Tides

Ch. 2 *Waves, Tides and Shallow-Water Processes*: J. Wright, A. Colling, & D. Park: Butterworth-Heinemann, Oxford UK, 1999, 2nd Edition, 227 pp.

AdOc 4060/5060 Spring 2013

Brutus:

There is a tide in the affairs of men.
Which, taken at the flood, leads on to fortune;
Omitted, all the voyage of their life
Is bound in shallows and in miseries.
On such a full sea are we now afloat,
And we must take the current when it serves,
Or lose our ventures.

Julius Caesar Act 4, scene 3, 218–224

Summary of tides on an idealized Earth or the Equilibrium Theory of Tides

- Most locations have two high tides and two low tides per lunar day
- Neither the two high tides nor the two low tides are of the same height because of the declination of the Moon and the Sun
- Yearly and monthly cycles of tidal range are related to the changing distances of the Moon and Sun from Earth
- Each week, there would be alternating spring and neap tides

What causes tides?

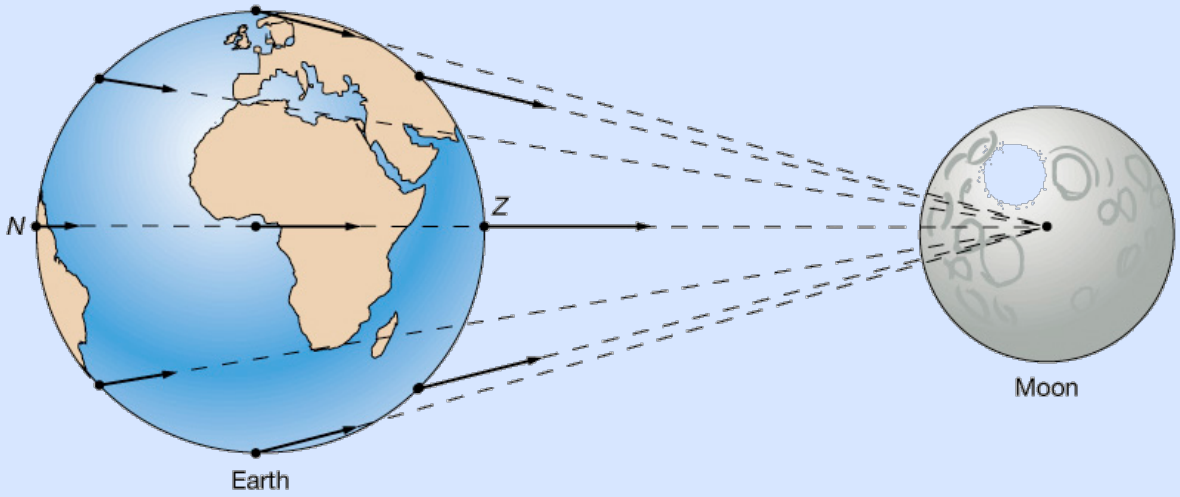
- Tides are created by the imbalance between two forces:
  1. Gravitational force of the Moon and Sun on Earth
     - If mass increases (↑), then gravitational force increases (↑)
     - If distance increases (↑), then gravitational force greatly decreases (↓↓)
  2. Centripetal (center-seeking) force required to keep bodies in nearly circular orbits (Inertial or centrifugal force is the equal force but in the opposite direction)

Newton's Law of gravitation

- Every particle of mass attracts all other particles of mass in the universe
- "the attractive gravitational force is directly proportional to the product of their masses (m_1m_2) and inversely proportional to the square of the distance (R) between the masses"
- $F_g = G(m_1m_2)/R^2$ $\quad$ $G = 6.672 \times 10^{-11}\ Nm^2kg^{-2}$

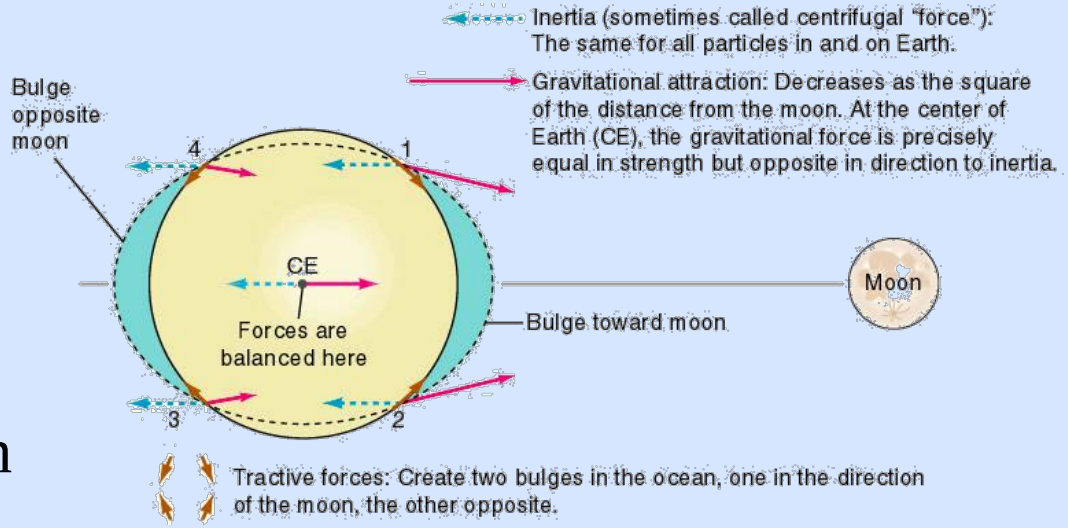
Gravitational forces on Earth due to the Moon

- Force decreases with increasing distance
- Force is directed toward the Moon's center of mass



Centrifugal forces on Earth due to the Moon

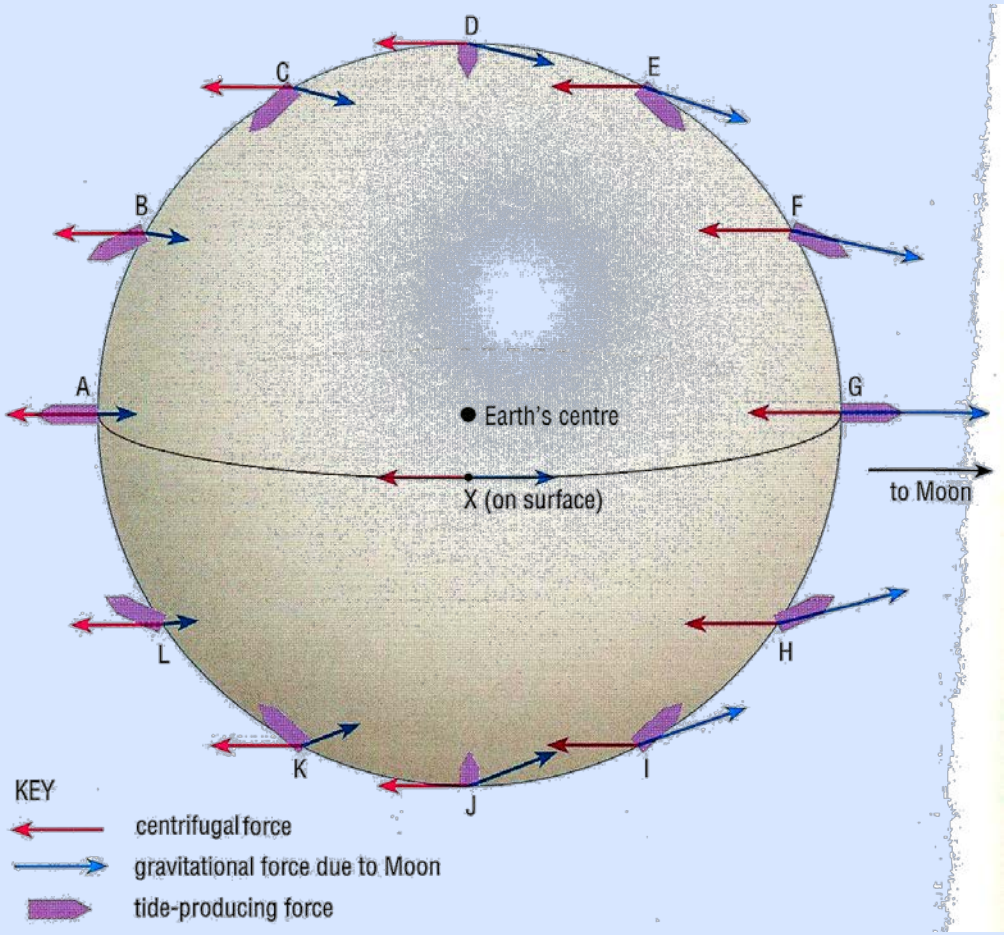
- Force is the same everywhere on Earth
- Force is directed perpendicular to Earth's center everywhere on Earth



Resultant tide-generating forces

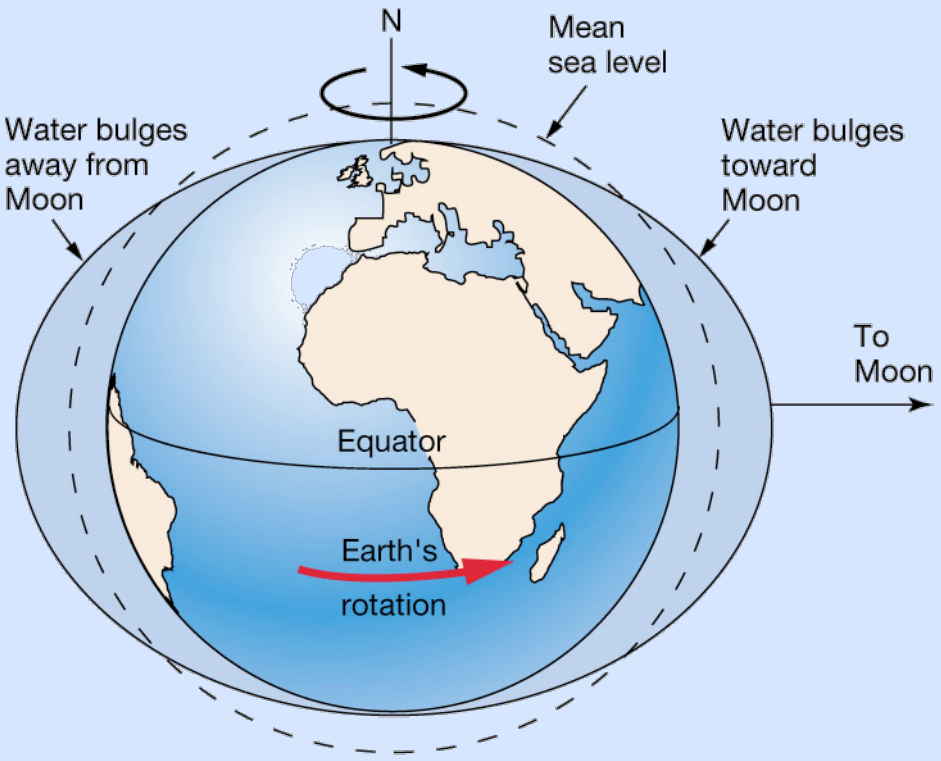
- Resultant forces are:
  - The difference between gravitational (G) and centrifugal (C) forces
  - Directed away from Moon on the side of Earth opposite Moon
  - Directed toward Moon on the side of Earth facing Moon
- Tide-generating forces (F_t) are the horizontal component of the resultant force
- The earth surface tidal force is

