Tides

AOS660, Professor McKinley
21 November 2013

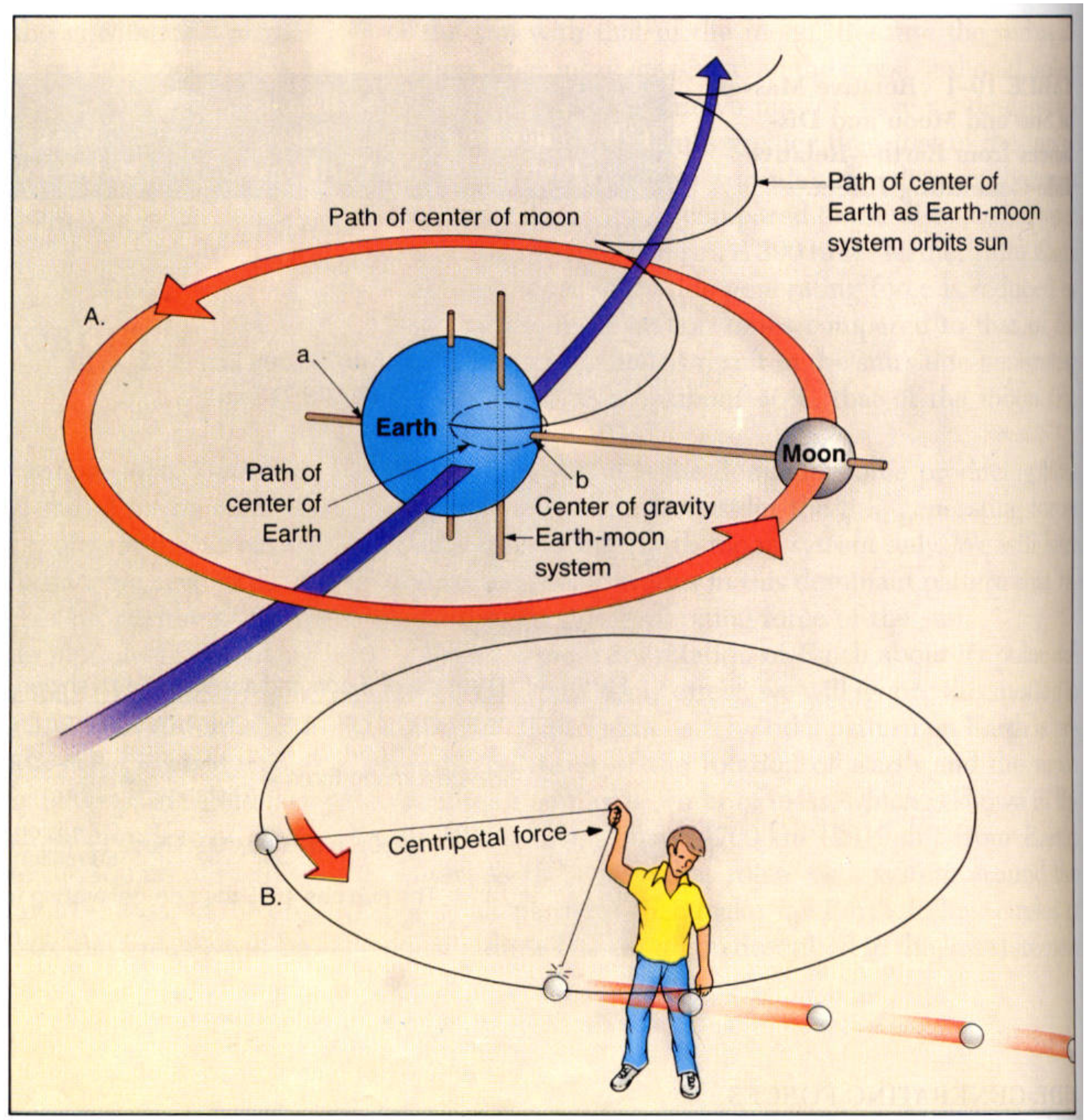
- Equilibrium Tides
  - Balance of Forces
  - Some key astronomical effects
- Dynamic Tides
  - Shallow water wave cannot “keep up” with Earth
    - Indirect and direct tides
  - The Earth is not a waterworld!
    - Kelvin Wave
    - Amphidromic points
  - Partial Tides and local fitting

What causes the tides?

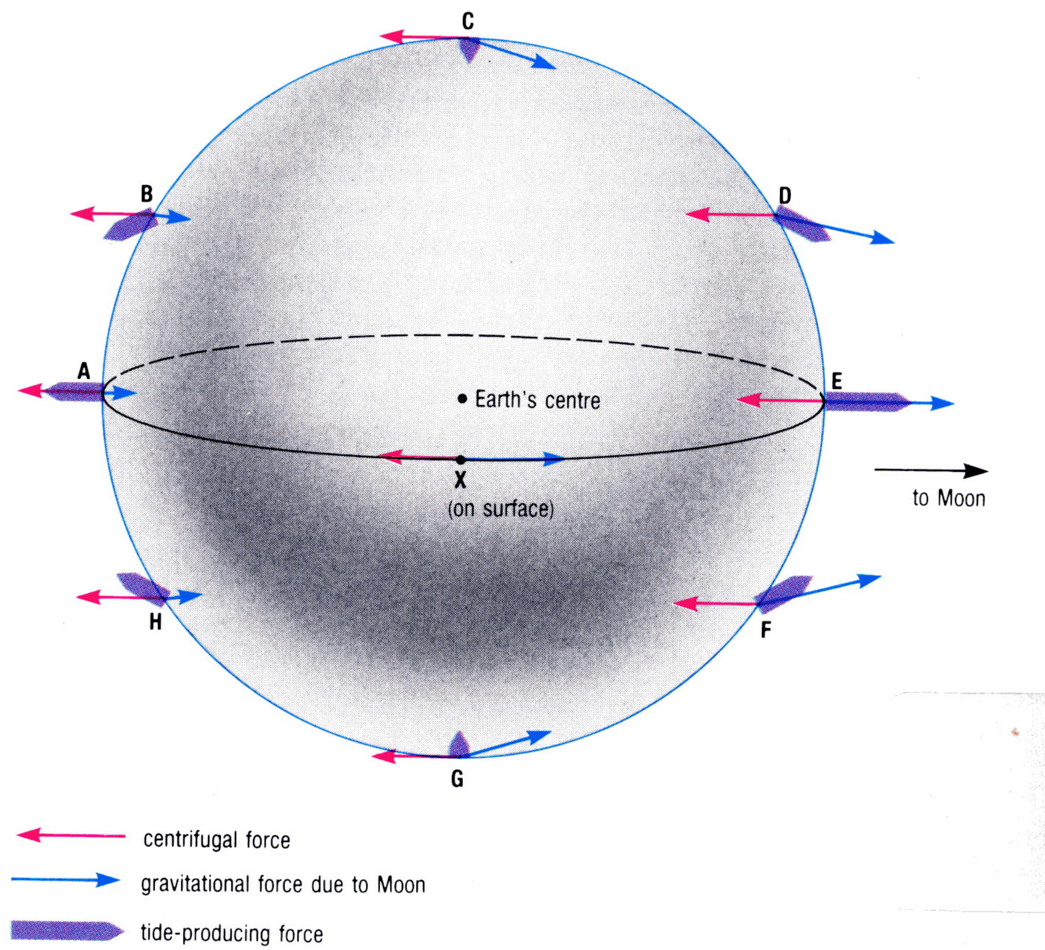
- Centrifugal force, an apparent force, caused by Earth-Moon system rotation
- Gravitational attraction of the
  - Moon
  - Sun

