TSUNAMI

THE GREAT WAVES

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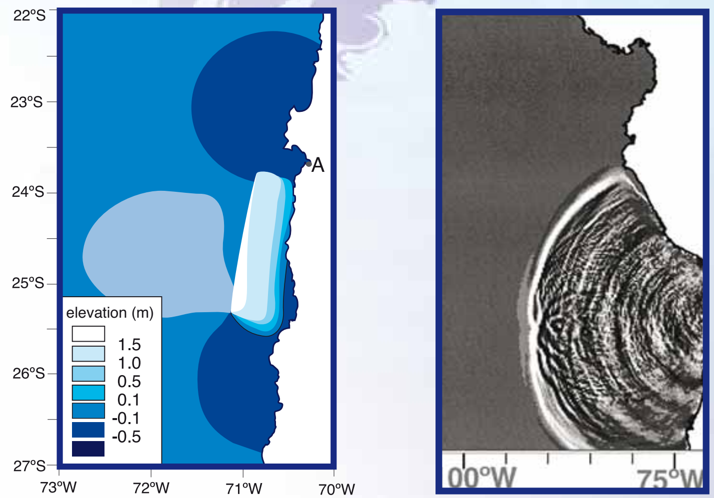
THE GREAT WAVES

The purpose of this brochure is to increase awareness and knowledge of tsunamis. Please share what you learn; knowing the right information may save your life and the lives of those you love.

The phenomenon we call "tsunami" (soo-NAH-mee) is a series of traveling ocean waves of extremely long length generated primarily by earthquakes occurring below or near the ocean floor. Underwater volcanic eruptions and landslides can also generate tsunamis. In the deep ocean, the tsunami waves propagate across the deep ocean with a speed exceeding 800 kilometers per hour ([km], ~500 miles per hour), and a wave height of only a few tens of centimeters (1 foot [ft]) or less. Tsunami waves are distinguished from ordinary ocean waves by their great length between wave crests, often exceeding 100 km (60 miles [mi]) or more in the deep ocean, and by the time between these crests, ranging from 10 minutes to an hour.

As they reach the shallow waters of the coast, the waves slow down and the water can pile up into a wall of destruction tens of meters (30 ft) or more in height. The effect can be amplified where a bay, harbor or lagoon funnels the wave as it moves inland. Large tsunamis have been known to rise over 30 meters (100 ft). Even a tsunami 3–6 meters (m) high can be very destructive and cause many deaths and injuries.

Tsunamis are a threat to life and property for all coastal residents living near the ocean. Globally over history, 279 tsunamis have caused more than 600,000 deaths, with nearly 90% of of the casualties from local tsunamis that hit within one hour. Most often (>80%), these tsunami are generated by great earthquakes that can cause damage before the tsunami arrives. During the 1990s, over 4,300 people were killed by 16 tsunamis, including 1100 lives lost in the 1992 Flores, Indonesia, and 2200 lives in the 1998 Aitape, Papua New Guinea tsunamis. Property damage was nearly one billion United States (U.S.) dollars. Although 60% of all tsunamis occur in the Pacific, they can also threaten coastlines of countries in the Indian Ocean, Mediterranean Sea, Caribbean region, and the Atlantic Ocean. Since 2000, there have been 13 tsunamis. The most devastating tsunami ever occurred in December 2004, when a M9.1 earthquake off of northwestern Sumatra, Indonesia produced a destructive tsunami that attacked coasts throughout the Indian Ocean, killing 228,000 people, displacing more than one million people, and causing billions of dollars of property damage. In March 2011, a M9.0 earthquake generated a giant local tsunami that overtopped sea walls, claiming nearly 19,000 lives in Tohoku, Japan.



Left: Computer model of the initial water surface changes at the time the July 30, 1995, Chilean tsunami was generated. A is Antofagasta, Chile. Right: Computer model of the same tsunami, three hours after it was generated.

Hilo Harbor, Hawaii, April 1, 1946, Aleutian Islands earthquake. Photo taken from the vessel Brigham Victory of tsunami breaking over Pier 1. The gentleman on the left did not survive. (NOAA)

At the Pacific Tsunami Warning Center (PTWC, USA) in Hawaii, the operational centre of the Pacific Tsunami Warning and Mitigation System (PTWS), scientists monitor seismographic and sea level stations, evaluate potentially tsunamigenic earthquakes, and disseminate international tsunami warning advisories to national authorities throughout the Pacific and Caribbean. Sub-regional warning centres also exist in Japan for the northwest Pacific and Alaska, USA for the northeast Pacific. As a result of the 2004 Indian Ocean tsunami, tsunami warning systems are now implemented globally, including in the Indian Ocean, Caribbean Sea, Atlantic Ocean, and Mediterranean Sea.

The UNESCO IOC International Tsunami Information Centre, staffed by the USA and Chile, monitors and evaluates the PTWS's effectiveness, helps establish new warning systems globally, and serves as an education and information resource for the IOC's Tsunami Programme.

WHAT CAU

Tsunamis, also called seismic sea waves or incorrectly tidal waves, are caused generally by earthquakes, less commonly by submarine landslides, infrequently by submarine volcanic eruptions and very rarely by large meteorite impacts in the ocean. Submarine volcanic eruptions have the potential to produce truly awesome tsunami waves. The 1883 Great Krakatau, Indonesia Volcanic Eruption generated giant wavesreaching heights of 40 meters above sea-level, killing more than 35,000 people and wiping out numerous coastal villages.

All oceanic regions of the world can experience tsunamis, but in the Pacific Ocean and its marginal seas, there is a much more frequent occurrence of large, destructive tsunamis because of the many large earthquakes along the margins of the Pacific Ocean.

