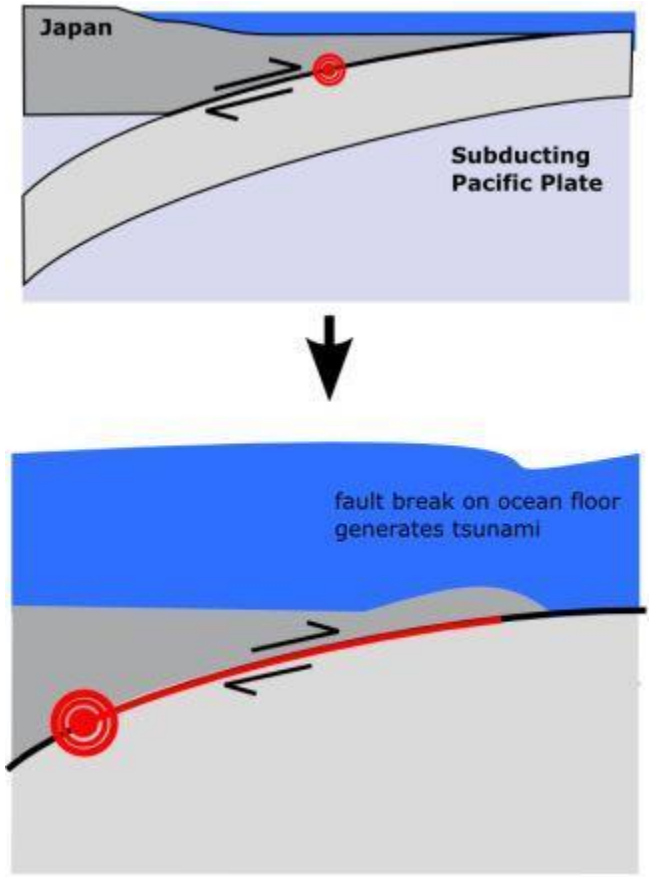
Tsunami

Tsunami

- Formed when a large volume of water is displaced
- When offshore, one set of waves moves onshore and another offshore
- Waves arrive in a series in a shorter amount of time closer to the epicenter
- Waves increase velocity with depth of ocean
- As wave approaches the shoreline:
  - the energy orbital collapses,
  - friction increases along the ocean bottom,
  - wave slows but energy is the same and drives the water onshore
  - Topography of shoreline influences height of surge

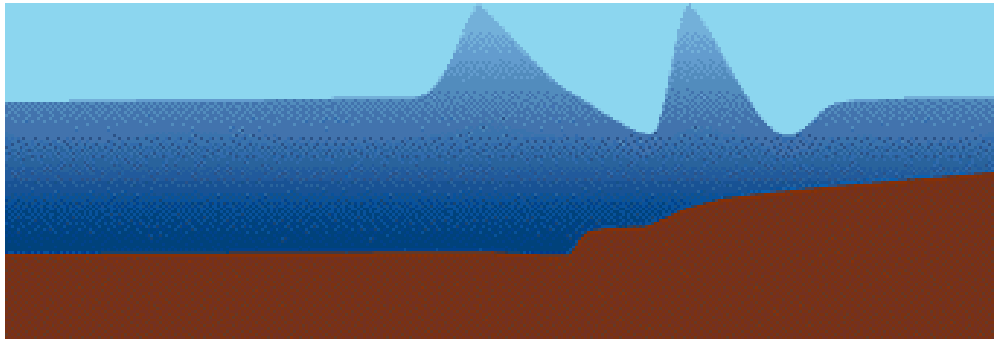
Why did the earthquake cause a tsunami?



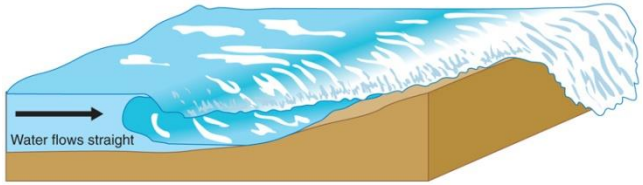
- Shallow focus earthquake
- Large volume of oceanic crust displaced
- The movement of the crust also displaces a large volume of water

Tsunami

- One wave moves toward the shoreline, another travels into the open



(b)



(c)

Tsunami at the **shoreline**

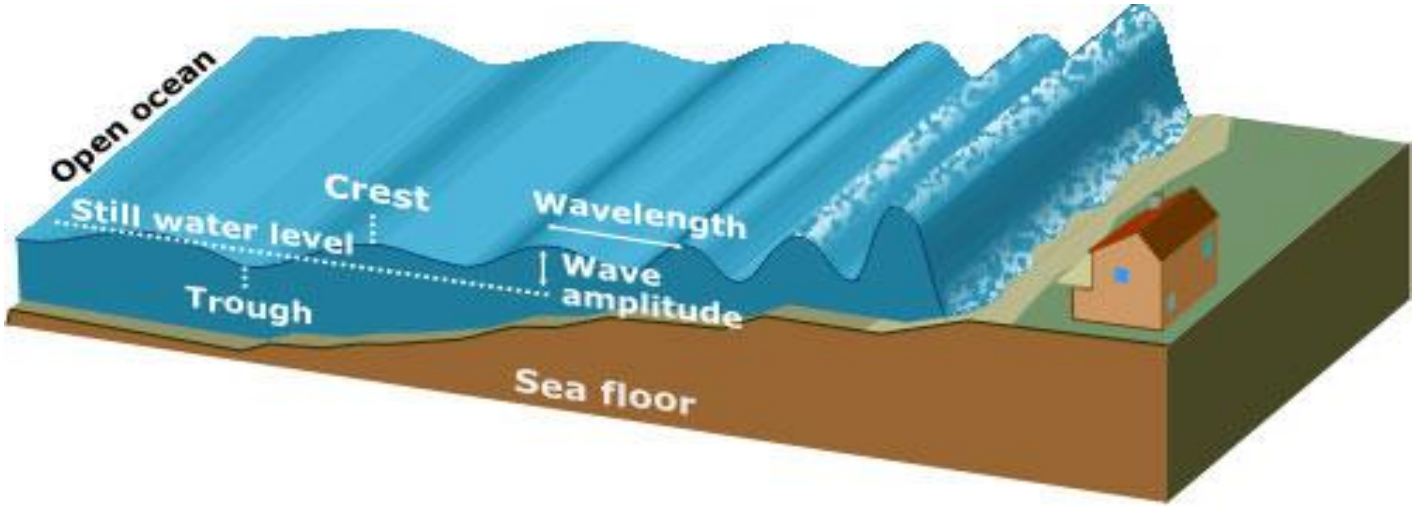
Not a gigantic version of breaking wave

Very rapidly rising tide, rushing inland

Sometimes water retreats first

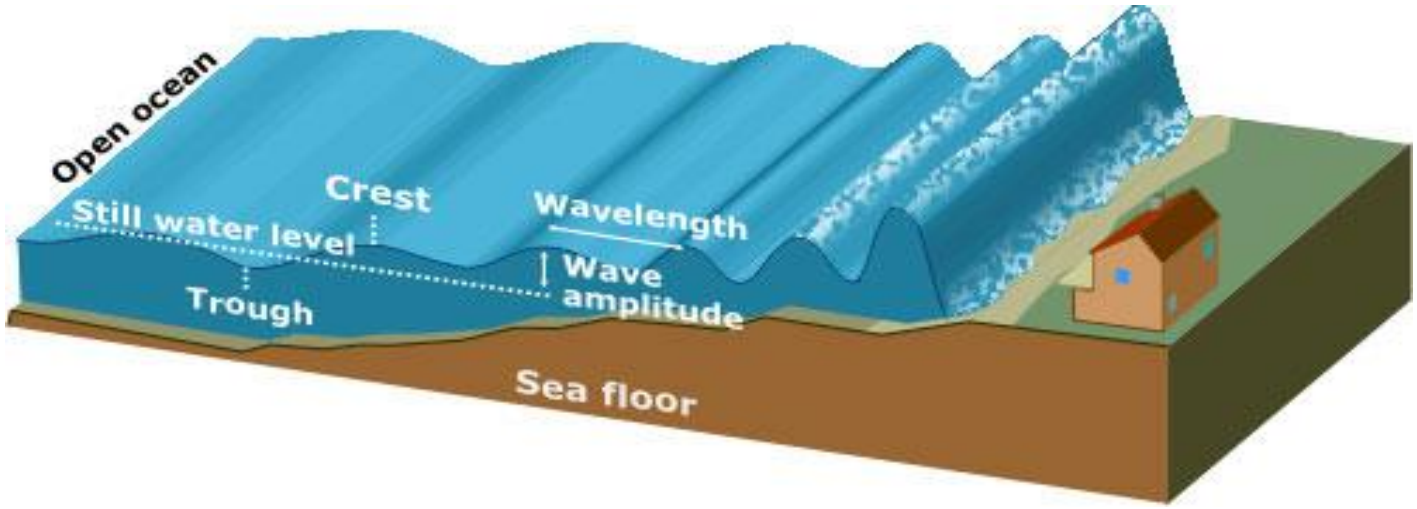
Period

- A series of waves may arrive every 10-60 minutes



Tsunami

- Shallow water waves because as they travel across the ocean and drag on the bottom (up to 18,000 feet)
- On the ocean's surface, the wave is barely detectable (3 feet high)



