

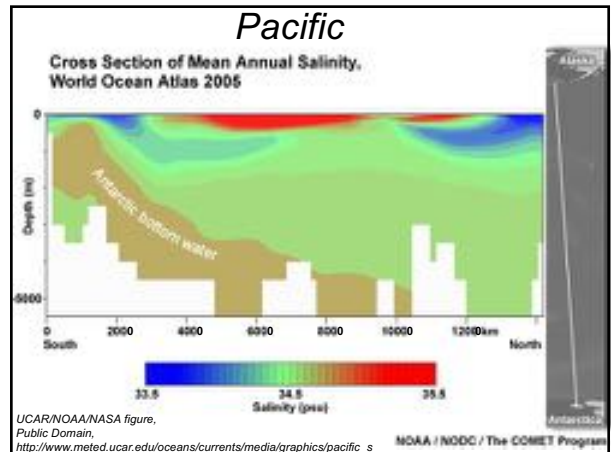
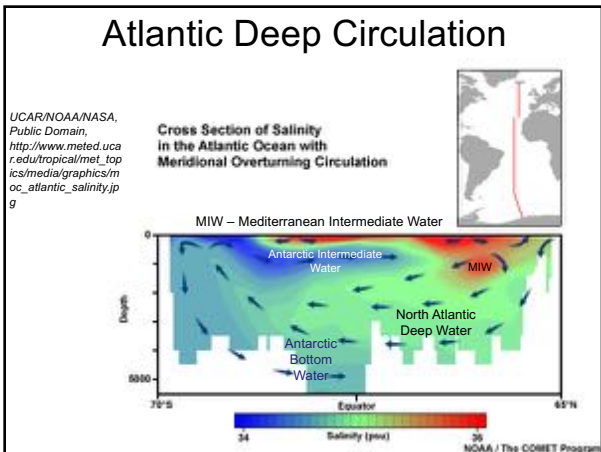
Water Mass Classifications

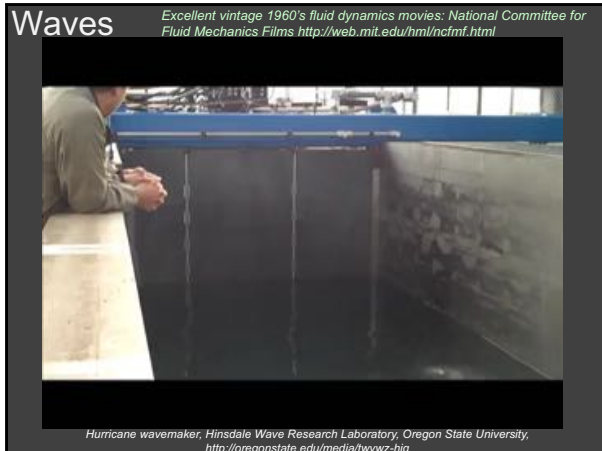
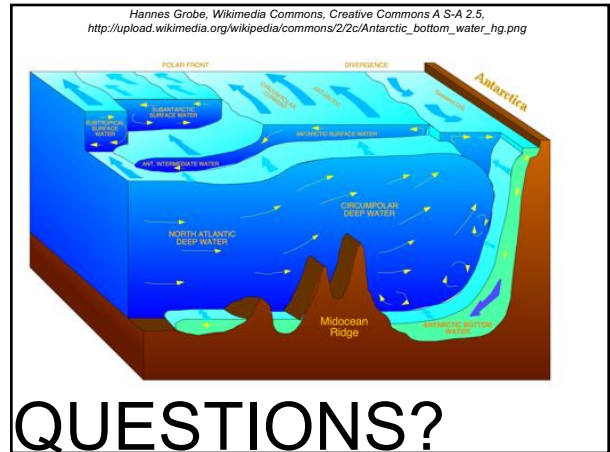
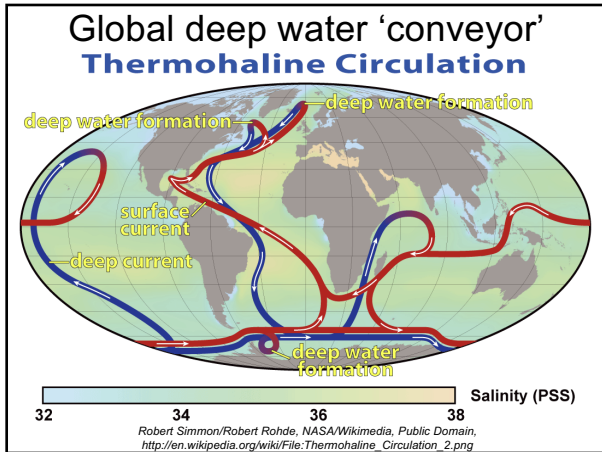
- Deep Waters:
 - North Atlantic Deep Water (NADW)
 - Vertical mixing & incorporation of salty N. Atlantic waters near Greenland
- Bottom Waters:
 - Antarctic Bottom Water (AABW)
 - Forms dominantly in Weddell Sea in regions of active sea ice formation (polynyas)
 - Cold, saline sinking water
 - Densest water mass in the oceans

