EOSC 114: Natural Disasters

Waves & Tsunami

Photograph: Aaron Favila/AP

Photo Credits:
Earthquakes: Karen Kasmauski, National Geographic
Volcanoes www.universetoday.com/60019/how-volcanoes-work/
Landslides: Brett Gilley
Storms: Wolf Read, 2010. Used with permission.
Tsunami: news.nationalgeographic.com
Meteor Impact: NASA

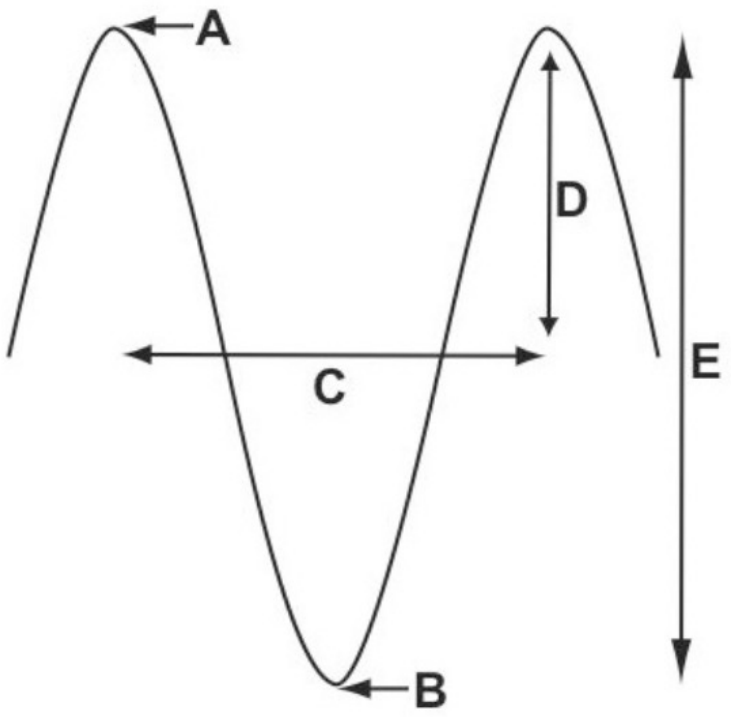
L. May Ver

LEARNING GOALS: SUMMARY

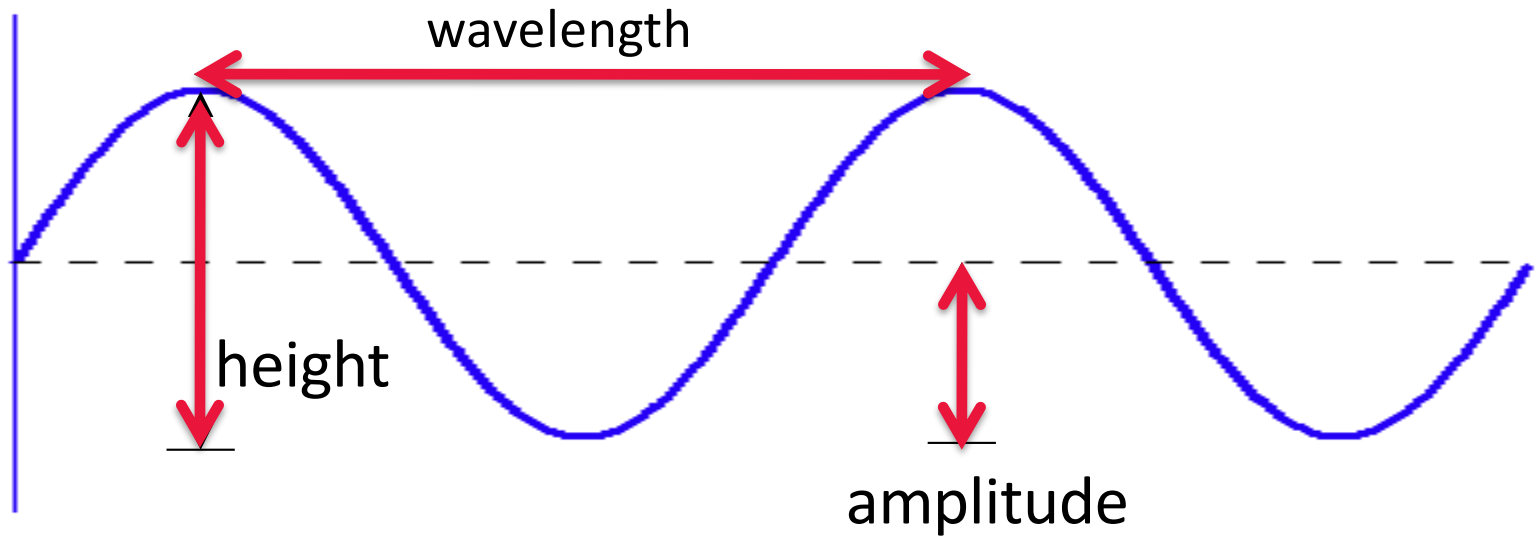
- ✓ Waves Move Energy.
  Matter (water) moves as waves pass, but NET motion is 0
- ✓ Key Properties:
  L (λ), H, steepness, T (f), c, wave base
- ✓ Deep Water Wave: $d \geq \frac{L}{2}$. $c = \frac{L}{T}$. $c = 1.56 \times T$
- ✓ Shallow Water Wave: $d \leq \frac{L}{20}$. $c = 3.1\sqrt{d}$
- ✓ Wave Dispersion:
  Waves travel in groups of similar wavelengths
  Longer wavelength waves travel fastest towards shore
- ✓ Shoaling Waves:
  Waves approaching shore transform from deep to transition to shallow water waves
- ✓ Generating forces:
  atmospheric and geological events, attraction between Earth-Moon-Sun
- ✓ Restoring forces:
  surface tension, gravity

9. Referring to the wave diagram to the right, which is the wave height?

A) A
B) B
C) C
D) D
E) E



Wave Anatomy: Shape



What units are used to describe wavelength?
Amplitude? Height? Steepness?

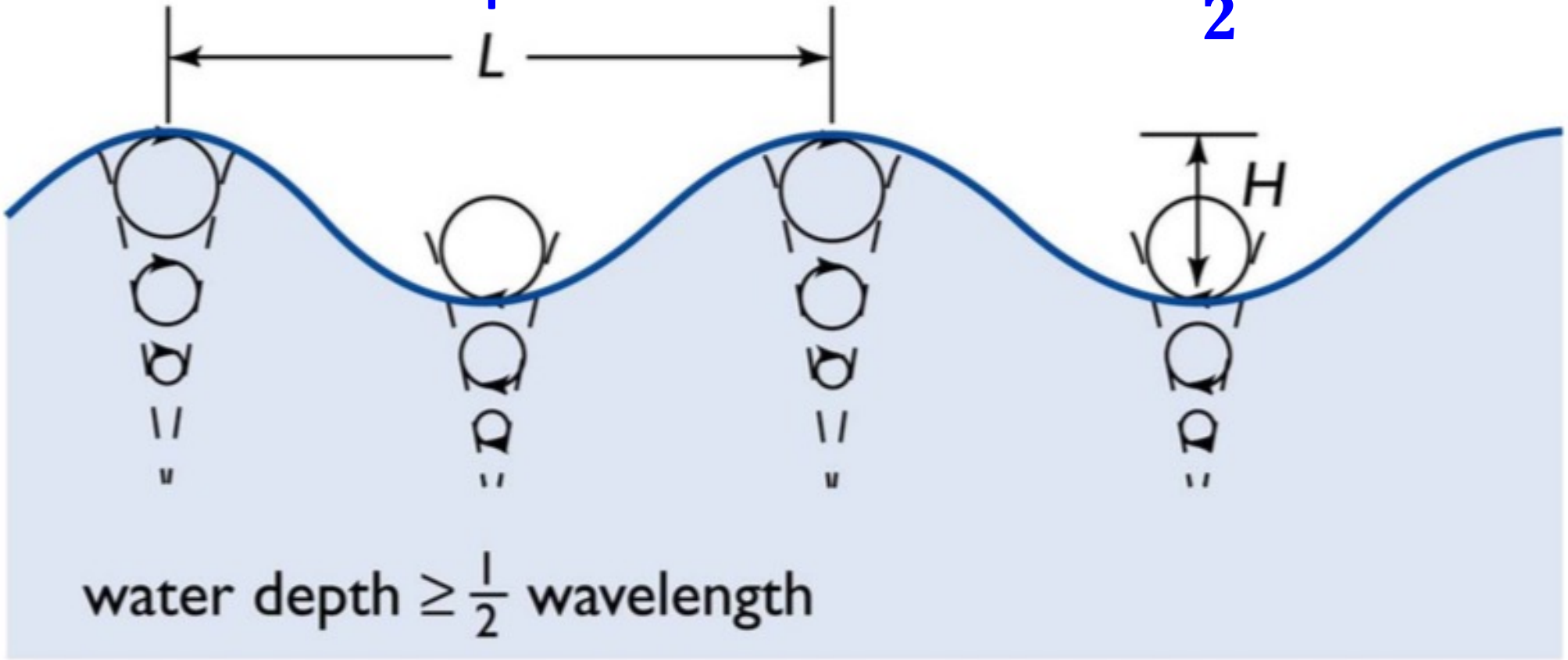
Wave Height (H) = vertical distance from crest to trough

