MFE659 Lecture 4a
EARTHQUAKES & TSUNAMIS

Tsunami on the coast of Sumatra

Japanese Tsunami

The death toll – 19,300+.

Deadly Whirlpool

Nuclear Disaster

Nuclear Disaster

Widespread Devistation

TSUNAMIS

Tsunami is the Japanese word for “harbor wave.” These fast traveling long waves are also known as seismic sea waves.

Tsunamis are generated by:

1. Sea floor earthquakes
2. Coastal earthquakes
3. Volcanic eruptions
4. Landslides

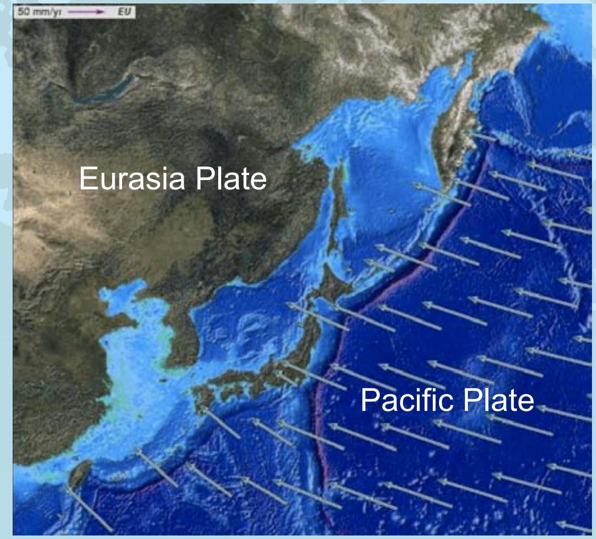
2011 Japanese Earthquake

The massive 9.0 earthquake on 3/11/11 was the strongest earthquake in recorded history to hit Japan and the 5th strongest overall. The earthquake moved the island closer to the United States by as much as 13 ft and shifted the planet's axis of rotation.

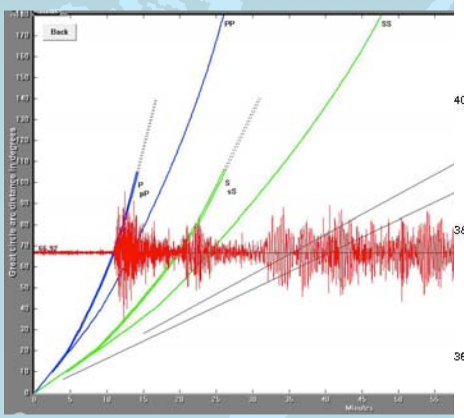
Japanese Tsunami

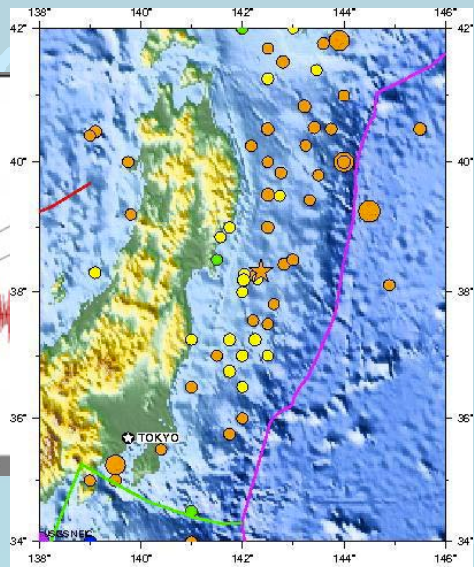
Epicenter: Latitude 38.322°N, 142.369°E. Depth: 24.4 kilometers

Japanese Trench



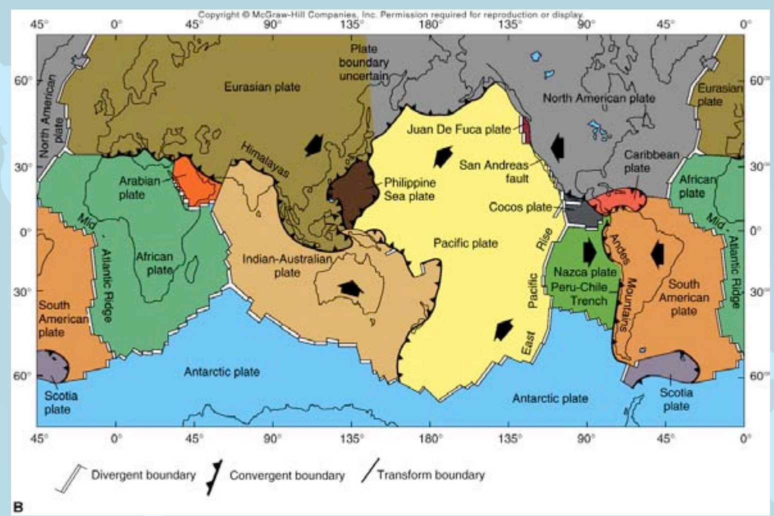
Epicenter & Seismograph





Magnitude 7 and 8 earthquakes since 1900.

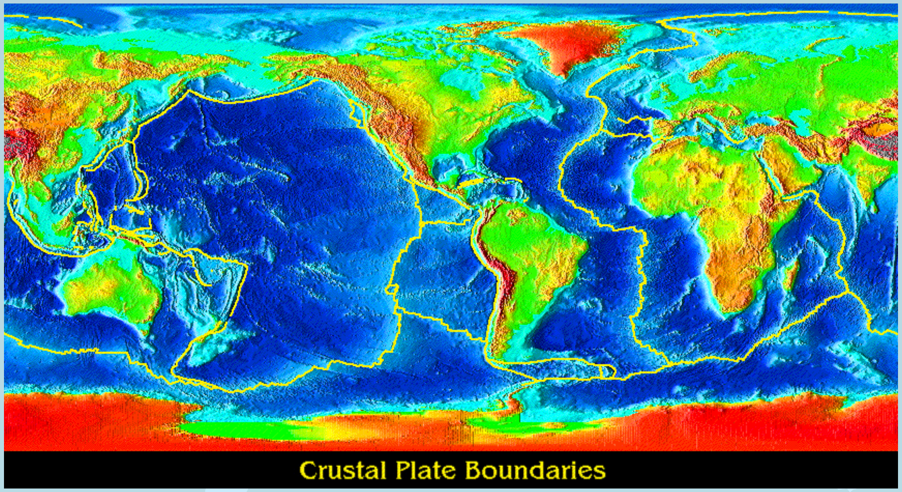
Relative Plate Motions and Boundaries



Different types of structures are associated with each boundary type:

- Divergent/rifting: extensional (normal faulting)
- Convergent/collisional: compressional (thrust faulting)
- Transform/transcurrent: shear-dominated (strike-slip faulting)

Crustal Plate Boundaries



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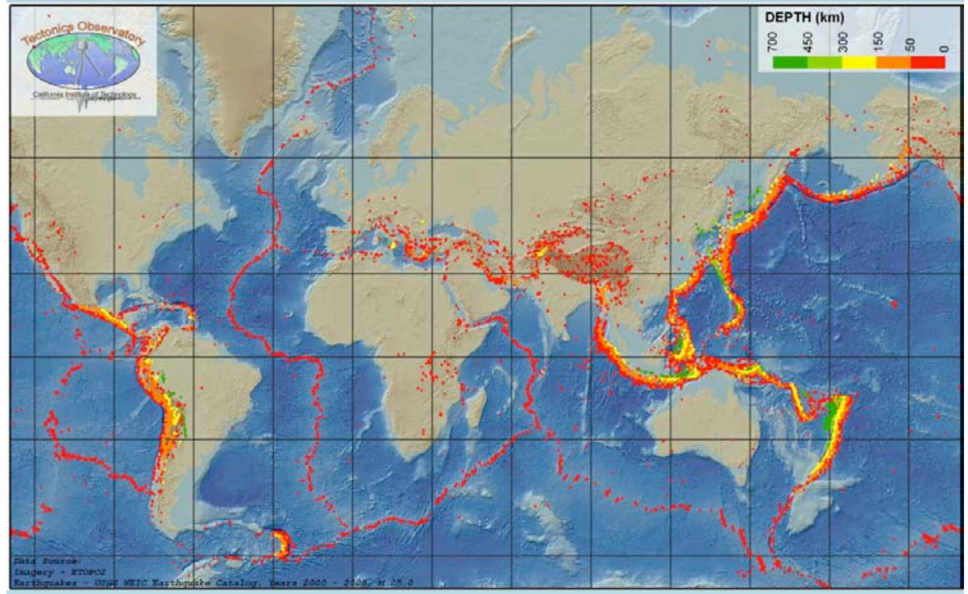
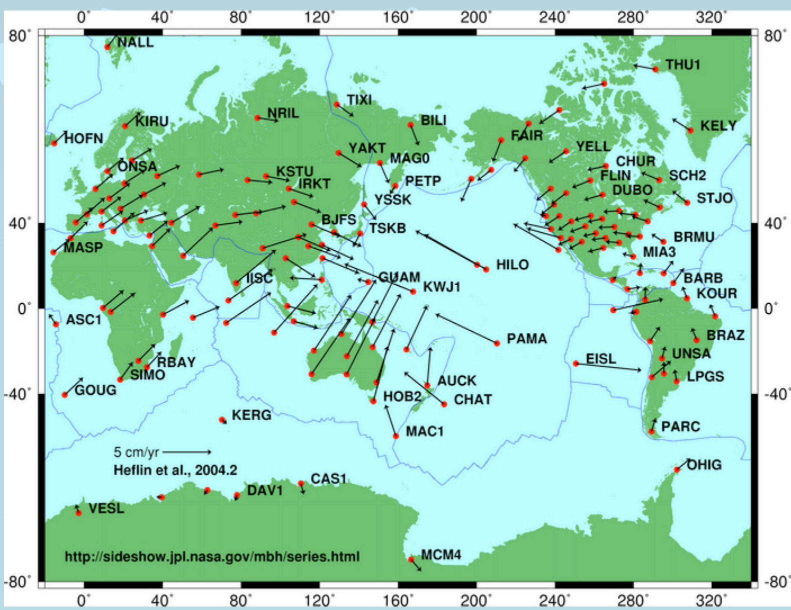
Earthquake Distribution