Deep Water Formation

Deep currents – sinking of dense water near the poles

Figure from Matthew England, Climate Change Research Centre (CCRC) University of New South Wales, <http://web.maths.unsw.edu.au/matthew@unsw.com.au/~meh11@unsw.edu.au>



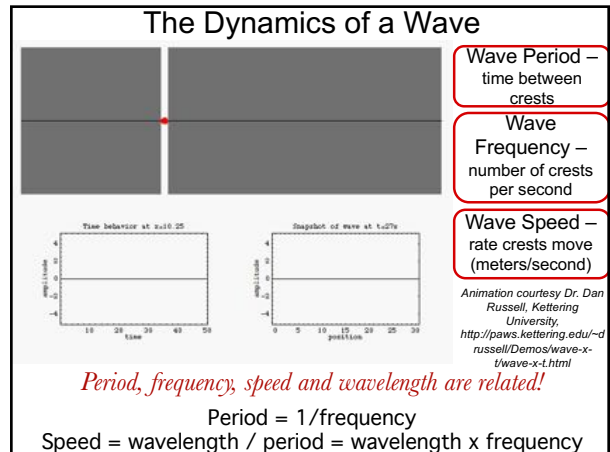
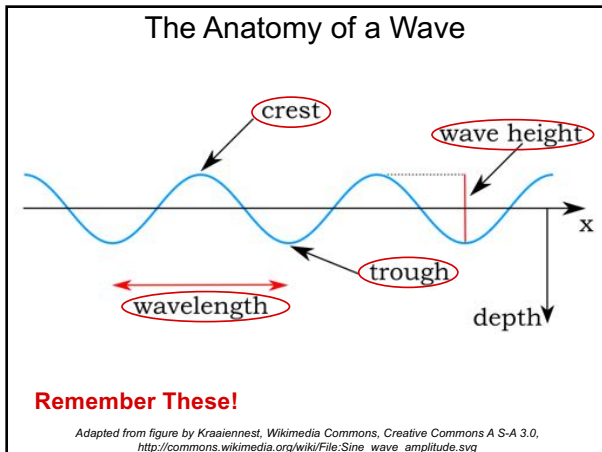


Waves

- Traveling disturbances of the water column
- Waves move **but** there is little or no net transport of the water
 - If you put dye in the water, a wave can pass through and the dye will basically remain in place
- Most familiar are wind waves - produced on the ocean surface by effects of time-varying winds

Animation courtesy Dr. Dan Russell, Kettering University, <http://paws.kettering.edu/~drussell/Demos/waves/wavemotion.html>

©1999, Daniel A. Russell



Oscillation: Water depth matters

Waves behave differently in "deep" water than they do in "shallow" water

Deep Water Waves:
depth > 1/2 length:
ocean bottom does not affect wave

Shallow Water Waves:
depth < 1/20 length:
ocean bottom strongly affects wave

Animations by Kraaiennest, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Deep_water_wave.gif and http://commons.wikimedia.org/wiki/File:Shallow_water_wave.gif

Deep vs. Shallow Water Waves

- Wave Speed: $Speed = WaveLength/period$
- Deep Water Waves (depth > L/2):**

$S \approx 1.25\sqrt{L}$

Only works when L is in meters.
- Wave Dispersion: at large distances, storm waves get sorted by wavelength
 - longest wavelength waves lead the pack

