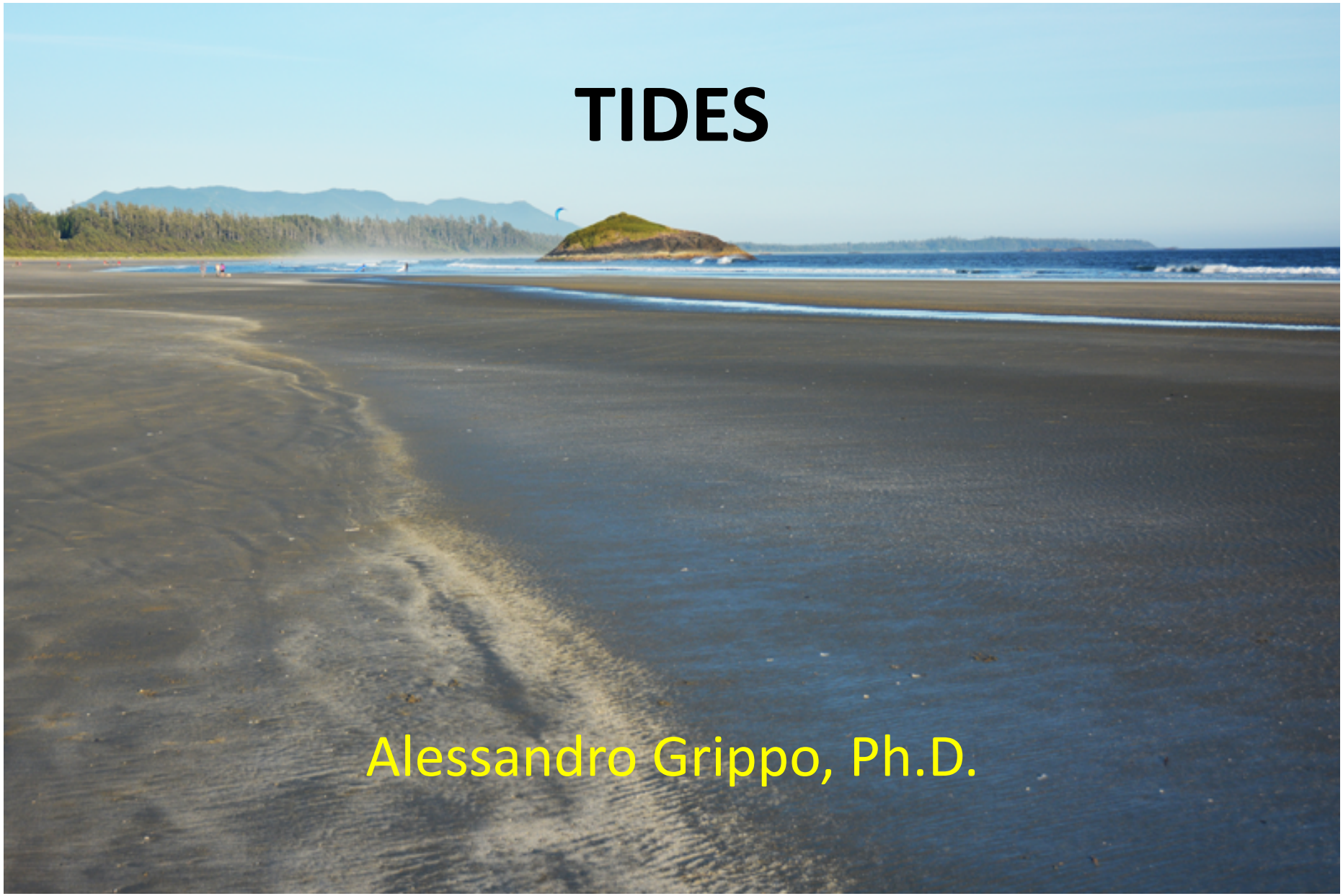
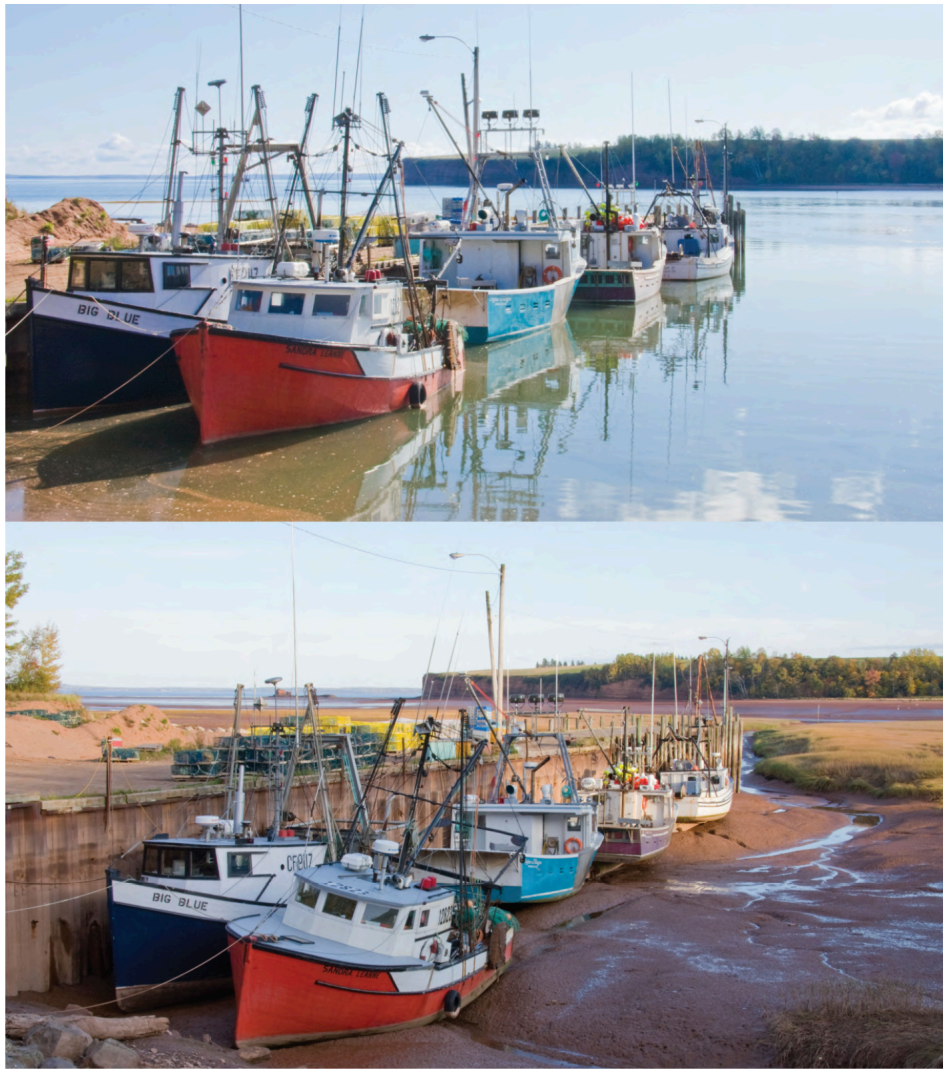
TIDES



Low tide along the Pacific Ocean coast on Vancouver Island
Tofino, British Columbia, Canada

Tides: overview

- Tides are rhythmic, daily rises and falls of sea level, caused by gravitational attraction of the Sun, Moon, and Earth
- Tides can be thought of as very long, regular shallow-water waves
- Different tidal patterns exist
- Isaac Newton's gravitational laws explain relationship



Extreme tidal variation in the Bay of Fundy, Nova Scotia, Canada

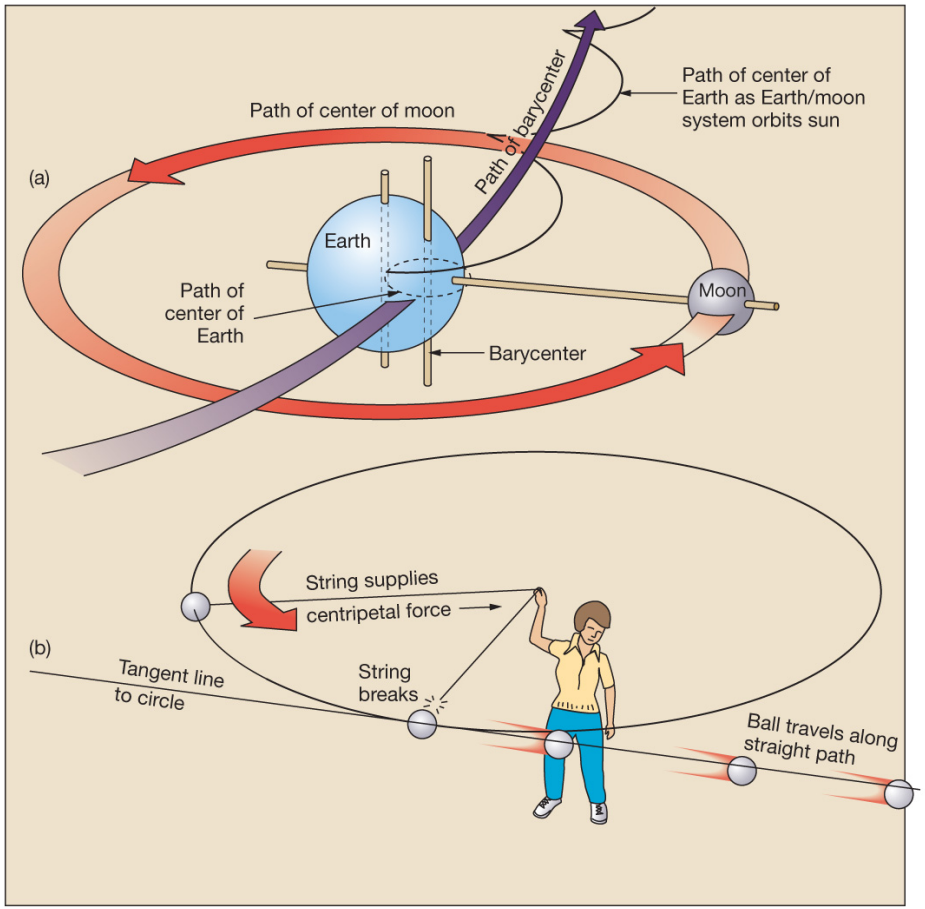
What causes ocean tides?

