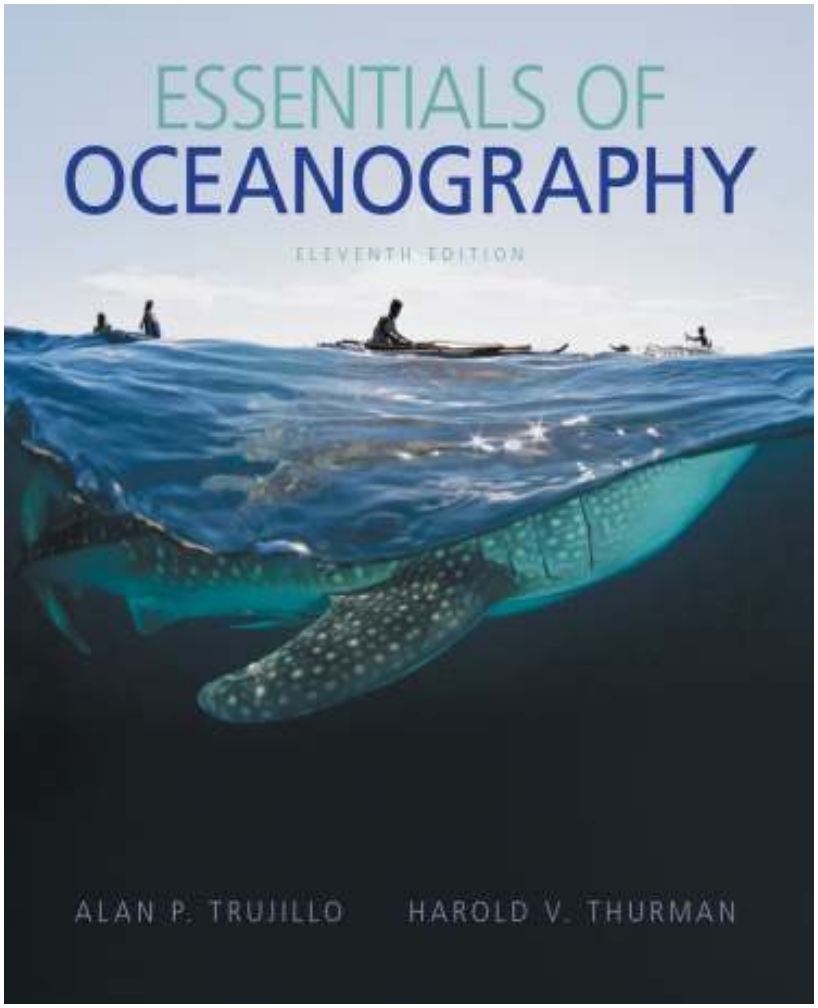
Chapter 9 Lecture

Essentials of Oceanography

Eleventh Edition



Tides

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Chapter Overview

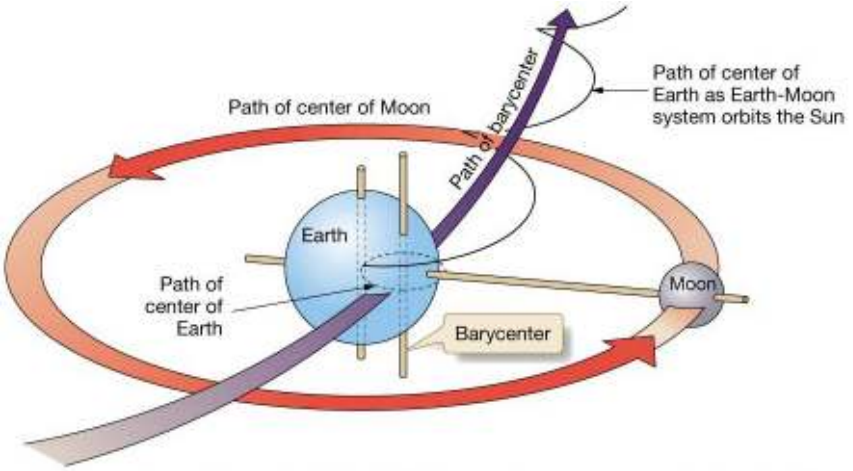
- Tides are the rhythmic rise and fall of sea level.
- Tides are very long and regular shallow-water waves.
- Tides are caused by gravitational attraction of the Sun, Moon, and Earth.
- Different tidal patterns exist.

