Chapter 4: The Changing Level of the Sea

Tides

Longer Scale Variations

Influence on Beaches

Tide - rhythmic oscillation of the ocean surface due to gravitational & centrifugal forces (‘inertia’) between the Earth, Moon and Sun.

Tide Patterns - regular, cyclic patterns of low water-high water

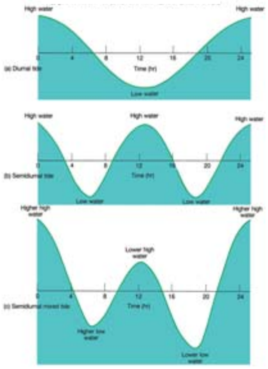
Tidal cycle – one low tide and one high tide consecutively

diurnal tide - one low tide, one high tide a day;

semidiurnal tide - high water-low water sequence twice a day;
2 high, 2 low, about the same level

semidiurnal mixed tide - same as semidiurnal but 2 highs and 2 lows
do not reach/drop to the same level; may be
the result of a combination of tide types

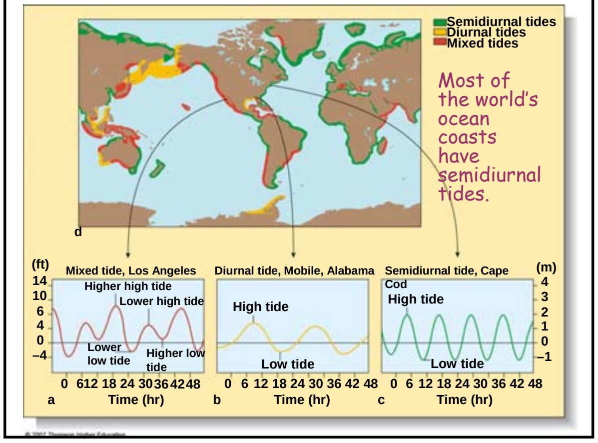
Tide Patterns - regular, cyclic patterns of low water-high water



diurnal tide

semidiurnal tide

semidiurnal mixed tide



Most of the world's ocean coasts have semidiurnal tides.

Flood Tide: tide wave is propagating (onto shore) onshore –
water level is rising

High Tide: water level reaches highest point

Ebb Tide: tide is moving out to sea – water level is dropping

Low Tide: water level reaches lowest point

Slack tide: period when tide wave is reversing –
low current velocity

Water currents are generated by the tides, the speed of the incoming tide is about the same but in the opposite direction of the outgoing tide. Moving waters have to slow down and reverse, from flood to ebb and vice versa (**slack tide)**. This is a good time for navigation through narrow places, particularly those characterized by strong tides (East River, for example).

Mean Tide Level = MTL - computed from measurements taken at a place over many years and averaging all water levels.

Mean High-Water = MHW.

Mean Low-Water = MLW.

For mixed tides:

Mean Higher High Water = MHHW

Mean Lower Low Water = MLLW

tidal range – difference between
MHW and MLW
(water level at high tide and
water level at low tide)

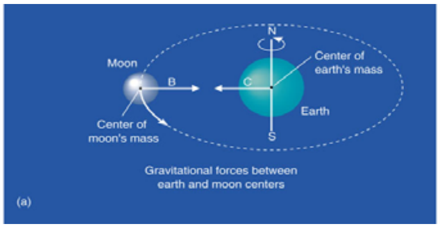
Study of Tides

Equilibrium Tidal Theory - ideal approach to understand basic principles, assumes an earth covered with water

Assumptions:
1: entire Earth surface covered in water
2: infinitely deep basin (no shoaling)
3: tidal bulge fixed relative to the moon

Dynamical Tidal Analysis - realistic approach, studying the tides as they occur on earth, accounts for modification due to landmasses, geometry of ocean basins, earth's rotation.

