulting from the gravitational attraction of the moon (and, in lesser degrees, of the sun) acting unequally on different parts of the rotating Earth.

Tide amplitude

One-half of the difference in height between consecutive high water and low water; hence, half of the tidal range.

Tide gauge

A device for measuring the change in sea level relative to a datum.

Tide station

A place where tide observations are obtained.

Tsunameter

An instrument for the early detection, measurement, and real-time reporting of tsunamis in the open ocean. Also known as a tsunamimeter. The DART® system and cable deep-ocean pressure sensor are tsunameters.

Tsunamis will damage all coastal facilities.This sea level gauge at Talcahuano was being used by the Chilean Navy to monitor the 27 February 2010 Chile tsunami. During the 11 March 2011 Japan tsunami, seven stations were destroyed or damaged and six stations stopped transmitting data leaving JMA unable to fully monitor the tsunami's severity. Photo courtesy of R. Núñez Gundlach.

5. TSUNAMI WARNING SYSTEM ACRONYMS & ORGANIZATIONS

The IOC Global Tsunami Warning and Mitigation Systems work in partnership with a number of organizations and utilize specific acronyms and lexicon to describe system governance, services, and the different tsunami products

GLOSS

Global Sea-Level Observing System. A component of the Global Ocean Observing System (GOOS). The IOC of UNESCO established GLOSS in 1985 originally to improve the quality of sea level data as input to studies of long-term sea level change. It consists of a core network of approximately 300 stations distributed along continental coastlines and throughout each of the world's island groups. The GLOSS network also supports sea level monitoring for tsunami warning with minimum operational standards of 15-minute data transmissions of one-minute sampled data.

GOOS

Global Ocean Observing System. GOOS is a permanent global system for observations, modelling, and analysis of marine and ocean variables to support operational ocean services worldwide. The GOOS Project aims to provide accurate descriptions of the present state of the oceans, including living resources; continuous forecasts of the future conditions of the sea for as far ahead as possible; and the basis for forecasts of climate change. The GOOS Project Office, located at the IOC headquarters in Paris since 1992, provides assistance in the implementation of GOOS.

GTS

Global Telecommunications System of the World Meteorological Organization (WMO) that directly connects national meteorological and hydrological services worldwide. The GTS is widely used for the near real-time transmission of sea level data for tsunami monitoring. The GTS and other robust communications methods are used for the transmission of tsunami warnings.

ICG

Intergovernmental Coordination Group. As subsidiary bodies of the IOC of UNESCO, the ICG meets to promote, organize, and coordinate regional tsunami mitigation activities, including the issuance of timely tsunami warnings. To achieve this objective requires the participation, cooperation and contribution of many national and international seismic, sea level, communication, and dissemination facilities throughout the region. The ICG is comprised of Member States in the region. Currently, these are ICGs for tsunami warning and mitigation systems in the Pacific, Indian Ocean, Caribbean and adjacent regions, and the north-eastern Atlantic, the Mediterranean and connected seas. (http://www.ioc-tsunami.org/)

ICG/CARIBE-EWS

Intergovernmental Coordination Group for the Tsunami and other Coastal Hazards Warning System for the Caribbean and Adjacent Regions established by Resolution XXIII-14 of the 23rd Session of the IOC General Assembly in 2005. The ICG is comprised principally of IOC Member States and regional organizations from the Wider Caribbean Region. Through the coordinating efforts of the IOCARIBE Sub-commission starting in 1993, a Group of Experts formulated a proposal for the building of the Intra-Americas Tsunami Warning System that was endorsed by the IOC General Assembly in 2002.

ICG/IOTWS

Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System established by Resolution XXIII-12 of the 23rd Session of the IOC General Assembly in 2005. The ICG/IOTWS Secretariat is presently located in Perth, Australia. There are presently 28 Member States in IOTWS.

Banda Aceh, Sumatra, Indonesia. The tsunami of 26 December 2004 completely razed coastal towns and villages, leaving behind only sand, mud, and water where once there had been thriving communities of homes, offices, and green space. Photo courtesy of DigitalGlobe.

ICG/ITSU

International Coordination Group for the Tsunami Warning System in the Pacific established by Resolution IV-6 of the 4th Session of the IOC Assembly in 1965. The ICG/ITSU was renamed to the ICG/PTWS in 2006 by Resolution EC-XXXIX.8 of the IOC Executive Council.

ICG/NEAMTWS

Intergovernmental Coordination Group for the Tsunami Early Warning and Mitigation System in the North-Eastern Atlantic, the Mediterranean and Connected Seas established by Resolution XXIII-13 of the 23rd Session of the IOC General Assembly in 2005. The ICG is comprised principally of IOC Member States bordering the north-eastern Atlantic and those bordering or within the Mediterranean or connected seas. Presently there are 39 Member States.

ICG/PTWS

Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System, former ICG/ITSU, was renamed by Resolution EC-XXXIX.8 of the IOC Executive Council in 2006 as proposed by ITSU at its 20th Session in 2005 (Recommendation ITSU-XX.1). The PTWS encompasses 46 countries.

IOC

Intergovernmental Oceanographic Commission of UNESCO. IOC is the focal point for ocean sciences and ocean services within the United Nations system, mandated to promote "international cooperation and coordinate programmes in research, services and capacity-building, in order to learn more about the nature and resources of the ocean and coastal areas and to apply that knowledge for the improvement of management, sustainable development, the protection of the marine environment, and the decision-making processes of its Member States". The IOC assists governments to address their individual and collective ocean and coastal problems through the sharing of knowledge, information and technology and through the coordination of national programmes. (http://ioc-unesco.org/)

ITIC

International Tsunami Information Center. ITIC was established in November 1965 by the IOC Assembly of UNESCO to support the ICG/ITSU in the Pacific. The ITIC also provides technical and capacity building assistance to Member States for the global establishment of tsunami warning and mitigation systems in the Indian and Atlantic Oceans, the Caribbean and Mediterranean Seas, and other oceans and marginal seas, and as the oldest, supports Tsunami Information Centres starting in other regions. In the Pacific, the ITIC specifically monitors and recommends improvements to the PTWS, coordinates tsunami technology transfer among Member States interested in establishing regional and national tsunami warning systems, acts as a clearinghouse for risk assessment and mitigation activities, works with the World Data Service for Geophysics to collect historical event data, and serves as a resource for the development, publication, and distribution of tsunami education and preparedness materials. (http://www.tsunamiwave.info)