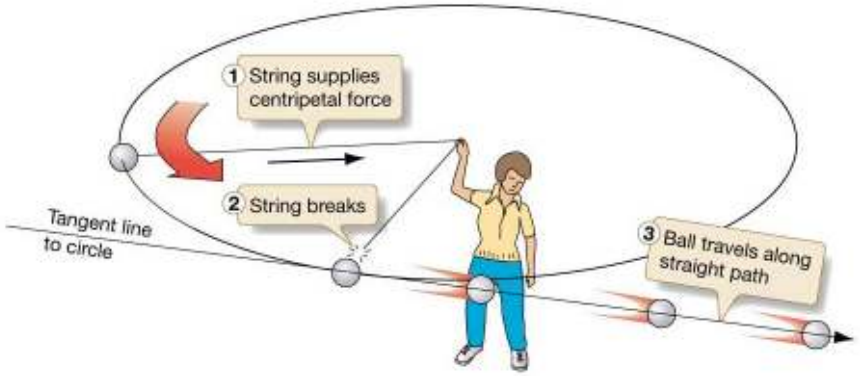
What Are Tides?

- 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

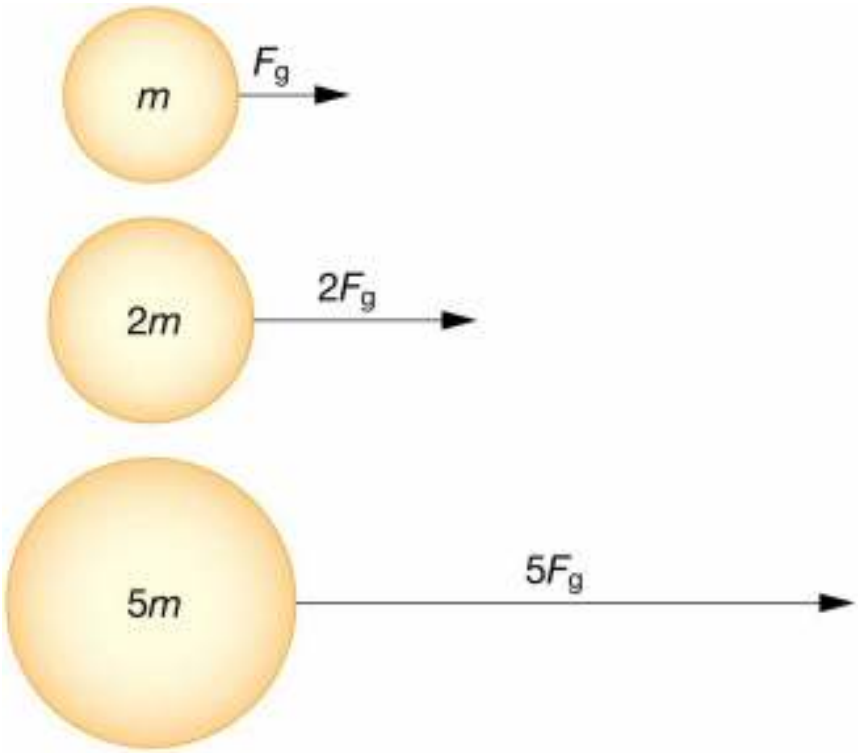
- Tides caused by combination of gravity and motion between Earth, Moon, and Sun
- Barycenter between Moon and Earth
  - Common center of mass or balance point
  - Beneath Earth's surface because of Earth's greater mass





