Ch. 11 Tides - The Last Wave

https://www.youtube.com/watch?v=KlWpFLfLFBI

https://www.youtube.com/watch?v=pwChk4S99i4

How have tides impacted you?

Tides are rhythmic variations of sea level with periods of approximately 6 or 12 hours, depending on where you are on Earth.

Tides are caused by an imbalance* between the gravitational attraction of the Sun and Moon and the inertia of water on a rotating Earth.

* forces must be unequal or no movement

-- Newton's 1st law (F=ma)

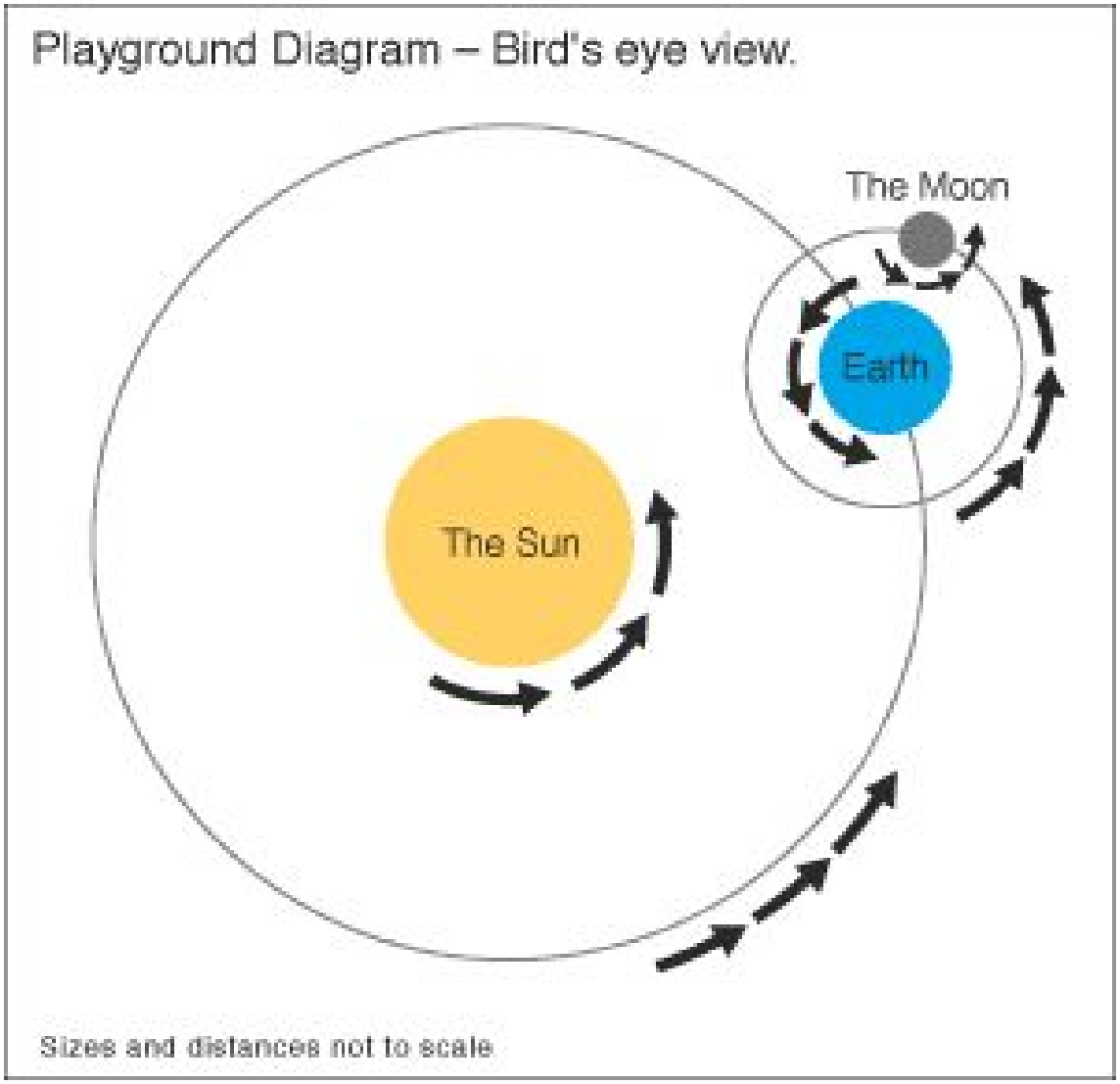
Some common ideas:

~~Does the Moon orbit around the Earth?~~

The Earth and Moon form a system that rotates around a common center of mass!

~~Tides are caused by the Moon's orbit~~

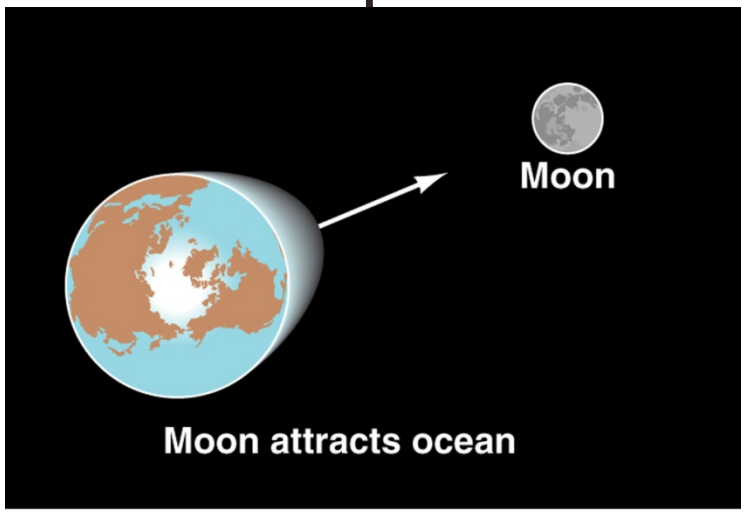
Tides result from the rotation of Earth on its axis every 24 hours.


Playground Diagram – Bird's eye view.
The Moon
Earth
The Sun
Sizes and distances not to scale

Let's begin with the gravitational pull of the Moon on the Earth:

