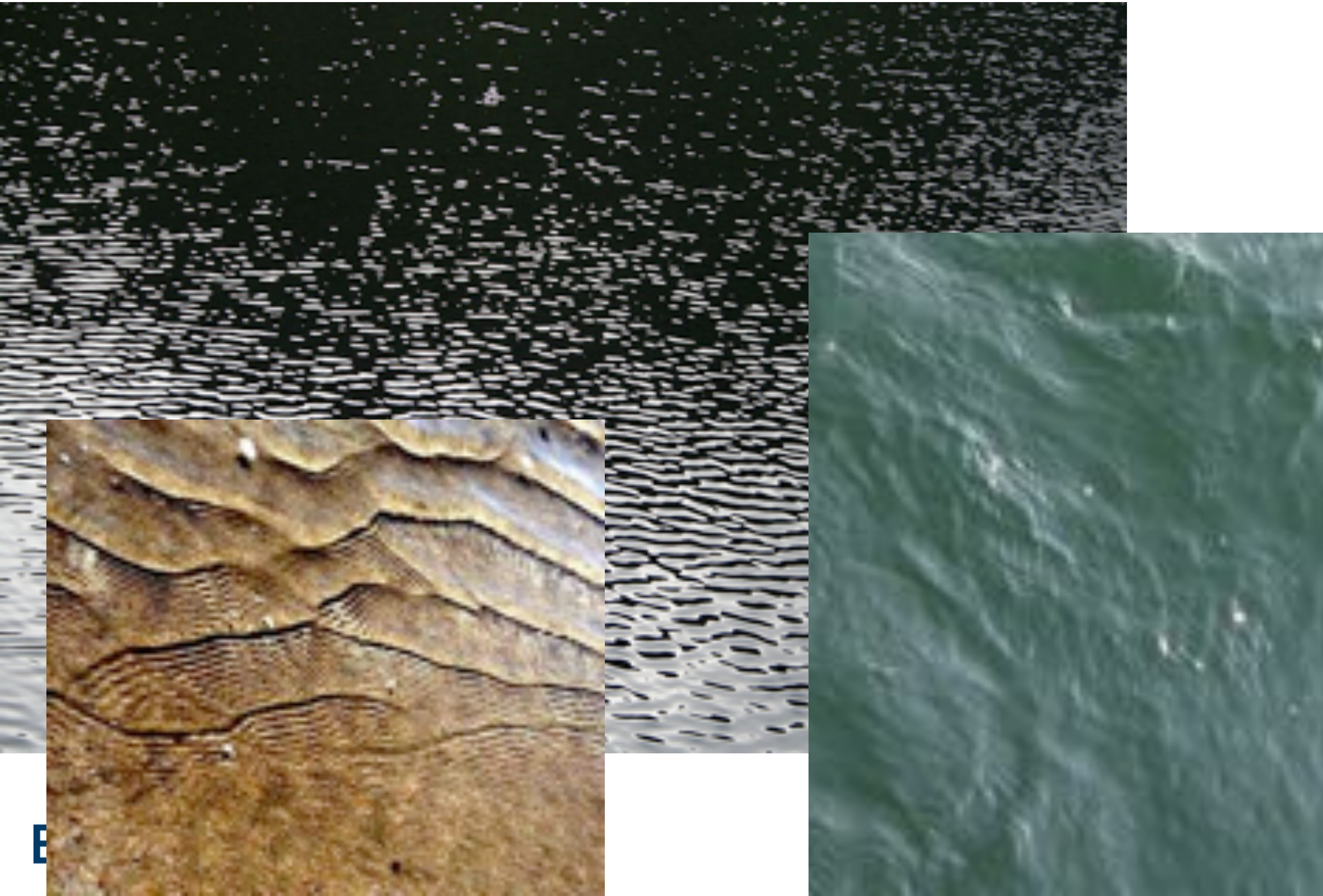
Waves (& Tides)

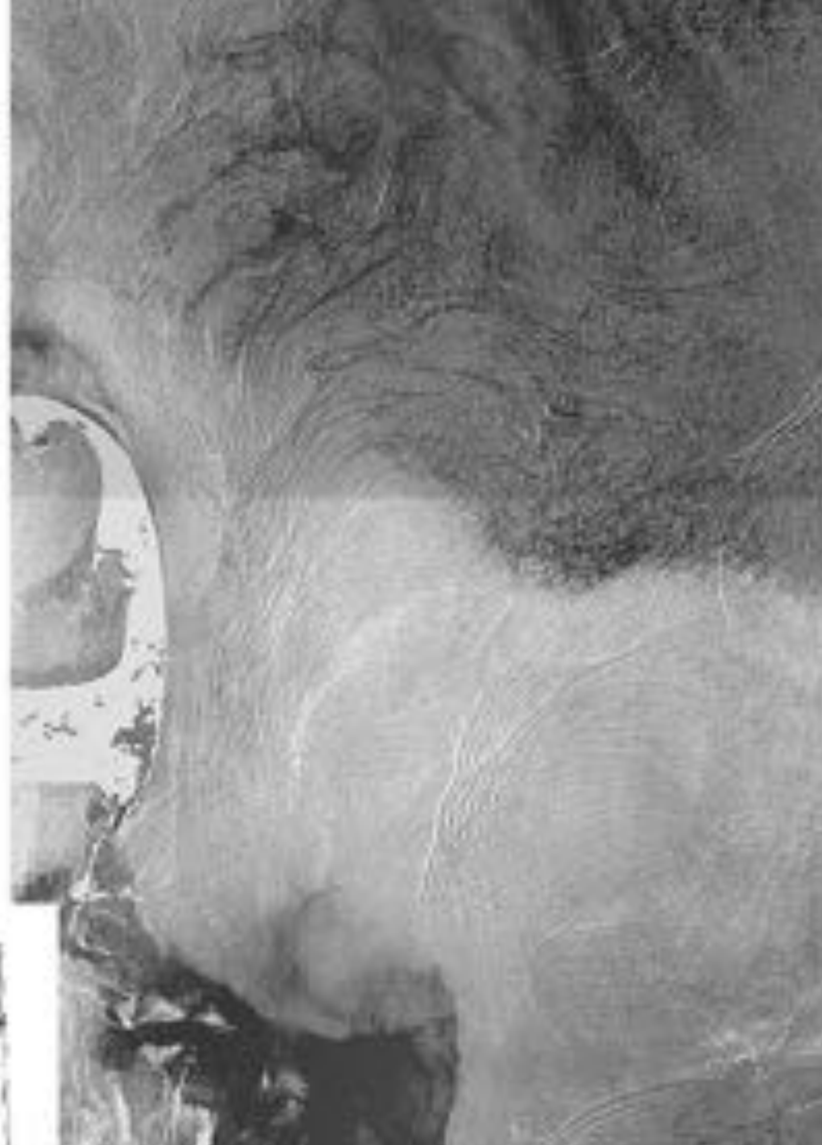
ES 383

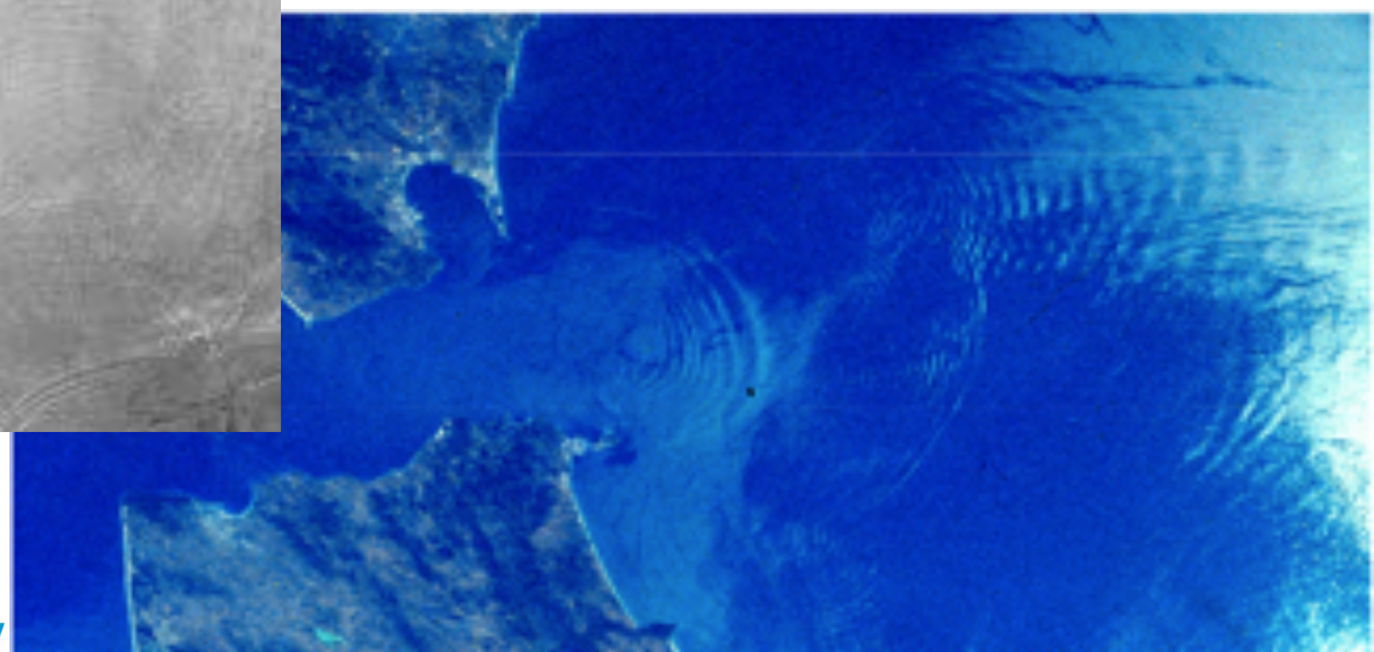
Colby at Bigelow, September 2017

Tiny “Capillary” Waves



Waves we can measure from outer space

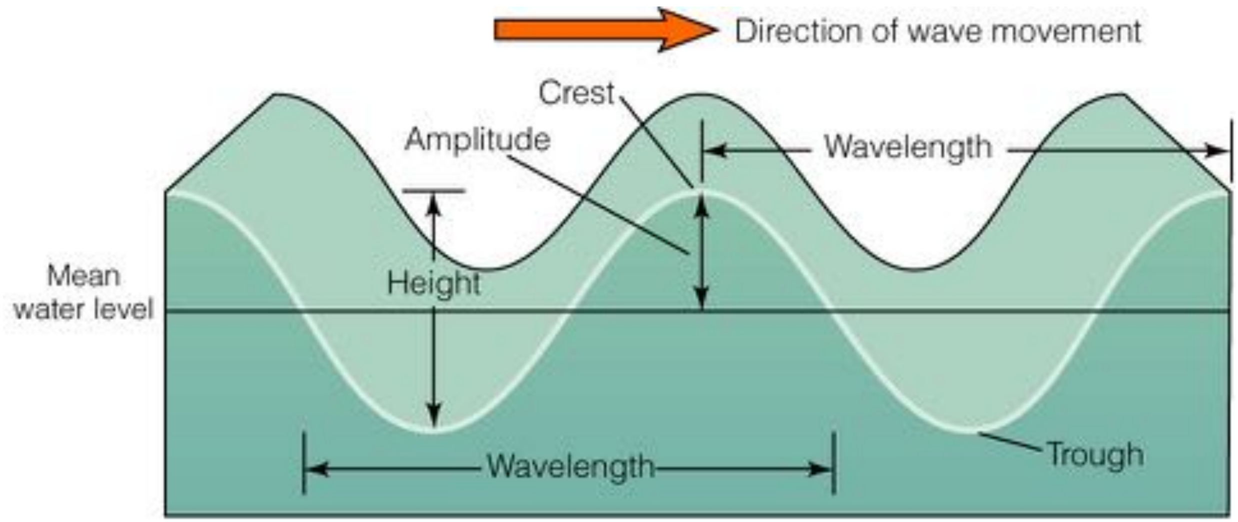




Office of Naval Research 2004

Similar process at all scales

Anatomy of a wave



(a)

period τ	s (i.e. seconds per wave)
frequency $f = 1 / \tau$	1/s (i.e. waves per second)
angular frequency $\omega = 2\pi / \tau$	radians / s
wavelength λ	m
wave speed (celerity) $c = \lambda / \tau$	m / s
wave height $H = 2A$ (A = amplitude)	m
wave steepness $\Delta = H / \lambda$	unitless

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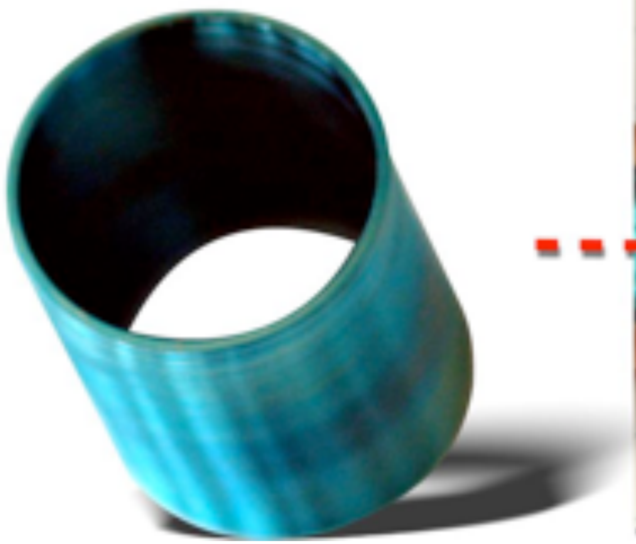
Anatomy of a wave