ITSU Master Plan

The principal long-term guide for improving the TWS. The Plan provides a summary of the basic elements which comprise the TWS, a description of its existing components, and an outline of the activities, data sets, methods, and procedures that need to be improved in order to reduce tsunami risk. The first edition of the ICG/PTWS Master Plan was released in 1989. The third edition was released in 2004 (IOC/INF-1124 Rev). (http://www.unesco.org/ulis/cgi-bin/ulis.pl?catno=117788&set=50C4D77D_0_77&gp=1&lin=1&ll=1)

IUGG

International Union of Geodesy and Geophysics. The IUGG is a non-governmental, scientific organization established in 1919, dedicated to promoting and coordinating studies of the Earth and its environment in space. The IUGG Tsunami Commission, established in 1960, is an international group of scientists concerned with various aspects of tsunamis, including an improved understanding of the dynamics of generation, propagation, and coastal runup of tsunamis, as well as their consequences to society. (http://iugg.org)

JMA

Japan Meteorological Agency. JMA established a tsunami warning service in 1952. JMA now serves as a National Tsunami Warning System that continuously monitors 24 hours-a-day all seismic activity in Japan, and issues timely information concerning earthquakes and tsunamis. In 2005, the JMA began operations of the Northwest Pacific Tsunami Advisory Center (NWPTAC). The NWPTAC provides supplementary tsunami information for events in and around Japan and the northwest Pacific, and interim services for the South China Sea region, in close coordination with the PTWC. From 2005-2012, JMA and PTWC provided interim services for the Indian Ocean. (http://www.jma.go.jp/jma)

Operational Users Guide for the Tsunami Warning System

The Guide includes a summary of the administrative and operational services and procedures, including monitoring and detection data networks used by the warning centres, the criteria for the reporting and issuing of tsunami information messages, samples messages, the recipients of the information, and the methods by which the messages are sent. Background information to assist users in understanding the products that are issued may also be included. In the Pacific, it was formerly called the Communications Plan for the TWSP.

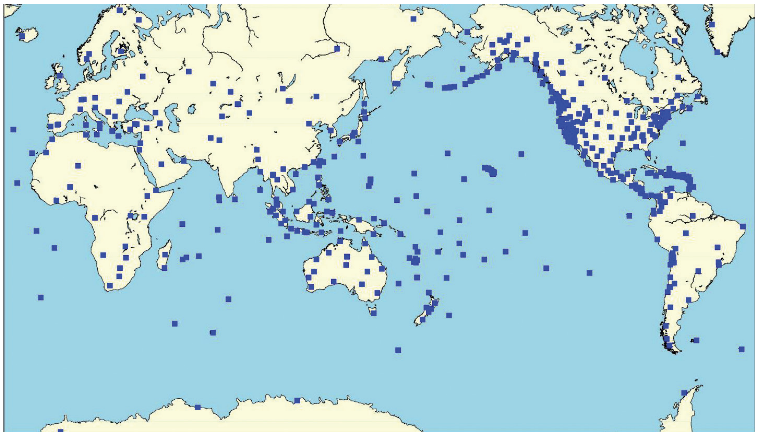
PTWC and WCATWC

Established in 1949, NOAA's Richard H. Hagemeyer **Pacific Tsunami Warning Center** (PTWC) in Ewa Beach, Hawaii, serves as the warning operations headquarters for the PTWS and works closely with sub-regional and national centres in monitoring and evaluating potentially tsunamigenic earthquakes. It provides international warning advisories for teletsunamis to countries in the Pacific, and warnings for Hawaii and US Pacific island interests. PTWC provided interim services for the Indian Ocean from 2005-2012, and since 2005 for the wider Caribbean. Established in 1964, NOAA's **West Coast and Alaska Tsunami Warning Center** (WCATWC) provides warning services to the continental USA, Puerto Rico, the US and British Virgin Islands, and Canada, and serves as a back up to PTWC. (http://ptwc.weather.gov) (http://wcatwc.arh.noaa.gov).

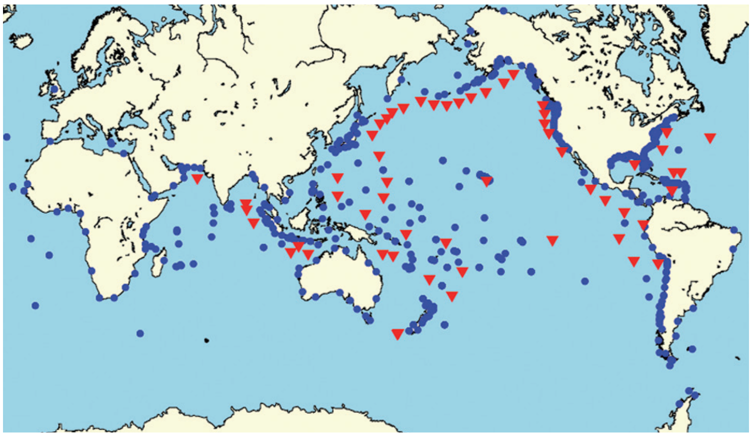
PTWC facilities located at Ewa Beach, Hawaii, USA

5

PTWC operations area



Global seismic network used by PTWC (November 2012)



Global sea level network used by PTWC (October 2012). Dots indicate coastal sea level stations and triangles DART deep-ocean stations.

RTSP

Regional Tsunami Service Provider. IOTWS Centre that provides timely earthquake information, tsunami forecasts, and other information to the Indian Ocean NTWCs. An RTSP may also serve a dual role as the NTWC for the country in which it operates.Threat-based assessment information is shared with NTWCs through secure communication methods and NTWCs report back the status of national tsunami warnings to the RTSPs. As of November 2012, authorized IOTWS RTSPs are Australia, India, and Indonesia.

TBB

Tsunami Bulletin Board. TBB is an ITIC-sponsored e-mail list serve that provides an open, objective scientific forum for the posting and discussion of news and information relating to tsunamis and tsunami research. The ITIC provides the service to tsunami researchers and other technical professionals for the purpose of facilitating the widespread dissemination of information on tsunami events, current research investigations, and announcements for upcoming meetings, publications, and other tsunami-related materials. All members of the TBB are welcome to contribute. Messages are immediately broadcast without modification. The TBB has been very useful for helping to rapidly organize post-tsunami surveys, for distributing their results, and for planning tsunami workshops and symposia. Members of the TBB automatically receive the tsunami bulletins issued by the PTWC and WCATWC.