Amplitude (a) = H/2 (one-half the height)

Steepness = H/L (height divided by wavelength)

WAVE MOTION

Deep water wave: $\boldsymbol{d \geq \frac{L}{2}}$

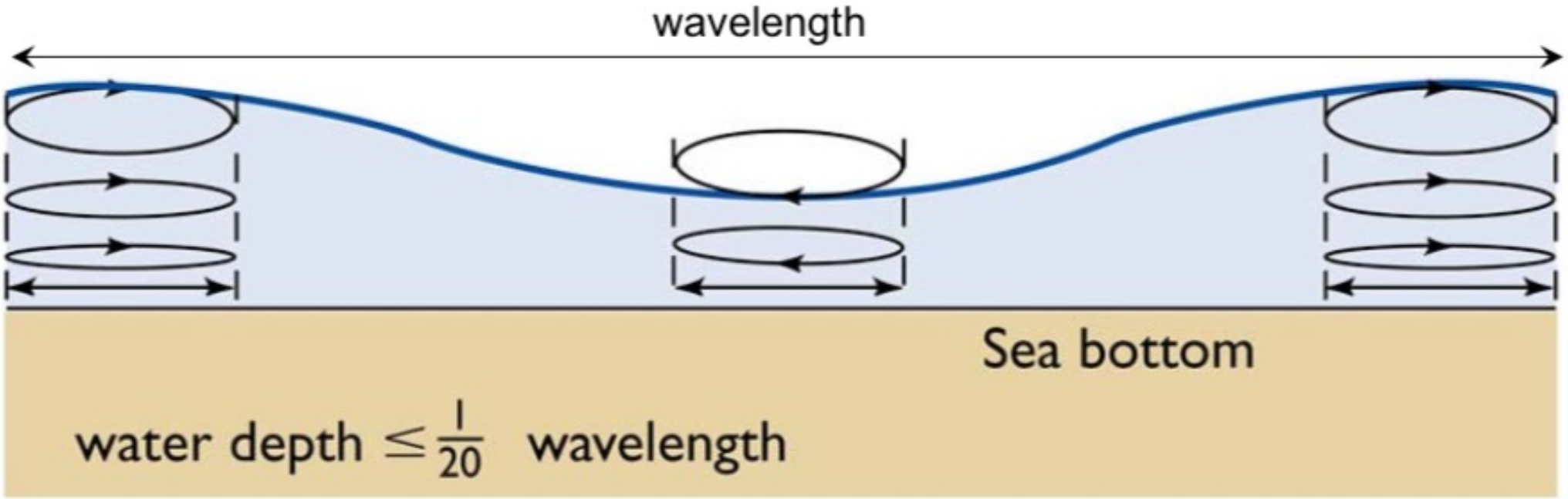


Ocean depth is deeper or equal to the wave base or $\boldsymbol{d \geq \frac{L}{2}}$

Waves don't feel the bottom

WAVE MOTION

Shallow water wave: $\boldsymbol{d \leq \frac{L}{20}}$



Ocean depth $\boldsymbol{d \leq \frac{L}{20}}$

Waves feel the bottom

Friction: causes orbits to flatten

10. A wave with wavelength 5 m moving through water of depth 15 m will transport water:
    A) horizontally, back and forth.
    B) up and down.
    C) sinusoidally.
    D) in orbitals.
    E) chaotically, impossible to predict.

A diver returning to the surface feels wave motion a few meters shallower than when she started her dive. She can predict that _____.

A. a tsunami is passing
B. the surface waves now have a shorter wavelength than earlier waves
C. the surface waves now have a greater wave height than earlier waves
D. conditions are identical as at the start of her dive
E. conditions are different than at the start of her dive, but it is impossible to predict how they've changed

22. Generating forces acting on waves are:

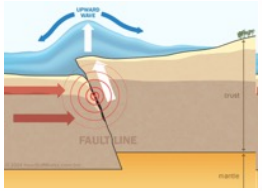
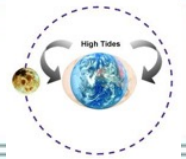
A) gravity and interference.
B) gravity and surface tension.
C) gravity and wind.
D) wind and interference.
E) wind and surface tension.

TYPES OF WAVES

WAVE CLASSIFICATION BASED ON…

1. The Generating Force

(the force that adds energy to the water)

GENERATING FORCE	WAVE TYPE	Length, λ
Wind over ocean 	Wind Wave	up to 150 m
Changes in atmospheric pressure; Storm surge; Tsunami	Seiche	1,000 m
Faulting of sea floor; Volcanic eruption; Landslide 	Tsunami	200,000 m
Gravitational attraction; Rotation of Earth 	Tide	20,000,000 m

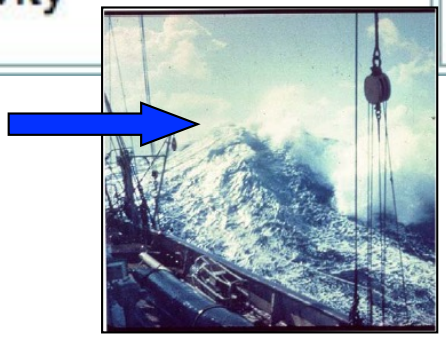
Types of Waves

WAVE CLASSIFICATION BASED ON…

2. The Restoring Force

(the force that returns water to its undisturbed state)