$F_t = Gm_1m_2 2a/R^3$ where a is earth's radius



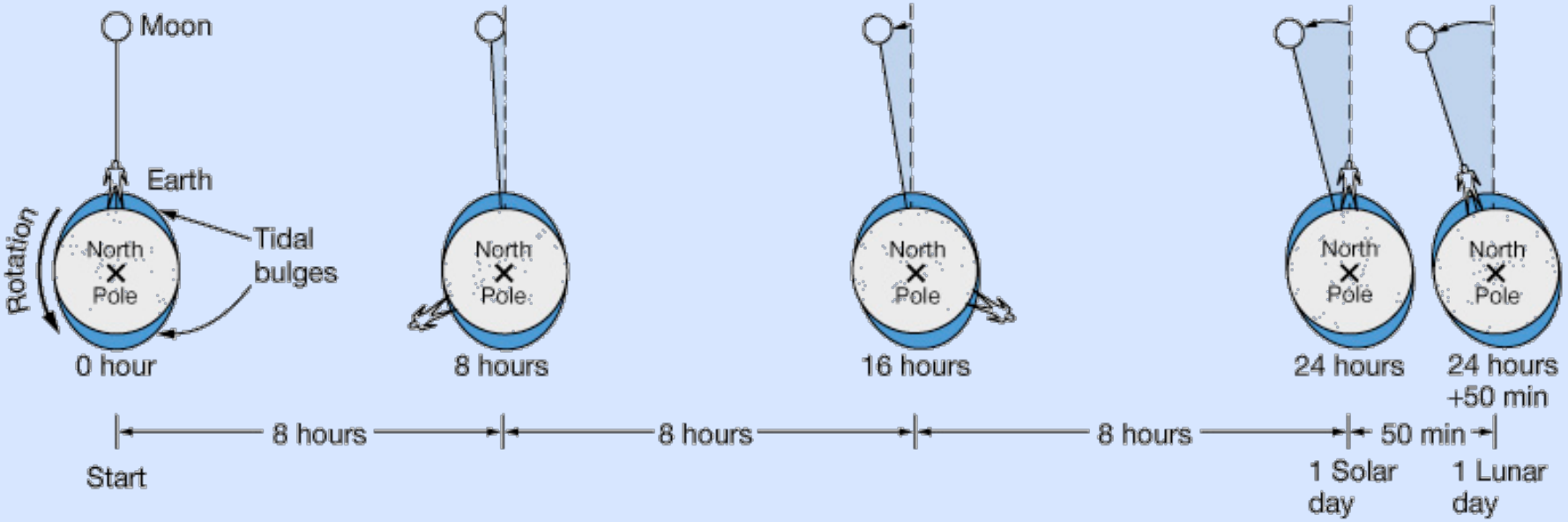
Tidal bulges

- Tide-generating forces produce 2 bulges:
  1. Away from Moon on side of Earth opposite Moon
  2. Toward Moon on side of Earth facing Moon
- Earth rotates into and out of tidal bulges, creating high and low tides



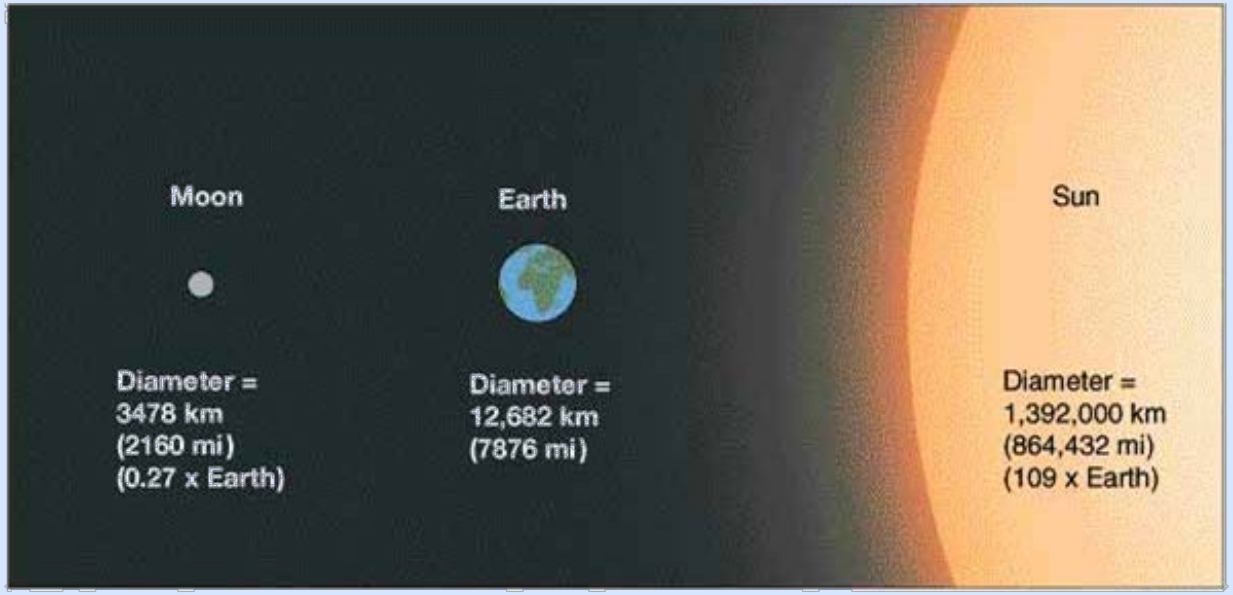
The lunar day

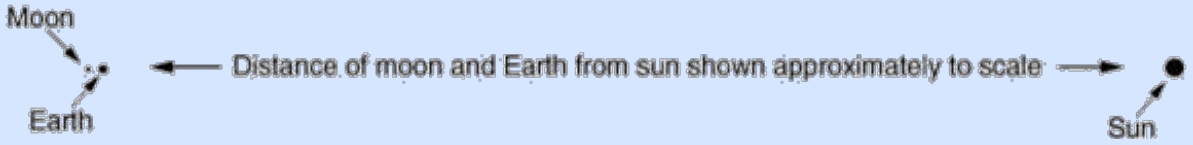
- Tidal bulges follow Moon as it rotates around Earth
- Lunar day is 50 minutes longer than a solar day because the Moon is moving in its orbit around Earth



Relative sizes and distances on Earth, Moon, & Sun

- The Sun is much more massive than the Moon but much further away
- Solar bulges are 46% the size of lunar bulges

