“Monday is an awful way to spend 1/7 of your week...”

“A clear conscience is usually a sign of a bad memory”

“I used to have an open mind, but my brains kept falling out”

The Surface of the Ocean: 2) Tides

a. Equilibrium tidal theory
Earth covered with a uniform and ideal layer of water (geoid)
simplification of the relationships between the Oceans and the tide-rising bodies, the Moon and the Sun.

The Earth-Moon System
The system orbits the Sun around a common center of mass: the barycenter (within the Earth’s mantle, ! radius from center)

Oceanography
Lecture 8

The surface of the Ocean: 2) Tides

Tides:
  a. Equilibrium tidal theory
  b. Dynamical tidal theory

a. Equilibrium tidal theory
The rotation of the Earth-Moon System creates a motion that is equal at all points within and upon the Earth. Each point will also have the same angular velocity and hence a similar centrifugal force (CF)
**a. Equilibrium tidal theory**

The total centrifugal force within the Earth-Moon system exactly balances the forces of gravitational attraction between the two bodies so that the system as a whole is in equilibrium. We should neither lose the Moon nor collide with it!

Therefore,

\[ F_g = \frac{GMm}{D^2} = CF \]

Where:
- \( G \): Universal gravity constant
- \( M \): Mass of the Earth
- \( m \): Mass of the Moon
- \( D \): Distance between M-E

Let’s work it out!

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**Tidal Producing Force (TPF)**

The tidal producing force at A is equal to the TPF at B but of opposite sign!

\[ TPF_A = \frac{GMm2r}{D^3} = TPF_B \]

How does it compare to the Earth’s gravitational force?

\[ \frac{TPF}{F_g} = \frac{GMm2r}{gM} = \frac{Gm2r}{gD^3} = 10^7 \]

The Tidal Force is 10 million times smaller than Earth’s gravitational pull! There is, therefore, no possible vertical movement of water!

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**Tidal Producing Force (TPF)**

Gravitational attraction and centrifugal force produce two tidal “bulges” of water of approximately the same size, positioned on opposite sides of the Earth.

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**Tidal Producing Force (TPF)**

The effects of tides are due to horizontal components (tractive forces) of the tidal producing force: It is the tractive forces that cause the water to move, because this horizontal component is unopposed by any other lateral force.

Formation of the tidal “bulge” Production of unequal tides!
Tidal Producing Force (TPF)
What about the Sun?

\[ TPF \propto \frac{\text{Mass}}{(\text{Distance})^3} = \frac{\text{Sun} - 27.10^6 \times M}{(\text{Sun} - 390 \times D)^3} = \frac{27.10^6}{59.10^6} = 0.46 \]

Thus the sun has 46% the tide-generating force of the Moon!

Tide inequalities
1) "Tidal Day"
While the Earth rotates upon its axis, the Moon is moving in the same direction along its orbit about the Earth. After 24 hours, the Earth point that began directly under the Moon is no longer under the Moon! The Earth must turn an additional 50 minutes to bring the starting point back in line with the Moon.

Therefore, a tidal day is not 24 hours but 24hrs and 50 min! (Tides arrive at locations an hour later each day)

2) "Spring Tides" and "Neap Tides"
The Moon orbits the Earth (29" days) and the Earth-Moon system orbits the Sun (365 days).
Tide inequalities

3) Additional Tidal variations
   - The Moon's declination

b. Dynamical tide theory
A more accurate depiction of tides is possible if we assume that the Oceans are dynamic (active) rather than static (still):

Dynamical model of tides
1) Water is assumed to respond actively to the tide-generating force. No longer have stationary tidal "bulge" of water that stay aligned with the Moon as the Earth rotates.
2) Consider the effects due to the presence of continents and shapes of basins (horizontal and vertical)

In the Dynamic model, the Ocean basins "drag" the tidal bulges with them each day as they rotate with the Earth.

Tide inequalities
The Moon's and Earth's elliptical orbits (REM: TPF ≈ 1/D^3)
- Perigee vs. Apogee (13% difference) (27.5 days)
- Perihelion vs. aphelion (4% difference) ("a year")

Maximum tides:
- Moon at Perigee
- Sun at Perihelion
- Sun and Moon at zero declination
- Full (or new) Moon

This condition occurs only every 1600 yrs! Next time is in 3300!

b. Dynamical tide theory
The propagation of the tidal wave is deflected due to the Coriolis Force (North to the right; South to the left): rotary wave.
1) The rotary wave creates high tides (the crest) and low tides (the trough) each day.
2) The water surface moves up and down about a node in the center of the basin! (the antinodes, where amplitude is greatest, are located furthest away from the node).

The amphidromic system:
- a) Cotidal lines: connect points at which any given tide level is simultaneous,
- b) Corange lines: connect points on the water surface that have equal tidal range.
Global Amphidromic System

Lines are cotidal lines that converge on nodes (amphidromic points)

- Cotidal lines are not evenly spaced:
  - Tides are shallow-water waves \( C = (gh)^{1/2} \)
  - Ocean basins have uneven shapes and depths
  - Combined effect of all these factors produces considerable regional variation in type and range of tides.

Standing waves (Resonance)

Standing waves do not move horizontally but remain stationary (Guitar string).

The water oscillates back and forth about a fixed point: Node.

The properties of a standing wave depend on the geometry of the basin. The larger the “container”, the longer its characteristic standing wave will take to oscillate. In an open basin (seiche),

Comparison of Actual and Forecasted Water Levels for Galveston (Spring 97)

Tides in coastal basins

Tides in coastal basins will differ from large amphidromic systems

- Broad and symmetrical basin (i.e. Gulf of St. Lawrence)
- Narrow elongated basin (i.e. Bay of Fundy)
Neural Network Forecasting of Water Levels

The neural network model was trained for a period of 90 days during the spring of 1997 and is applied here to a frontal passage during the spring of 1999. The accuracy of the 24 hour neural network forecast shows the ability to predict the timing and the intensity of frontal passages.

- Measures water levels (black),
- Tidal chart forecasts (blue),
- 24 hour neural network forecasts (red)

The neural network model was trained for a period of 90 days during the spring of 1997 and is applied here to a frontal passage during the spring of 1999. The accuracy of the 24 hour neural network forecast shows the ability to predict the timing and the intensity of frontal passages.

Galveston Pleasure Pier during the spring of 1999 (Cox, Tissot, Michaud)