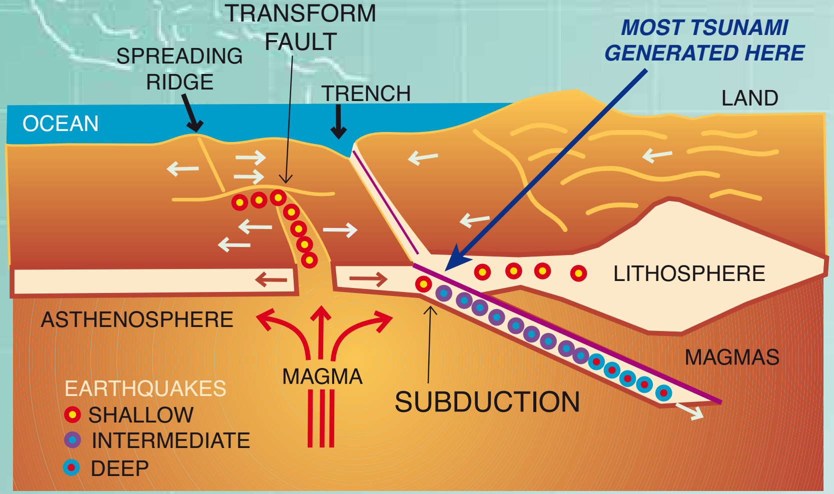


PLATE TECTONICS

Plate Tectonic theory is based on an earth model characterized by a small number of lithospheric plates, 70 to 250 km (40 to 150 mi) thick, that float on a viscous underlayer called the asthenosphere. These plates, which cover the entire surface of the earth and contain both the continents and seafloor, move relative to each other at rates of up to ten cm/year (several inches/year). The region where two plates come in contact is called a plate boundary, and the way in which one plate moves relative to another determines the type of boundary: spreading, where the two plates move away from each other; subduction, where the two plates move toward each other and one slides beneath the other; and transform, where the two plates slide horizontally past each other. Subduction zones are characterized by deep ocean trenches, and the volcanic islands or volcanic mountain chains associated with the many subduction zones around the Pacific rim are sometimes called the Ring of Fire.

EARTHQUAKES AND TSUNAMIS

An earthquake can be caused by volcanic activity, but most are generated by movements along fault zones associated with the plate boundaries. Most strong earthquakes, representing 80% of the total energy released worldwide by earthquakes, occur in subduction zones where an oceanic plate slides under a continental plate or another younger oceanic plate.

Not all earthquakes generate tsunamis. To generate a tsunami, the fault where the earthquake occurs must be underneath or near the ocean, and cause vertical movement of the seafloor (up to several meters) over a large area (up to a hundred thousand square kilometers). Shallow focus earthquakes (depth less 70 km or 42 mi) along subduction zones are responsible for most destructive tsunamis. The amount of vertical and horizontal motion of the sea floor, the area over which it occurs, the simultaneous occurrence of slumping of underwater sediments due to the shaking, and the efficiency with which energy is transferred from the earth's crust to the ocean water are all part of the tsunami generation mechanism.

Tsunami generated by December 26, 2004, M9.1 northwest Sumatra earthquake approaching Hat Rai Lay Beach, Krabi, southern Thailand. Foreign tourists scramble for safety in advance of the first of six tsunami waves after venturing out when the water first receded (AFP/AFP/Getty Images).

SES TSUNAMI?

TSUNAMI EARTHQUAKES

The September 2, 1992 earthquake (magnitude 7.2) was barely felt by residents along the coast of Nicaragua. Located well off-shore, its intensity, the severity of shaking on a scale of I to XII, was mostly II along the coast, and reached III at only a few places. Twenty to 70 minutes after the earthquake occurred, a tsunami struck the coast of Nicaragua with wave amplitudes 4 m (13 ft) above normal sea level in most places and a maximum runup height of 10.7 m (35 ft). The waves caught coastal residents by complete surprise and caused many casualties and considerable property damage.

This tsunami was caused by a tsunami earthquake — an earthquake that produces an unusually large tsunami relative to the earthquake magnitude. Tsunami earthquakes are characterized by a very shallow focus, fault dislocations greater than several meters, and fault surfaces that are smaller than for a normal earthquake.

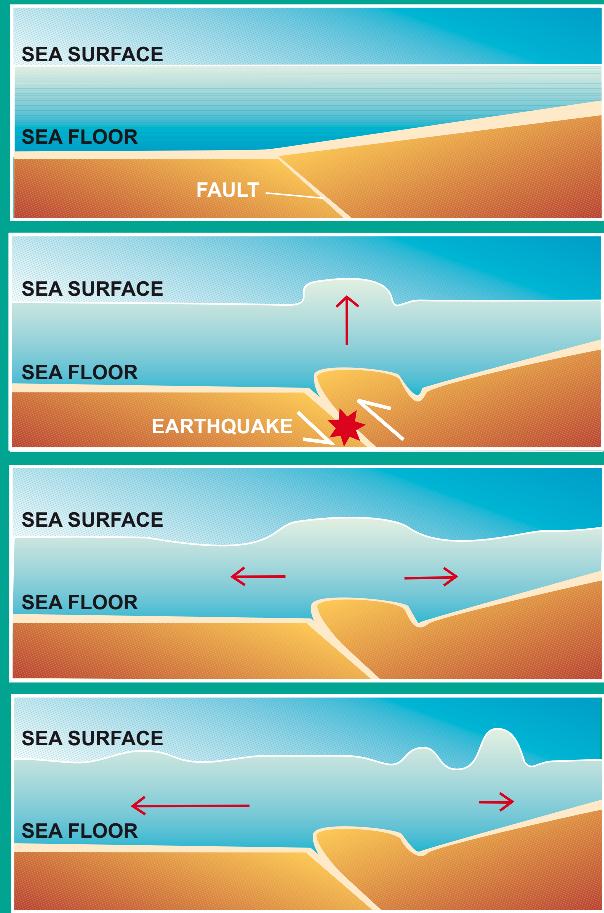
They are also slow earthquakes, with slippage along the fault beneath the sea floor occurring more slowly than it would in a normal earthquake. One known method to quickly recognize a tsunami earthquake is to estimate a parameter called the seismic moment using very long period seismic waves (more than 50 seconds / cycle). Three other deadly tsunamis from tsunami earthquakes have occurred in recent years off Indonesia (June 2, 1994; July 16, 2007; October 25, 2010) and Peru (February 21, 1996).

