TSUNAMIS

What is a Tsunami?

A tsunami is a *very long ocean wave that is generated by a sudden displacement of the sea floor*.

The term is derived from a **Japanese** word meaning "**harbor wave**."

Tsunamis are sometimes referred to as **seismic sea waves** because submarine and near-coast earthquakes are their primary cause.

They are also popularly called "**tidal waves**," but this is a **misnomer**; tsunamis have nothing to do with tides.


BEFORE
AFTER

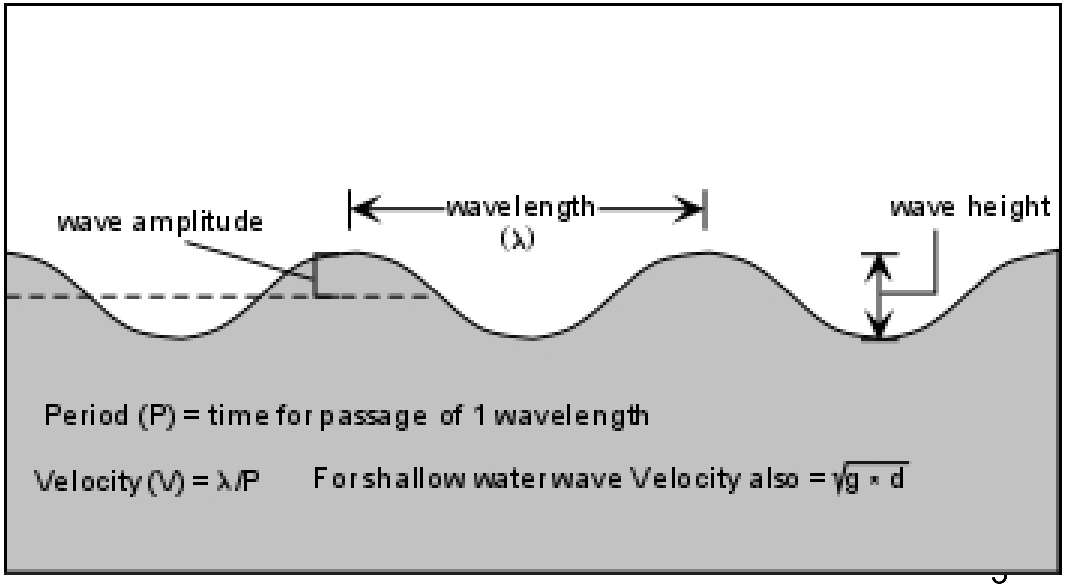
Physical Characteristics of Tsunamis

1 Wavelength

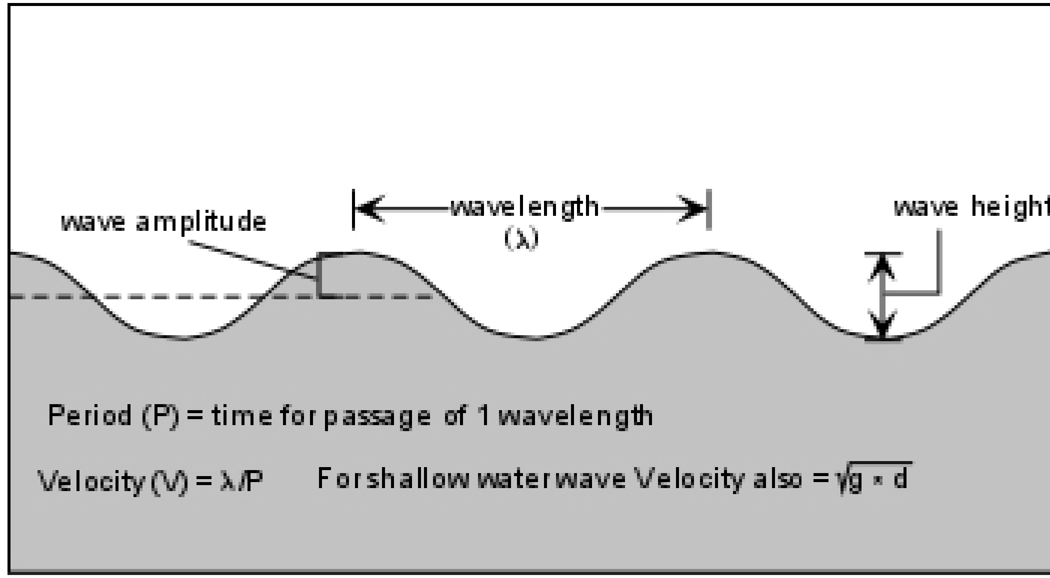
For all types of waves, the term **wavelength** is used to refer to the ***distance from one crest to the next***.