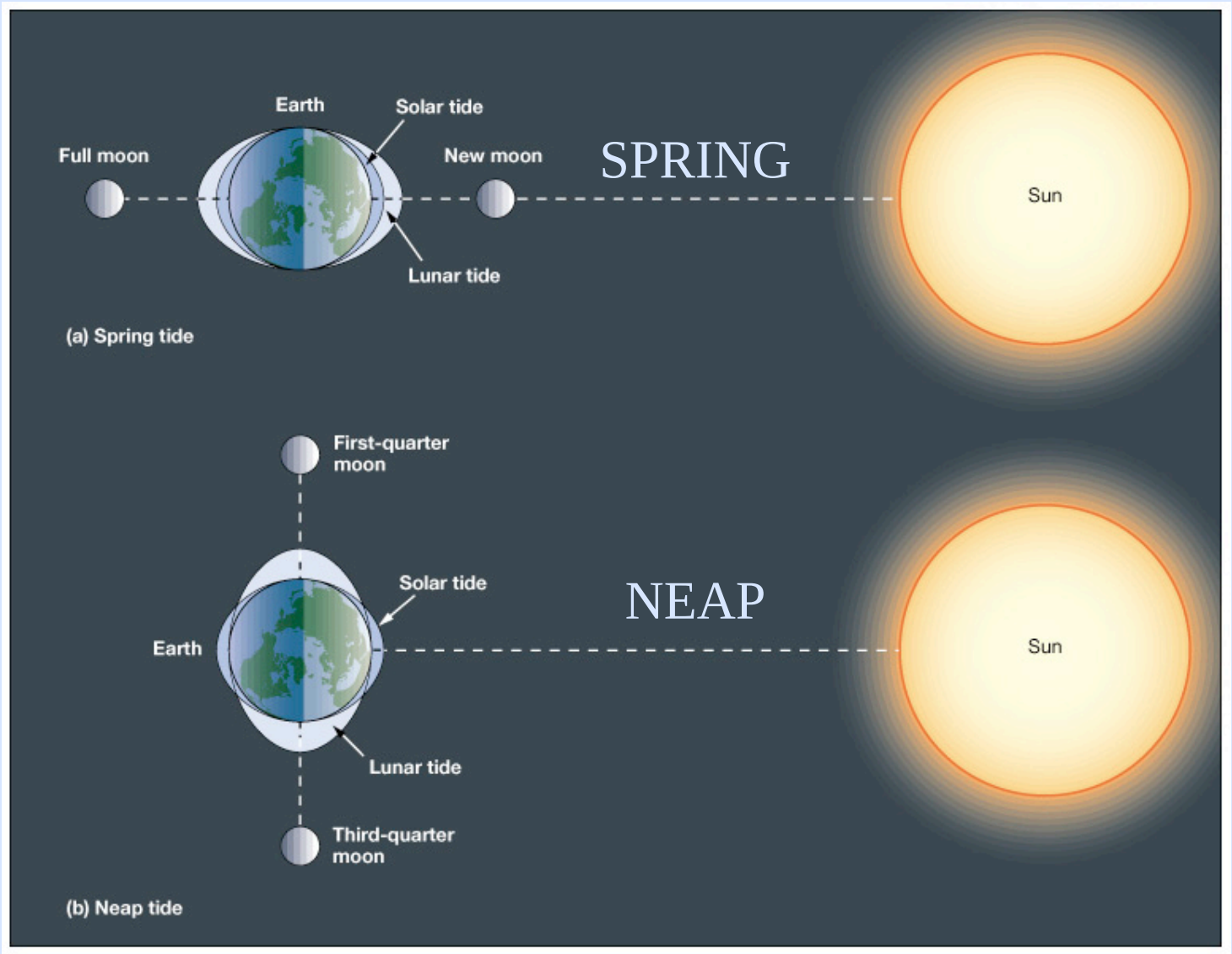




$F_t \alpha (m_1 m_2)/\text{distance}^3$

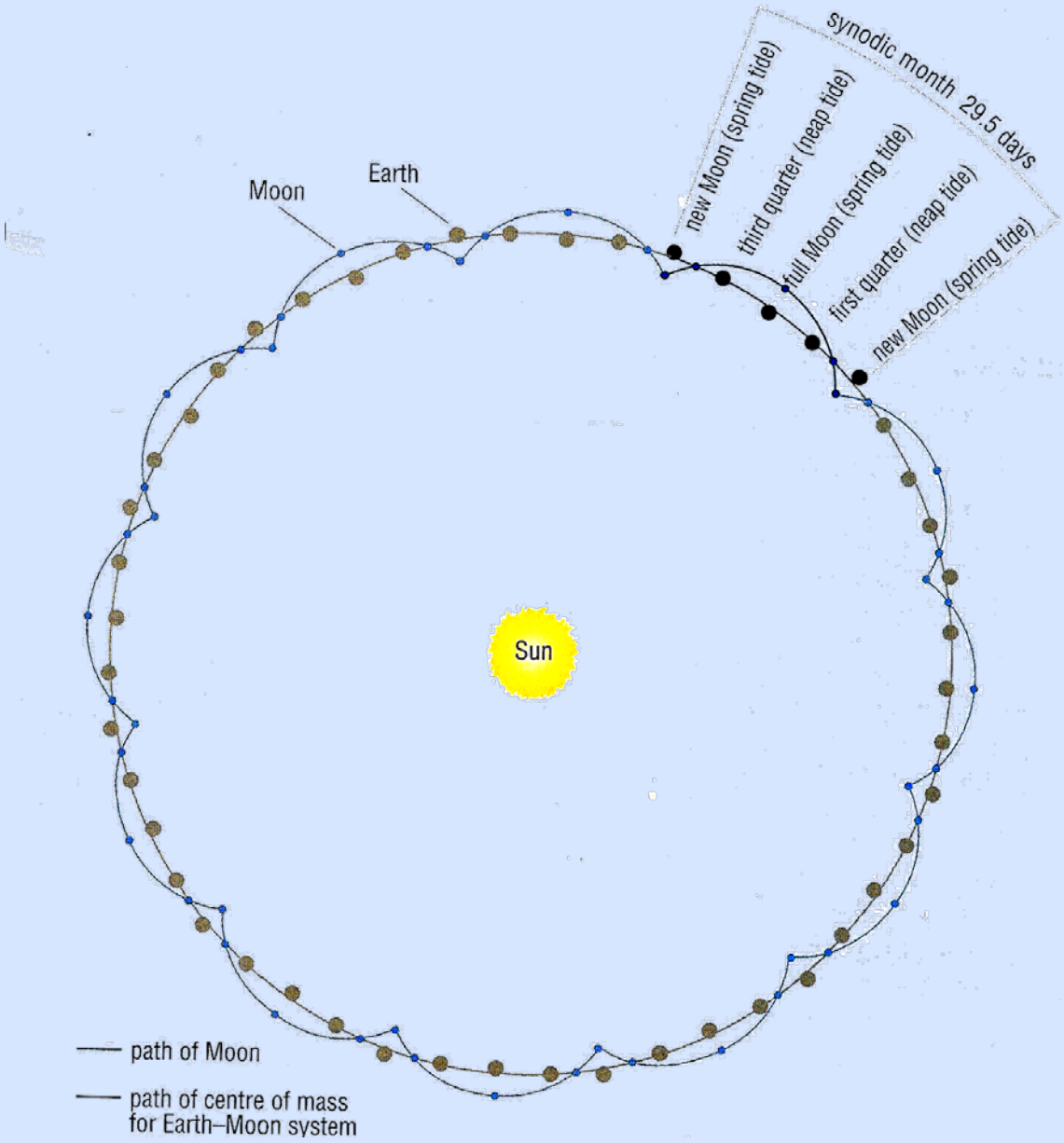
thus though the sun is 27 million times more massive than the moon, it is 390 times farther away and when cubed we have the ratio of 27million divided by 59million to get a value of 0.46, i.e. the sun has 46% of the tide-generating power of the moon

Earth-Moon-Sun positions and the monthly tidal cycle



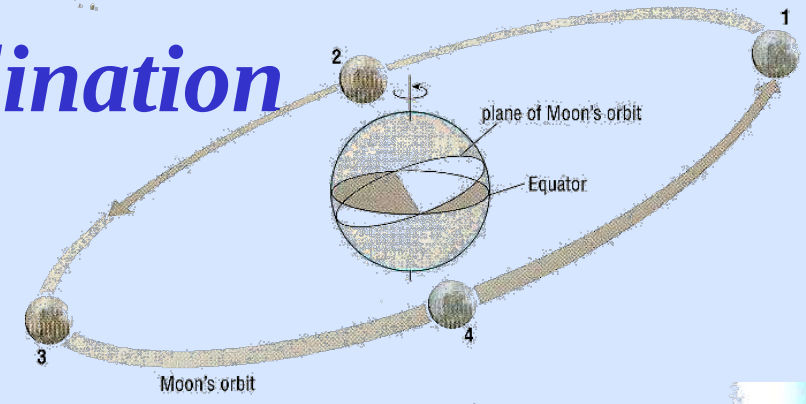
The monthly tidal cycle (29 days)

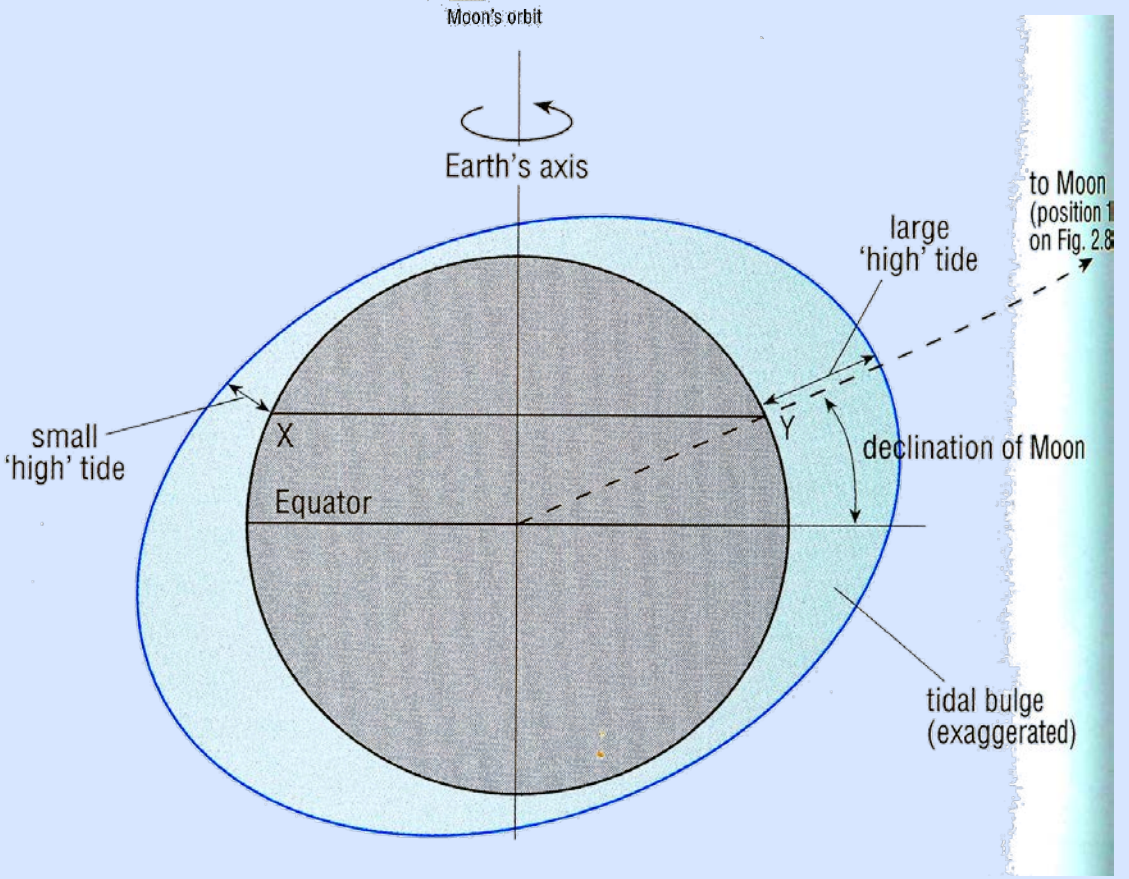
- About every 7 days, Earth alternates between:
  - Spring tide
    - Alignment of Earth-Moon-Sun system
    - Lunar and solar bulges constructively interfere
    - Large tidal range
  - Neap tide
    - Earth-Moon-Sun system at right angles (quadrature)
    - Lunar and solar bulges destructively interfere
    - Small tidal range


synodic month 29.5 days
new Moon (spring tide)
third quarter (neap tide)
full Moon (spring tide)
first quarter (neap tide)
new Moon (spring tide)
Moon
Earth
Sun
path of Moon
path of centre of mass for Earth–Moon system