El Transito, Nicaragua, September 1, 1992. Nine-meter high waves destroyed the town, killing 16 and injuring 151 in this coastal community of 1,000 people. The first wave was thought to be small providing time for people to escape the destructive second and third waves. More than 40,000 people were affected by the loss of their homes or means of income. (Harry Yeh, Univ. of Washington)

The earthquake focus is the point in the earth where the rupture first occurs and where the first seismic waves originate. The epicenter is the point on the Earth's surface directly above the focus.

The magnitude is a measure of the relative size of an earthquake. A number of different magnitude scales exist besides the Richter scale, including the moment magnitude which measures the energy released and gives the most reliable estimate for large earthquakes. An increase in one unit of magnitude corresponds to a factor of 10 increase in seismic wave amplitude, and a 30-fold increase in released energy. The moment magnitude is measurable nearly immediately thanks to the advent of modern seismometers, digital recording, and real time communication links. This allows warning centres to provide initial tsunami advisories within minutes after the earthquake's occurrence.

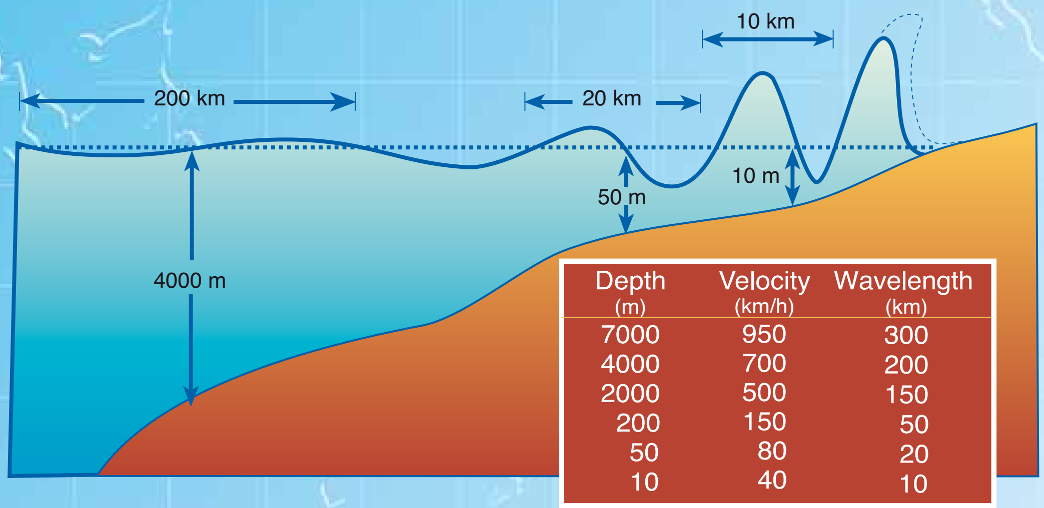
TSUNAMI: THE RELATION WITH THE SEISMIC SOURCE



TSUNAMIS ON

In the deep ocean, destructive tsunamis can be small – often only a few tens of centimeters or less in height – and cannot be seen nor felt on ships at sea. But as the tsunami reaches shallower coastal waters, wave height can increase rapidly. Sometimes, coastal waters are drawn out into the ocean just before the tsunami strikes. When this occurs, more shoreline may be exposed than even at the lowest tide. This major withdrawal of the sea should be taken as a natural warning sign that tsunami waves will follow.

Tsunami Speed is reduced in shallow water as wave height increases rapidly.



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

In the open ocean a tsunami is less than a few tens of centimeters (1 ft) high at the surface, but its wave height increases rapidly in shallow water. Tsunami wave energy extends from the surface to the bottom in even the deepest waters. As the tsunami attacks the coastline, the wave energy is compressed into a much shorter distance and a much shallower depth, creating destructive, life-threatening waves.

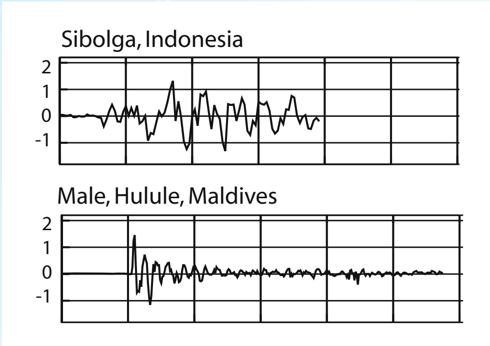
OCEAN-WIDE AND LOCAL TSUNAMIS

The last large tsunami that caused significant ocean-wide death and destruction in the Pacific was generated by an earthquake located off the coast of Chile in 1960. It caused loss of life and property damage not only along the Chile coast, but in Hawaii and as far away as Japan 22 hours later. On March 11, 2011, a deadly local tsunami in Japan caused USD 210 billion in damage, including USD 100 million in Hawaii and California, and one death each in Oregon and Indonesia. The Great Alaskan Earthquake of 1964 produced deadly tsunami waves in Alaska, Oregon and California.

In July 1993, a tsunami generated in the Sea of Japan killed over 120 people in Japan. Damage also occurred in Korea and Russia but not in other countries since the tsunami wave energy was confined within the Sea of Japan. The 1993 tsunami is known as a "local or regional event" since its impact was confined to a relatively small area. For people living along the northwestern coast of Japan, the local tsunami waves followed the earthquake within a few minutes.