Displacement + Restoring force



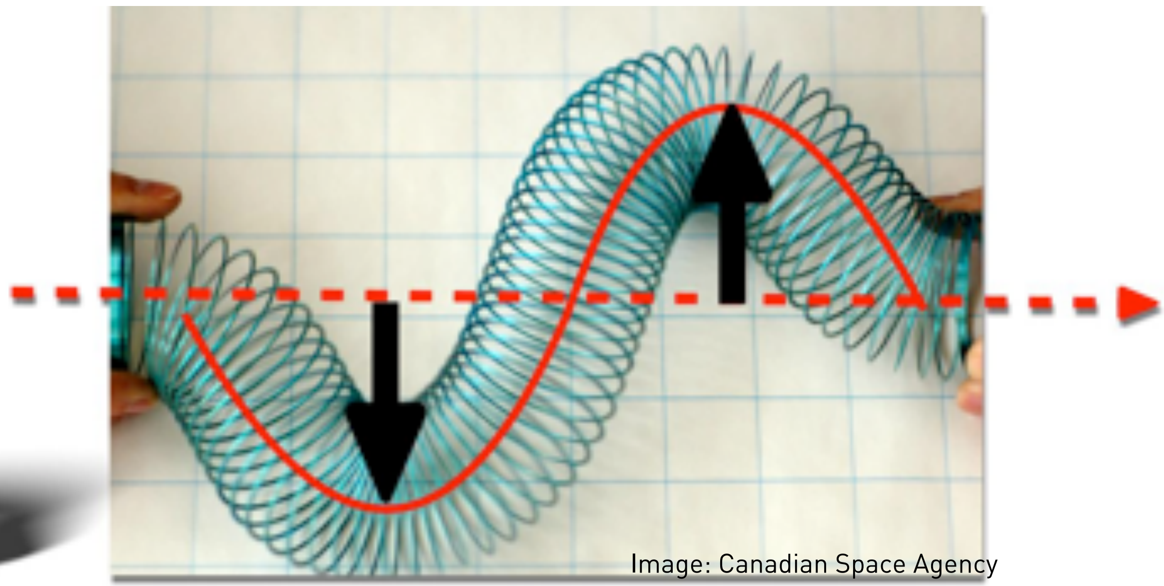


Image: Canadian Space Agency

Some properties of a wave

Diffraction – bending around an object

Refraction– bending due to speed change

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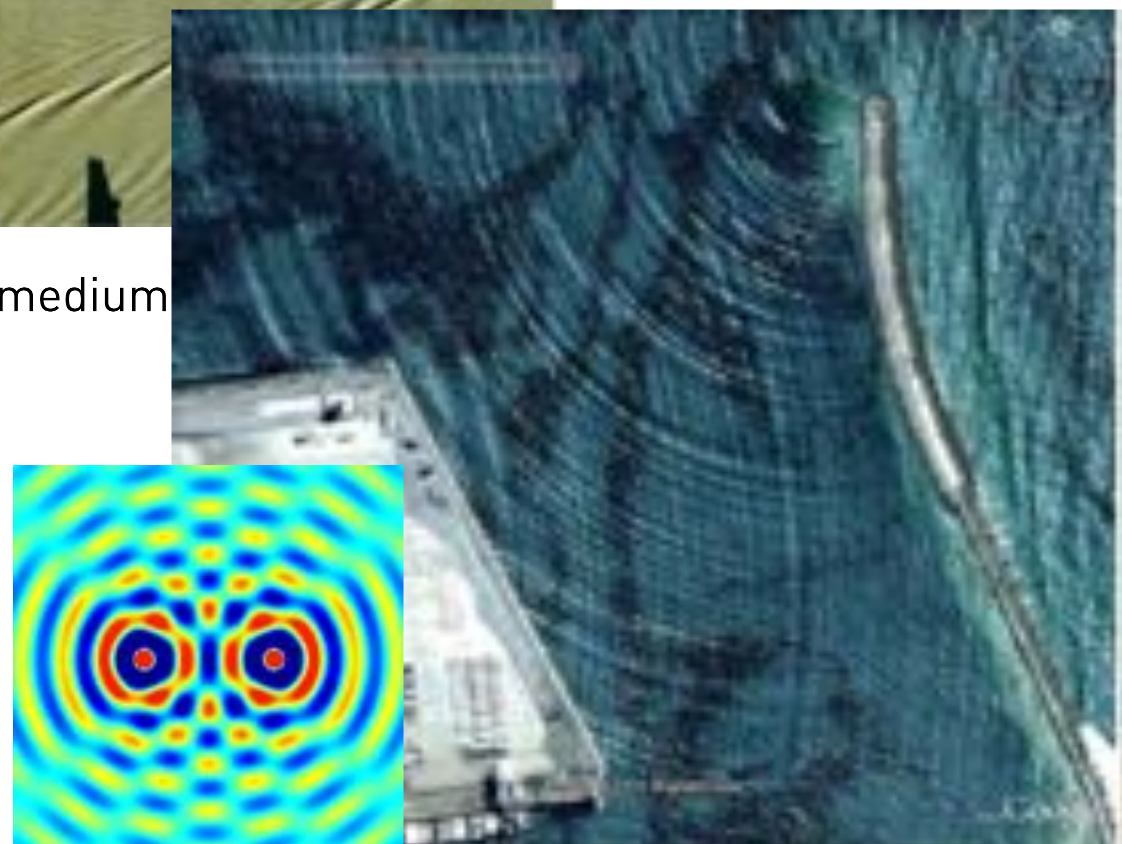
Some properties of a wave

Interference – multiple waves



Reflection – redirected by change in medium

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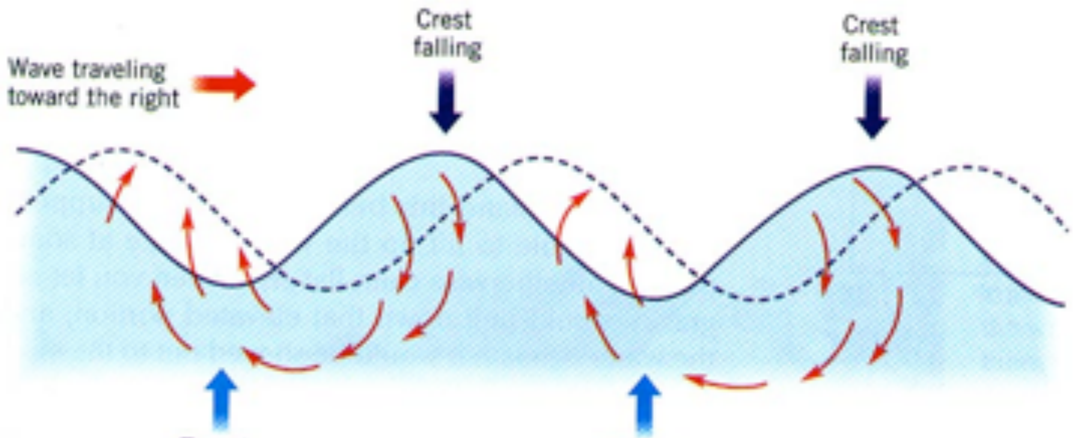
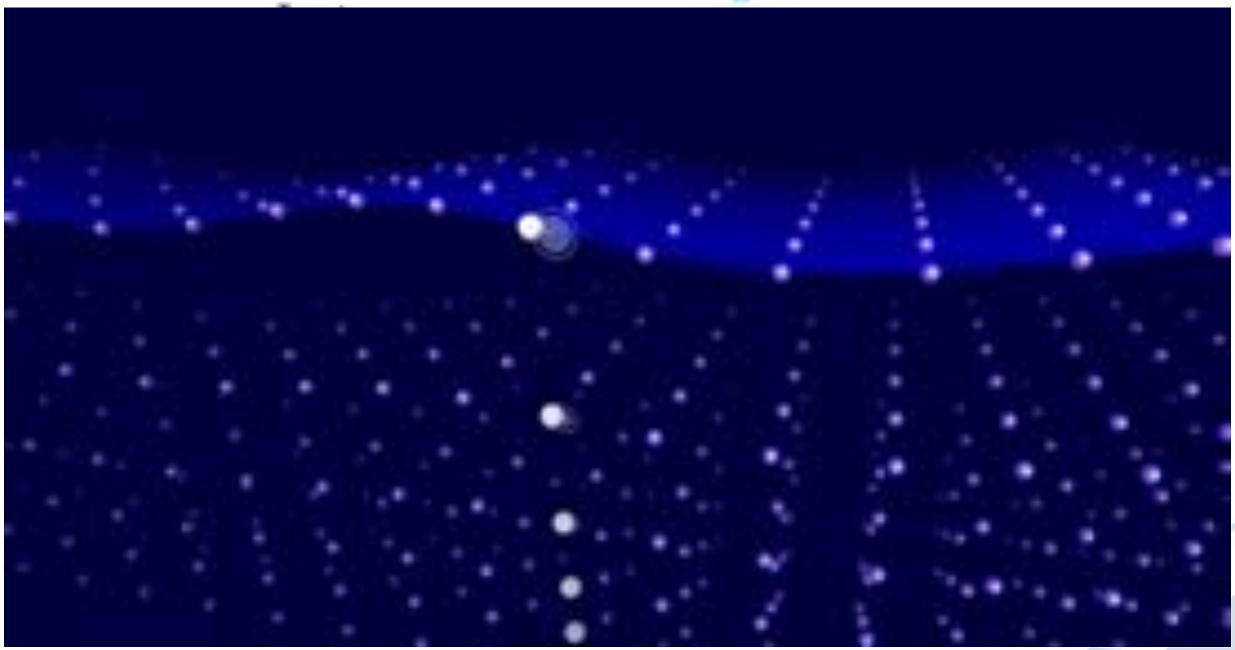
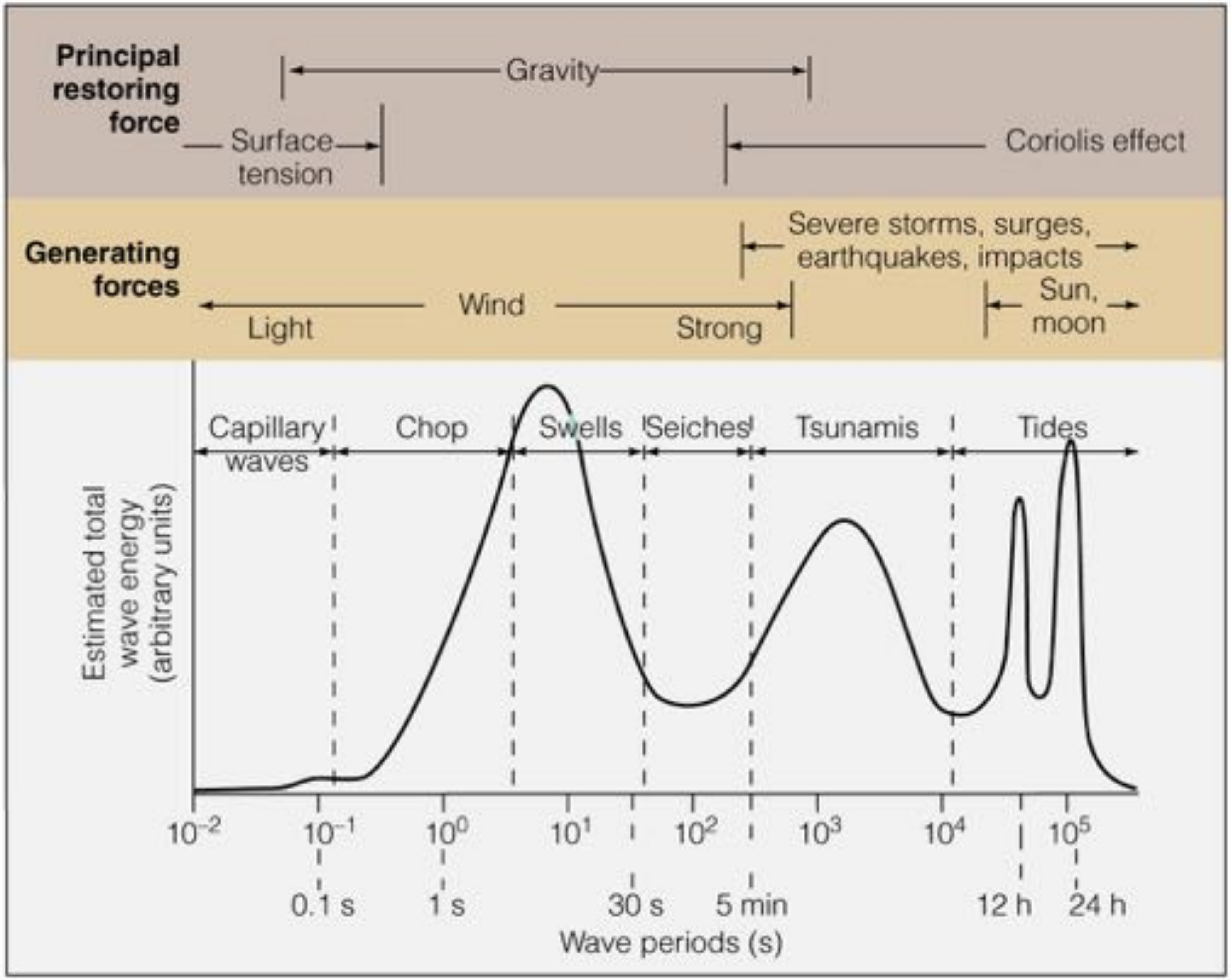




<u>Wave speed ≠ particle speed</u>

Waves propagate energy, not water (mostly)

Waves in the ocean



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Waves classified by generation:

- Meteorological – wind swells, chop, capillary waves
- Geological – tsunamis
- Astronomical – tides

Waves classified by behaviors:

- Deep-water waves $\lambda < 2d$
- Shallow-water waves $20d < \lambda$

(Transitional waves are those in between)

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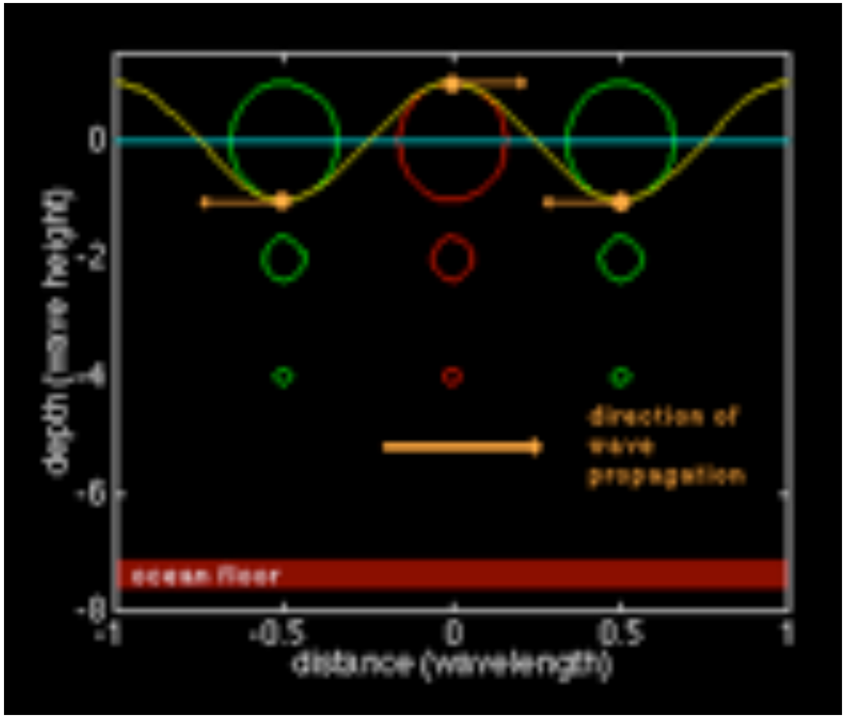
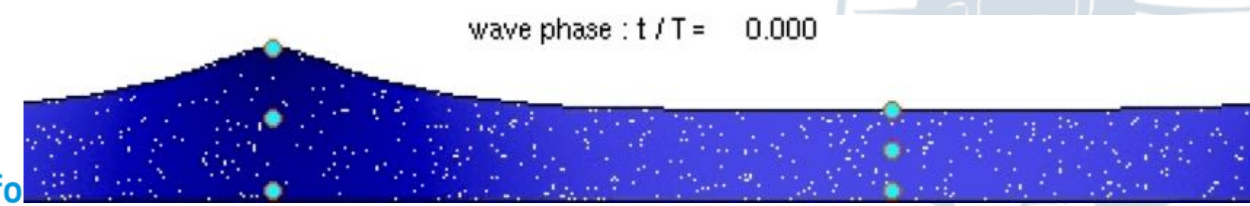


Deep water:

- wavelength = 1 unit
- depth = 7 units
- → wavelength < 2 × depth
- circular orbital motion
- bottom does not influence wave

Shallow water:

- wavelength > 20 × depth
- depth = 1 unit
- elliptical orbital motion
- bottom influences wave