- Tides are generated by forces imposed on Earth by a combination of **gravity** and **motion** among Earth, the Moon, and the Sun

- Technically, all celestial bodies would exert some influence on Earth, but the Moon (because of its proximity to Earth) and the Sun (because of its size) are the ones that really pull the tides
  - All celestial bodies affect each other somehow by slowly modifying each other's orbit (Milankovitch cycles)

“Earth orbits the Sun and the Moon orbits Earth”

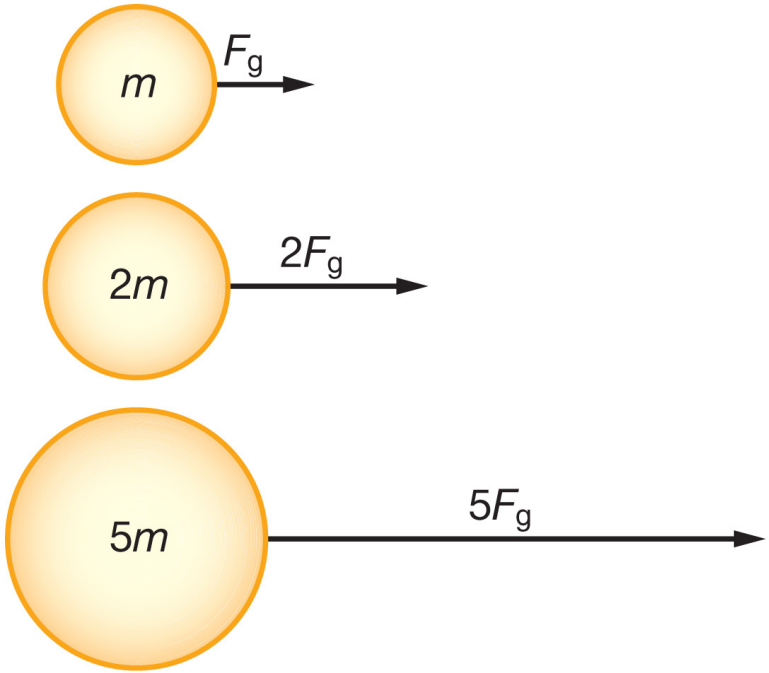
– That is a simplification: they rotate around a common center of gravitation, their barycenter
  - Function of distance and mass
  - Notice in the figure how it is the barycenter moving in a continuous line (purple curve), while Earth itself is moving in “bumps” (thin black curve)



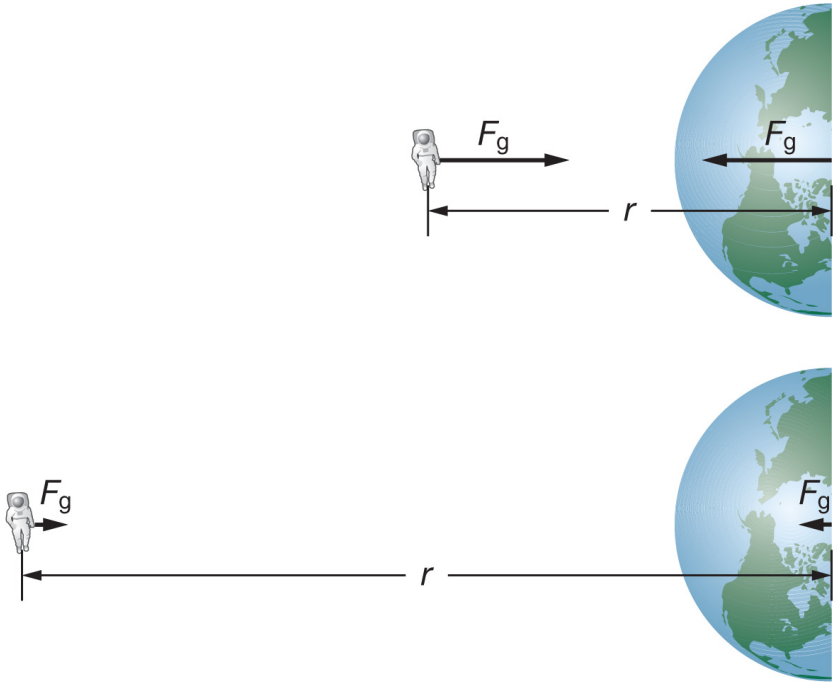
Newton's law of gravitational attraction

$$F_g = \frac{Gm_1m_2}{r^2}$$

- Every particle attracts every other particle
- Gravitational force is:
  - directly proportional to product of masses (m_1m_2)
    - increase mass, increase force
  - inversely proportional to square of separation distance (r^2)



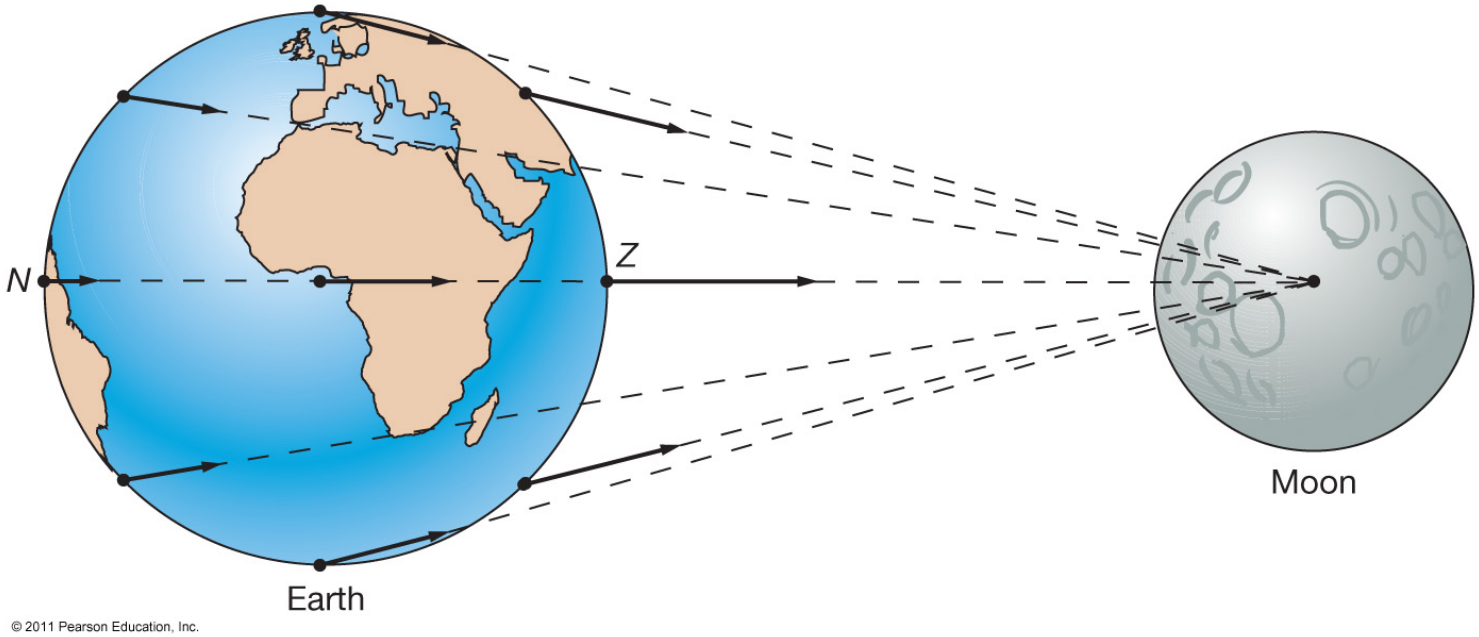
(a) The effect of mass on gravitational attraction