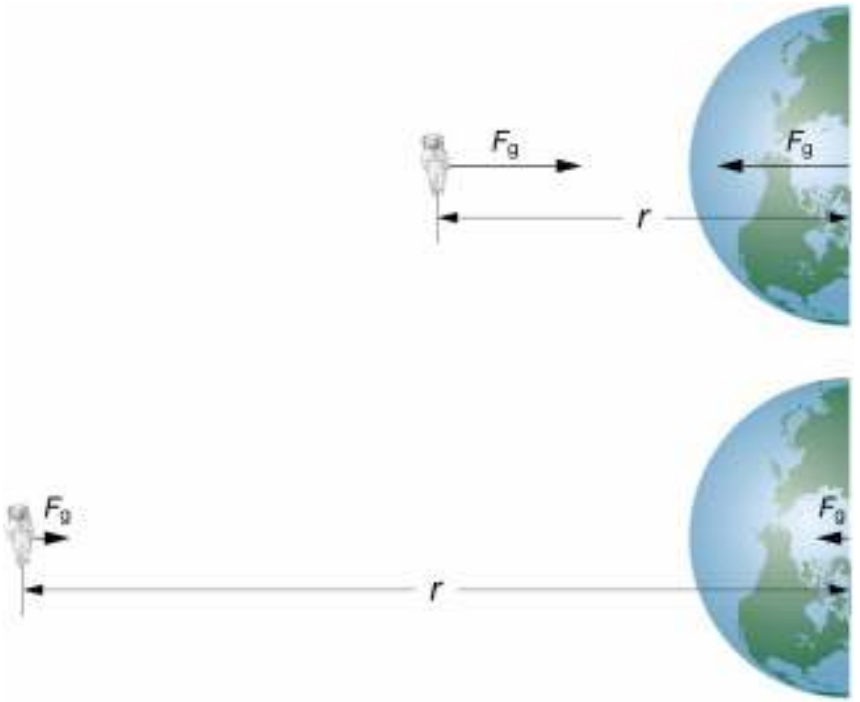
Gravitational Forces

- Gravitational force derived from Newton's Law of Universal Gravitation
  - Every object that has mass in the universe is attracted to every other object.



Gravitational Forces

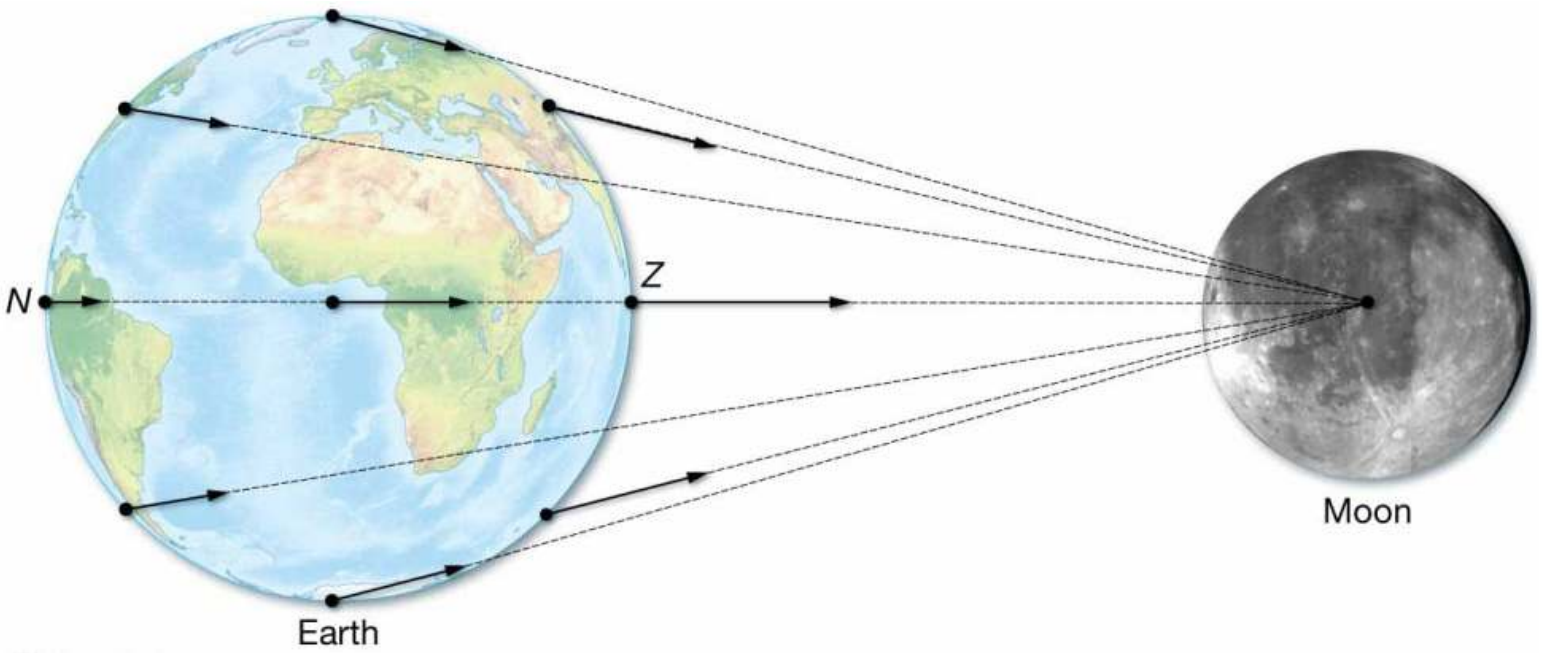
- Gravitational force proportional to product of masses
  - Increase mass, increase force
- Inversely proportional to square of separation distance