Normal ocean waves average about **100 m** in wavelength.

A **tsunami**, in contrast, can exceed **200 km** in wavelength.



2 Velocities



Tsunamis travel very quickly compared to normal ocean waves.

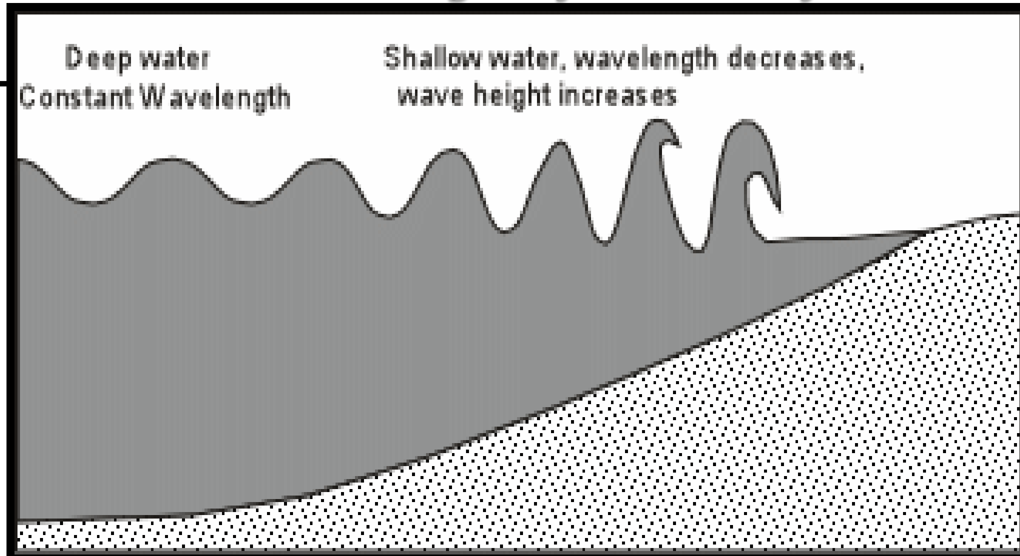
This is particularly true in open water because wave velocities increase with water depth.

Normal ocean waves travel at velocities closer to **90 km/h**.

In the open water, where the water is deepest, **tsunami** velocities can reach **950 km/h** or more.

