

a little tidal haiku:

- *the tide rushes in*
- *essential for life on Earth*
- *all thanks to Luna*

### What Are Tides?

- **Tides** – periodic raising and lowering of ocean sea level
- Occur daily
- **Isaac Newton's** gravitational laws explain relationship
- Tides recognized even by early sailors

### Tide-Generating Forces

- **Barycenter** between Moon and Earth
  - Common center of mass or balance point
  - Beneath Earth's surface because of Earth's greater mass

### Gravitational Forces

- Every particle attracts every other particle
- **Gravitational force** proportional to product of masses
  - Increase mass, increase force
- Inversely proportional to square of separation distance

(a) The effect of mass on gravitational attraction

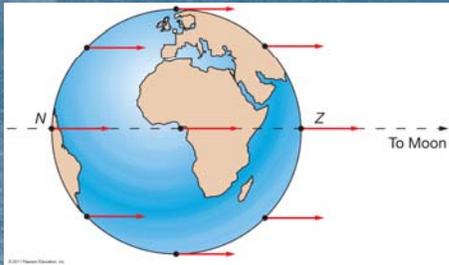
(b) The effect of distance on gravitational attraction

### Gravitational Forces

- Greatest force at **zenith** – closest to moon
- Least force at **nadir** – furthest from moon and opposite zenith

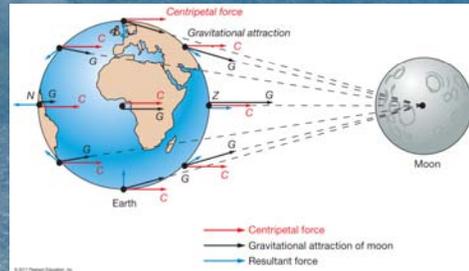
## Centripetal Force

- Center-seeking force
- Tethers Earth and Moon to each other



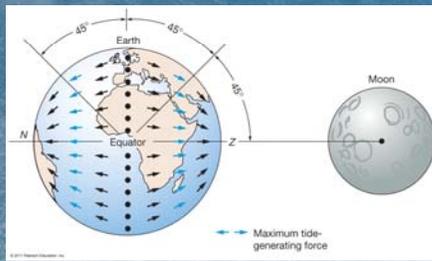
## Resultant Forces

- Mathematical difference between gravitational and centripetal forces
- Relatively small



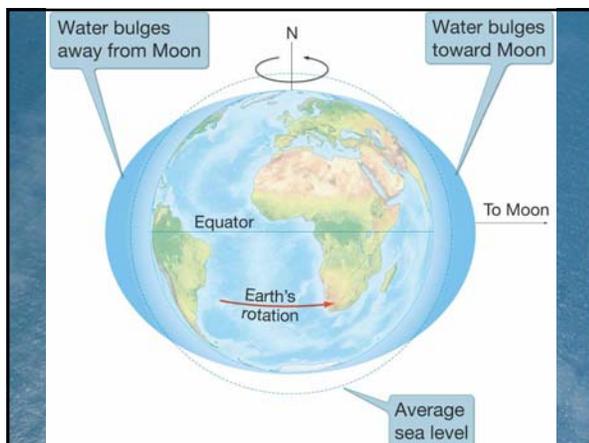
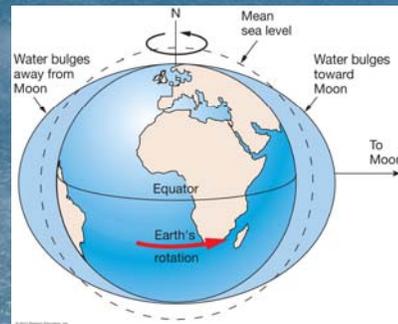
## Tide-Generating Forces

- Resultant force has significant horizontal component
- Pushes water into two simultaneous bulges
  - One toward Moon
  - One away from Moon



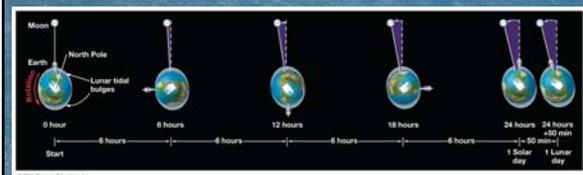
## Tidal Bulges – Moon's Effect

- Small horizontal forces push seawater into two bulges.
- Opposite sides of Earth