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

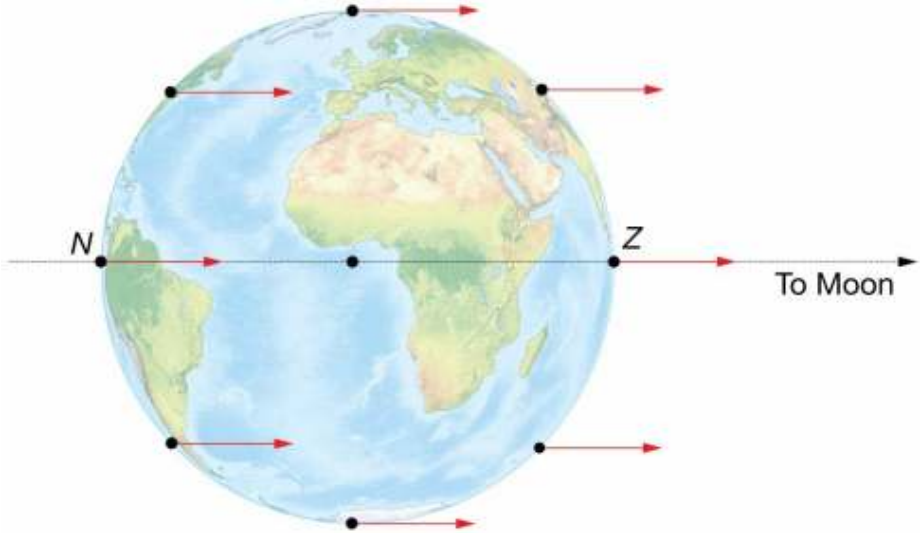
Gravitational Forces

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



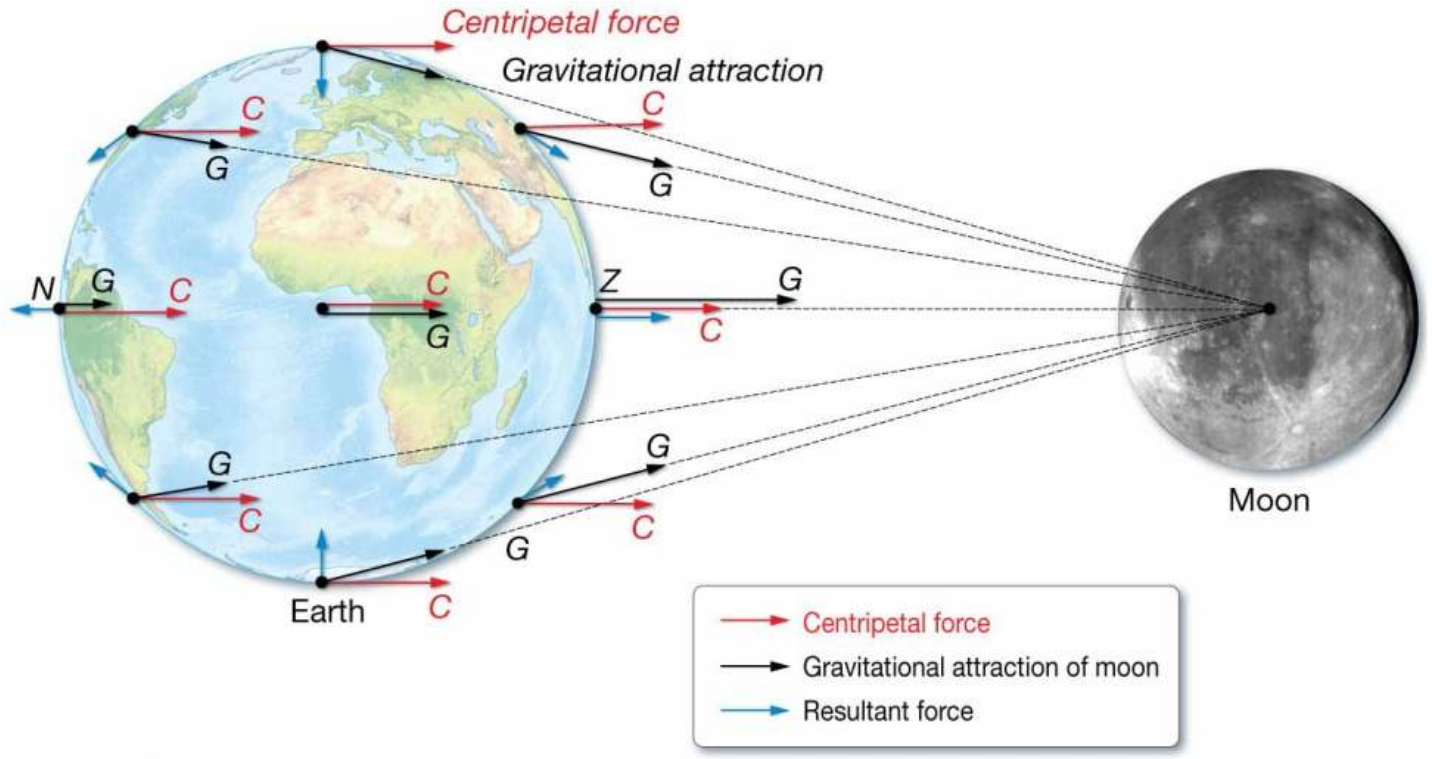
Centripetal Force

- Center-seeking force