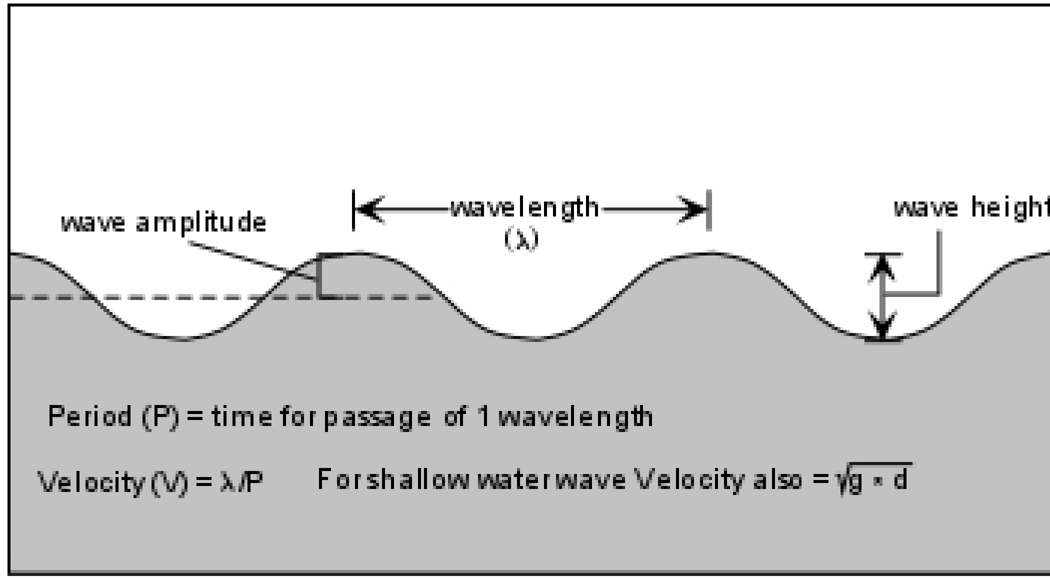
3 Amplitude

The **amplitude** of a tsunami is the ***height of the wave from the still water line***.



Because of the relationship between velocity and water depth, when the waves reach shallower coastal waters they slow down abruptly – in a sense, they "pile up" on themselves.

This causes the amplitude of the waves to increase dramatically from about **1 m** in the **open water** (little more than a broad, gentle bulge) to about **5 or 10 m**, and in the most dramatic cases to about **40 m** above normal sea level, once they reach the **shore**.



4 Frequency

The **frequency** of the tsunami depends on both velocity and wavelength. Thus, although tsunamis have high velocities, their long wavelengths result in a **long time interval between crests (as much as an hour)**.

5 Run-up

The ***water level achieved by a tsunami once it hits the shore*** is called its **run-up** (usually expressed as height in meters above normal high tide).

The run-up of a tsunami is usually determined by a combination of

1. **Eyewitness accounts** and
2. **Physical indicators** such as
   a) Water marks on the sides of buildings,
   b) The locations of seaweed and other debris transported by the wave,
   c) The height to which vegetation has been damaged or killed by saltwater,
   d) The landward limits of sand deposition, and
   e) The height to which buildings or trees have been damaged by transported objects.

6 Magnitude

Various scales are in use for the measurement of tsunami **magnitudes**.

These scales define the magnitude of a tsunami in terms of the ***logarithm of the maximum wave amplitude observed locally***. (In this respect, **tsunami magnitude** scales are analogous to the **Richter earthquake magnitude** scale)

One such scale is the **Imamura-Iida scale**, in which tsunami magnitude is calculated as a function of the maximum wave height along the coast.

This type of formula leads to **<u>different estimates of magnitude for a given tsunami</u>** because of

1. **The variability of run-ups along a given stretch of shoreline**
2. **The difficulties inherent in measuring the maximum run-up.**

How Tsunamis Are Generated?

Any event that causes a significant displacement of the sea floor causes the displacement of an equivalent volume of water; which can generate tsunamis.

Tsunamis are generated by:

- **Earthquakes**
- **Volcanic Eruptions**
- **Submarine Landslides**
- **Human activity**