Wind versus tsunami wave

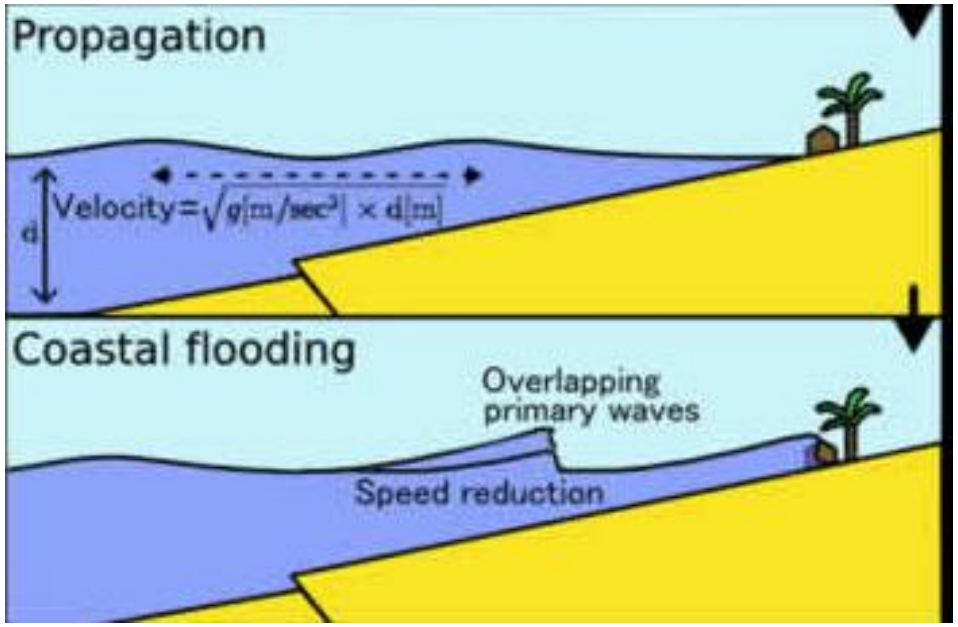
- **Wind waves**
  - Single wave is entire water mass
  - Velocity depends on period of wave
    - 17 mph for 5-second wave; 70 mph for 20-second wave
- **Tsunami**
  - Huge mass of water with tremendous momentum

(a)

(d)

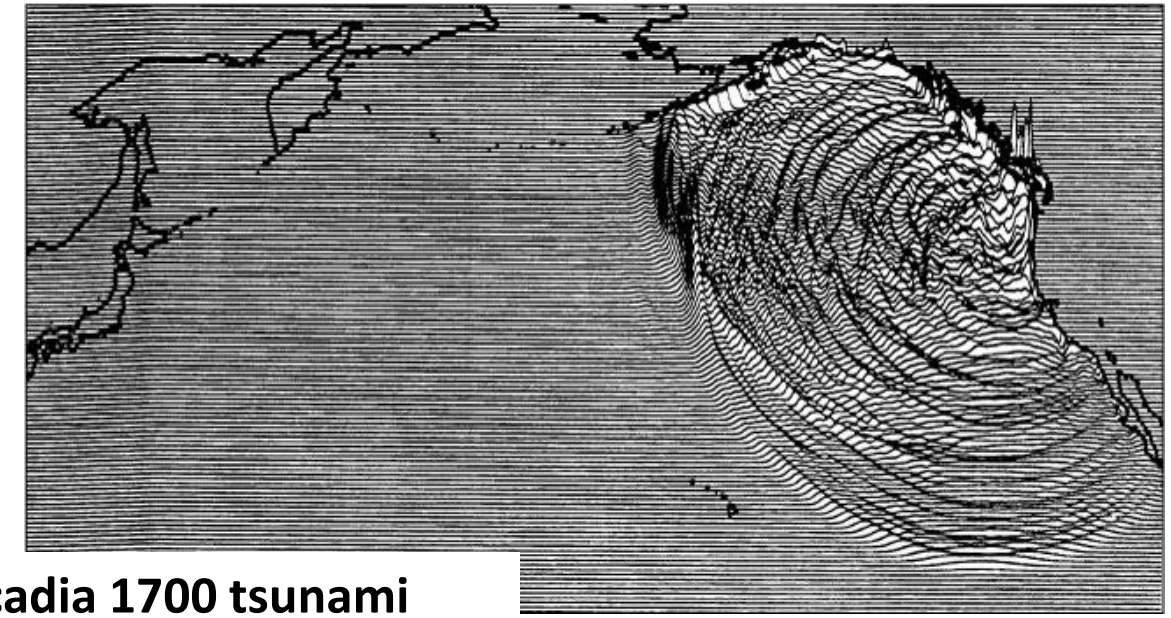
Velocity

- Increase in velocity with an increase in depth
  - Velocity: **v = (g x D) ½**
    - g – acceleration due to gravity; D – depth of water
    - For average D = 5,500 m, v = 232 m/sec (518 mph)
    - Actual observations of tsunami speed peak at 420 to 480 mph
    - Wave will slow as approaches shore, but still fast



Tsunami: velocity

- Related to depth of ocean water
- Pacific Ocean: average depth 18,000 feet
- Velocities in the open ocean: >500 mph



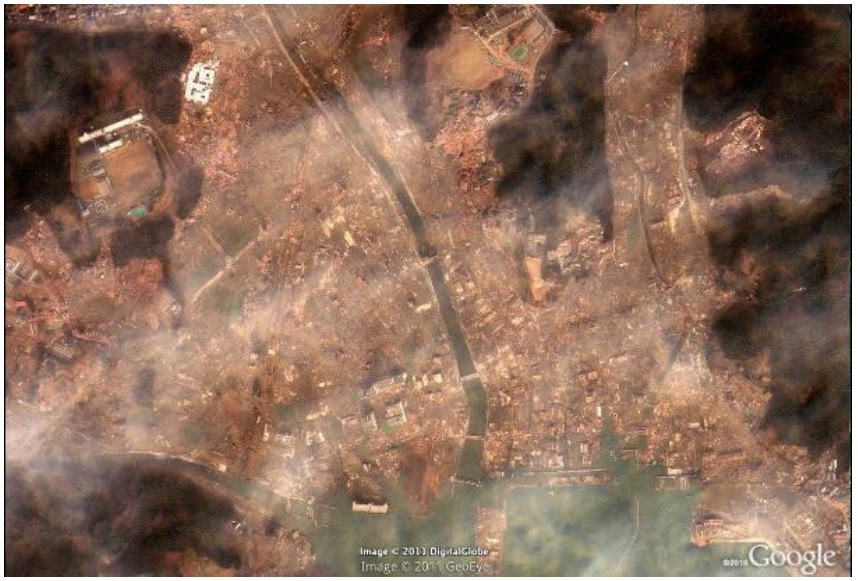
Model of Cascadia 1700 tsunami

Tsunami, Japan, 2011

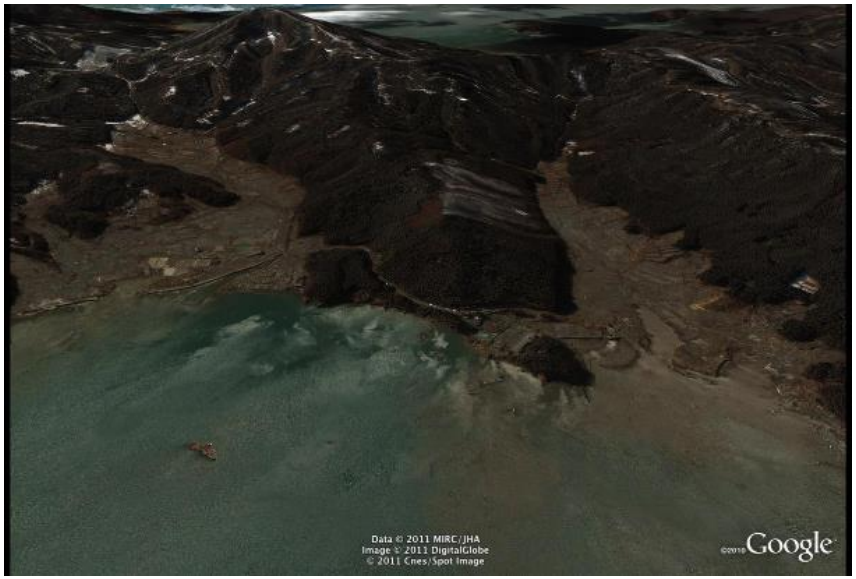
- 90 feet high
- Up to 2.5 miles of inundation
- 8-10 minute warning

Village of Minamisanriku, where up to 10,000 people—60 percent of its population—are now missing, according to the *Telegraph*.