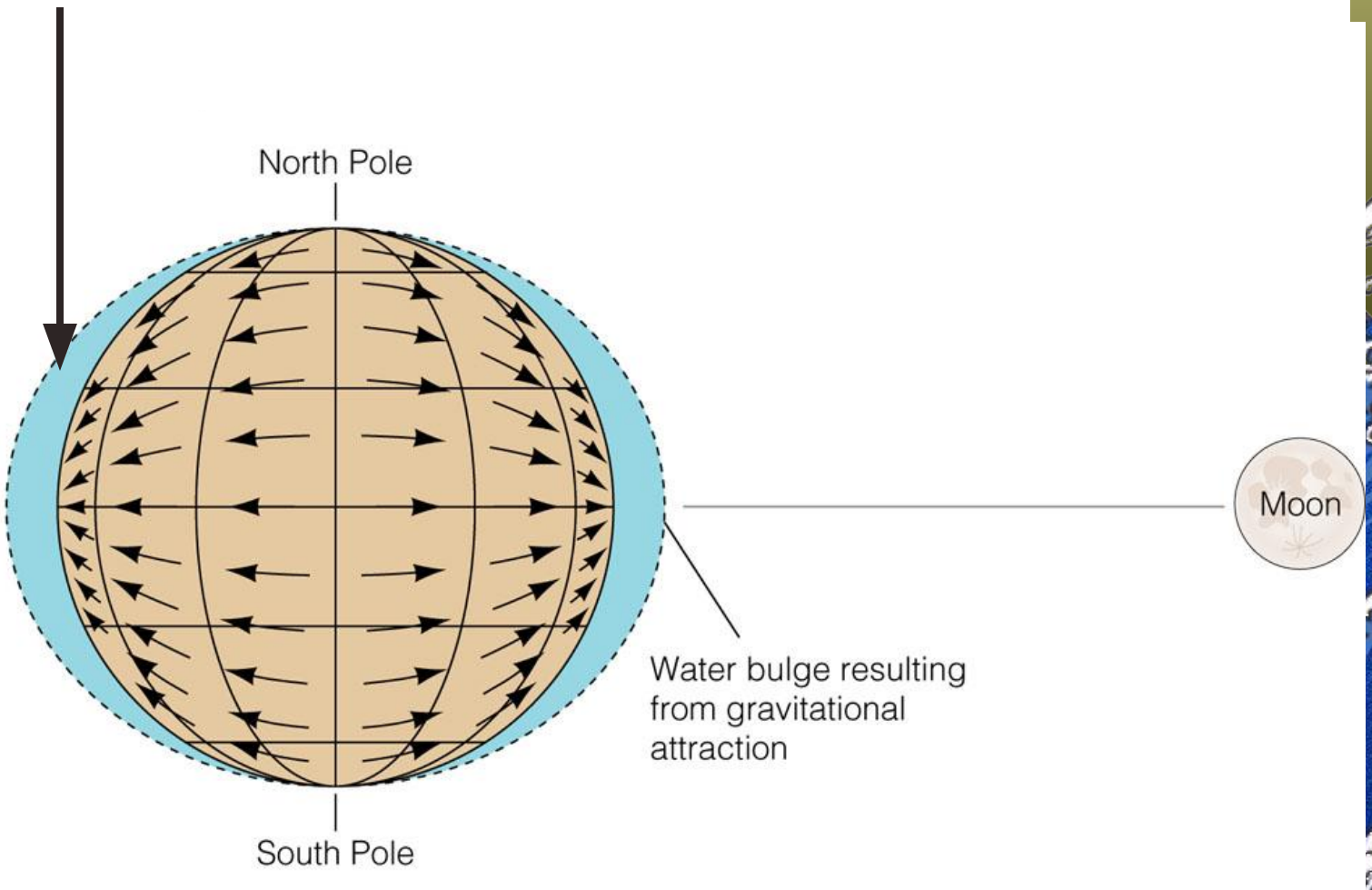
gravity again!

$$F = \frac{Gm_{moon}m_{earth}}{r^2}$$

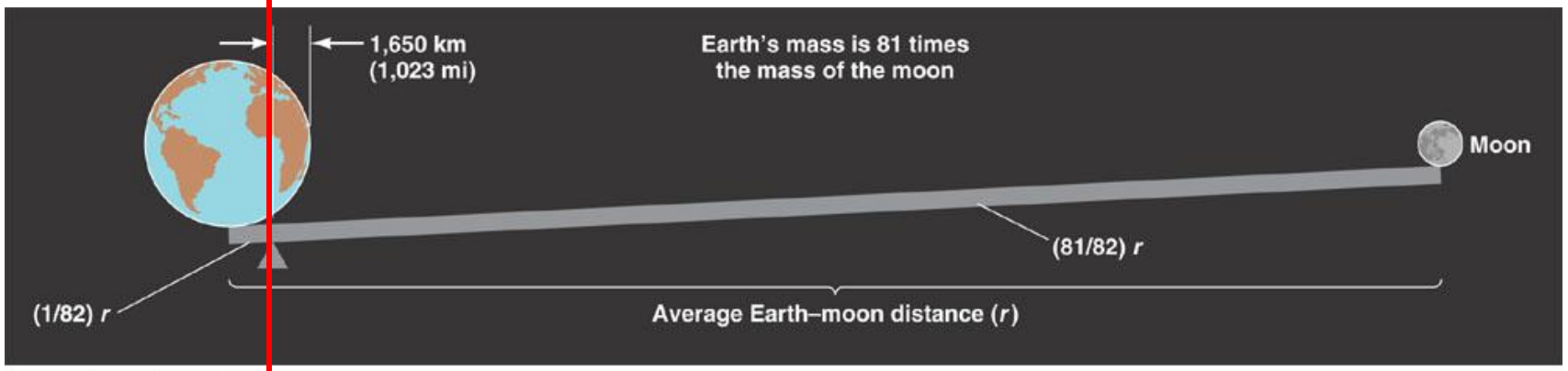


This explains the bulge of water towards the Moon, but ….

… how do we explain the bulge away from the Moon?



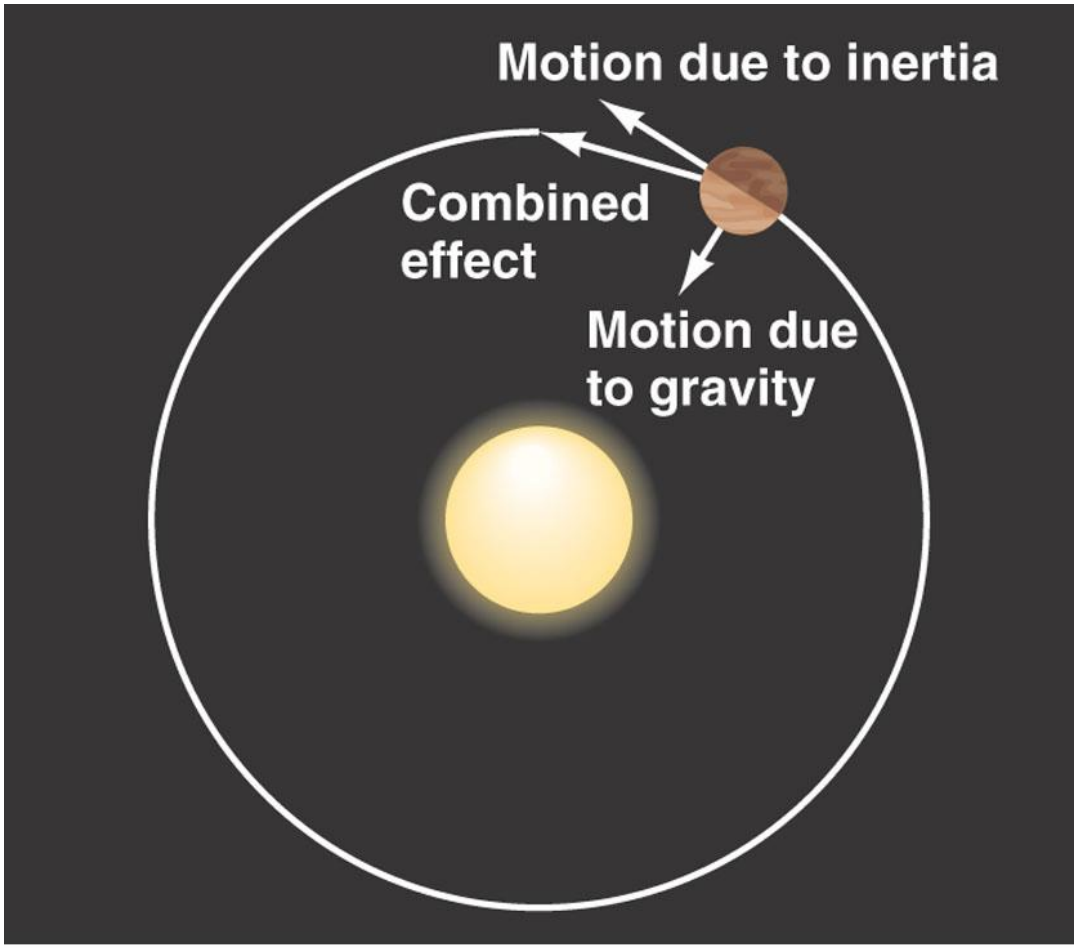
This other bulge is the result of both the Earth and the Moon orbiting around a common center of mass:



The center of mass of the Earth-Moon system is located 1650 km deep in the Earth. Both the Earth and Moon rotate around this same axis

(If they did not, then the unbalanced force of the Moon would cause the Earth to leave its orbit.)