## Tidal Phenomena

- **Tidal period** – time between high tides
- **Lunar day**
  - Time between two successive overhead moons
  - 24 hours, 50 minutes
- Moon orbits Earth
- High tides are 12 hours and 25 minutes apart



## Tidal Bulges – Sun's Effect

- Similar to lunar bulges but much smaller
- Moon closer to Earth

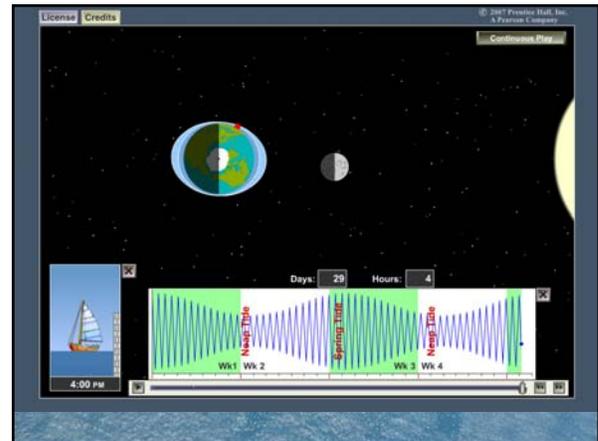


## Earth's Rotation and Tides

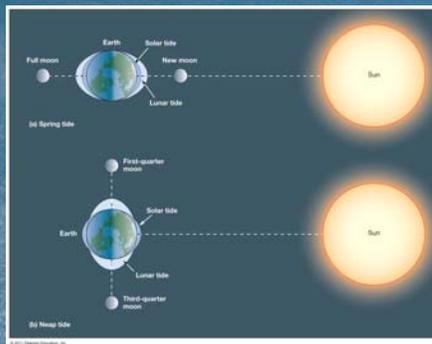
- **Flood tide** – water moves toward shore
- **Ebb tide** – water moves away from shore
- Tidal bulges are fixed relative to the Sun's and Moon's positions
  - Earth's rotation moves different geographic locations into bulges

## Monthly Tidal Cycle

- **Spring tides**
  - New or full moons
  - Tidal range greatest
  - Syzygy (def. - conjunction or opposition)
- **Neap tides**
  - Quarter moons
  - Tidal range least
  - Quadrature

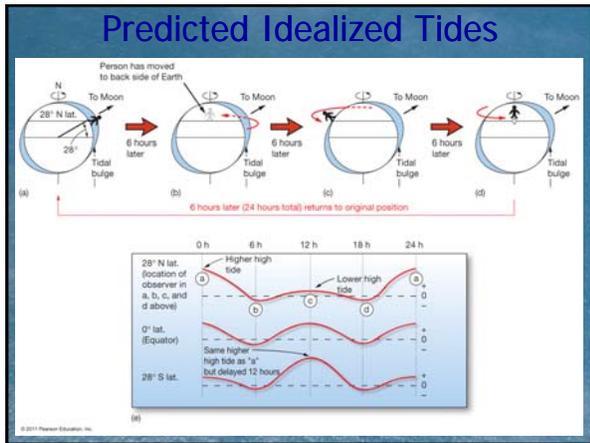
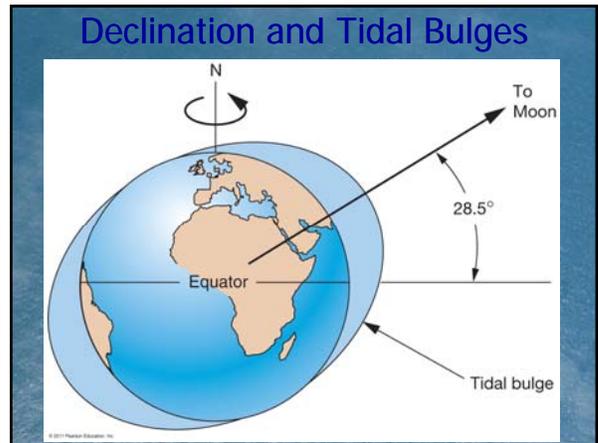
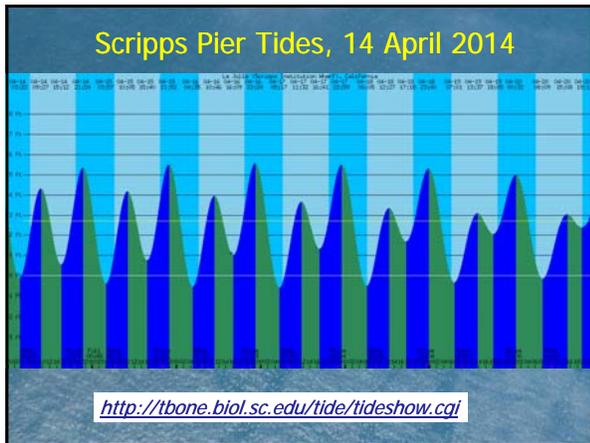