Tides are caused by the difference in gravitational forces resulting from the change of position of the Sun and the Moon relative to points on Earth



universal law of gravitation

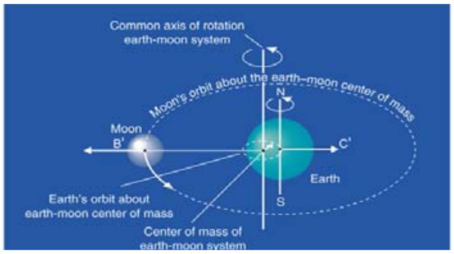
$F = G m_1 m_2 / R^2$

G = universal gravitational constant

m_1, m_2 = mass of bodies

R = distance between centers of mass of bodies

B & C = gravitational forces



Centripetal force is a force that makes a body follow a curved path; it is always directed orthogonal to the velocity of the body, toward the instantaneous center of curvature of the path. The term *centripetal force* comes from the Latin words *centrum* ("center") and *petere* ("tend towards", "aim at"), signifying that the force is directed inward toward the center of curvature of the path.

Nowhere on Earth's surface will the force of attraction by the Moon be exactly equal in magnitude and direction to the centripetal force ($F = Gm_m m_e/R^2$).

The difference between these forces at any point provides the net force that is responsible for tide generation on Earth.

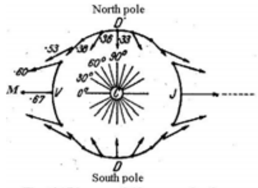


Fig. 104 Diagram of tide generating force
[G.H.Darwin: Ebb and flood]

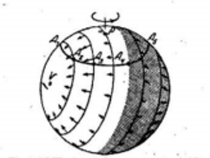
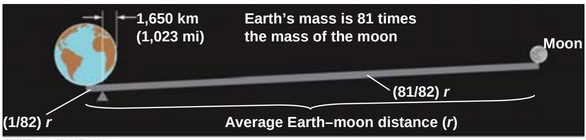
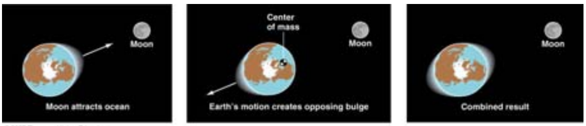


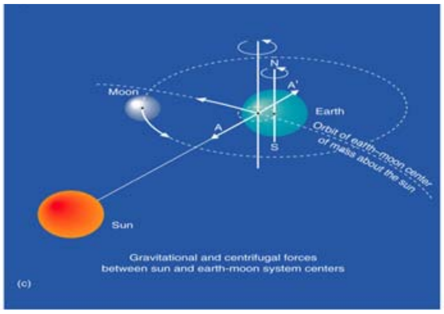
Fig. 105 Horizontal component of tide generating force.
A_1 . . . A_5 denotes one circle of latitude

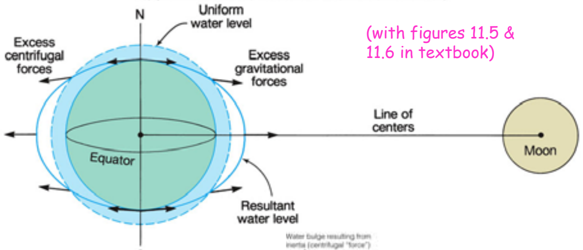




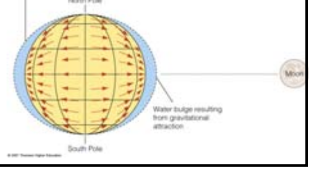
The tide producing force creates two tidal bulges, one toward the moon and the other directed away from the moon.