Earthquake Distribution



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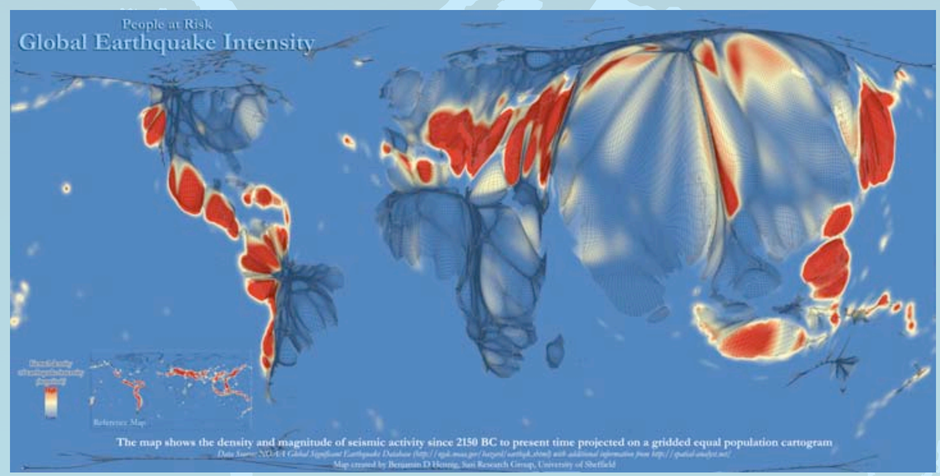
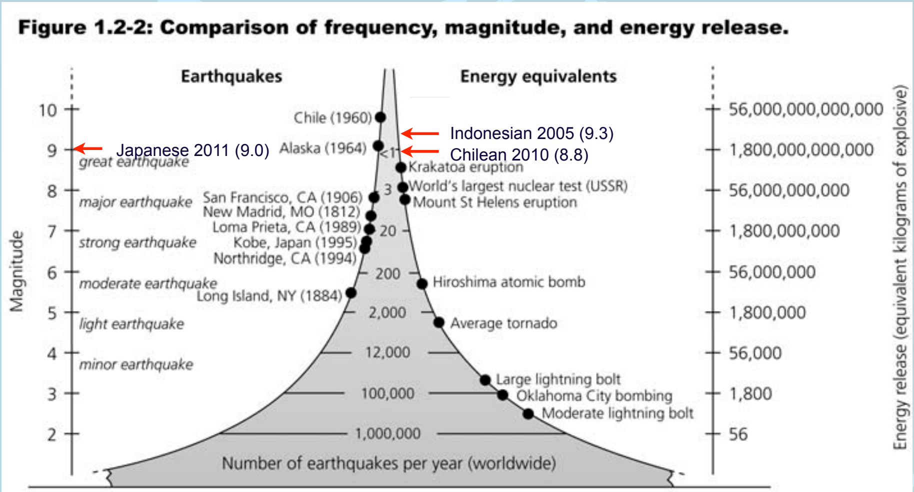


Magnitude of seismic activity projected on a gridded equal population cartogram.

Energy of Earthquakes



At magnitude 9.0 the Japan quake was one of the largest earthquakes since seismometer invented ~ 1900

San Francisco 1906 (7.8)

1964 Alaska Earthquake (9.2)

C

Photo by National Geophysical Data Center

2010 Chilean Earthquake

The massive 8.8 earthquake, the seventh strongest earthquake in recorded history, hit Chile on 2/27/2010 and shortened the length of an Earth day by 1.26 milliseconds, according to research scientist Richard Gross at NASA's Jet Propulsion Laboratory in Pasadena, Calif.

Chile 2010 (8.8)

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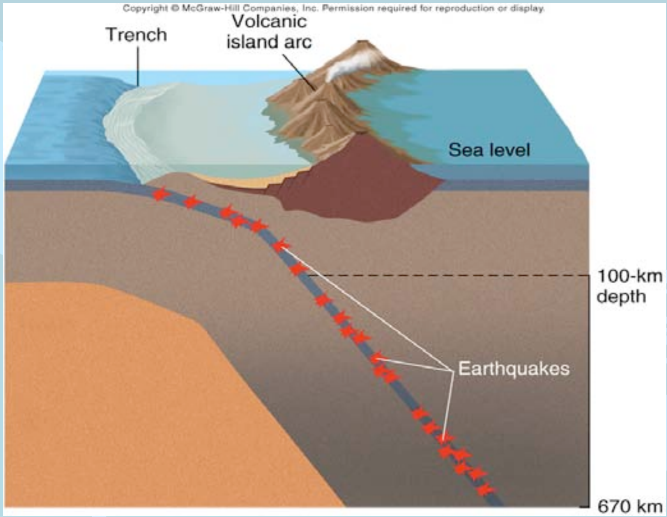
Convergent Boundary Earthquakes



The Japanese earthquake occurred in a subduction zone at a relatively shallow depth under the Pacific ocean.

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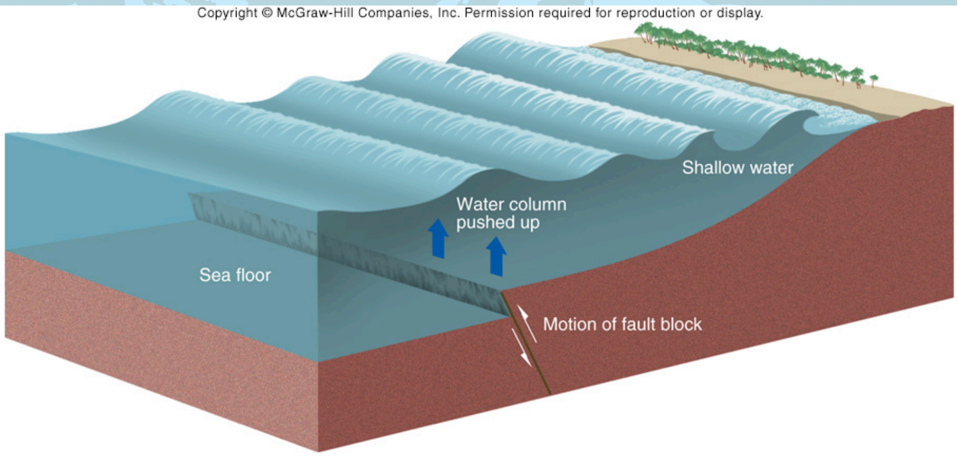
Tsunami Generation



1958 Lituya Bay, Alaska, landslide generated tsunami 450 m (1500 ft)

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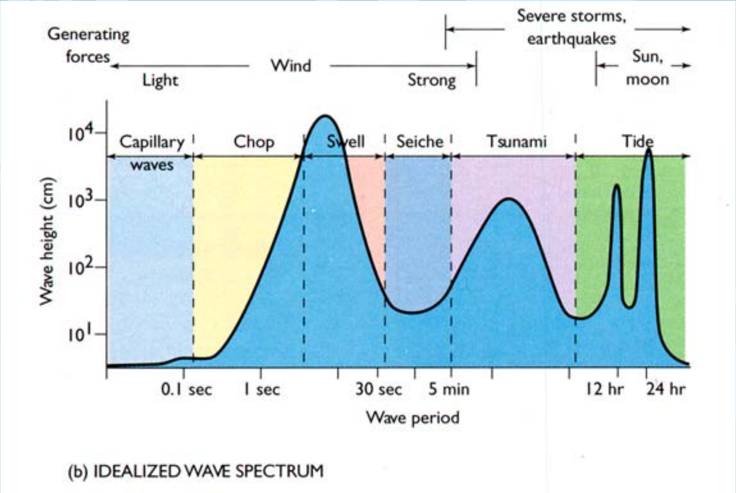
Wave Spectra