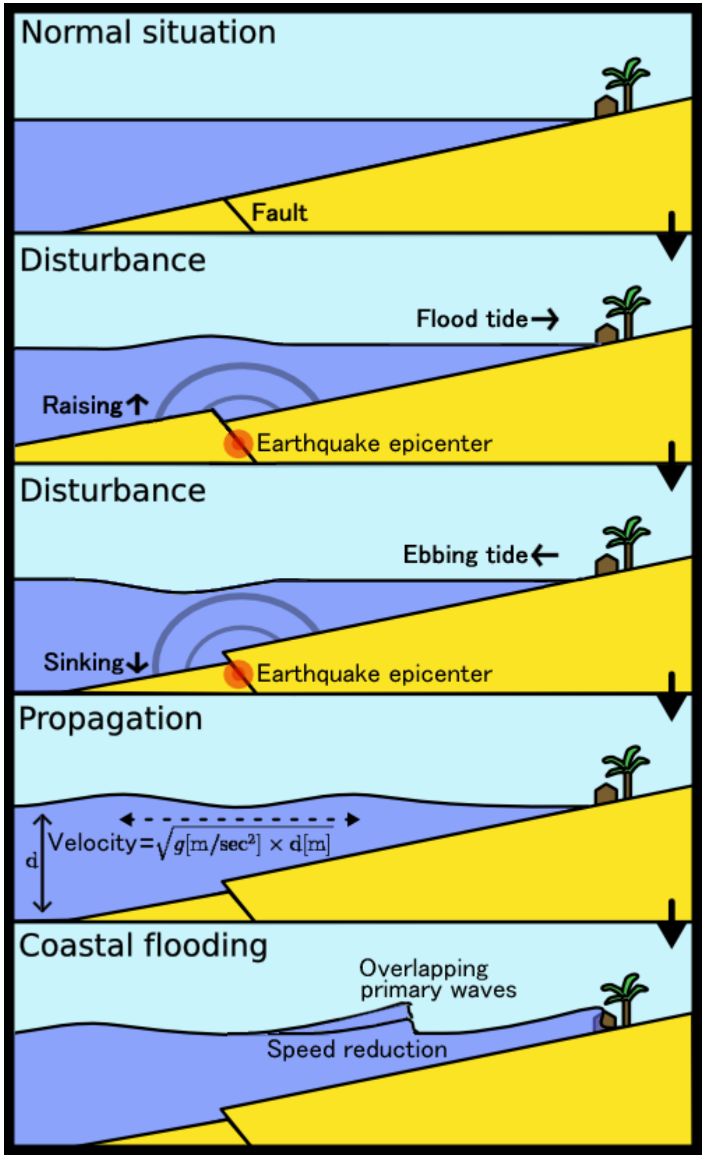
Tsunamis Generated by Earthquakes

Most tsunamis are produced by **near-shore** or **offshore earthquakes**.

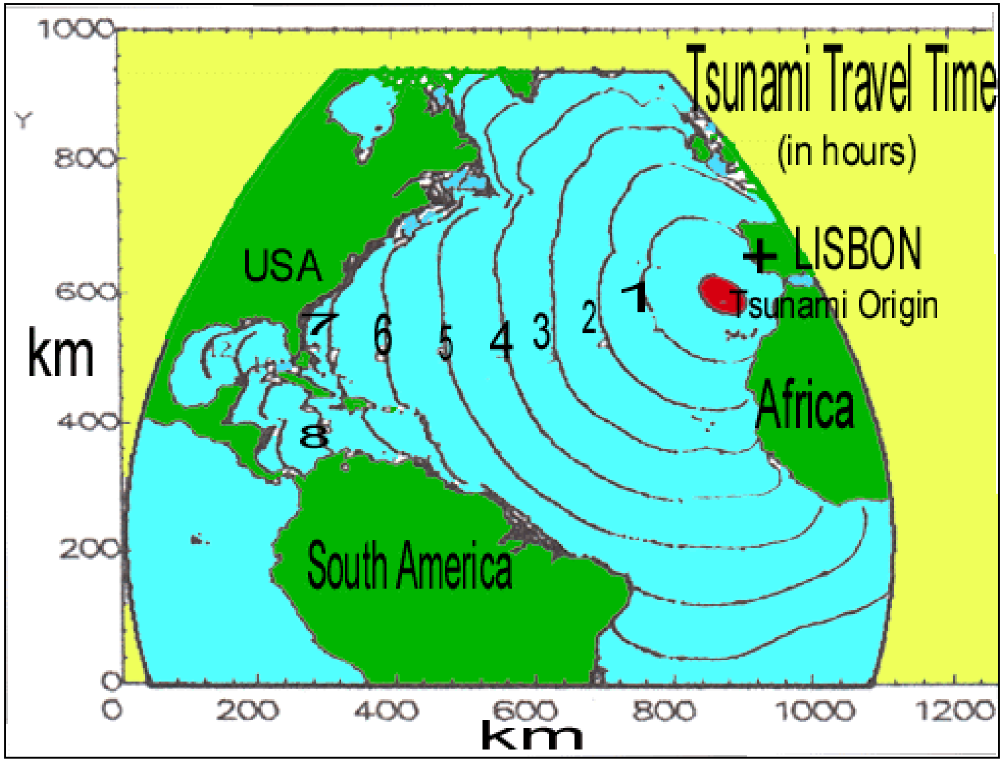
Any ***earthquake that generates a tsunami*** is called a **tsunamigenic earthquake**.

Tsunamis can be generated when the **sea floor abruptly deforms and vertically displaces the overlaying water**.