(b) The effect of distance on gravitational attraction

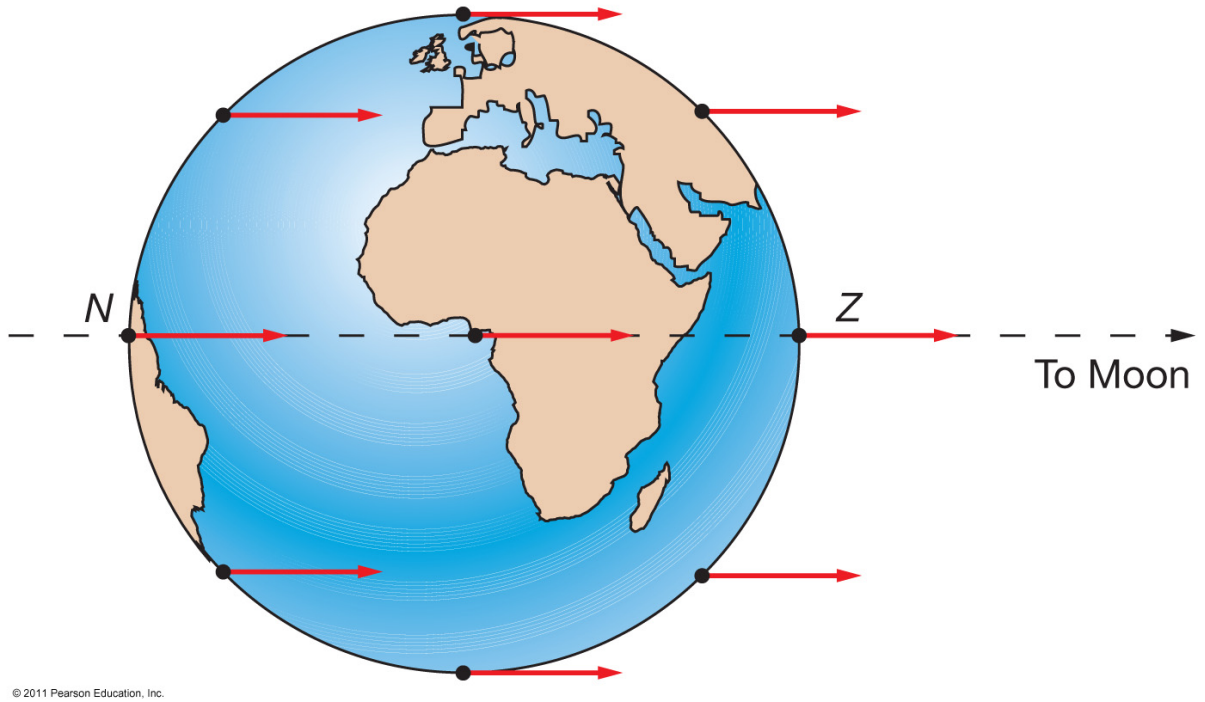
The component of the gravitational attraction caused by the Moon depends on the distance from the Moon itself

- Greatest force at zenith (Z) – closest to the Moon
- Least force at nadir (N) – furthest from the Moon and opposite zenith



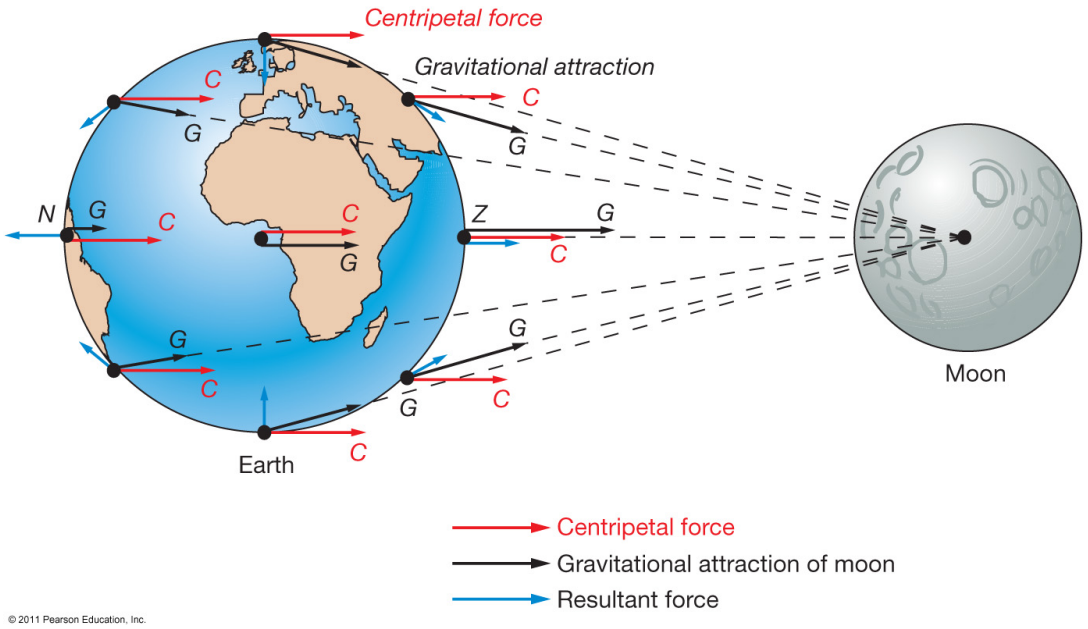
Centripetal Force

- Center-seeking force (it is the same at N and at Z)
- Tethers Earth and Moon to each other



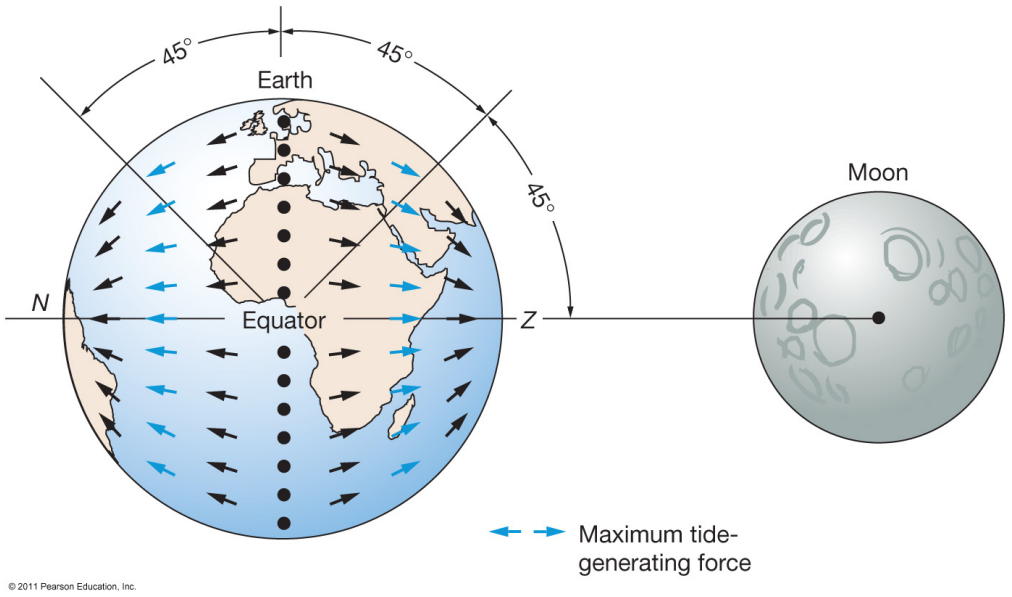
Resultant Forces

- Mathematical difference between gravitational and centripetal forces
- Relatively small