Deep vs. Shallow Water Waves

- Wave Speed: $S = wavelength/period$
- Shallow Water Waves (depth < L/20):**

$S = \sqrt{gd} \approx 3.1\sqrt{d}$

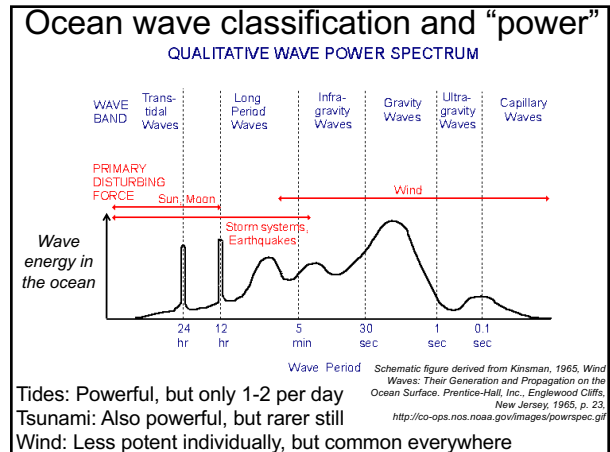
– Speed (S) increases with water depth (d)



Ocean Waves

- Wind waves:** Driven by wind
- Seiches: Basin-scale oscillation, driven by large-scale pressure changes
- Tsunamis:** Seismic sea waves, driven by earthquakes, volcanic eruptions or underwater landslides
- Tides:** Planetary-scale waves driven by gravitational pull of sun & moon

Tidal Bore, Arnold Price, Creative Commons A S-A 2.0, <http://www.geograph.org.uk/photo/324581>



Deep vs. Shallow Water Waves

WAVE TYPE	Deep vs. Shallow
Wind Wave	Deep
Tsunami	Shallow
Tides	Shallow

QUESTIONS

Wind ripples, Lifjord, Norway, Karl Laurits Olsen, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Ripples_Lifjord.jpg

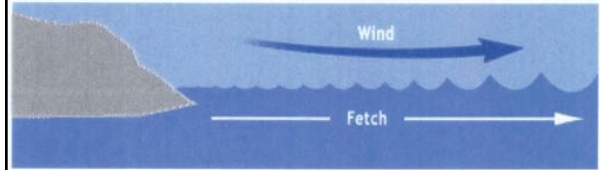
Wind-Driven Ocean Waves



Initial wave excitation by slowly (2 m/s) blowing wind. Waves Research Laboratory, Tel-Aviv University, Israel. <http://www.eng.tau.ac.il/research/laboratories/waves/index.htm>

Wind-Driven Ocean Waves

Wind wave size increases with speed, distance, and duration of wind...



Tammy Pelletier, WSU Dept of Ecology, http://www.vos.noaa.gov/MWL/apr_06/waves.shtml

Wind-Driven Ocean Waves

- Maximum wave size/speed depends on:
 - **Fetch:** distance over which the wind blows to generate waves
 - **Duration:** Length of time the wind blows across the fetch
 - **Wind Speed:** Difference between wave speed & wind speed
 - **Long fetch, long duration, high wind speed = BIG waves**

Fully-Developed Seas: seas reach maximum size for given fetch & wind (long duration)

Wind sea, N. Pacific, Winter 1989, M/V NOBLE STAR/NOAA, Public Domain

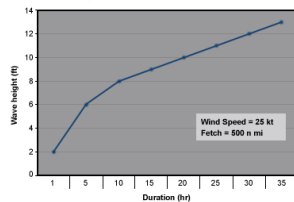


Figure from Comet Program/UCAR, approved for educational use.
http://www.meted.ucar.edu/marine/mod2_wlc_agen/print.htm