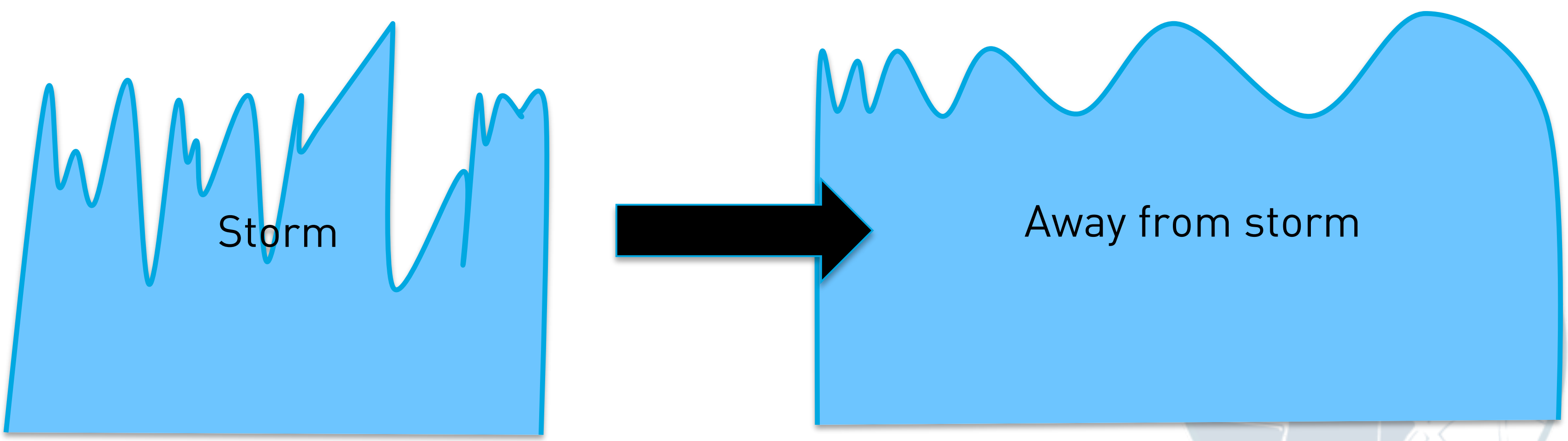
Deep-water waves

- wave speed c = λ / τ m / s

- For deep water waves, speed is related to wavelength:

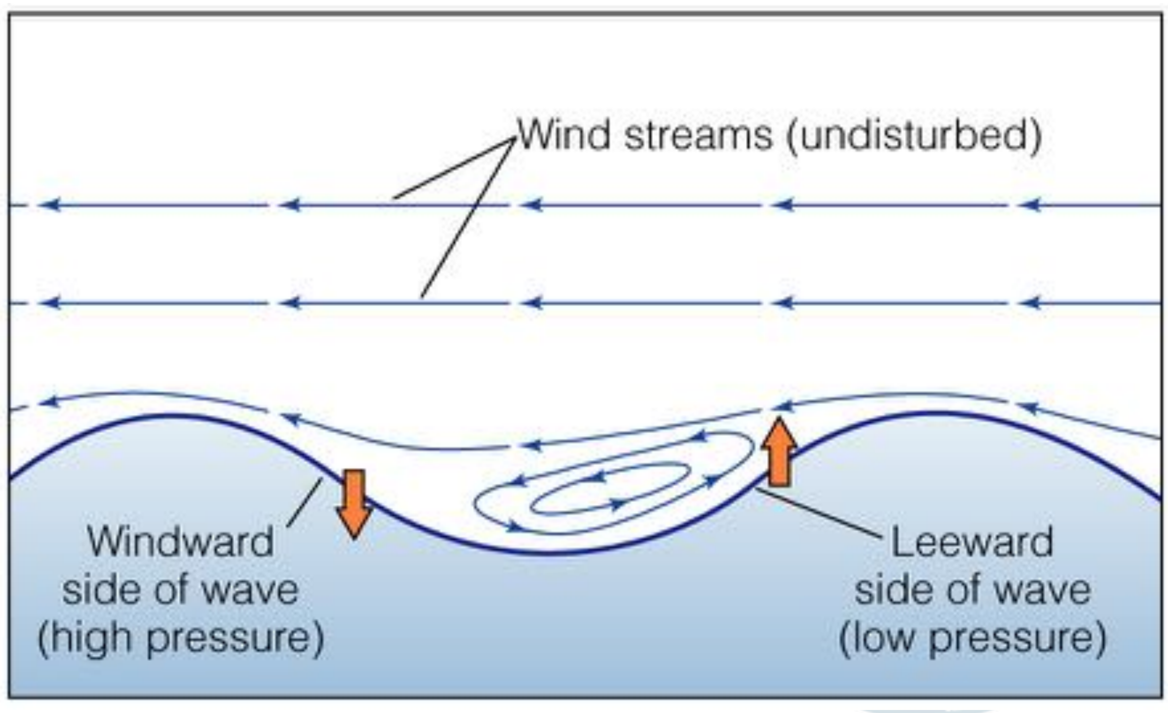
$$c \approx 1.25 \times \sqrt{\lambda}$$

(only works for wavelength in meters – otherwise convert)



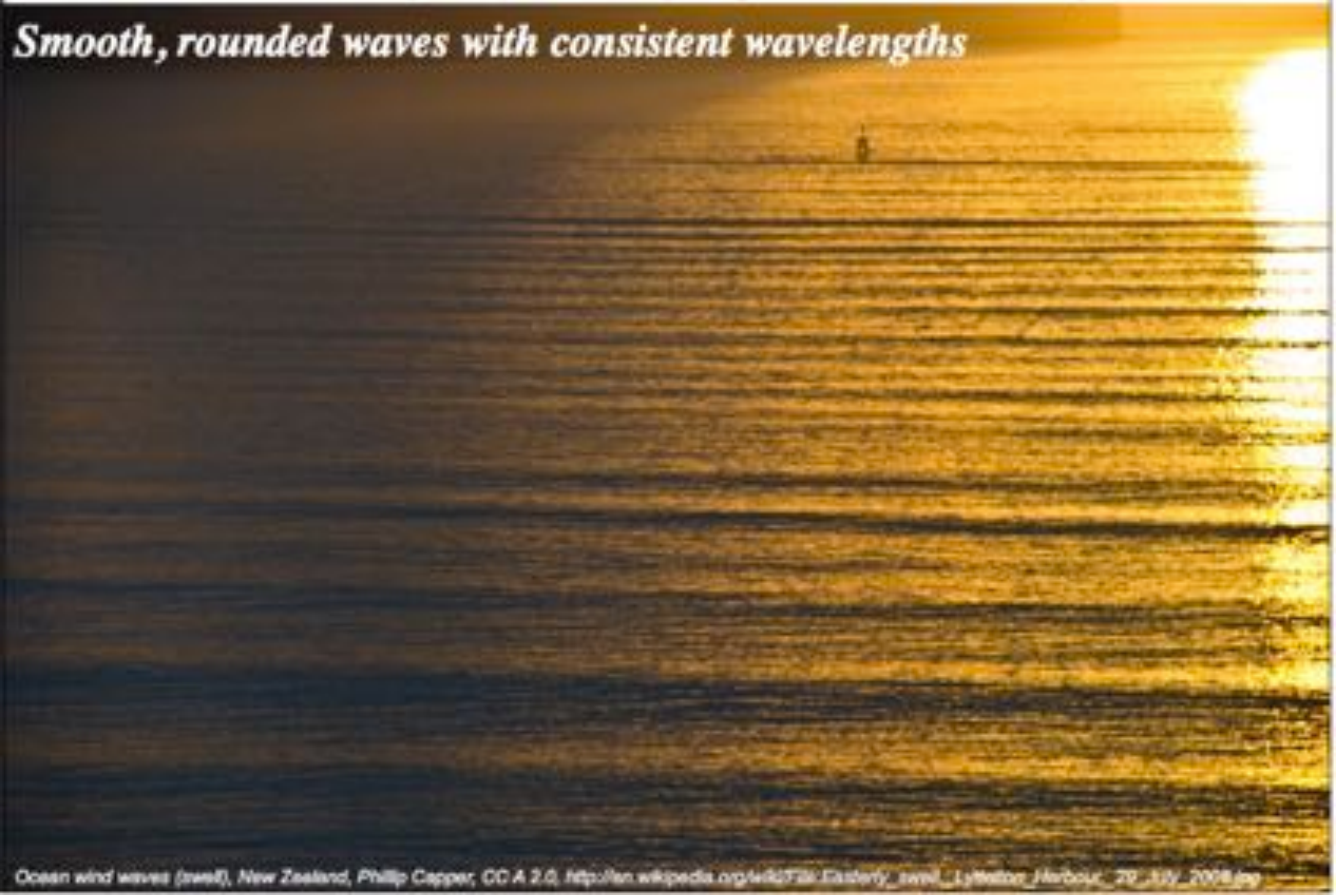
Deep water waves

Most wind waves are deep water waves
Size of waves depends on:
- fetch (distance across which wind blows)
- duration (length of time wind blows)
- wind speed

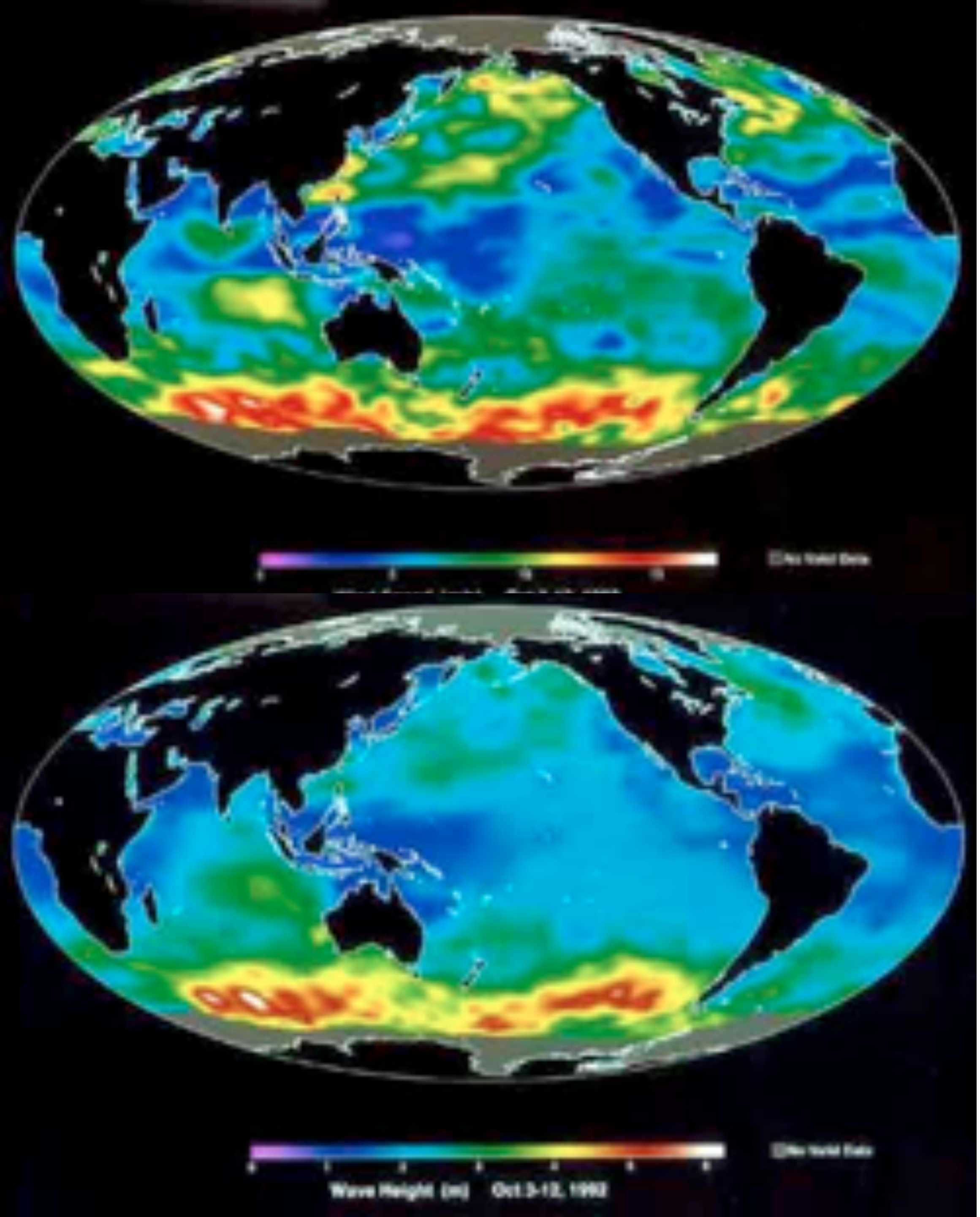


Swell: waves that have left their birthplace
Sorted by dispersion (longest move fastest)

Slide credit:
E. Schauble




Choppy waves with whitecaps
Wind sea, N. Pacific, Winter 1989, M/V NOBLE STAR/
NOAA, Public Domain, http://commons.wikimedia.org/
wiki/File:Wea00816.jpg