44 miles south of Sendai



Town of Yagawahama



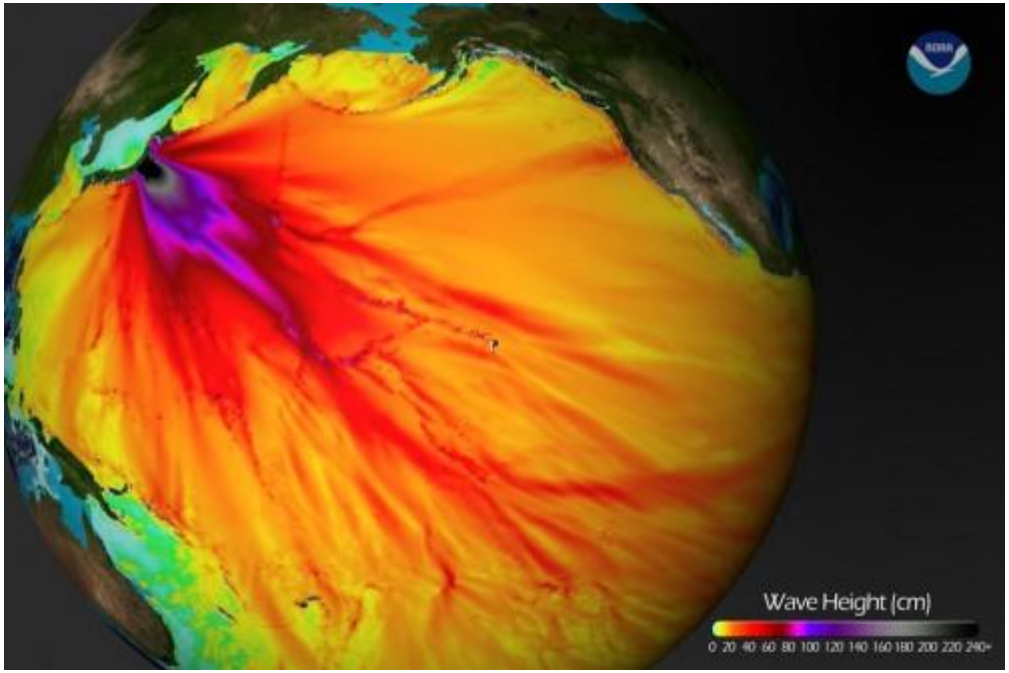
Sendai Airport

Japan, 2011 tsunami

- Billions of dollars spent
- 40% of Japan's coastline contains up to 39' high walls
- Tsunami destroyed
- 6 feet- wood structures
- 12 feet- concrete destroyed
- 70 feet-everything

Gates close seconds after earthquake

Projection of Japan tsunami moving across the Pacific Ocean



Santa Cruz and Emeryville

Crescent City, California

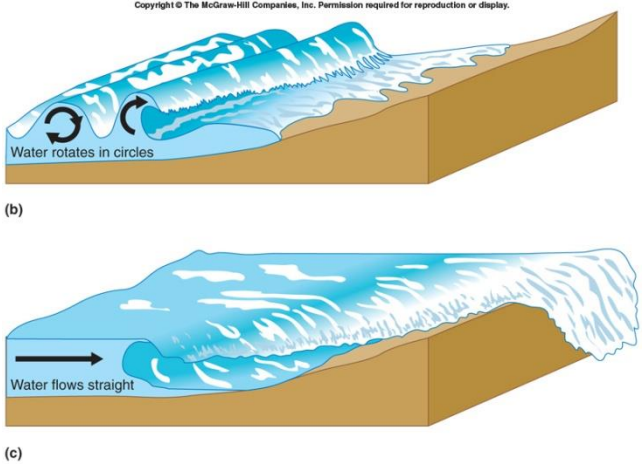
Shoreline arrival of tsunami

- **Tsunami** reach greater height when they enter harbor or other narrow space
  - **8 m** wave on open coastline → **30 m** wave in narrow harbor

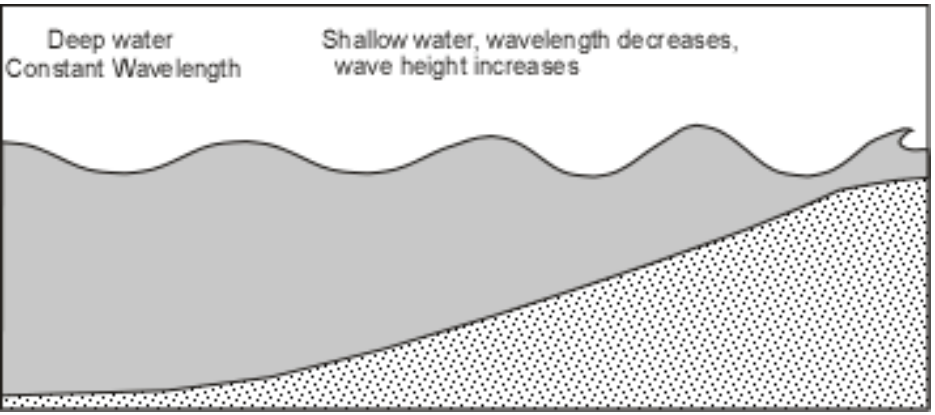
Narrow bay, deeper closer to shore

Same depth, farther from shore, open shoreline

Tsunami



- As the waves reach shore, **speed is reduced**
- Height is increased



Tsunami and You

- If You Feel the Earthquake
  - Mild shaking for more than 25 seconds: powerful, distant earthquake may have generated tsunami
  - Sea may withdraw significantly, or may rise, before first big wave
  - Water may change character, make unusual sounds

Tsunami and You

- **Tsunami Warnings**
  - Coastal Maps
    - Tsunami-hazard map of Hawaii Big Island, based on local topography
    - Coastline mapping of Indonesia, India and Sri Lanka after 2004 tsunami indicated where **human activities** increased damage and loss of life
      - Removal of vegetation, reefs increased impact of waves
  - Buoys and Pressure Sensors
    - Before 2004, NOAO operated six-buoy warning system in northern Pacific Ocean
    - Funding since provided for 32 buoys around world, transmitting information to scientists
    - New tide-gauge stations and seismometers along coastlines

Tsunami and You

TABLE 5.4

Surviving a Tsunami

Abandon your belongings.
Many lives are lost while trying to save possessions.
Head for high ground—and stay there.
If there is no high ground nearby, then
Climb to an upper floor or roof of a strong building.
If there is no sturdy building, then
Climb a tree.
If there are no climbable trees, then
Grab onto something that floats.
Look for something to use as a raft.