TER

Tsunami Emergency Response describes the actions taken to ensure public safety by responsible agencies after notification by the Tsunami Warning Focal Point (TWFP), typically the national Tsunami Warning Centre. It includes Standard Operating Procedures and Protocols for emergency response and action, organizations and individuals involved and their roles and responsibilities, contact information, timeline and urgency assigned to action, and means by which both ordinary citizens and special needs populations (physically or mentally handicapped, elderly, transient, and marine populations) will be alerted. For tsunami response, emphasis is placed on the rapidness, efficiency, conciseness, and clarity of the actions and instructions to the public. A Tsunami Emergency Response Plan should also include post-tsunami actions and responsibilities for search and rescue, relief, rehabilitation, and recovery.

PTWC issued a tsunami warning in 1986 for an Aleutian Islands earthquake, prompting Hawaii emergency officials to evacuate all low-lying coasts. Waimea Bay, Oahu, Hawaii. Photo courtesy of Honolulu Star-Bulletin.

TNC

ICG Tsunami National Contact. The person designated by an ICG Member State government to represent his/her country in the coordination of international tsunami warning and mitigation activities. The person is part of the main stakeholders of the national tsunami warning and mitigation system programme. The person may be the Tsunami Warning Focal Point from the national disaster management organization, from a technical or scientific institution, or from another agency with tsunami warning and mitigation responsibilities.

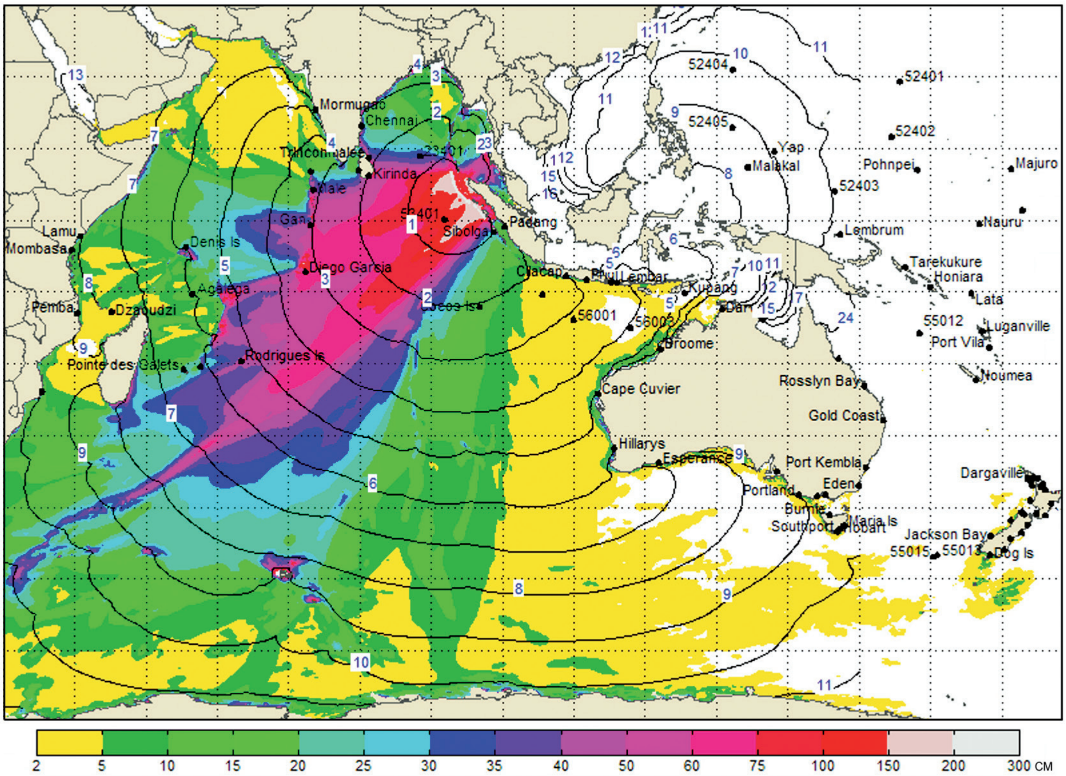
Tsunami All-Clear

After a warning is cancelled, an All-Clear condition is issued by local authorities (not the TWC) to the public when it is safe for them to return to the evacuated zones. As local conditions can cause wide variations in tsunami wave action, the All-Clear will depend on the degree of damage and can vary from locality to locality. In general, after receipt of a Tsunami Warning Cancellation, agencies can assume All-Clear status when their area is free from damaging waves for at least two hours, unless additional ETAs have been announced by the TWC (for example for a significant aftershock) or local conditions cause continued seiching or particularly strong currents in channels and harbours that require the continuation of the Tsunami Warning status. Local damage to structures and critical infrastructure, and/or secondary impacts caused by fires or hazardous materials leakage, may delay substantially the All-Clear announcement.