Wave spectra as a function of wave period

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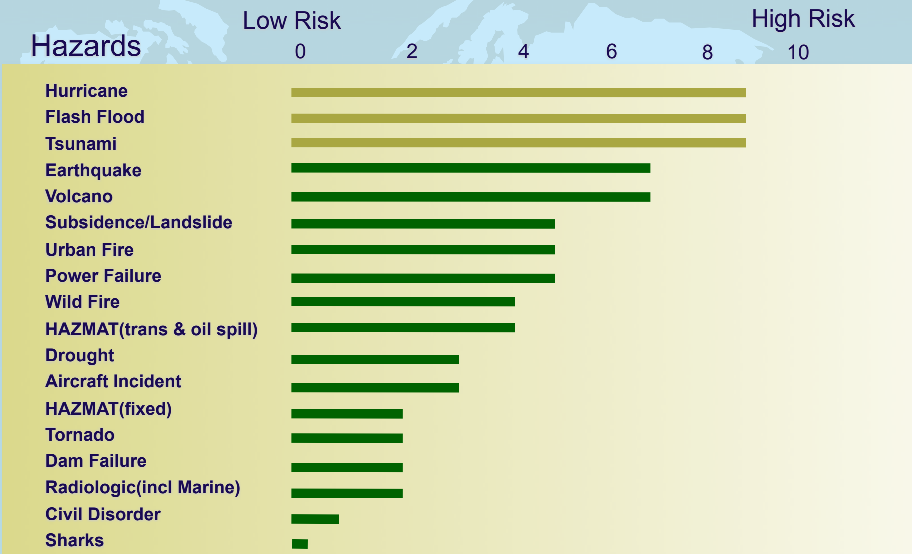
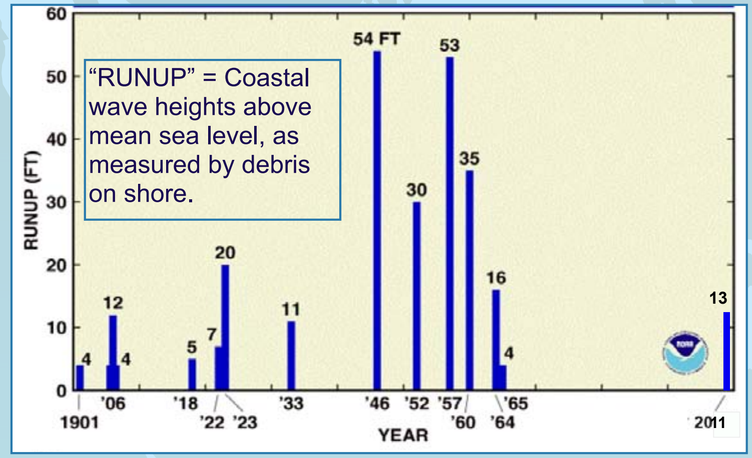
Hawaii Hazard and Risk Analysis



Risk Ranking includes likelihood and effect on population and property

Maximum Run-ups in Hawaii from 13 Pacific-wide Tsunamis



The three most destructive tsunamis caused a combined total of 222 deaths and hundreds of injuries in Hawaii.

Hilo, April 1946

Hilo, May 1960

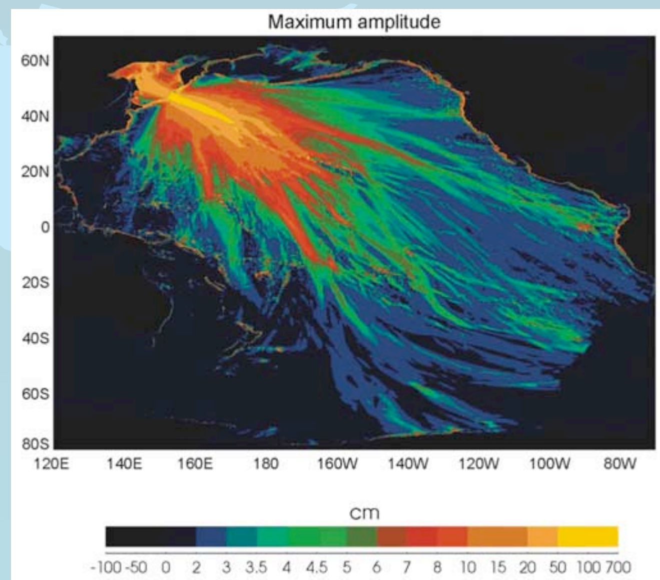
Indonesian Tsunami

Indonesian Tsunami

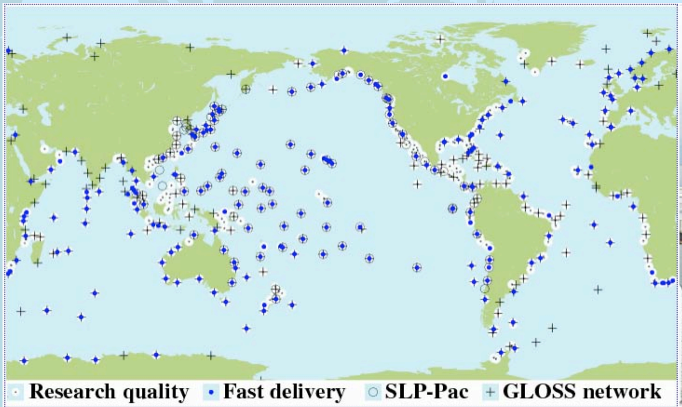
Indonesian Tsunami

BEFORE AFTER

Tsunami Prediction: What Observations are Needed?