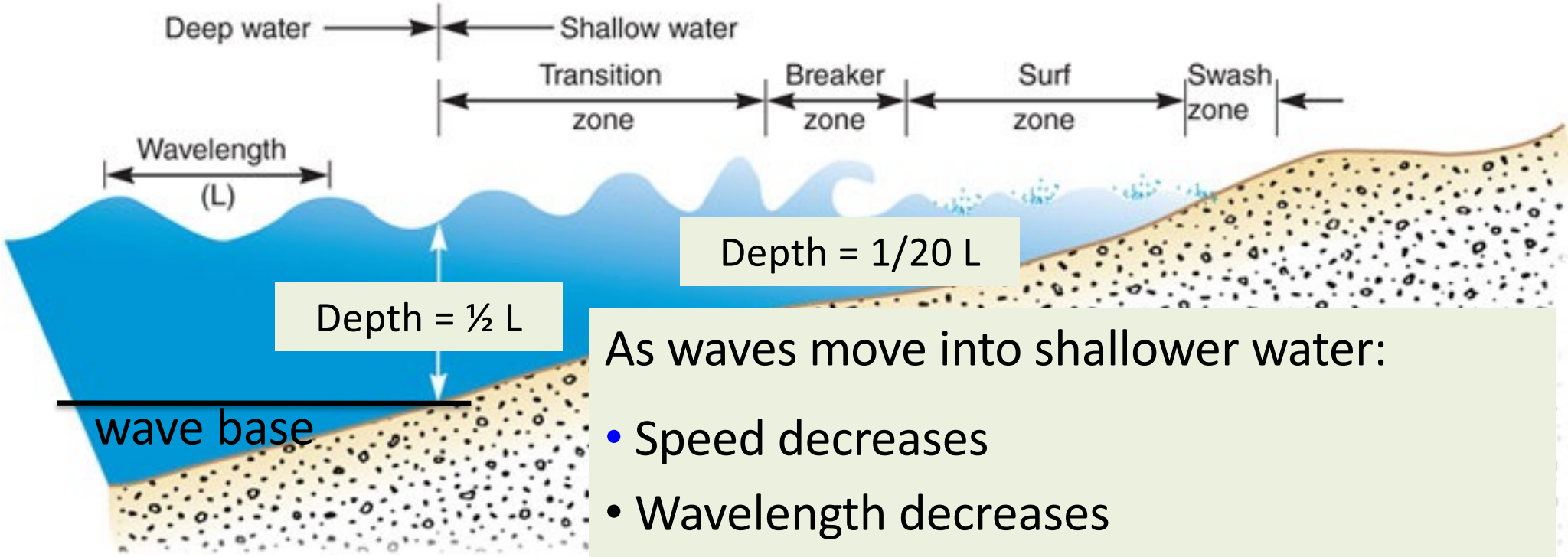
RESTORING FORCE	WAVE TYPE	Length, λ
Surface tension	Capillary Wave	< 1.7 cm
Gravity	Surface Gravity Waves: (Wind Wave, Seiche, Tsunami, Tide)	>1.7 cm (m to km)



11. As a wave shoals:
    A) the wave height stays the same.
    B) the wave length stays the same.
    C) the wave period stays the same.
    D) the wave speed stays the same.
    E) the wave steepness stays the same.

WAVE MOTION

some energy is transformed to KE, PE, friction



As waves move into shallower water:

- Speed decreases
- Wavelength decreases
- Height increases
- Steepness increases
- Period stays the same
- Orbitals flatten, become elliptical
- Waves “break”

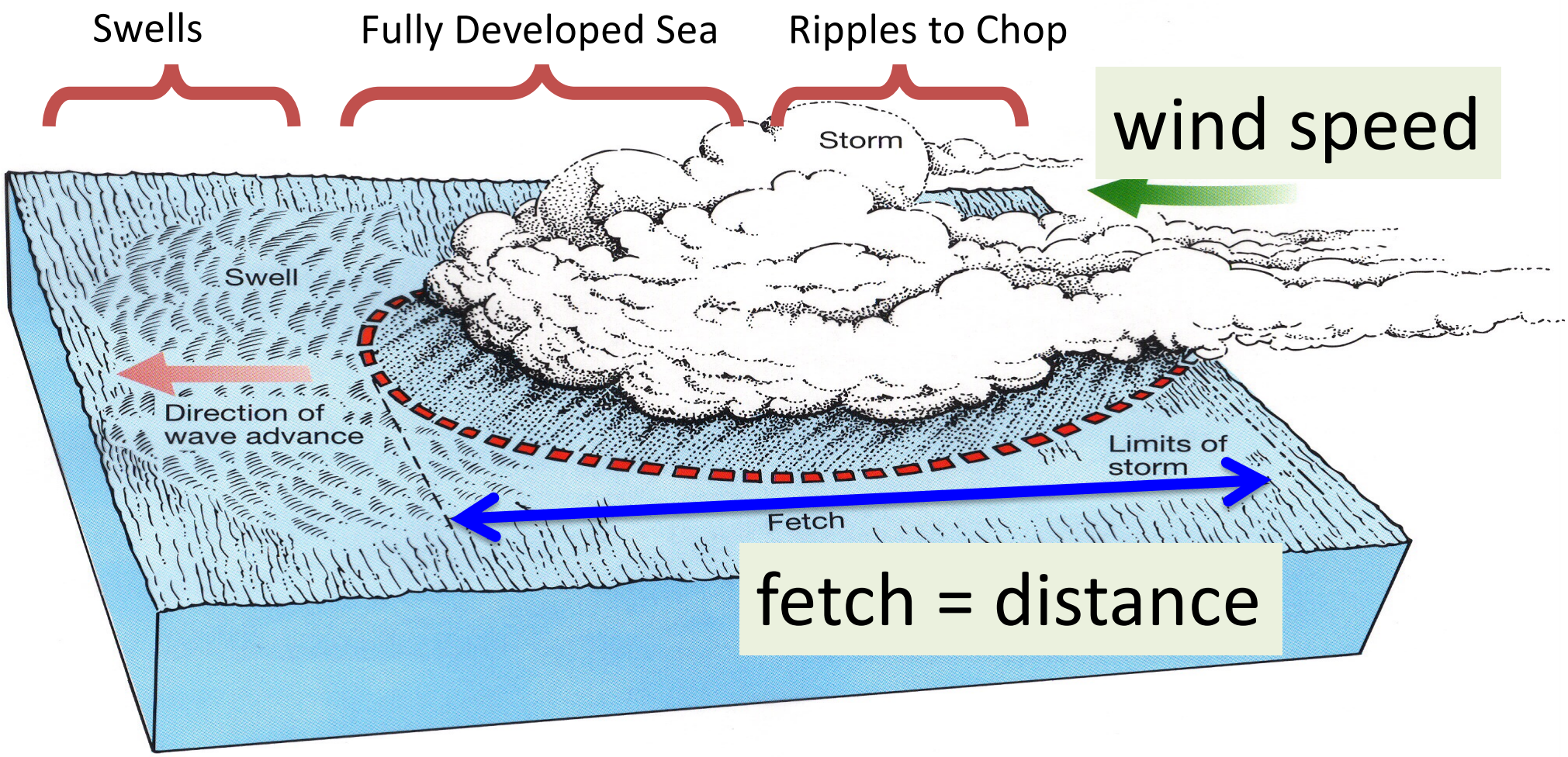
LEARNING GOALS: SUMMARY

- ✓ Roughness of the sea controlled by:
  wind speed, wind duration, fetch
- ✓ Wave interaction:
  constructive or destructive
- ✓ Rogue waves:
  unpredictable, massive waves generated by constructive interference

LEARNING GOALS: SUMMARY

- ✓ Seiche (saysh):
  seiche=wave that sloshes back and forth within body of water
- ✓ Resonance:
  tendency to sway back and forth; can amplify when constructively interfered
- ✓ Marine hazards:
  seiches and rogue waves

HOW DOES THE SEA STATE DEVELOP?