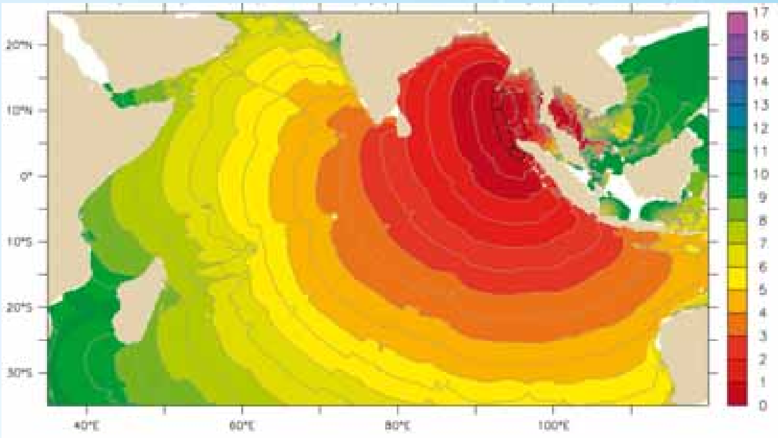
Since the 1990s, 28 destructive local or regional tsunamis have occurred in South America (Chile, Peru), Central America (Costa Rica, Nicaragua), Japan, the Philippines, Indonesia, the Pacific Islands (American Samoa, Samoa, Solomon Islands, Tonga, Vanuatu), and the Caribbean (Haiti), killing more than 200,000 people. Damage also occurred ocean-wide in the February 21, 1996 Peru, December 26, 2004 Indian Ocean, February 27, 2010 Chile, and the March 11, 2011 Japan tsunamis.

In less than a day, tsunamis can travel from one side of the Pacific to the other. However, people living near areas where large earthquakes occur may find that the tsunami waves will reach their shores within minutes. For these reasons, the tsunami threat to many areas, e.g., Caribbean, Indonesia and Makran source areas, Pacific Ring of Fire, and Eastern Mediterranean,can be immediate from local tsunamis that take only a few minutes to reach coastal areas or less urgent from distant tsunamis that can take up to a day to hit arrive.



Sea level records of the tsunami recorded at Sibolga on the northwest coast of Sumatra, Indonesia, and Male, Hulule, Maldive Islands from the December 26, 2004 tsunami that caused ocean-wide destruction. The first wave was not the largest at Sibolga. Vertical axis in meters. (University of Hawaii Sea Level Center, BAKOSURTANAL, Indonesia)

THE MOVE



Calculated tsunami travel times for the December 26, 2004 earthquake off western Sumatra. Each concentric curve represents 30 minutes of tsunami travel time. Destructive tsunami hit Indonesia in 15 minutes, Sri Lanka in two hours, and Kenya nine hours after the earthquake (NOAA PMEL).

HOW FAST?

Where the ocean is over 6,000 m deep, unnoticed tsunami waves can travel at the speed of a commercial jet plane, over 800 km per hour (~500 mi per hour). They can move from one side of the Pacific Ocean to the other in a day and across the Indian Ocean in 12 hrs. This great speed makes it important to be aware of the tsunami as soon as it is generated. Scientists can predict when a tsunami will arrive at various places by knowing the source characteristics of the earthquake that generated the tsunami and the characteristics of the seafloor along the paths to those places. Tsunamis travel much slower in shallower coastal waters where their wave heights begin to increase dramatically.

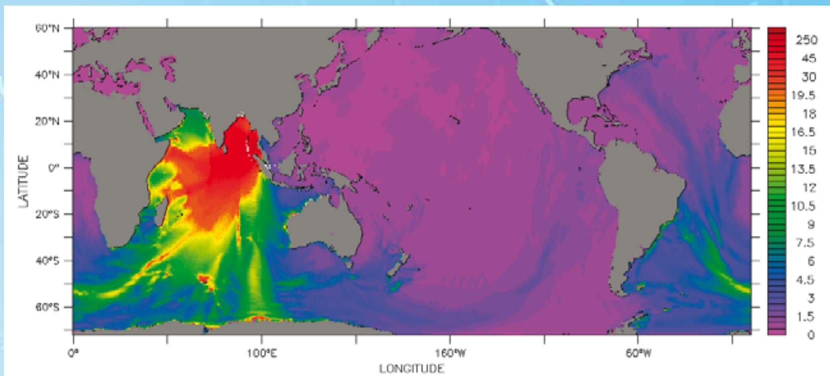
HOW BIG?

Offshore and coastal features can determine the size and impact of tsunami waves. Reefs, bays, entrances to rivers, undersea features and the slope of the beach all help to modify the tsunami as it attacks the coastline. When the tsunami hits the coast, often as a wall of water, sea levels can rise many meters. In extreme cases, water level has risen to more than 15 m (50 ft) for tsunamis of distant origin and over 30 m (100 ft) for tsunami waves generated near the epicenter. The first wave may not be the largest in the series of waves. One coastal community may see no damaging wave activity while in another nearby community destructive waves can be large and violent. The flooding can extend kilometers (~0.5 mi) inland or more, flooding large expanses of land with water and debris.

During post-tsunami field surveys, inundation and runup measurements are taken to describe the tsunami effects. Inundation is the maximum horizontal distance inland that a tsunami penetrates. Runup is the maximum vertical height above mean sea level that the sea surface attains during a tsunami. Actual tsunami wave heights are measured from the amplitude of the waves seen on tide gauge. These data are crucial for creating good inundation and evacuation maps.

HOW FREQUENT?

Since scientists cannot predict when earthquakes will occur, they cannot determine exactly when a tsunami will be generated. However, by looking at past historical tsunamis, scientists know where tsunamis are most likely to be generated. Past tsunami height measurements are useful in predicting future tsunami impact and flooding limits at specific coastal locations and communities. Paleotsunami research, in which scientists look for sediments deposited by giant tsunamis, is helping to extend the documented historical tsunami record further back in time. As more events are found, better estimates of the frequency of occurrence of tsunamis in a region are obtained. During each of the last five centuries, there were three to four Pacific-wide tsunamis, most of them generated off the Chilean coasts. The tsunami on December 26, 2004 claimed 228,000 lives and caused damage throughout the Indian Ocean, making it the worst tsunami catastrophe in history. It was also the first known basin-wide destructive tsunami in the Indian Ocean.