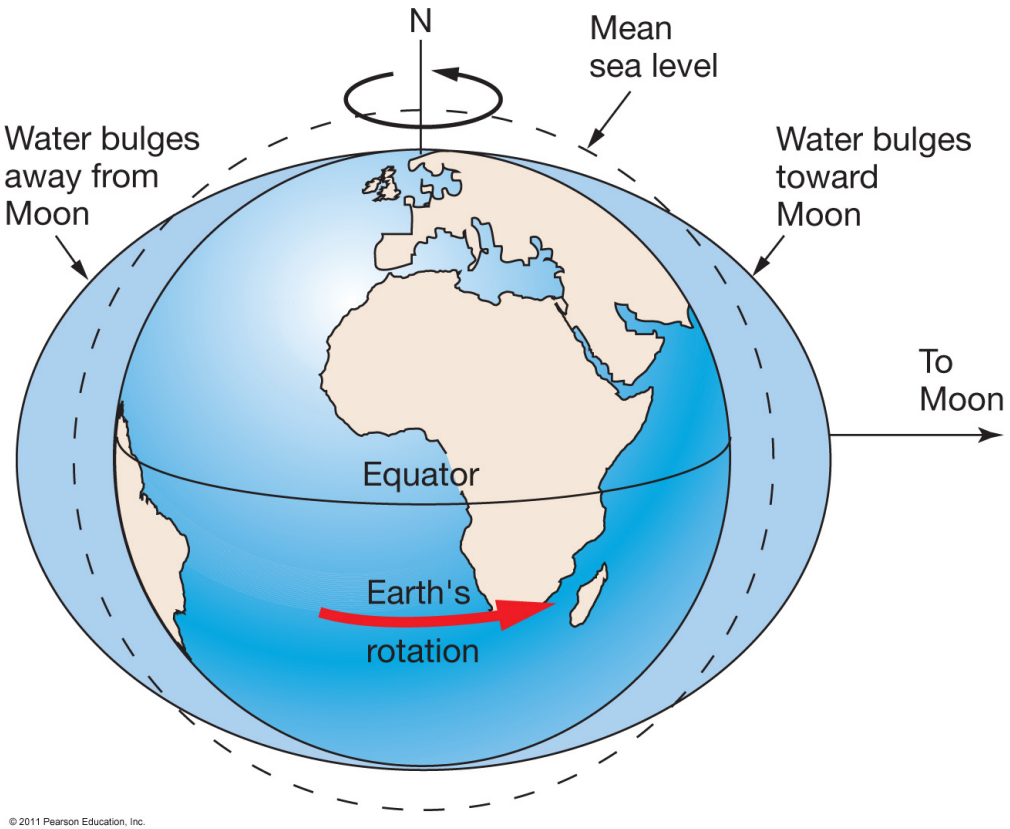


Tide-Generating Forces

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



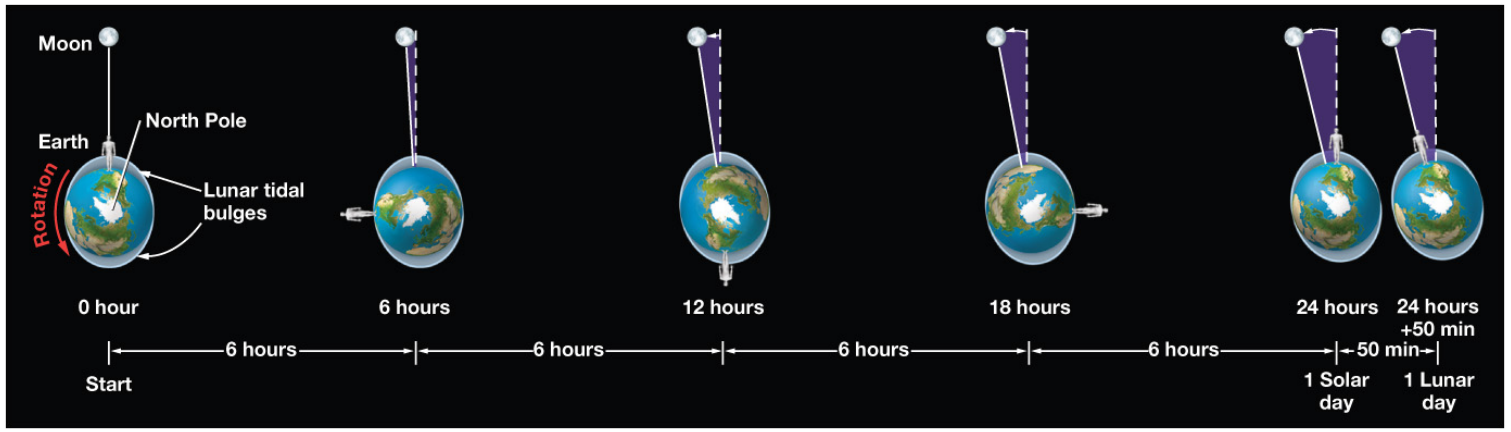
Tidal Bulges – Moon's Effect



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

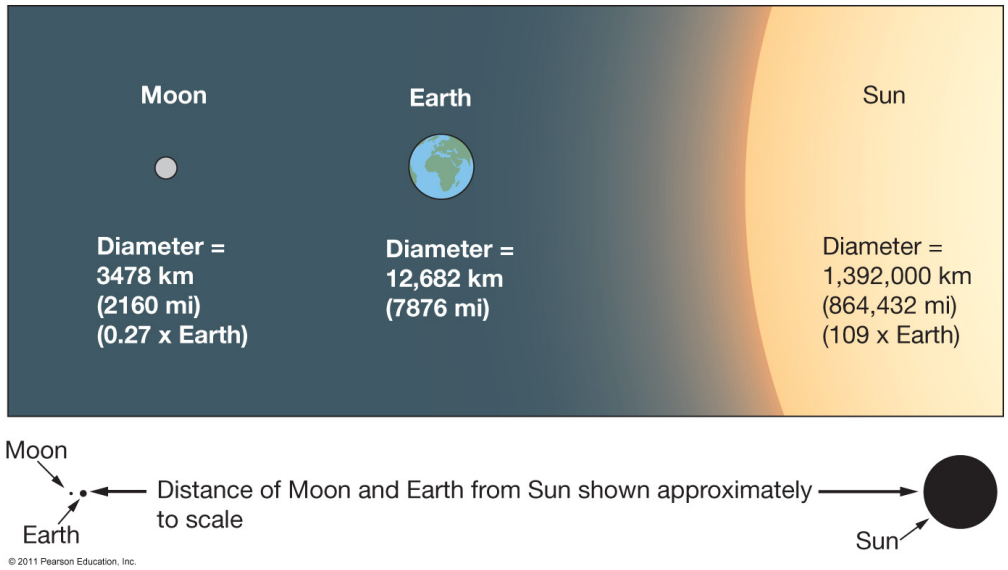
Tidal Phenomena

- Tidal period – time between high tides
- Solar day
  - 24 hours
- Lunar day
  - Time between two successive overhead moons
  - 24 hours, 50 minutes
  - While Earth rotates in 24 hours, Moon moves too, and it takes 50 more minutes to be under it again!
- Moon orbits Earth
- High tides are 12 hours and 25 minutes apart



Tidal Bulges – Sun's Effect

- Similar to lunar bulges but much smaller
- Why? The Moon is closer to Earth



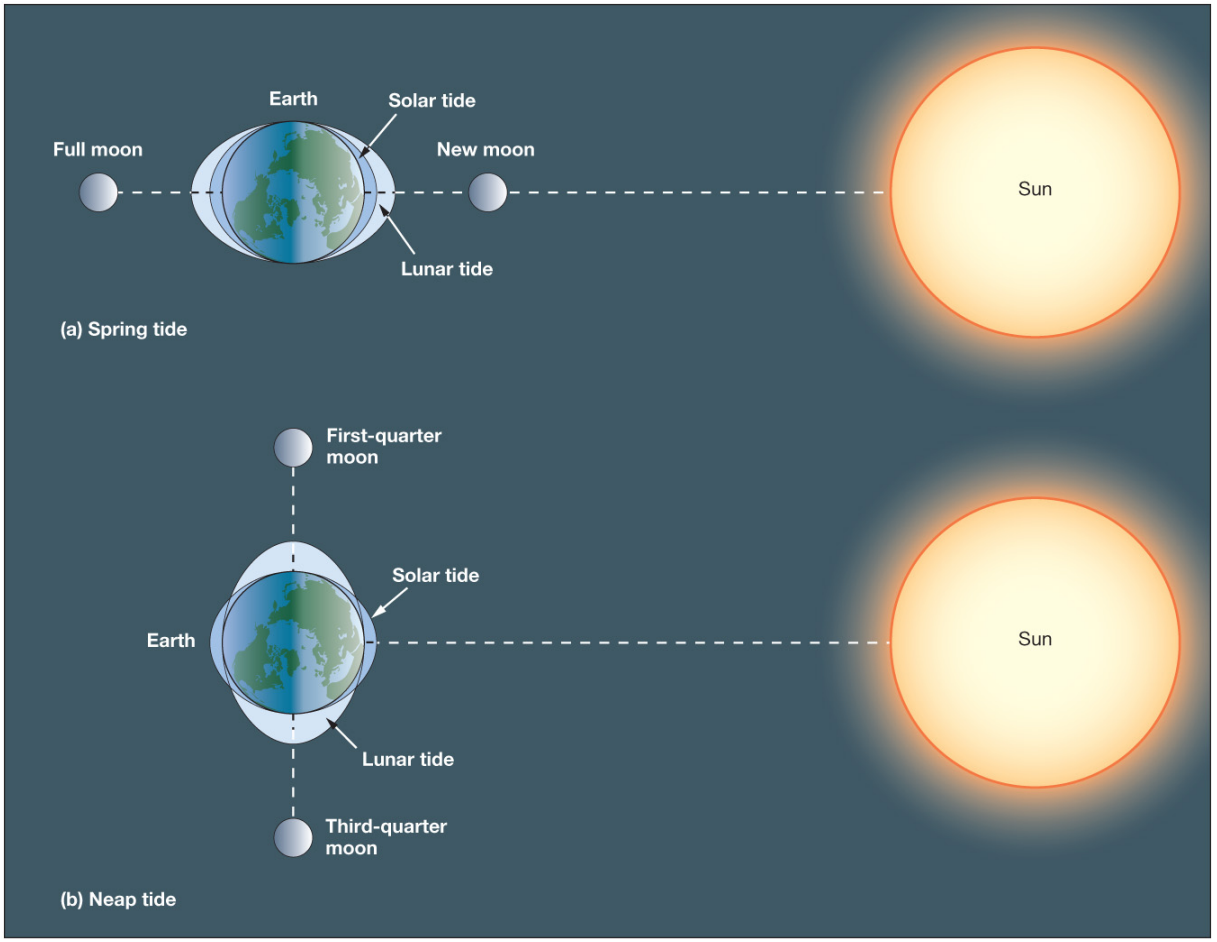
Earth's Rotation and Tides

- 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

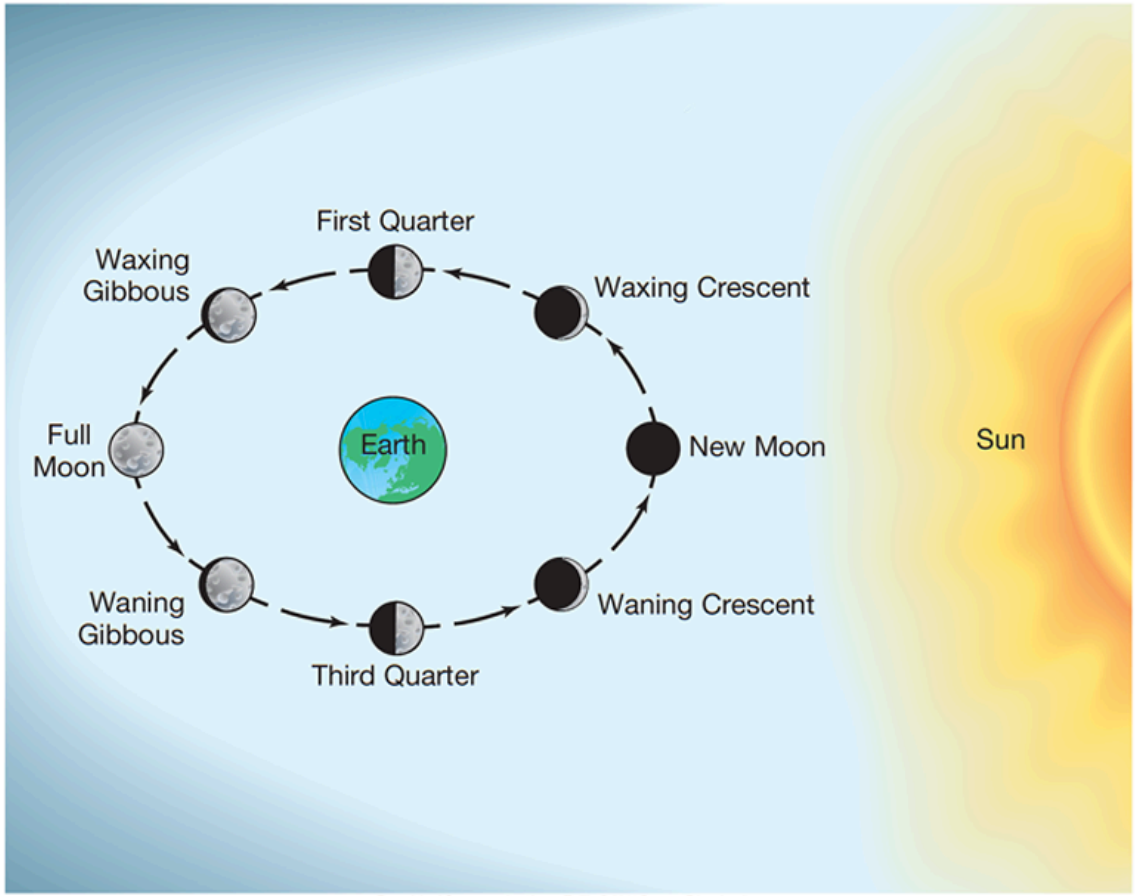
Monthly Tidal Cycle

- Spring tides
  - New or full moons
  - Tidal range greatest
  - Syzygy
- Neap tides
  - Quarter moons
  - Tidal range least
  - Quadrature