Add the Sun



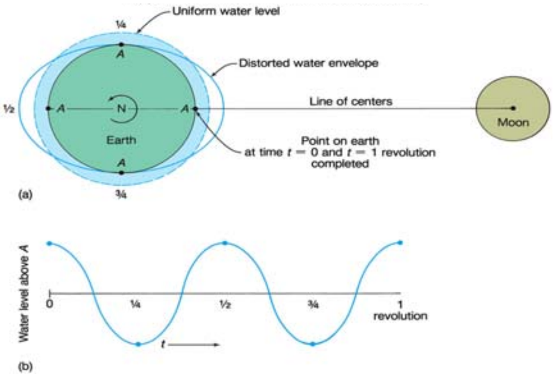


(with figures 11.5 & 11.6 in textbook)



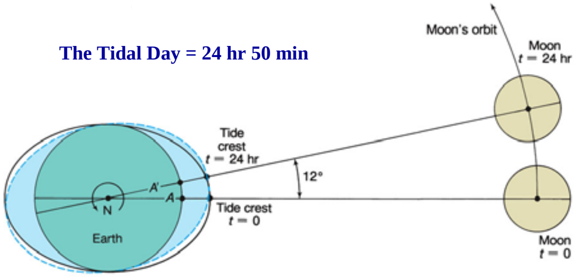
© 2007 Thomson Higher Education

The **Tide Producing Force** (difference between gravitational forces and centrifugal forces at the earth surface) is proportional to **GM/R³**



The Moon Tide and how we get a 'wave'

The Tidal Day = 24 hr 50 min

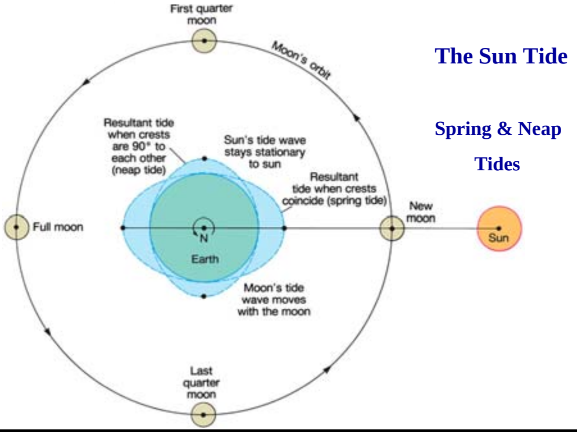


Diurnal = 24 hr 50 min

Semidiurnal = 12 hr 25 min

Lunar Cycle: the Earth – Moon system has a period of 29.5 days

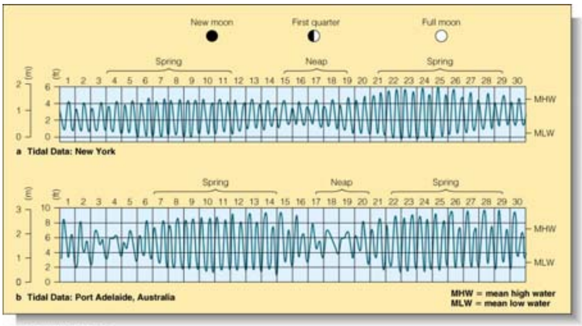
---



The Sun Tide

Spring & Neap Tides

Spring and Neap tides at two places on Earth



© 2007 Thomson Higher Education

Dynamic Tidal Analysis (Pierre-Simon Laplace)

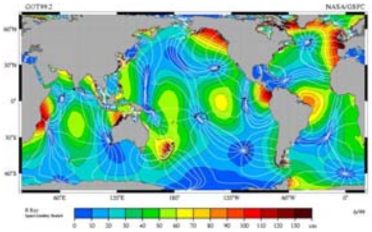
A mathematical study of tides as they occur. It looks at the **tide wave**, which is similar to the tide wave of the ideal water covered earth, but varies from place to place.

- Continents break up wave propagation
- Tide wave moves continuously around the globe only in the Southern Ocean (Antarctica).
- **shallow-water wave**: speed is controlled by depth of ocean
- **standing wave**: oscillates because it is contained in ocean basins (wave 'contained' in ocean basin)
- **reflected** by continents, **refracted** by changes in depth, and **diffracted** (spread of energy sideways) as it passes through gaps
- **Coriolis** affects the water movement because it is a large scale phenomenon.