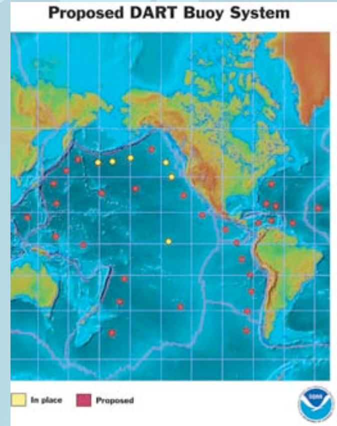


Tide Gages

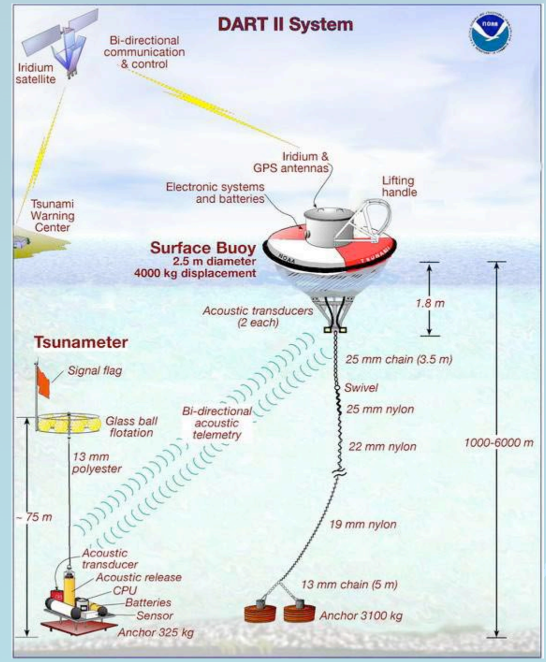


Tide gages are used to determine the amplitude of tsunami waves.