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



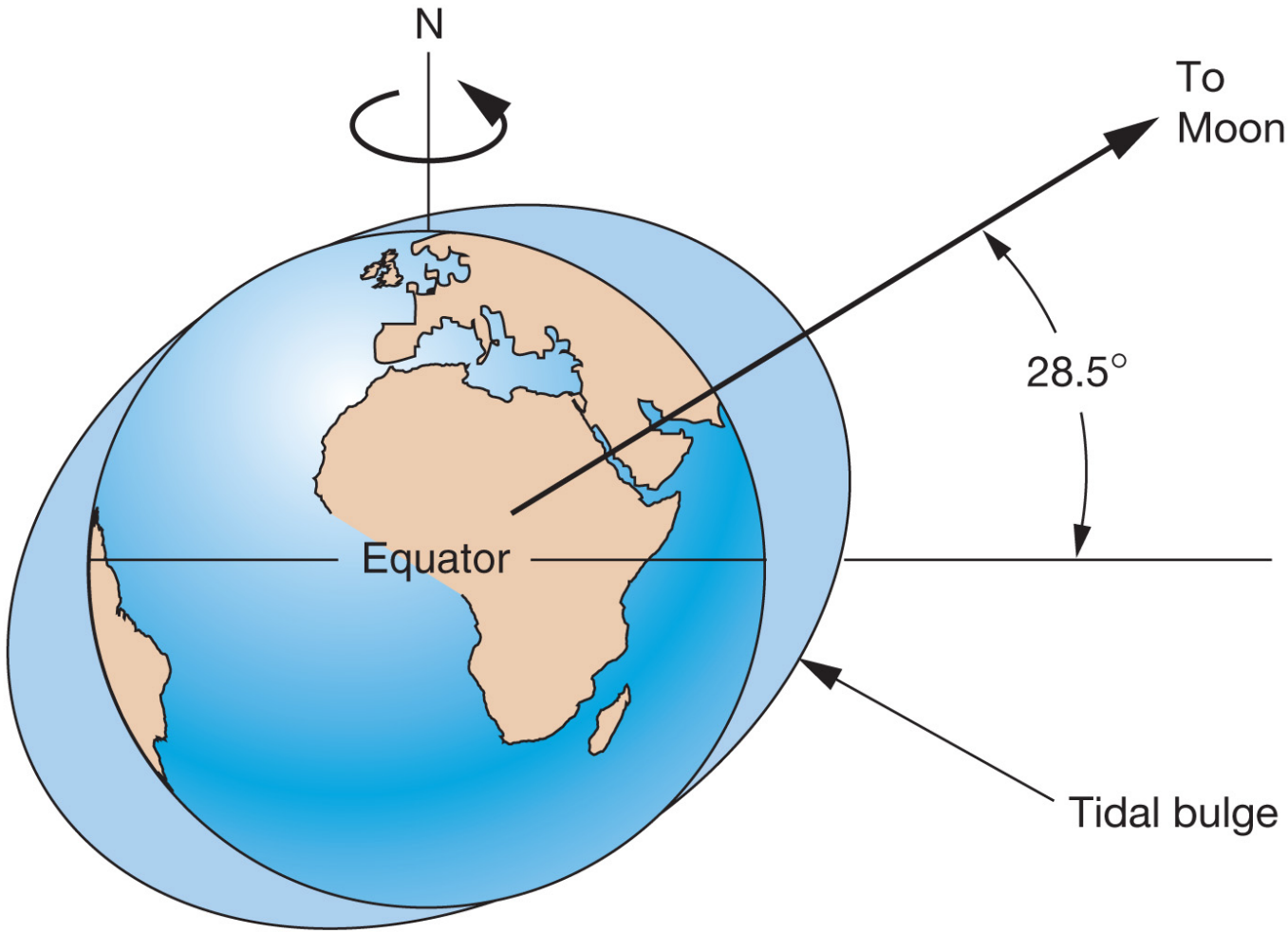
Phases of the Moon



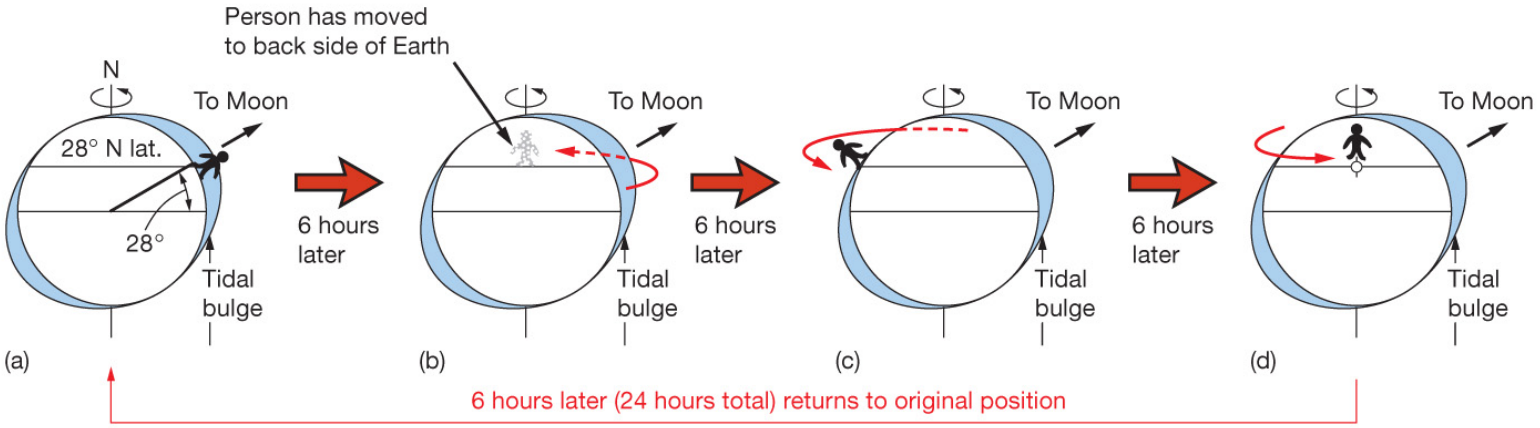
Complicating Factors

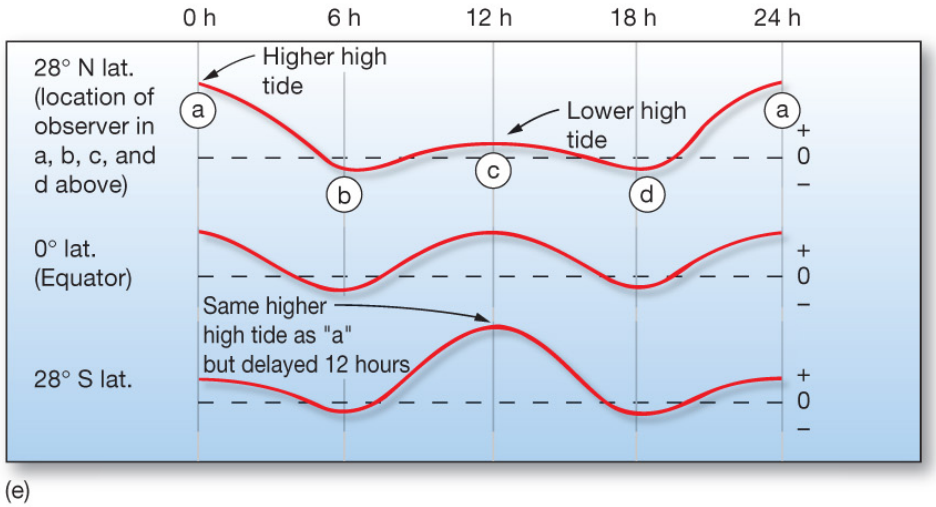
- Declination – Angular distance of the Moon or Sun above or below Earth's equator
- Sun to Earth: 23.5 degrees north or south of equator
- Moon to Earth: 28.5 degrees north or south of equator
- Lunar and solar bulges shift from equator
  - Unequal tides

