Introduction to Oceanography

Lecture 13: Waves

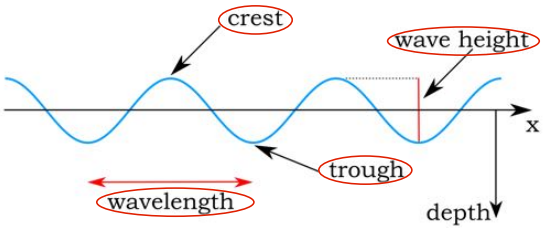
Porto Covo, Portugal, photo by Joaquim Alves Gaspar, Creative Commons A S-A 2.5, http://en.wikipedia.org/wiki/File:PortoCovoJan07-4.jpg

Midterm 2: May 23 (Tuesday)

Review Session Friday, May 19 in Moore 100, 3:00p-4:30p
Video Screening Tuesday, May 23 in Moore 100, 4:00p-5:00p

Breaking wave and sea foam, Vero Beach, FL, Robert Lawton, Creative Commons A S-A 2.5, http://commons.wikimedia.org/wiki/File:Sea_foam.JPG

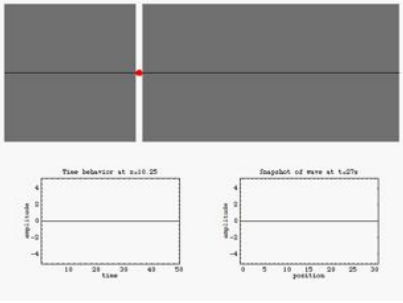
The Anatomy of a Wave



Remember These!

Adapted from figure by Kraaiennest, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Sine_wave_amplitude.svg

The Dynamics of a Wave



- Wave Period – time between crests
- Wave Frequency – number of crests per second
- Wave Speed – rate crests move (meters/second)

Animation courtesy Dr. Dan Russell, Kettering University, http://paws.kettering.edu/~drussell/Demos/wave-x-t/wave-x-t.html

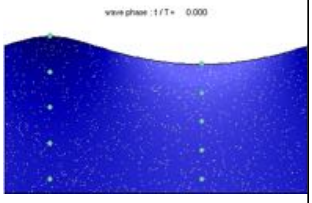
Period, frequency, speed and wavelength are related!

Period = 1/frequency
Speed = wavelength / period = wavelength x frequency

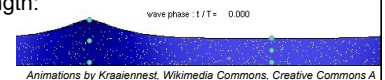
Oscillation: Water depth matters

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)**

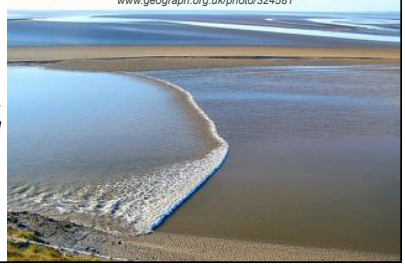
QUESTIONS

Ocean wind waves (swell), New Zealand, Phillip Capper, Creative Commons A 2.0, http://en.wikipedia.org/wiki/File:Easterly_swell,_Lyttelton_Harbour,_29_July_2008.jpg

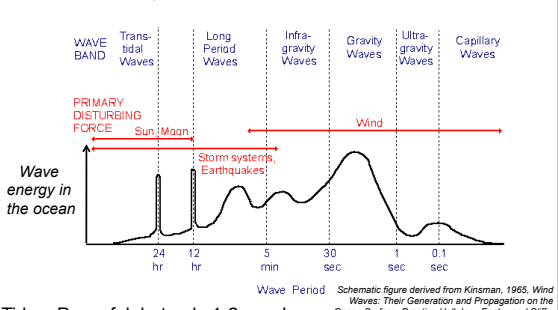
Ocean Waves

- ***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



Ocean wave classification and "power"