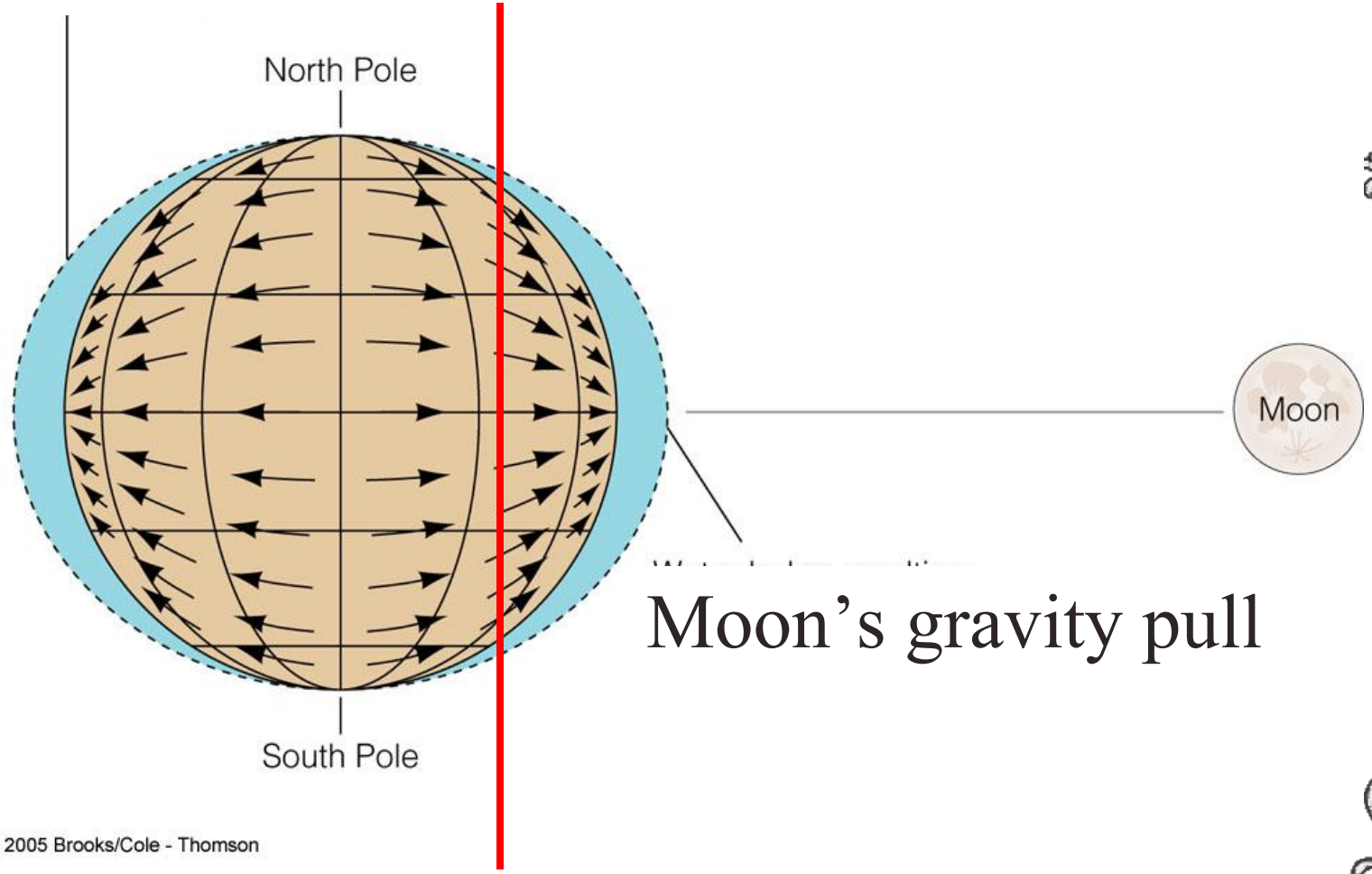
Just as you seem to feel a force pulling you outward on a merry-go-round, the water on the side away from the Moon experiences the same 'force':

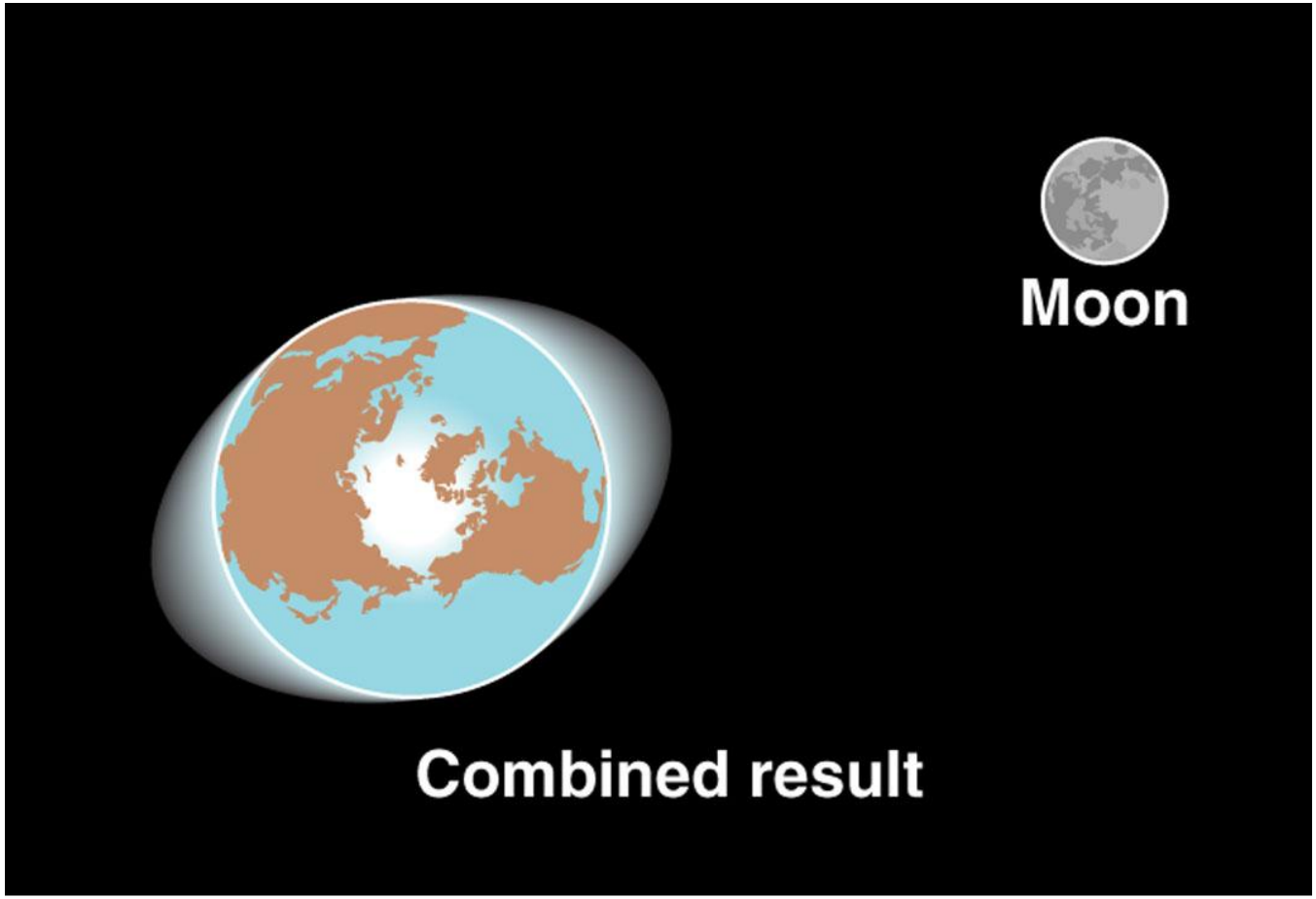


It is not really a force, but just the tendency of an object to continue in a straight line unless acted on a by a force (Newton's 2nd law). This is called <u>inertia</u>.

One bulge is due to gravity and the other is due to inertia.