Declination and Tidal Bulges

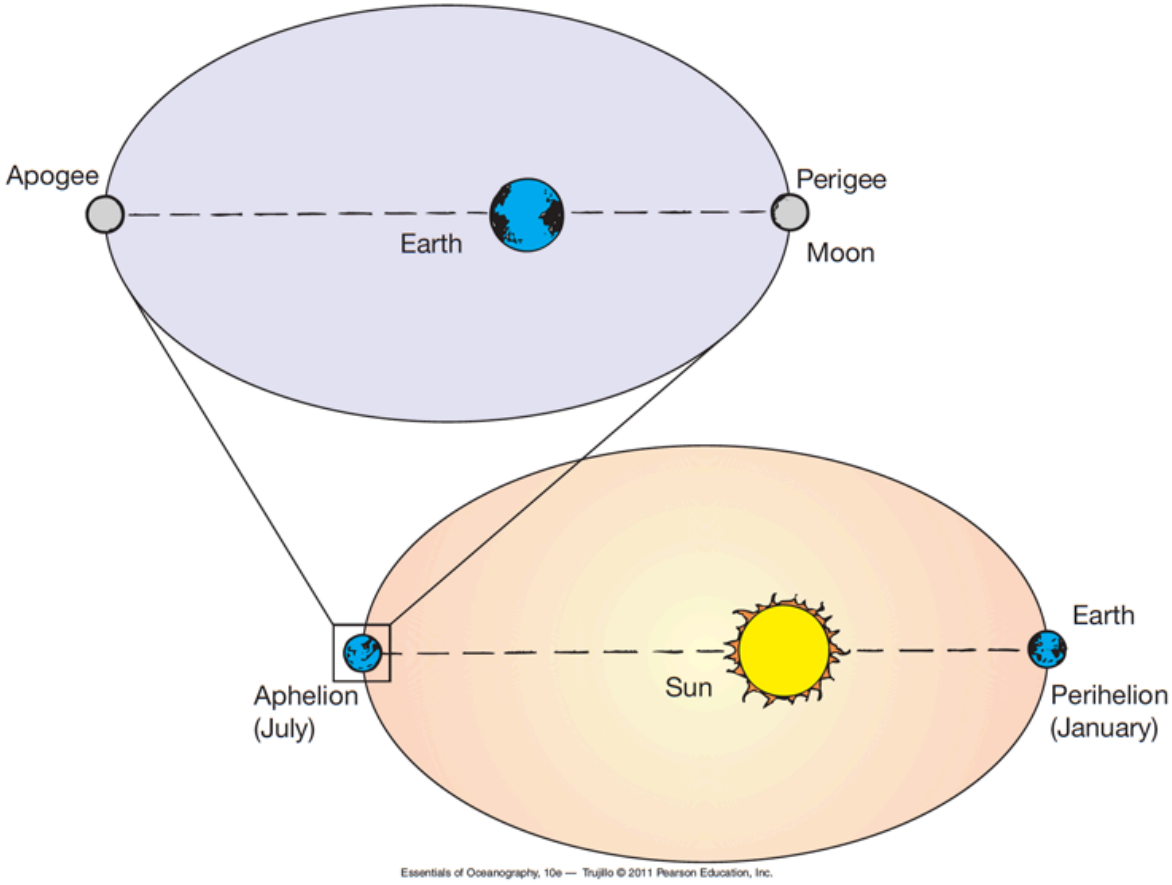


Predicted Idealized Tides





Effects of elliptical orbits



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

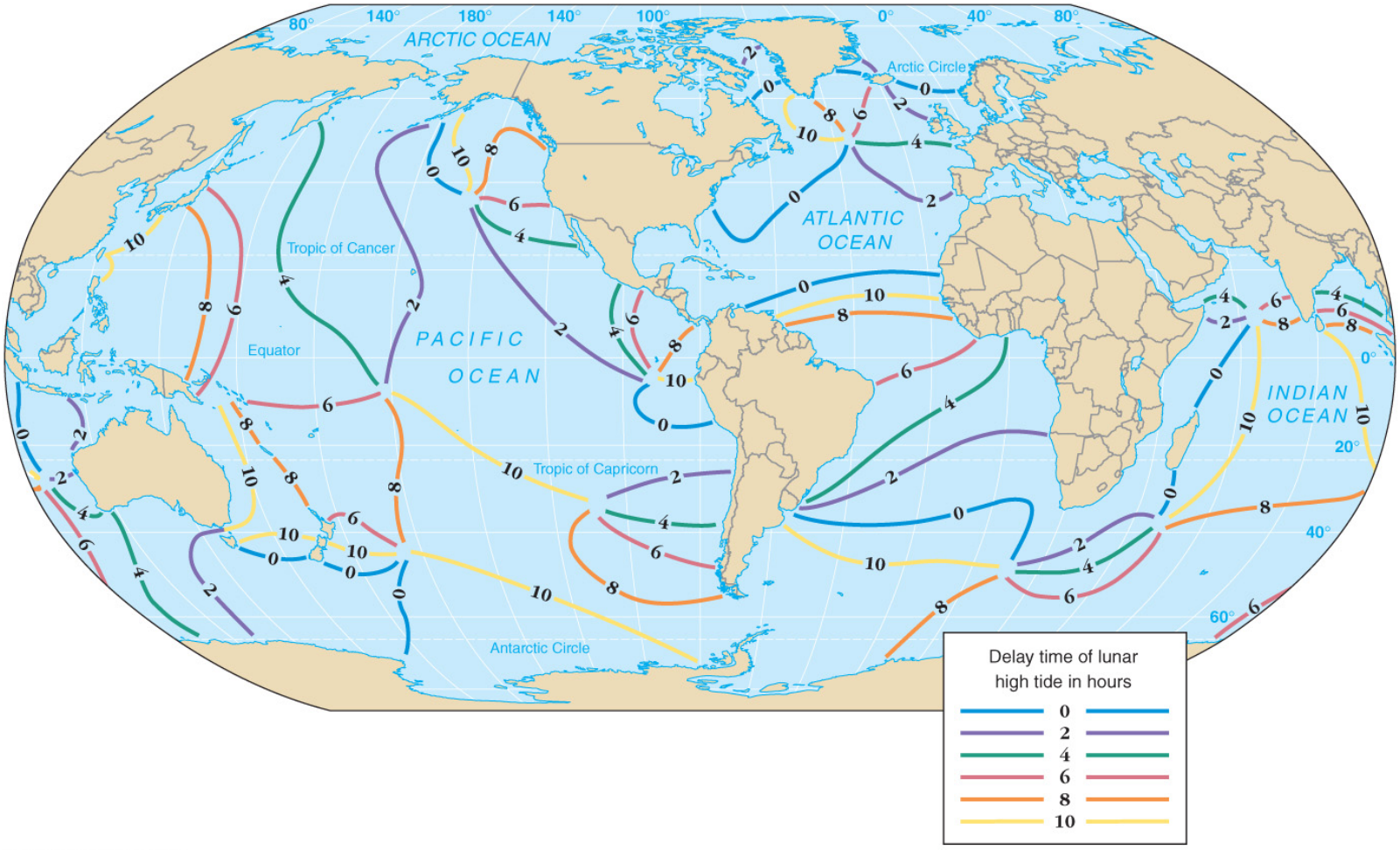
Real Tides

- 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



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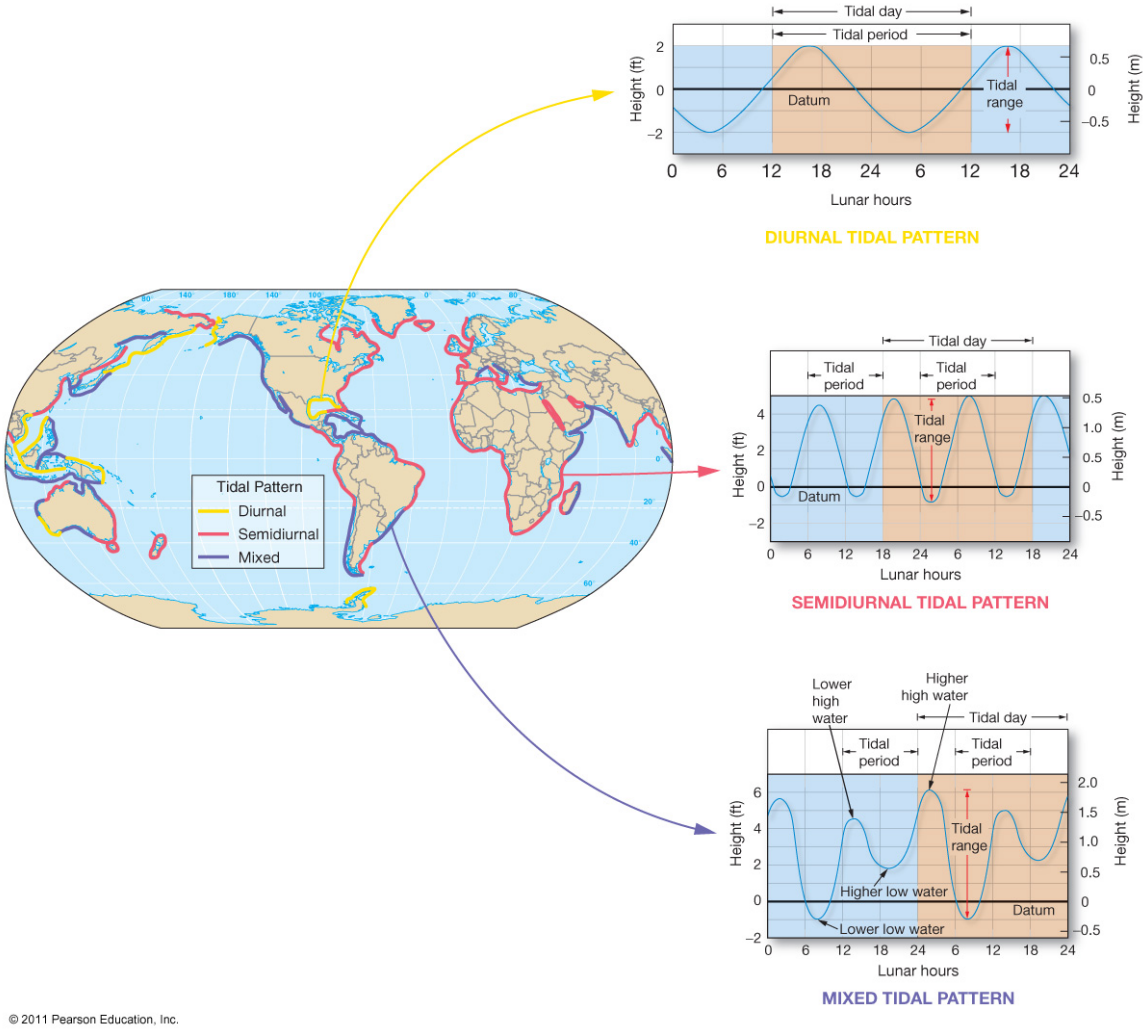