Amplitude -- One-half the range of a tidal constituent.

Amplitudes are in Feet Phases are in degrees, referenced to Local Z0 (MLLW): 0 Feet

Name	Amp	Period (solar hours)	
M2	2.189	12.42	Main lunar semidiurnal
S2	0.420	12.00	Main solar semidiurnal
N2	0.507	12.66	Lunar constituent due to monthly variation in the Moon's distance
K1	0.333	23.93	Solar-Lunar constituent
O1	0.169	25.82	Main lunar diurnal constituent



Ocean Basin Natural Period of Resonance

$$T_n = \frac{2L_b}{\sqrt{gh}}$$

L_b = length of the basin

h = water depth

If the natural period corresponds to the periodicity of the tide-generating force there will be a resonant condition and the amplitude of the standing wave will increase.

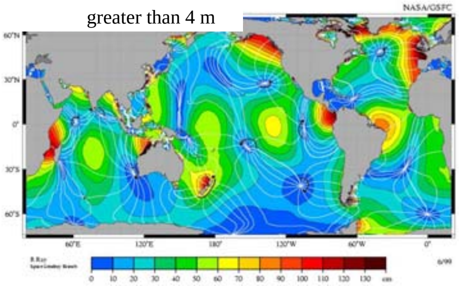
Defant (1958): Form of the tide can be characterized by the relative magnitudes of the tidal constituents M_2, S_2, K_1 and O_1

$$N_f = \frac{K_1 + O_1}{M_2 + S_2}$$

Nf = 0-0.25	semidiurnal form
Nf = 0.25-1.5	mixed, predominately semidiurnal
Nf = 1.5-3.0	mixed, predominately diurnal
Nf >3.0	diurnal form

Davies (1964): classification based on spring tidal ranges

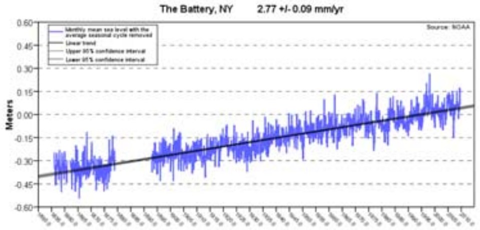
Microtidal:	less than 2m
Mesotidal:	2-4 m
Macrotidal:	greater than 4 m



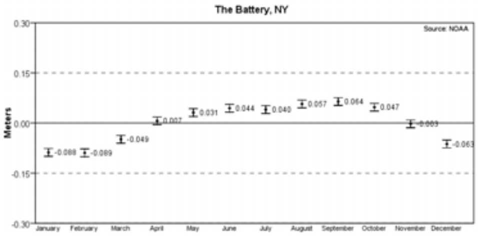
Tidal Asymmetry: shallow water effects on tidal waves

$$C = \left(1 + \frac{3}{2}\frac{\eta}{h}\right)\sqrt{gh}$$

η = local height of tidal wave above still-water level, small in deep water



- The mean sea level trend is 2.77 millimeters/year with a 95% confidence interval of +/- 0.09 mm/yr based on monthly mean sea level data from 1856 to 2006 which is equivalent to a change of 0.91 feet in 100 years.
- The plot shows the monthly mean sea level without the regular seasonal fluctuations due to **coastal ocean temperatures, salinities, winds, atmospheric pressures**, and **ocean currents**.

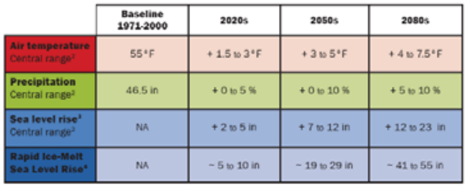


The average seasonal cycle of mean sea level,

caused by regular fluctuations in coastal temperatures, salinities, winds, atmospheric pressures, and ocean currents

