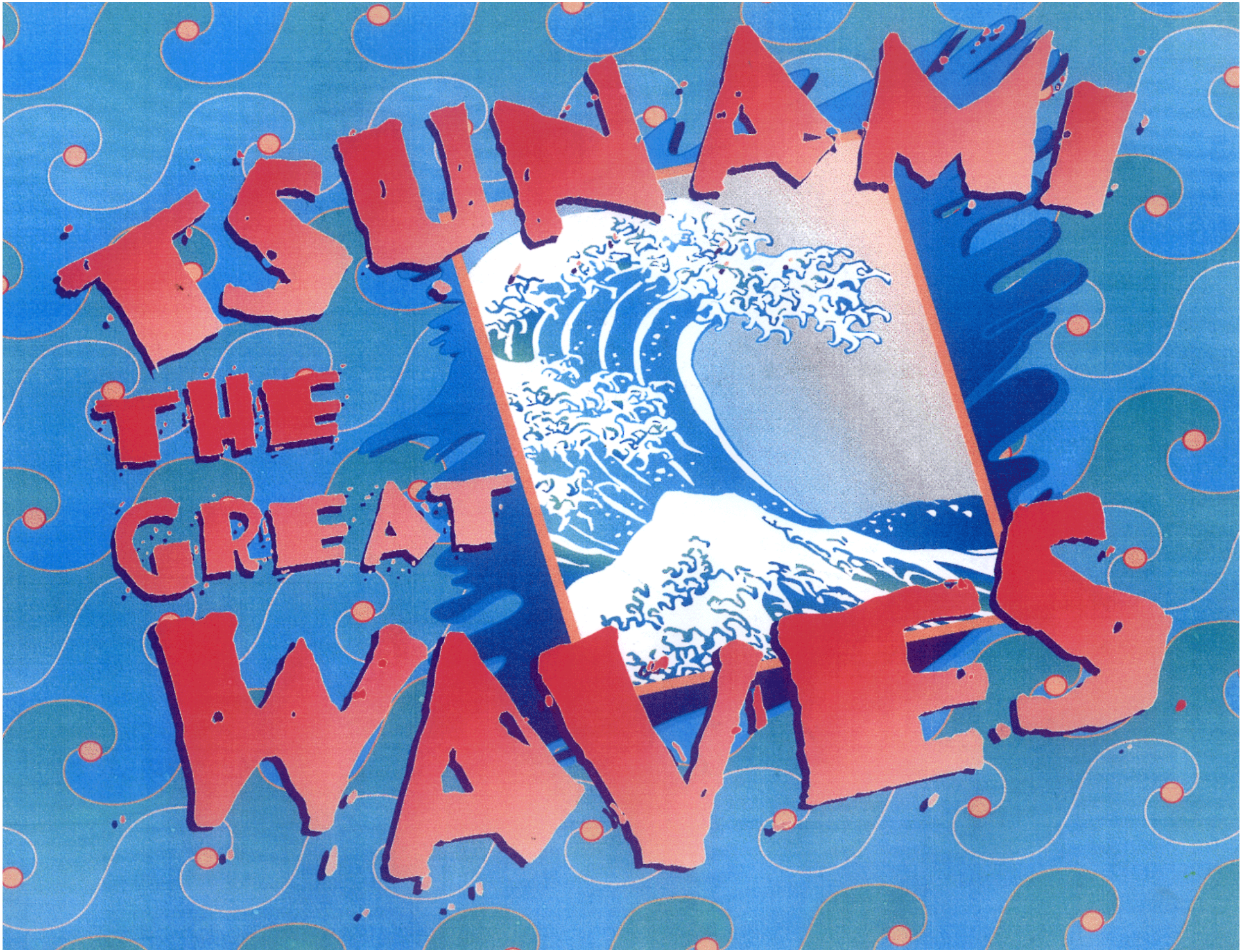

TSUNAMI
THE GREAT WAVES

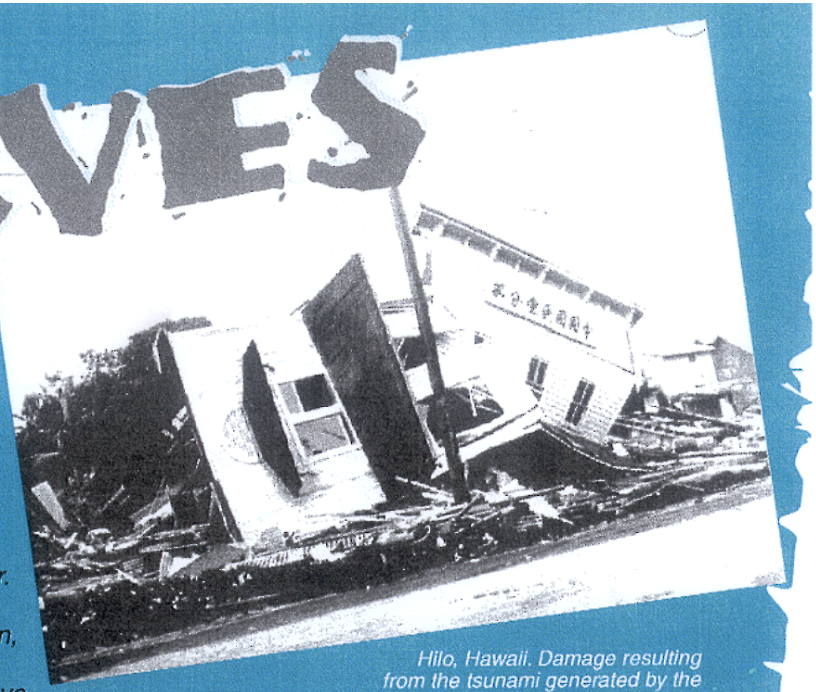
PRESENTATED BY

IOC

U.S DEPARTMENT OF COMMERCE
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
UNESCO/INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION
INTERNATIONAL TSUNAMI INFORMATION CENTER
LABORATOIRE DE GEOPHYSIQUE, FRANCE

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.



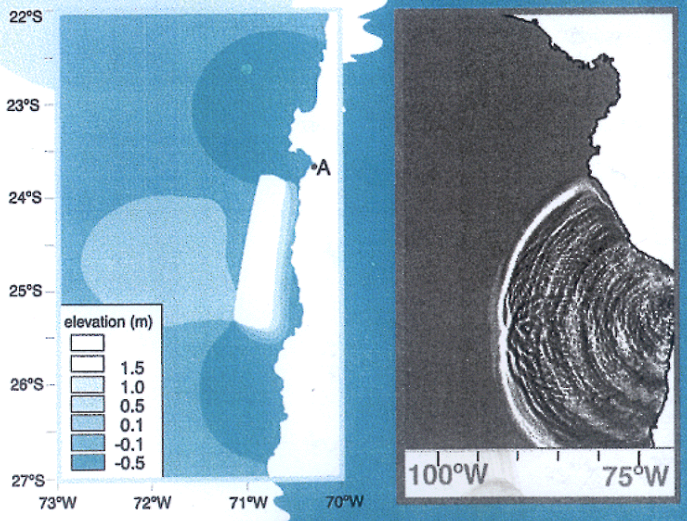
Hilo, Hawaii. Damage resulting from the tsunami generated by the earthquake of April 1, 1946, in the Aleutian Islands.

The phenomenon we call "tsunami" (soo-NAH-mee) is a series of traveling ocean waves of extremely long length generated by disturbances associated primarily with earthquakes occurring below or near the ocean floor. Underwater volcanic eruptions and landslides can also generate tsunamis. In the deep ocean, their length from wave crest to wave crest may be a hundred kilometers or more but with a wave height of only a few tens of centimeters or less. They cannot be felt aboard ships nor can they be seen from the air in the open ocean. In deep water, the waves may reach speeds exceeding 800 kilometers per hour.

Tsunamis are a threat to life and property to all coastal residents living near the ocean. For example, in 1992 to 1996 over 2,000 people were killed by tsunamis occurring in Nicaragua, Indonesia, Japan, the Philippines and Peru.