Effect of declination

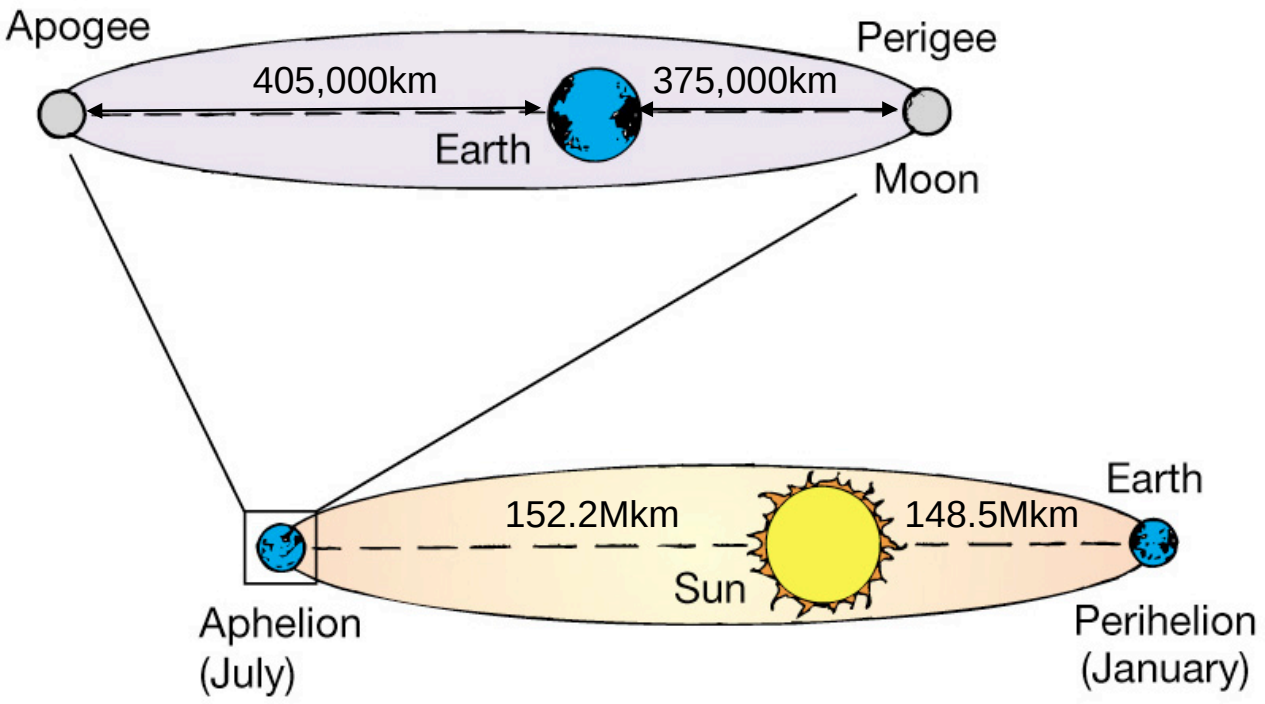
- The plane of the Moon's orbit is tilted 5º with respect to the ecliptic (tilt of earth rotation with its orbit)
- The center of the tidal bulges is at a minimum when the moon crosses the equator (known as equatorial tides) and reach a maximum when the moon is 28.5º off the Equator (i.e. the earth's tilt of 23.5°+5°) and produce what is known as tropic tides



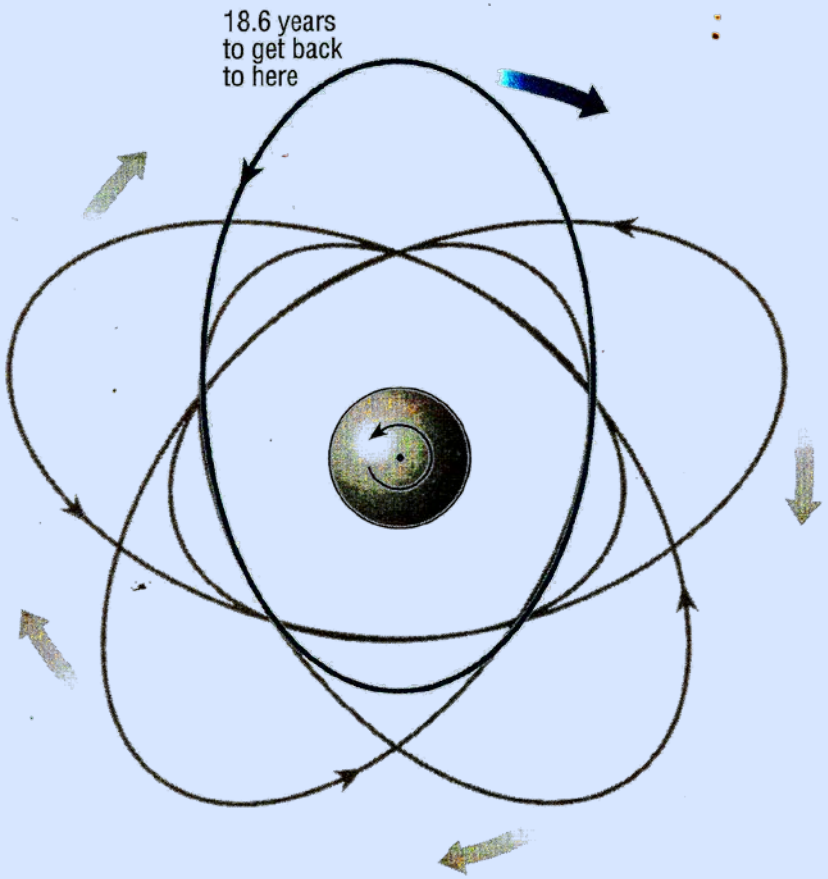


Effect of elliptical orbits

- Tidal ranges are greater when:
  - The Moon is at perigee (+20%)
  - The Earth is at perihelion (+6%)



Moon's Precession



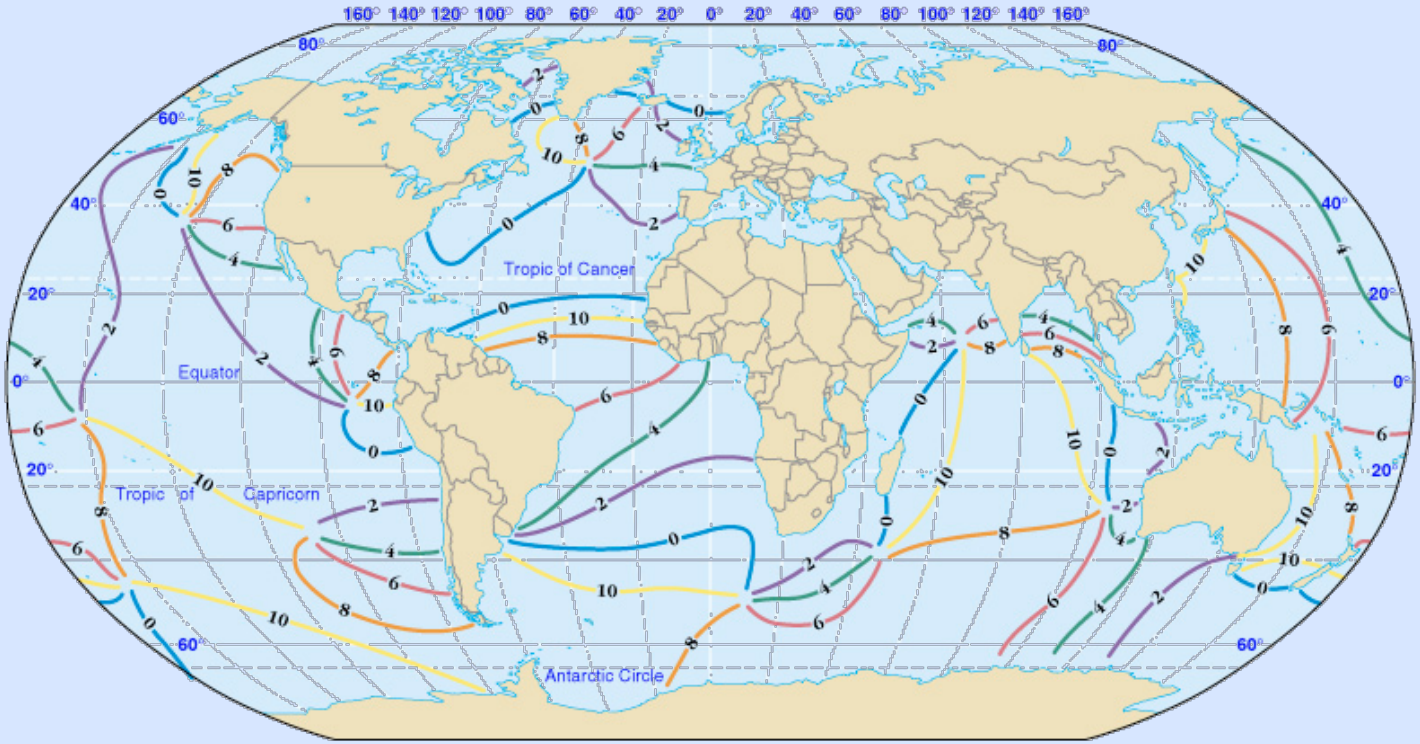
- The moons elliptical orbit itself precesses (i.e. orbit rotates) over 18.6 years, with the max declination of the moon ranging from 18.4° to 28.4°

