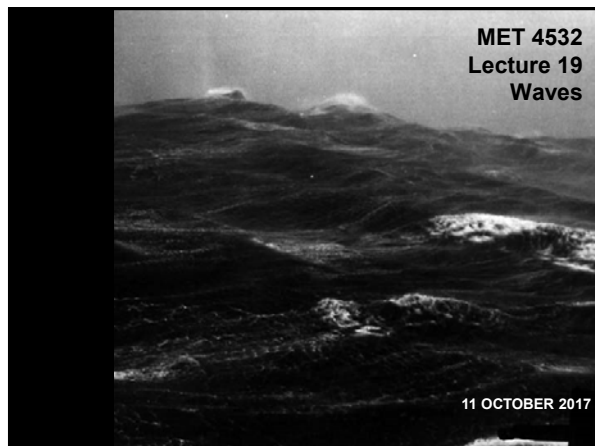
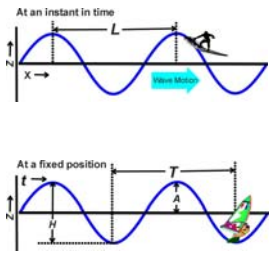




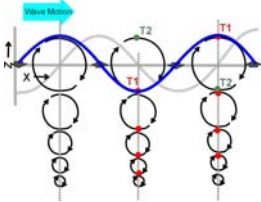
About Waves



- A wave is characterized by:
 - Wavelength L
 - Wave period T
 - Height H
- The crests (or troughs) are L meters apart
- One passes an observer every T seconds
- So the wave speed is $C = L/T$
- In ocean, multiple wavelengths and periods are always present

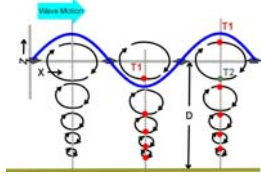
Deep-Water Ocean Waves

- Wavelength less than half the water depth
- Water moves in circular orbits
- Waves fade away with depth
- Waves move because water converges ahead of the crest and diverges behind the crest
- Water in the troughs moves opposite to the wave motion and accelerates in the direction of wave propagation as the crest approaches
- Water on the crest moves in the direction of wave motion and decelerates as the trough approaches
- Deep-water wave speed depends only on length
- Longer waves move faster



$$C_{\text{deep}} = \sqrt{\frac{gL}{2\pi}}$$

Intermediate-Depth Waves

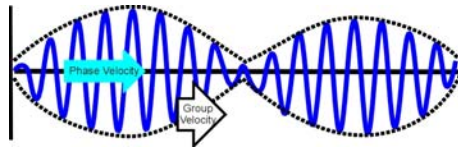
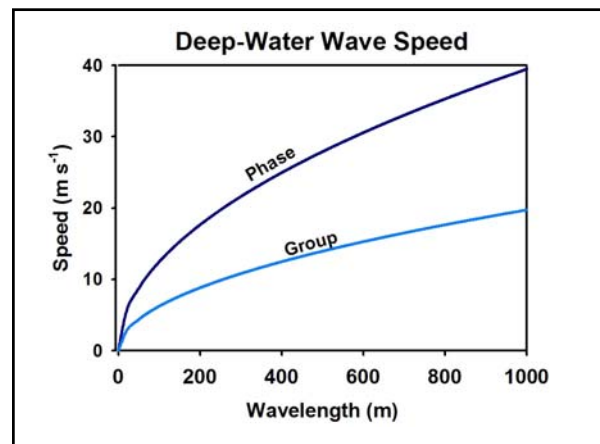


- Wavelength more than half the depth
- Circular orbits distort into ellipses
- These waves always move more slowly than deep-water waves
- When the water is shallow, $D < 0.1L$, the fluid moves back and forth, not in circles
- Shallow-water wave propagation depends only on water depth

$$C_{\text{shallow}} = \sqrt{gD}$$

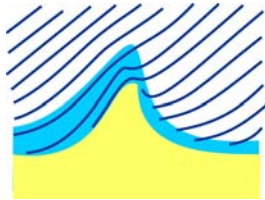
Group Velocity

- Deep- and intermediate- water waves are **dispersive**; their propagation speed depends upon wavelength
- When more than one wavelength is present, wave energy moves in packets
- Which carry the wave energy, moving at the **group velocity**
- Individual wave crests and troughs move with the (faster) phase velocity
- For deep-water gravity waves the group velocity is half the phase velocity

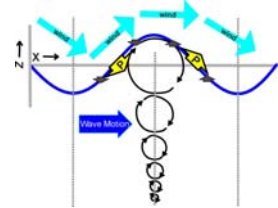
Wave Refraction

- As waves approach shore they slow
- Parts of the crest in shallow water move more slowly than in deep water
- Focuses energy on promontories
- And away from bays