Inertia

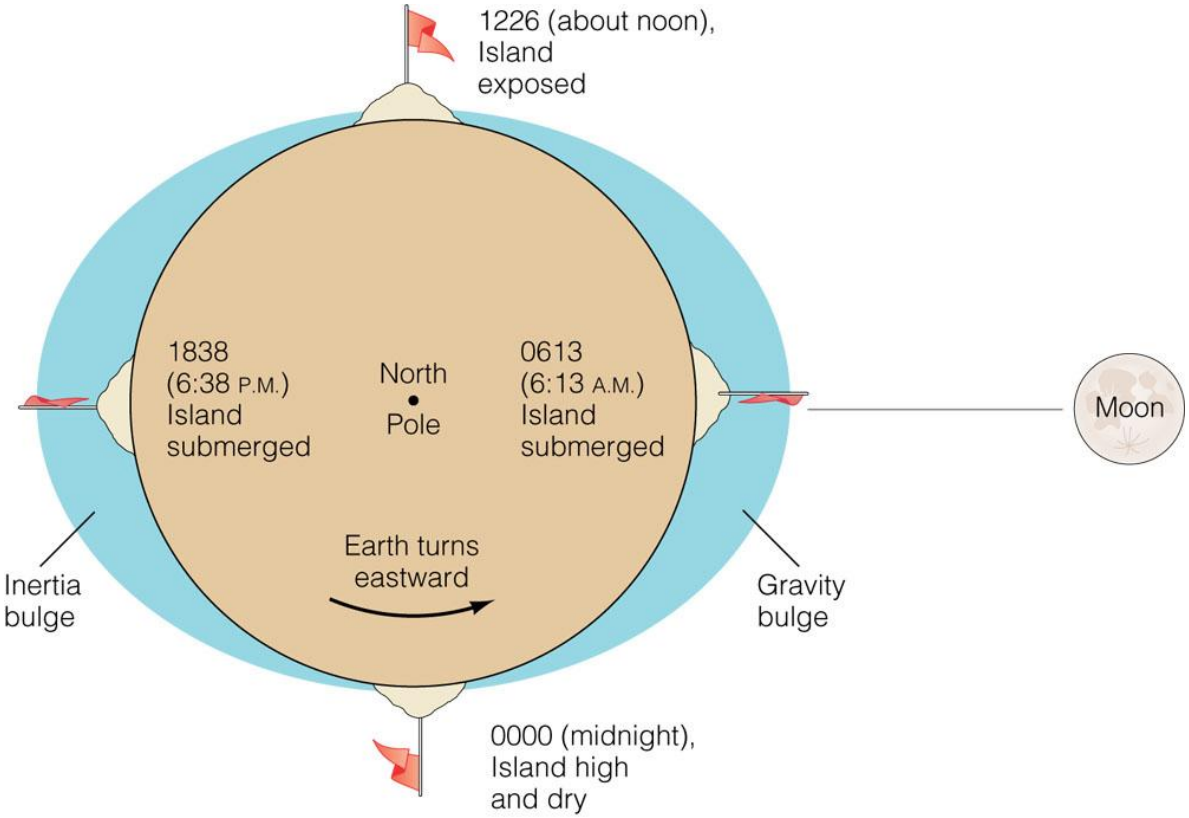


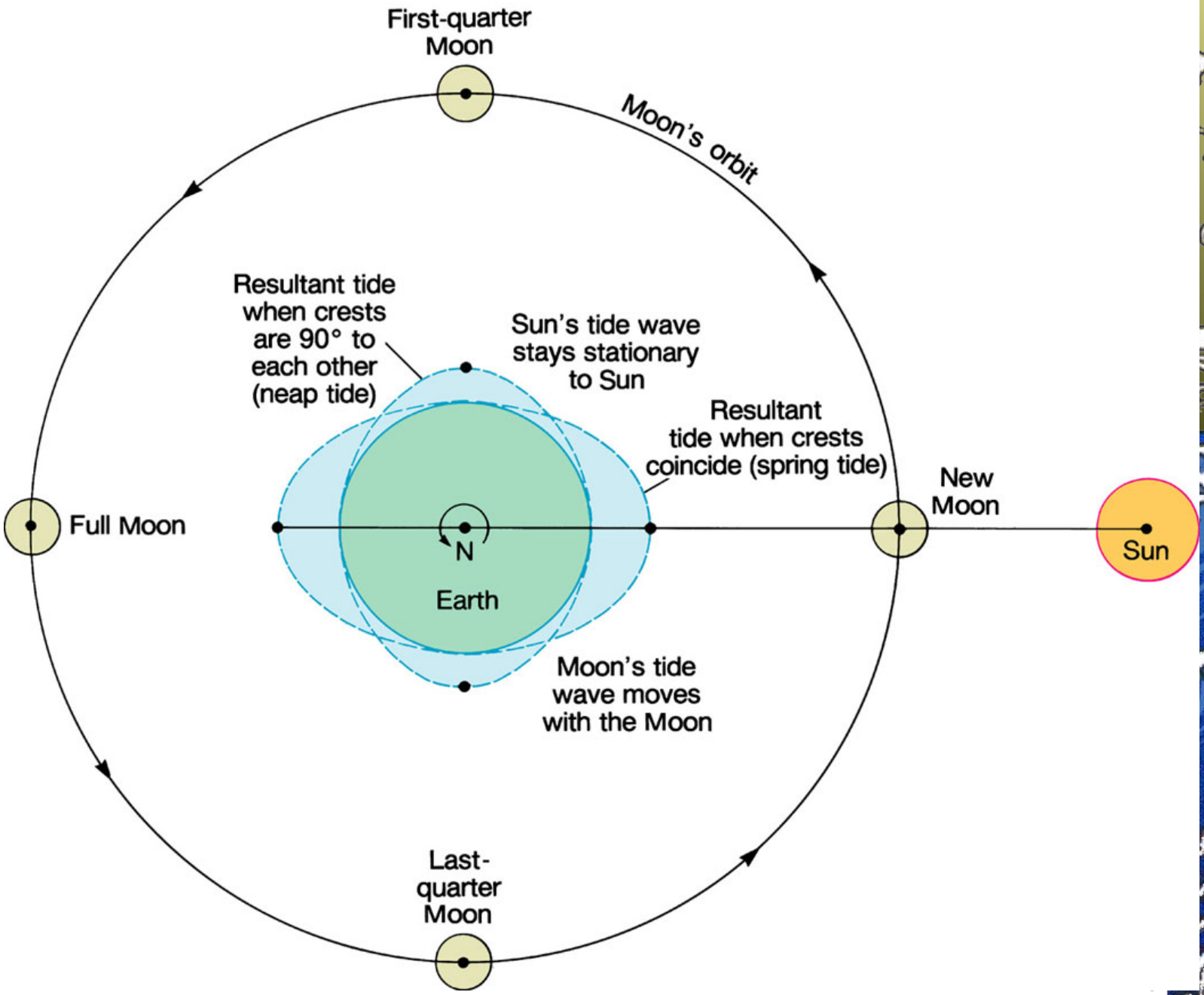


Because the Earth-Moon system complete one revolution every 27.3 days, the bulge goes completely around the Earth in 27.3 days. Right? **NO!**

Write this down:

The 12 hour period seen in tides is due to the spin of the Earth on its axis, one revolution every 24 hours. They are NOT due to the orbit of the Moon.

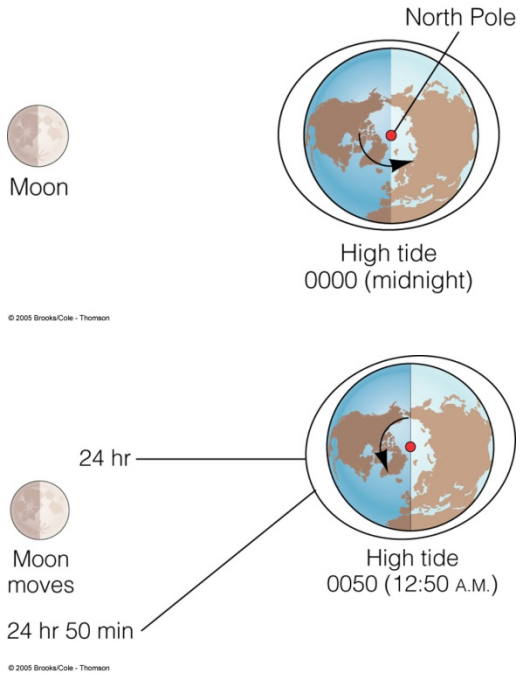




Complications:

The lunar tidal period is not exactly 12 hours

In the time it has taken the Earth to complete one revolution, the Moon has moved 360°/(27.3 days)= 13.2° farther along, so the Earth has to rotate 360+13.2=373.2° for a point to move directly beneath the Moon again.