Centrifugal Force due to Earth-Moon rotation around their joint center of gravity

period = 27.3 days



Centrifugal force at each point on Earth is constant, and is balanced by Moon's gravity… The resultant is the Tide Producing Force (TPF)

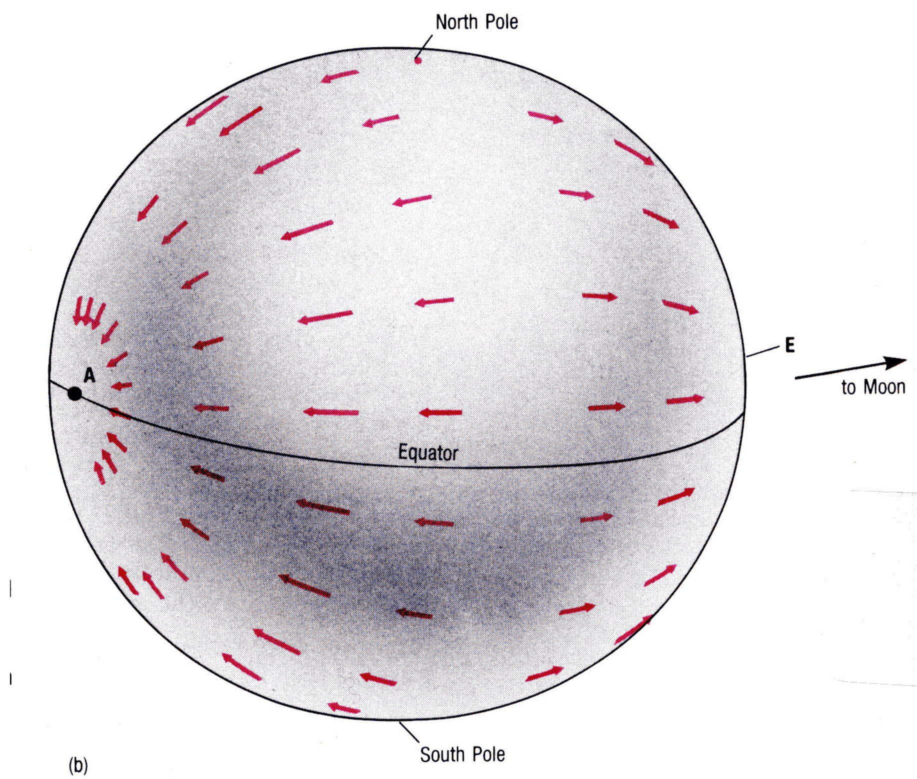


Tide Producing Force

$$TPF \propto \frac{(Gm_1m_2)*(2a)}{R^3}$$

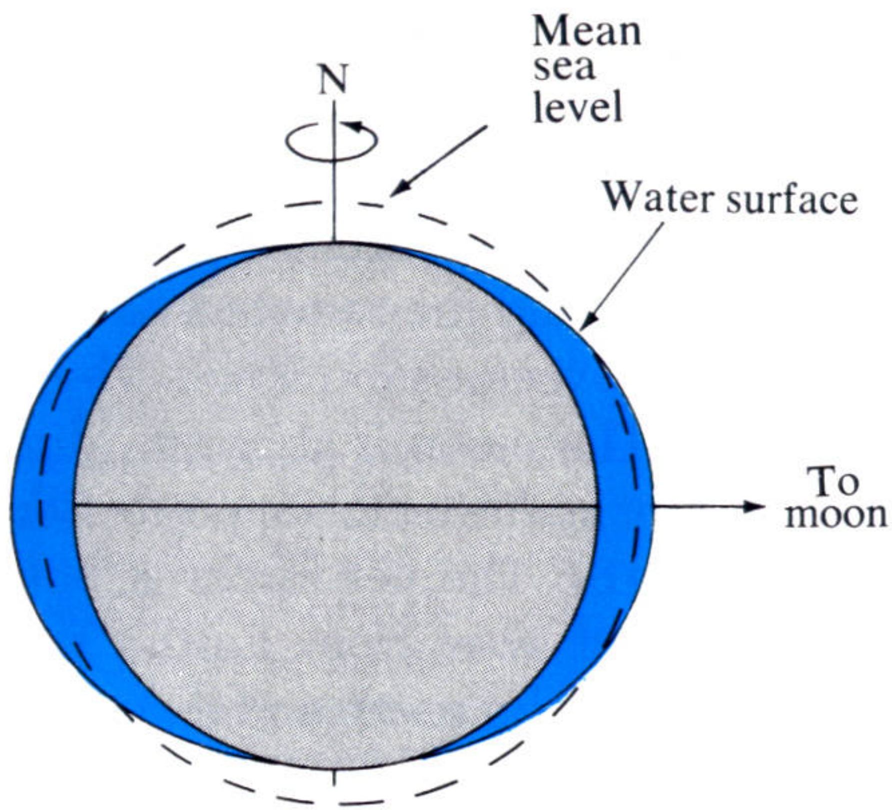
Sun is much larger, but its also 360 times as far away, so its TPF is only 46% that of the moon

Tractive Force (TF) is the horizontal component (along the Earth Surface) that is not balanced by Earth's gravity



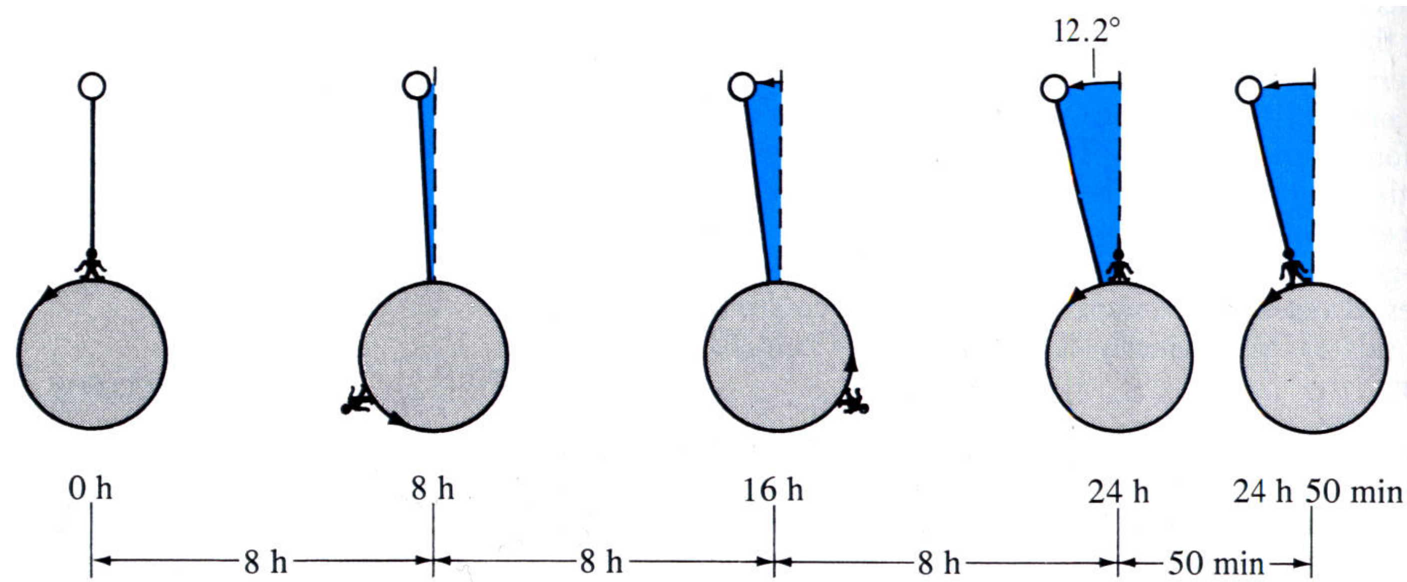
Tidal Bulge for Equilibrium Tide

assuming moon directly over equator, no land



Moon goes around Earth-Moon center as the Earth rotates on its axis –

Period of lunar equilibrium tide is 24 hr, 50min



Solar Tide

- Period = 24 hrs
- Neap tide = Moon and Sun in Quadrature
- Spring Tide = Syzygy (‘sizzijee’)
  - Conjunction
  - Opposition