Global correlation between Wind speed & Wave height

TOPEX/Poseidon satellite measurements

Shallow-water waves

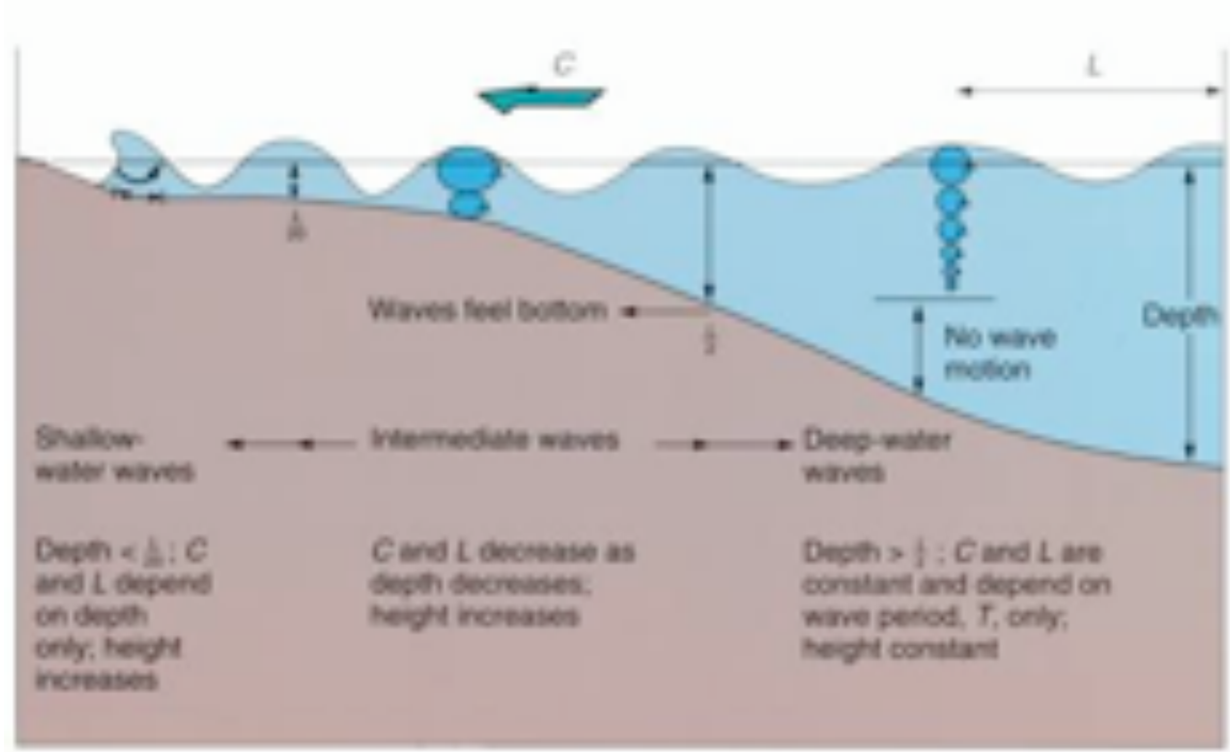
- wave speed c = λ / τ m / s

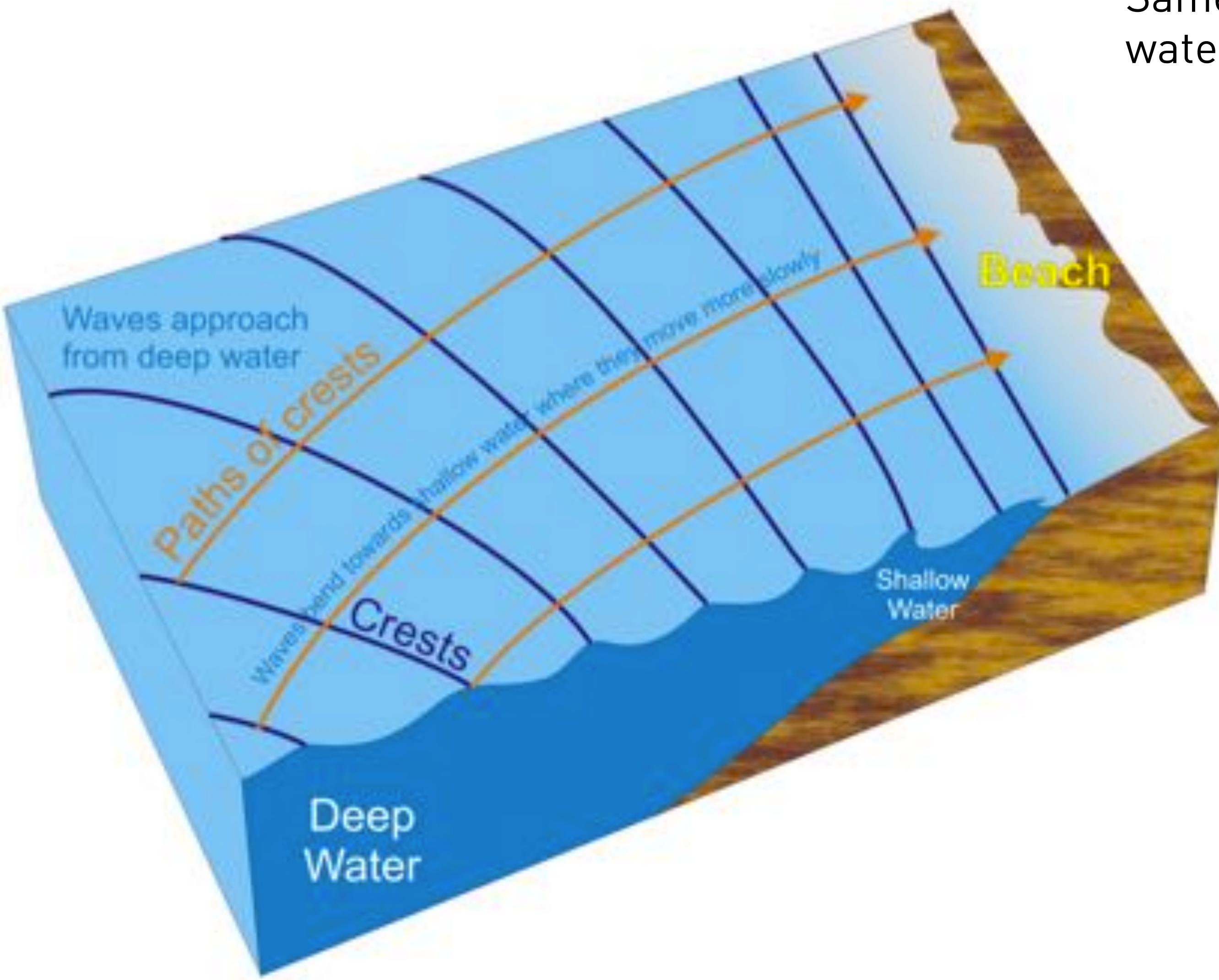
- For shallowwater waves, speed is related to water depths:

$$c = \sqrt{gd} \approx 3.1 \times \sqrt{d}$$

(only works for depth in meters – otherwise convert)

Waves slow down as they begin to “feel” bottom





Recall that all waves bend toward where speed is slowest

Same for shallow-water waves

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Shallow-water waves: Tsunamis

- The name “tidal wave” is a bit of a misnomer (nothing to do with tides)
- “Tsunami” translates to “harbor wave”
- Caused by earthquakes & landslides (and meteorites)
- Can cross entire oceans rapidly
- ***Why are they shallow-water waves?***

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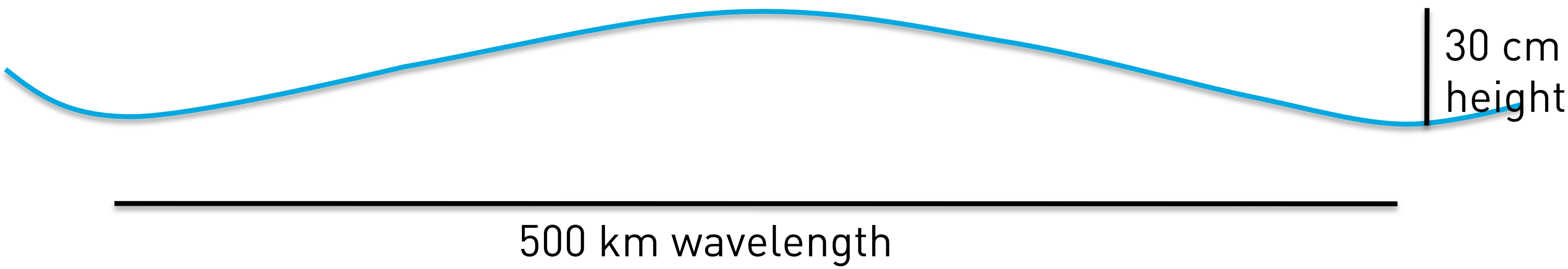
Shallow-water waves: Tsunamis

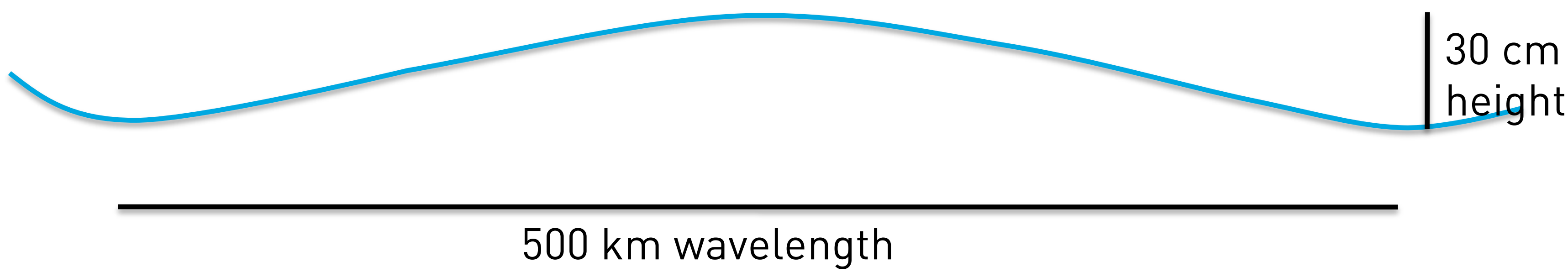
- ***Why are they shallow-water waves?***



Deepest part of the ocean: 10 km
$20d$ = 200 km < λ

Shallow-water waves: Tsunamis

- ***Why are they shallow-water waves?***



Wave speed $\approx$ sqrt(g d) $= \text{sqrt}(9.8\ \text{m s}^{-2}\ 4000\ \text{m})$
$= 200$ m / s

$$200\ \frac{\text{m}}{\text{s}} \times \frac{1\ \text{km}}{1000\ \text{m}} \times \frac{3600\ \text{s}}{\text{h}} = 720\ \text{km/hr}$$

Shallow-water waves: Tsunamis

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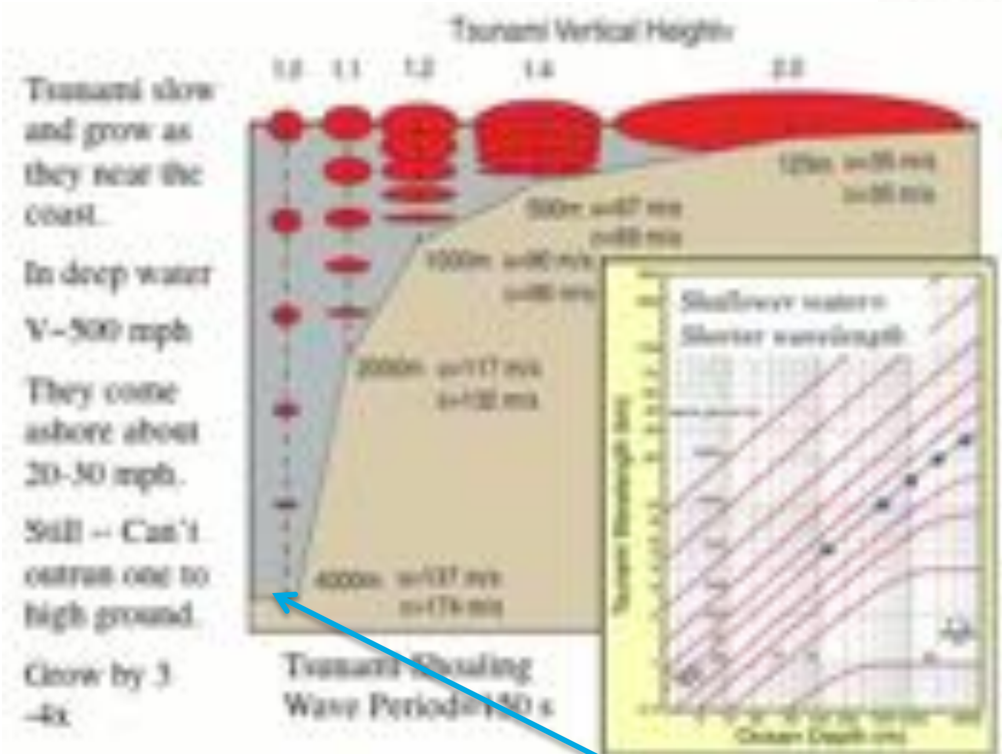
Shallow-water waves: Tsunamis



Orbital currents reach 1000s of meters to sea floor

Stephen Ward, USCS

Shallow-water waves: Tsunamis

By the time it reaches the coast, the wave has already essentially broken

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Shallow-water waves: Tsunamis

Shallow-water waves: Tsunamis

http://news.nationalgeographic.com/news/2011/03/pictures/110315-nuclear-reactor-japan-tsunami-earthquake-world-photos-meltdown/?rptregcta=reg_free_np&rptregcampaign=20130924_rw_membership_n1p_w#/japan-earthquake-tsunami-nuclear-unforgettable-pictures-houses_33282_600x450.jpg

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Tsunami waves

- http://news.nationalgeographic.com/news/2011/03/pictures/110324-japan-tsunami-pictures-new-fukushima-science-world/#/japan-tsunami-earthquake-new-pictures-before_33636_600x450.jpg
- http://news.nationalgeographic.com/news/2011/03/pictures/110315-nuclear-reactor-japan-tsunami-earthquake-world-photos-meltdown/?rptregcta=reg_free_np&rptregcampaign=20130924_rw_membership_n1p_w#/japan-earthquake-tsunami-nuclear-unforgettable-pictures-houses_33282_600x450.jpg
- http://news.nationalgeographic.com/news/2010/03/photogalleries/100301-chile-earthquake-tsunami-quake-pictures/#/chile-earthquake-tsunami-beach-debris_13228_600x450.jpg

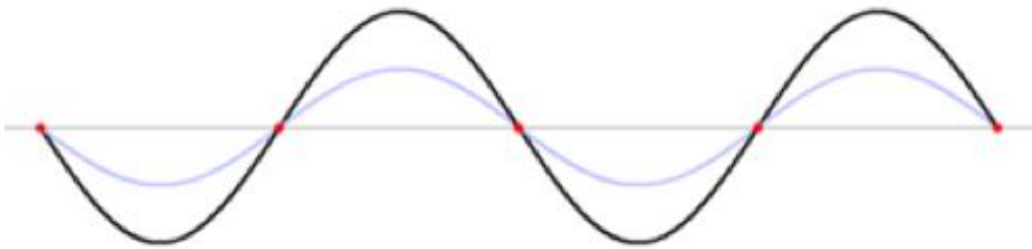
Hypothetical tsunamis

http://www.youtube.com/watch?v=7c4bPuaA1wE&list=UUypN3QKwo-Fajp391i0IQ0A&index=20&feature=plcp

http://www.youtube.com/watch?v=DeHmbhrEEmQ&list=UUypN3QKwo-Fajp391i0IQ0A&index=18&feature=plcp

Other waves

Standing waves: Seiche



http://www.youtube.com/watch?v=NpEevfOU4Z8

http://www.lakesuperiorstore.com/nosta/weather.ht

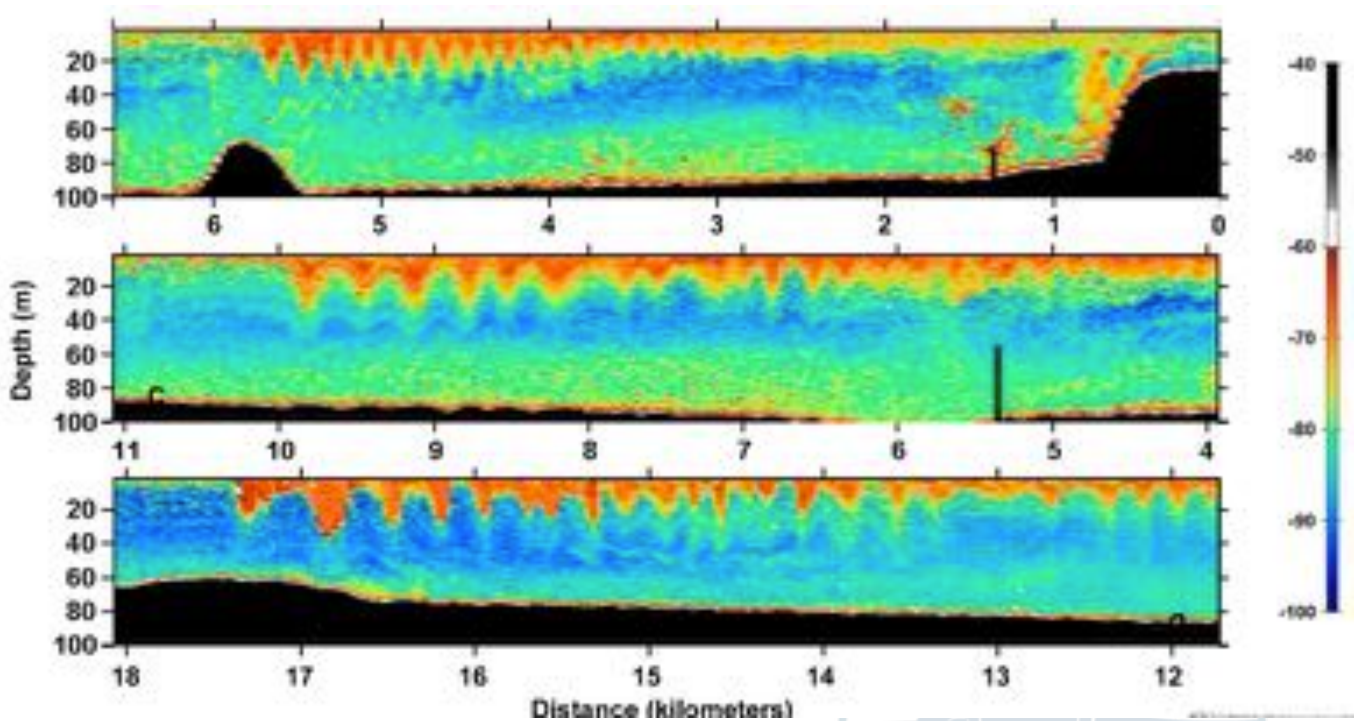
Other waves

Standing waves: Seiche

Sort of like a ~30-min tide
Lake Superior

http://www.paddlinglight.com/articles/great-lakes-seiche-the-joys-of-kayaking-on-the-big-lakes/