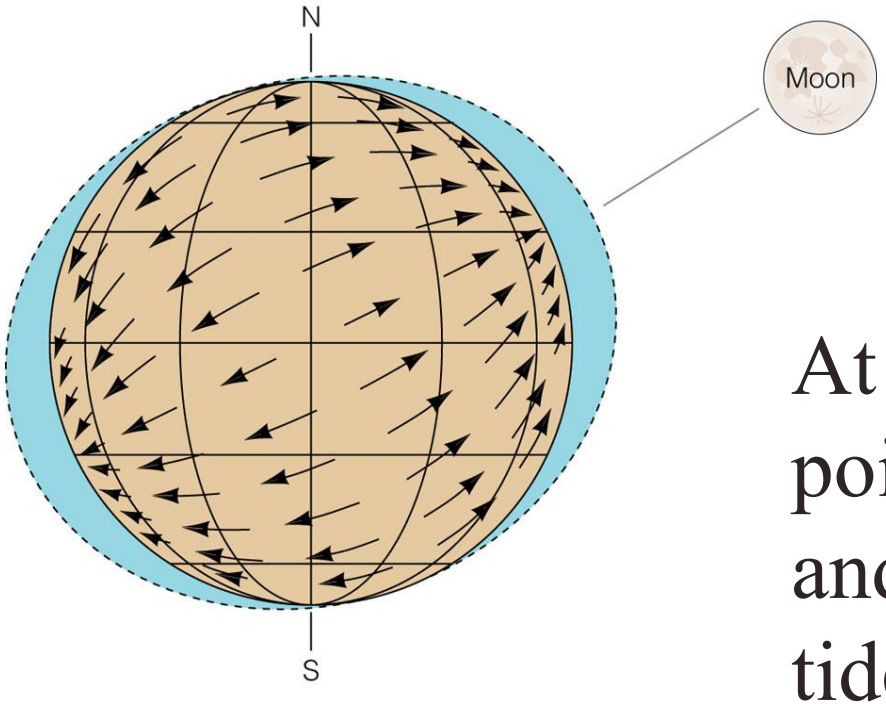


This takes the Earth 24 hours $* \frac{373.2}{360} = 24\text{h } 53\text{m}$

The tidal period is thus 12h 26.5m

MORE complications:

The Earth's spin axis is tilted, so the Moon moves from 28.5° below the equator to 28.5° above the equator every 27.3 days.



At one point, day and night tides differ

But the BIGGEST complication is something you see every day -- **the Sun**!

The Sun also exerts a tidal force (gravity ALWAYS sucks), but to understand this we must first examine the equation for the combined gravity-inertia force.

Both of these forces depend on the inverse square distance and on the mass of the Moon, so the **difference** can be shown to be proportional to the inverse cube of distance:

$$\text{Net tidal force} \propto \frac{m_{object}}{\quad}$$

Taking the ratio of the tidal force of the Sun to that of the Moon ($m_{sun} = 27{,}000{,}000 m_{moon}$ but $r_{sun} = 387 r_{moon}$):

$$\frac{\text{Tidalforce}_{sun}}{\text{Tidalforce}_{moon}} = \frac{m_{sun} / r_{sun}^{3}}{m_{moon} / r_{moon}^{3}}$$

$$= \frac{(27X10^{6} * m_{moon}) / (387 r_{moon})^{3}}{m_{moon} / r_{moon}^{3}} = \frac{27X10^{6}}{387^{3}}$$

$$= \frac{.46}{1.0}$$

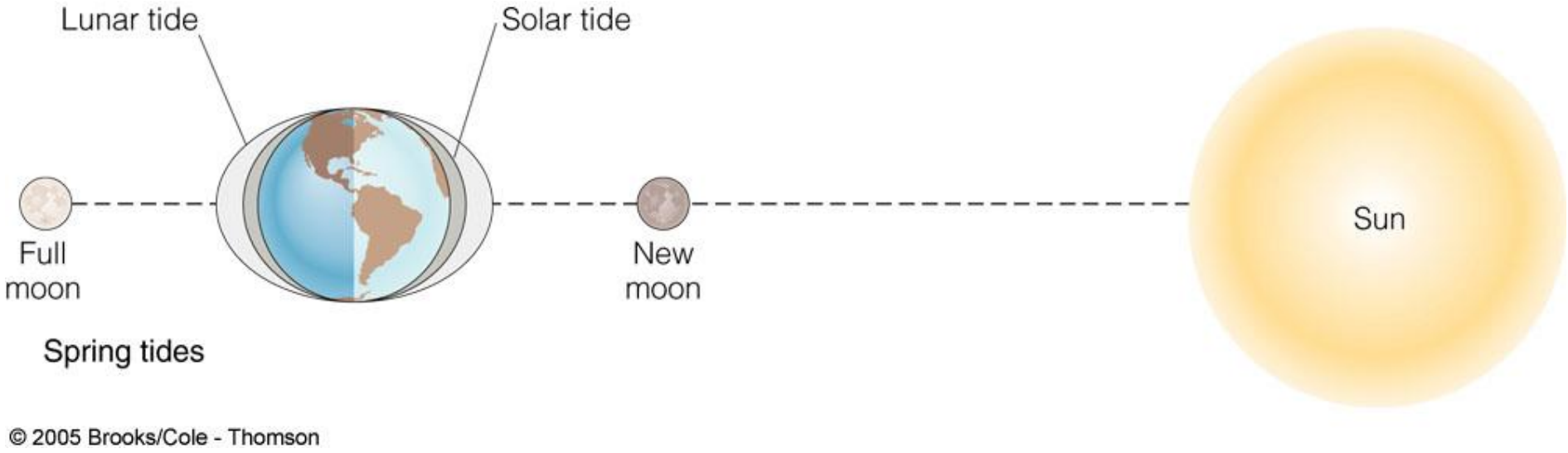
The Sun exerts a tidal force approximately HALF of that of Moon.

No, but I expect students to answer questions like:

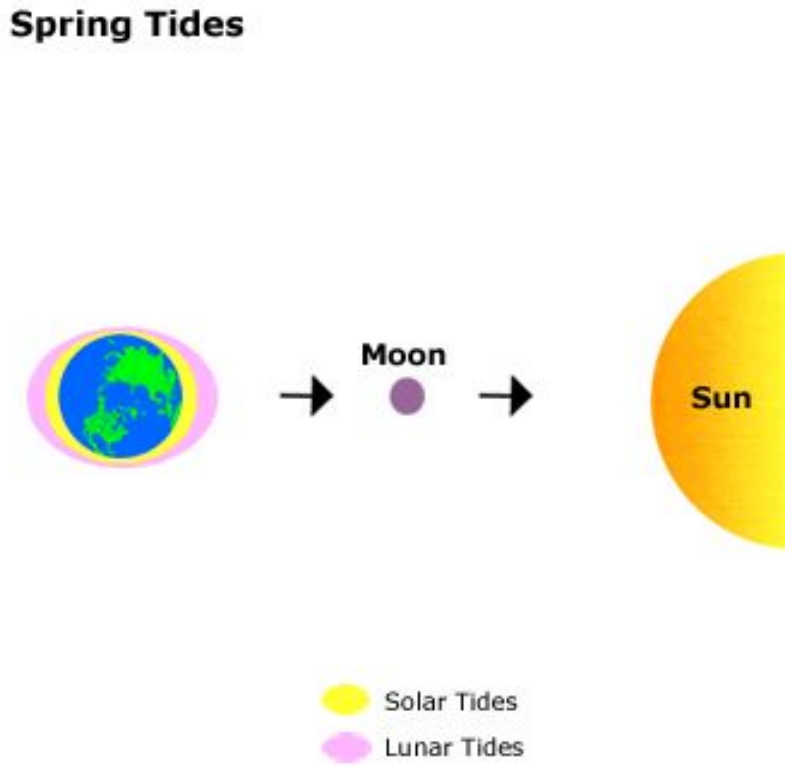
What is the ratio between the tidal forces of the Moon and Sun?