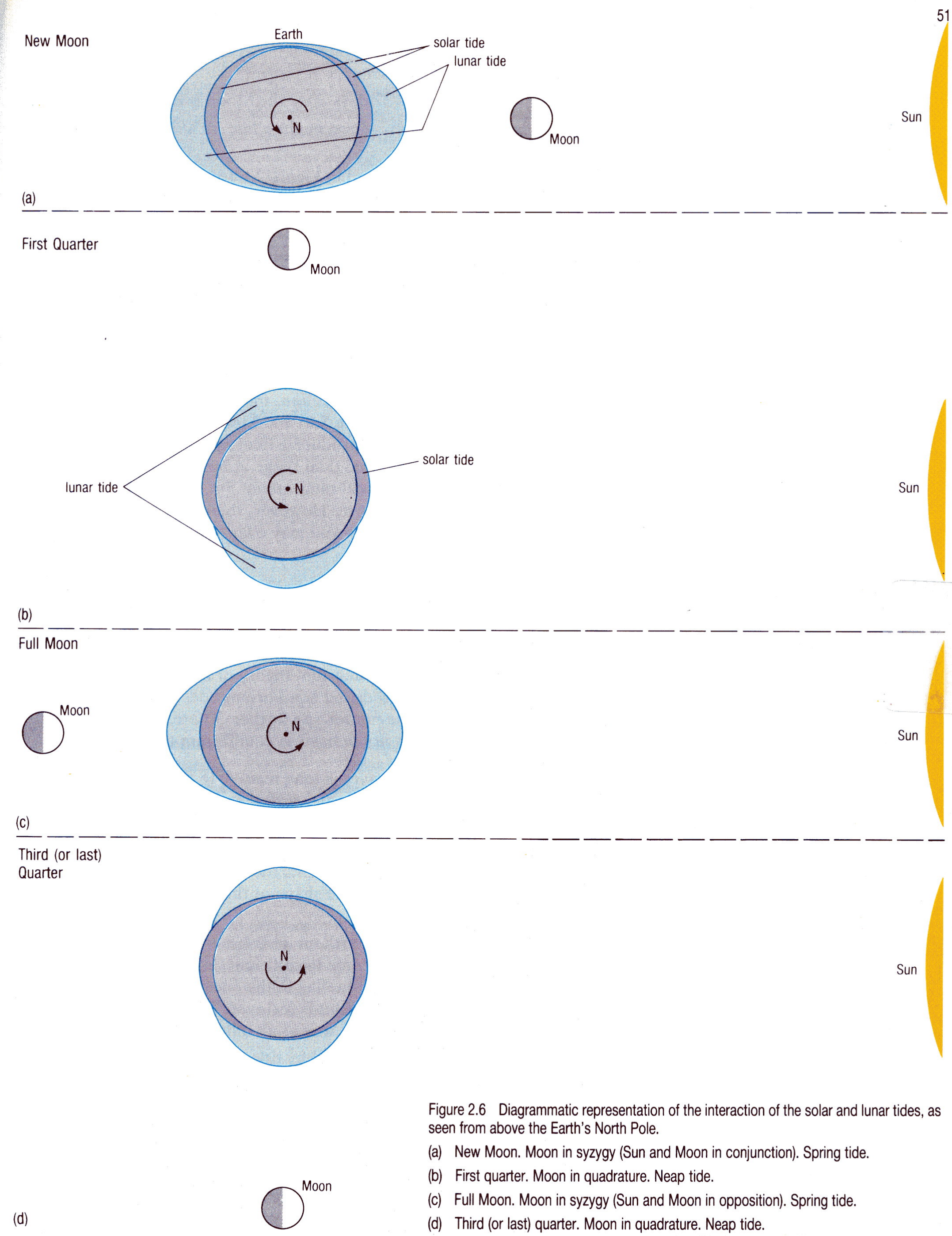


Figure 2.6 Diagrammatic representation of the interaction of the solar and lunar tides, as seen from above the Earth's North Pole.

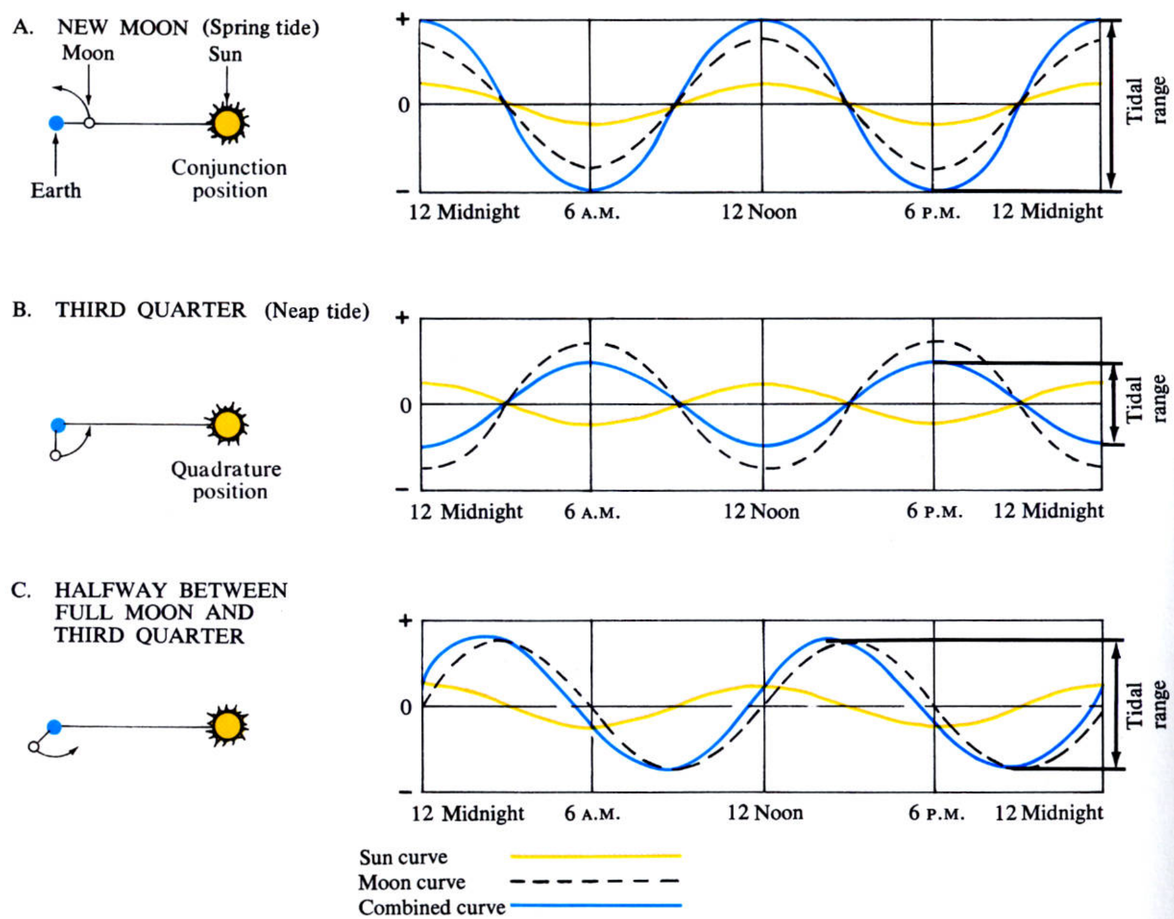
(a) New Moon. Moon in syzygy (Sun and Moon in conjunction). Spring tide.