NOAA DART Mooring Buoy

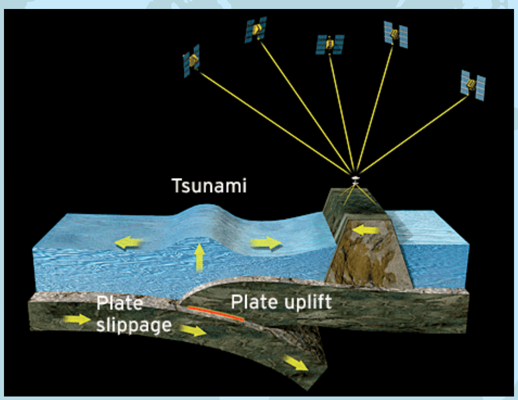


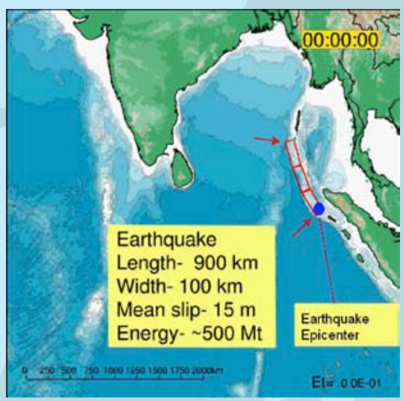
$37.5 million Investment



Deep-Ocean Assessment and Reporting of Tsunamis

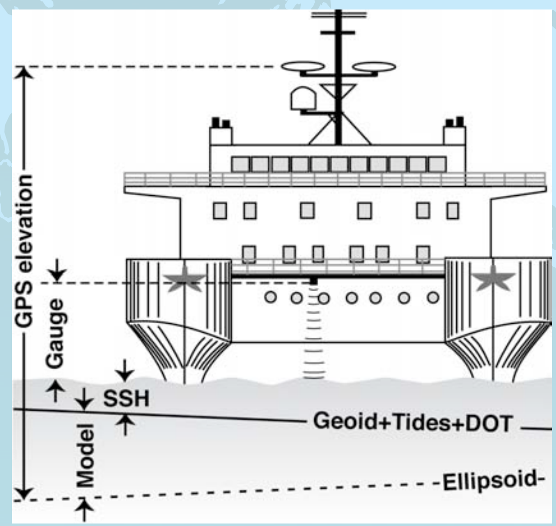
GPS Observations



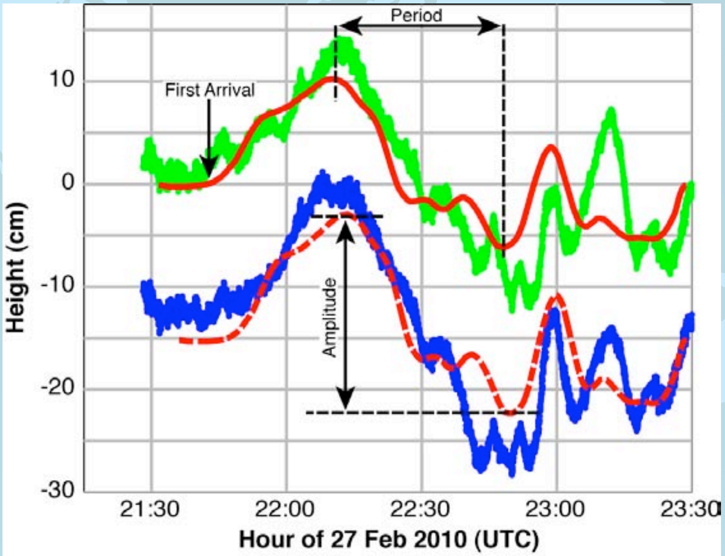


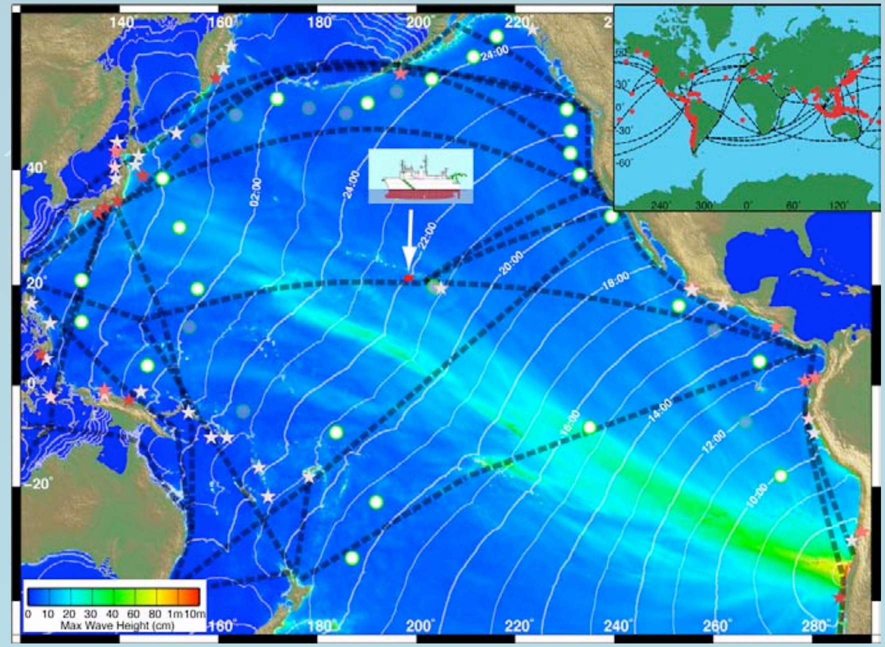
GPS satellites and ground based receiver network and pinpoint the size and shape of the displacement.

Detecting Tsunamis with Ships



The 27 Feb 2010 Chile Tsunami





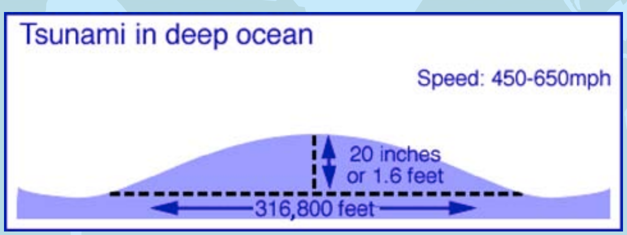
Wave Propagation in Deep Water

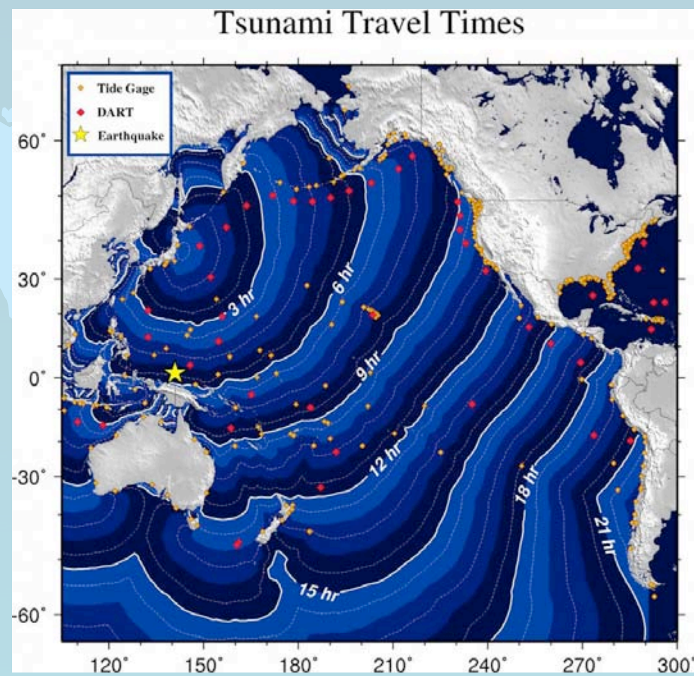
In deep water the speed of propagation is given by:

$$c = (g\,D)^{1/2}$$

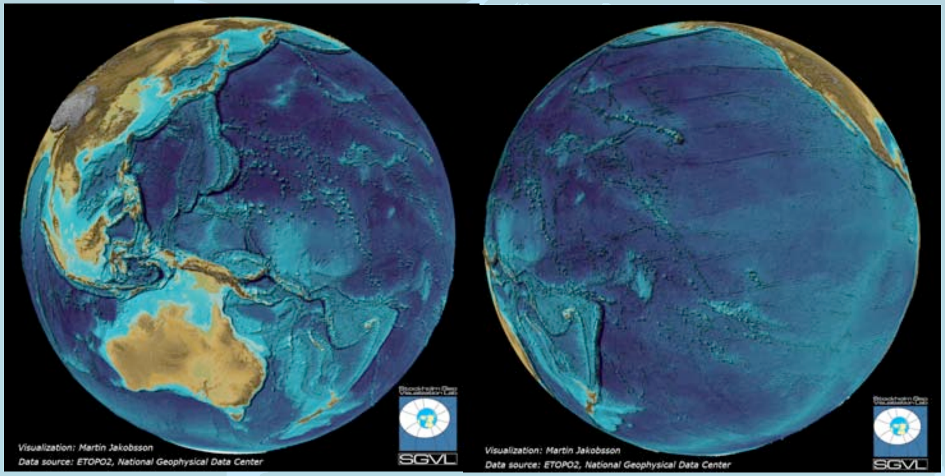
The average depth (D) of the of the Pacific Basin is 5,500 meters. This gives a velocity of:

$c = (9.81 \times 5500)^{1/2} = 230$ m/s = 830 km/hr ≈ 500 mph !





Tsunami



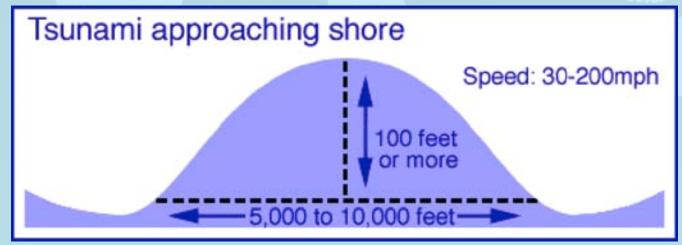
Wave propagation is very sensitive to ocean depth or bathymetry.