Property damage was nearly one billion dollars. The 1960 Chile Earthquake generated a Pacific-wide tsunami that caused widespread death and destruction in Chile, Hawaii, Japan and other areas in the Pacific. Large tsunamis have been known to rise over 30 meters while tsunamis three to six meters high can be very destructive and cause many deaths and injuries.

The Tsunami Warning System (TWS) in the Pacific, comprised of 25 participating international Member States, has the functions of monitoring seismological and tidal stations throughout the Pacific Basin to evaluate potentially tsunamigenic earthquakes and disseminating tsunami warning information. The Pacific Tsunami Warning Center (PTWC) is the operational center of the Pacific TWS. Located in Honolulu, Hawaii, PTWC provides tsunami warning information to national authorities in the Pacific Basin. Some other countries are also operating National or Regional Warning Centers.



Left: Computer model of the 30 July 1995 Chilean Tsunami being generated (water surface initialization). A is Antofagasta, Chile. Right: Computer model of the same tsunami, 3 three hours after it was generated.

WHAT

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 a large meteorite impact in the ocean. Submarine volcanic eruptions have the potential to produce truly awesome tsunami waves. The Great Krakatau Volcanic Eruption of 1883 generated giant waves reaching heights of 40 meters above sea-level, killing thousands of people and wiping out numerous coastal villages.

All oceanic regions of the world can experience tsunamis, but in the Pacific Ocean and it's 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.