## Earth, Moon, and Sun Positions Relative to Spring and Neap Tides

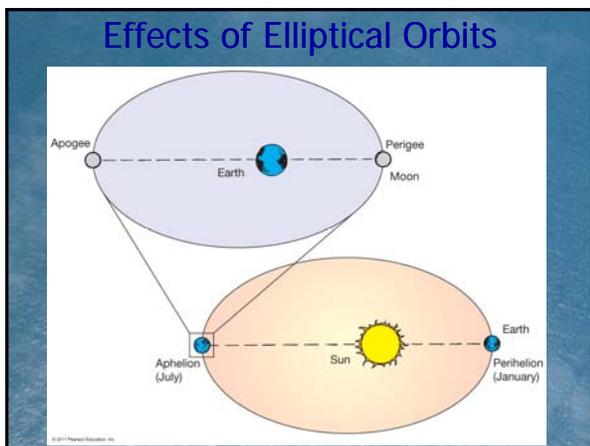


## Complicating Factors

- **Declination** – Angular distance of the Moon or Sun above or below Earth's equator
- Sun to Earth: 23.5 degrees north or south of equator
- Moon to Earth: 28.5 degrees north or south of equator
- Lunar and solar bulges shift from equator
  - Unequal tides



- ### Complicating Factors
- Elliptical orbits
  - Earth around Sun:
    - Tidal range greatest at **perihelion** (January)
    - Tidal range least at **aphelion** (July)
  - Moon around Earth:
    - Tidal range greatest at **perigee** (Moon closest to Earth)
    - Tidal range least at **apogee** (Moon furthest from Earth)
    - Perigee–apogee cycle is 27.5 days



- ### Idealized Tide Prediction
- Two high tides/two low tides per lunar day
  - Six lunar hours between high and low tides

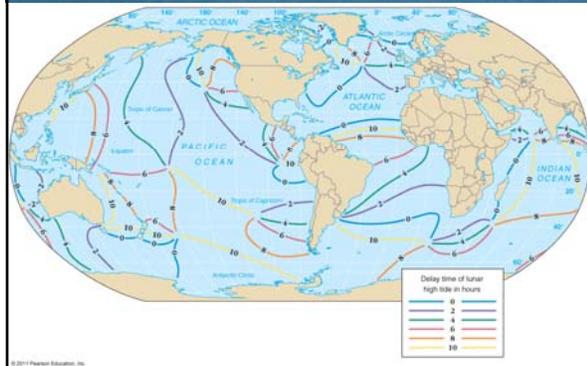
## Real Tides

- Continents and friction with seafloor modify tidal bulges
- Tides are shallow-water waves with speed determined by depth of water
- Idealized tidal bulges cannot form
  - Cannot keep up with Earth's rotation

## Real Tides

- Crests and troughs of tides rotate around **amphidromic point**
  - No tidal range at amphidromic points
- Cotidal lines** – connect simultaneous high tide points
  - Tide wave rotates once in 12 hours