Maximum calculated global wave heights (cm) from the December 26, 2004 Indian Ocean tsunami. Waves were recorded on sea level gauges in Antarctica, and along the coasts of South and North America and Canada in both the Pacific and Atlantic Oceans (NOAA PMEL).

HOW WE

The Great Alaska Earthquake of March 27, 1964 generated a tsunami which caused 21 deaths and $30 million US dollars in damage in and near the city of Kodiak.

The Wave. Painting by Lucas Rawah of Aitape, done to commemorate the July 17, 1998, Papua New Guinea event. A magnitude 7.1 earthquake is thought to have triggered a submarine landslide generating a tsunami that destroyed entire villages along the Aitape coast.

International Tsunami Information Center (ITIC)

Located in Honolulu, Hawaii, and staffed by the USA, Chile, and Japan, the ITIC is the oldest information center serving the UNESCO Intergovernmental Oceanographic Commission (IOC)'s Global Tsunami Warning and Mitigation System. The IOC Tsunami Unit located in Paris, France, coordinates the global system. The ITIC directly serves Member States in the PTWS and other regions by monitoring and recommending improvements to the tsunami warning systems, helping Member States to establish regional and national tsunami warning systems, supporting capacity building through training programmes in tsunami mitigation, and serving as an information clearinghouse for the promotion of research, and the development and distribution of educational and preparedness materials to mitigate against the tsunami hazard. The ITIC regularly publishes the Tsunami Newsletter, maintains a library, hosts the Tsunami Bulletin Board listserve, and conducts the ITIC Training Programme in tsunami warning systems.

SAVE LIVES

TSUNAMI WARNING CENTERS

The IOC is coordinating the implementation of the global tsunami warning and mitigation system, building upon its experiences in the Pacific to establish warning systems for the Indian Ocean, Caribbean, Atlantic, and the Mediterranean. The USA Pacific Tsunami Warning Center (PTWC) serves as the Pacific warning centre. This international warning effort became a formal arrangement in 1965 when PTWC assumed responsibility as the operational centre for the PTWS. The ICG/PTWS, encompassing 46 Pacific countries, oversees warning system operations and facilitates coordination and cooperation in all international tsunami mitigation activities. In 2005, the PTWC and the Japan Meteorological Agency (JMA) began cooperatively providing interim services for the Indian Ocean, and in 2006, sub-regionally for the South China Sea of the Pacific. In 2006, PTWC began providing interim services for the Caribbean.

The initial objective of PTWC is to detect, locate and determine the seismic parameters of potentially tsunamigenic earthquakes occurring in the Pacific Basin or its immediate margins. To accomplish this, it continuously receives seismographic data from more than 400 stations around the world through cooperative data exchanges with the U.S. Geological Survey, Incorporated Research Institutions for Seismology Global Seismic Network, International Deployment of Accelerometers, GEOSCOPE, the U.S. West Coast/Alaska Tsunami Warning Center (WC/ATWC), and other national and international agencies running seismic networks.

If an earthquake has the potential to generate a destructive tsunami based on its location, depth, and magnitude, a tsunami warning is immediately issued to advise of an imminent tsunami hazard. Initial warnings apply only to areas the tsunami could reach within a few hours and bulletins include the predicted tsunami arrival times and/or wave heights. Coastal forecasts exceeding 0.5 m in height with strong water currents can cause significant damage and death as waves crush structures and floating debris become battering rams.

Warning centres then monitor incoming sea level data to determine whether a tsunami has occurred. If a significant tsunami with long-range destructive potential is detected, warnings are extended to the entire ocean basin. PTWC receives sea level data from more than 400 coastal stations through cooperative data sharing between US agencies, research centers, countries, and international networks such as the Global Sea Level Observing System (GLOSS). It also receives data from more than 40 deep-ocean or DART sensors around the world. These data enable accurate forecasts to be done. In Japan, GPS wave gauges provide offshore sea surface heights of oncoming tsunami. Warnings are then disseminated to designated emergency officials and the general public by a variety of communication methods.

Countries may operate National or Sub-regional Centres to provide more rapid or detailed warnings for regional or local tsunamis. The JMA provides local warnings to Japan, and its Northwest Pacific Tsunami Advisory Center provides earthquake and tsunami wave forecasts to countries in the northwest Pacific and its marginal seas, the South China region, and island nations in the North Pacific. In the Pacific, the Centre Polynesien de Prevention des Tsunamis in French Polynesia, Chile, and Russia have operated national warning systems for decades. Australia, Canada, Colombia, Ecuador, El Salvador, Indonesia, Korea, Malaysia, New Zealand, Nicaragua, Peru, Philippines, and Thailand have improved their systems since 2004.

In the US, the WC/ATWC warns North America, including Canada, Puerto Rico and the Virgin Islands and the PTWC warns Hawaii, and US Pacific interests. Through the open and timely sharing of data, Warning Centres can provide backup and supplemental analyses of events should a Centre become disabled. The Centres can also serve as focal points for regional tsunami awareness, education, and other mitigation activities.

Information about the IOC

The Intergovernmental Oceanographic Commission (IOC), a body with functional autonomy within the United Nations Educational, Scientific and Cultural Organization (UNESCO), provides Member States with an essential mechanism for global co-operation in the study of the ocean. 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 and regional programs.