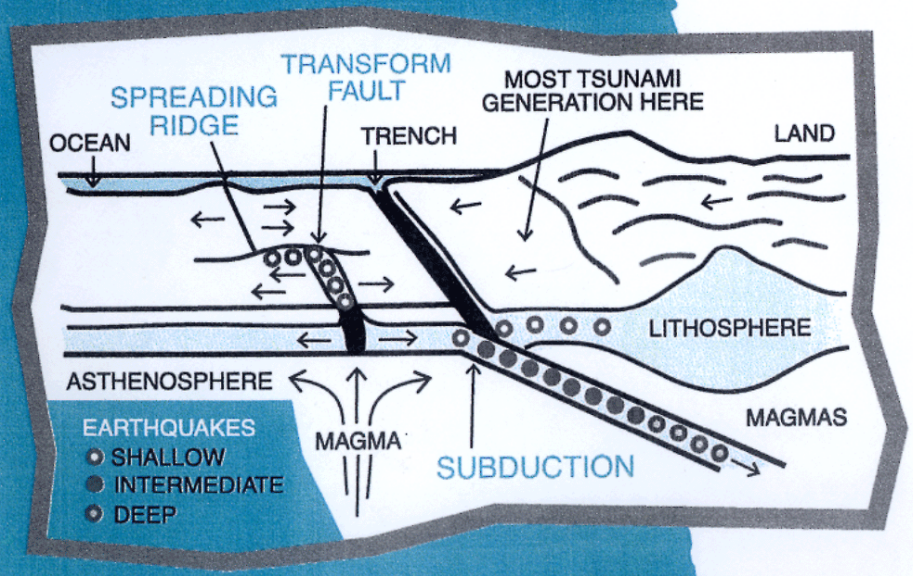


PLATE TECTONICS

Plate Tectonic theory is based on an earth model characterized by a small number of lithospheric plates, 70 to 250 km 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, are in motion relative to each other at rates up to several cm/year. The region where two plates come in contact is called a plate boundary, and the way one plate moves with respect to another one determines the type of boundary: spreading, where the two plates are moving away from each other; subduction, where the two plates are moving towards each other and one is sliding beneath the other; and transform, where the two plates are sliding 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 is sometimes called the Ring of Fire.

EARTHQUAKES AND TSUNAMIS

An earthquake can be caused by volcanic activity, but most are produced by movements along fault zones associated with the plate boundaries. Most strong earthquakes, representing 80% of the total energy released worldwide by earthquakes, happen in subduction zones where an oceanic plate slides under a continental plate or another younger oceanic plate. The focus of an earthquake is the point in the earth where the rupture first occurs and where the first seismic waves originate. The epicenter of an earthquake is the point on the Earth's surface directly above the focus.

Not all earthquakes generate tsunamis. To generate a tsunami, the fault where the earthquake occurs must be underneath or near the ocean, and create a vertical movement (up to several meters) of the sea floor over a large area (up to

CAUSES TSUNAMIS?

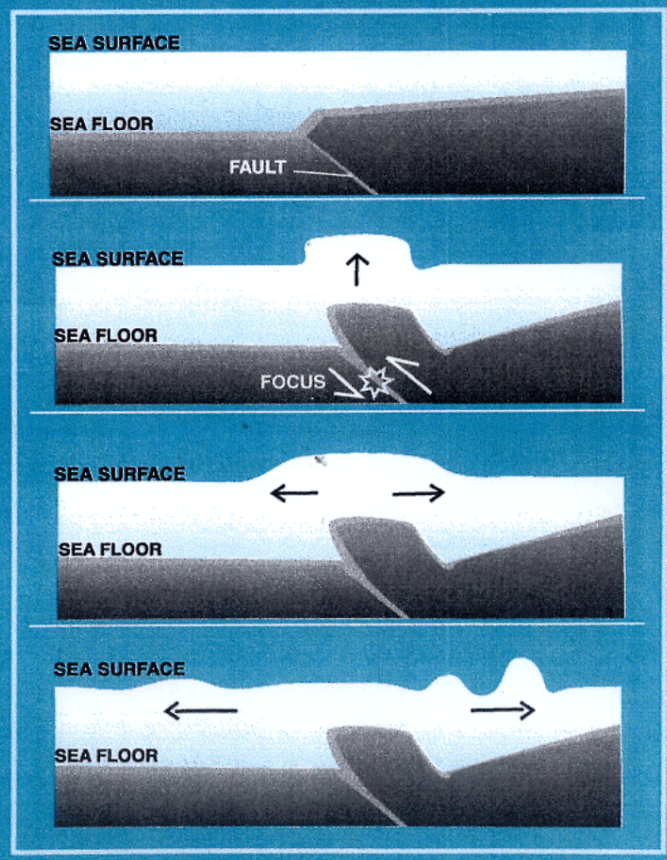
a hundred thousand square kilometers). Shallow focus earthquakes along subduction zones are responsible for most destructive tsunamis. The amount of vertical motion of the sea floor, the area over which it occurs, the simultaneous occurrence of slumping of underwater sediments due to the shaking, and 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 EARTHQUAKES

The September 2, 1992 earthquake was barely felt by residents along the coast of Nicaragua. Its body wave magnitude was only 5.3, and 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. Forty to seventy minutes after earthquake occurred, a tsunami struck the coast of Nicaragua with amplitudes 4 m above normal sea level in most places and a maximum runup height of 10.7 m. The waves caught coastal residents by complete surprise and caused many casualties and considerable property damage.