Other waves: internal waves



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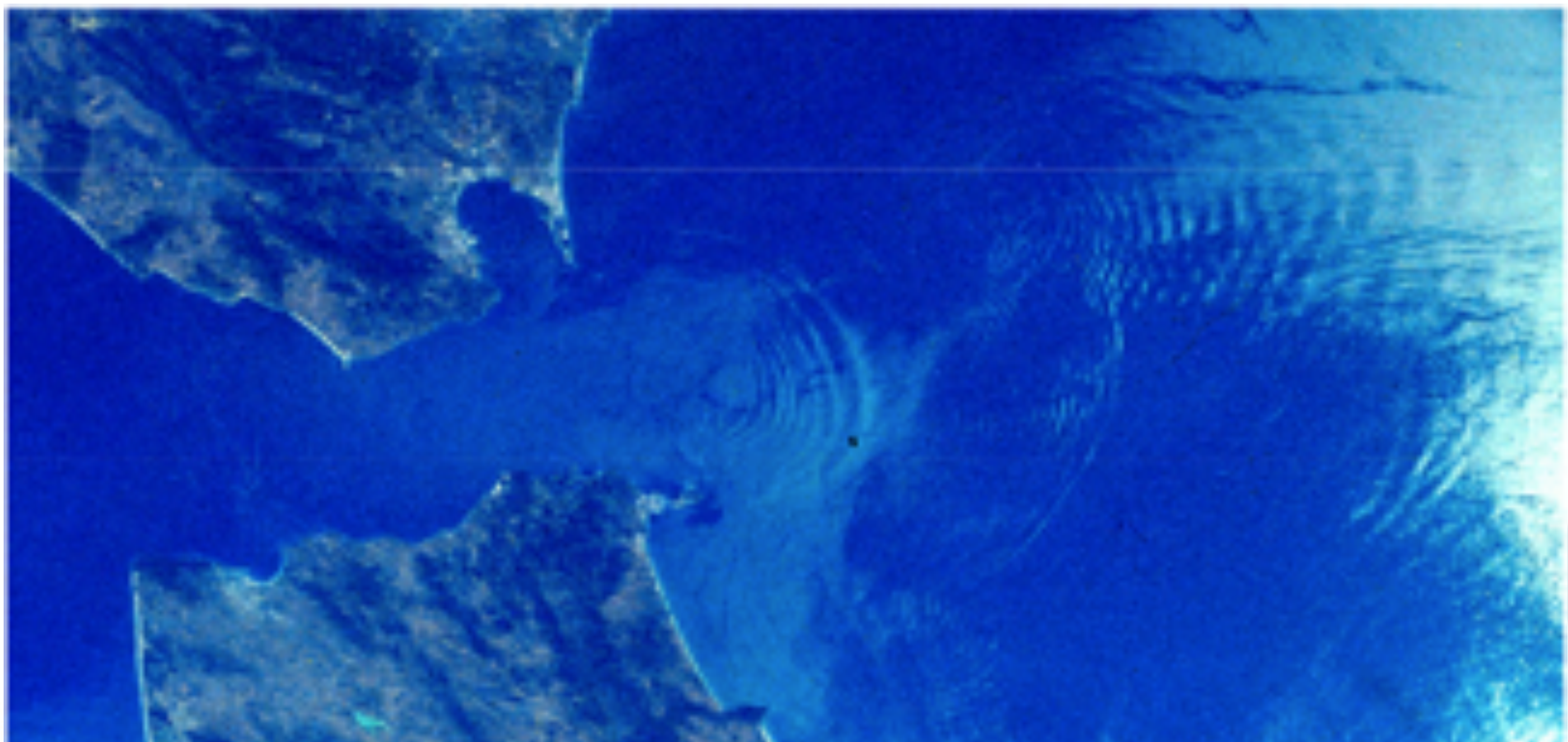
Other waves: internal waves

Internal waves in the atmosphere

M. Tomczak

Other waves: internal waves



Other waves: internal waves

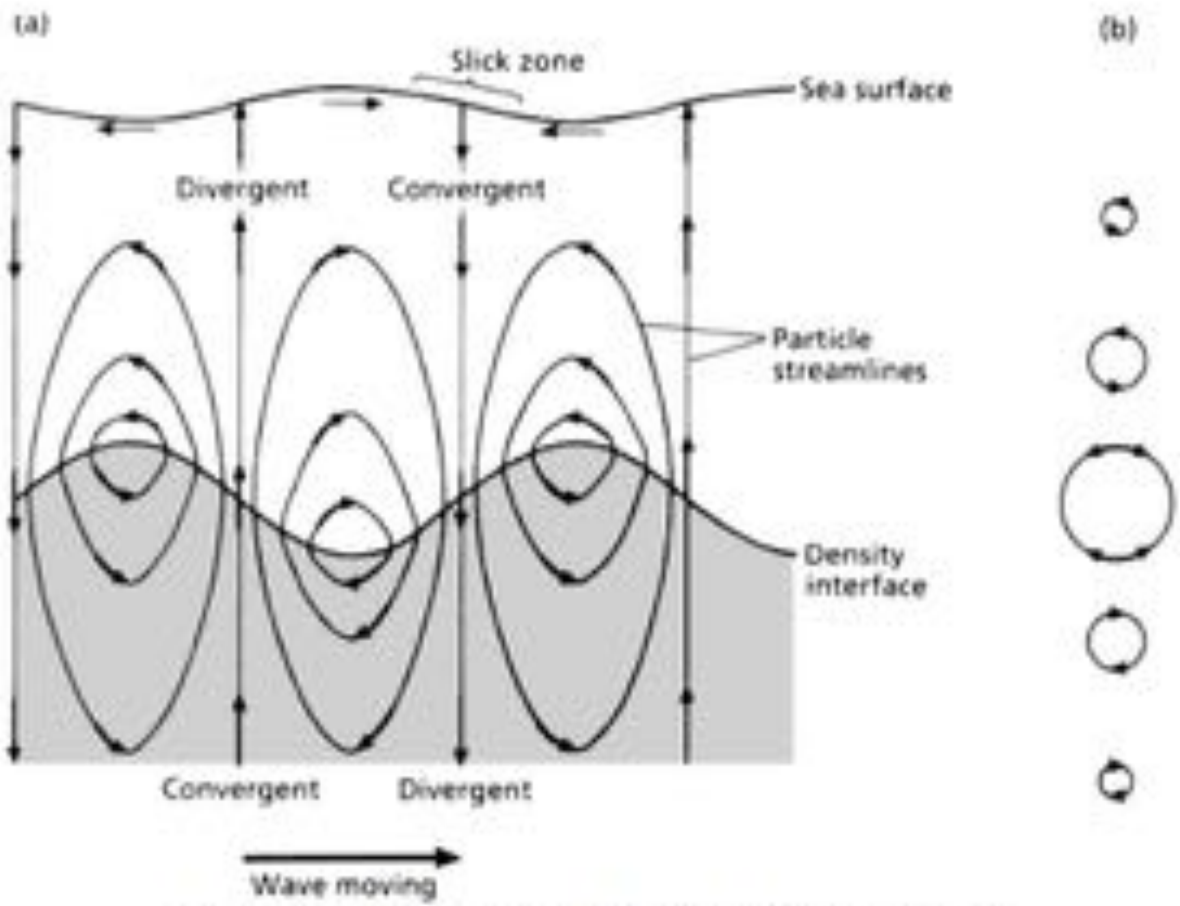
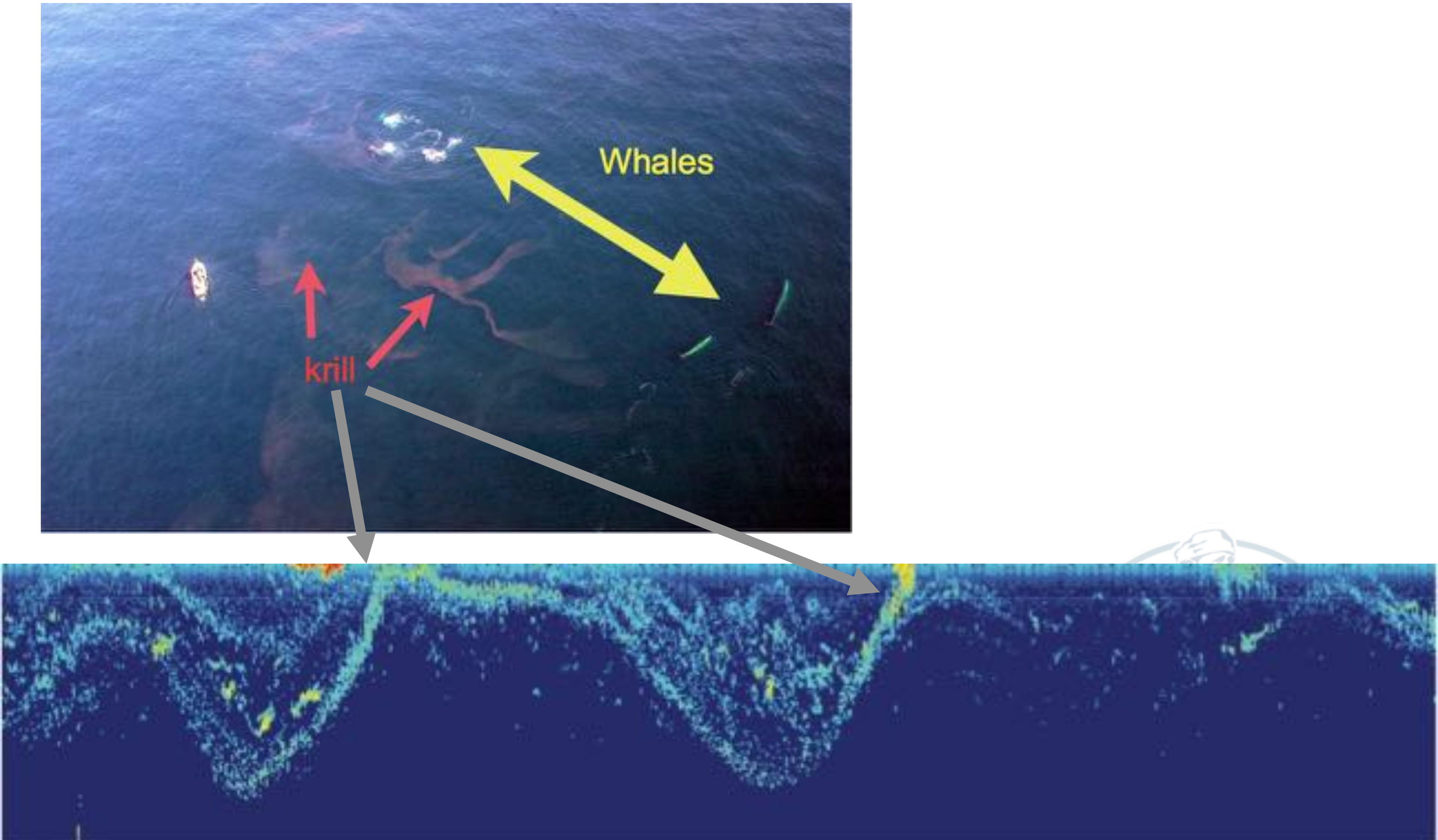


figure 7.08 from Mann and Lazier

Other waves: internal waves

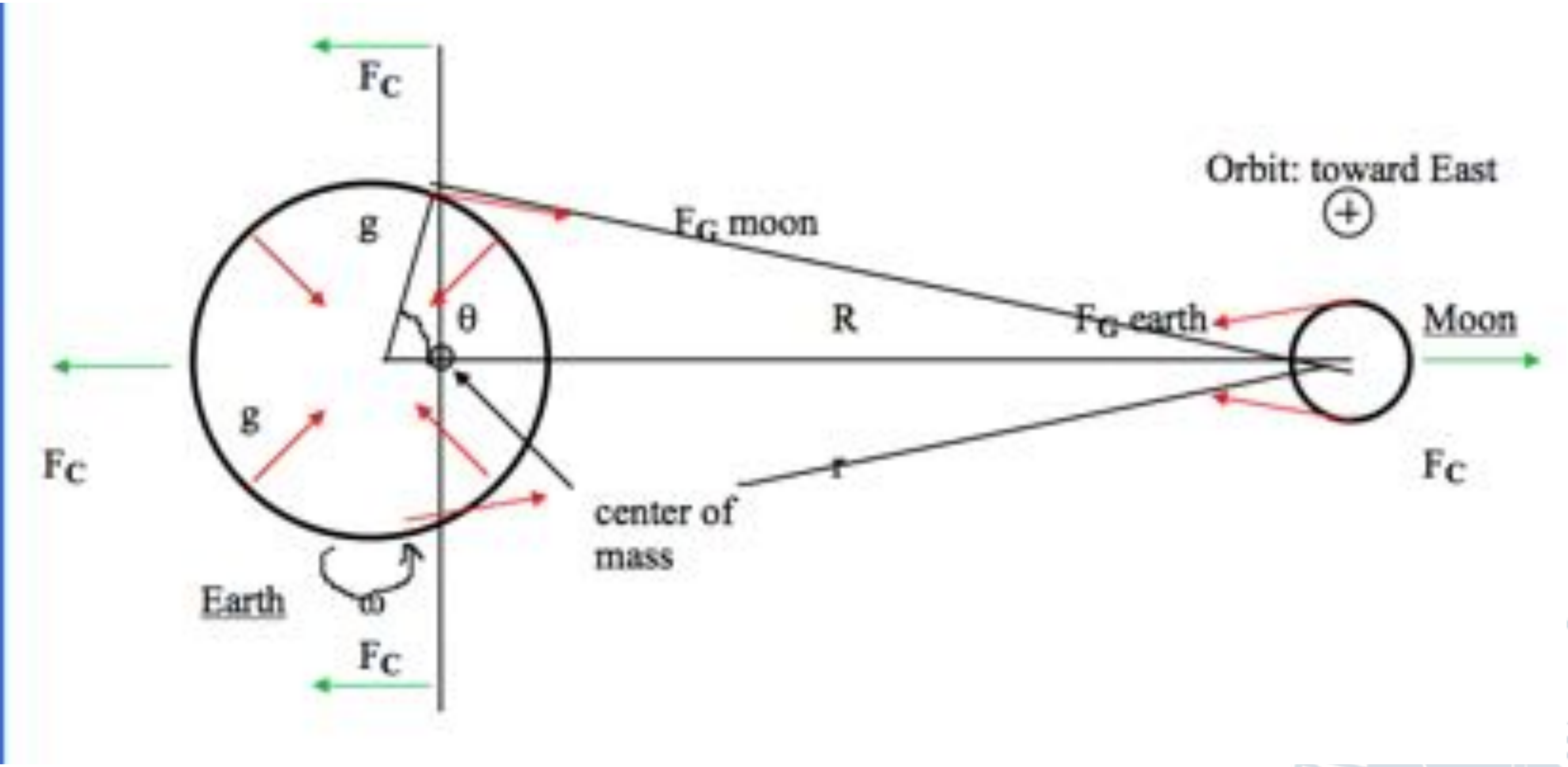
M. Tomczak

Other waves: internal waves



Images courtesy of L Incze, P. Stetson

Tides


F_C
Orbit: toward East
F_G moon
g
θ
R
F_G earth
Moon
g
F_C
F_C
r
center of
mass
Earth
ω
F_C

http://www.youtube.com/watch?v=Qe5fgdXiDbg

Lunar Tide

Diurnal tide: 1 rotation of earth + the moon has moved somewhat

= 24.84 hours (24 hours, 50.5 minutes)