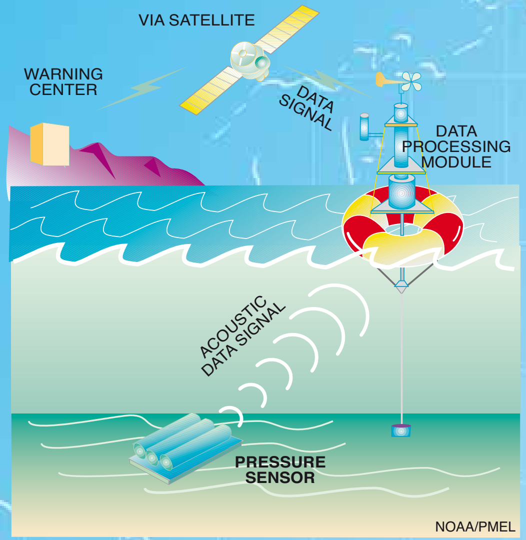
The functions of the IOC are to develop, recommend and coordinate international programs for scientific study of the oceans and related ocean services; to promote and make recommendations for the exchange of oceanographic data and the publication and dissemination of scientific investigation results; to promote and coordinate the development and transfer of marine science and its technology; to make recommendations to strengthen education and training and to promote scientific investigation of the oceans and application of the results thereof for the benefit of all mankind. 141 Member States are currently part of the IOC. The Assembly meets every two years at the UNESCO headquarters in Paris, France.

The IOC consists of an Assembly, an Executive Council, a Secretariat and such subsidiary bodies as it may establish. Under this concept, the Commission has created Global and Regional Programmes which examine and execute specific projects, or consist of committees composed of Member States interested in such projects. This is the case for the Intergovernmental Tsunami Warning and Mitigation Coordination Groups in the Pacific (ICG/PTWS), Indian Ocean (ICG/IOTWS), Caribbean (ICG/CARIBE-EWS), and northeastern Atlantic and Mediterranean (ICG/NEAMTWS).

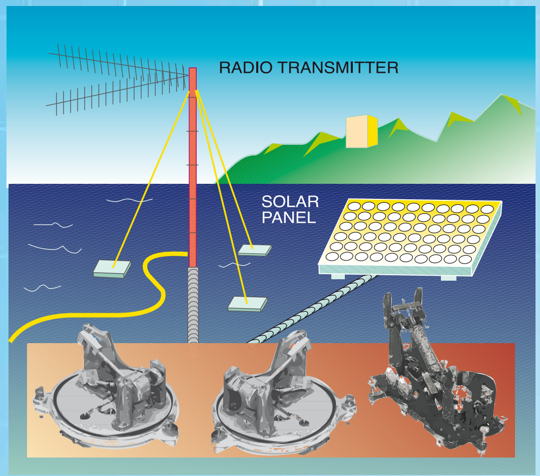
LOOKING INTO THE

April 1, 1946. People flee as the tsunami attacks downtown Hilo, Hawaii. The tsunami struck without warning 4.5 hours after being generated by a M8.1 Aleutian Islands earthquake 3500 km to the north, and resulted in the start of the US Seismic Sea Wave Warning System (now PTWC) in 1949. (Bishop Museum Archives).

DEEP-OCEAN ASSESSMENT AND REPORTING ON TSUNAMIS (DART Project)



INDEPENDENT 3 COMPONENT BROAD -BAND SEISMIC STATION



An effective tsunami warning system reaches all persons in danger before the wave hits

An effective tsunami early warning system is achieved when all persons in vulnerable coastal communities are prepared and respond appropriately, and in a timely manner, upon recognition that a potentially destructive tsunami is coming. Timely tsunami warnings issued by a recognized tsunami warning centre are essential. When these warning messages are received by the designated government agency, national tsunami emergency response plans must already be in place so that well-known and practiced actions are immediately taken to evaluate the scientifically-based warning, and communicate an appropriate course of action to ordinary citizens. Tsunami preparedness programmes must already have started so that good decisions can be made without delay.

Essential activities of an effective warning system are:

- *Identification of the tsunami hazard, assessment of risk, and mitigation to reduce wave impact. Tsunami evacuation maps that show where flooding is likely are based on this information.*
- *Issuance of timely warnings. For a distant tsunami, real-time earthquake and sea level monitoring to confirm the generation of a destructive tsunami, followed by immediate dissemination to the public, is critical. For a local tsunami where there may not be time for an official warning, people must already know a tsunami's natural warning signals and respond immediately.*
- *Continuous and sustained awareness activities. Education is fundamental to building an informed citizenry and to ensure that the next generation is equally prepared. Political support, laws and regulations, and institutional responsibility are key.*

EYES OF THE MONSTER

Tsunami Research Activities

Since the 2004 Indian Ocean tsunami, there has been great progress in tsunami research. Post-tsunami surveys provided detailed and comprehensive data sets that have improved our understanding of tsunamis and thus our ability to mitigate losses from tsunamis. Scientists can numerically model tsunami generation, open ocean propagation, and coastal runup.

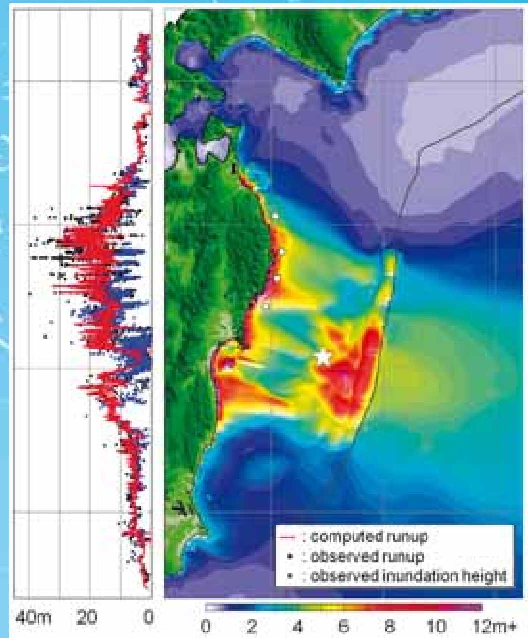
Ocean-bottom pressure sensors, able to measure tsunamis in the open ocean, are providing important data on tsunami propagation in deep water, and satellite communications have enabled the data to be used in real time to detect and measure tsunami waves in the deep ocean. NOAA has pioneered the development and operation of these tsunami detection buoys over the last 20 years. Measurements from these buoys are now helping warning centres to issue or cancel warnings and other alerts with more precision. Numerical modeling methods are also enabling centres to issue wave forecasts thus giving customers information on the expected wave impact.