1. **When tectonic earthquakes occur beneath the sea, the water above the deformed area is displaced from its equilibrium position.**
2. **Waves are formed as the displaced water mass, which acts under the influence of the gravity, attempts to regain its equilibrium.**
3. **When large areas of the sea floor elevate or subside, a tsunami can be created.**



One of the most famous **tsunamigenic earthquakes** is the one that occurred off the coast of **Portugal in 1755**.



It produced a series of tsunamis with run-ups as high as **5 m** above normal high tide that caused the deaths of **60,000 people** in **Lisbon** (population 235,000).

The waves were observed a few hours later as far away as the **West Indies**.

It is NOT always that large earthquakes may generate large tsunamis.

Tsunamis are much more likely to result from vertical deformation of the crust than from horizontal deformation.

For example, no tsunami resulted from the great 1906 San Francisco earthquake, even though displacements of up to 6 m occurred along portions of the fault that are partly underwater.

The San Andreas Fault, along which the earthquake occurred, is characterized by horizontal (strike-slip) motion, in which there is no vertical displacement of the sea floor.

Tsunamis Generated by Volcanic Eruptions

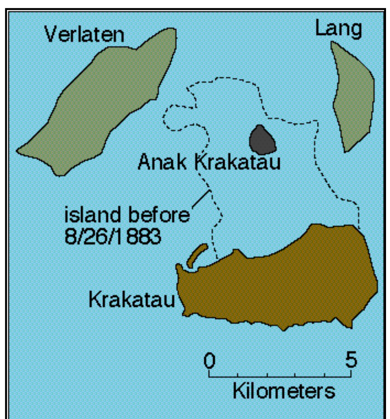
Volcanic eruptions can also be efficient generators of tsunamis.

An **explosive eruption** can displace enormous volumes of rock; if the volcano is partly or mostly submerged, a corresponding volume of water will also be displaced, causing a tsunami.

The **collapse of steep walls of a volcanic structure** and associated underwater debris or ash flows can contribute to the formation of a tsunami.

For example, the **Krakatau eruption in 1883** generated a series of at least three great tsunamis and many smaller waves. Most of the **36,417 people** who died as a result of the eruption were swept away by the tsunamis; hot ash caused a number of injuries but only a few fatalities. Underwater ash flows may have generated some of the tsunamis.

Krakatau is located west of **Java in the Strait of Sunda**, which was an important shipping corridor at the time.



From Simkin and Fiske, 1983

Tsunamis Generated by Landslides

Tsunamis can also be caused by coastal and **submarine landslides**.

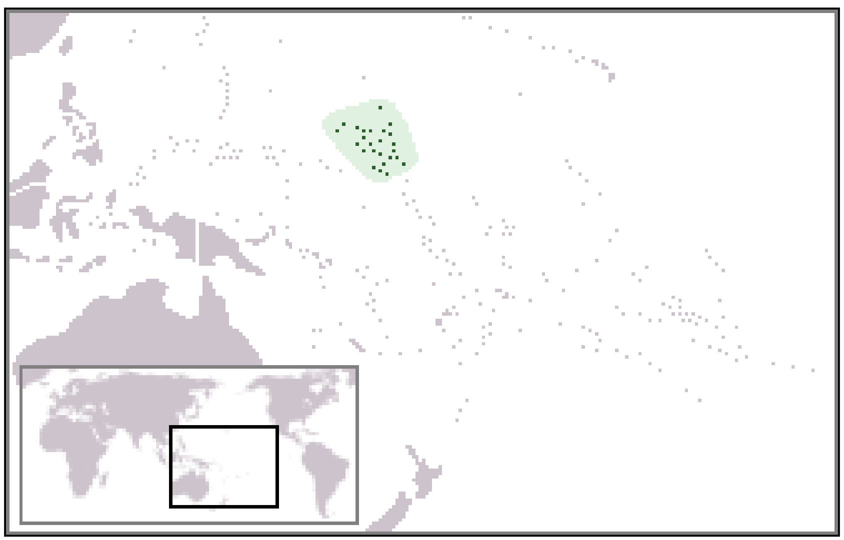
In most such cases the **landslides** themselves have been generated by **earthquakes** or **volcanoes**.