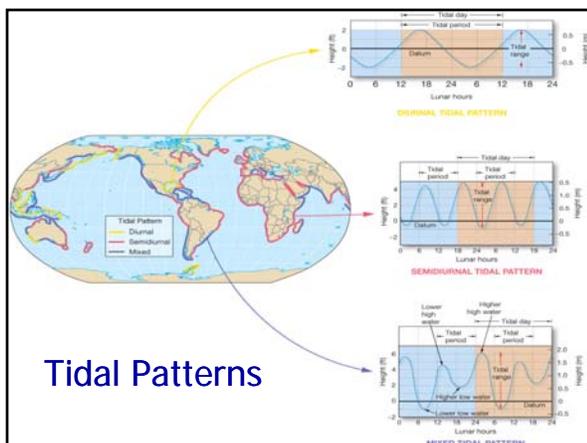
## Cotidal Map



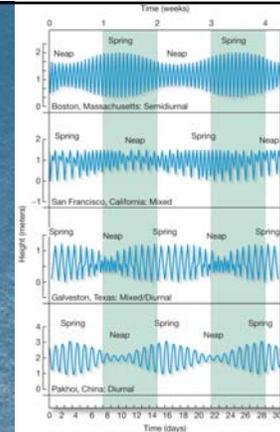
## Tidal Patterns

- Diurnal**
  - One high tide/one low tide per day
- Semidiurnal**
  - Two high tides/two low tides per day
  - Tidal range about same
- Mixed**
  - Two high tides/two low tides per day
  - Tidal range different
  - Most common

## Tidal Patterns



## Monthly Tidal Curves



## Tides in Coastal Waters

- **Standing Waves**
  - Tide waves reflected by coast
  - Amplification of tidal range
  - Example: Bay of Fundy maximum tidal range 17 meters (56 feet)



## Bay of Fundy Tides

[http://www.youtube.com/watch?v=qfhNjpu\\_IU4](http://www.youtube.com/watch?v=qfhNjpu_IU4)

## Tides in coastal waters

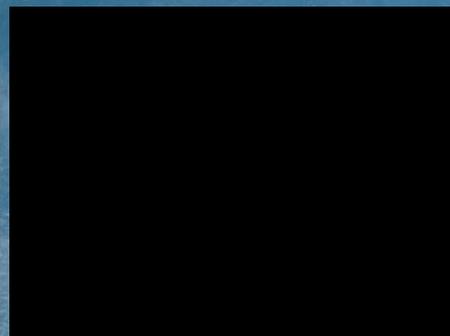
- **Ripple Rock, Seymour Narrows**
  - Tide flows through a narrowing channel
  - North of Campbell River, British Columbia
  - Top of Ripple Rock was 9 feet below the surface before being blown up by the “world’s largest non-nuclear explosion” in 1958
  - Still requires skill to negotiate!

## Ripple Rock, Seymour Narrows



<http://www.youtube.com/watch?v=1V00vkh31WY>

## CBC coverage, 5 April 1958



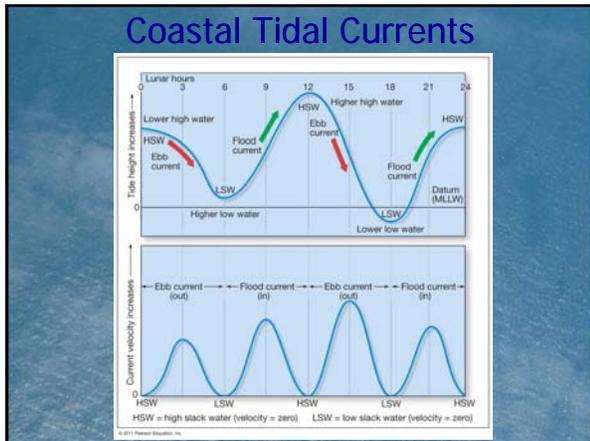
<http://www.youtube.com/watch?v=xO820xpFmZ1>

## Tides in Coastal Waters

- **Tidal Bores**
  - Wall of water
  - Moves up certain rivers
  - Tide-generated

## Coastal Tidal Currents

- **Rotary Current**
- **Reversing current**
  - Flood current
  - Ebb current
  - High velocity flow in restricted channels
- No current at high slack water or low slack water



## Coastal Tidal Currents

- **Whirlpool**
- Rapidly spinning seawater
- Restricted channel connecting two basins with different tidal cycles

## Tides and Marine Life

- Tide pools and life
- Grunion spawning

## Tide-Generated Power

- Does not produce power on demand
- Possible harmful environmental effects
- Renewable resource
- First Asian power plant in 2006
- United Kingdom proposed building world's largest tidal power plant

## Power Plant at La Rance, France

- Successfully producing tidal power since 1967