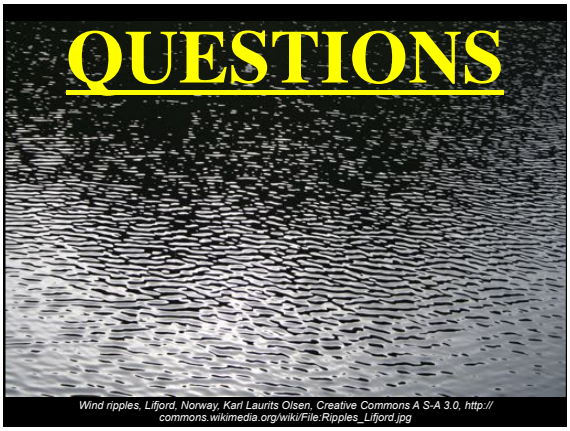
Schematic figure derived from Kinsman, 1965, Wind Waves: Their Generation and Propagation on the Ocean Surface. Prentice-Hall, Inc., Englewood Cliffs, New Jersey. 1965, p. 23, http://co-ops.nos.noaa.gov/images/powrspec.gif

Tides: Powerful, but only 1-2 per day
Tsunami: Also powerful, but rarer still
Wind: Less potent individually, but common everywhere

Deep vs. Shallow Water Waves

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

QUESTIONS



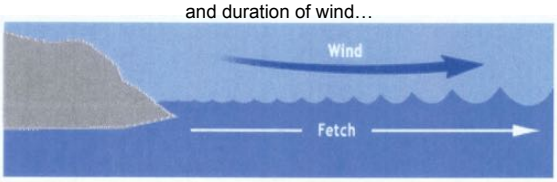
Wind ripples, Lifjord, Norway, Karl Laurits Olsen, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Ripples_Lifjord.jpg

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…

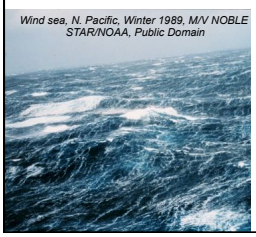


Tammy Pelletier, WSU Dept of Ecology, http://www.vos.noaa.gov/MWL/apr_06/waves.shtml

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

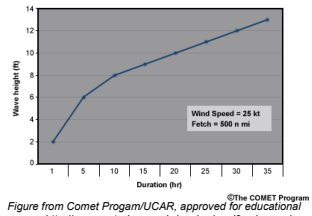


Figure from Comet Progam/UCAR, approved for educational use, http://www.meted.ucar.edu/marine/mod2_wlc_gen/print.htm

Wind-Seas and Swells:

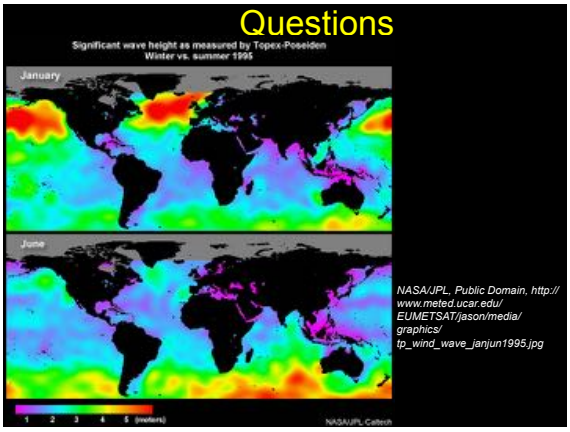
Wind Sea: wind & storm create and grow new waves

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

Swell: waves that have left their birthplace
Sorted by dispersion (longest move fastest)

Ocean wind waves (swell), New Zealand, Phillip Capper, Creative Commons A 2.0, http://en.wikipedia.org/wiki/File:Easterly_swell,_Lyttelton_Harbour,_29_July_2008.jpg

Questions



NASA/JPL, Public Domain, http://www.meted.ucar.edu/EUMETSAT/jason/media/graphics/tp_wind_wave_janjun1995.jpg