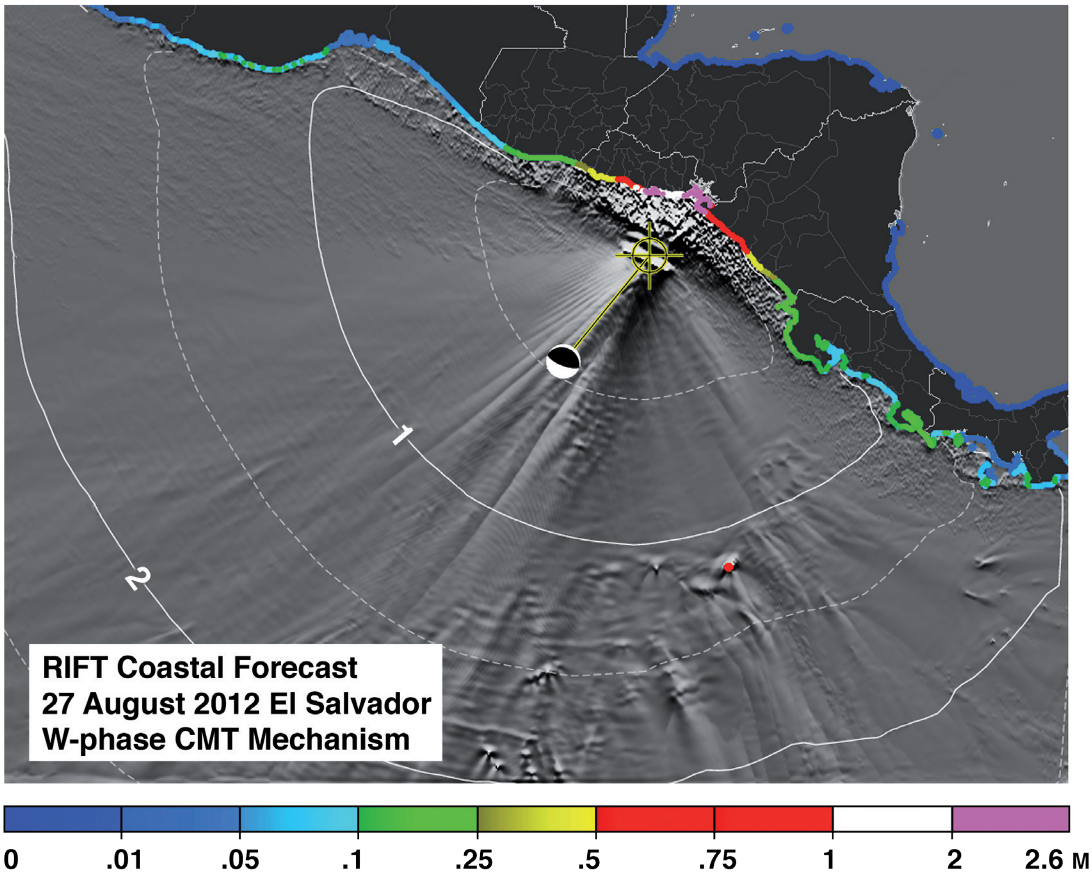
Tsunami Forecast

A quantitative estimate of any property of the tsunami hazard that is made in advance. Properties that may be forecast include the time of initial wave arrival, the time of maximum wave arrival, the amplitude of the maximum tsunami waves, and the duration of the tsunami hazard. Forecasts are primarily produced by warning centres using the output of numerical models. These may include travel time models, propagation models, and inundation models. All models rely on assumptions, primarily regarding the tsunami source that may or may not be accurate and can contribute to errors in the forecast. Most models can be constrained with observations of the tsunami as they become available, thus make the forecast more accurate. Tsunami forecasts may be issued at forecast points, for sub-blocks geographically or according to geopolitical jurisdictions within a country in order to provide detailed advice on the tsunami threat.

5



IOTWS RTSP Australia tsunami threat map for the Indian Ocean from the 26 December 2004 M9.1 earthquake off Sumatra, Indonesia. This forecast would have been issued if there had been international warning centres in operation in 2004. Colour bands show tsunami energy propagation directions and maximum offshore amplitudes. Expected tsunami travel time contours are shown at 1-hr intervals. Courtesy of Joint Australia Tsunami Warning Centre.



PTWC RIFT tsunami threat forecast from the 27 August 2012 M7.7 thrust earthquake off El Salvador.Colours along the coast indicate expected maximum tsunami amplitudes at those locations with pink indicating the highest amplitudes. Expected tsunami travel time contours (white) are shown at 30 min. intervals. Grey-shaded relief shows directivity of propagating tsunami energy. Courtesy of PTWC.

Tsunami Forecast Point

The location where the Tsunami Warning Centre, or other organization, provides an estimate of tsunami arrival time and/or wave height. They may correspond to important coastal cities or populations, and/or to the locations of sea level gauges.

Tsunami Threat Levels

Describes the types of tsunami threats according to its potential hazard and impact to people, structures, and ecosystems on land or in near-shore marine environments. Depending on the type of threat, a NTWC may issue a warning, watch, advisory, or an information bulletin or statement.

Land Inundation Threat. Tsunamis that threaten land can inundate coastal communities possibly causing significant destruction if there is a major land threat. When there is a land threat, people should immediately evacuate tsunami hazard zones.

Marine Coastal Waters Threat. Tsunamis that are a marine threat may generate strong local currents in coastal waters. When this is a marine threat, people should stay out of the water and away from the open ocean or inlets of water.

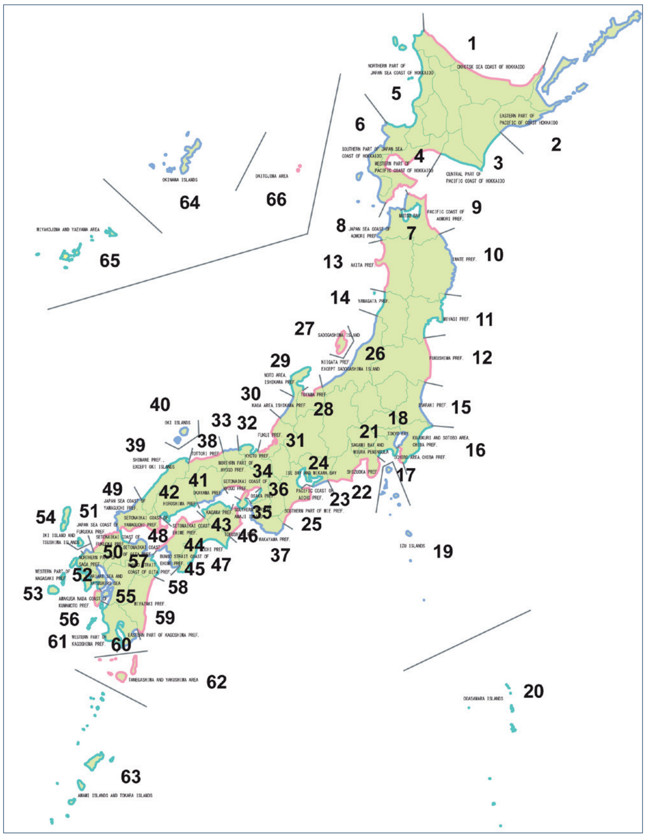
No Threat. Tsunamis that are no threat are not expected to cause damage.