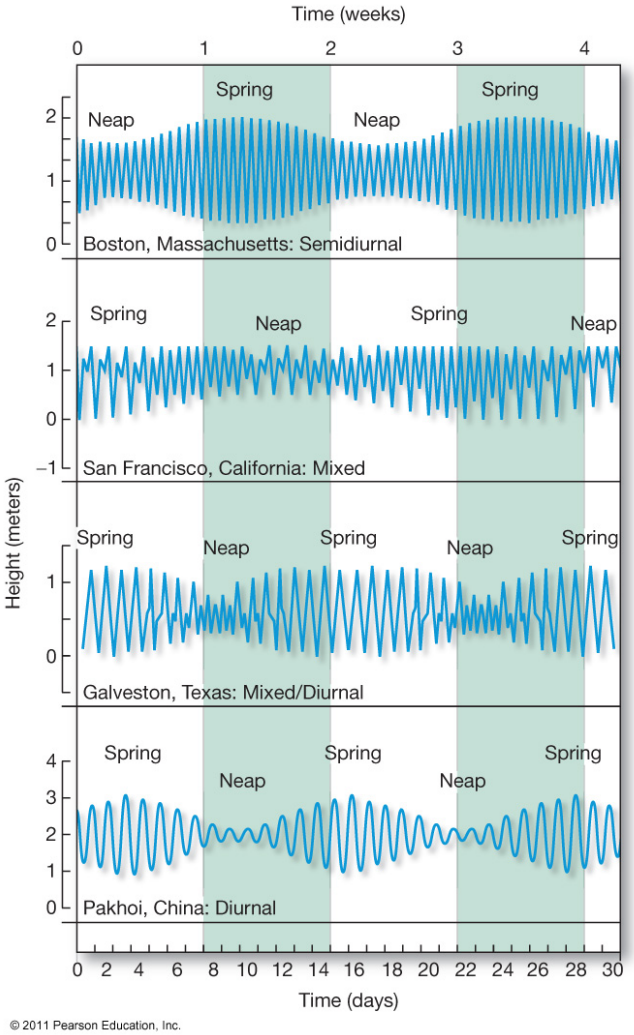
Tidal Patterns

- 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



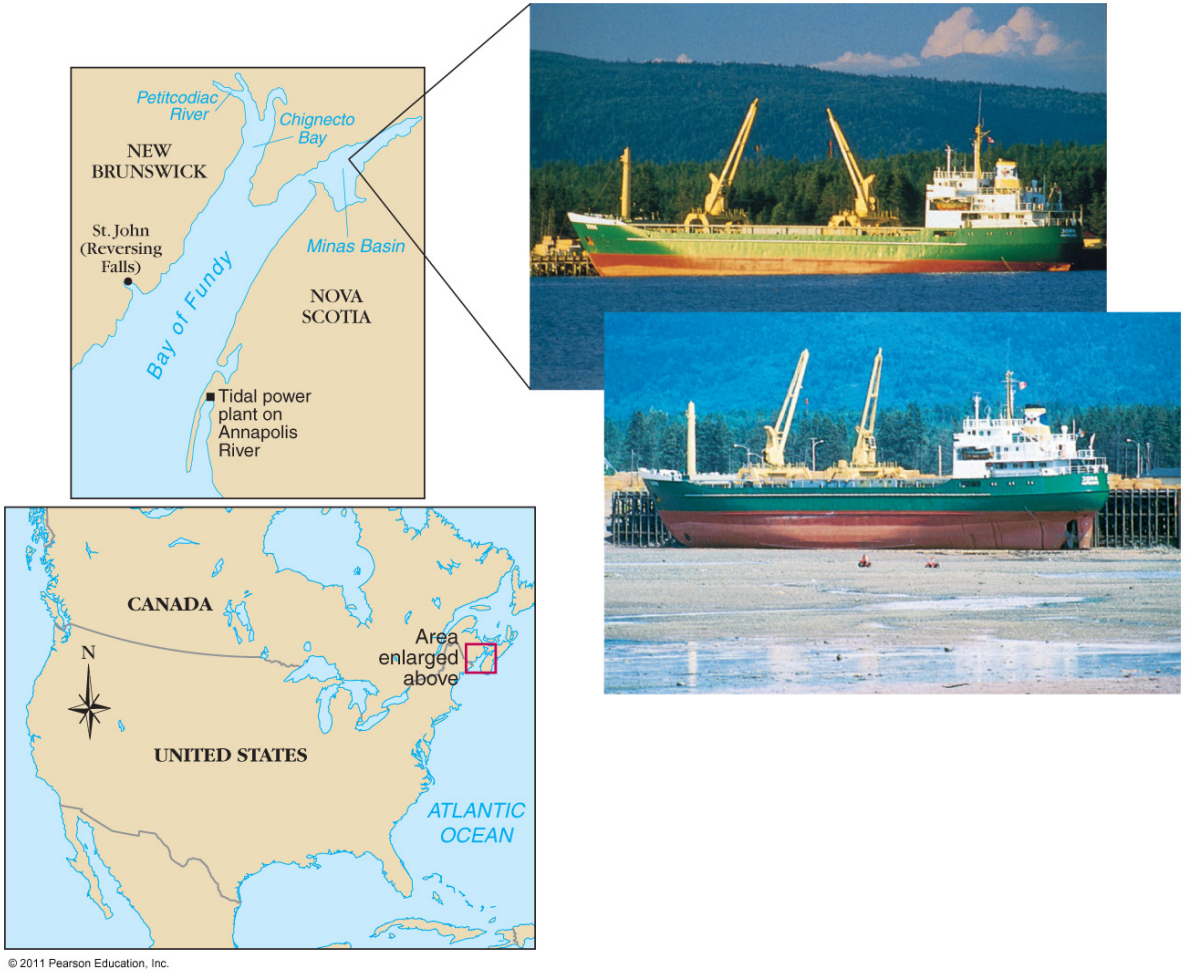
Monthly Tidal Curves



Tides in Coastal Waters

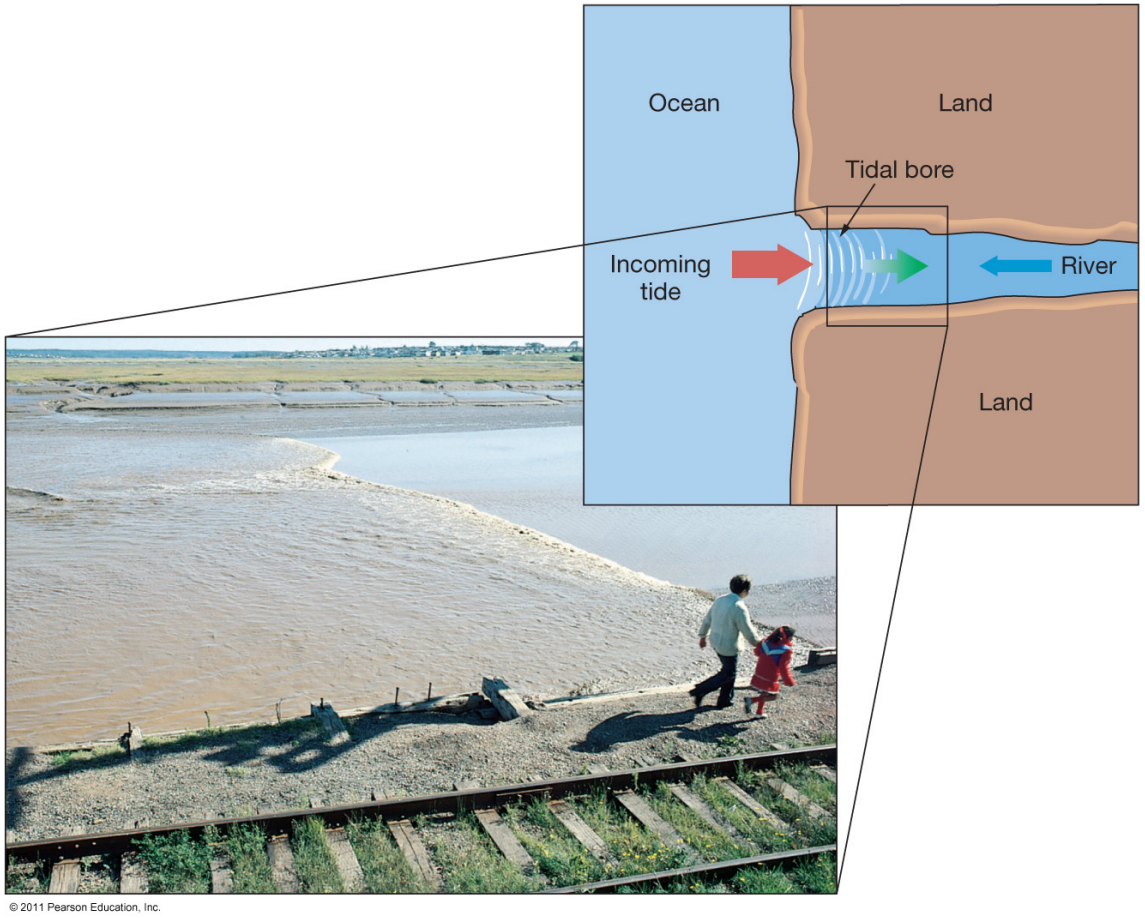
- Standing Waves
  - Tide waves reflected by coast
  - Amplification of tidal range
  - Example: Bay of Fundy maximum tidal range 17 meters (56 feet)