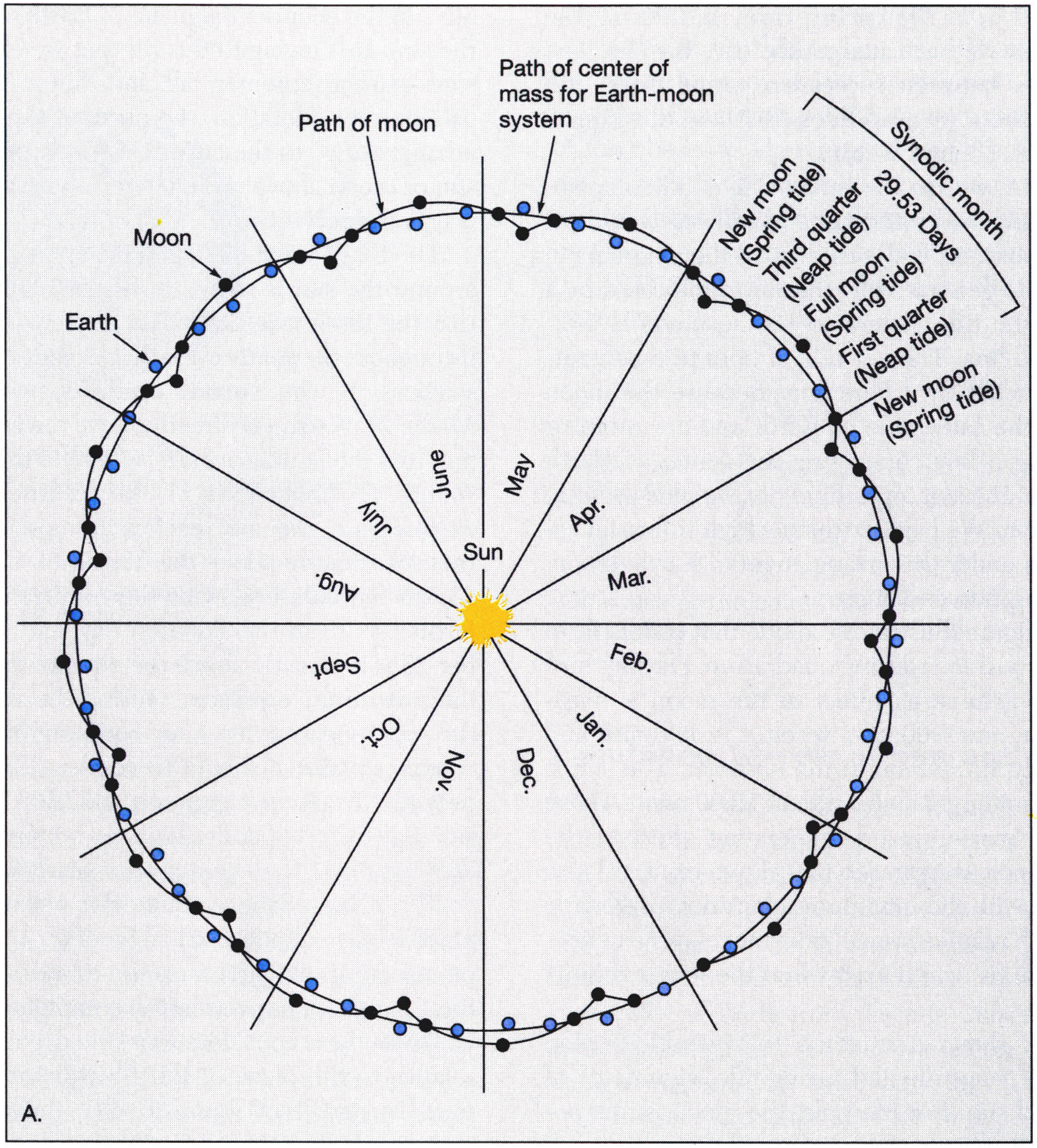
(b) First quarter. Moon in quadrature. Neap tide.

(c) Full Moon. Moon in syzygy (Sun and Moon in opposition). Spring tide.

(d) Third (or last) quarter. Moon in quadrature. Neap tide.

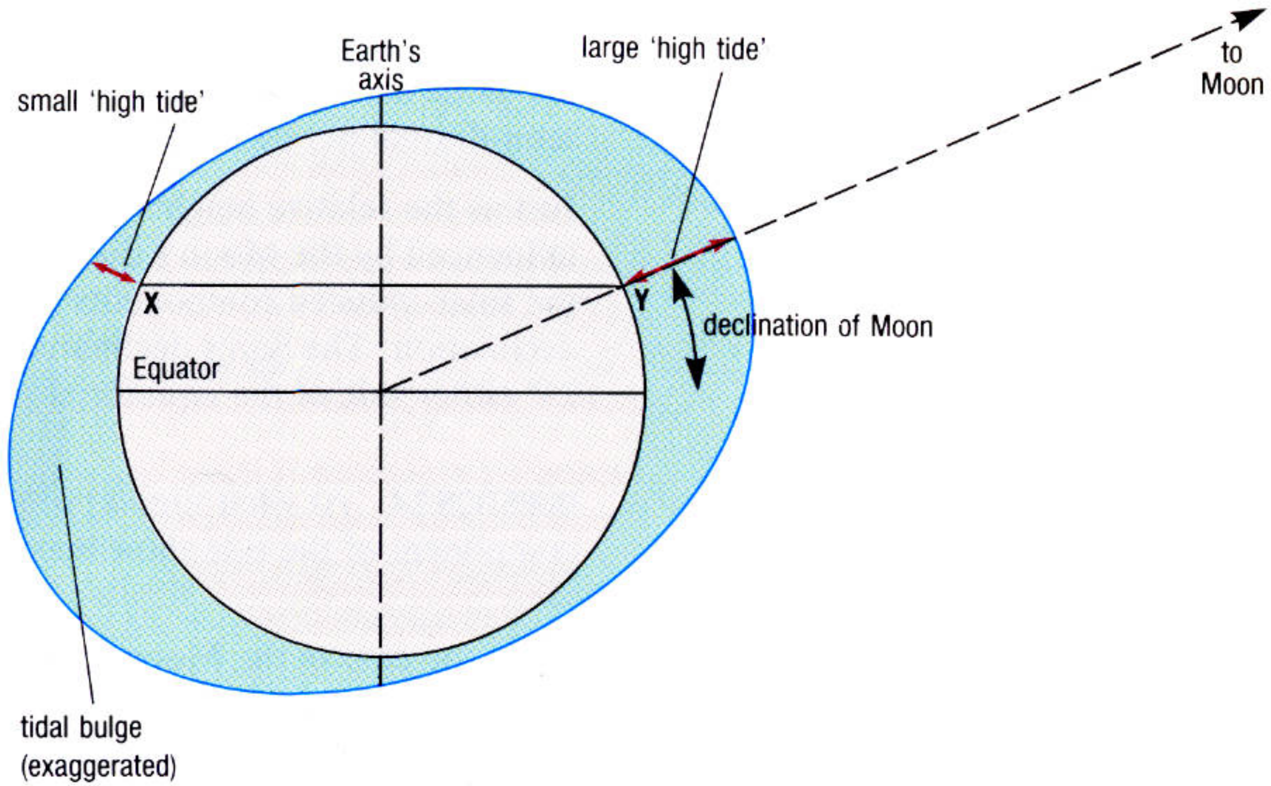
Spring and Neap Tides




Path of center of mass for Earth-moon system
Path of moon
Synodic month
29.53 Days
New moon (Spring tide)
Third quarter (Neap tide)
Full moon (Spring tide)
First quarter (Neap tide)
New moon (Spring tide)
Moon
Earth
Sun
June
May
July
Apr.
Aug.
Mar.
Sept.
Feb.
Oct.
Jan.
Nov.
Dec.
A.