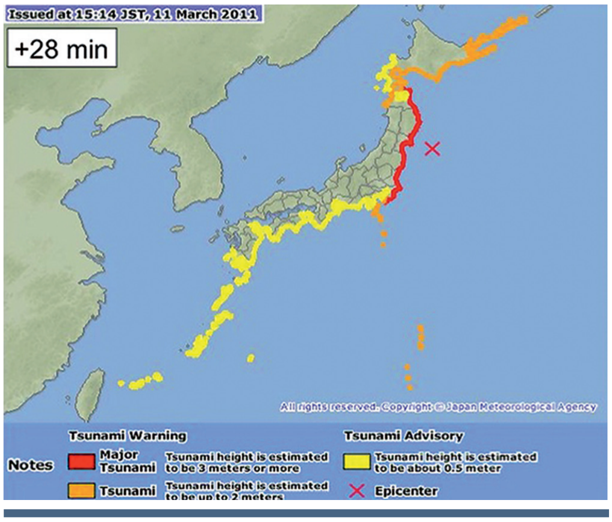
Tsunami Warning

A tsunami warning is an alert, usually issued by a National Tsunami Warning Centre (NTWC), to indicate that a tsunami hazard is expected and imminent. A tsunami warning may be issued for different levels of tsunami threat. For example, a low-level threat is one characterized by small sea level changes and strong ocean currents, and the tsunami is only a hazard at beaches, in harbours, and for recreational ocean activities. During a major threat, high amplitude waves along with powerful currents can be expected and could cause significant inundation and complete destruction of most near-shore structures. Dangerous waves may continue for several hours after arrival of the initial wave.

Different levels of warning should trigger different types of response by emergency officials and by the at-risk public. Appropriate public safety action taken when there is a major threat includes the evacuation of low-lying coastal areas, and the repositioning of ships to deep waters if there is time. Warnings may be updated, adjusted geographically, downgraded, or cancelled. To provide the earliest alert, initial warnings are normally based only on seismic information. Threat levels may be given different names by different countries depending upon their language and the standard nomenclature they use for other hazards such as weather events.

In Japan, there are 66 coastal forecast regions, and warnings are issued specifically for each. There are three levels of threat based on the tsunami height forecast (major tsunami warning, tsunami warning, and advisory).





JMA tsunami forecast regions (left) and 11 March 2011 Japan tsunami warning (top). The entire eastern coast of Japan was placed on alert 28 minutes after the M9.0 earthquake, with northern Japan under a Major Tsunami and the rest of the Pacific coast under a tsunami warning or advisory. All warnings and advisories were cancelled after 2 days, 3 hours and 12 minutes.

Tsunami Warning Cancellation

A warning will be cancelled when damaging waves have stopped coming ashore. A cancellation is issued when sea level readings indicate that the tsunami is below destructive levels and subsiding in most monitored locations.

The 29 September 2009 Samoa tsunami starting flooding Pago Pago Harbour 11 minutes after the earthquake, and the second wave, 14 minutes later, overtopped banks, pushing boats onto the roofs off shore-side buildings, American Samoa. Photo courtesy of R. Madsen.

TWC

Tsunami Warning Centre. Centre that issues timely tsunami messages to emergency response agencies and/or the public. International TWC messages are advisory to a country's TWFP. National TWC (NTWC) messages are advisory to the country's official emergency agencies. International TWCs monitor and provide tsunami information to Member States on potential distant and regional tsunamis using global data networks, and can often issue messages within 10 minutes of the earthquake. Local TWCs monitor and provide tsunami information on potential local tsunamis that will strike within minutes. Local TWCs must have access to continuous, real-time, densely-spaced data networks in order to characterize the earthquakes within seconds and issue a warning within minutes.

An example of an International Tsunami Warning Centre (ITWC) is the Pacific Tsunami Warning Center that provides international tsunami alerts to the Pacific. Examples of Regional ITWC's are the NWPTAC operated by the Japan JMA, and the WCATWC operated by the US NOAA. In the Pacific, these centres, along with long-time national centres in Chile, France, and Russia, also act as national TWCs providing tsunami warnings for their countries.

In the IOTWS, RTSP issue products to NTWCs through a secure service. In the PTWS and CARIBE-EWS, PTWC, NWPTAC, and WCATWC issue products simultaneously to TWFPs and the public. In the NEAMTWS, TWPs issue products to NTWCs and TWFPs.

Tsunami Warning Centre Products

Tsunami Warning Centres issue four basic types of messages: 1) information bulletins when a large earthquake has occurred but there is little or no tsunami threat; 2) local, regional, or basin-wide watch, advisory, or warning bulletins when there is an imminent tsunami threat; 3) cancellation bulletins when destructive tsunami waves are gone; and 4) tsunami communication test messages to regularly exercise the system. Tsunami Messages should contain useful emergency official decision-making information, namely the tsunami's urgency, its severity, its certainty, and the area it will affect. To provide the earliest alert, initial warnings are based only on the faster arriving seismic information, specifically earthquake location, magnitude, and depth. Tsunami messages are updated regularly, or as needed, or cancelled when the threat is gone.

Tsunami Messages are structured in a consistent manner, and should contain the following:

Message Header (Message Number, Issuing Centre, Issue Time), Message Type and Affected Area; Authority Statement; Earthquake Parameters; Tsunami Wave Measurements (as they become available); Evaluation Statement or Assessment of Threat (may include advice on appropriate response actions, certainty; Estimated Arrival Times; Wave Forecasts); and Next Message Schedule.

TWFP

ICG Tsunami Warning Focal Point. 7x24 contact person, or other official point of contact or address for rapidly receiving and issuing tsunami event information (such as warnings). The Tsunami Warning Focal Point either is the emergency authority (civil defence or other designated agency responsible for public safety), or has the responsibility of notifying the emergency authority of the event characteristics (earthquake and/or tsunami), in accordance with national standard operating procedures. The Tsunami Warning Focal Point receives international tsunami advice from PTWS centres (PTWC, WCATWC, NWPTAC within the JMA), IOTWS RTSPs (in 2012, Australia, India, Indonesia), NEAMTWS Candidate TWPs (in 2012, France, Turkey, Greece) or other regional international warning centres.

TWP

Tsunami Watch Providers are accredited NEAMTWS NTWCs willing and able to provide tsunami alert information to other Member States at designated Forecast Points; Watch Recipients are those TWFPs choosing to receive such information; usually they will themselves be NTWCs. In order to be recognized as part of the NEAMTWS, Candidate TWPs must meet a number of requirements and be approved by the ICG/NEAMTWS. Member States will have the freedom to decide from which TWP they would like to receive tsunami watch messages, and can receive tsunami watch messages from more than one TWP.