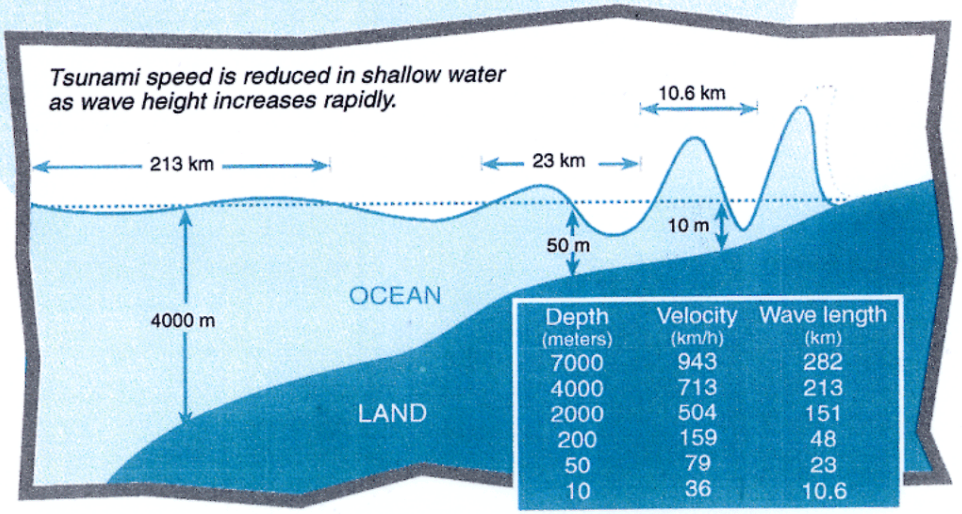
This tsunami was caused by a tsunami earthquake — an earthquake that produces an unusually large tsunami relative to the earthquake magnitude. Tsunami earthquakes are characterized by a very shallow focus, fault dislocations greater than several meters, and fault surfaces that are smaller than for a 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. The only 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). Two other destructive and deadly tsunamis from tsunami earthquakes have occurred in recent years in Java, Indonesia (June 2, 1994) and Peru (February 21, 1996).

TSUNAMIS: 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 can they be felt by ships. 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 warning of the tsunami waves that will follow.



Depth (meters)	Velocity (km/h)	Wave length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

In the open ocean a tsunami is less than a few tens of centimeters 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.

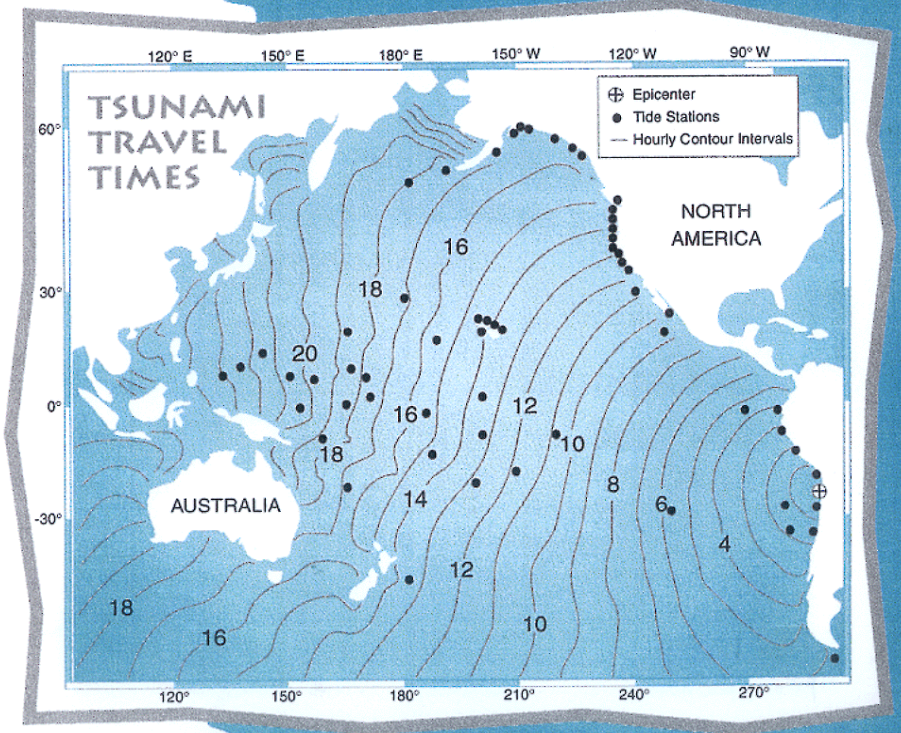
PACIFIC-WIDE AND REGIONAL TSUNAMIS

The last large tsunami that caused widespread death and destruction throughout 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. 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 Sea of Japan tsunami is known as a "regional event" since its impact was confined to a relatively small area. For people living along the northwestern coast of Japan, the tsunami waves followed the earthquake within a few minutes. From 1992 to 1996, regional tsunamis also occurred in Nicaragua, Indonesia, the Philippines and Peru, killing thousands of people. Others caused property damage in Chile and Mexico. Some damage also occurred in the far field in the Marquesas Islands (French Polynesia) due to the 30 July 1995 Chilean tsunami and 21 February 1996 Peruvian tsunami.