wind speed

fetch = distance

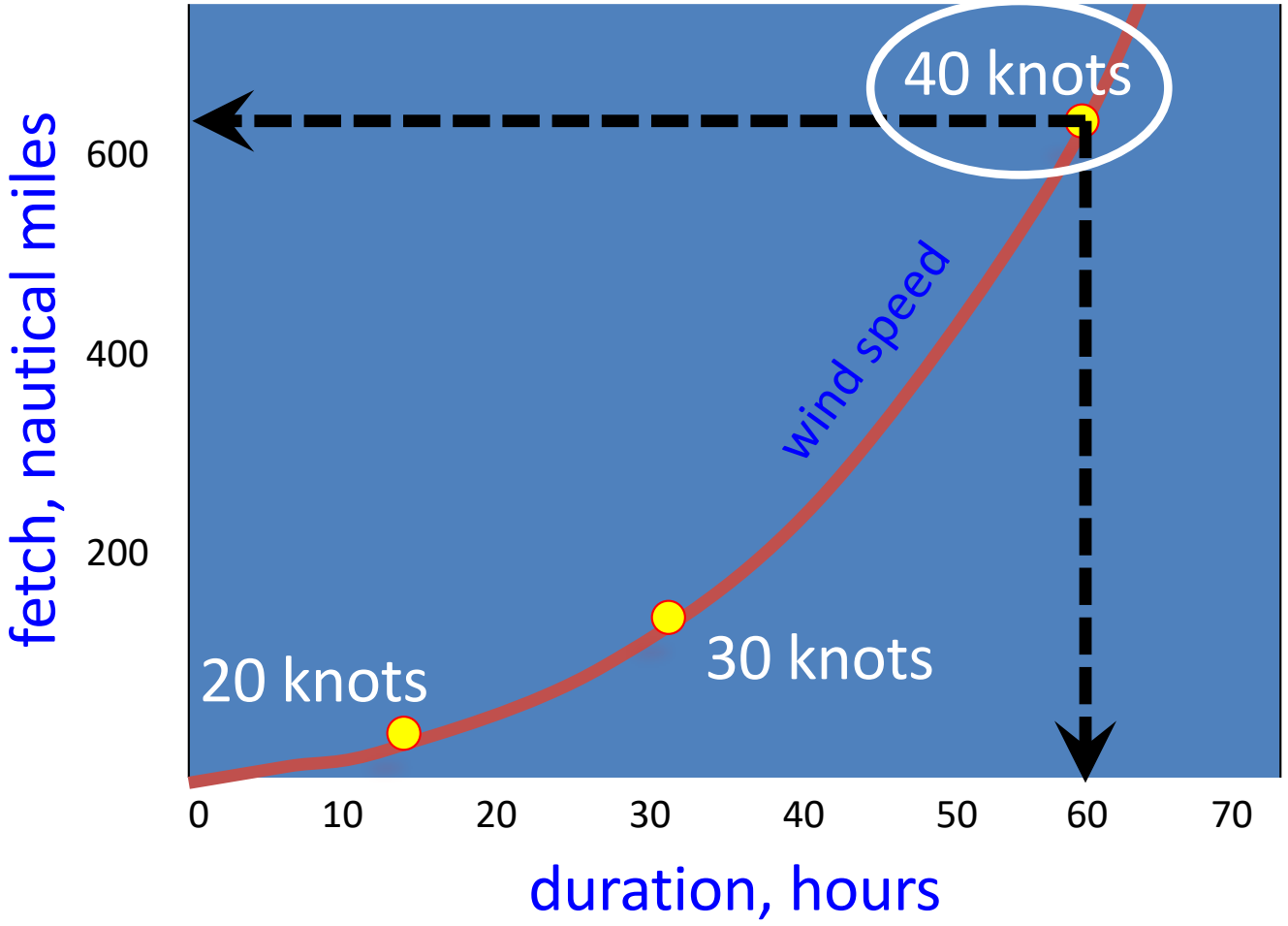
duration = time

IS THERE A MAXIMUM SEA STATE?

Yes – the FULLY DEVELOPED SEA!

Every wind speed has a matching practical limit over which time or distance will not produce larger waves

Excess Energy into sea (wind) = Energy out (breaking waves)

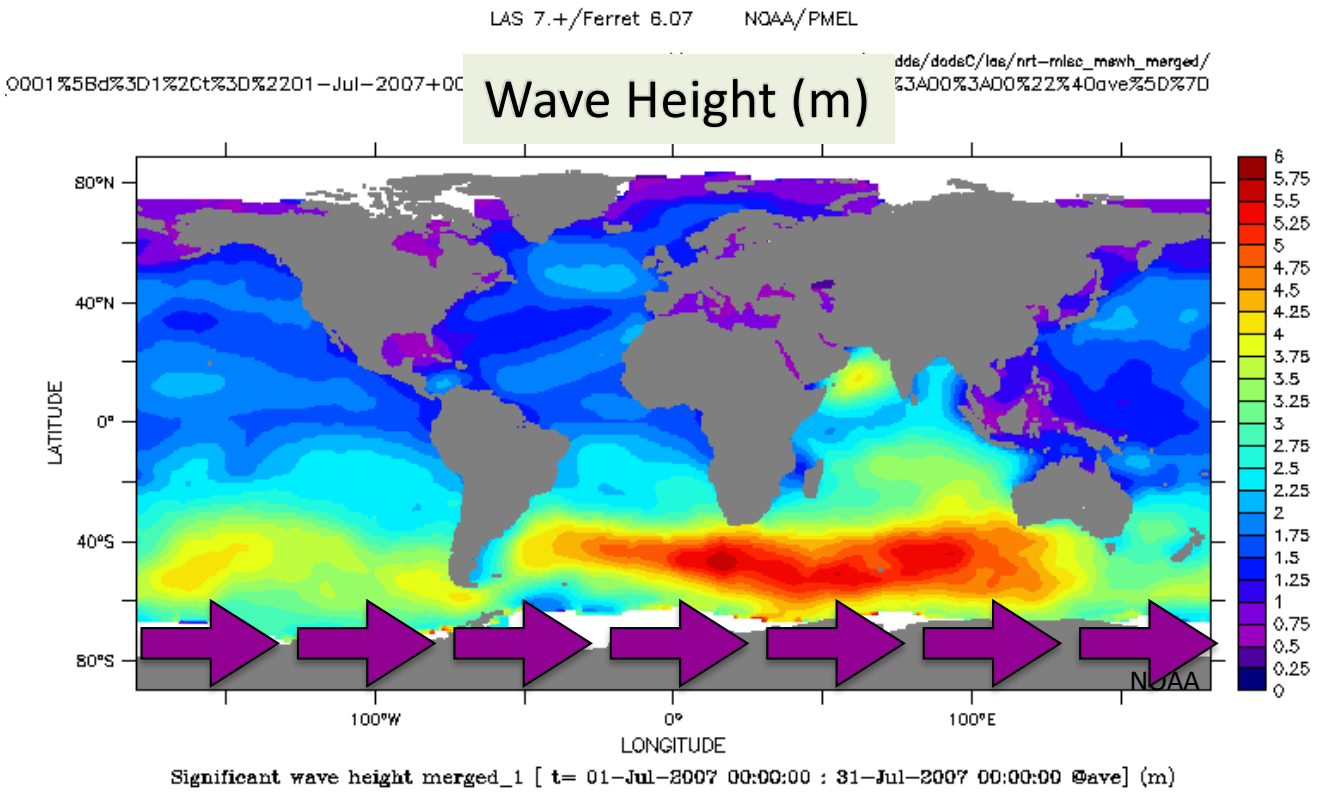


SO…
If speed = 40 knots

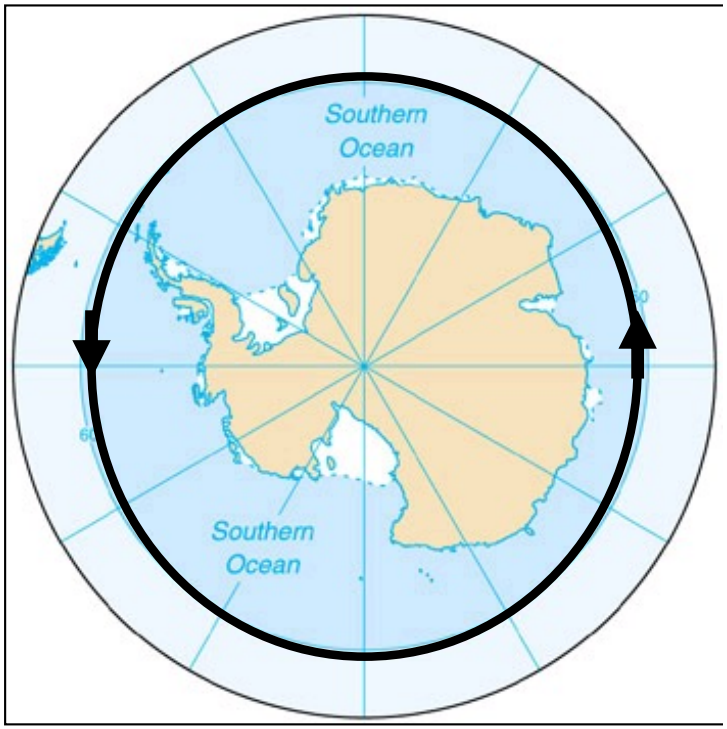
fully developed sea:

duration = 60 hours

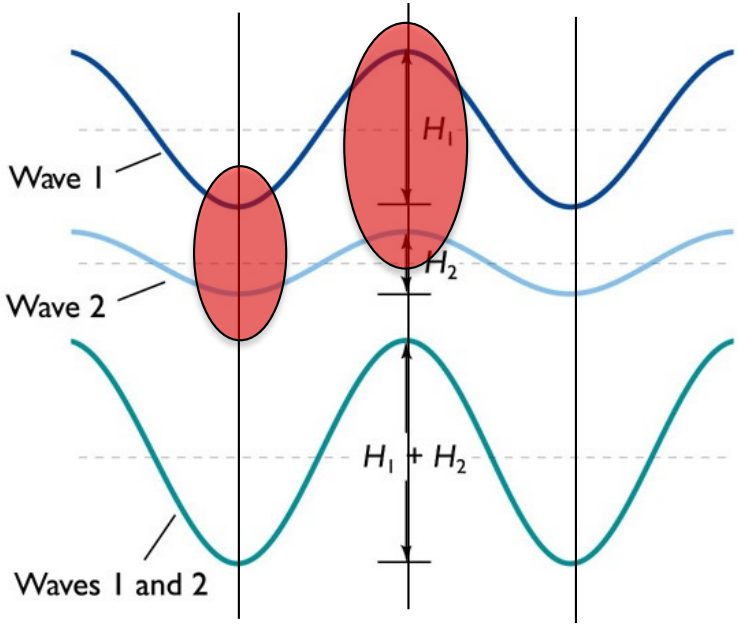
fetch ~ 650 nm



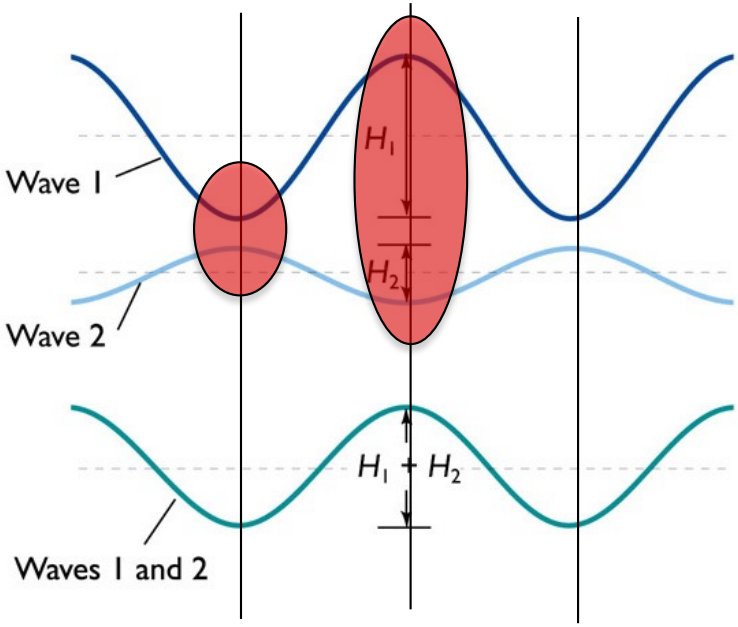
D. Fetch is infinite



CONSTRUCTIVE & DESTRUCTIVE INTERFERENCE



CONSTRUCTIVE WAVE INTERFERENCE



DESTRUCTIVE WAVE INTERFERENCE

Constructive interference:

Crests line up, Troughs line up

➔➔BIGGER WAVES

High Energy Packet!

Destructive interference:

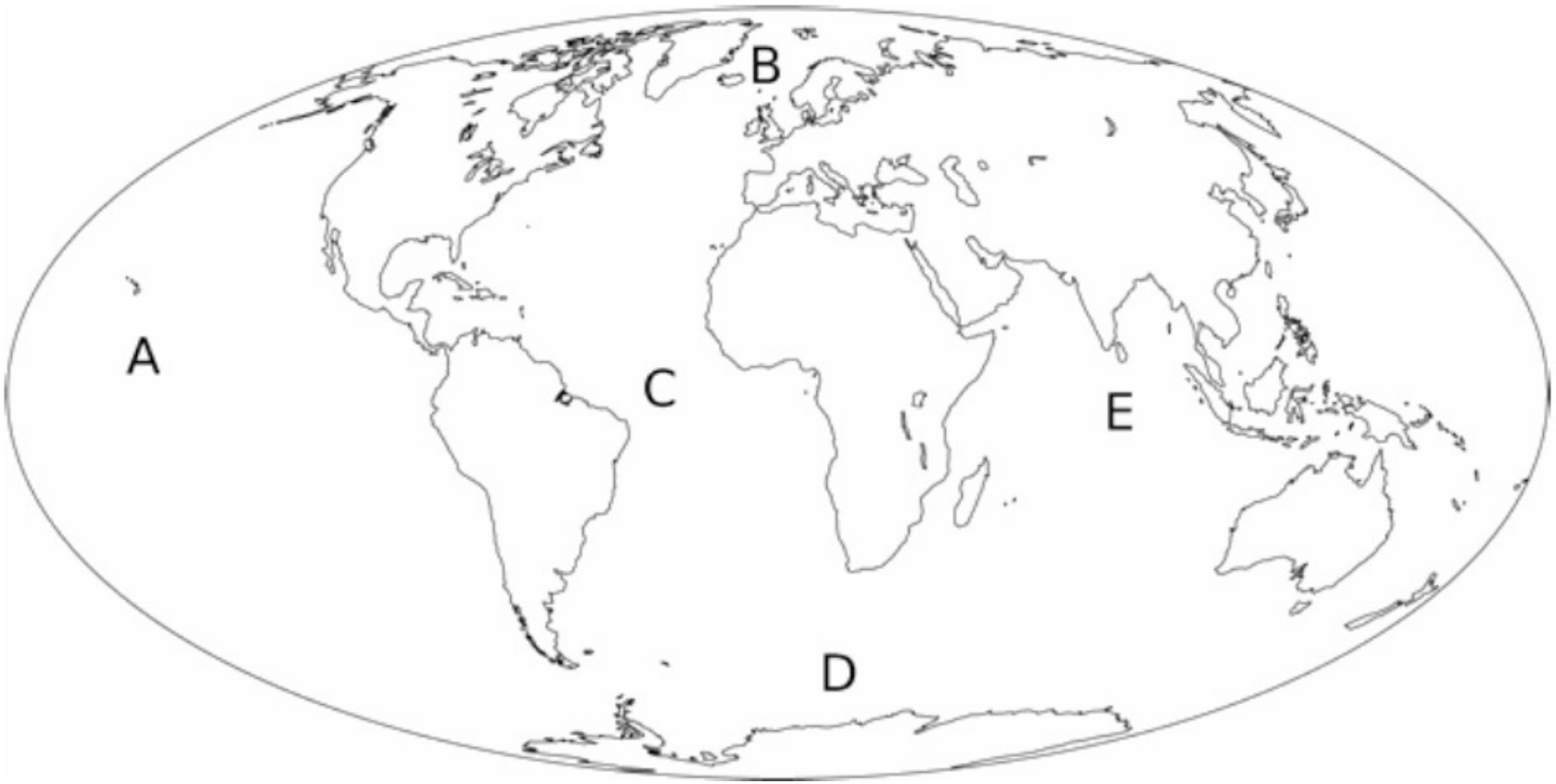
Crests line up with troughs…

➔➔smaller waves

Low Energy Packet!