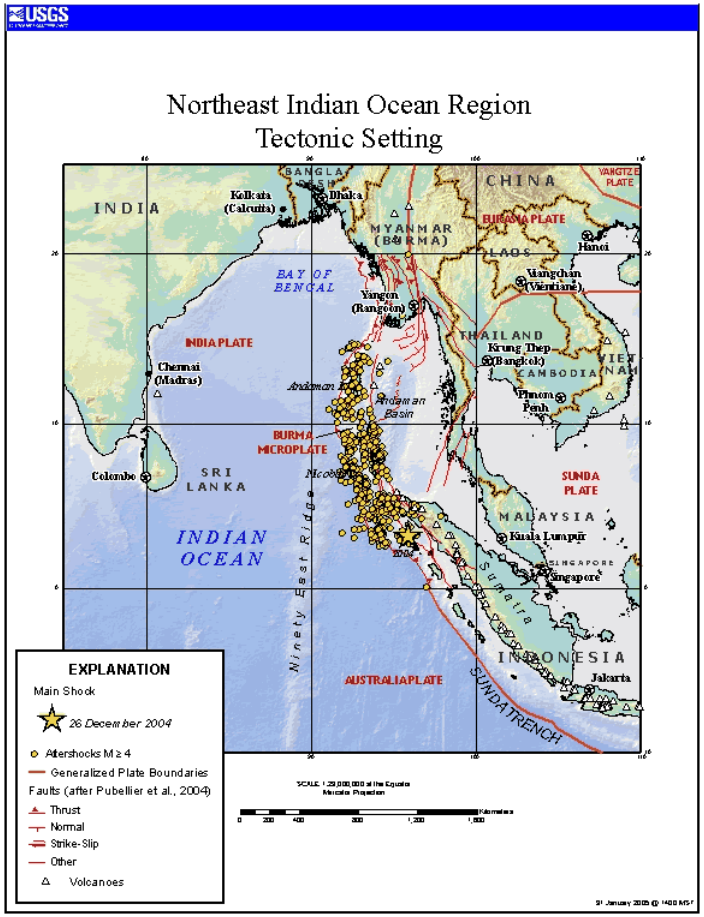
Tsunami and You

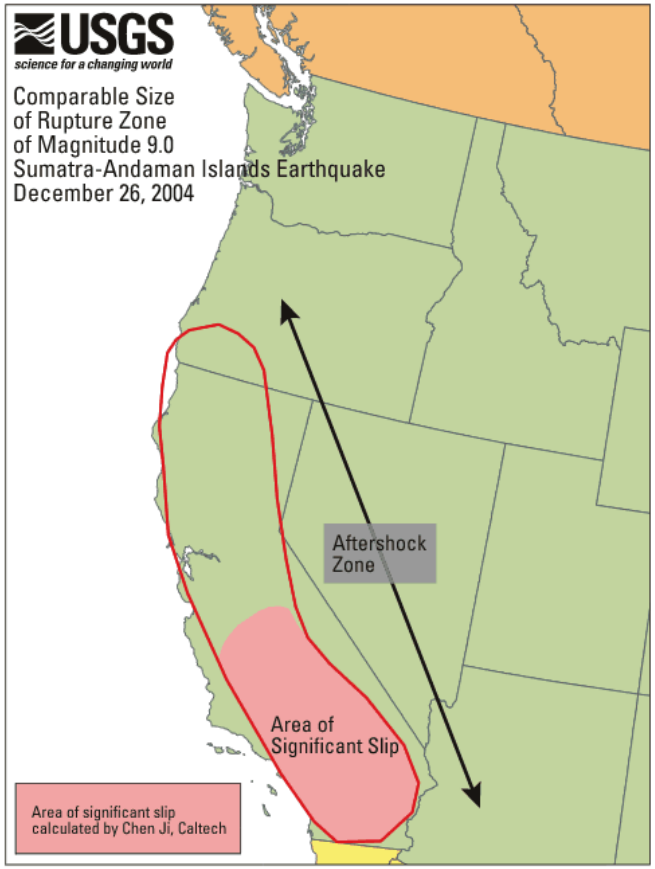
- **Simuele Island, Indonesia, 26 December 2004**
  - Closest inhabited land to epicenter of magnitude 9.2 earthquake
  - After shaking stopped, residents fled uphill immediately
  - **Only 7 out of 75,000 inhabitants were killed**
  - Oral history reminded people: when ground shakes, run to hills before giant waves arrive

Applied information from school project

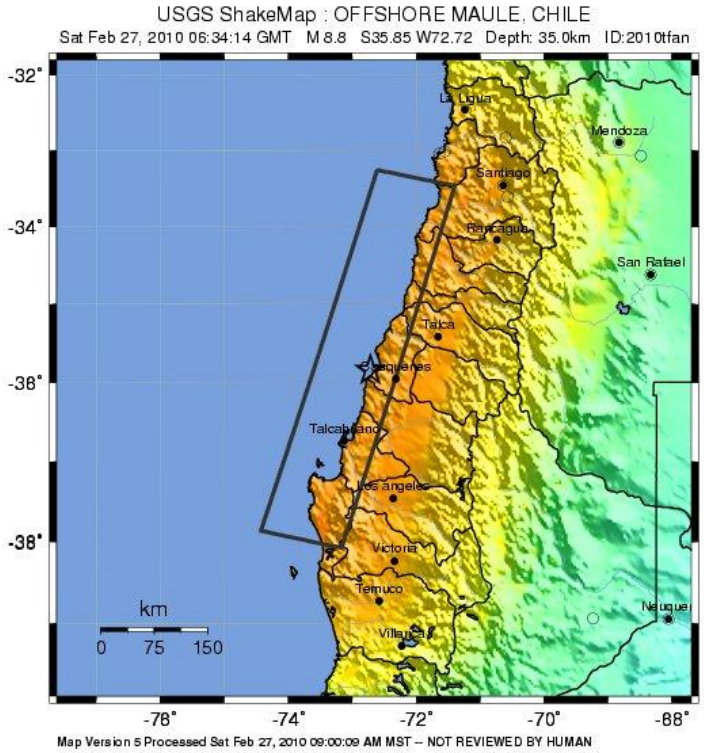
- Noticed bubbles and water retreated from the shoreline
- Notified parents and other hotel residents
- All moved to higher ground
- Phuket, Thailand

2004 Indonesia earthquake and tsunami

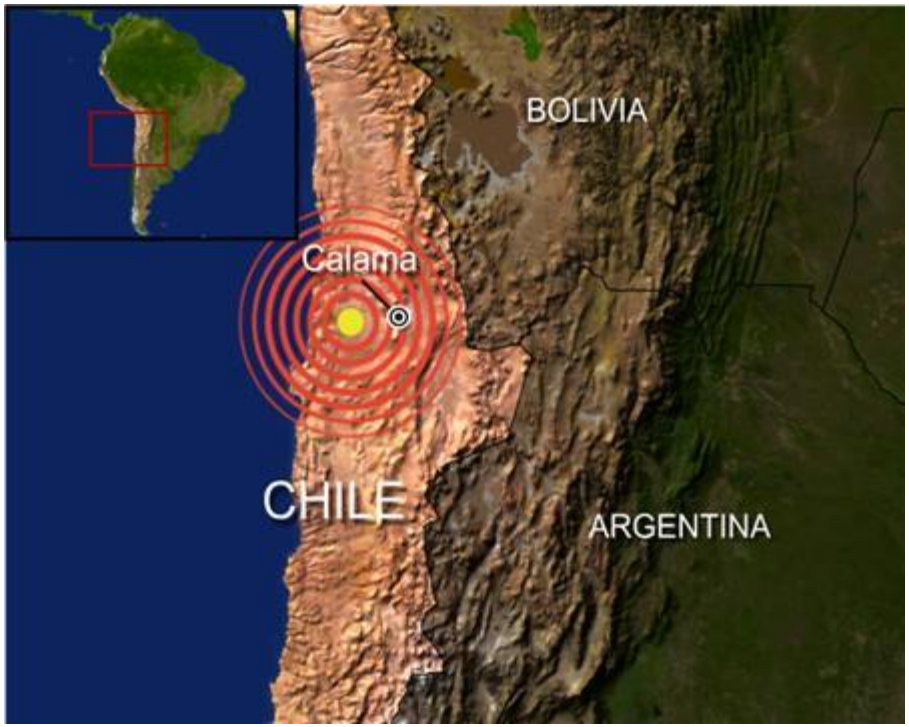




Chile earthquake, February 27, 2010

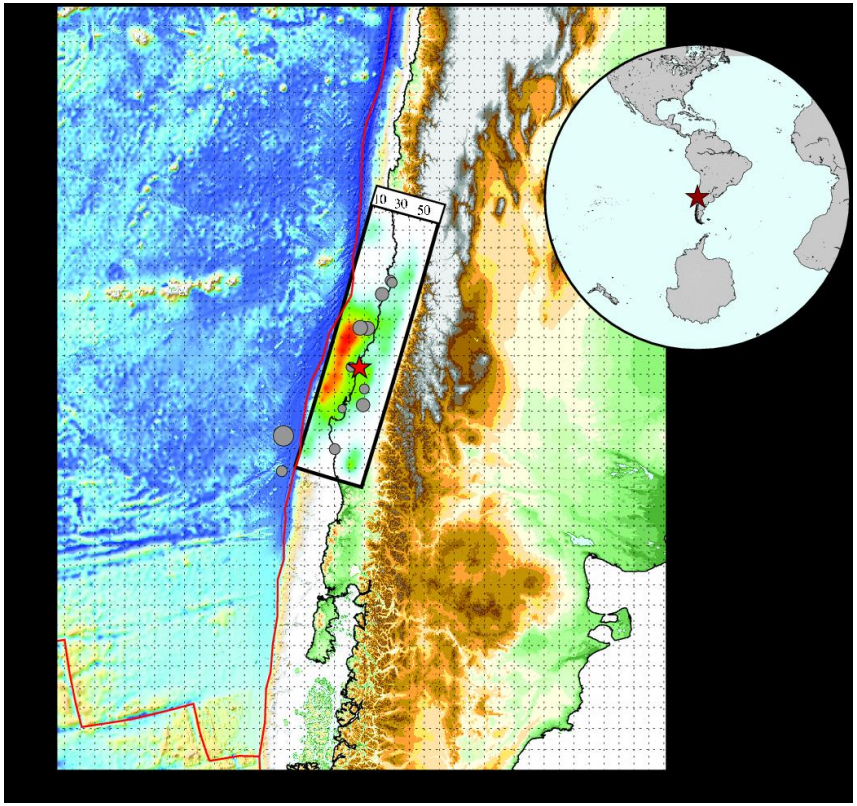


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	*8.1-16*	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