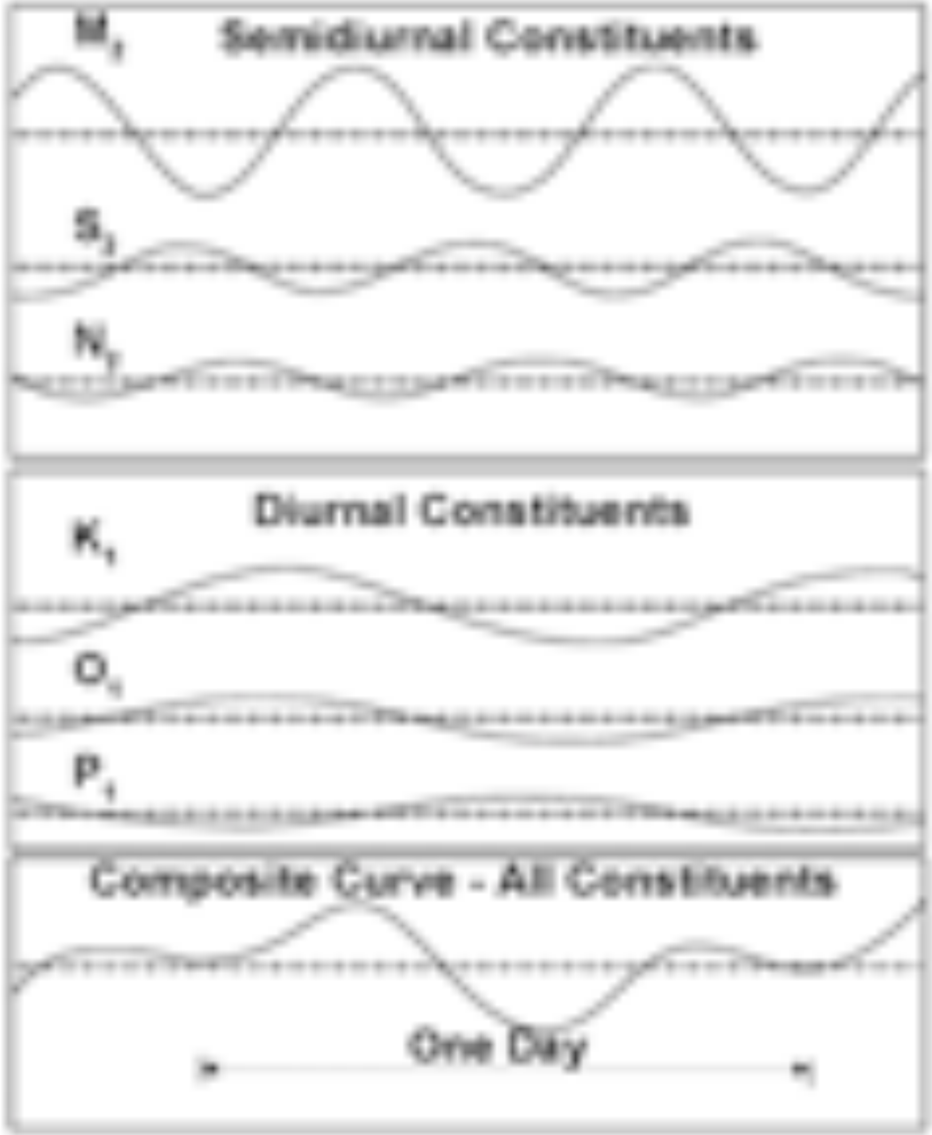
Semidiurnal tide (because there are two bulges): half diurnal

= 12.42 hours (12 hours 25.25 minutes)

Solar Tide

Similar, but very close to 12 & 24 hour period

TIDAL PREDICTIONS



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wikipedia.com

Tides align on a fortnightly basis

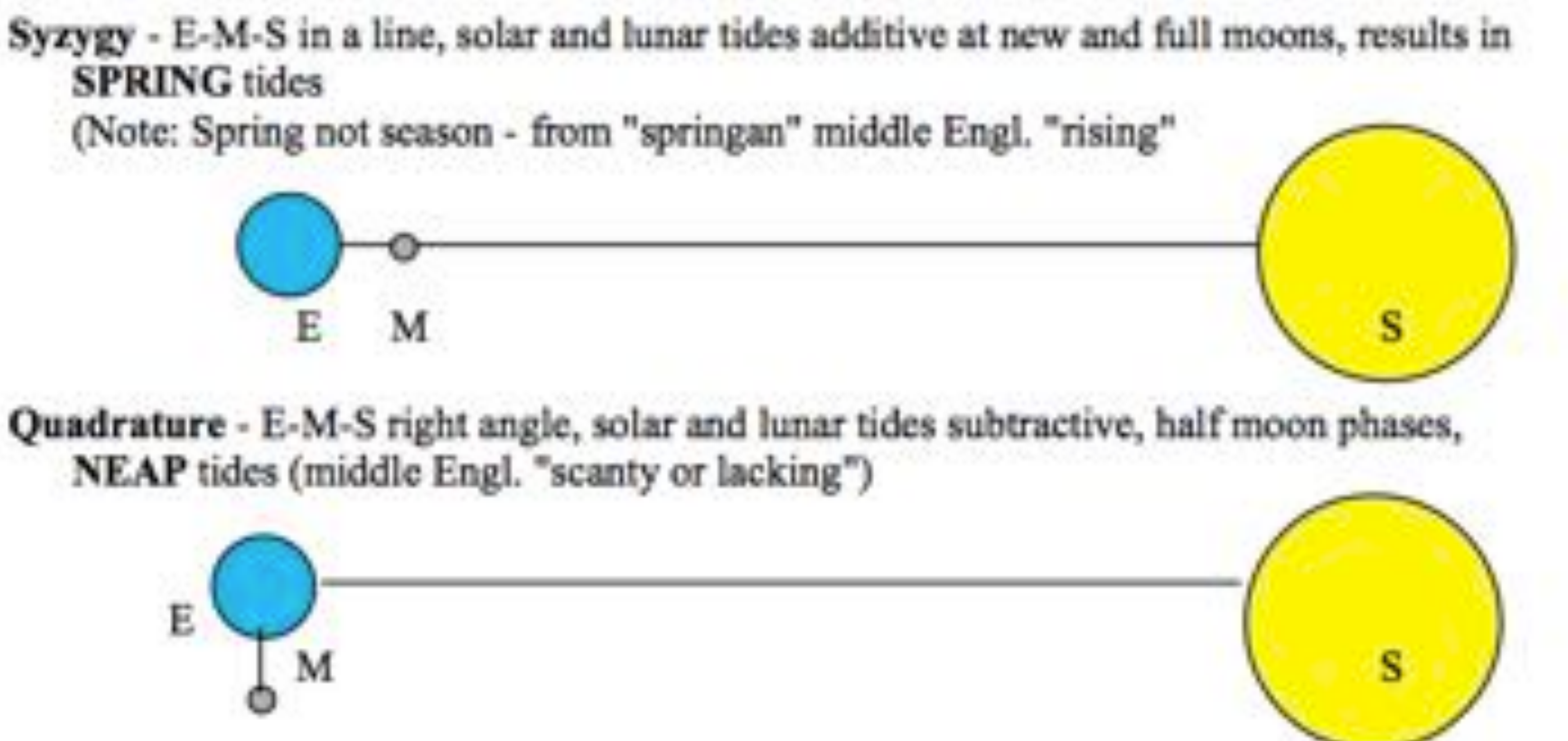
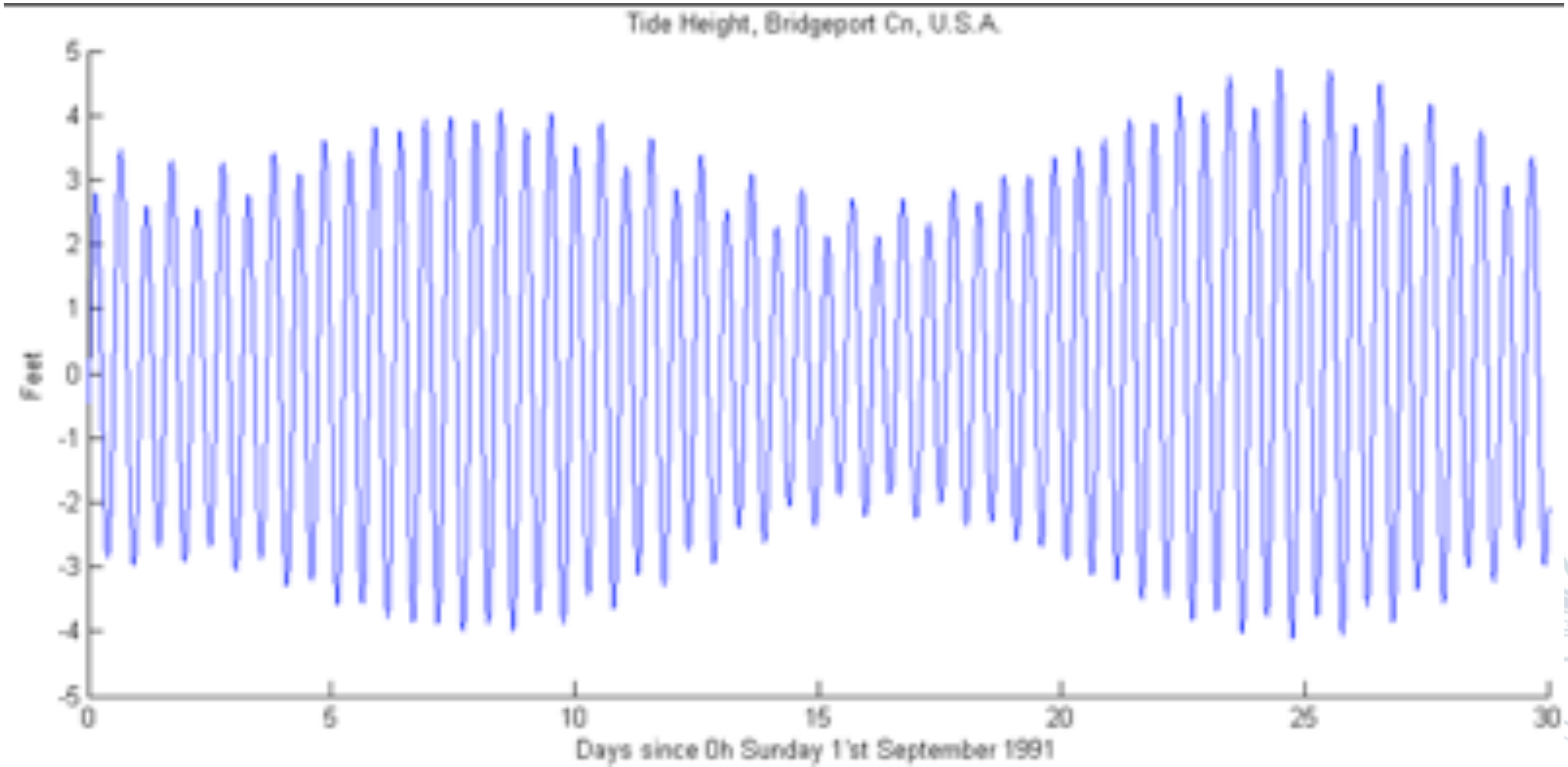


Figure: D. Belknap

Tides align on a fortnightly basis



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Tides align on a fortnightly basis

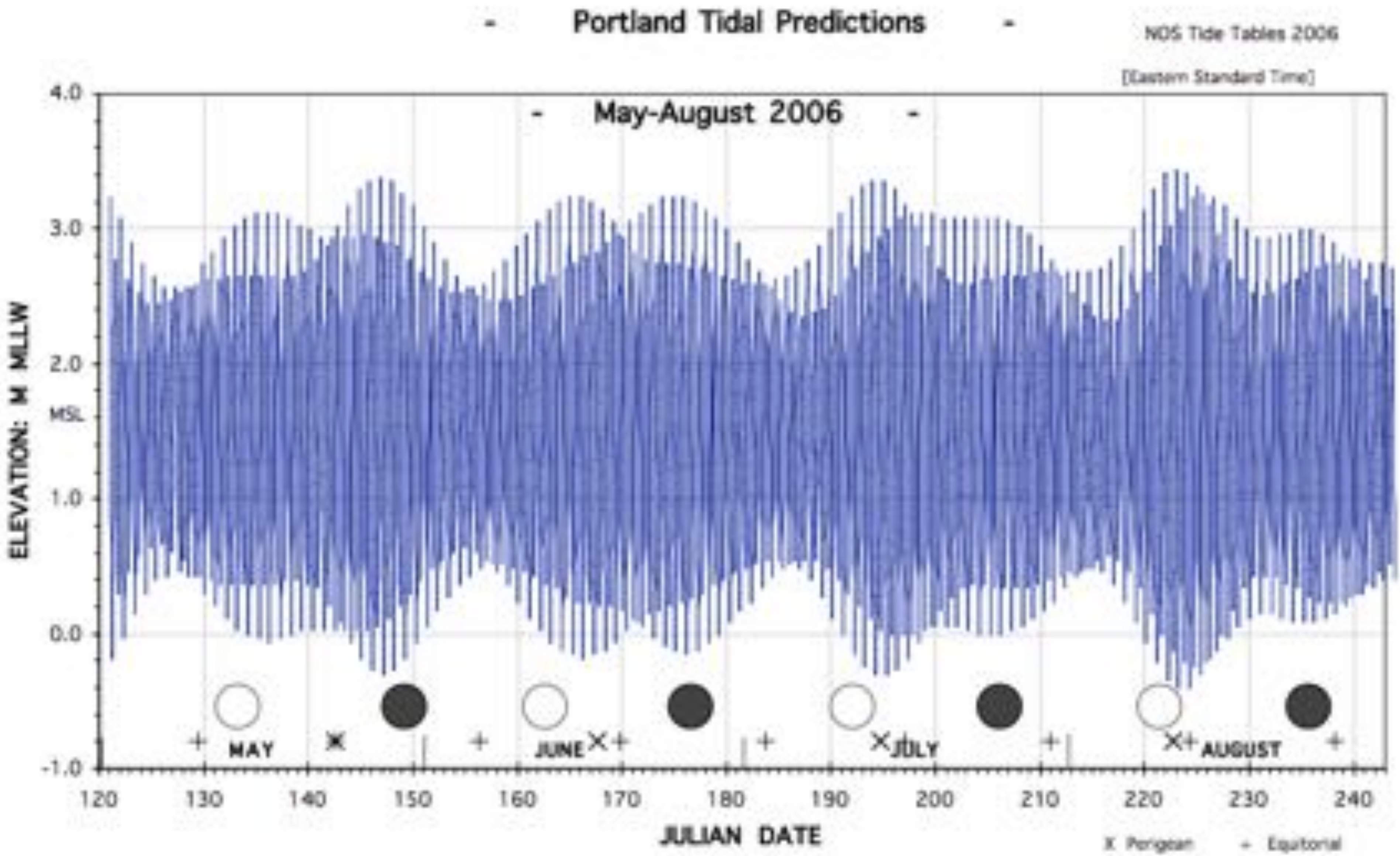
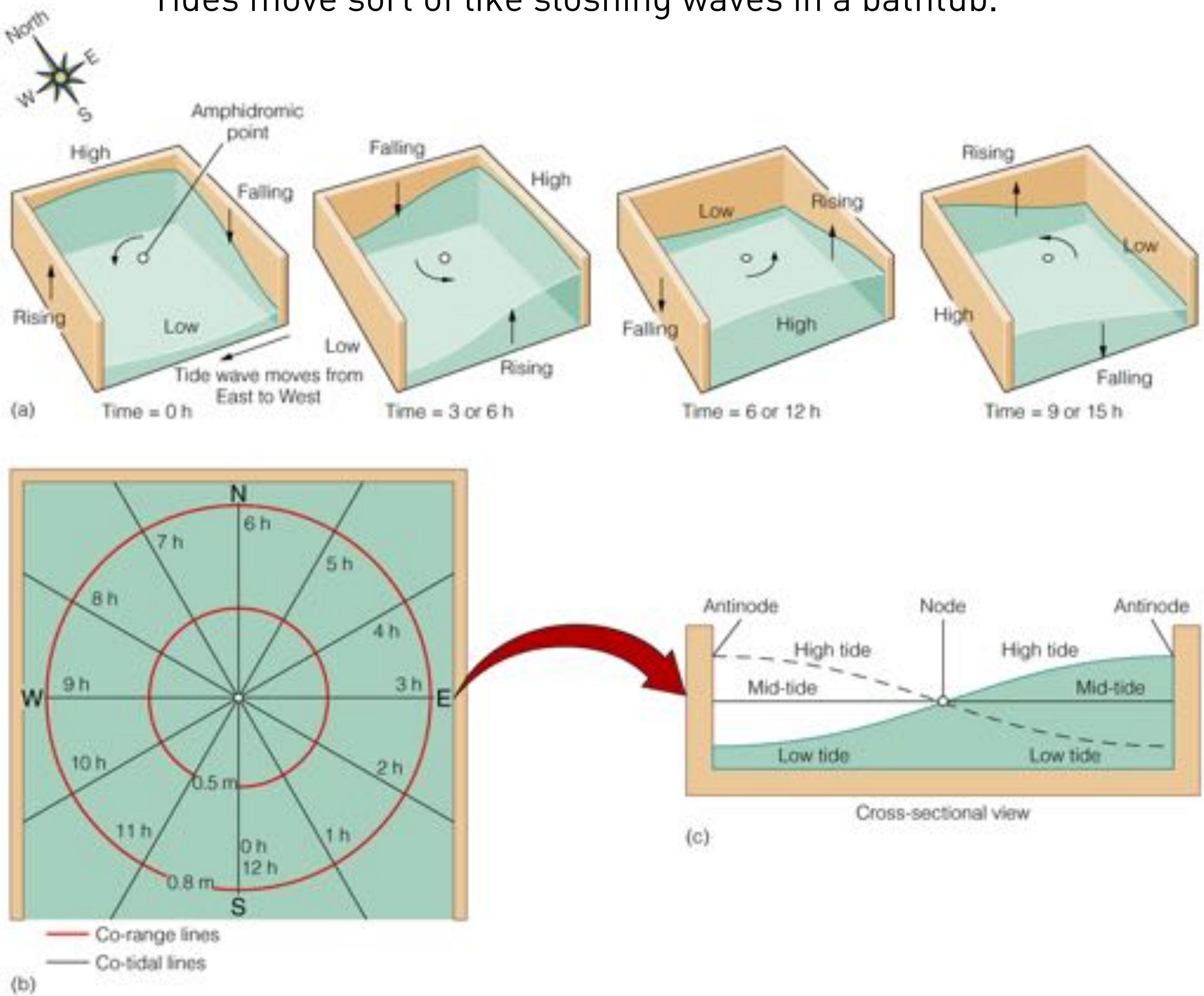