UNESCO

United Nations Educational, Scientific and Cultural Organization. Established in 1945, UNESCO promotes international cooperation among its Member States in the fields of education, science, culture and communication. Today, UNESCO works as a laboratory of ideas and standard setter to forge universal agreements on emerging ethical issues. The Organization also serves as a clearinghouse that disseminates and shares information and knowledge, while helping Member States to build their human and institutional capacities in diverse fields. The UNESCO Constitution states: "Since wars begin in the minds of men, it is in the minds of men that the defences of peace must be constructed." (http://www.unesco.org/)

WDS and NGDC

International Council of Science (ICSU) **World Data System** was created through a decision of the General Assembly of the ICSU in its 29th Session in 2008. WDS builds on the 50-year legacy of the ICSU World data Centre (WDC) system. WDS promotes disciplinary and multidisciplinary applications with a broader disciplinary and geographic base build on the potential offered by advanced interconnections between data management components. At the moment, includes 49 Member organizations.

NOAA's **National Geophysical Data Center** (NGDC) operates a collocated World Data Service for Geophysics which includes the Marine Geology and Geophysics Division that manages global geophysical, sea floor, and natural hazards data, including tsunamis. These data cover time scales ranging from seconds to millennia and they provide baseline information for research in many disciplines.

(http://www.icsu-wds.org/, http://www.ngdc.noaa.gov/hazard/)

6. BIBLIOGRAPHY

GENERAL

Atwater, Brian F., et al., *Surviving a tsunami – Lessons from Chile, Hawaii, and Japan*. USGS Circular 1187. Washington DC: GPO, rev 2005. In English online. Spanish version *Sobreviviendo a un tsunami: lecciones de Chile, Hawai y Japón*. USGS Circular 1218, rev 2009. Online.

Bernard, E.N., ed., *Developing tsunami-resilient communities: The National Tsunami Hazard Mitigation Program*. Dorchedt: Springer, 2005.

Bernard, E.N., and A. R. Robinson, *Tsunamis, The Sea*, Volume 16. Cambridge: Harvard University Press, 2009.

Dudley, W. and M. Lee, *Tsunami!*, 2nd Edition. Honolulu: University of Hawaii Press, 1998.

UNESCO/IOC, *Master plan for the Tsunami Warning System in the Pacific*, Third Edition. IOC Information document No. 1124 rev. Paris: UNESCO, 2004. In English online.

UNESCO/IOC, *Post-tsunami survey field guide, Second Edition*. IOC Manuals and Guides No. 37. Paris: UNESCO, 1998, rev 2012. First Edition (1998) in Russian, French and Spanish online.

UNESCO/IOC International Tsunami Information Center, *Tsunami Newsletter*. Honolulu: ITIC, 1965 to present. In English online.

UNESCO/IOC International Tsunami Information Center, Tsunami, *The Great Waves*. IOC Brochure 2012-4. Paris: UNESCO, rev 2012 (original NOAA PA 7407, 1975). In English; Spanish and French versions online.

UNESCO/IOC International Tsunami Information Center, *Tsunami Glossary*. IOC Technical Series 85. Paris: UNESCO, rev 2013. In English; Spanish and French versions online.

UNESCO/IOC International Tsunami Information Center, *Tsunami Warning!*. IOC Information Document No. 1223. Paris: UNESCO, rev 2005 (original 2000).

EVENT CATALOGUES

Berninghausen, W.H., *Tsunamis and seismic seiches of Southeast Asia*. Bulletin of the Seismological Society of America, 59, 289-297, 1969.

Berninghausen, W.H., *Tsunamis and seismic seiches reported from regions adjacent to the Indian Ocean*. Bulletin of the Seismological Society of America, 56(1), 69-74, 1966.

Berninghausen, W.H., *Tsunamis and seismic seiches reported from the Western North and Atlantic and the coastal waters of Northwestern Europe*. Informal Report No. 68-05, Washington DC: Naval Oceanographic Office, 1968.

Berninghausen, W.H., *Tsunamis reported from the west coast of South America*, 1562-1960. Bull. Seismol. Soc. Amer., 52, 915-921, 1962.

Berninghausen, W. H., *Tsunamis and seismic seiches reported from the eastern Atlantic south of the Bay of Biscay*. Bull. Seismol. Soc. Amer., 54, 439-442, 1964.

Dunbar, P.K., P. A. Lockridge, and L. S. Whiteside, *Catalogue of Significant Earthquakes*. 2150BC-1991AD. US Department of Commerce, NOAA, National Geophysical Data Center, Boulder, USA, World Data Center A for Solid Earth Geophysics Reports SE-49, 320 pp, 1992.

Everingham, I.B., *Preliminary Catalogue of Tsunamis for the New Guinea / Solomon Island Region 1768-1972*. Bureau of Mineral Resources, Canberra, Australia, Report 180, 78 pp, 1977.

Heck, N.H., *List of seismic sea waves*. Bulletin of the Seismological Society of America, Vol. 37, No. 4, p. 269-286, 1947.

Lida, K., D. Cox, and G. Pararas-Carayannis, *Preliminary catalog of tsunamis occurring in the Pacific Ocean*. Data Report No. 5, Hawaii Institute of Geophysics, HIG-67-10. Honolulu: University of Hawaii, re-issued 1972. http://www.soest.hawaii.edu/Library/Tsunami%20Reports/Iida_et_al.pdf.

Lida, K., *Catalog of tsunamis in Japan and its neighboring countries*. Aichi Institute of Technology, Yachigusa, Yakusa-cho,Toyota-shi, 470-03, Japan, 52 p, 1984.

Kanamori, H. and K. Yomogida, *First results of the 2011 Off the Pacific Coast of Tohoku earthquake*, Earth, Planets Space, 63, 511–902, 2011.

Lander, J. F., L. S. Whiteside, and P. A. Lockridge, *Two Decades of Global Tsunamis*, 1982-2002, Science of Tsunami Hazards, the International Journal of the Tsunami Society, Honolulu, Hawaii, USA, 21, 3-82, 2003.

Lander, J.F, *Tsunamis Affecting Alaska 1737-1996*. KGRD No. 31, National Oceanic and Atmospheric Administration, National Geophysical Data Center, Boulder, Colorado, USA, September, 155, 1996.

Lander, J.F, P.A. Lockridge, and M.J. Kozuch, *Tsunamis affecting the West Coast of the United States 1806-1992*. US Department of Commerce, NOAA, National Geophysical Data Center, Boulder, USA, NGDC Key to Geophysical Records Documentation KGRD-29. 242 pp, 1993.