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 of the earthquake. For these reasons, the tsunami threat to many areas; like Alaska, the Philippines, Japan or the U.S. West Coast, **can be immediate** (for tsunamis from nearby earthquakes taking only a few minutes to reach coastal areas) **or less urgent** (for tsunamis from distant earthquakes taking from 3 to 22 hours to reach coastal areas).

THE MOVE



Calculated tsunami travel times for an earthquake occurring off the coast of Chile. Each concentric curve represents one hour of tsunami travel time.

HOW FAST?

Where the ocean is over 6,000 meters deep, unnoticed tsunami waves can travel at the speed of a commercial jet plane, nearly 1,000 kilometers per hour. They can move from one side of the Pacific Ocean to the other in less than a day. 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 by knowing the origin time of the quake, the location of it's epicenter and the focal depth. 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 reaches the coast and moves inland, the water level can rise many feet. In extreme cases, water level has risen to more than 15 meters for tsunamis of distant origin and over 30 meters for tsunami waves generated near the earthquake's 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 community destructive waves can be large and violent. The flooding can extend inland by 300 meters or more, covering large expanses of land with water and debris.

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. Historical tsunami research may prove helpful in analyzing the frequency of occurrence of tsunamis. During each of the last five centuries, there were 3 to 4 Pacific-wide tsunamis, most of them generated off the Chilean coasts.

Kodiak, Alaska. The 27 March, 1964 tsunami caused 21 deaths and $30 million damage in and near the city of Kodiak.

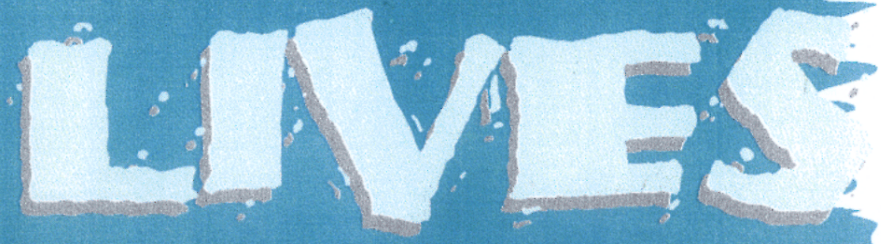
HOW WE SAVE

TSUNAMI WARNING CENTERS

The Pacific Tsunami Warning Center (PTWC) in Ewa Beach, Hawaii, serves as the international warning center for tsunamis that pose a Pacific-wide threat. It is also the regional tsunami center for Hawaii, and the national warning center of the U.S.A. This international warning effort became a formal arrangement in 1965 when PTWC assumed the international warning responsibilities of the Pacific Tsunami Warning System (PTWS). The PTWS is comprised of 25 international Member States that are organized as the International Coordination Group for the Tsunami Warning System in the Pacific.

The initial objective of the PTWS is to detect, locate and determine the seismic parameters of potentially tsunamigenic earthquakes occurring in the Pacific Basin or its immediate margins. Earthquake information is provided by seismic stations operated by PTWC, the National/Regional Tsunami Warning Centers and other international sources. If the location and seismic parameters of an earthquake meet the known criteria for generation of a tsunami, a tsunami warning is issued to warn of an imminent tsunami hazard. The warning includes predicted tsunami arrival times at selected coastal communities within the geographic area defined by the maximum distance the tsunami could travel in a few hours. A tsunami watch with additional predicted tsunami arrival times is issued for a geographic area defined by the distance the tsunami could travel in a subsequent time period.

If a significant tsunami is detected by sea-level monitoring instrumentation, the tsunami warning is extended to the entire Pacific Basin. Sea-level information is provided by PTWC, and the participating nations of the PTWS.
Tsunami watches, warning, and information bulletins are disseminated to appropriate emergency officials and the general public by a variety of communication methods.



INFORMATION ABOUT THE IOC

The Intergovernmental Oceanographic Commission (IOC) is a body with functional autonomy within the United Nations Educational, Scientific and Cultural Organization (UNESCO), established to promote marine scientific investigations and related ocean services with a view to learning more about the nature and resources of the ocean through the concerted actions of its members.

In general terms, the functions of the IOC among others are: to develop, recommend and coordinate international programmes for scientific investigation of the oceans and related ocean services; to promote and make recommendations for the exchange of oceanographic data and the publication and dissemination of results of scientific investigation of the oceans; 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.

124 Member States are part of the IOC (as of 28-Jun-1995). The Assembly meets each two years at the UNESCO headquarters in Paris.