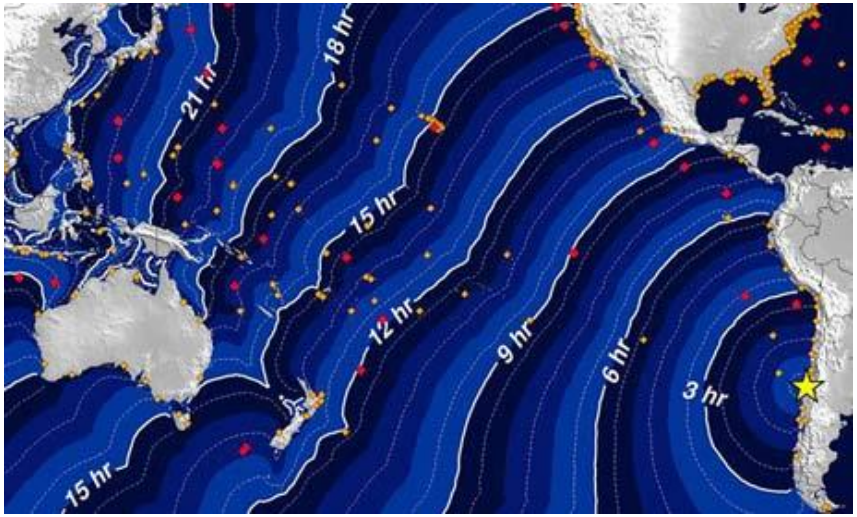


Chile earthquake and tsunami

Magnitude 8.8; hypocenter 21 miles

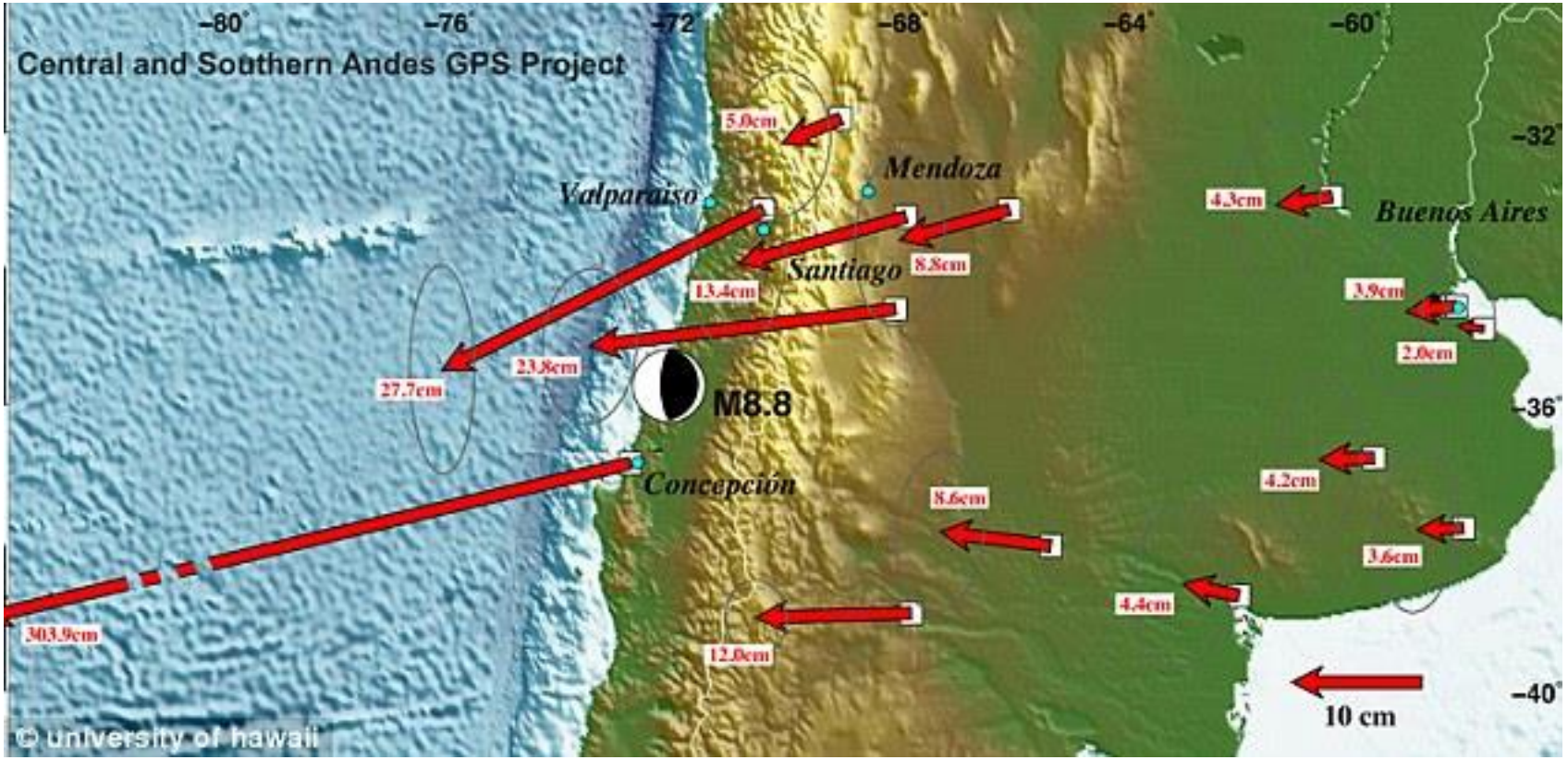


Tsunami

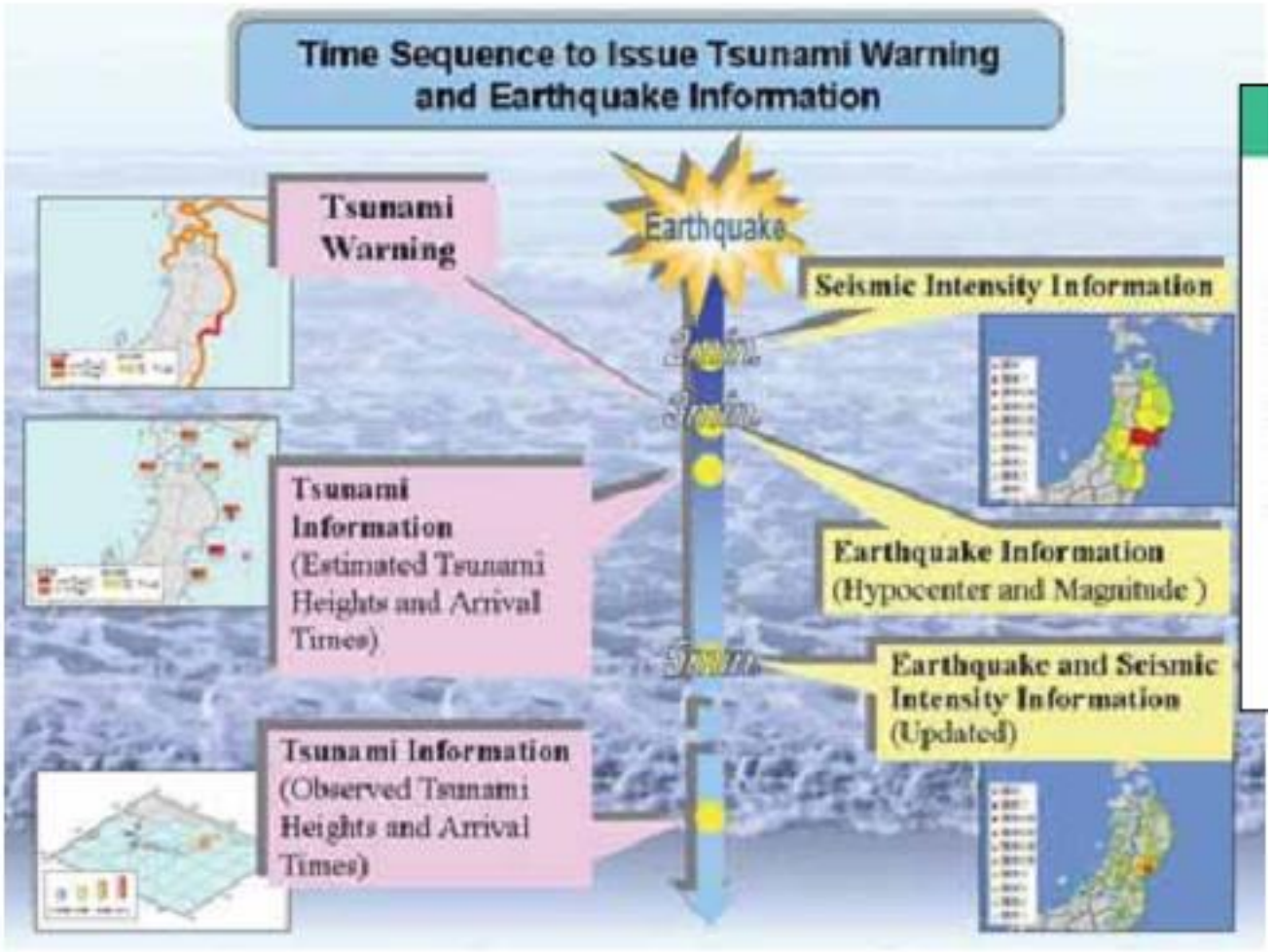


February 27, 2010

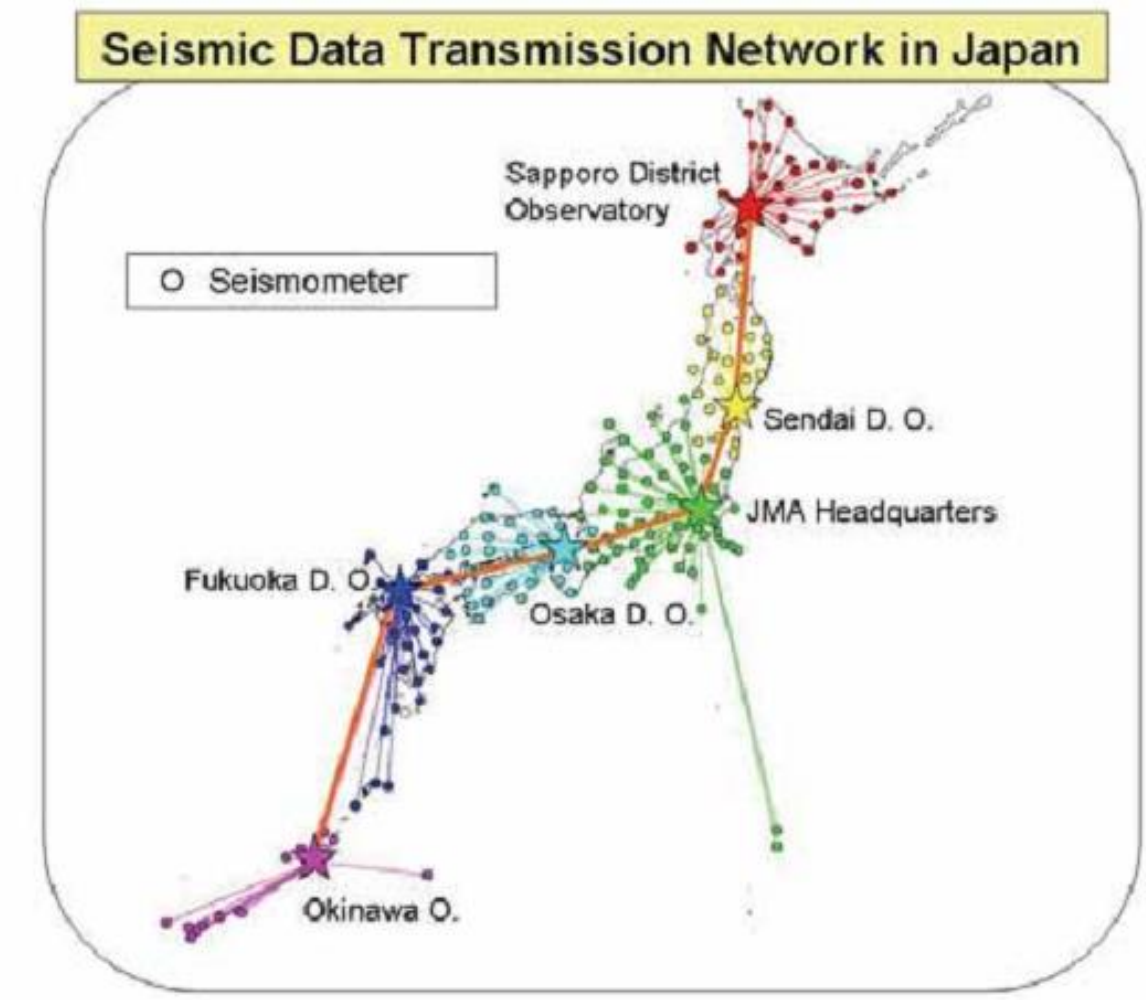
Concepcion: moved 10 feet to the west



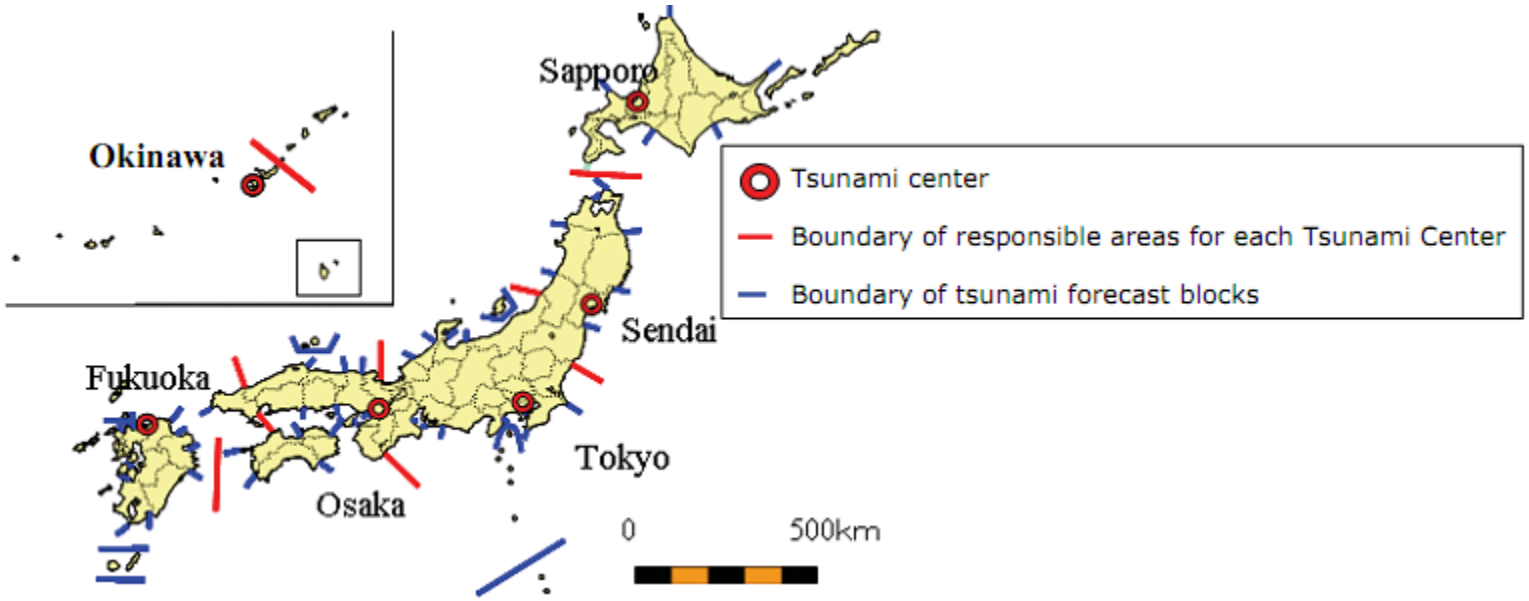