Dynamic Theory of Tides

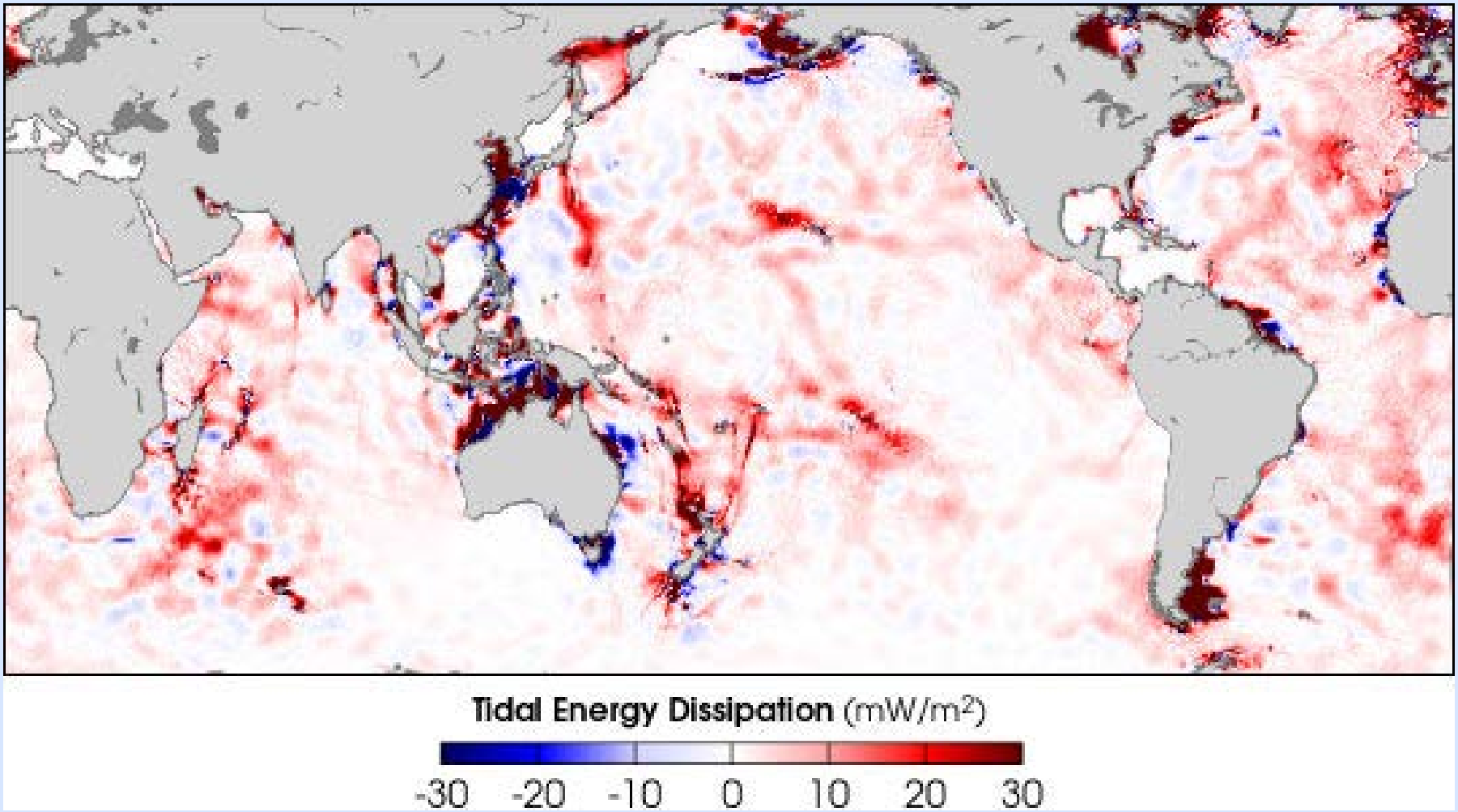
- for the tidal bulge to move 1/2 the circumference of the earth (20,000 km) every 12 hr and 50 min, the tide wave would need to move a speed of 1600 km/hr as a shallow water wave
- given the theory on shallow-water waves and the dependence on water depth, the ocean depth should be 22 km deep. However since the mean depth of the ocean is only 3.9 km deep, the tide wave moves as a **forced wave** with the speed determined by ocean depth, i.e. about 700 km/hr
- with this limitation of speed and earth circumference, the tides cannot simply bulge out as described in the prediction of equilibrium tides
- instead the ocean breaks up into smaller cells where the tide waves revolves around 15 pts of no motion called **amphidromic pts.** 7 in the Pacific and 4 each in the Atlantic and Indian Oceans
- radiating from these points we can draw lines where the tide will be high at the same time, these lines are called **cotidal lines**

Tides in the ocean

- Cotidal map shows tides rotate around amphidromic points
- More realistic pattern of tides in the ocean



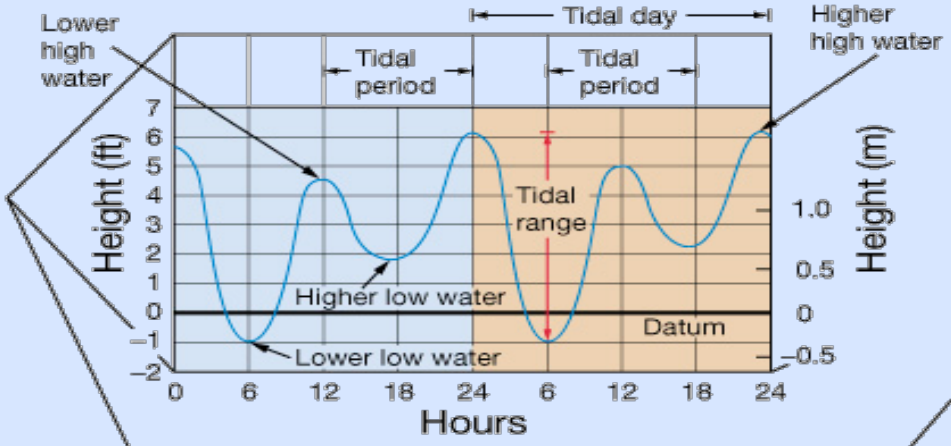
Tidal energy is dissipated along the coastline and within the deep ocean

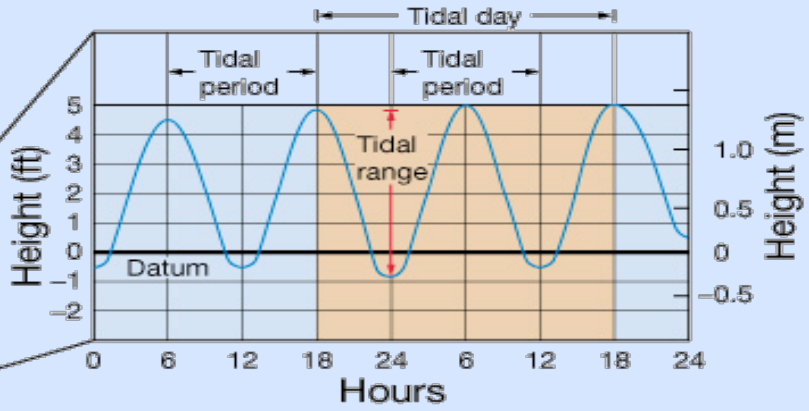


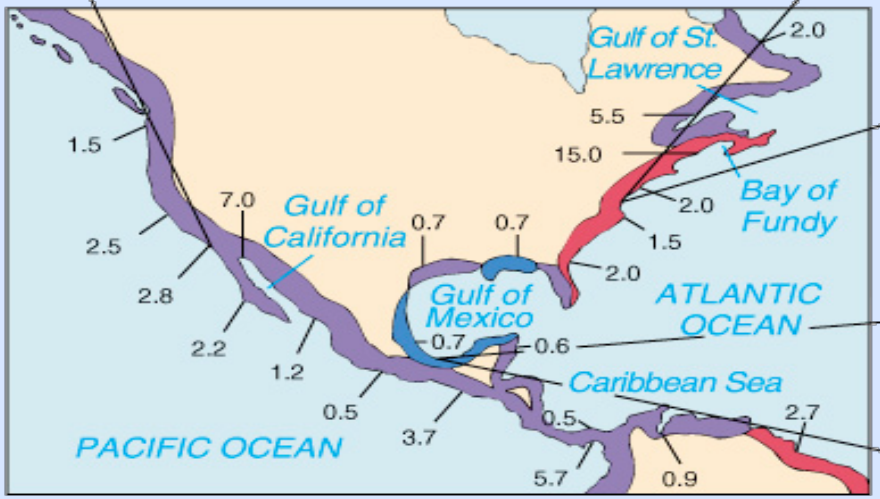
Tidal patterns

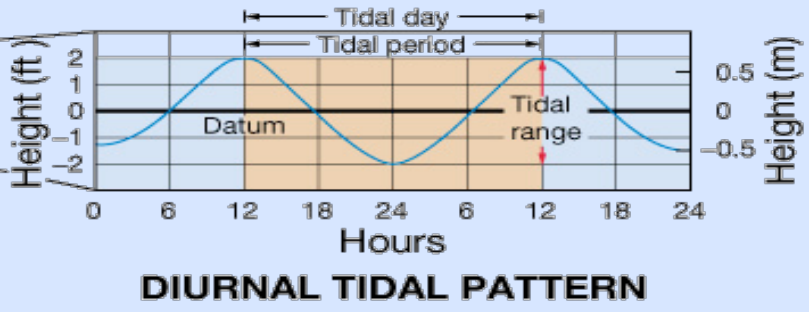
- Diurnal
  - One high and one low tide each (lunar) day
- Semidiurnal
  - Two high and two low tides of about the same height daily
- Mixed
  - Characteristics of both diurnal and semidiurnal with successive high and/or low tides having significantly different heights

Tidal patterns in the U.S.