Lander, J., and P. Lockridge, *United States Tsunamis (including United States Possessions) 1690-1988*. Publication 41-2, Boulder: National Geophysical Data Center, 1989.

Lockridge, P.A., *Tsunamis in Peru-Chile*, Report SE-39, World Data Center A for Solid Earth Geophysics, NOAA, National Geophysical Data Center, Boulder, CO, USA, 97, 1985.

Lockridge, P.A., L.S. Whiteside and J.F. Lander, *Tsunamis and Tsunami-like Waves of the Eastern United States*. Science of Tsunami Hazards, the International Journal of the Tsunami Society, Honolulu, Hawaii, USA, 20 (3), 120-144, 2002.

Molina, E.e (Seccion de Sismologia, INSIVUMEH, Guatemala). *Tsunami catalogue for Central America 1539-1996* [Report]. Reduction of natural disasters in Central America. Universitas Bergensis Technical Report no. II 1-04, Bergen, Norway: Institute of Solid Earth Physics, University of Bergen; 1997.

Murty, T.S. and M. Rafiq, *A tentative list of tsunamis in the marginal seas of the north Indian Ocean*. Natural Hazards, 4 (1), 81-83, 1991.

NOAA National Geophysical Data Center (NGDC), US Dept of Commerce, Boulder, CO, *Global Historical Tsunami Database, 2000 BC to present, 2012*, online http://www.ngdc.noaa.gov/hazard/tsu_db.shtml

NOAA National Geophysical Data Center and UNESCO/IOC-NOAA International Tsunami Information Center, *2012 Global Tsunami Sources, 1410 BC to 2012 AD Map*. Also online

O'Loughlin, K.F. and J.F. Lander, *Caribbean tsunamis: A 500-year history from 1498-1998, Advances in Natural and Technological Hazards Research*, Vol. 20 Boston, MA: Kluwer Academic Publishers, 2003.

Pararas-Carayannis G., *Catalogue of Tsunamis in the Hawaiian Islands*. US Department of Commerce, NOAA National Geophysical Center, Boulder, USA, World Data Center A for Solid Earth Geophysics Publication, 94 pp, 1969.

Sanchez Devora, A. J., and S. F. Farreras Sanz, *Catalog of tsunamis on the western coast of Mexico*. Report SE-50, World Data Center A for Solid Earth Geophysics, NOAA, National Geophysical Data Center, Boulder, Colorado, USA, 79 p., 1993.

Satake, K., A. B. Rabinowich, U. Kanoglu, and S. Tinti, *Tsunamis in the World Ocean: Past, Present, and Future*. Volume I, Pure Appl. Geophys, 168 (6-7), Topical Issue, 2011a.

Satake, K., A. B. Rabinowich, U. Kanoglu, and S. Tinti, *Tsunamis in the World Ocean: Past, Present, and Future*. Volume II, Pure Appl. Geophys, 168 (11), Topical Issue, 2011b.

Satake, K., A.B. Rabinowich, D. Dominey-Howes, and J.C. Borrero, *Historical and Recent Catastrophic Tsunamis in the World: Volume I. The 2011 Tohoku Tsunami.*, Pure Appl. Geophys., 170 (6/8), Topical Issue, 2012a.

Satake, K., A.B. Rabinowich, D. Dominey-Howes, and J.C. Borrero, *Historical and Recent Catastrophic Tsunamis in the World: Volume II. Tsunamis from 1755 to 2010*, Pure Appl. Geophys., 170 (9/10), Topical Issue, 2012b.

Sato, S., *Special Anniversary Issue on the 2011 Tohoku earthquake tsunami*, Coastal Engineering Journal, 54 (1), 2012.

Soloviev, S.L., et al., *Tsunamis in the Mediterranean Sea 2000 BC-2000AD. Advances in Natural and Technological Hazards Research*, Vol. 13, Dordrecht: Kluwer Academic Publishers, 2000.

Soloviev, S.L., and C. N. Go, *A catalogue of tsunamis on the western shore of the Pacific Ocean*. Academy of Sciences of the USSR, Nauka Publishing House, Moscow, 310 pp. Canadian Translation of Fisheries and Aquatic Sciences No. 5077, 1984, translation available from Canada Institute for Scientific and Technical Information, National Research Council, Ottawa, Ontario, Canada K1A OS2, 447 pp, 1974.

Soloviev, S.L., and C. N. Go, *A catalogue of tsunamis on the eastern shore of the Pacific Ocean*. Academy of Sciences of the USSR, Nauka Publishing House, Moscow, 204 pp. Canadian Translation of Fisheries and Aquatic Sciences No. 5078, 1984, translation available from Canada Institute for Scientific and Technical Information, National Research Council, Ottawa, Ontario, Canada K1A OS2, 293 pp, 1975.

Soloviev, S.L., C. Go, and C. S. Kim, *Catalogue of Tsunamis in the Pacific 1969-1982*, Results of Researches on the International Geophysical Projects. Moscow: Academy of Sciences of the USSR, 1992.

Soloviev, S.L. and M.D. Ferchev, *Summary of Data on Tsunamis in the USSR*. Bulletin of the Council for Seismology, Academy of Sciences of the USSR [Byulleten Soveta po Seismologii Akademiya Nauk, SSSR], 9, 23-55, Moscow, USSR, 37, 1961.

Tinti S., A. Maramai and L. Graziani. *A new version of the European Tsunami Catalogue: updating and revision*. Natural Hazards and Earth System Sciences, 1, 1-8, 2001.

Tsunami Laboratory, ICMMG SD RAS, Novosibirsk, Russia, *Historical Tsunami Database for the World Ocean (HTDB/WLD), 1628 B.C to present, 2011*, online http://tsun.sscc.ru/nh/tsunami.php

Watanabe, H., *Comprehensive List of Tsunamis to Hit the Japanese Islands*, 2nd Ed., University of Tokyo Press, 1998, 245 p, 1998, in Japanese.

TECHNICAL

Abe, K., *Size of great earthquakes 1837-1974 inferred from tsunami data*, J. Geophys. Res, 84, 1561-1568, 1979.

Abe, Katsuyuki, *A new scale of tsunami magnitude, Mt. in Tsunamis: Their science and engineering*, Iida and Iwasaki, eds., Tokyo: Terra Scientific Publishing Company, 91-101, 1983.

Ambraseys, N.N., *Data for the investigation of the seismic sea-waves in the Eastern Mediterranean*, Bulletin of the Seismological Society of America, 52:4, 895-913, 1962.