Japan's tsunami warning system



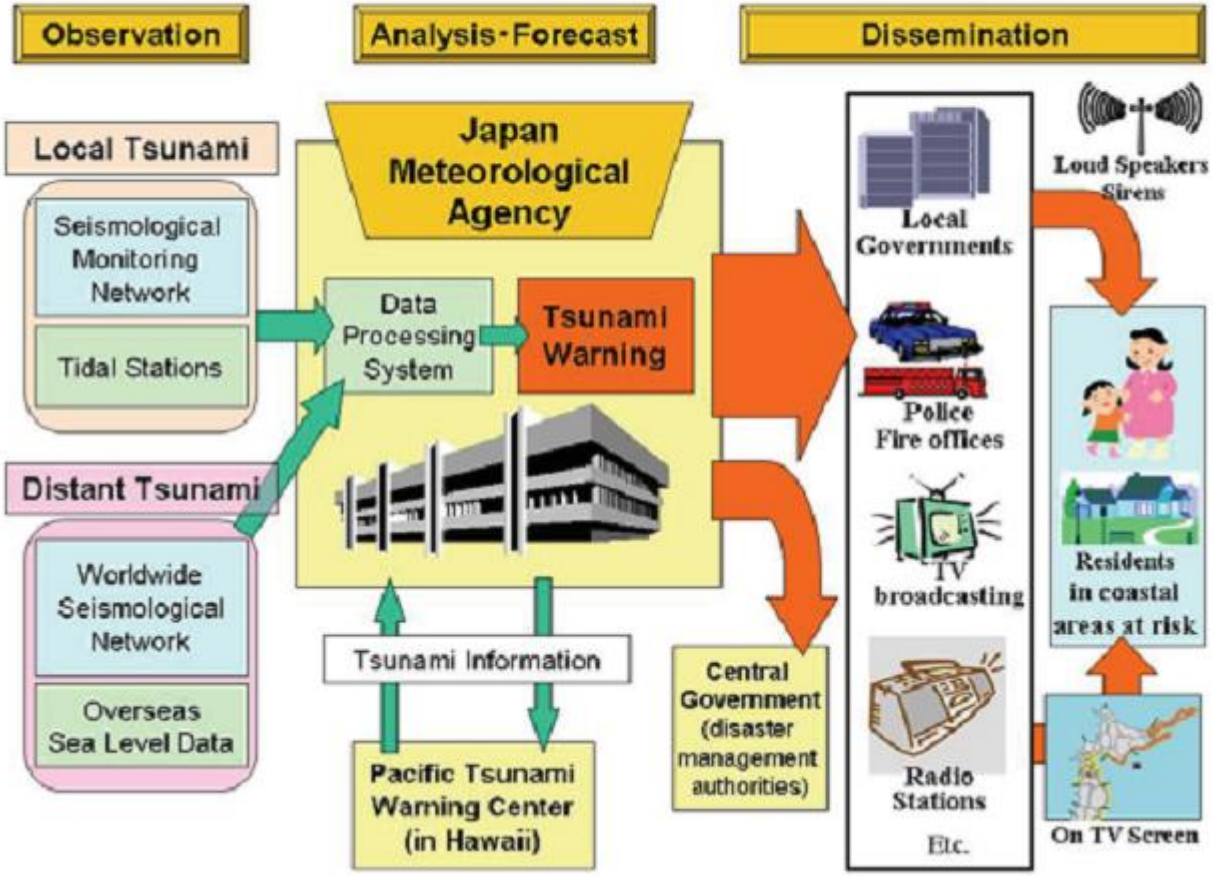
Seismic recording stations



Tsunami warning system



Transmission of Tsunami Warning



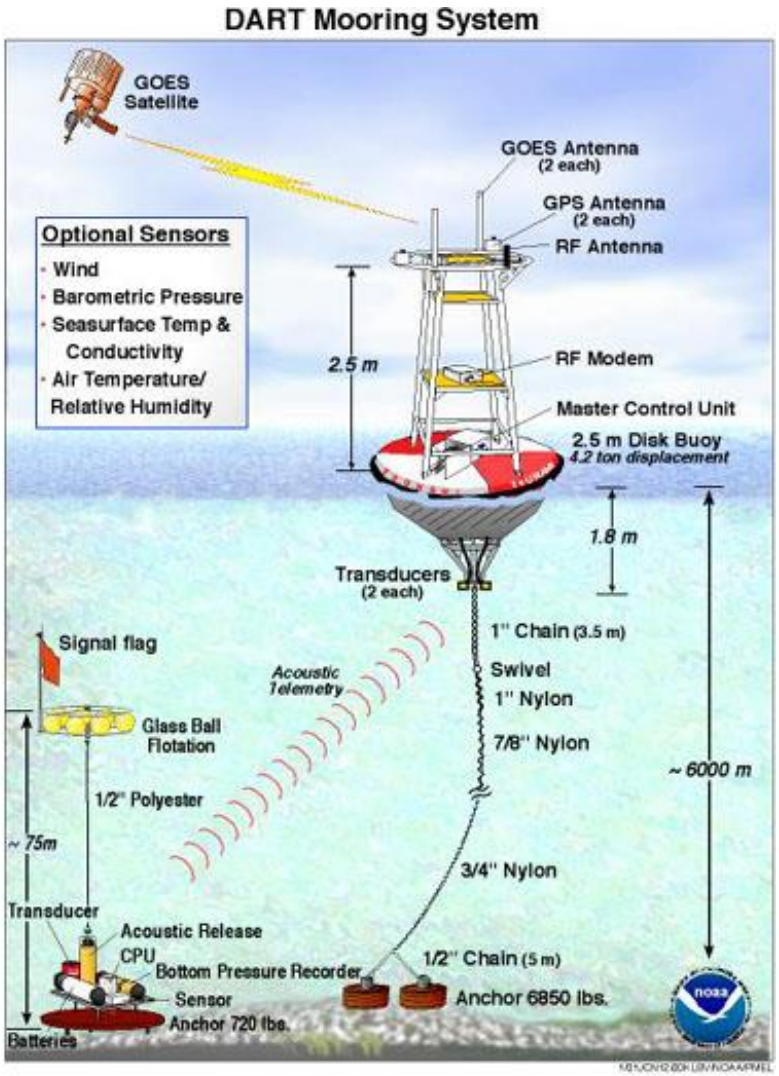
Pacific Tsunami Warning Center: 1967

- Alaska: west coast of North America
- Hawaii: the remainder portion of the Ring of Fire