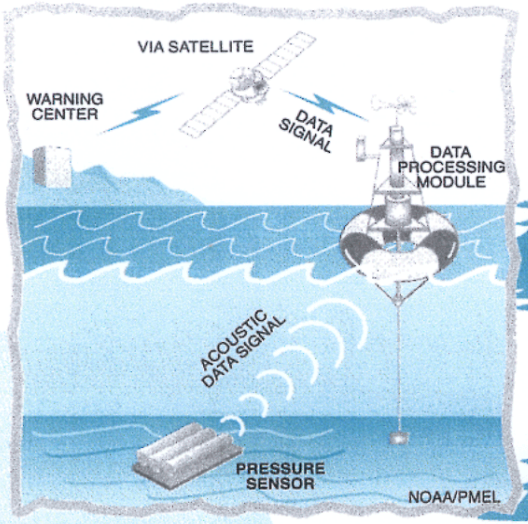
The Commission consists of an Assembly, an Executive Council, a Secretariat and such subsidiary bodies as it may establish. Under this last concept, the Commission creates, for the examination and execution of specific projects, committees or other subsidiary bodies composed of Member States interested in such projects. That is the case of the International Coordinating Group for the Tsunami Warning System in the Pacific, established by the IOC, that gather together 25 Member States from the Pacific rim.

THE INTERNATIONAL TSUNAMI INFORMATION CENTER

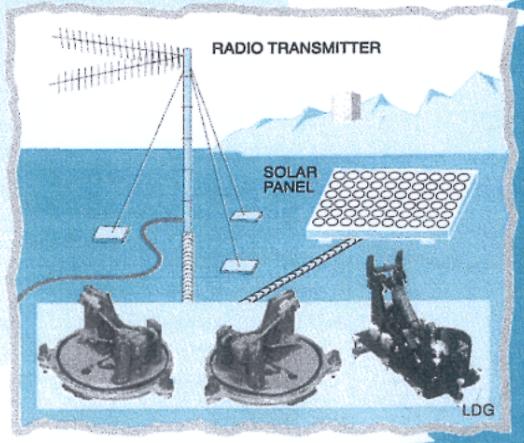
The International Tsunami Information Center, supported in part by the Intergovernmental Oceanographic Commission, monitors and evaluates the performance and effectiveness of the Pacific Tsunami Warning System. This effort encourages the most effective data collection, data analysis, tsunami impact assessment, warning dissemination to all TWS participants, and tsunami education and training in part through the annual Visiting Expert's Program. ITIC arranges for the availability of technical information on equipment required of an effective tsunami warning system.

LOOKING INTO

DEEP WATER TSUNAMI WAVE MONITORING SYSTEM



INDEPENDENT 3 COMPONENT BROAD -BAND SEISMIC STATION



April 1, 1946. People flee as tsunami attacks downtown Hilo, Hawaii. (BISHOP MUSEUM).

WARNING DISSEMINATION

- Tsunami watch, warning and information bulletins issued by PTWC and ATWC are disseminated to local, state, national and international users as well as the media. These users, in turn, disseminate the tsunami information to the public, generally over commercial radio and television channels.

- The NOAA Weather Radio System, based on a large number of VHF transmitter sites, provides direct broadcast of tsunami information to the public.

- The US Coast Guard also broadcasts urgent marine warnings and related tsunami information to coastal users equipped with medium frequency ((MF) and very high frequency (VHF) marine radios.

- Local authorities and emergency managers are responsible for formulating and executing evacuation plans for areas under a tsunami warning. The public should stay-tuned to the local media for evacuation orders should a tsunami warning be issued. And, the public should NOT RETURN to low lying areas until the tsunami threat has passed and the "all clear" is announced by the local authorities.

THE TALES OF THE MONSTER

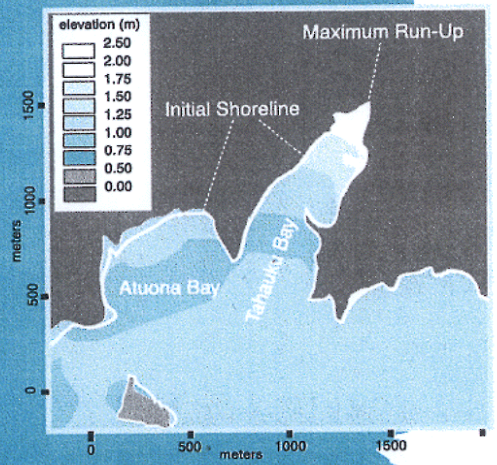
TSUNAMI RESEARCH ACTIVITIES

With the broad availability of relatively inexpensive yet powerful computers and desktop workstations, there is growing interest and activity in tsunami research.