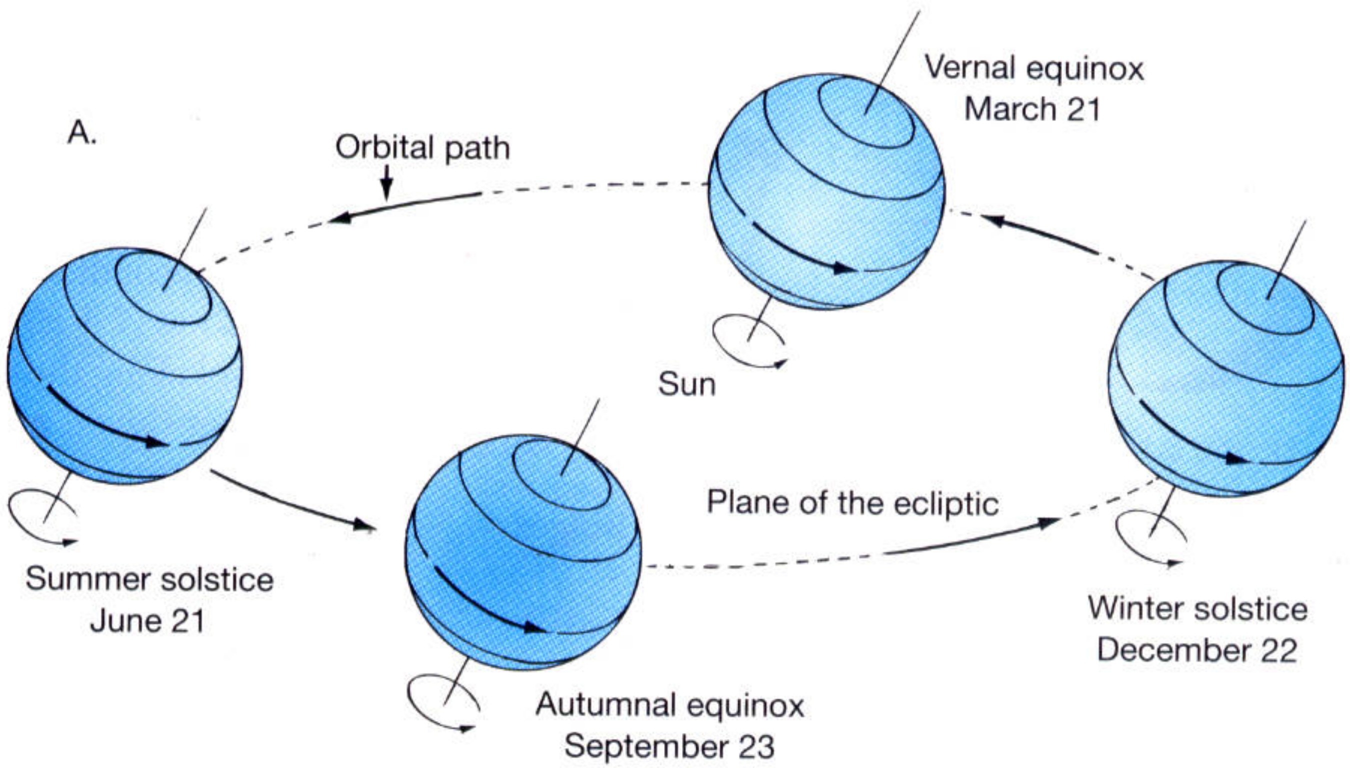
Lunar declination

max angle = 28^o, period = 27.2 days

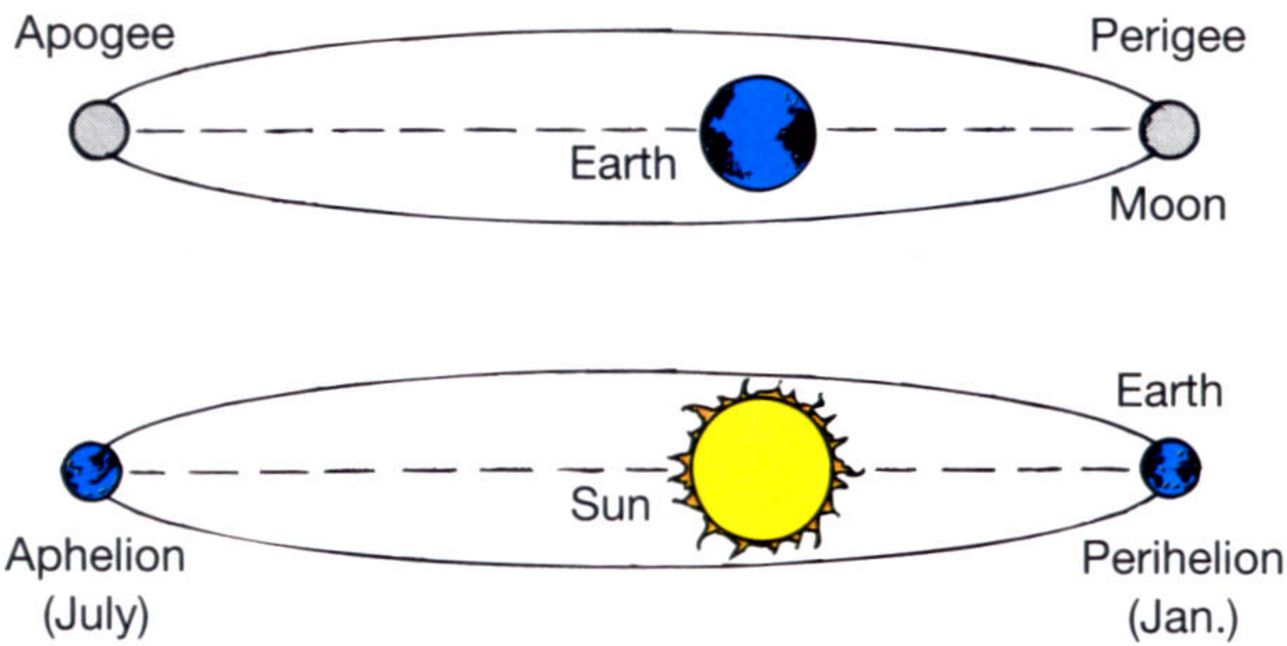


Solar declination

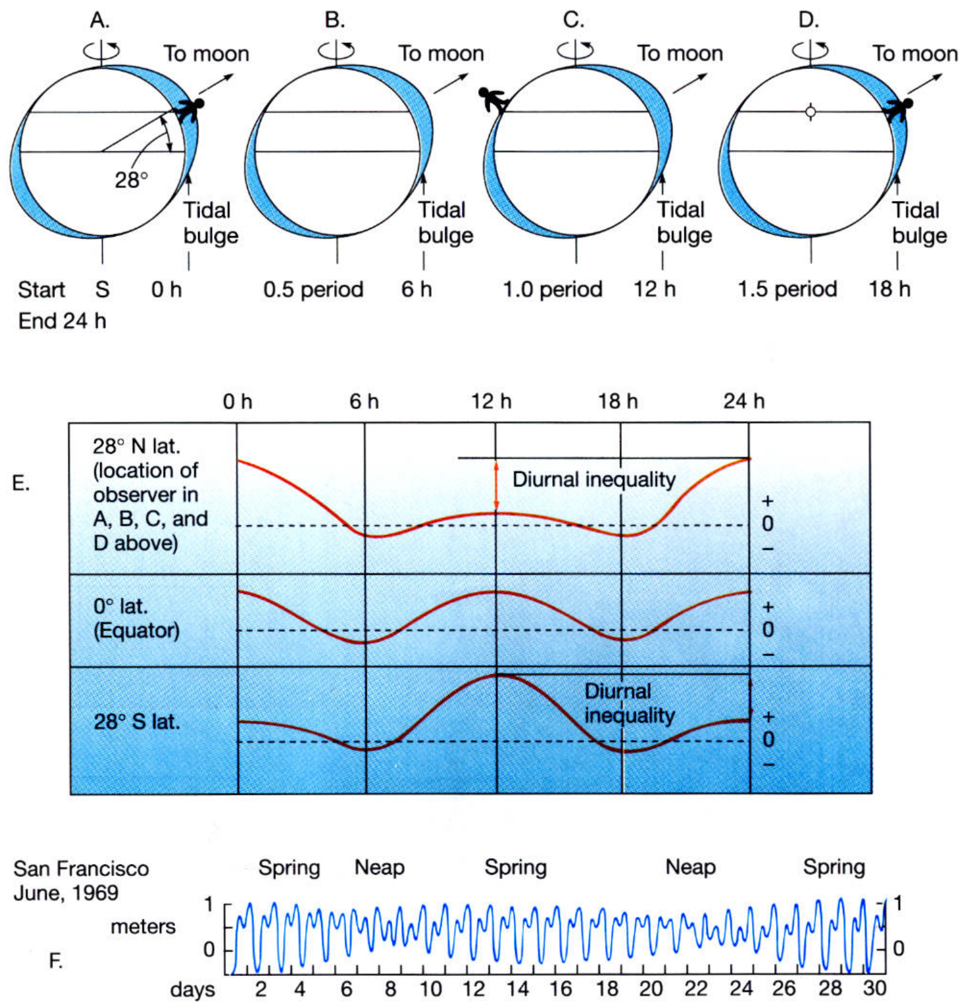
max angle = 23^o, period = 365.25 days



Distance effects



Predicted equilibrium tides



Dynamical theory of the tides

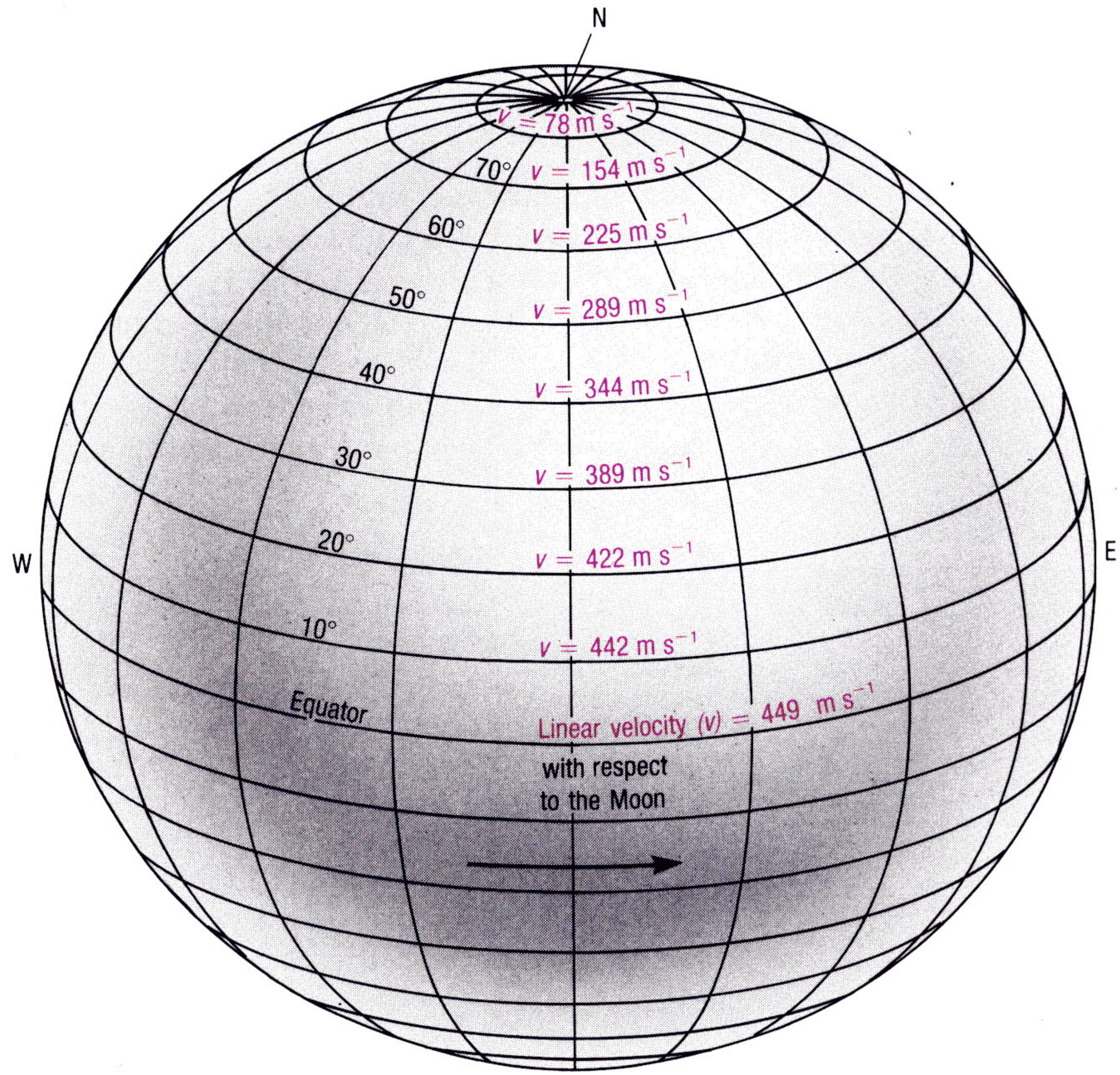
Assume a single equilibrium tide, with Sun and Moon in Syzygy, zero declination
Calculate at the equator
(a_{earth} = 6.37x10^6m)

- How fast would the tidal bulge have to move to remain in equilibrium?
- Assume this disturbance traveled as a wave. What dispersion relationship would be appropriate?
- How deep would the ocean have to be?

The ocean is not this deep, so the tides are not in equilibrium.