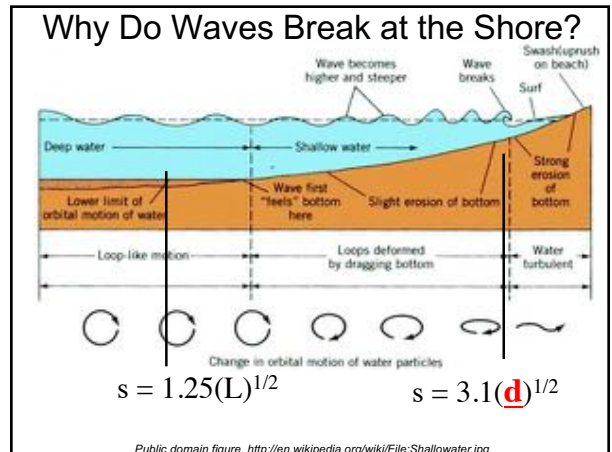
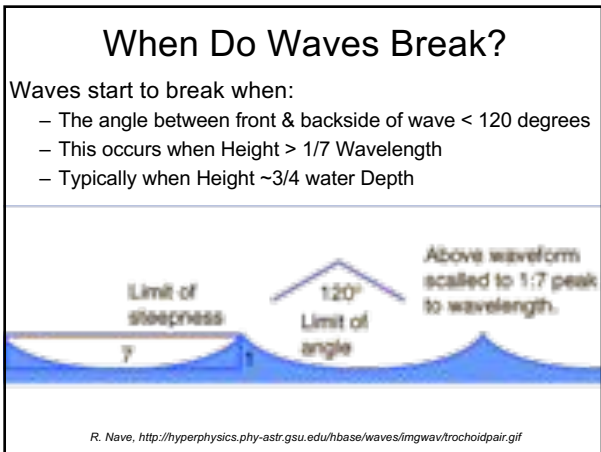
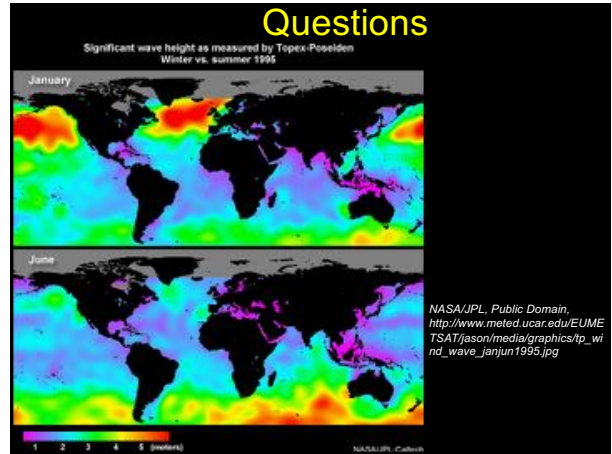
Wind-Seas and Swells:

Wind Sea: wind & storm create and grow new waves

Wind sea, N. Pacific, Winter 1989, M/V NOBLE STAR/NOAA, Public Domain

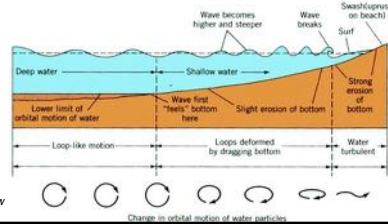
Choppy waves with whitecaps





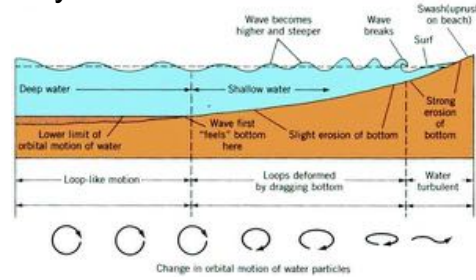
Why Do Waves Break at the Shore?

- What happens to waves at the coastline to make them break?
 - They interact with the ocean bottom
 - Crests travel faster than troughs ($S = [gd]^{1/2}$)
 - As the crest catches up with the trough ahead of it, the wave "breaks"
 - i.e., crest overtakes the leading trough, the wave steepens and then breaks



Public domain figure, http://en.wikipedia.org/wiki/File:Shallow_water.jpg

Why Do Waves Break at the Shore?



Public domain figure, http://en.wikipedia.org/wiki/File:Shallow_water.jpg

- Deep water to shallow water transition: **Wave Shoaling**
- Analogy: Try sprinting from asphalt into mud
 - You will tend to fall over!