Seismologists, studying the dynamics of earthquakes with broad band seismometers (20 to 0.003 Hertz), are formulating new methods to analyze earthquake motion and the amount of energy released. Where the traditional Richter (surface wave) magnitude of earthquakes is not accurate above 7.5, the seismic moment and the source duration are now used to better define the amount of energy released and the potential for tsunami generation. Real-time determination of earthquake depth, type of faulting, and extent, direction and speed of rupture are significantly improving the warning centres' ability to identify the likelihood of a threatening tsunami.

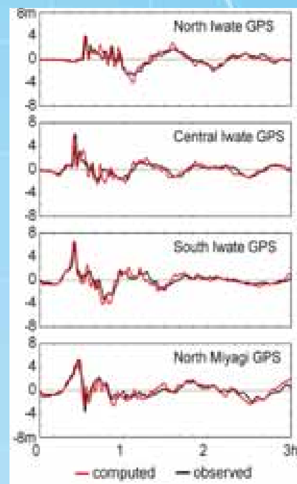
In the last decade, paleotsunami and tsunami deposit field research has extended the historical tsunami record to improve risk assessments. Post-tsunami structural studies, together with laboratory wave tank experiments, are helping engineers design tsunami-resistant structures through knowledge of how waves impact coasts and scour and erode building foundations. As a result, tsunami building design provisions will be included in the International Building Code in the next few years.

Tsunami inundation models, defining the extent of coastal flooding, are an integral aspect of tsunami hazard and preparedness planning. Using worst-case inundation scenarios, these models are critical to defining evacuation zones and routes so that coastal communities can be evacuated quickly when a tsunami warning is issued.

Although a tsunami cannot be prevented, its impact can be mitigated through community preparedness, timely warnings, effective response, and public education. The U.S. National Tsunami Hazard Mitigation Program is a good example of a comprehensive effort to reduce tsunami risks.



11 March 2011 Japan Tsunami. Left: Computed model (red line) compares well with observed runup (black) and inundation height (blue). Right: Maximum wave amplitude along the northern Tohoku coast. At sea, the model shows up to 11-m amplitudes around the epicenter (star), and up to 7-m at nearshore GPS buoys (white circle). At the coast, local maximum runup heights 15-40 m were measured in many places.



Computed sea surface elevations show excellent agreement with the observed GPS buoy data. (Y. Yamazaki and K.F. Cheung, Univ. of Hawaii).

THE FACTS

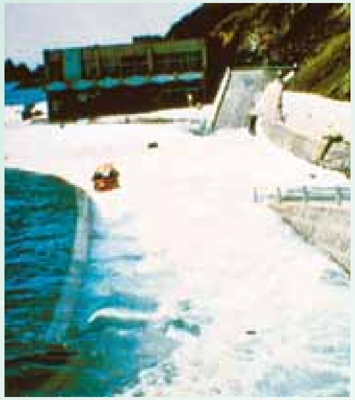
- Tsunamis that strike coastal locations are almost always caused by earthquakes. The earthquakes might occur far away or near where you live. While earthquakes occur in all ocean basins around the world, most do not generate tsunamis.
- Some tsunamis can be very large. In coastal areas their height can be as great as 10 m or more (30 m in extreme cases), and they cause impacts like flash floods. Later waves are often full of debris.
- All low lying coastal areas can be struck by tsunamis.
- A tsunami consists of a series of waves with crests arriving every 5 to 60 minutes. Often the first wave may not be the largest. The danger from a tsunami can last for several hours after the arrival of the first wave. Tsunami waves typically do not curl and break, so do not try to surf a tsunami!
- Tsunamis can move faster than a person can run.
- Sometimes a tsunami initially causes the water near the shore to recede, exposing the ocean floor.
- The force of some tsunamis is enormous. Large rocks weighing several tons, along with boats and other debris, can be moved inland hundreds of meters by tsunami wave activity, and homes and buildings destroyed. All this material and water move with great force, and can kill or injure people.
- Tsunamis can occur at any time, day or night.
- Tsunamis can travel up rivers and streams from the ocean.
- Tsunami can easily wrap around islands and be just as dangerous on coasts not facing the source of the tsunami.

WHAT YOU SHOULD DO

Be aware of tsunami facts. This knowledge could save your life!

Share this knowledge with your relatives and friends. It could save their lives!

- If you are in school and you hear there is a tsunami warning, you should follow the advice of teachers and other school personnel.
- If you are at home and hear there is a tsunami warning, you should make sure your entire family is aware of the warning. Prepare a family emergency plan beforehand so that everyone knows what to do. Your family should evacuate your house if you live in a tsunami evacuation zone. Move in an orderly, calm, and safe manner to the evacuation site or to any safe place outside your evacuation zone. Follow the advice of local emergency and law enforcement authorities.
- If you are at the beach or near the ocean and you feel the earth shake strongly or for a long time, move immediately to higher ground. DO NOT WAIT for a tsunami warning to be announced. Stay away from rivers and streams that lead to the ocean as you would stay away from the beach and ocean if there is a tsunami. A tsunami from a local earthquake could strike before a tsunami warning can be announced.
- Tsunamis generated in distant locations will generally give people enough time to move to higher ground. For locally generated tsunamis, where you might feel the ground shake, you may only have a few minutes to move to higher ground.
- High, multi-story, reinforced concrete hotels are located in many low-lying coastal areas. The upper floors can provide a safe place to find refuge should there be a tsunami warning and you cannot move quickly inland to higher ground. Local Civil Defense procedures may, however, not allow this type of evacuation in your area. Homes and small buildings located in low-lying coastal areas are not designed to withstand tsunami impacts. Do not stay in these structures should there be a tsunami warning.
- Offshore reefs and shallow areas may help break the force of tsunami waves, but large and dangerous waves can still be a threat to coastal residents in these areas. Staying away from all low-lying coastal areas is the safest advice when there is a tsunami warning.