- With H = 5.5km, Max speed about 230 m/s
- Thus, tides are ever trying to keep up with the tractive force, but aren’t fast enough

Actually, speed of Earth varies with latitude



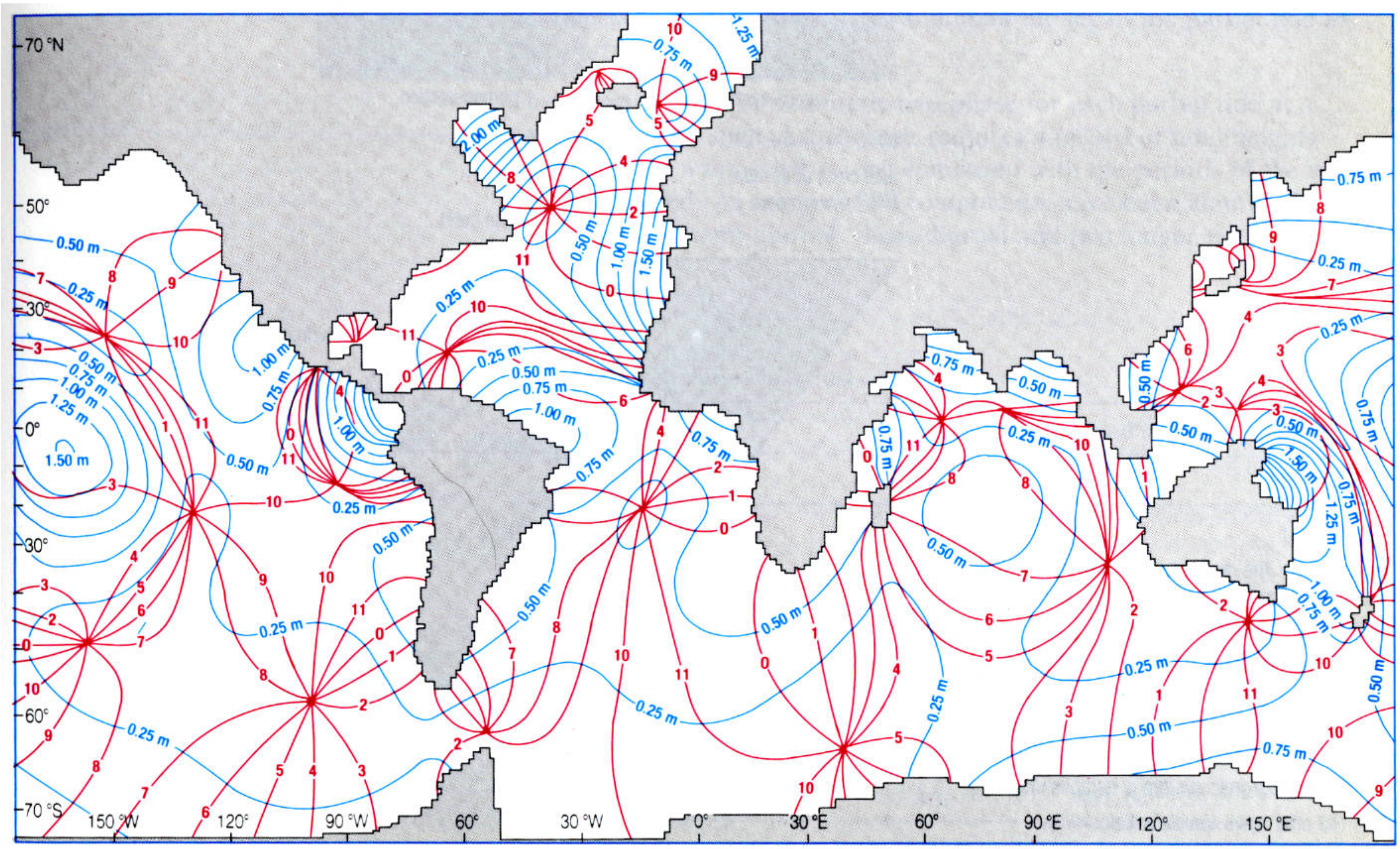
Indirect vs. Direct tide

- Direct tide (>65^{o}) – tide is faster than Earth
  - On “Waterworld Earth”, tide could keep up with Moon overhead

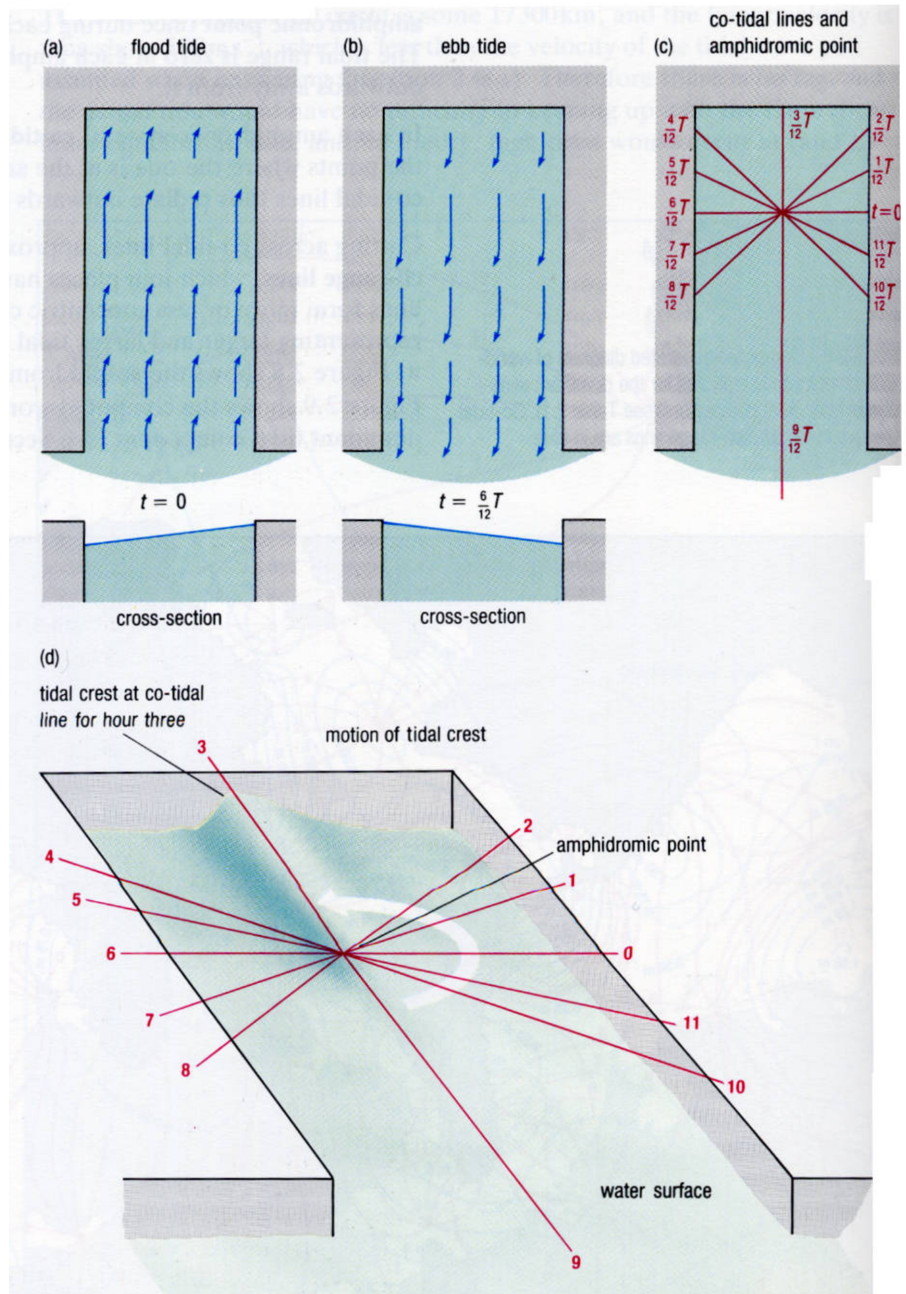
- Indirect tide (<26^{o}) – tide achieves maximum lag of 6 hr, 12 min