- NOAA: National Oceanographic and Atmospheric Administration
- Pacific Marine Environmental Laboratory

Deep-Ocean Assessment and Reporting of Tsunami: DART

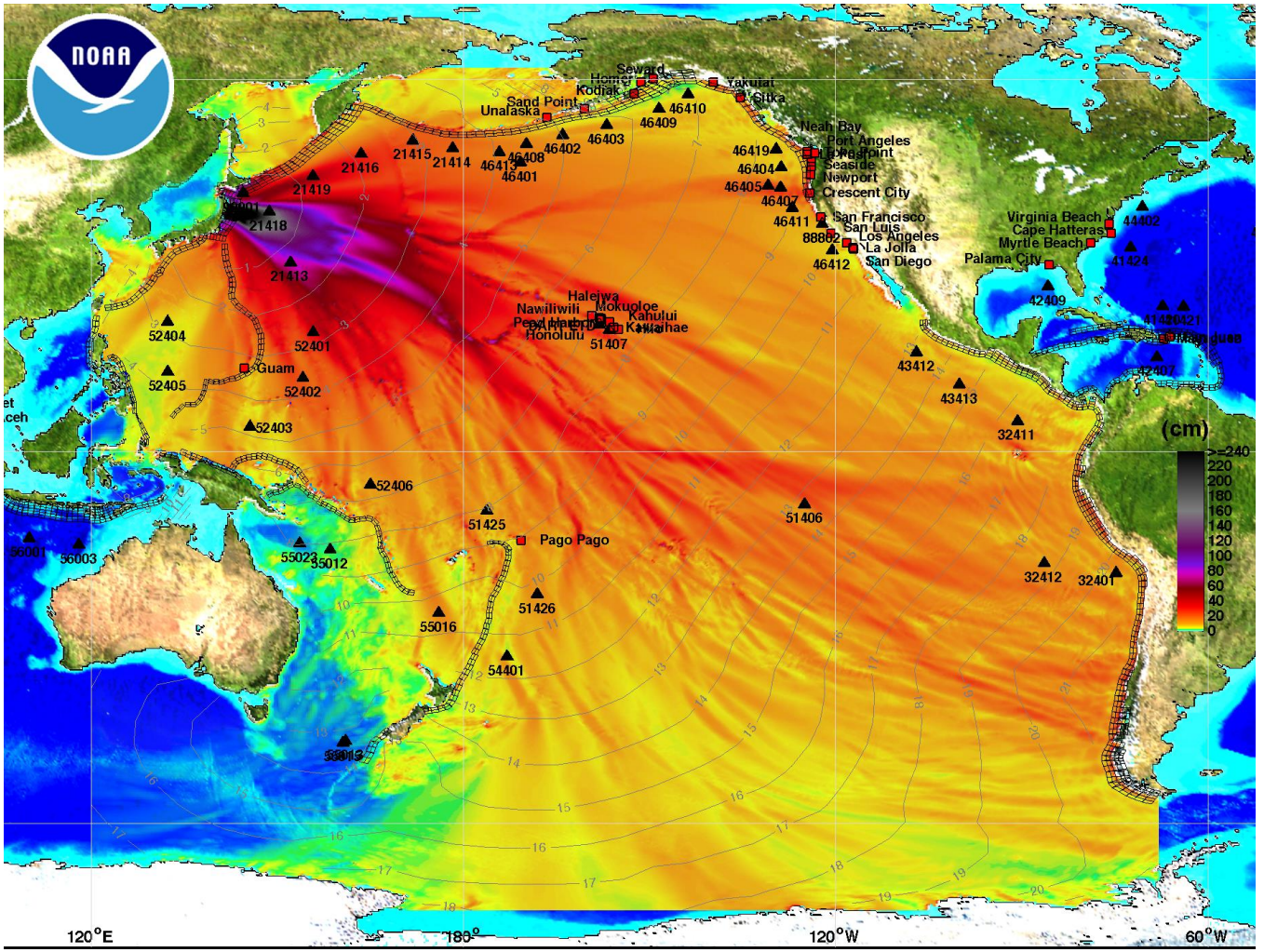
- Goal is to reduce the loss of life and property
- Eliminate false alarms
- Stations are positioned in regions that traditionally produce tsunamis