Breaking Waves

Teahupoo, Tahiti, Photo by Duncan Rawlinson, Creative Commons A 2.0 Generic, http://thelastminuteblog.com/photos/album/72157603098986701/photo/1973927918/teahupoo-surfing-november-2-2007-

Waves can't transport energy as efficiently in shallow water

aokomoriuta, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Breaking_wave_in_wavemaker.ogv

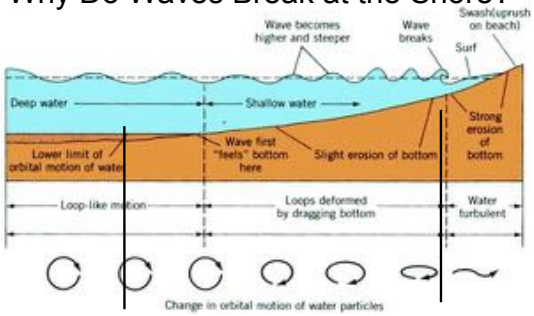
When Do Waves Break?

Waves start to break when:

- The angle between front & backside of wave < 120 degrees
- This occurs when Height > 1/7 Wavelength
- Typically when Height ~3/4 water Depth

R. Nave, http://hyperphysics.phy-astr.gsu.edu/hbase/waves/imgwav/trochoidpair.gif

Why Do Waves Break at the Shore?



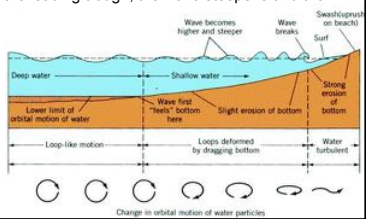
$s = 1.25(L)^{1/2}$ $s = 3.1(d)^{1/2}$

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

Why Do Waves Break at the Shore?

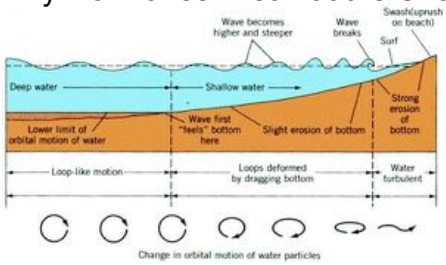
- What happens to waves at the coastline to make them break?
  - **They interact with the ocean bottom**
  - Crests travel faster than troughs ($S = [gd]^{1/2}$)
  - As the crest catches up with the trough ahead of it, the wave "breaks"

    i.e., crest overtakes the leading trough, the wave steepens and then breaks



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

Why Do Waves Break at the Shore?



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

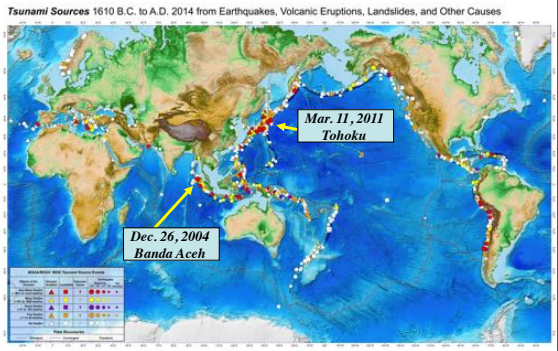
- Deep water to shallow water transition: **Wave Shoaling**
- Analogy: Try sprinting from asphalt into mud
  - You will tend to fall over!