How can the Sun exert a smaller tidal force than the Moon when it is SO much bigger.

Only once every 27.3 days are the tidal forces of the Moon and Sun aligned:



Depending on the time of month, we can have large or small tides:

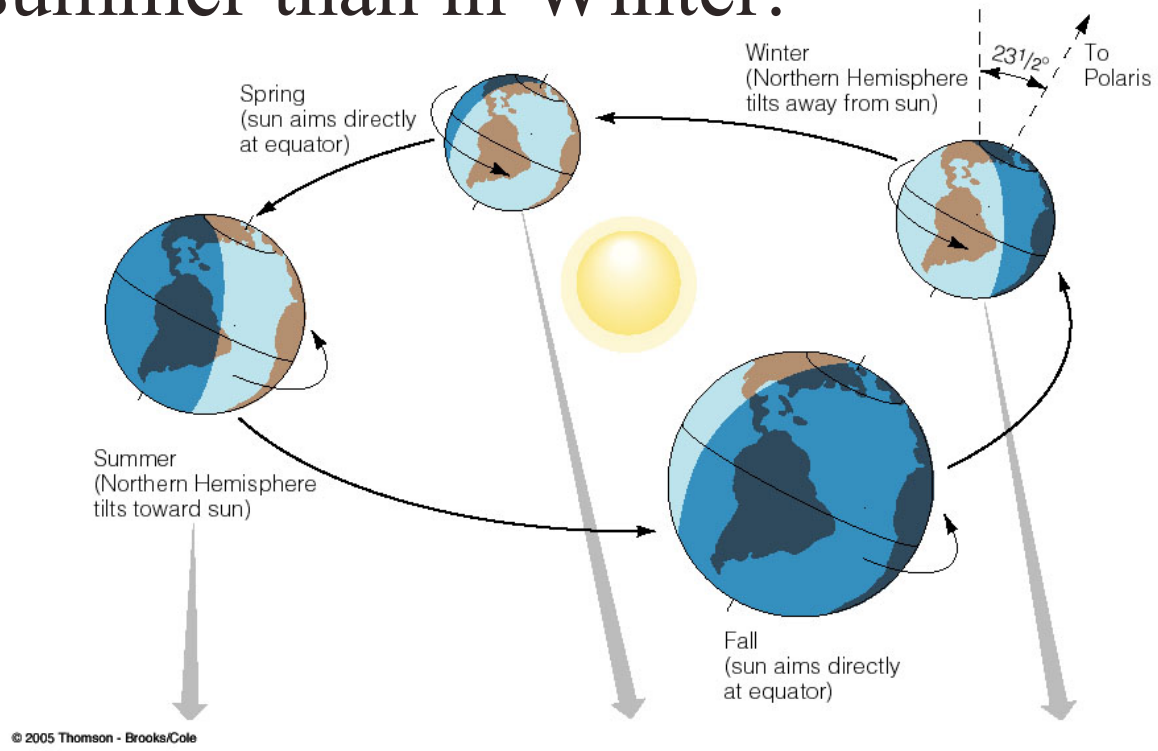


Spring (‘jump’) tide	large ht.	new,full moon
Neap (‘hardly disturbed’)tide	short ht.	waxing,waning moon

Another complication:

There is a seasonal dependence.

Earth is 3,700,000 km farther from the Sun in summer than in Winter:



Winter tides in the northern hemisphere tend to be larger than summer tides.

Now, let's consider the wave properties of tides*:

Period? 12 h 53 m (=43,518 s)

Wavelength? 1/2 circumference of Earth = 20,000 km

Speed? Governed by rotation rate of Earth - 1600 km/hr at Equator (444 m/s)

Does C=L/T? L/T = 460 m/s

*Remember, tides ARE waves!

Not quite!

Are tidal waves **deep water** or **shallow water** waves?

Consider wavelength = 20000 km

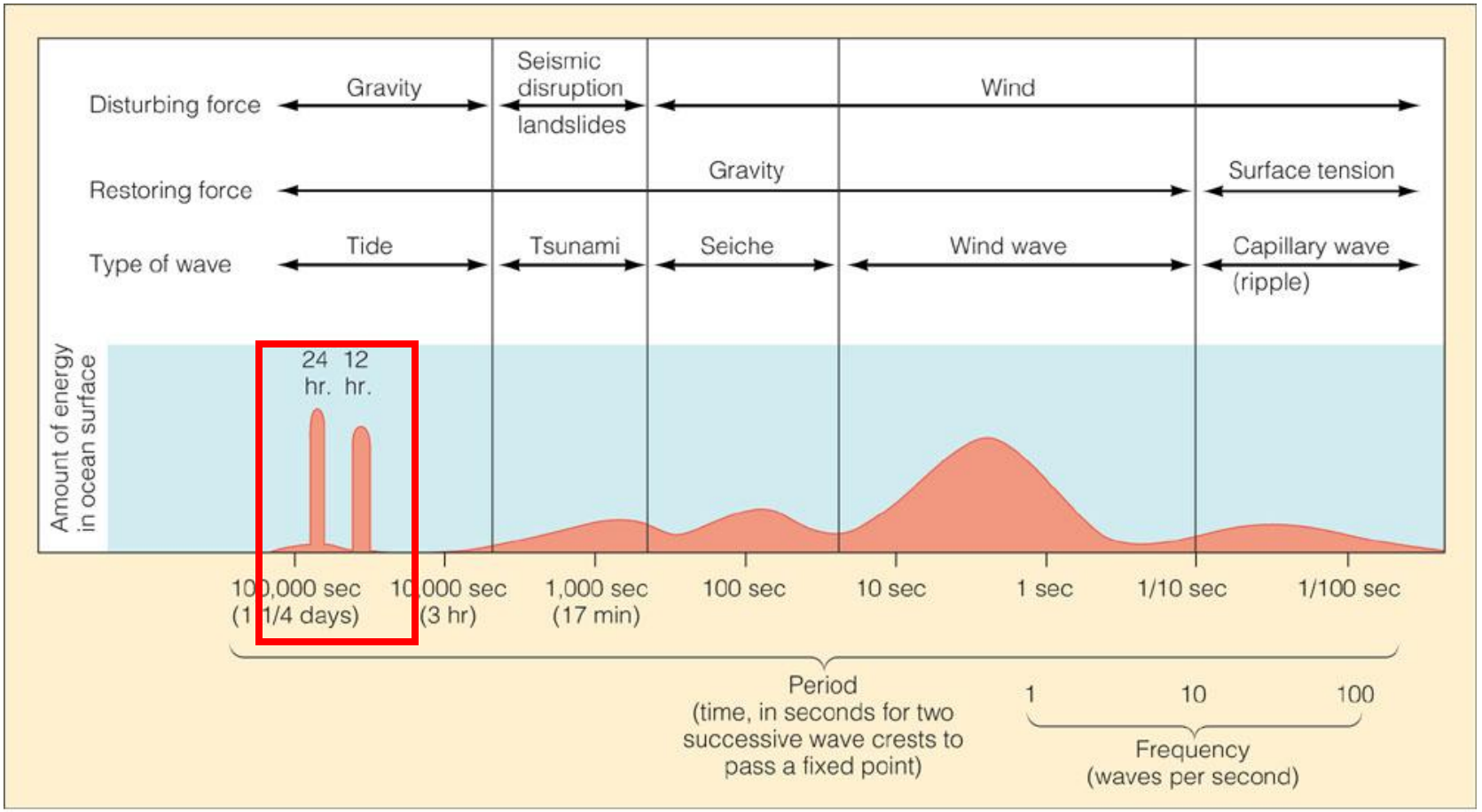
For deep water, ocean depth > 20000/2 km

Max ocean depth = 11 km and average ~3.8 km

For shallow water, depth < 20000/20 = 1000 km

Tides are shallow water waves!