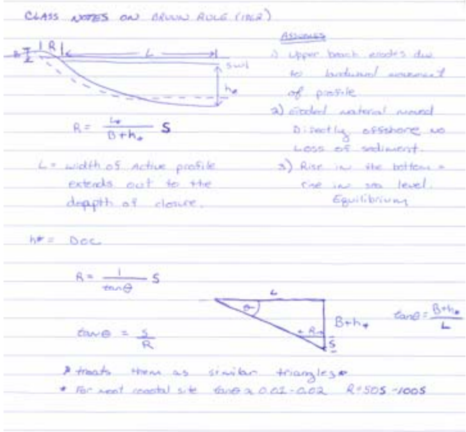
The plot shows the interannual variation of monthly mean sea level and the 5-month running average. The average seasonal cycle and linear sea level trend have been removed. Interannual variation is caused by irregular fluctuations in coastal ocean temperatures, salinities, winds, atmospheric pressures, and ocean currents.

New York City Panel on Climate Change, 2009



	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central range[2]	55°F	+ 1.5 to 3°F	+ 3 to 5°F	+ 4 to 7.5°F
Precipitation Central range[2]	46.5 in	+ 0 to 5 %	+ 0 to 10 %	+ 5 to 10 %
Sea level rise[3] Central range[2]	NA	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Rapid Ice-Melt Sea Level Rise[4]	NA	~ 5 to 10 in	~ 19 to 29 in	~ 41 to 55 in

1 Based on 16 GCMs (7 GCMs for sea level rise) and 3 emissions scenarios. Baseline is 1971-2000 for temperature and precipitation and 2000-2004 for sea level rise. Data from National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA). STET and sea level data is from the Battery at the southern tip of Manhattan (the only location in NYC for which comprehensive historic sea level rise data are available).
2 Central range = middle 67% of values from model-based probabilities; temperatures ranges are rounded to the nearest half-degree, precipitation to the nearest 5%, and sea level rise to the nearest inch.
3 The model-based sea level rise projections may represent the range of possible outcomes less completely than the temperature and precipitation projections. See page 18 for more information.
4 "Rapid ice-melt scenario" is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic Ice sheets and paleoclimate studies.



CLASS NOTES ON BRUUN RULE (1962)

Assumes
1) Upper beach erodes due to landward movement of profile
2) eroded material moved directly offshore no loss of sediment.
3) Rise in the bottom = rise in sea level. Equilibrium

$R = \frac{L_*}{B+h_*} S$

L = width of active profile extends out to the depth of closure.

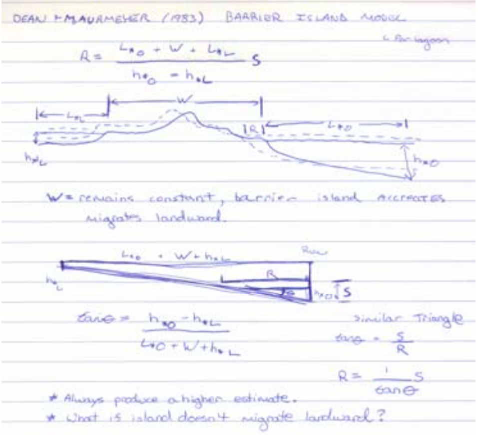
h* = DOC

$R = \frac{1}{\tan\theta} S$

$\tan\theta = \frac{S}{R}$

$\tan\theta = \frac{B+h_*}{L}$

* treats them as similar triangles *
* For most coastal site $\tan\theta \approx 0.01 - 0.02$ R = 50S - 100S



DEAN + MAURMEYER (1983) BARRIER ISLAND MODEL

L for lagoon

$R = \frac{L_{*O} + W + L_{*L}}{h_{*O} - h_{*L}} S$

W = remains constant, barrier island accretes migrates landward.

$\tan\theta = \frac{h_{*O} - h_{*L}}{L_{*O} + W + h_{*L}}$

similar Triangle

$\tan\theta = \frac{S}{R}$

$R = \frac{1}{\tan\theta} S$

* Always produce a higher estimate.
* What is island doesn't migrate landward?