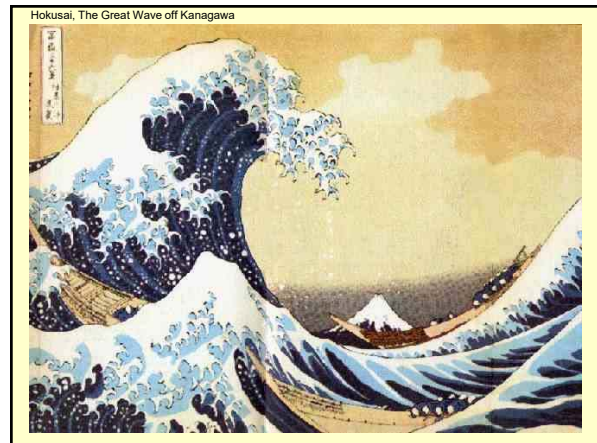
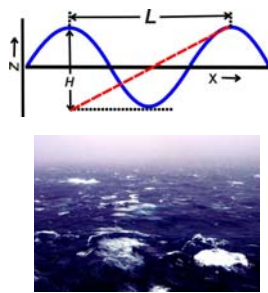
Wave Growth

- Wind pushes on the wave crests
 - Pressure on the back of the crests
 - Acceleration of the orbital motion
- Waves moving at 1/6 of the wind speed grow fastest
- A **sea** is growing due to local wind
- **Swells** grew somewhere else and propagated here
- Sea state may be limited by:
 - **Fetch**—the upwind distance over which it grew
 - **Duration**—time over which the wind blew
- If it is not limited by neither fetch nor duration, it is said to be **Fully Arisen**



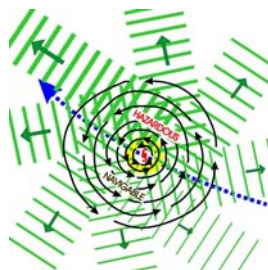
Wave Steepness and Whitecaps

- Wave steepness is the ratio of height to length.
- It is not the slope of the wave front
- When it is $> 1/7 = 0.143$, waves break
- Even in deep water
- Hazard to mariners

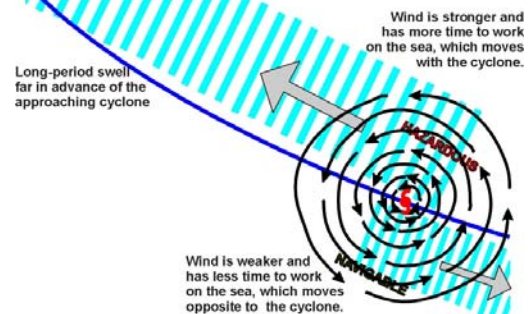


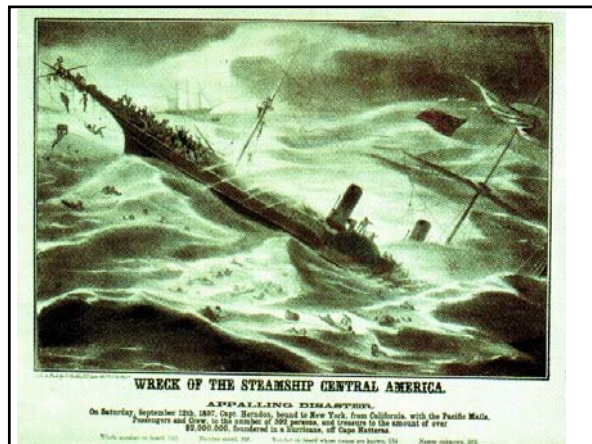
Seas Around a Hurricane

- In the Hazardous semicircle
 - Winds are stronger
 - Seas move downwind with the storm
 - Still fetch/duration limited
- In the Navigable semicircle
 - Winds are weaker
 - Seas move downwind opposite to the storm
- Low-frequency swells propagate ahead of the storm
- Weaker swells radiate in all directions
- Seas within the storm are confused



Redfield & Reid, Including the Ocean





SUMMARY

- Definitions:
 - Sea: Waves excited locally by the wind
 - Swell: Waves excited elsewhere
 - Wavelength: distance from crest-to-crest
 - Period: time between crests or troughs
 - Height: Vertical distance from trough to crest
 - Phase speed = Wavelength/Period
- Deep-water waves
 - Water moves in circular orbits
 - Converges ahead of troughs and diverges behind crests
 - Longer waves move faster than short ones
- Shallow-water waves
 - Water moves back and forth horizontally
 - Waves in shallow water move faster than waves in not-so-shallow water
- Near shore, wave slowing in shallow water focus energy on promontories and away from bays
- Waves grow as the wind pushes on their backs
 - Fastest growing move with 1/6 of wind speed
 - Limited by Fetch or Duration in many cases
 - Fully arisen sea—max possible for a given wind speed
- Waves break when their steepness (H/L) > 1/7
- Waves are higher in the hazardous semicircle because winds are stronger and because the waves move with the hurricane
- Long-period swell is a harbinger of hurricanes

For next time:
Exam 1 Review
Storm Surge
Emanuel 165-171
Wednesday