Figure: D. Belknap

Tides move sort of like sloshing waves in a bathtub.



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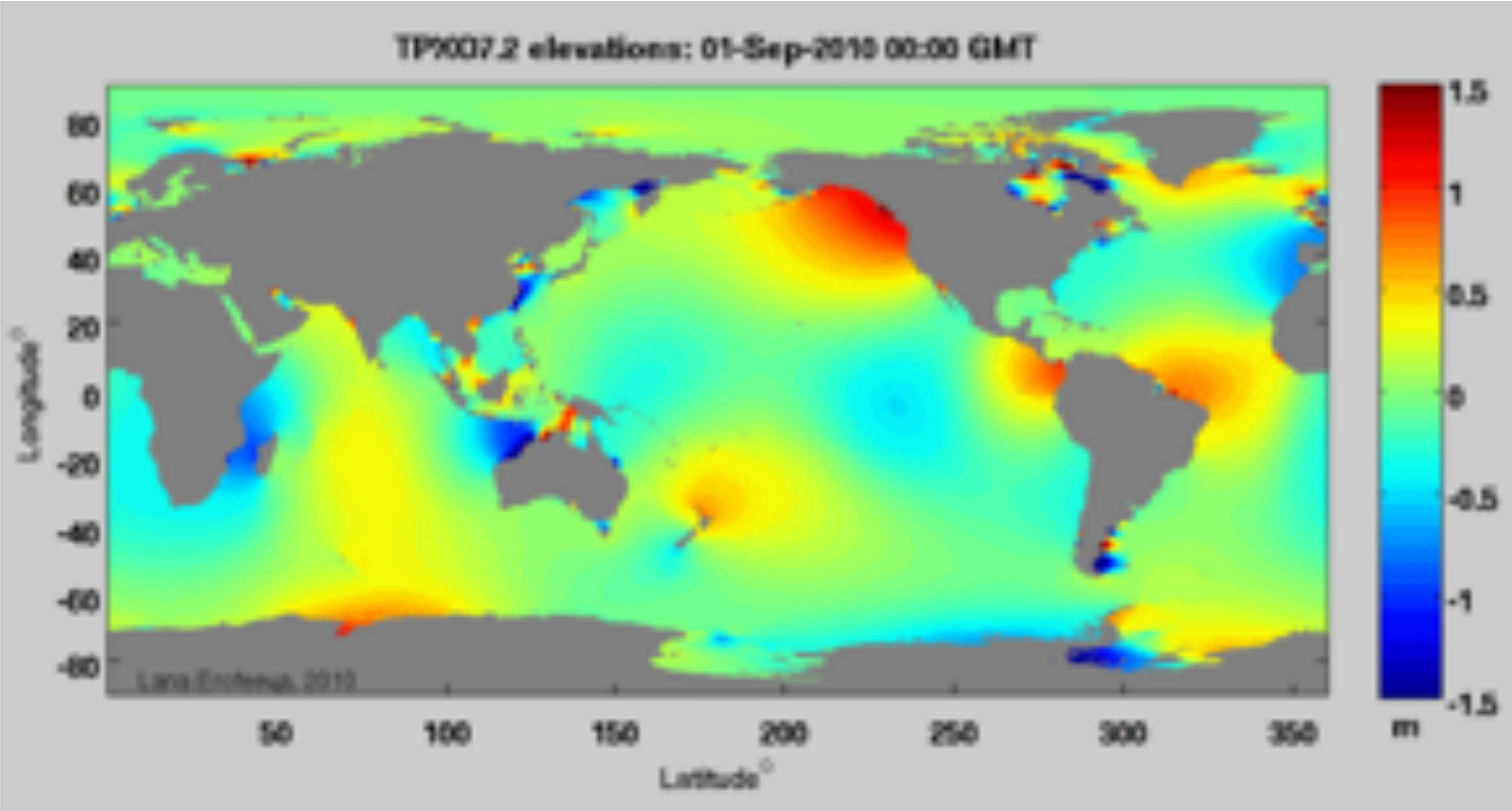


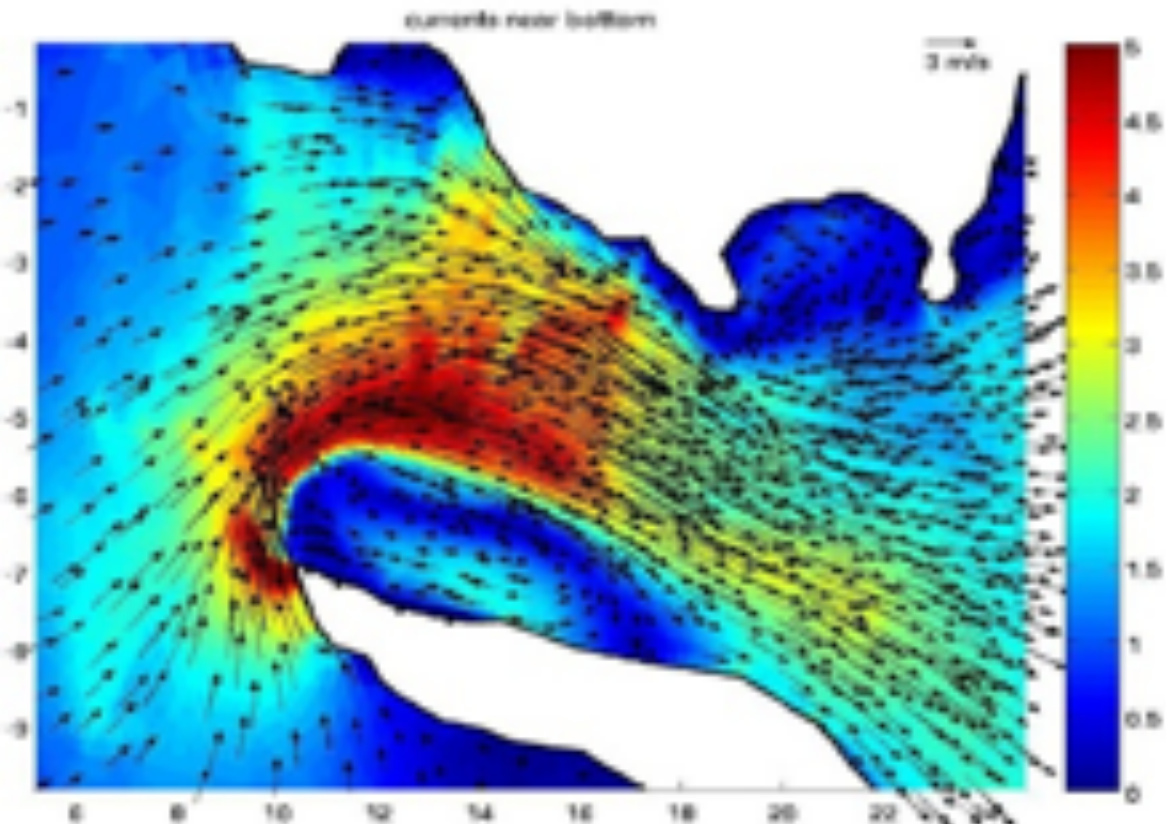
http://www.youtube.com/watch?v=mJorZMT6W3M

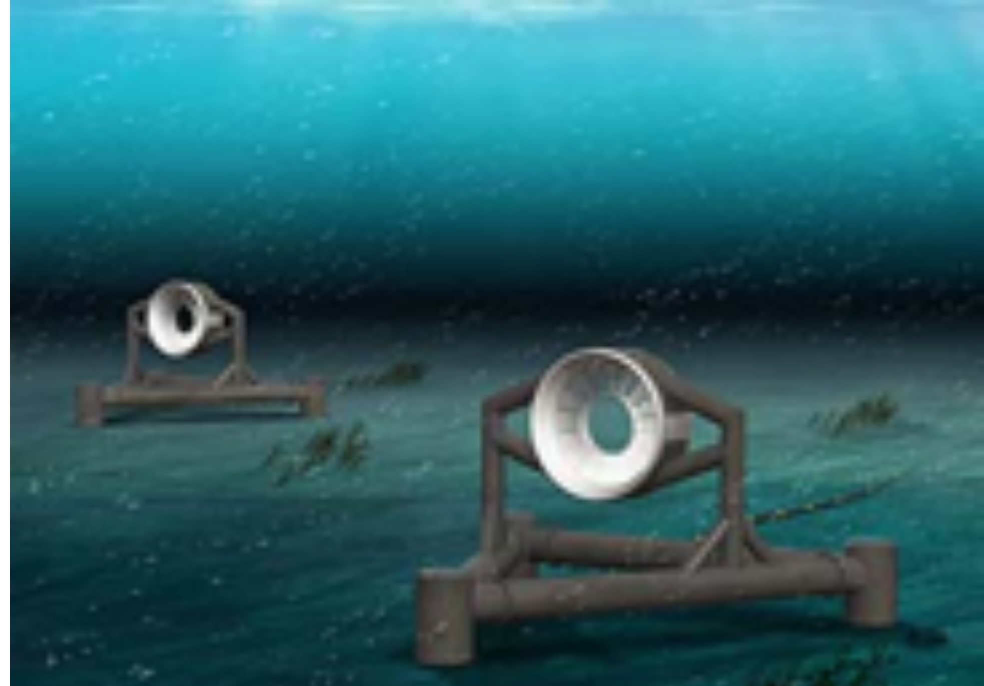

58° N
50° N
6° W
0°
6° E
< 0.5
< 1
> 8
> 11

Plate 10. Representative M_2 tidal ellipses. Ellipses were selected to be representative and located at approximately mid-water depth. Numbers inside or near the ellipses are the instrument depths in meters below the sea surface. Tick marks along the edge of the ellipse indicate the Greenwich hour. The time of Boston high water is shown by a solid circle between 3- and 4-hour Greenwich. Asterisks are stations 1 mab.

Moody et al. 1984

5 m/s ≈ 20 km/hr
(The fastest rivers are typically just a few km/hr)