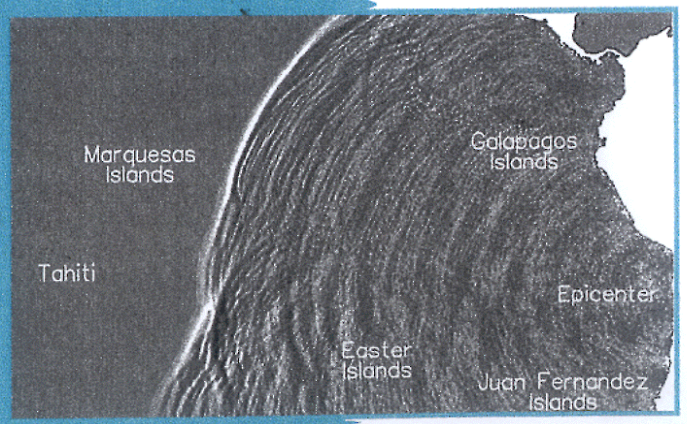
*Using the latest in computer technology, scientists are able to numerically model tsunami generation, open ocean propagation and coastal runup. Recent advances in the technology have led to improved propagation and runup models. Subsurface pressure sensors, able to measure tsunamis in the open ocean, are providing important data on the propagation of tsunamis in deep water. The recent development of better equipment and numerical modelling methods is helping scientist understand the mechanism of tsunami generation. Seismologists, studying the dynamics of earthquakes, 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 **moment magnitude** is designed to better define the amount of energy released and the potential for tsunami generation. It is hoped that this relationship between moment magnitude and the potential for tsunami generation can be refined so that the near-real time analysis of earthquakes can be performed for tsunami warning purposes.*

Tsunami generation is initiated by 3-dimensional deformation of the ocean bottom due to movement of the fault. Numerical models of propagation generally use an implicit-in-time finite difference method.

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 has been issued.



July 30, 1995 Chilean Tsunami. Left: Model results showing the maximum run-up and inundation relative to the normal sea level and shoreline (white line) at Tahauku Bay, Hiva Hoa, in the Marquesas Islands, French Polynesia. Two small boats sunk in Tahauku Bay as a result of this event. Below: Model of the tsunami in the southeast Pacific, 9 hours after its generation.



THE FACTS

- Tsunamis that strike coastal locations in the Pacific Ocean Basin are most always caused by earthquakes. These earthquakes might occur far away or near where you live.

- Some tsunamis can be very large. In coastal areas their height can be as great as 10 meters or more (30 meters in extreme cases), and they can move inland several hundred meters.

- All low lying coastal areas can be struck by tsunamis.

- A tsunami consists of a series of waves. 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.

- Tsunamis can move faster than a person can run.

- Sometimes a tsunami causes the water near 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 feet by the tsunami wave activity. Homes and other buildings are 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 that lead to the ocean.

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.

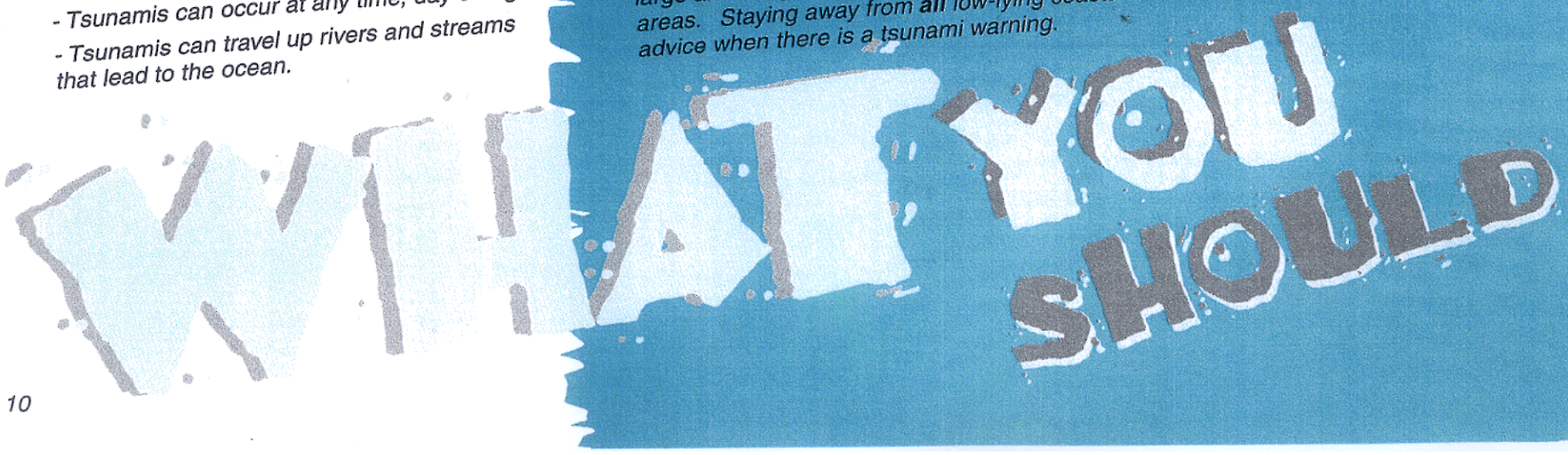
- If you are at home and hear there is a tsunami warning, you should make sure your entire family is aware of the warning. Your family should evacuate your house if you live in a tsunami evacuation zone. Move in an orderly, calm and safe manner to the evacuation site or to any safe place outside your 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, 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 regional tsunami from a local earthquake could strike some areas before a tsunami warning could be announced.