Sediments can build up along the walls of a submarine canyon and, when shaken by an earthquake, collapse into the bottom of the canyon.

For example, the **Good Friday earthquake** triggered at least **20 separate landslide tsunamis**. About **80 of the 119 deaths** linked to the quake were caused by those tsunamis.

Tsunamis Generated by Underwater Explosions

Tsunamis are occasionally caused by **human activity**.



For example, tsunamis were generated by **submarine nuclear testing** at **Bikini Atoll in the Marshall Islands in the 1940s and 1950s**.

Mitigation of Risk and Hazards

Tsunami Hazards

The main source of damage from a tsunami is the **direct action of the wave on coastal structures**.

However, a variety of **indirect** mechanisms can also cause further damage.

The most serious hazard associated with tsunamis is loss of life.

Over the past century, 94 destructive tsunamis have caused the deaths of a total of over 51,000 people.

Debris such as trees, cars, and parts of destroyed structures can become projectiles;

Flotation and drag can move houses, machinery, and railroad cars;

Fires can result from the combustion of oil spilled by damaged ships and storage facilities.

Strong currents can erode foundations, leading to the collapse of buildings, bridges, and seawalls; and

Prediction and Early Warning

The **prediction** of tsunamis centers on ***efforts to understand the mechanisms through which earthquakes generate tsunamis***.

As mentioned earlier, the **magnitude** of an earthquake is not the sole determinant of the magnitude of a tsunami; the **degree**, **direction**, and **disposition** of crustal deformation are also important.

Tsunamis and tsunamigenic earthquakes are a particular hazard for **Pacific Ocean islands** and locations around the **Pacific rim**.

Hawaii is especially vulnerable to dangerous tsunamis because of its location in the path of waves generated at many seismically active points around the Pacific rim.

Sirens and **radio newscasts** alert Hawaii's population to arriving tsunamis, and **maps printed in telephone books** show the coastal zones at greatest risk; both measures have helped reduce the loss of life from tsunamis.

Regional Warning Systems

In spite of the **rapid onset** and **quick travel times** of **tsunamis**, there is often **ample** opportunity to **warn residents of coastal areas**, especially if they are located **more than 750 km** (approximately 1 hour in tsunami travel time) from the source of the wave.

Several different types of early warning systems now exist in the Pacific basin.

One such system is operated by the **National Oceanic and Atmospheric Administration (NOAA) Pacific Tsunami Warning Center (PTWC)** near **Honolulu**.

PTWC

It is an international monitoring network consisting of about:
30 seismic stations and
78 tide station
located around the Pacific basin.

When an earthquake occurs, it is detected by the seismic stations.

If the quake meets certain criteria with respect to location and magnitude, local tidal gauges are monitored for signs of a tsunami.