Ocean Sciences

Rpsgroup.com

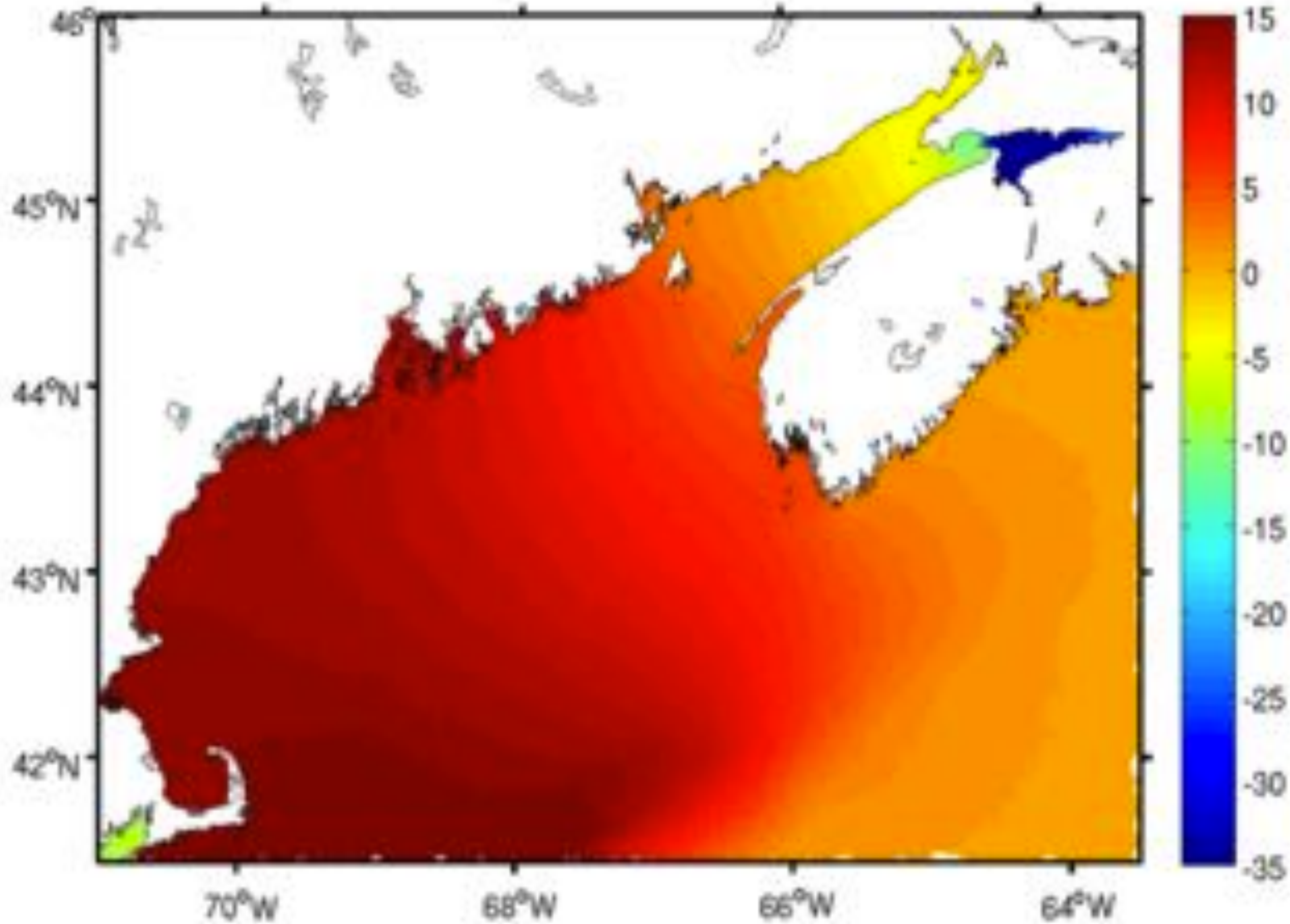
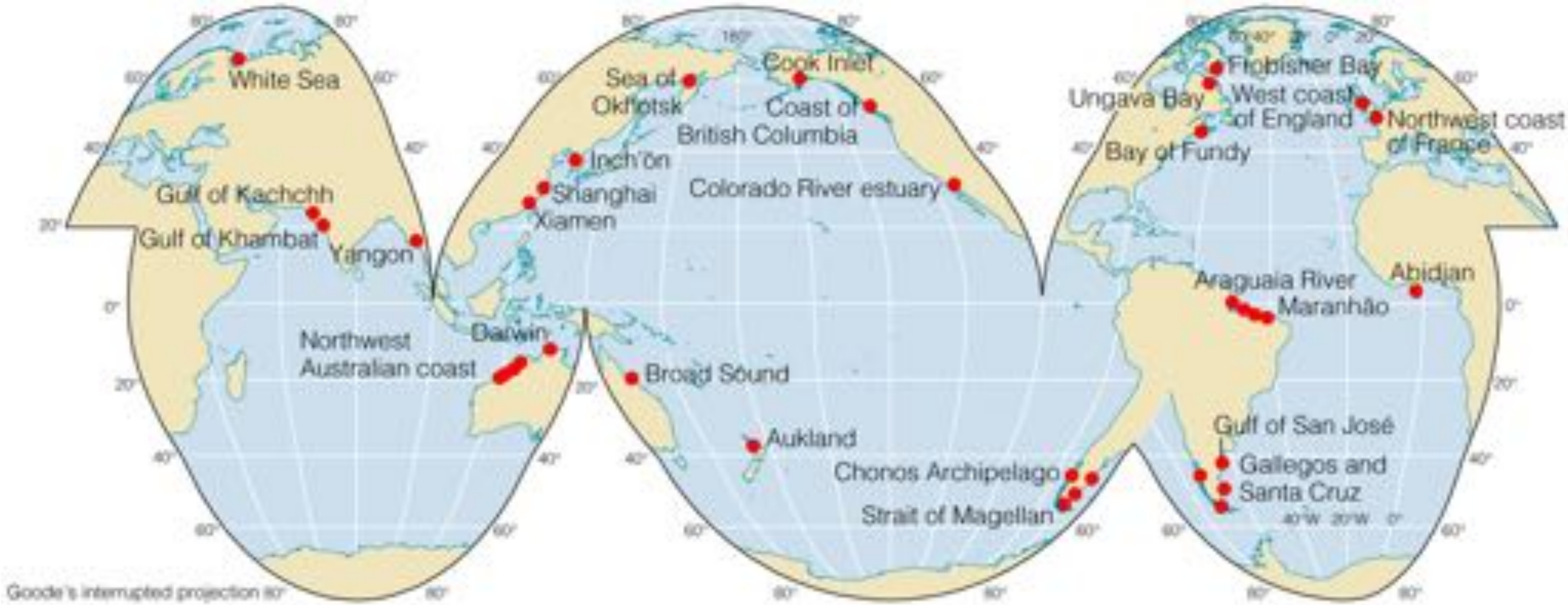


Figure 6: The relative change in amplitude (%) of the tides as a result of extracting the maximum amount of power from the Minas Passage.

Minas Passage stats

- At mid tides: 4 km^3 hr^{-1}
  - → 39,238,518 cfs
  - #1 Amazon ≈ 6 - 7,000,000 cfs
  - #2 Ganges ≈ 1,470,000 cfs
  - # 12 Mississippi ≈ 570,000 cfs
  - Highest recorded Mississippi flow = 2,345,000 cfs
  - Global rivers combined ≈ 28,000,000 cfs



Where tides are strong
enough to generate
significant power

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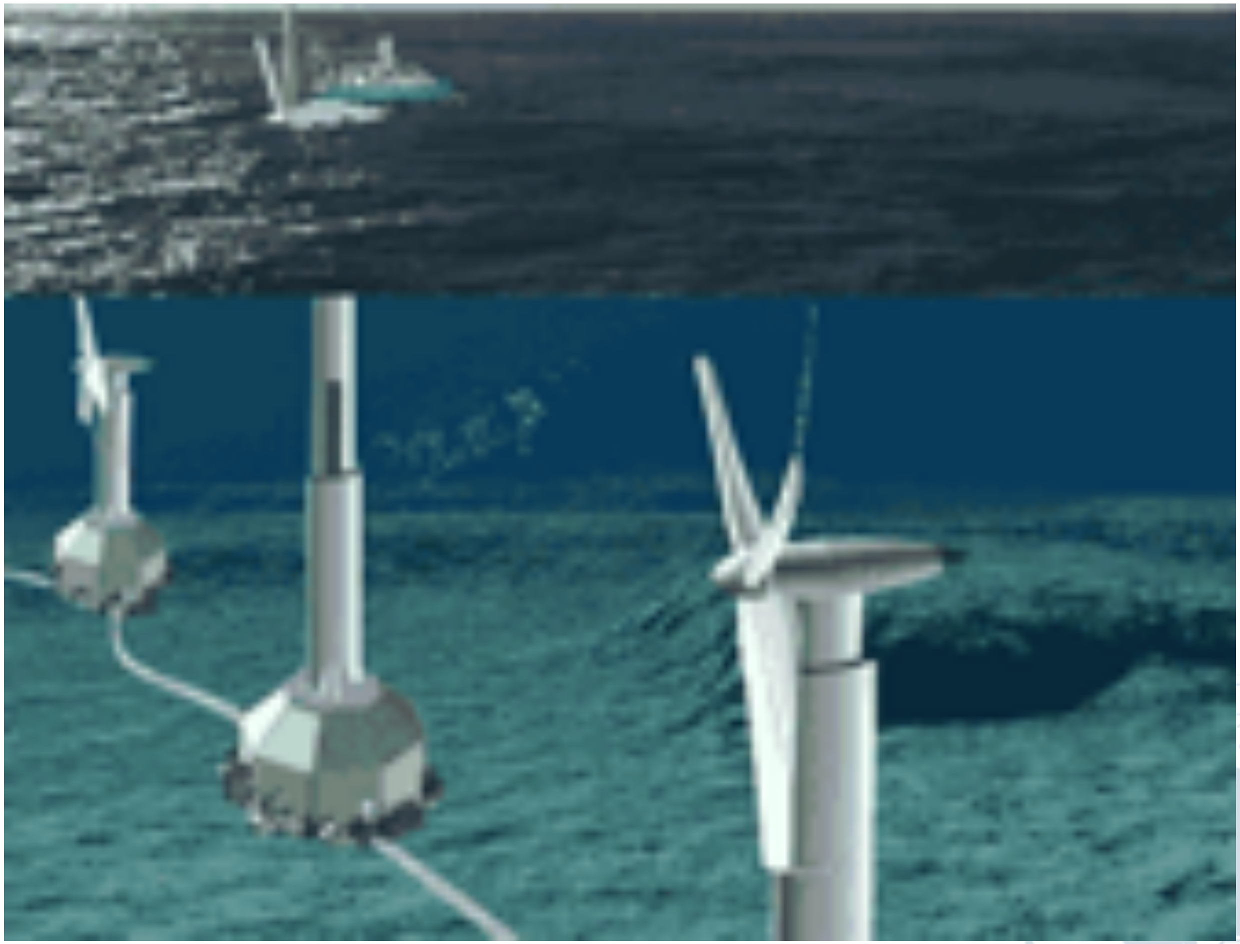

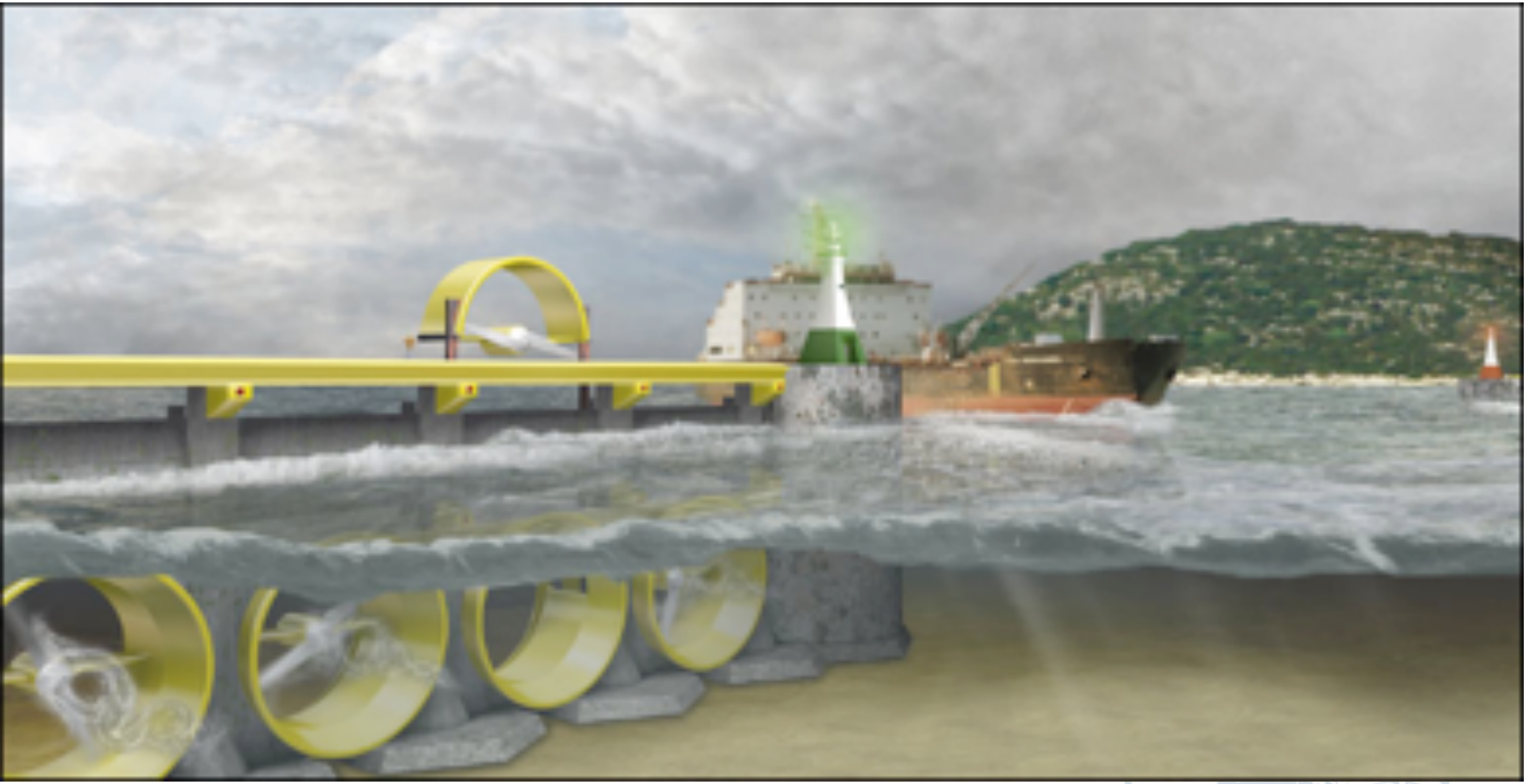

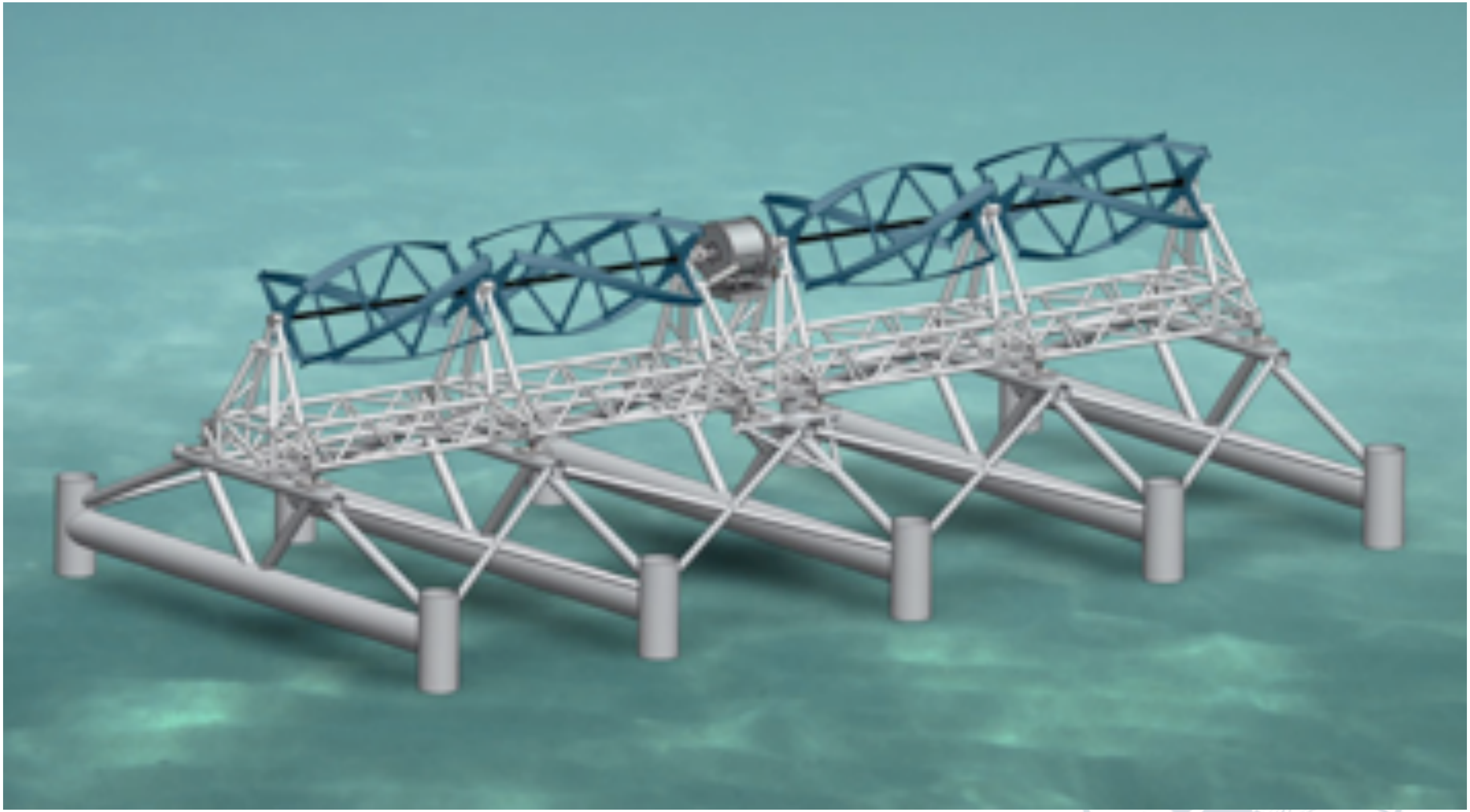

Other tides

The earth’s crust has a ~25 cm tide

Galaxies produce tides on stars systems (produce comets)

Roche radius: inside of which, tidal forces pull objects apart