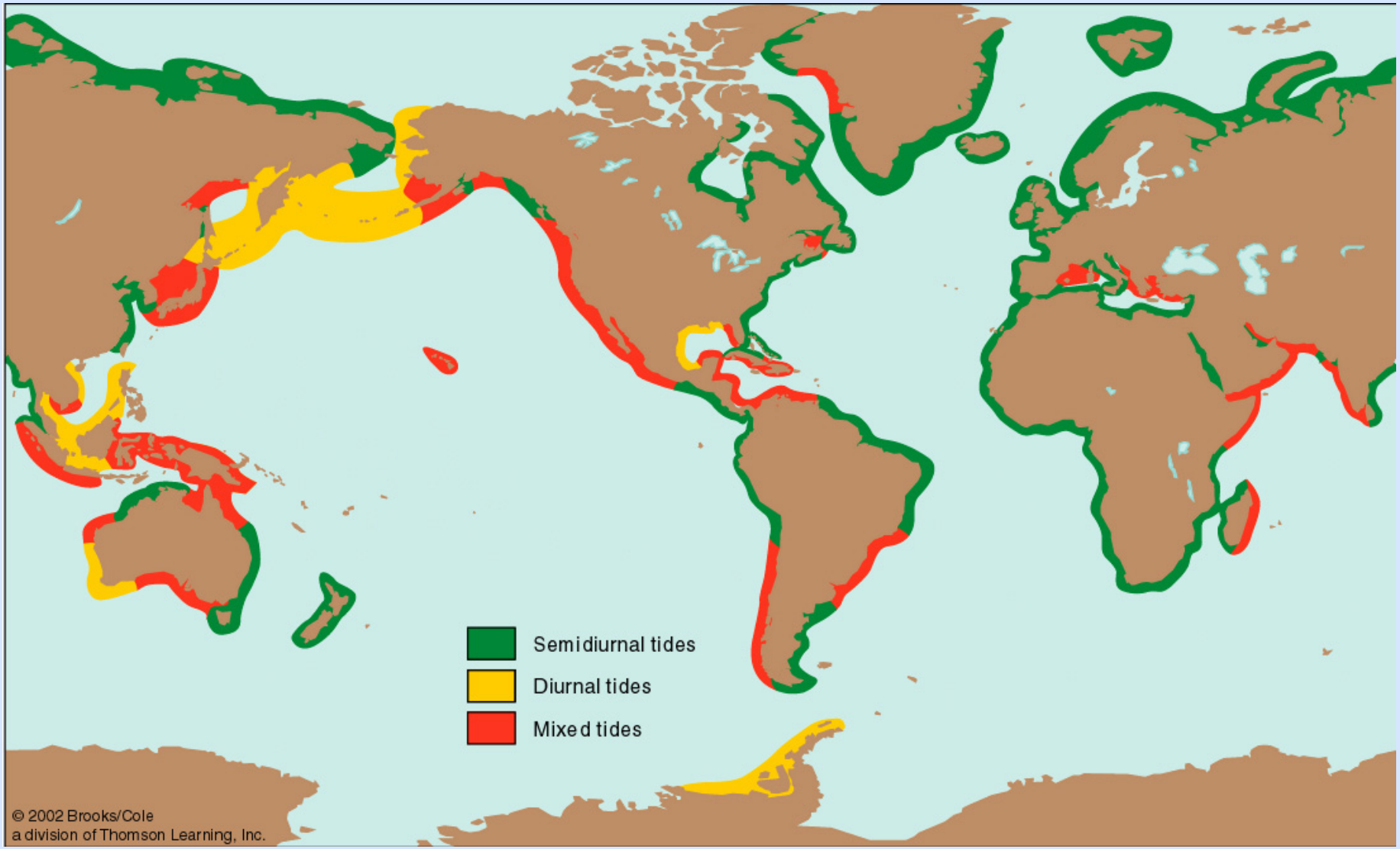




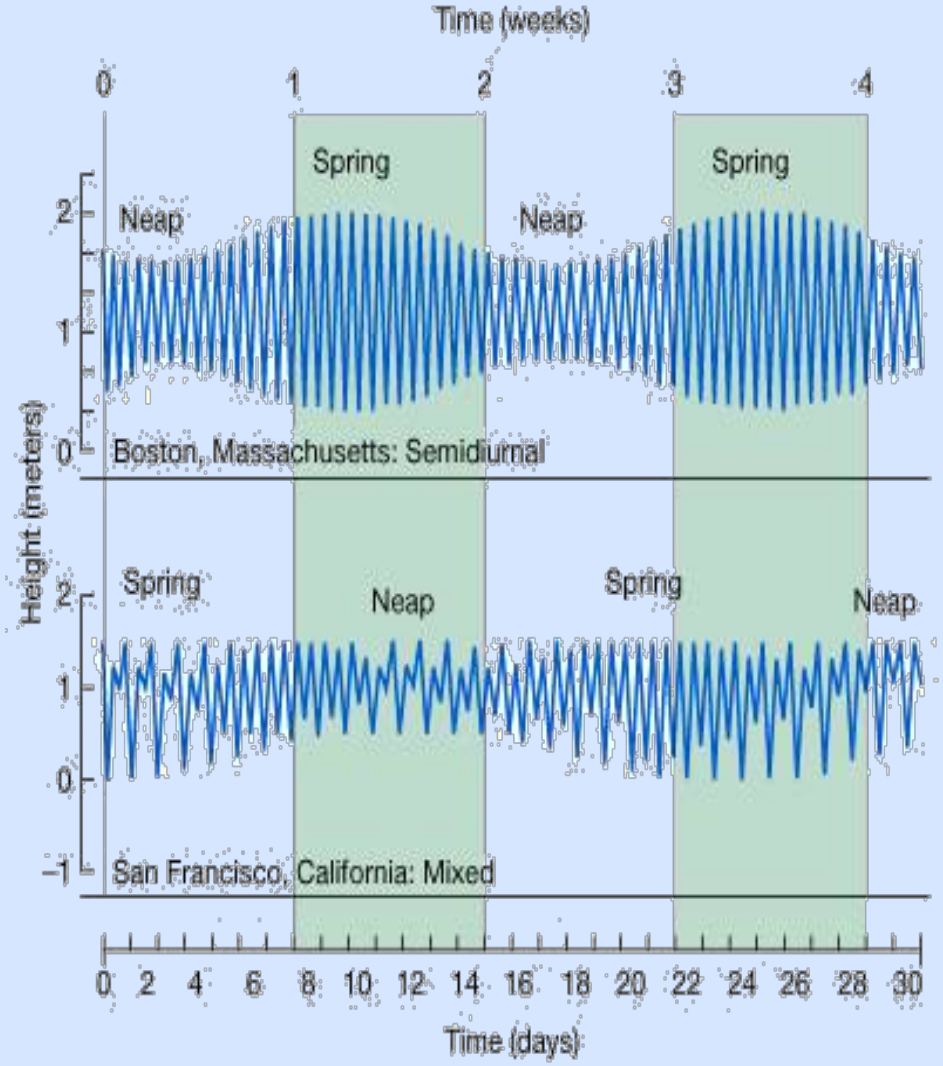


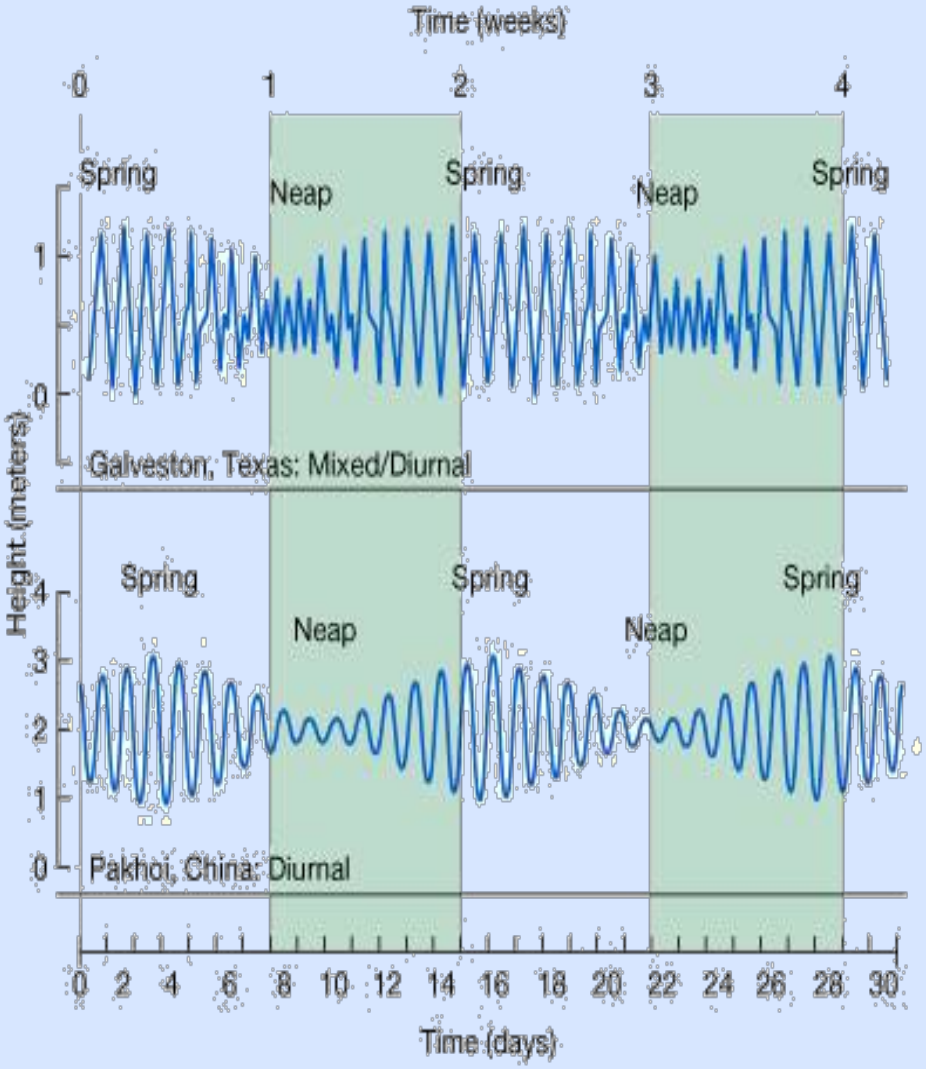


Global Pattern



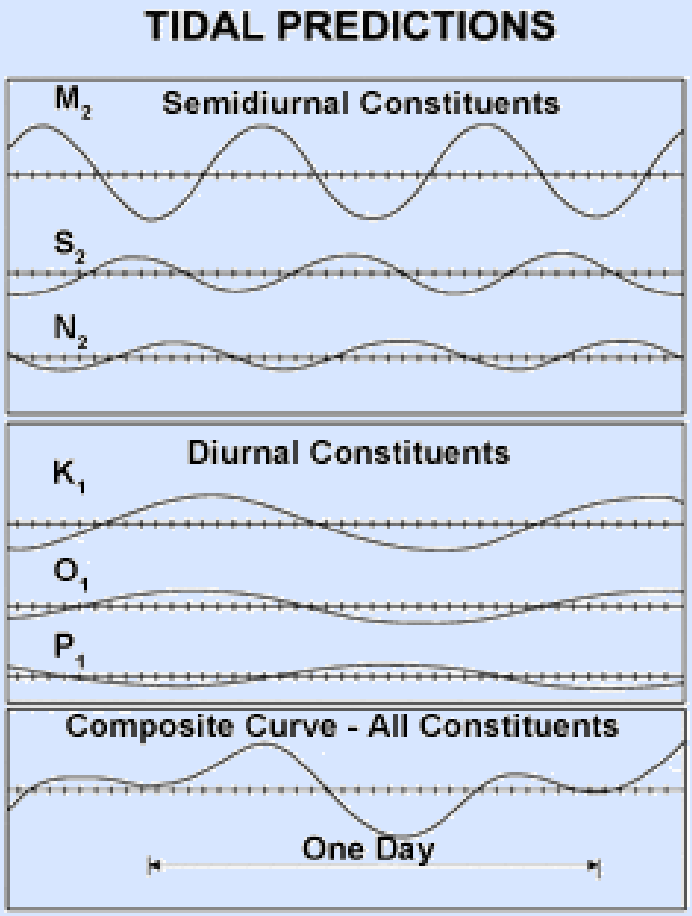
Monthly tidal curves



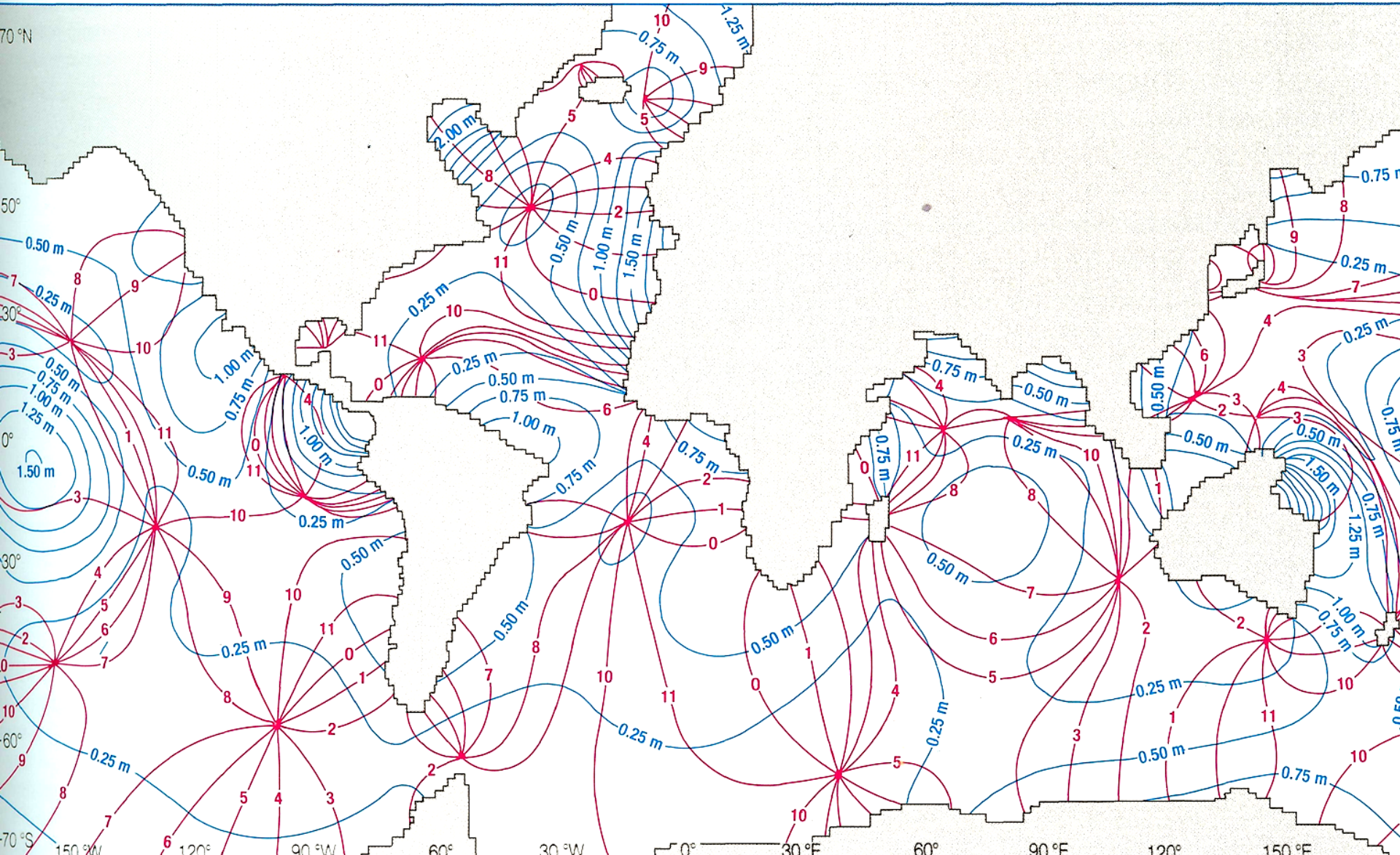


Some principal tidal constituents

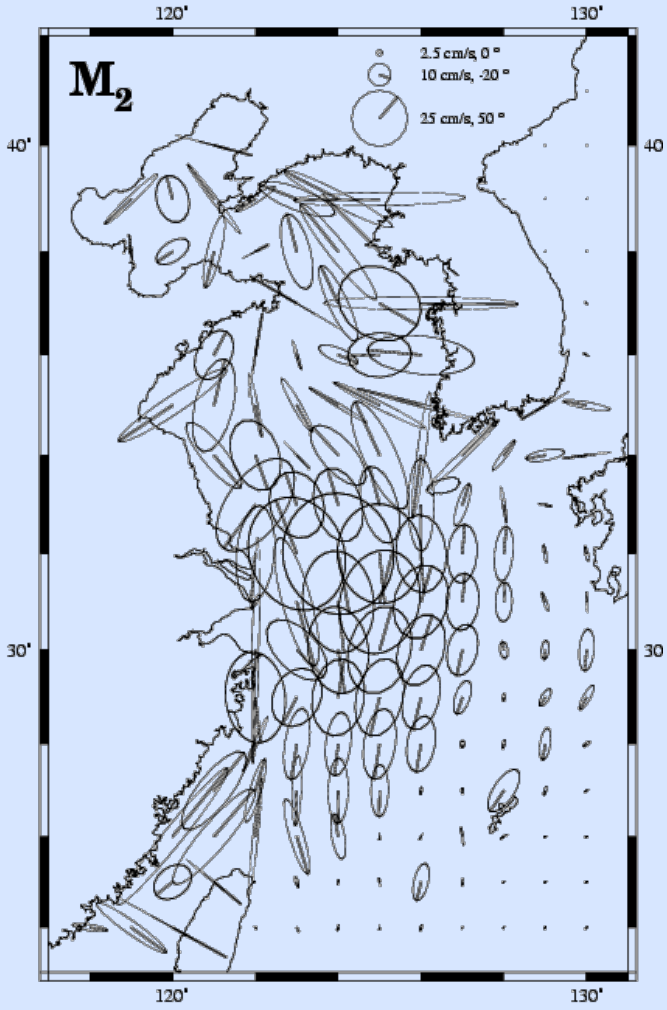
Component Name	Symbol	Period hours	Coefficient Ratio M_2=100
Semi-diurnal:			
principal lunar	M_2	12.42	100
principal solar	S_2	12.00	46.6