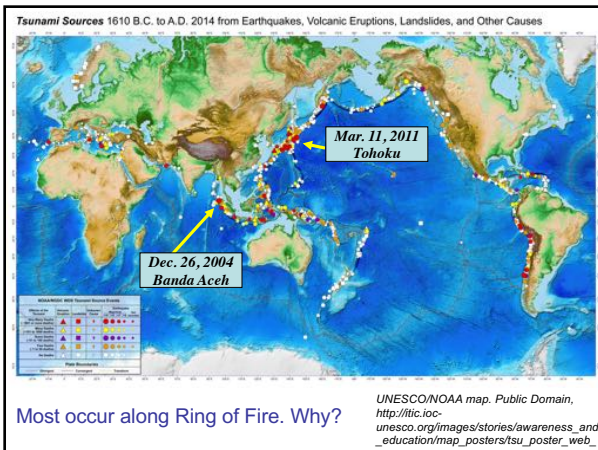


Plunging breaker, Boat wake, Malene Thyssen, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Boelge_stor.jpg

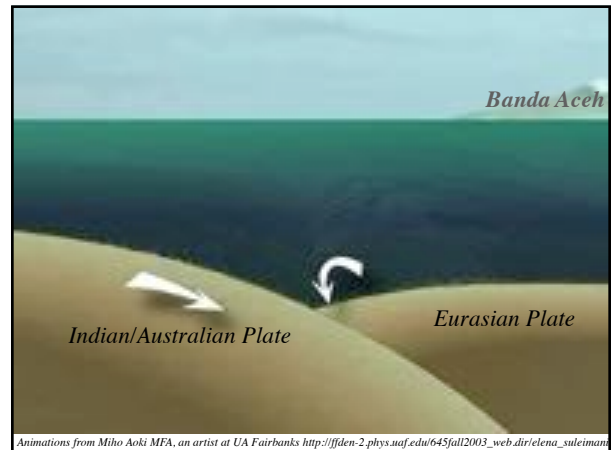
Tsunami

津波 *tsu* -- port, harbor
波 *nami* -- wave

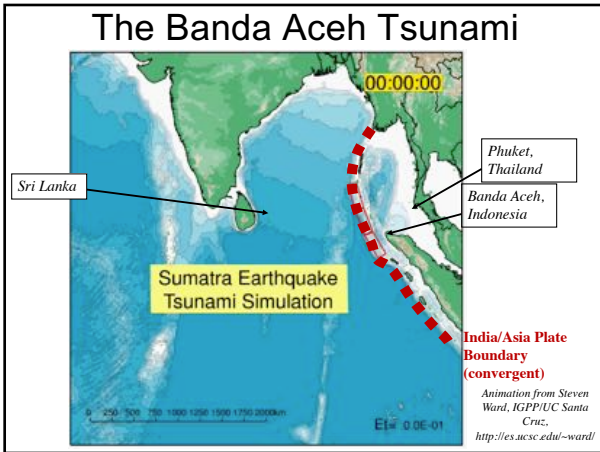
- From Japanese: <http://www.rfic.org/kanji-names.htm>
- English synonym: Tidal wave, even though they are *NOT* caused by tides -- *confusion resulting from long period?*
- **Origin:** Seismic sea waves, driven by earthquakes, volcanic eruptions or underwater landslides



Most occur along Ring of Fire. Why?



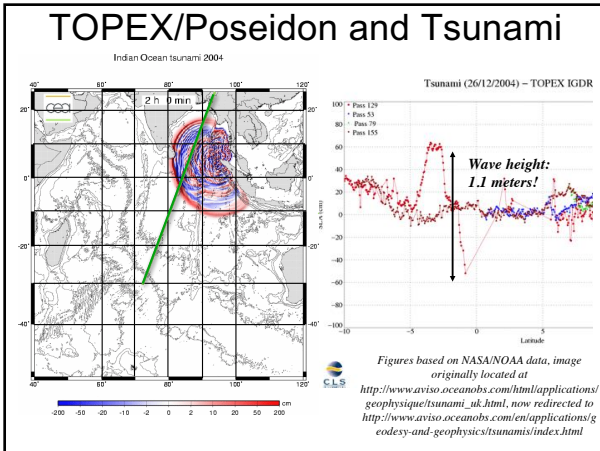
Animations from Miho Aoki MFA, an artist at UA Fairbanks http://jfdn-2.phys.uaf.edu/645fall2003_web_dir/elena_suleimani



Detecting tsunami in the open ocean:

- Created by a large earthquake and traveling 100's of km/hr, tsunami have such long wavelengths and periods that they would normally be too small & gradual to notice in the open ocean.
- By chance, the TOPEX/Poseidon and Jason-1 satellites passed over the Indian Ocean just after the earthquake.
- They were able to detect and measure the tsunami on its way across the Indian Ocean.