Wave Propagation in Shallow Water

For shallow water waves, wave speed remains a function of the depth of the water (D).

$$C = (gD)^{1/2}$$

- Waves "Feel the Bottom"at depth < 1/2 wavelength – causes refraction
- Wave speed and length decrease with depth, but period and energy remain same.
- Thus, wave height increases as a result of shoaling.
- Waves break when the ratio of height/wavelength ≥ 1/7.



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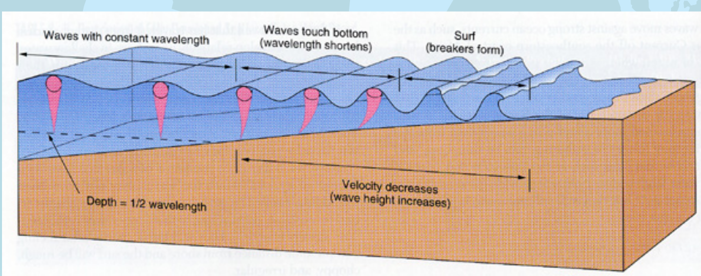
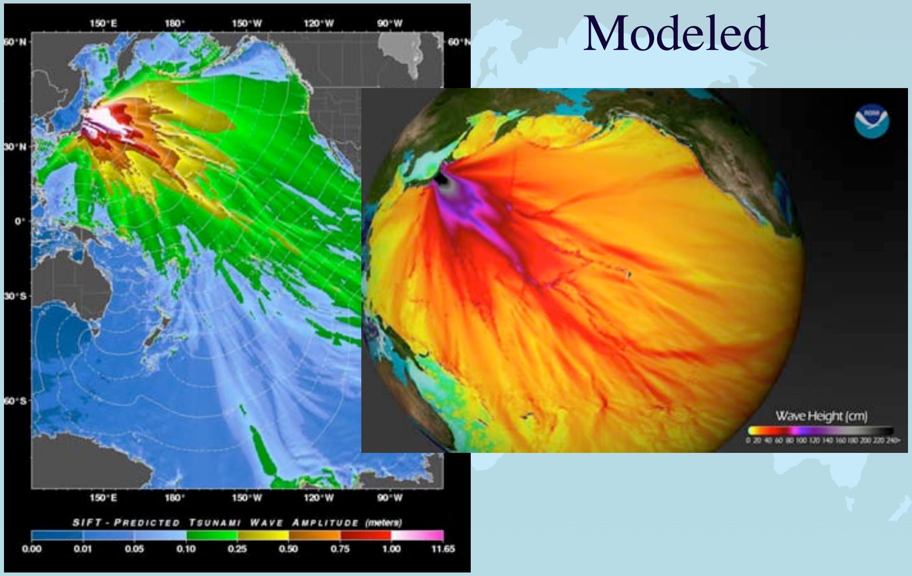


Scuba Gear Required

A wave of amplitude 5 m moving at 400 mph in deep water may be refracted to a 30 m-high wave traveling at 32 mph at the coastline. At the coastline the amplitude of a wave depends on:

1. Source of disturbance
2. Distance from the source
3. Depth of the water along the route
4. Local bathymetry--sea floor shape along the coast

Japanese Tsunami Modeled



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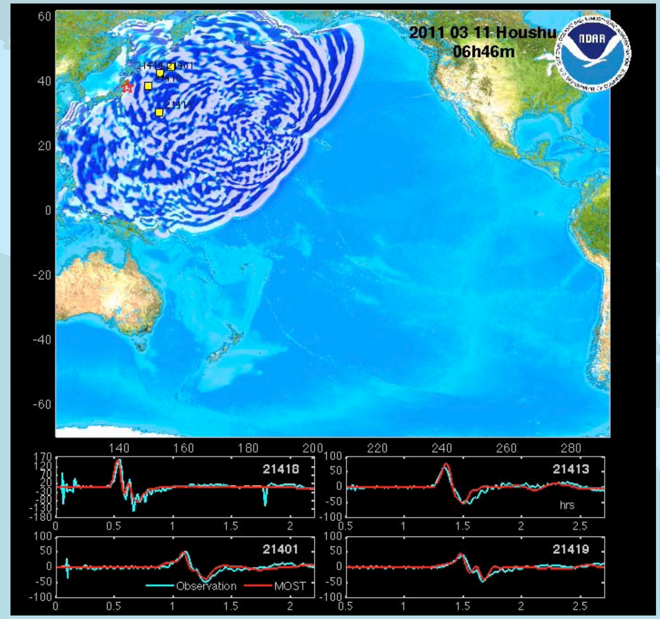
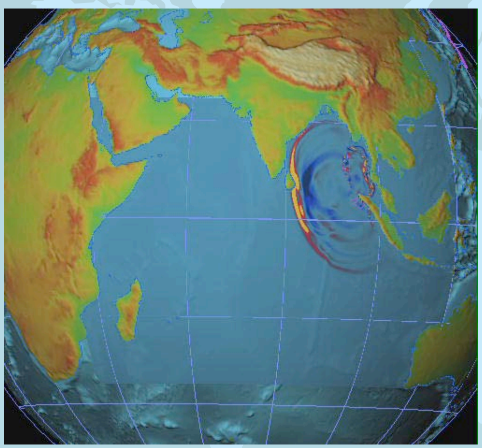
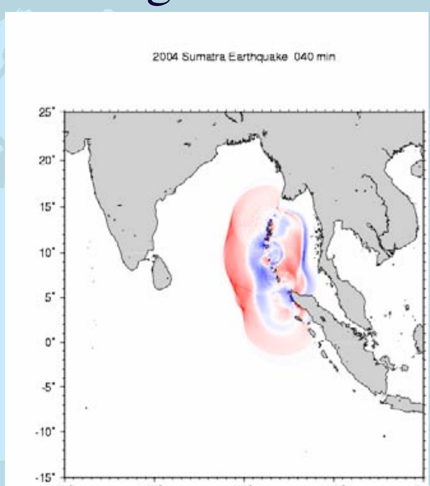