QUESTIONS

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

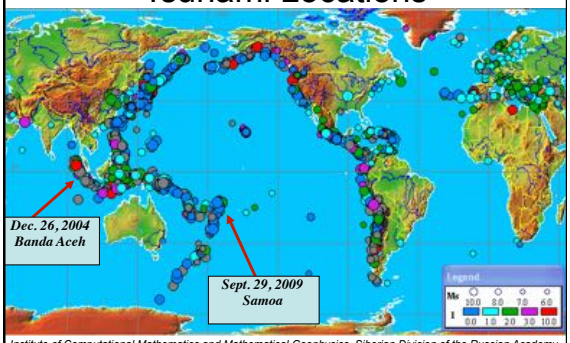
- From Japanese: *http://www.rffc.org/kanji-names.htm*
  津 *tsu -- port, harbor*
  波 *nami -- wave*
- English synonym: Tidal wave, even though they are *NOT* caused by tides -- *confusion resulting from long period?*
- **Origin**: Seismic sea waves, driven by earthquakes, volcanic eruptions or underwater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



Most occur along Ring of Fire. Why?

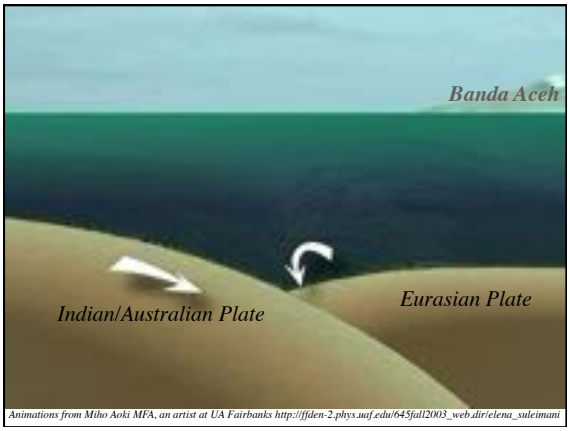
UNESCO/NOAA map. Public Domain, http://itic.ioc-unesco.org/images/stories/awareness_and_education/map_posters/tsu_poster_web_20140808.jpg

Tsunami Locations



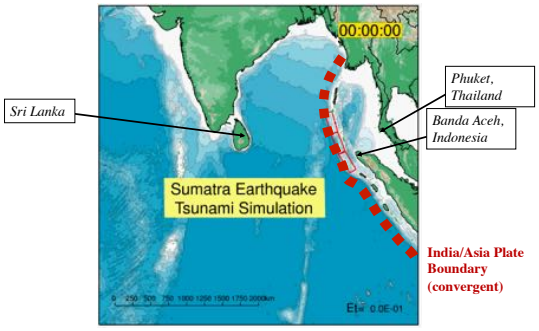
Institute of Computational Mathematics and Mathematical Geophysics, Siberian Division of the Russian Academy of Sciences, http://tsun.sscc.ru/tgi_1.htm

- Most occur along Ring of Fire. Why?



Animations from Miho Aoki MFA, an artist at UA Fairbanks http://ffden-2.phys.uaf.edu/645fall2003_web.dir/elena_suleimani

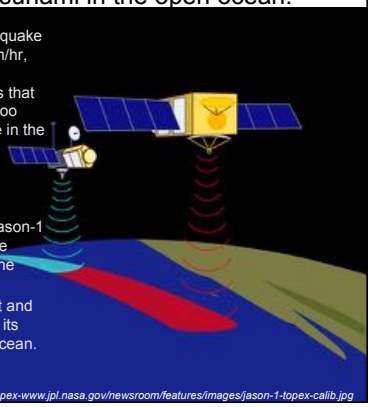
The Banda Aceh Tsunami



Animation from Steven Ward, IGPP/UC Santa Cruz, http://es.ucsc.edu/~ward/

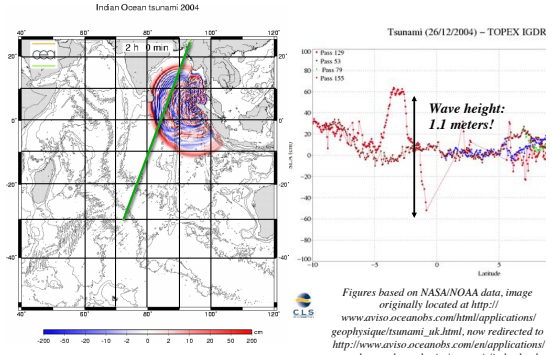
Detecting tsunami in the open ocean:

- 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://topex-www.jpl.nasa.gov/newsroom/features/images/jason-1-topex-calib.jpg

TOPEX/Poseidon and Tsunami



Figures based on NASA/NOAA data, image originally located at http://www.aviso.oceanobs.com/html/applications/geophysique/tsunami_uk.html, now redirected to http://www.aviso.oceanobs.com/en/applications/geodesy-and-geophysics/tsunamis/index.html

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.