Tides have lots of energy!



But small wave height:

(theoretical max)

solar	lunar
0.24 m	0.55 m

Why are tides so much larger than theory predicts?
(Compare **2 m** in open ocean versus theoretical maxima of 0.55 m and 0.24 m predicted for lunar and solar tides)

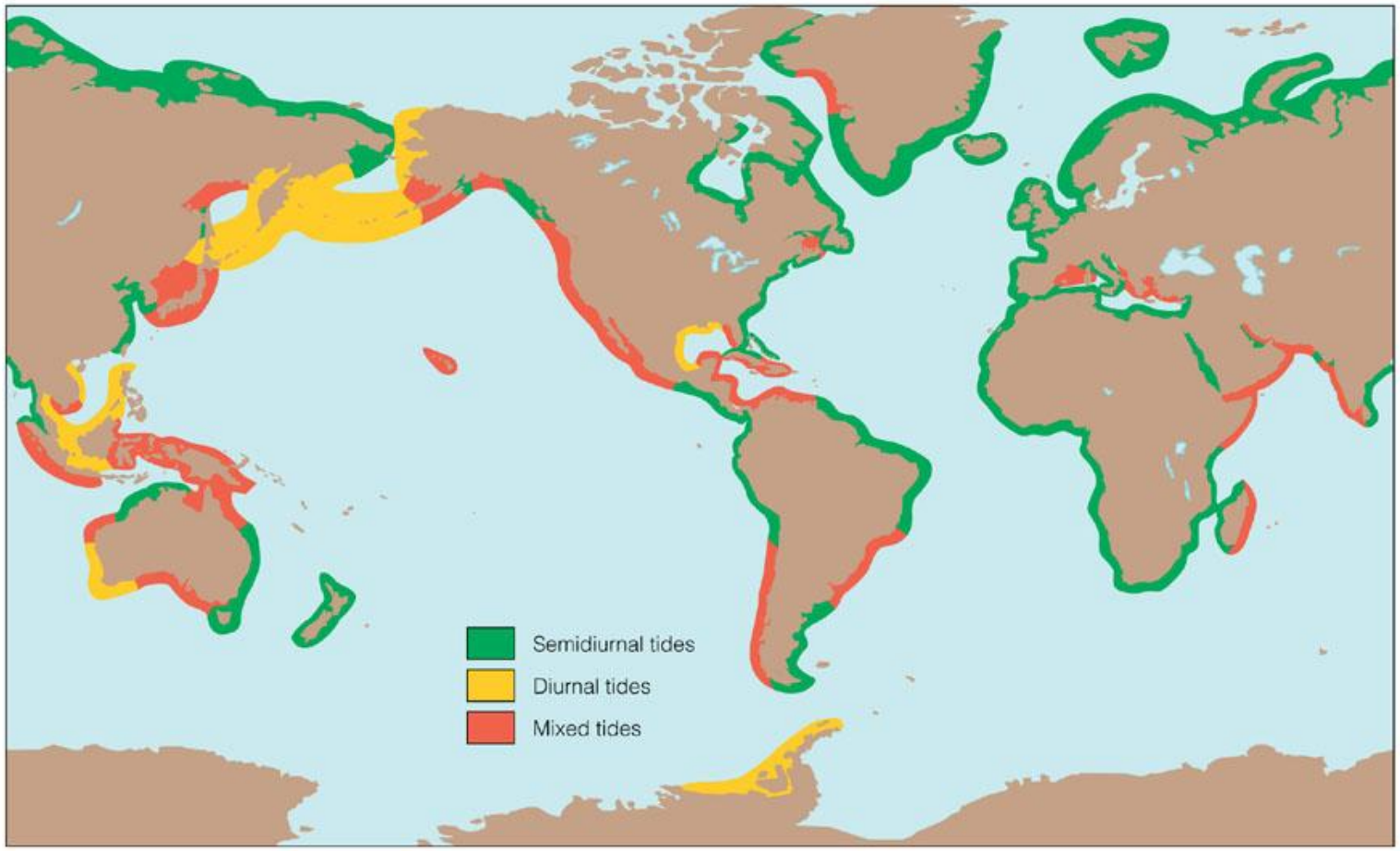
This led to Laplace proposing the "Dynamic Theory of Tides"

Dynamic Theory of Tides

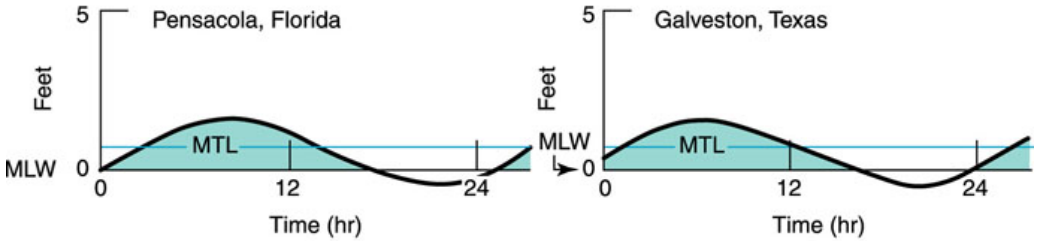
Tides are shallow water waves and are forced waves because the driving forces are always there

Tidal waves get reflected and refracted by land masses, and these waves constructively and destructively interfere with each other. This leads to…

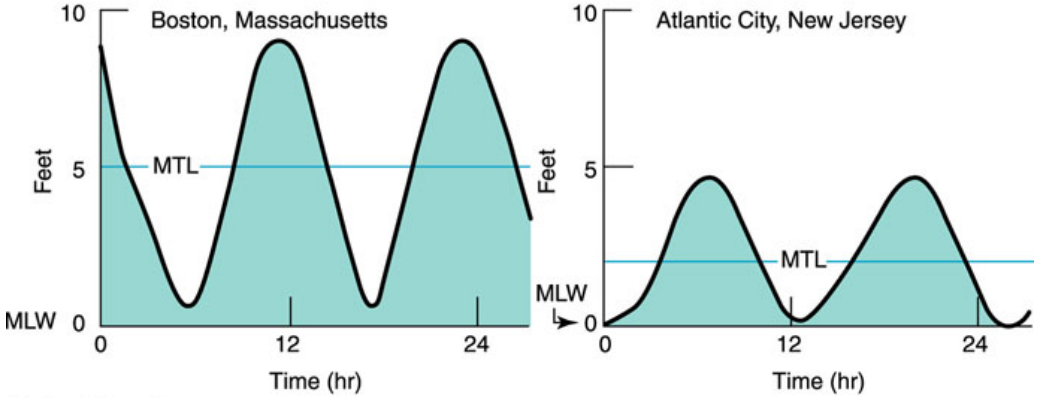
.. a complicated pattern of tides.