Tsunami Modeling





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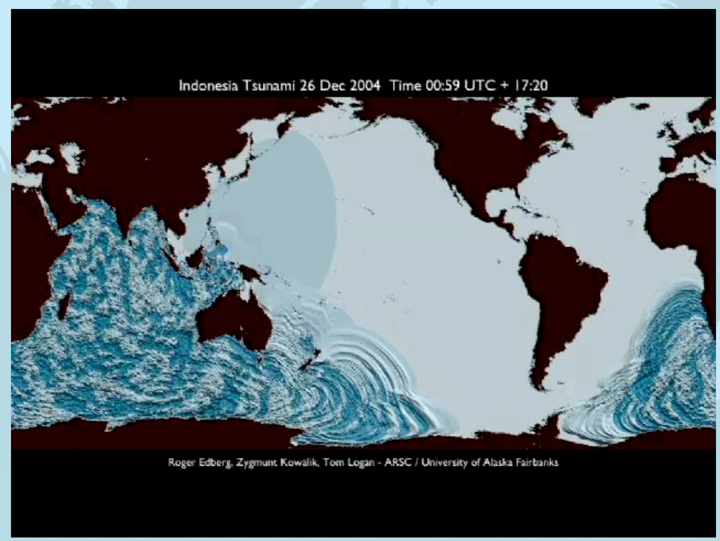
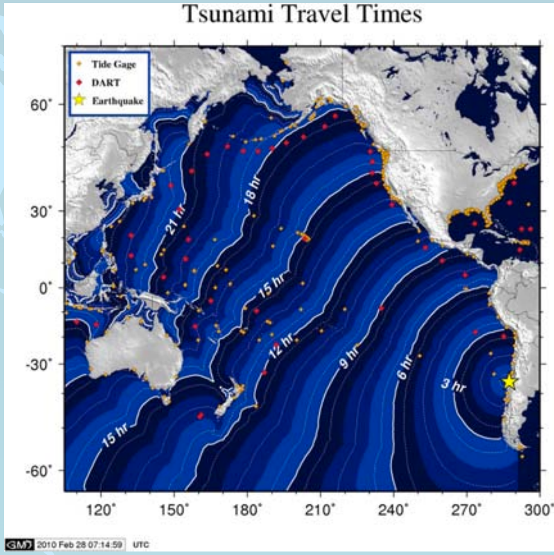
Tsunami Modeling

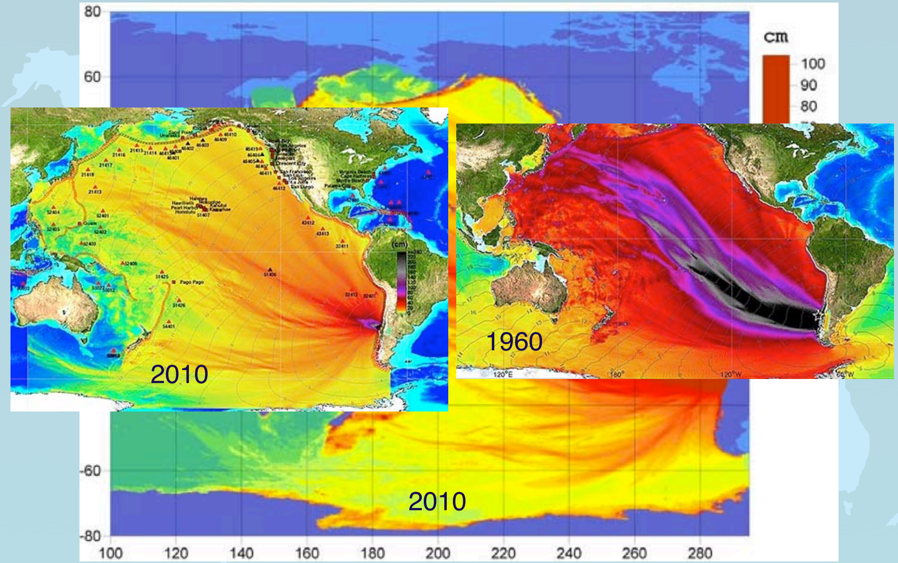


Tsunami



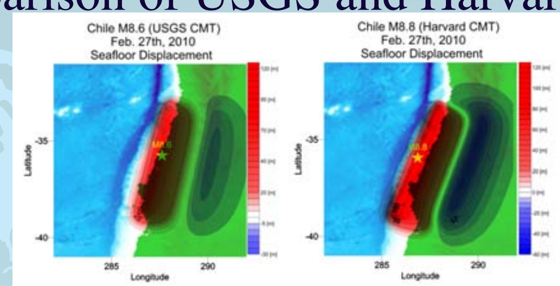
Travel times for Chilean Quake

Tsunami



24-hour depiction of maximum wave amplitude predicted at every grid point

Comparison of USGS and Harvard Runs



The USGS solution had less energy released from the earthquake, (8.6 vs 8.8), which accounts for some of the difference. However, the Harvard solution has the displacement further out into the trench, while the USGS solution is nearer the continent. This is important for the strength of the tsunami, because of the depth of the water column, (i.e. the amount of water you displace from an upward motion on the seafloor in deep ocean trenches is more than in shallow water, resulting in a larger wave - or more destructive tsunami, for events occurring farther out into the deep ocean trenches). Also, note that the USGS depth (34 vs 24 km) is about 10 km deeper than that of the Harvard solution. Again, this makes the resulting tsunami for the USGS solution less due to the amount of energy released at the surface. Extremely shallow earthquakes (5-15km) produce much more destructive tsunamis than