18. Using the map to below , where in the world is the risk of rogue waves the GREATEST?

A) A
B) B
C) C
D) D
E) E

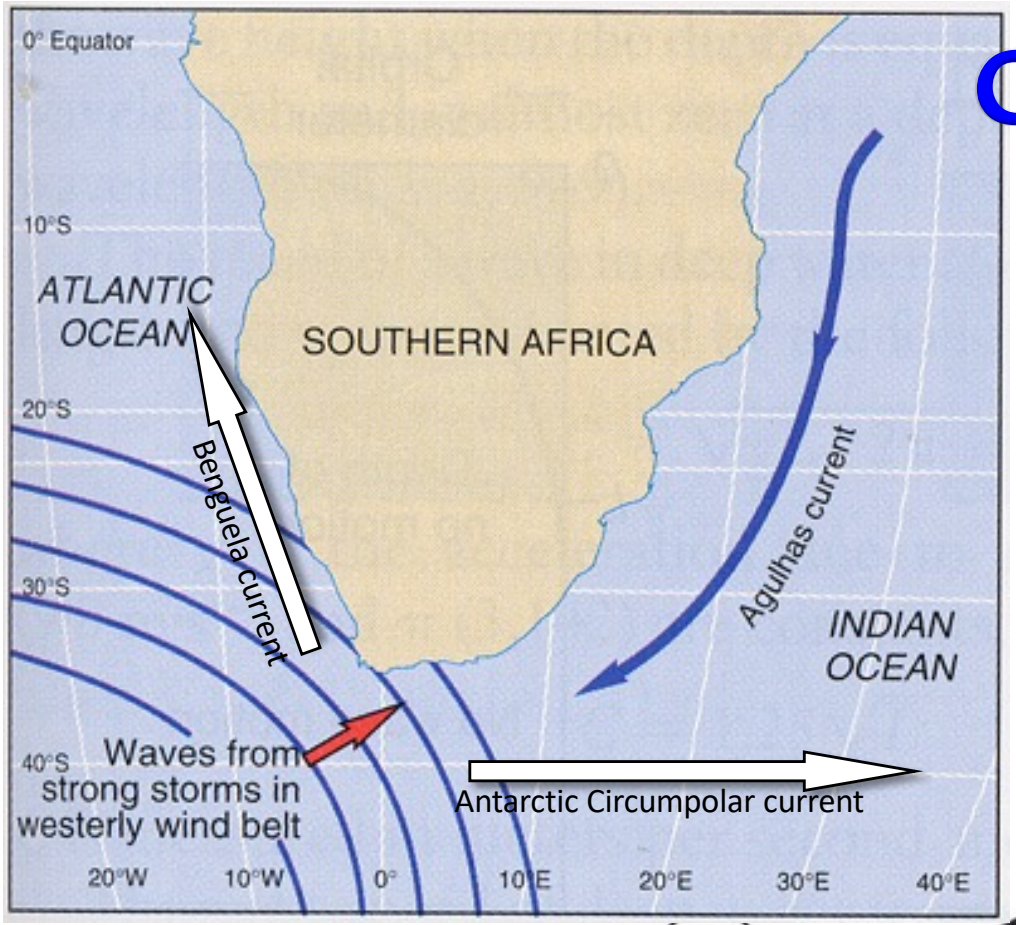


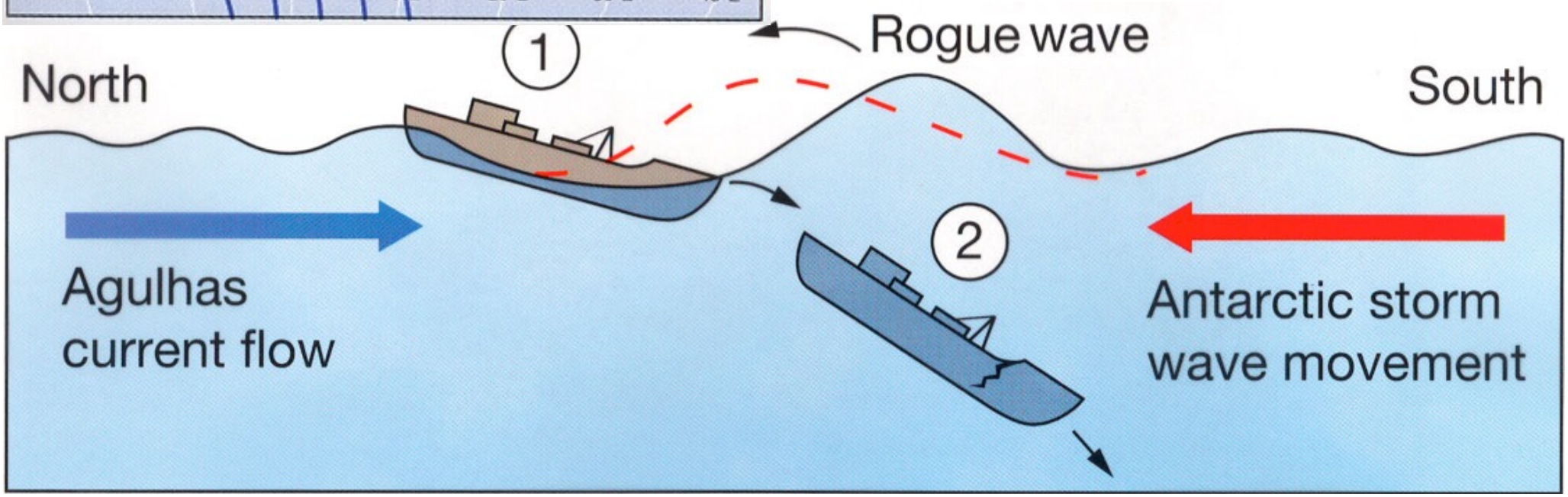
ROGUE WAVES

- Generated by Constructive Interference
- Can be very dangerous, and unpredictable – especially if over-steepened!
- Also called monster wave, freak wave…
- Can be 3-4 times larger than other waves in same area
- Can appear and disappear very quickly