larger lunar elliptic	N_2	12.66	19.2
luni-solar	K_2	11.97	12.7
Diurnal:			
luni-solar	K_1	23.93	58.4
principal lunar	O_1	25.82	41.5
principal solar	P_1	24.07	19.4
Longer Period:			
lunar fortnightly	M_f	327.86	17.2
lunar monthly	M_m	661.30	9.1

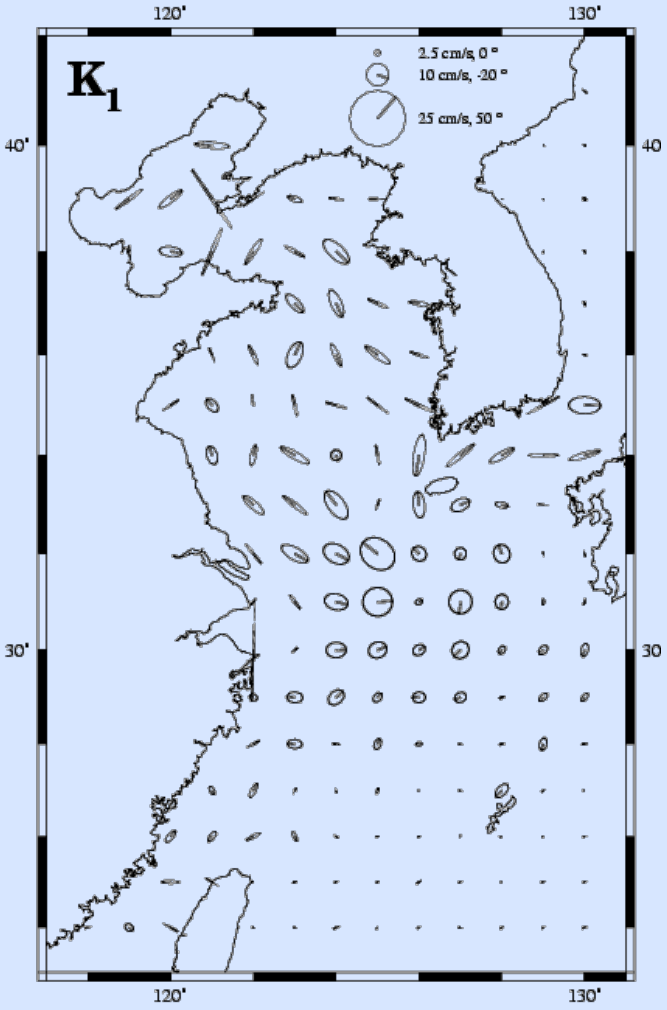


The M_2 tide is one of many components



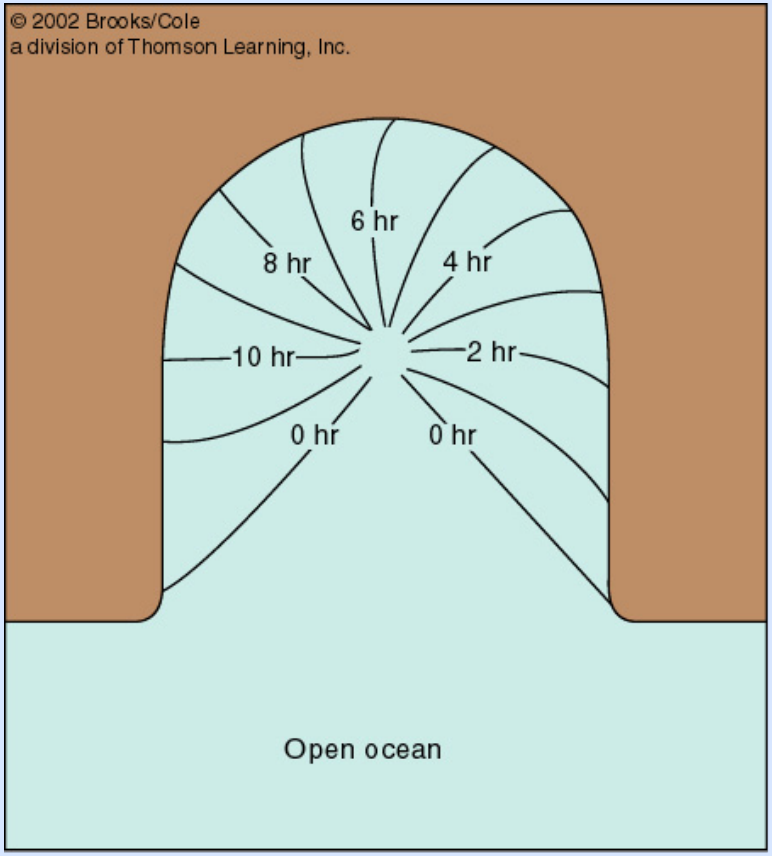
Tidal components vary locally in coastal waters due to resonance and friction