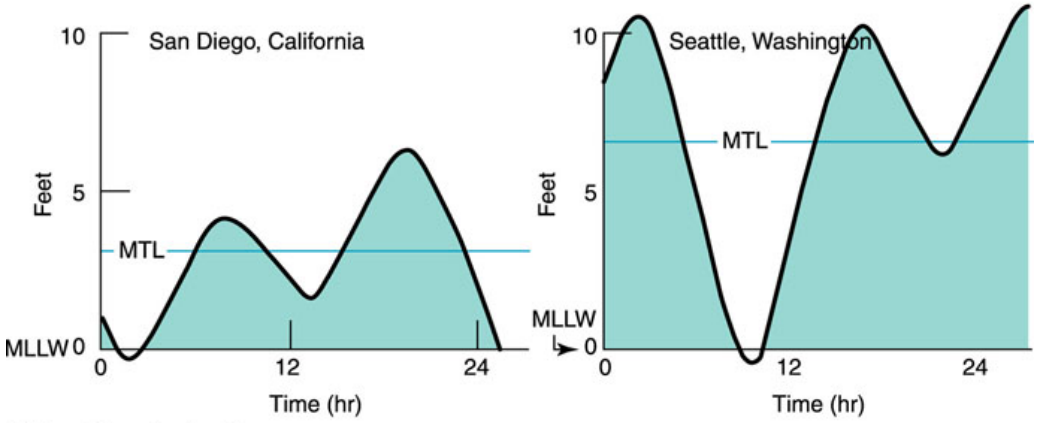
Semidiurnal tides - 2 high and 2 low per day (12 hr period)
Diurnal tides - 1 high and 1 low per day (24 hr period)
Mixed tides - unequal high and low (12 hr periods)



(a) Diurnal type



(b) Semidiurnal type



(c) Semidiurnal mixed type

Table 11.2 **Predicted Times and Heights of High and Low Waters for July 6–9, 2006, San Diego, California, United States (32.7133° N, 117.1733° W)**

Day	Time (h:min)[1]	Height (ft)
6	01:26	0.80 low
	07:42	3.19 high
	11:47	2.46 low
	18:35	5.84 high
7	02:09	0.15 low
	08:39	3.43 high
	12:42	2.55 low
	19:17	6.26 high
8	02:49	−0.94 low
	09:23	3.66 high
	13:31	2.54 low
	19:59	6.69 high
9	03:27	−0.94 low
	10:02	3.87 high
	14:18	2.44 low
	20:42	7.05 high

1. hours:minutes. Time meridian 120°W. 00:00 is midnight; 12:00 is noon—Pacific Daylight Time. Heights are referred to mean lower low water, which is the chart datum of soundings.

Source: www.tidepredictor.com,University of South Carolina.

More reality:

Tides get amplified in confined basins if the resonant period in the basin (remember seiches?) is close to the tidal period:

tidal waves in open ocean = **2 m**

coastal tides as large as **8 m** but usually only **1 m**

<u>tidal bore</u> = true tidal wave moving up river inlet

Tidal bore = true tidal wave (now you can say you've seen one!)

1-8 m high (this one is 2-3 m)

Bay of Fundy, New Brunswick, Canada:

resonant period = tidal period

BIGGEST tides in world (15 m)

Energy flow in tides

Tides acquire gravitational potential energy from pull of Sun and Moon (water higher)

▼

Tidal waves transmit energy to coasts

▼

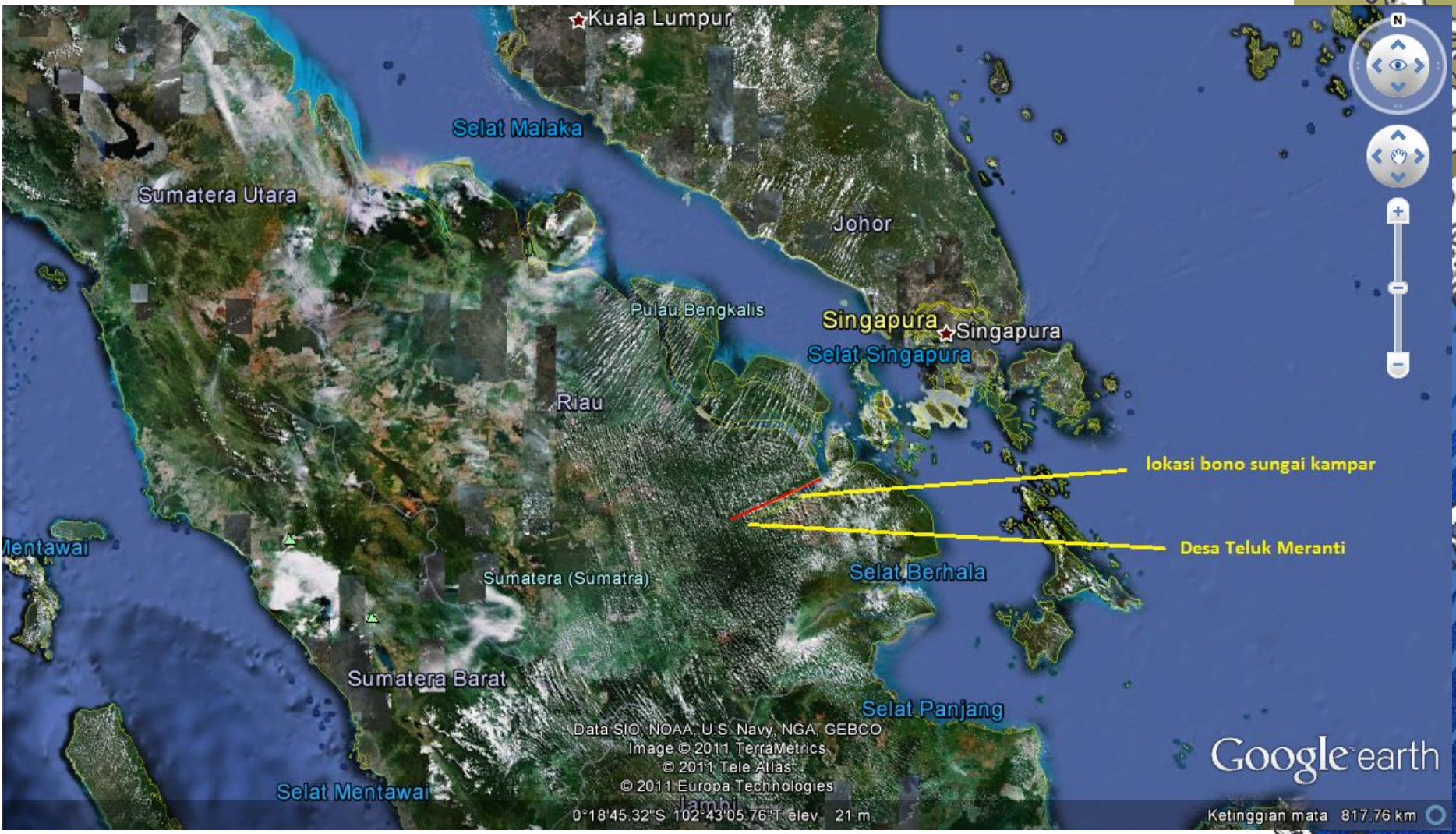
Energy dissipated as heat and turbulence at shores

+

slowing Earth's rate of rotation!!
(22 hours/day 450 My ago)

Seven Ghosts Surf Camp

- The tidal wave “Bono” breaking in the Kampar River in Sumatra, Indonesia, is a bit different from European river waves. Bono, also known by the Rip Curl Movie “Seven Ghosts”, can produce faces up to 10 feet and offers rides of several minutes. Breaking in comfortable 27 degrees Celsius, this wave can travel up to 50 kilometers with you riding it! So far the record for a ride is more than 1 hour on one and the same wave.
- Bono has no seasonal peaks, but it works only on special days around the full moon and the new moon. During rainy season the Kampar River has more water thus the bore is stronger and the waves are bigger. Bono works similar to the Brazilian wave “Prororoca”. At high tide, sea water is flowing into the river mouth of the Kampar River and produces a bore together with the flowing river water. There are several peaks which produce daily up to 4 hours of surfable waves with the length more than 50 kilometers.


Kuala Lumpur
Selat Malaka
Sumatera Utara
Johor
Pulau Bengkalis
Singapura
Singapura
Selat Singapura
Riau
lokasi bono sungai kampar
Desa Teluk Meranti
Selat Berhala
Sumatera (Sumatra)
Sumatera Barat
Selat Panjang
Selat Mentawai
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2011 TerraMetrics
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© 2011 Europa Technologies
0°18'45.32"S 102°43'05.76"T elev 21 m
Google earth
Ketinggian mata 817.76 km