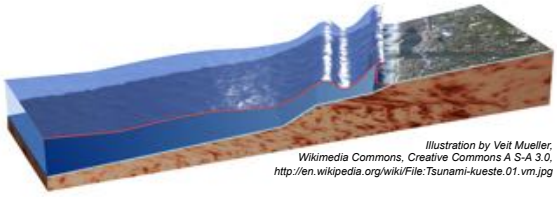


Illustration by Veit Mueller, Wikimedia Commons, Creative Commons A S-A 3.0, http://en.wikipedia.org/wiki/File:Tsunami-kueste.01.vm.jpg

Tsunami waves come to shore

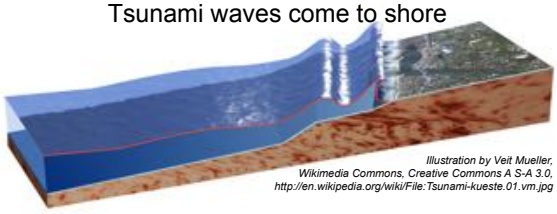


Illustration by Veit Mueller, Wikimedia Commons, Creative Commons A S-A 3.0, http://en.wikipedia.org/wiki/File:Tsunami-kueste.01.vm.jpg

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

Animations from Miho Aoki MFA, an artist at UA Fairbanks http://ffden-2.phys.uaf.edu/645fall2003_web.dir/elena_suleimani

Tsunami waves come to shore

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

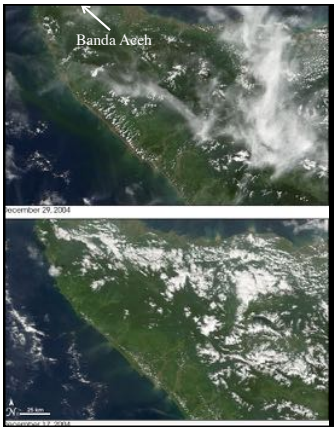
Images Quickbird/DigitalGlobe, http://homepage.mac.com/demark/tsunami/

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

Near-quake tsunami run-up, Tohoku Japan

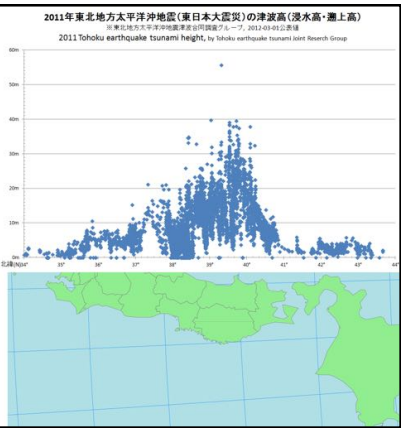
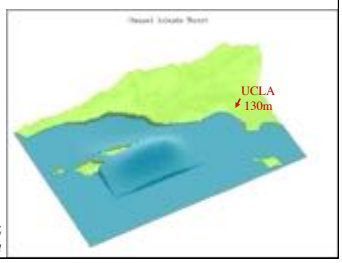


Figure by Pekachu from Tohoku earthquake tsunami Joint Research Group data. Wikimedia Commons, Creative Commons A-S A 3.0 Unported, http://commons.wikimedia.org/wiki/File:2011_Tohoku_tsunami_height_by_Joint_Research_Group_2012-03-01.png

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/video_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, barriers islands, mangrove swamps & estuaries dilute impact of waves.