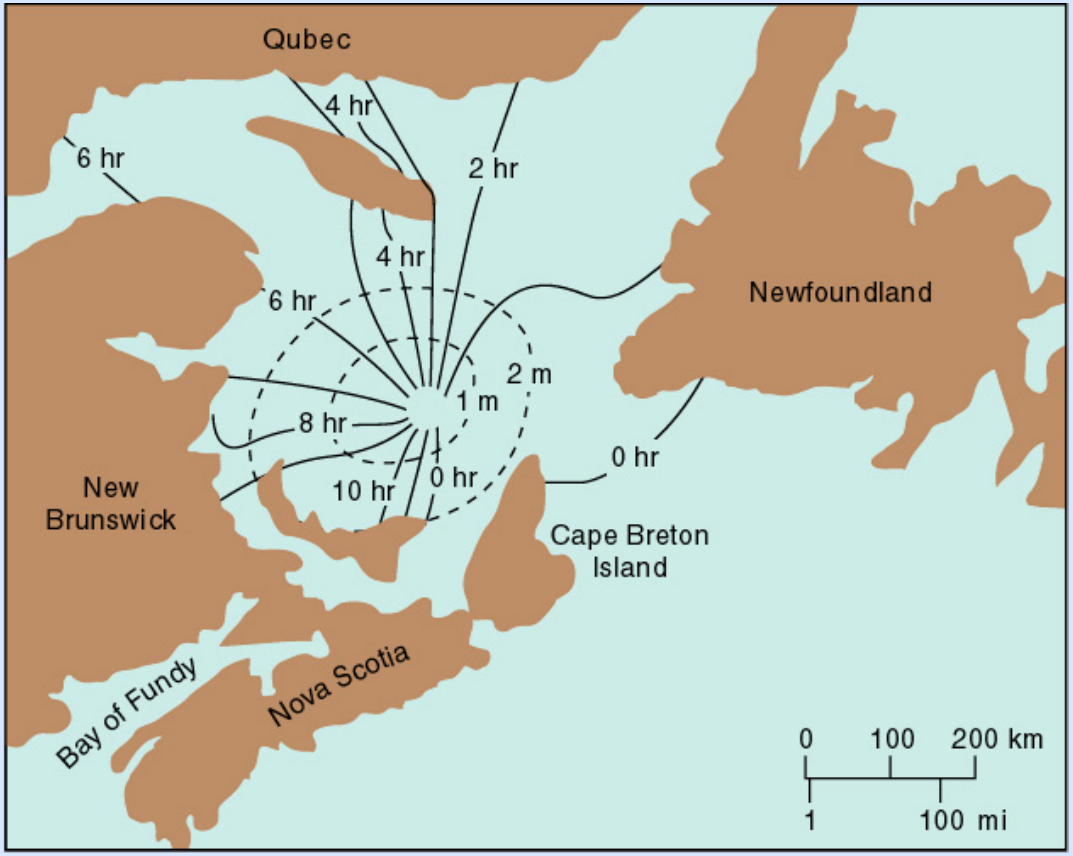
Tides in Confined Basins

The tidal range is determined by basin configuration.



a Broad basin

Imaginary amphidromic system in a broad, shallow basin.

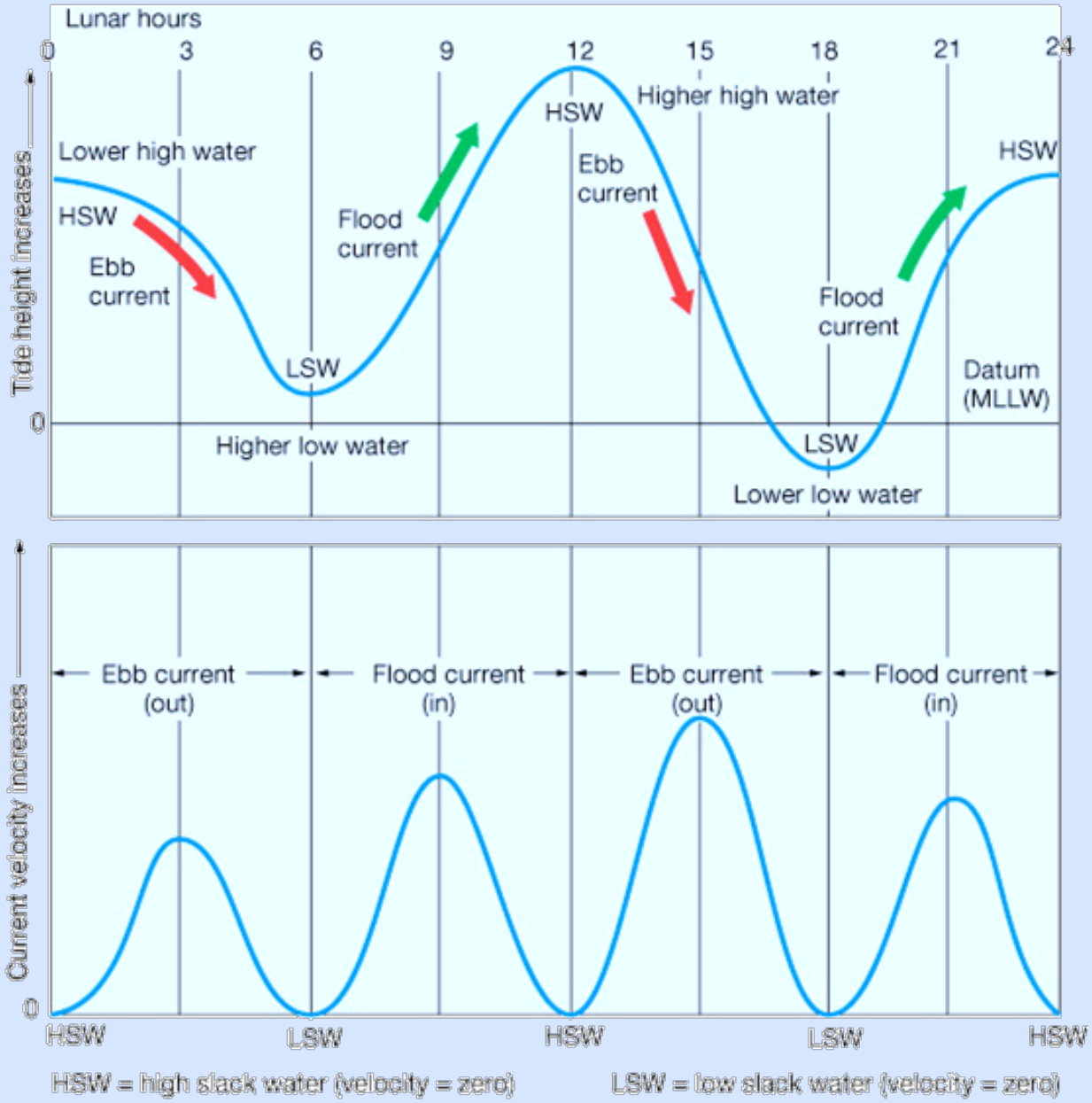


b Amphidromic system: Gulf of St. Lawrence. Dashed lines show tide height

Real amphidromic system in a broad, shallow basin.

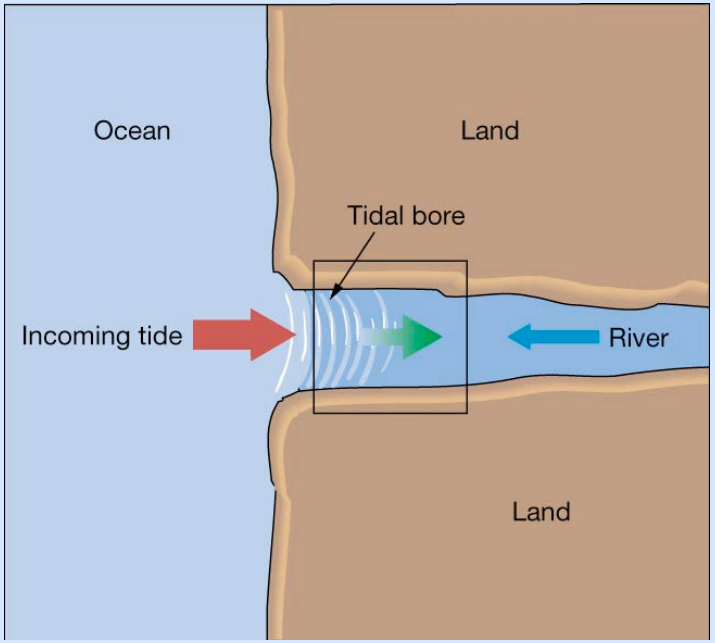
Coastal tidal currents

- Tidal currents occur in some bays and rivers due to a change in tides
  - Ebb currents produced by outgoing tides
  - Flood currents produced by incoming tides



Tidal bore = a true tidal wave

- Wall of water that moves upriver
- Caused by an incoming high tide
- Occurs in some low-lying rivers
- Can be large enough to surf or raft



The pororoca
http://www.youtube.com/watch?v=4ZuZiLuHM1A

Severn Bore
http://www.youtube.com/watch?v=rUuUlSKCecY&feature=related

Qiantang River

http://www.youtube.com/watch?v=HcuFdGbdOMU&feature=related

Sites with high potential for tidal power generation

1 - Cook Inlet
2 - Strait of Georgia
3 - Gulf of California
4 - Frobisher Bay
5 - Ungava Bay
6 - Bay of Fundy/ Passamaquoddy Bay
7 - Sao Luis
8 - Golfo San Jorge
9 - Straits of Magellan
10 - Abidjan
11 - Rance River/ Chausey I.
12 - Severn River
13 - Mezan/Kislaya
14 - Sea of Okhotsk
15 - Asan Bay
16 - Shanghai
17 - Amoy
18 - Rangoon
19 - Darwin
20 - Broad Sound
21 - Auckland