CAPE OF GOOD HOPE NOTORIOUS FOR ROGUE WAVES

Rogue waves produced when strong currents collide with large wind-driven waves



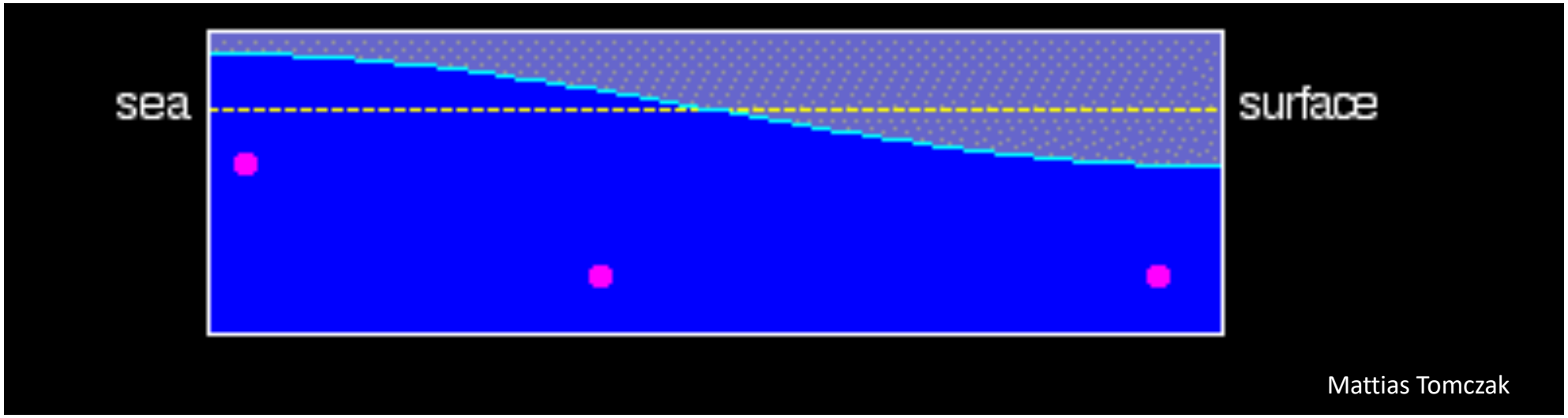


19. A resonant wave in a body of water is called a:
    A) monster wave.
    B) seismic sea wave.
    C) harbour wave.
    D) storm surge.
    E) seiche.

SEICHE: RESONANT OSCILLATION

A standing wave in an enclosed or Semi-enclosed body of water

- natural resonance frequency or period
- resonance T is longer for larger bodies of water: $T_{coffeecup} < 1$ second while $T_{Lake} \sim$ minutes-hours
- period depends on the shape of the water body and its shoreline



LEARNING GOALS: SUMMARY

- ✓ Tsunami can be generated by:
  earthquakes, landslides, volcanic eruptions, meteor impacts
- ✓ Tsunami vs common wind-driven waves:
  c, L, H, T, steepness, energy, particle motion
- ✓ Tsunami come ashore so violently:
  tremendous energy carried by humongous mass of water!

LEARNING GOALS: SUMMARY

- ✓ Tsunami warning signs:
  earthquakes, drawdown, very loud sound, animal behaviour
- ✓ Detection and Monitoring:
  Tsunami Warning Centres; DART™
- ✓ How to survive a tsunami
- ✓ Tsunami hazards for the coast of BC:
  flooding, powerful wall of water, fires, etc.

WHAT ARE TSUNAMI?

Rapid displacement of large amounts of ocean water

Japanese for ‘harbour wave’

tsu = harbour nami = wave

Tsunami can be caused by:

- Earthquakes (vertical submarine fault motion)
- Volcanic eruptions
- Meteor impacts (potentially the BIGGEST)
- Landslides
- Icebergs falling from glaciers (usually smallest)

23. A tsunami event may be caused by:
    A) a landslide.
    B) an iceberg calving from a glacier.
    C) an earthquake.
    D) a meteor impact.
    E) all of the above.

The damage from a tsunami _____.

A. occurs during both the advance and retreat of the waves
B. may be avoided
C. is a result of the high wave steepness in the open ocean
D. can be entirely mitigated with an early warning system
E. All of the above.

29. If you feel strong shaking while at the beach, you should:
    A) hide in the nearest house.
    B) find a boat and sail to open ocean.
    C) head for high ground.
    D) put on a life vest.
    E) do nothing unless you hear an official warning.

HOW TO SURVIVE A TSUNAMI

- Heed natural warnings: earthquake, receding water
- Heed official warnings
- Abandon belongings
- Head for high ground and stay there. If there is no high ground, head inland as far as possible.
- If time is lacking, go to an upper floor or roof of a strong building
- If time is really lacking, climb a tall sturdy tree or climb onto something that floats
- Help neighbours
- Expect devastation

LEARNING GOALS: SUMMARY

- ✓ Waves become unstable when $\frac{H}{L} \geq \frac{1}{7}$
- ✓ Breaking waves = Energy transforms
- ✓ Breaker types/beach slopes
  spilling/flat or gentle; plunging/steep; surging/very steep

LEARNING GOALS: SUMMARY

- ✓ Man-made structures
  Groins, jetties, breakwaters, seawalls
- ✓ Storm surges
  Pressure and wind surge
- ✓ Where the maximum surge is
- ✓ How the maximum surge is produced

12. A wave will form a plunging breaker if it encounters:
    A) a flat beach.
    B) a gently sloping beach.
    C) a steeply sloping beach.
    D) a sandy beach.
    E) a rocky beach.

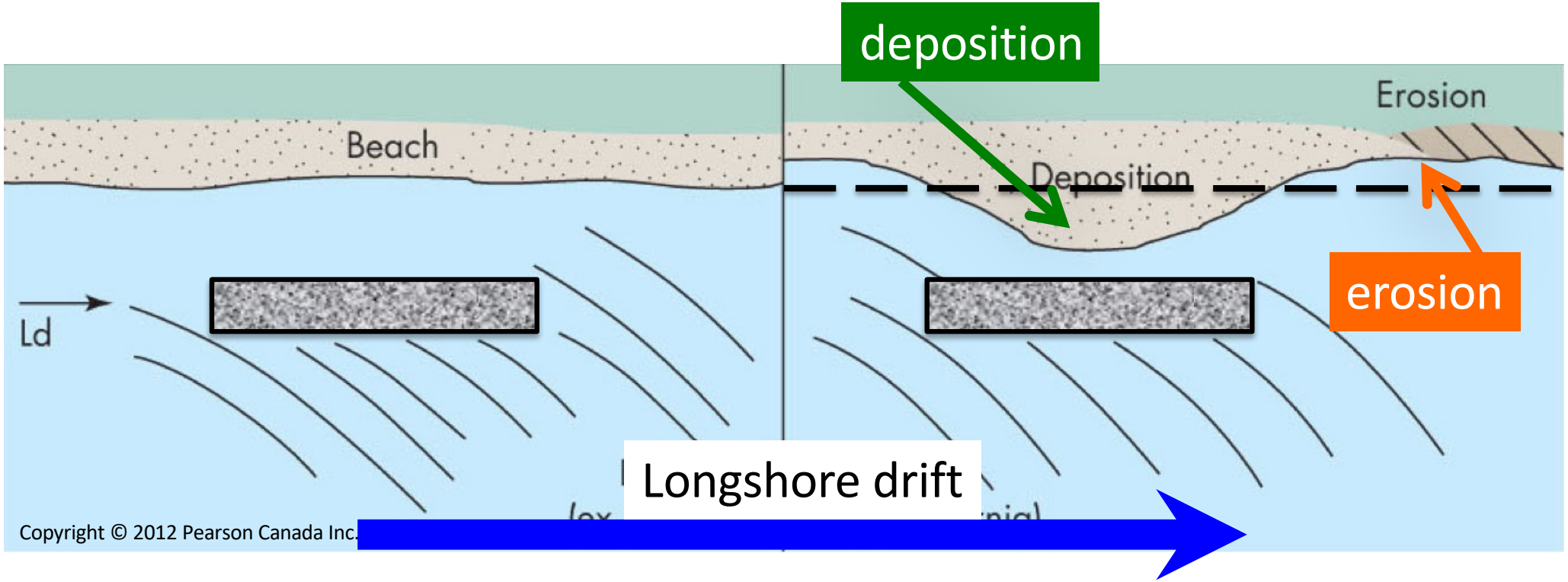
17. A community installs a porous breakwater. After installation:

A) erosion will occur updrift, and depletion downdrift of the breakwater.
B) rip currents will be much stronger.
C) wave energy will be reflected.
D) wave energy will be dissipated.
E) sediment transport will cease.