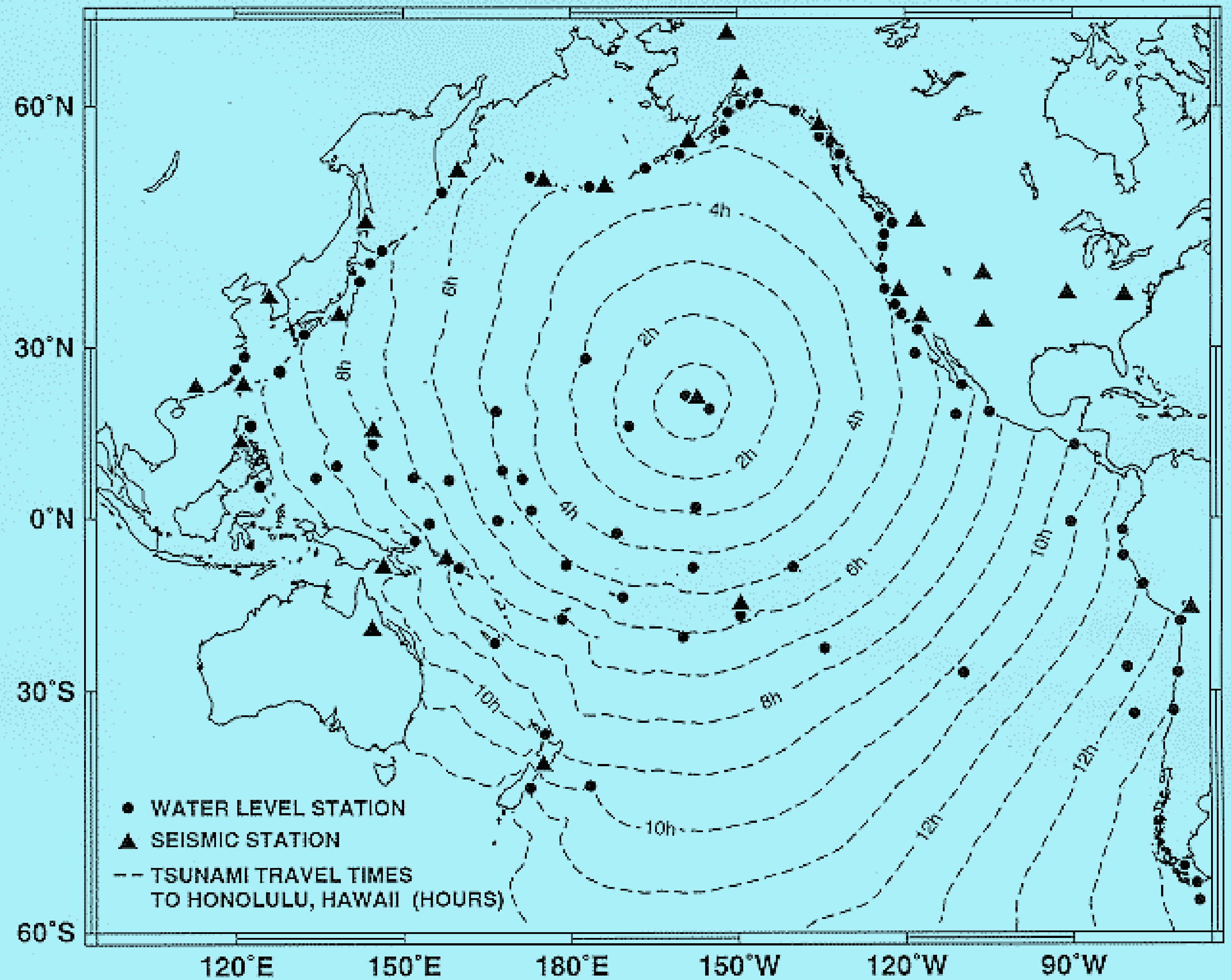
Arrival rimes for the tsunami can be calculated for different localities around the Pacific rim.

Information is relayed from the seismic station to the tsunami warning station via NOAA satellites.

- **The minimum time required to gather this information and issue a warning is 1 hour; since tsunamis typically travel at 750 km/h, this means that the Pacific-wide early-warning system is effective only for communities located more than 750 km from the epicenter.**


RICHARD H. HAGEMEYER
PACIFIC TSUNAMI
WARNING CENTER
NATIONAL WEATHER SERVICE

Pacific Tsunami Warning System



Regional warning systems are designed to provide warnings to areas in a **100- to 750-km radius** (i.e., between about 10 minutes and 1 hour) from the epicenter.

Regional systems have been established in areas that are known to be particularly **susceptible to earthquake-generated tsunamis**, including Japan, Alaska, and French Polynesia.

The regional centers issue warnings on the basis of **earthquake magnitude** and **location** alone; warnings typically can be issued within 10 and 12 minutes of the earthquake’s occurrence.

Local early-warning systems can be designed to provide warnings for populations less than 10 minutes (**less than 100 km**) from the source.

An example of such a system is **THRUST** (**Tsunami Hazards Reduction Utilizing Systems Technology**), a pilot project in Valparaiso, Chile.

The effectiveness of tsunami early-warning systems is impressive.

For example, before the Japanese system was established, a total of over **6000 people** had been killed by 14 tsunamis; since then, 20 tsunamis have killed a total of **215 people** in **Japan**

The success of **local early-warning systems** depends heavily on:

1. **Emergency operations planning,**
2. **Access to timely information about earthquake occurrences and water levels,**
3. **The ability of local authorities to assess the danger,**
4. **The ability to disseminate information very quickly, and**
5. **Education of the public to respond appropriately in the event of a tsunami emergency.**