Bay of Fundy – World's Largest Tidal Range



Tides in Coastal Waters

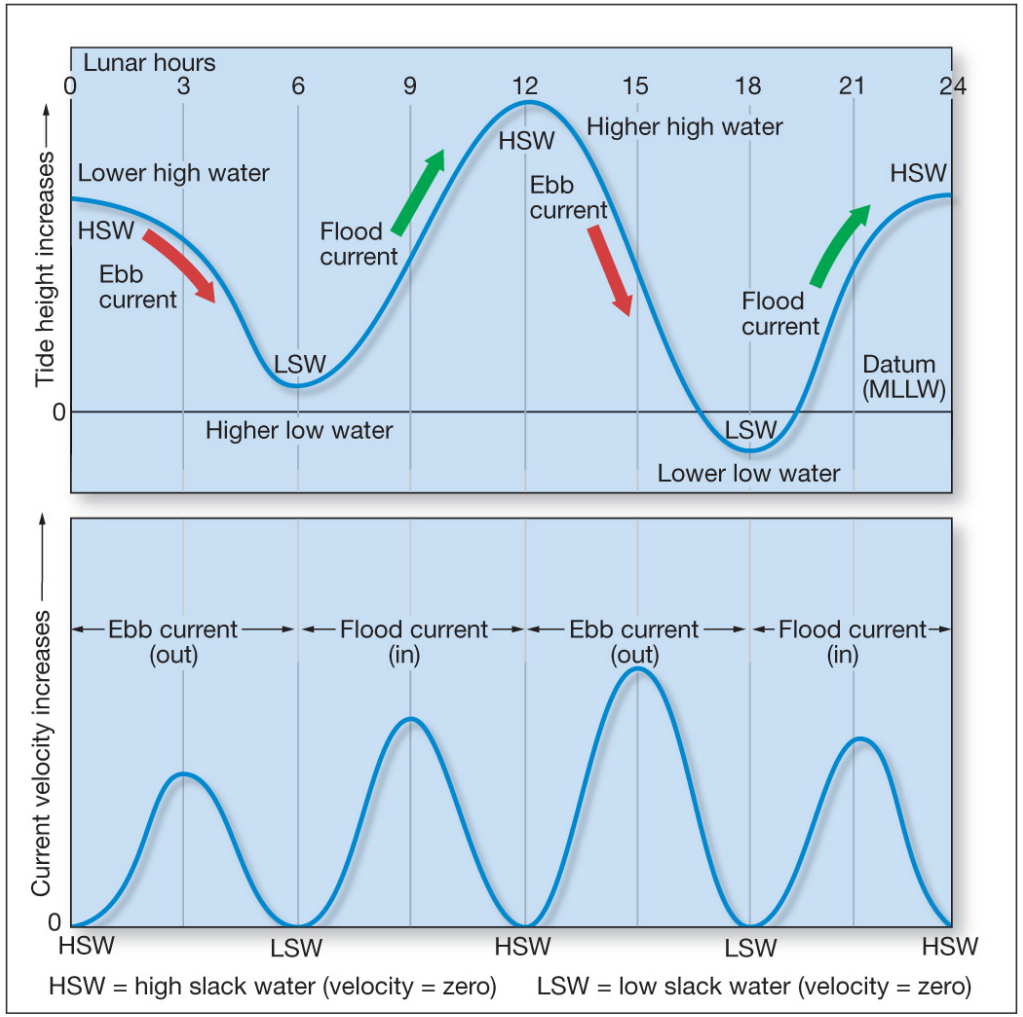
- Tidal Bores
  - Wall of water
  - Moves up certain rivers
  - Tide-generated



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

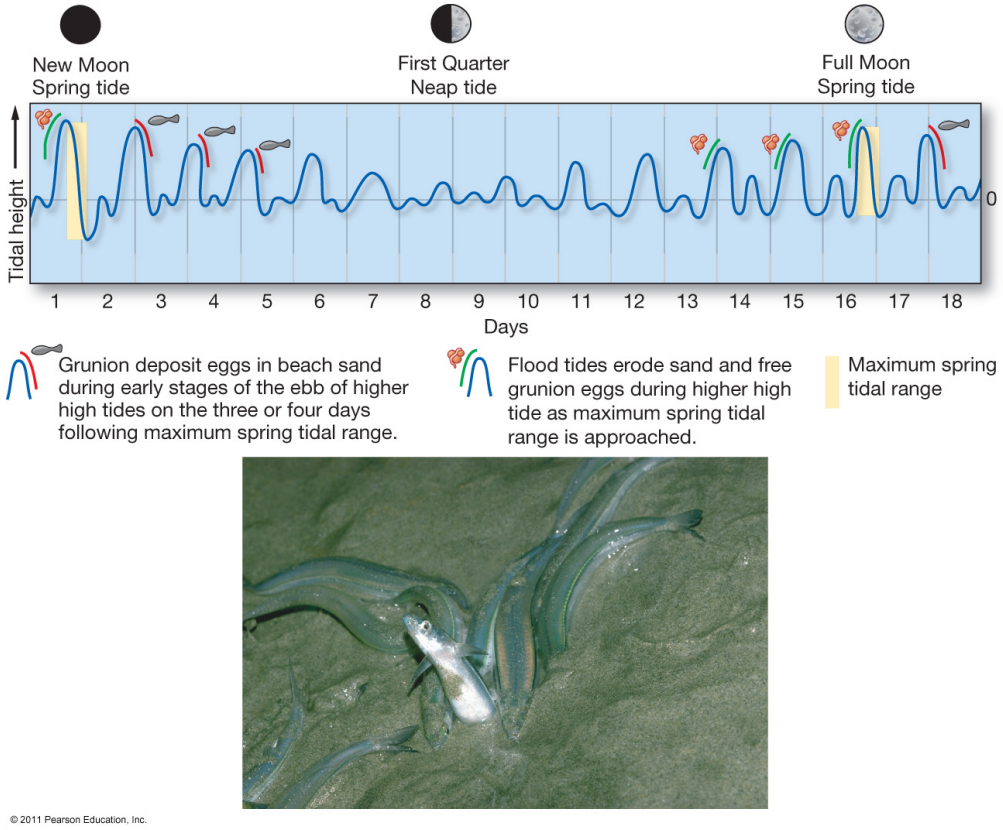


Coastal Tidal Currents

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

Tides and Marine Life

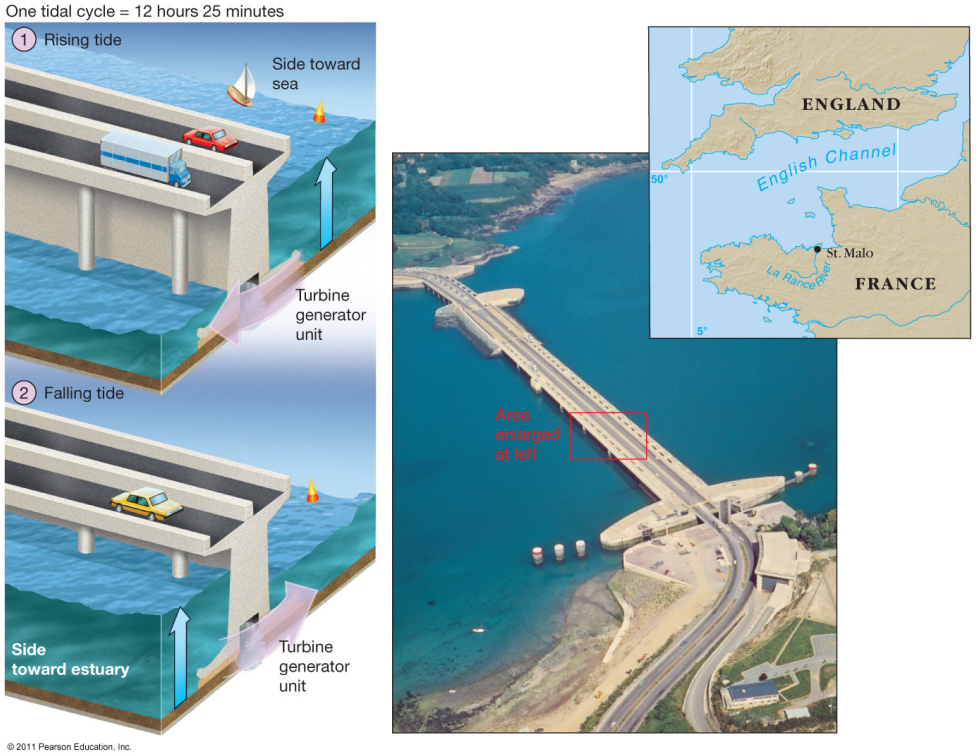
- Tide pools and life
- Grunion spawning



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

Tides

the end