Deep-Ocean Assessment and Reporting of Tsunami: DART

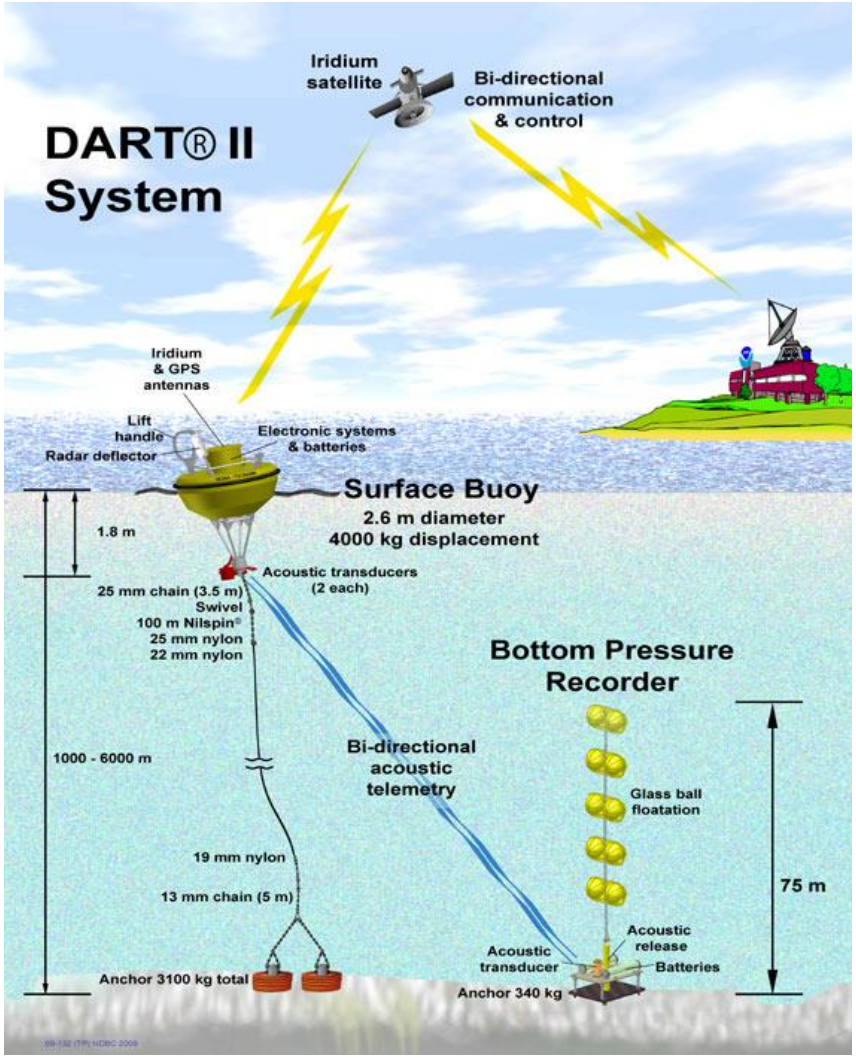


- Seafloor pressure recording system
- An acoustic link is used to transmit data from the pressure recording system
- The data is relayed via satellite

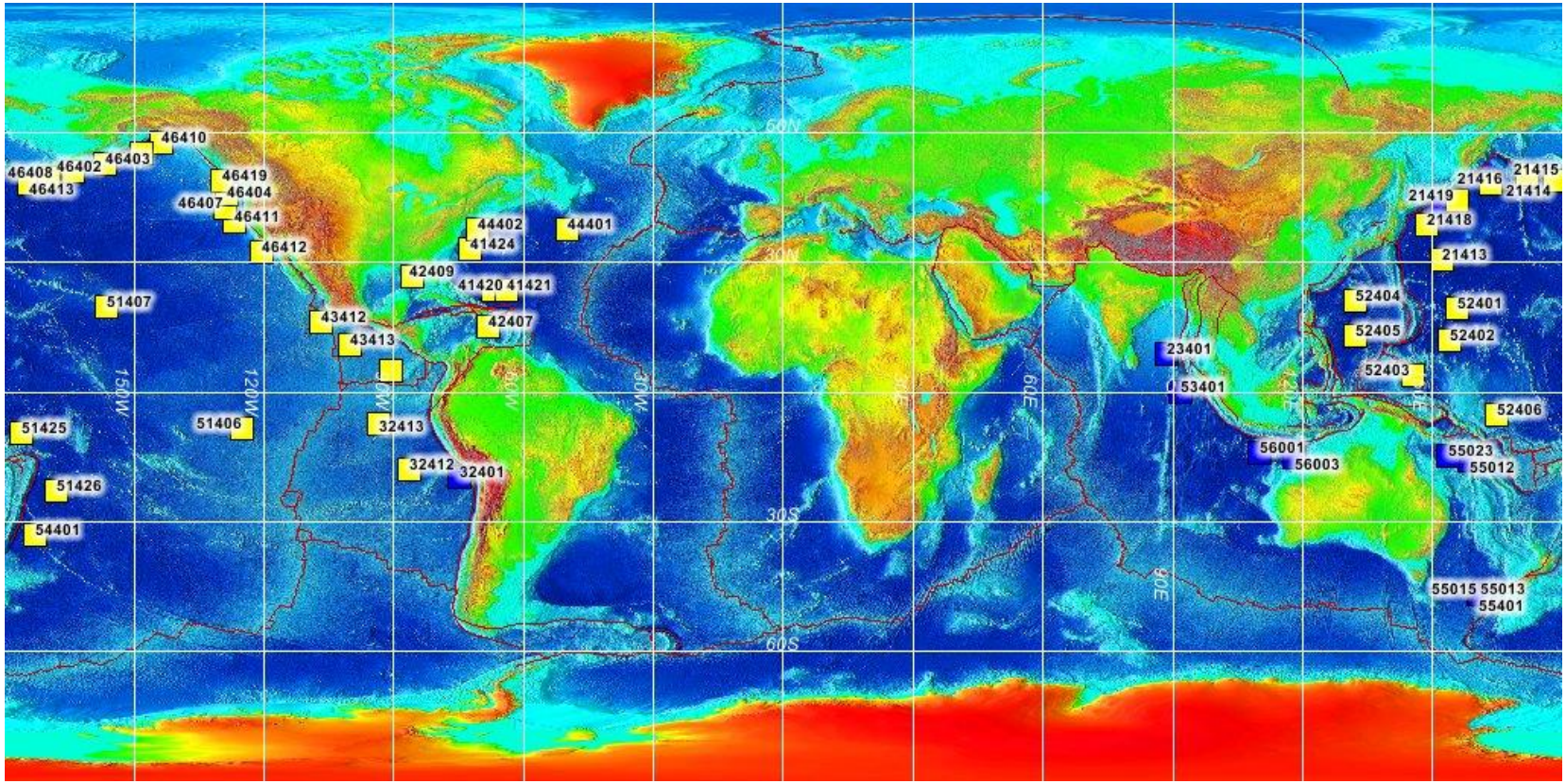
DART Locations



DART II


Iridium satellite
Bi-directional communication & control
DART® II System
Iridium & GPS antennas
Lift handle
Radar deflector
Electronic systems & batteries
Surface Buoy
2.6 m diameter
4000 kg displacement
1.8 m
Acoustic transducers (2 each)
25 mm chain (3.5 m)
Swivel
100 m Nilspin®
25 mm nylon
22 mm nylon
Bottom Pressure Recorder
1000 - 6000 m
Bi-directional acoustic telemetry
Glass ball floatation
75 m
19 mm nylon
13 mm chain (5 m)
Acoustic release
Acoustic transducer
Batteries
Anchor 3100 kg total
Anchor 340 kg

Deep-Ocean Assessment and Reporting of Tsunami: DART



DART locations: Indian Ocean