Cummins, P.R., L.S.L. Kong, and K. Satake, *Tsunami Science Four Years after the 2004 Indian Ocean Tsunami. Part I: Modelling and Hazard Assessment*, Pure Appl. Geophys. 165 (11/12), Topical Issue, 2008.

Cummins, P.R., L.S.L. Kong, and K. Satake, *Tsunami Science Four Years after the 2004 Indian Ocean Tsunami. Part II: Observation and data Analysis*, Pure Appl. Geophys. 166 (1/2), Topical Issue, 2009.

Dmowska, R. and B. Saltzman, eds., *Tsunamigenic earthquakes and their consequences. Advances in Geophysics*, Vol. 39, San Diego: Academic Press, 1998.

European Commission. Directorate General for Science, Research and Development, UNESCO and Commissariat à l'Energie Atomique (CEA), *International Conference on Tsunamis, 26-28 May 1998.* France: CEA, 1998.

Fukuyama, E., J. B. Rundle, and K. F. Tiampo, eds., *Earthquake Hazard Evaluation*, ISBN 978-3-0348-0587-2

Hatori, T., *Relation between tsunami magnitude and wave energy*, Bull. Earthquake Res. Inst. Univ. Tokyo, 54, 531-541, 1979. In Japanese with English abstract.

Hatori, T., *Classification of tsunami magnitude scale*, Bull. Earthquake Res. Inst. Univ. Tokyo, 61, 503-515, 1986. In Japanese with English abstract.

Lida, K. and T. Iwasaki, eds., Tsunamis: *Their science and engineering, Proceedings of the International Tsunami Symposium (1981)*, Tokyo: Terra Scientific, 1983.

Kanamori, H., *Mechanism of tsunami earthquakes,* Phys. Earth Planet. Inter, 6, 346-359, 1972.

Keating, B., Waythomas, C., and A. Dawson, eds., *Landslides and Tsunamis*. Pageoph Topical Volumes, Basel: Birhäuser Verlag, 2000.

Mader, C., *Numerical modeling of water waves*, 2nd ed. Boca Raton, FL: CRC Press, 2004.

Papadopoulus, G., and F. Imamura, *A proposal for a new tsunami intensity scale*, International Tsunami Symposium Proceedings, Session 5, Number 5-1, Seattle, 2001.

Satake, K., ed., *Tsunamis: Case studies and recent developments*. Dordrecht: Springer, 2005.

Satake, K. and F. Imamura, eds., *Tsunamis 1992-1994: Their generation, dynamics, and hazard*, Pageoph Topical Volumes. Basel: Birhäuser Verlag, 1995.

Satake, K., E.A. Okal, and J.C. Borrerro, *Tsunami and its hazards in the Indian and Pacific oceans*, Pure Appl. Geophys., 164(2-3), Topical Issue, 2007

Sauber, J. and R. Dmowska, *Seismogenic and tsunamigenic processes in shallow subduction zones*. Pageoph Topical Volumes. Basel: Birhäuser Verlag, 1999.

Shuto, N., *Tsunami intensity and disasters, in Tsunamis in the World*, S. Tinti, ed., Dordrecht: Kluwer Academic Publishers, 197-216, 1993.

Sieberg, A., Erdbebenkunde, Jena: Fischer, 102-104, 1923. Sieberg's scale.

Soloviev, S.L., *Recurrence of earthquakes and tsunamis in the Pacific Ocean, in Tsunamis in the Pacific Ocean*, edited by W. M. Adams, Honolulu: East-West Center Press, 149-164, 1970.

Soloviev, S.L., *Recurrence of earthquakes and tsunamis in the Pacific Ocean*, Volny Tsunami (Trudy SahkNII, Issue 29), Yuzhno-Sakhalinsk, 7-46, 1972. In Russian.

Tinti, S., ed., *Tsunamis in the World: Fifteenth International Tsunami Symposium, 1991, Advances in Natural and Technological Hazards Research*, Vol. 1. Dordrecht: Kluwer Academic Publishers, 1993.

Tsuchiya, Y. and N. Shuto, eds., *Tsunami: Progress in prediction, disaster prevention and warning. Advances in Natural and Technological Hazards Research*, Vol. 4. Dordrecht: Kluwer Academic Publishers, 1995.

Yeh, H., Liu, P., and C. Synolakis, *Long-wave runup models*, Singapore: World Scientific, 1996.

7. TEXTBOOKS AND TEACHERS

GUIDEBOOKS (in English and Spanish)

Pre-elementary school: Earthquakes and tsunamis Chile: SHOA/IOC/ITIC, 1996. Revised 2003 in Spanish.

2-4 Grade: I invite you to know the earth I. Chile: SHOA/IOC/ITIC, 1997.

5-8 Grade: I invite you to know the earth II. Chile: SHOA/IOC/ITIC, 1997.

High School: Earthquakes and tsunamis. Chile: SHOA/IOC/ITIC, 1997.

8. INDEX

7

8

INTERNATIONAL TSUNAMI INFORMATION CENTER A UNESCO/IOC - NOAA Partnership 737 Bishop Street, Suite 2200, Honolulu, Hawaii 96813, USA Tel: (1) 808-532-6422, Fax: (1) 808-532-5576. http://www.tsunamiwave.info, E-mail: itic.tsunami@noaa.gov

Located in Honolulu, the International Tsunami Information Center (ITIC) was established on 12 November 1965 by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO). The first session of the International Coordination Group for the Tsunami Warning System in the Pacific (ICG/ITSU) convened in 1968. In 2006, the ICG/ITSU was renamed as the Intergovernmental Coordination Group for the Pacific Tsunami Warning and Mitigation System (ICG/PTWS) to emphasize the comprehensive nature of risk reduction.

The ITIC thanks the following scientists for their review assistance: Thorkild Aarup, Jose Borrero, Paula Dunbar, Fumihiko Imamura, Osamu Kamigaichi, Laura Kong, Emilio Lorca, Charles McCreery, Modesto Ortiz, William Power, Alexander Rabinovich, Kenji Satake, François Schindele, Fred Stephenson, Costas Synolakis, and Masahiro Yamamoto.

International Tsunami (ITSU) wave courtesy of Aqualog, France.

Technical Series 85

United Nations
Educational, Scientific and
Cultural Organization

Intergovernmental
Oceanographic
Commission