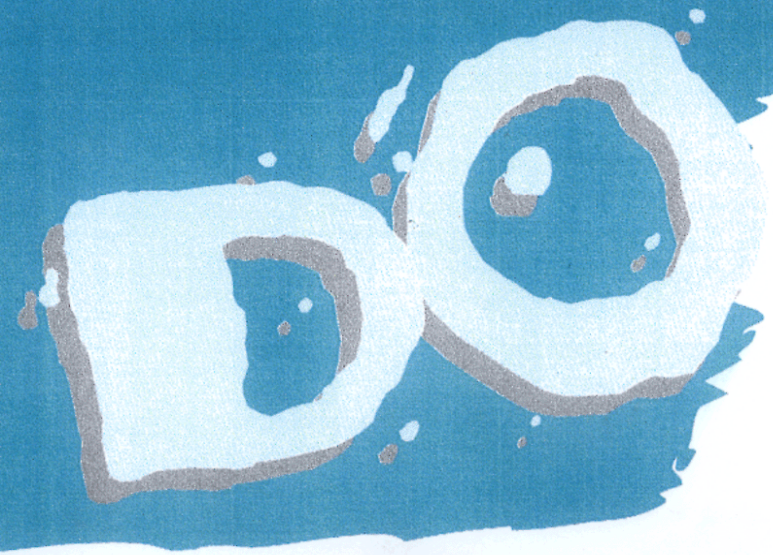
- Tsunamis generated in distant locations will generally give people enough time to move to higher ground. For locally generated tsunamis, where you might feel the ground shake, you may only have a few minutes to move to higher ground.

- High, multi-story, reinforced concrete hotels are located in many low-lying coastal areas. The upper floors of these hotels 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.



Aonae, Okushiri Island, Japan. Total destruction of houses and other buildings resulting from the tsunami of 12 July, 1993, in the Sea of Japan. Numerous fires broke out following the tsunami adding to the property loss and misery. Over 120 people were killed by the tsunami in Japan.



IF YOU ARE ON A BOAT OR SHIP

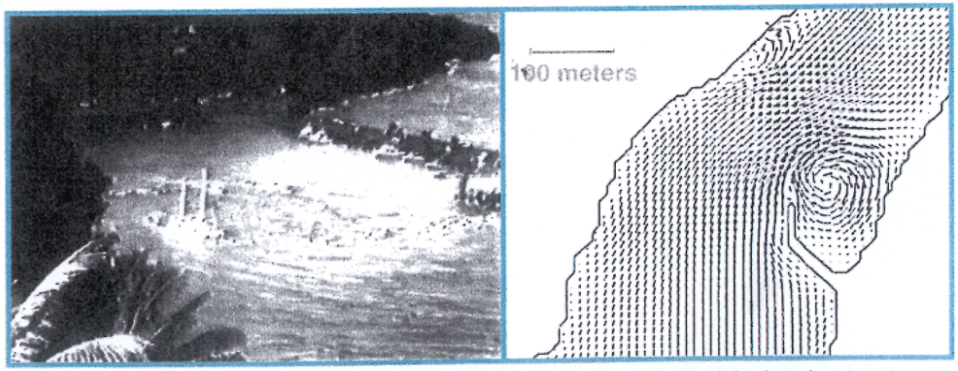
- Since tsunami wave activity is imperceptible in the open ocean, do not return to port if you are at sea and a tsunami warning has been issued for your area. Tsunamis can cause rapid changes in water level and unpredictable dangerous currents in harbors and ports.

- If there is time to move your boat or ship from port to deep water (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 (should a tsunami be expected), 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 and you have time to move your vessel to deep water, then you may want to do so in an orderly manner, in consideration of other vessels. Owners of small boats 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 safe 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 effect harbors for a period of time 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.



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 modelling of the Chilean tsunami. The modelling reproduces the same kinds of ocean currents seen in the photo.

Ala Wai Yacht Harbor, Honolulu, Hawaii. Withdrawal of water caused by tsunami generated by earthquake of November 4, 1952, in Kamchatka, Russia. The spectators in this picture are needlessly risking their lives and should be evacuating to higher ground. (ITIC)

KNOWLEDGE IS SAFETY

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 under your feet or you hear there is a warning, tell your relatives and friends, and **MOVE QUICKLY TO HIGHER GROUND.**

ACKNOWLEDGMENTS

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NATIONAL OCEAN SERVICE
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FURTHER INFORMATION ON THE TSUNAMI WARNING SYSTEM IN THE PACIFIC, ITIC AND TSUNAMIS MAY BE OBTAINED FROM:

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