Oga Aquarium, Akita Japan. Parking lot of aquarium is flooded stranding car during the May 26, 1983, Japan Sea tsunami. (Takaaki Uda, Public Works Research Institute, Japan)

WHAT YOU SHO

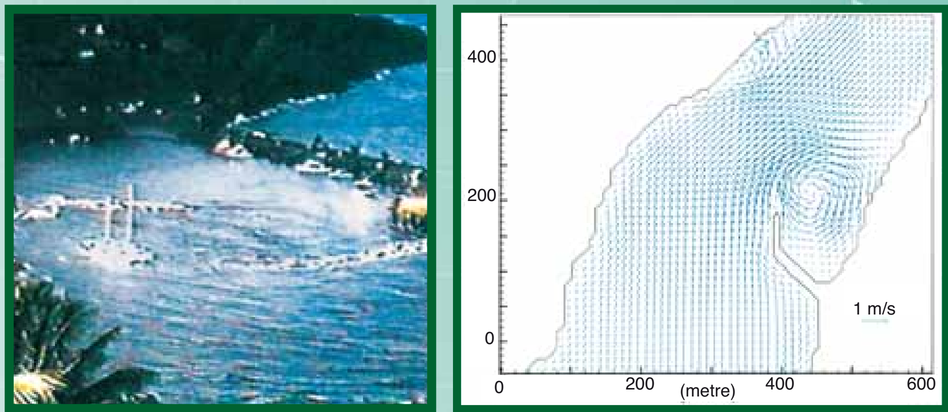
IF YOU ARE ON A SHIP OR BOAT

Since tsunami wave activity is imperceptible in the open ocean, do not return to port if you are at sea and a tsunami warning has been issued for your area. Tsunamis can cause rapid changes in water level and unpredictable dangerous currents in harbors and ports.

If there is time to move your boat or ship from port to a location in deep water (100-500 m deep, depending on local conditions), and after you know a tsunami warning has been issued, you should weigh the following considerations:

- Most large harbors and ports are under the control of a harbor authority and/or a vessel traffic system. These authorities direct operations during periods of increased readiness, including the forced movement of vessels if deemed necessary. Keep in contact with the authorities should a forced movement of vessels be directed.
- Smaller ports may not be under the control of a harbor authority. If you are aware there is a tsunami warning, be sure you have enough time to motor your vessel safely into deep water. Small boat owners may find it safest to leave their boat at the pier and physically move to higher ground, particularly in the event of a locally-generated tsunami. Concurrent severe weather conditions (rough seas outside of the harbor) could present a greater hazardous situation to small boats, so physically moving yourself to higher ground may be the only option.
- Damaging wave activity and unpredictable currents can affect harbors for hours following the initial tsunami impact on the coast. Contact the harbor authority before returning to port making sure to verify that conditions in the harbor are safe for navigation and berthing.

Banda Aceh, Sumatra, Indonesia. The tsunami of December 26, 2004 completely razed coastal towns and villages, leaving behind only sand, mud, and water (middle) where once there had been thriving communities of homes, offices, and green space (top). (DigitalGlobe QuickBird satellite imagery, US Navy photo)



July 30, 1995 , Chilean Tsunami. Left: An observation of the tsunami effects behind the breakwater at Tahauku Bay in the Marquesas Islands, French Polynesia, several thousand kilometers away from the tsunami source. Right: Currents in Tahauku Bay based on numerical modeling of the Chilean tsunami. The modeling reproduces the same kinds of ocean currents seen in the photo.

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KNOWLEDGE IS SAFETY

Onagawa, Japan, March 11, 2011 (ITIC). Tsunami attacked eastern Japan ~25 minutes after the earthquake, crushing homes, flooding 4th-floor buildings, and inundating inland up to 6 km. Tsunami warnings broadcast on television and radio in three minutes were followed immediately by sirens to evacuate. Thanks to pre-event preparedness that identified hazard zones, practiced evacuation to safety, and educated schools and the public, lives were saved. Nearly 19,000 people died, but representing only ~5% of the exposed population. Nonetheless, as in previous tsunamis, a disproportionate number of casualties were the elderly, women, and young children.

As dangerous as tsunamis are, they do not happen very often. You should not let this natural hazard diminish your enjoyment of the beach and ocean. But, if you think a tsunami may be coming, the ground shakes strongly or for a long time under your feet, the ocean recedes out to sea exposing the sea bottom, you hear a train-like roar, or you know that there is a warning, tell your relatives and friends, and

Move Quickly Inland and to Higher Ground!

North Shore of Oahu, Hawaii. During the tsunami generated by the March 9, 1957, Aleutian Island earthquake, people foolishly searched for fish on the exposed reef, unaware that tsunami waves would return in minutes to inundate the shoreline. (Honolulu Star-Bulletin)

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- *Richard H. Hagemeyer Pacific Tsunami Warning Center, http://ptwc.weather.gov/*
- *West Coast / Alaska Tsunami Warning Center, http://wcatwc.arh.noaa.gov*

U.S. National Ocean Service, http://www.nos.noaa.gov
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FURTHER INFORMATION ON IOC TSUNAMI WARNING AND MITIGATION SYSTEMS, TSUNAMIS, AND THE ITIC MAY BE OBTAINED FROM:

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