BREAKWATERS

Protects shoreline against wave action and erosion

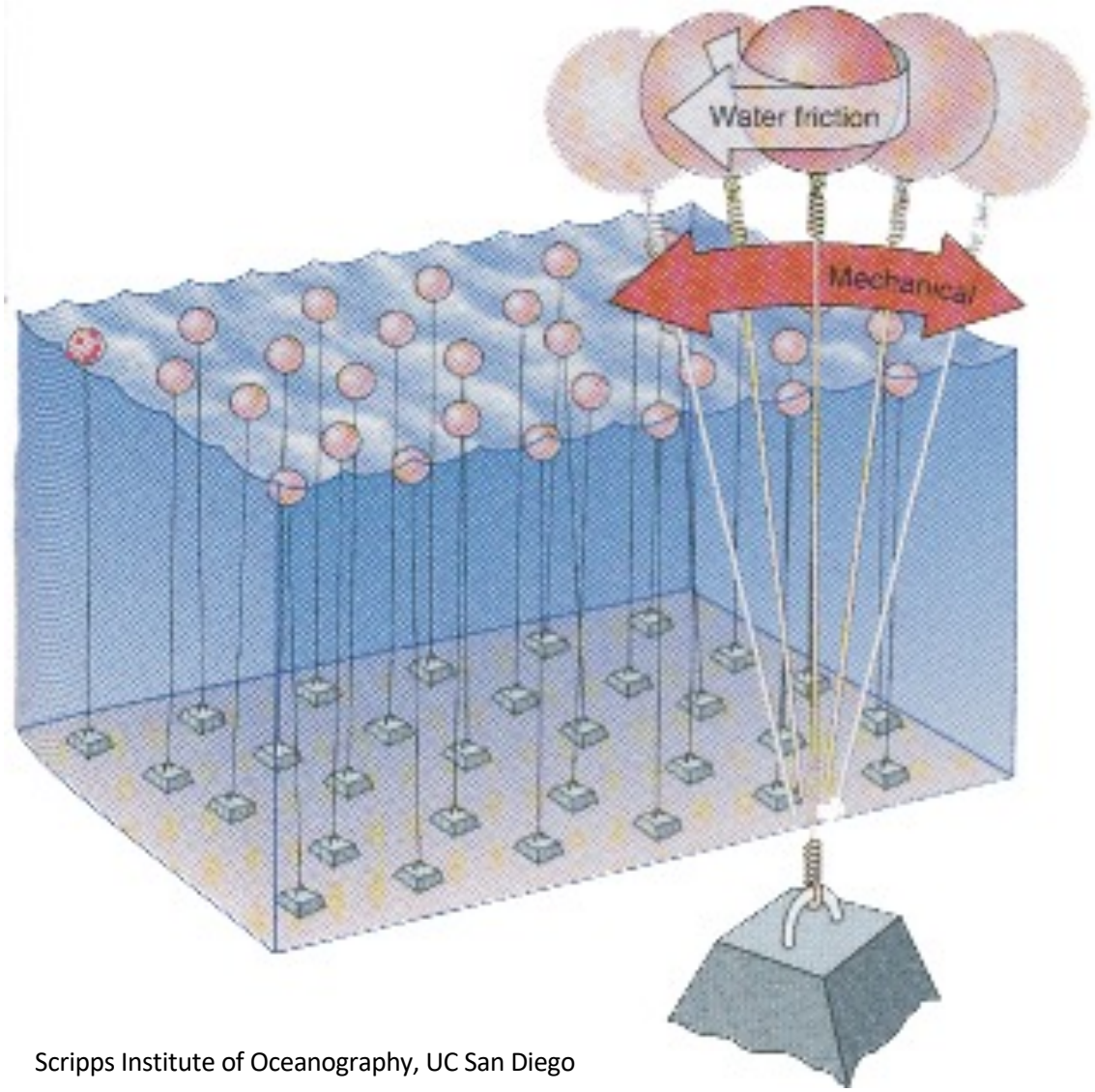
Built at a distance away from the coast being protected



- Breakwater dissipates wave energy as waves hit it
- Area behind breakwater becomes a safe harbour for boats and ships

TETHERED-FLOAT BREAKWATER

DISSIPATES wave energy but
ALLOWS flow of sediments



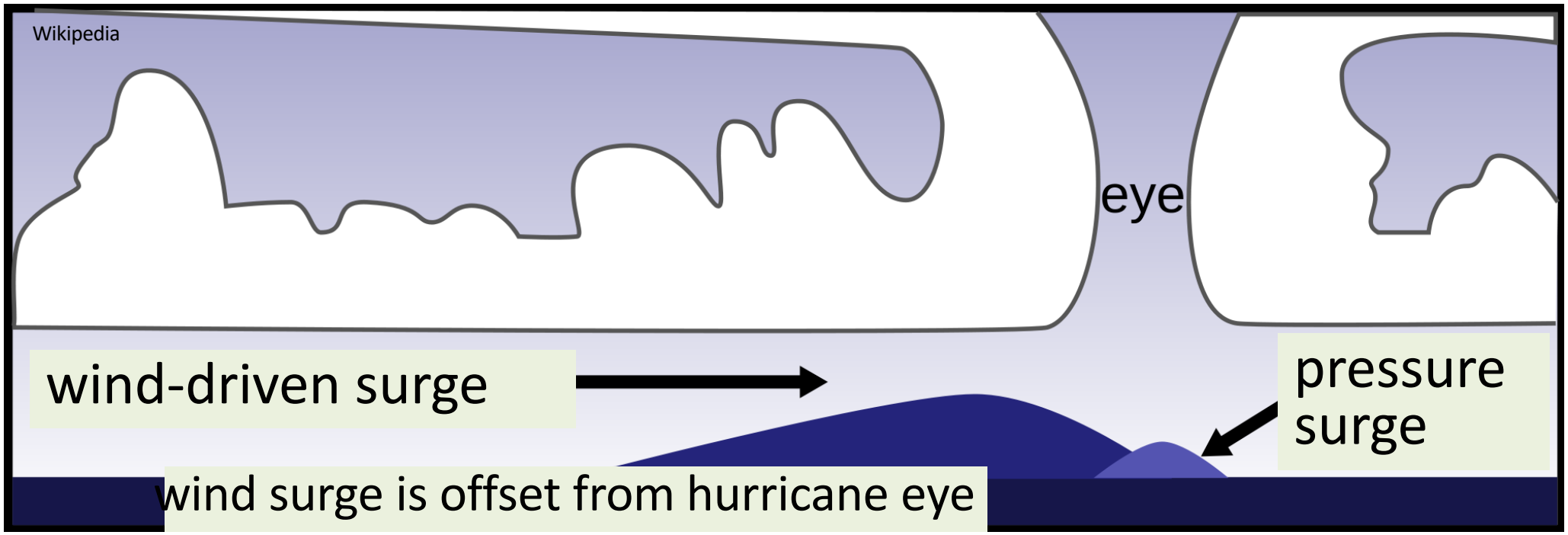
A better solution, but less common, and more expensive

Scripps Institute of Oceanography, UC San Diego

30. A storm surge can last:
    A) seconds to minutes.
    B) minutes to hours.
    C) hours to days.
    D) days to weeks.
    E) weeks to months.

STORM SURGE

- Produced by two forces:
  - Low pressure in hurricane eye (small effect)
  - Wind with very high speed (LARGE EFFECT!)
- Not a true wave: a local change in sea level (10 m+)
- May last a few hours - few days (same as hurricane)
- Damage from hurricane-driven waves are amplified!



GOOD LUCK ON MIDTERM 2!