Of course, continents and bathymetry mess up theory in a big way

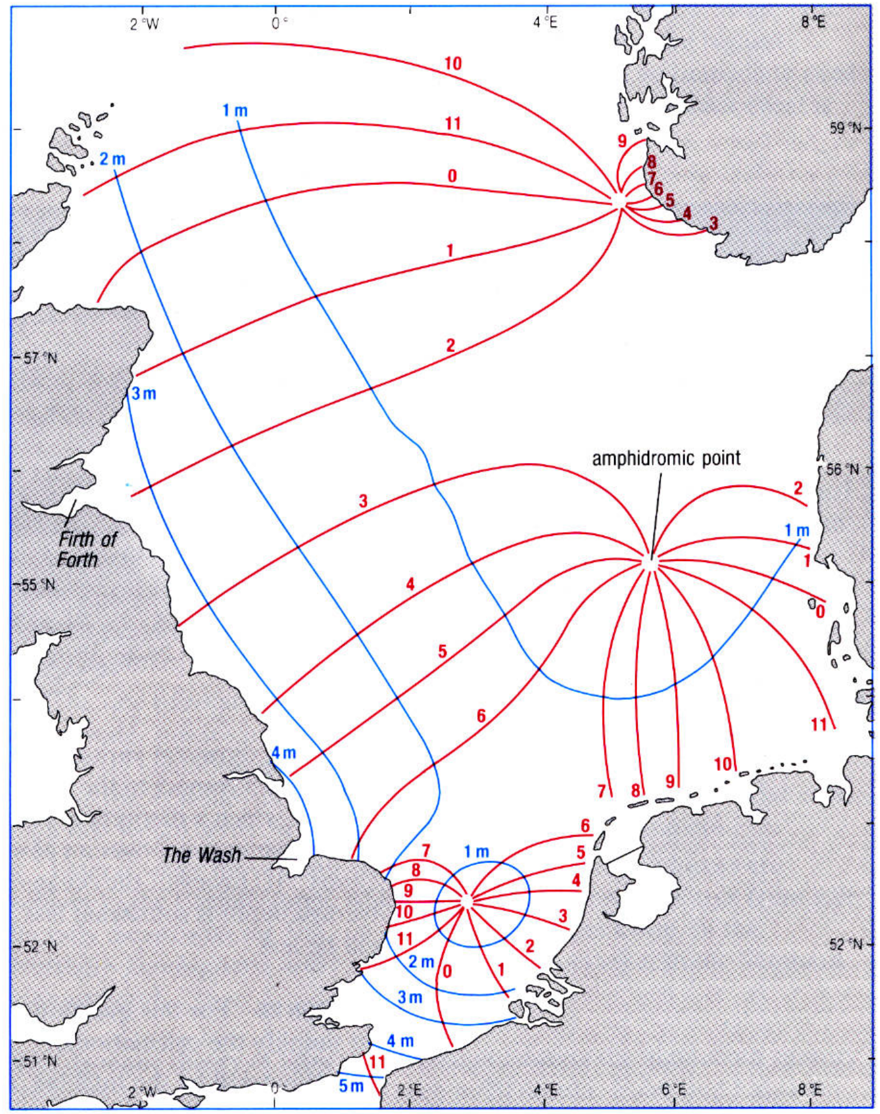
Global amphidromic system, M_2 partial tide



Kelvin Wave – CF and distribution of land that sets rotation direction for amphidromic system



North Sea



2 °W
0 °
4 °E
8 °E
59 °N
57 °N
56 °N
55 °N
52 °N
51 °N
2 °E
6 °E
1 m
2 m
3 m
4 m
5 m
amphidromic point
Firth of Forth
The Wash

Bay of Fundy – Shape makes for resonance (T_{bay} = 12.5hr) with natural tides

Photo Credit: Flickr

Partial Tides

- The actual position of the tide depends on the balance of tractive forces and shallow-water wave movement
  - Including effects of basin shape, bathymetry
- So, the solution at any single place is complex

Partial Tides

- There are 399 tide-generating variables considered in the full equations, these are the “partial tides”
- Luckily, a good model can be derived with only first 7

Seven Principle Partial Tides

	T (hr)	*Amp.*	*Description*
M_2	12.42	100	Main lunar (semi-diurnal)
S_2	12	46.6	Main solar (semi-diurnal)
N	12.66	19.1	Lunar - Earth distance
K_2	11.97	12.7	Soli-lunar - declination
K_1	23.93	58.4	Soli-lunar - declination
O	25.82	41.5	Main lunar (diurnal)
P	24.07	19.3	Main solar (diurnal)

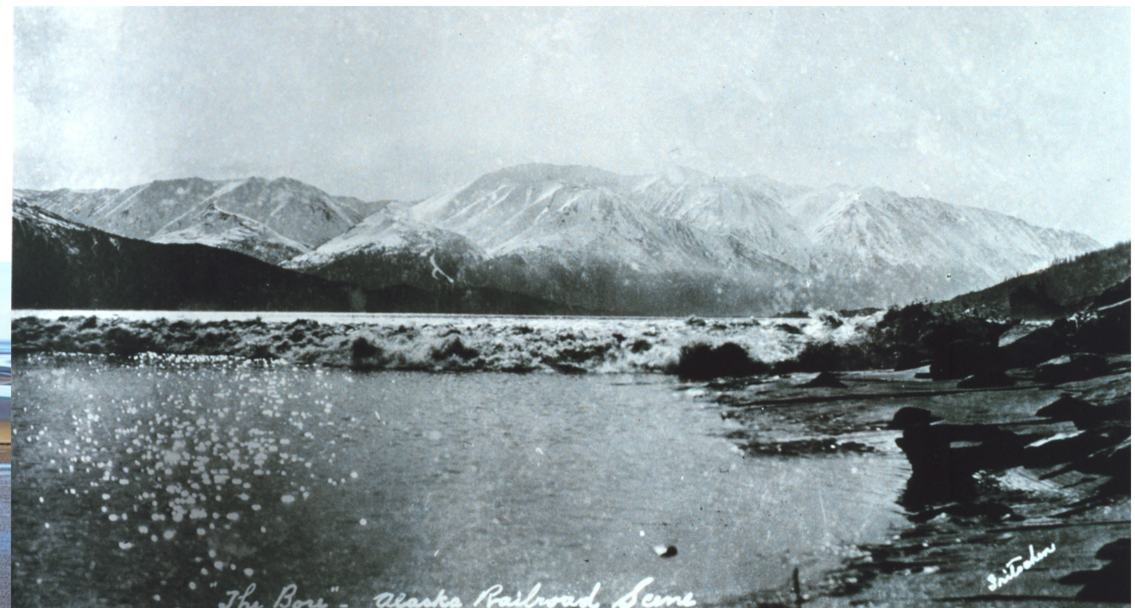
Applying the partial tides

- Much complexity due to far-field and local bathymetry, so fit partial tides to observed tides – Kelvin’s method
  - Harmonic analysis of tidal records for 1 year lead to very accurate local predictions
- In open ocean, satellite altimetry allows verification of predicted tides

Tidal Bore

With rising tide, the tidal wave front is faster than shallow-water wave

Turnagain Arm, Anchorage, AK



Arnside Estuary, UK

Tidal predictions and comparison to observations:

http://tidesonline.nos.noaa.gov/

And/Or

http://tidesandcurrents.noaa.gov/

Figure Credits

- Thurman, Introductory Oceanography, Chapter 10
- Open University, Waves, Tides and Shallow Water Processes, Chapter 2