NASA image. Public Domain. <http://topep-www.jpl.nasa.gov/newsroom/features/images/jason-1-topep-calib.jpg>



How does a tsunami cause harm?

- In the open ocean the tsunami was only 1 meter high. This is about waist deep. The wave period is minutes: *up-and-down motion was too slow to feel at sea.*
- Tsunami are rarely destructive at sea, "The Poseidon Adventure" notwithstanding.
- Danger comes from run-up and breaking of tsunami at shoreline.

Illustration by Veit Mueller, Wikimedia Commons, Creative Commons A S-A 3.0. <http://en.wikipedia.org/wiki/File:Tsunami-kueste.01.vm.jpg>

Tsunami waves come to shore


Illustration by Veit Mueller, Wikimedia Commons, Creative Commons A S-A 3.0. <http://en.wikipedia.org/wiki/File:Tsunami-kueste.01.vm.jpg>

Wind waves, with wavelengths up to ~100 meters, extend to ~50 m depth, have periods of seconds.
Tsunami have wavelengths > 100 km, always extend to seafloor.
 In shallow water energy becomes concentrated between bottom and surface. Wave height increases up to 10x.
 Decreasing wave speed leads to decreasing wavelength, further concentrating energy.
 Long period of waves (~10 minutes) means crest can push inland for a great distance before receding.



Tsunami waves come to shore

- Far from seismic origin, first indication is often drawing out of water.




Kalutara Beach, Sri Lanka

Images Quickbird/DigitalGlobe, <http://homepage.mac.com/demark/tsunami/>

Tsunami waves come to shore

Several wave-sets may follow, compounding damage.

Gleebruk, Sumatra, Indonesia




DigitalGlobe/QuickBird images, <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=14418>

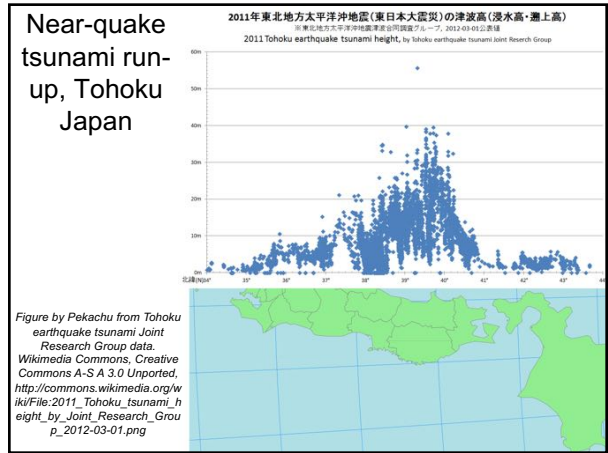
Tsunami waves come to shore

Several wave-sets may follow, compounding damage.

Northwest Sumatra, Indonesia




DigitalGlobe/QuickBird images, <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=14402>



Is California at Risk?

- YES! We live on the ring of fire (Pacific Plate Boundary).
- Local risks from offshore faults and landslides near Catalina and the Channel Islands
- Very large prehistoric landslides off Hawaiian islands, other volcanic islands probably generated mega-tsunami.



USC Tsunami Research Center, http://cwis.usc.edu/dept/tsunamis/2005/video/vid_eo_socal.html

Minimizing Tsunami Damage

- Tsunami will occur, and triggering events are generally not predictable.
- DYNAMIC DEFENSE
 - Seismic networks can warn of tsunami-generating earthquakes and landslides
 - Seismic waves travel ~5 km/sec, = 18,000 km/hr.
 - Tsunami travel slower, ≈ 1000 km/hr
 - Most damage from Indonesian tsunami came more than 1 hour after the earthquake.
 - Buoys can also detect tsunami at sea

Warning networks and evacuation plans vital!

Preventing Tsunami Damage

- Triggering events are generally not predictable, but damage patterns are.
- **STATIC DEFENSE**
 - Training vulnerable populations to heed warnings
 - Earthquake shaking
 - Anomalous, sudden “low tides”
 - Preserving natural buffers
 - Reefs, barrier islands, mangrove swamps & estuaries dilute impact of waves.