- Keeps planets in orbit via gravitational attraction
- Tethers Earth and Moon to each other



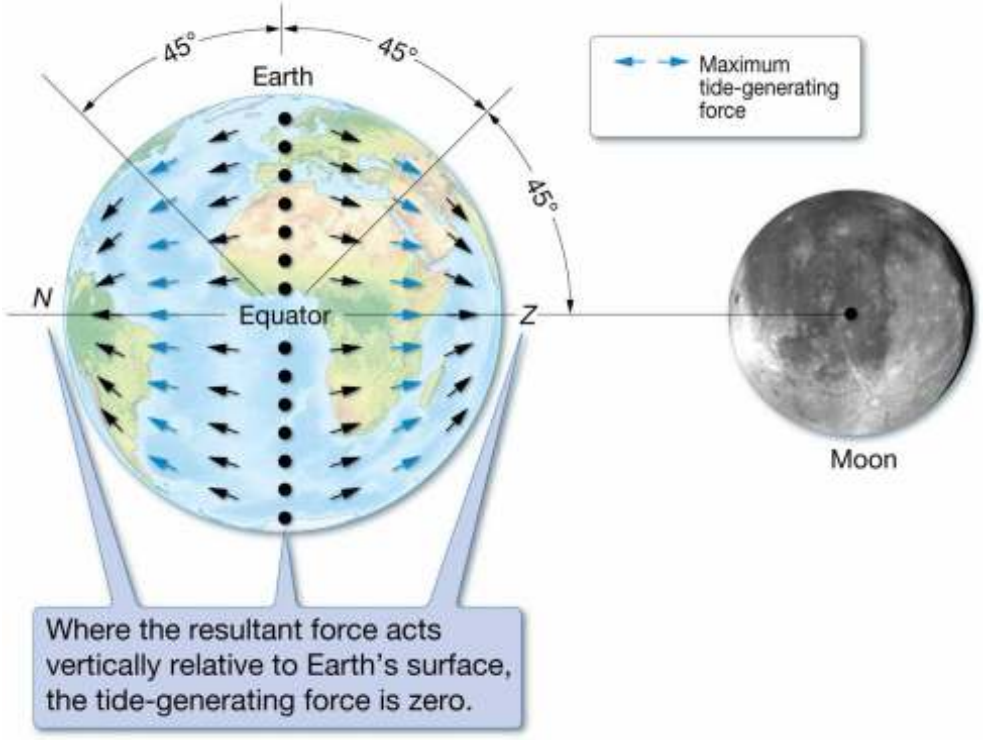
Resultant Forces

- Mathematical difference between gravitational and centripetal forces
- Relatively small

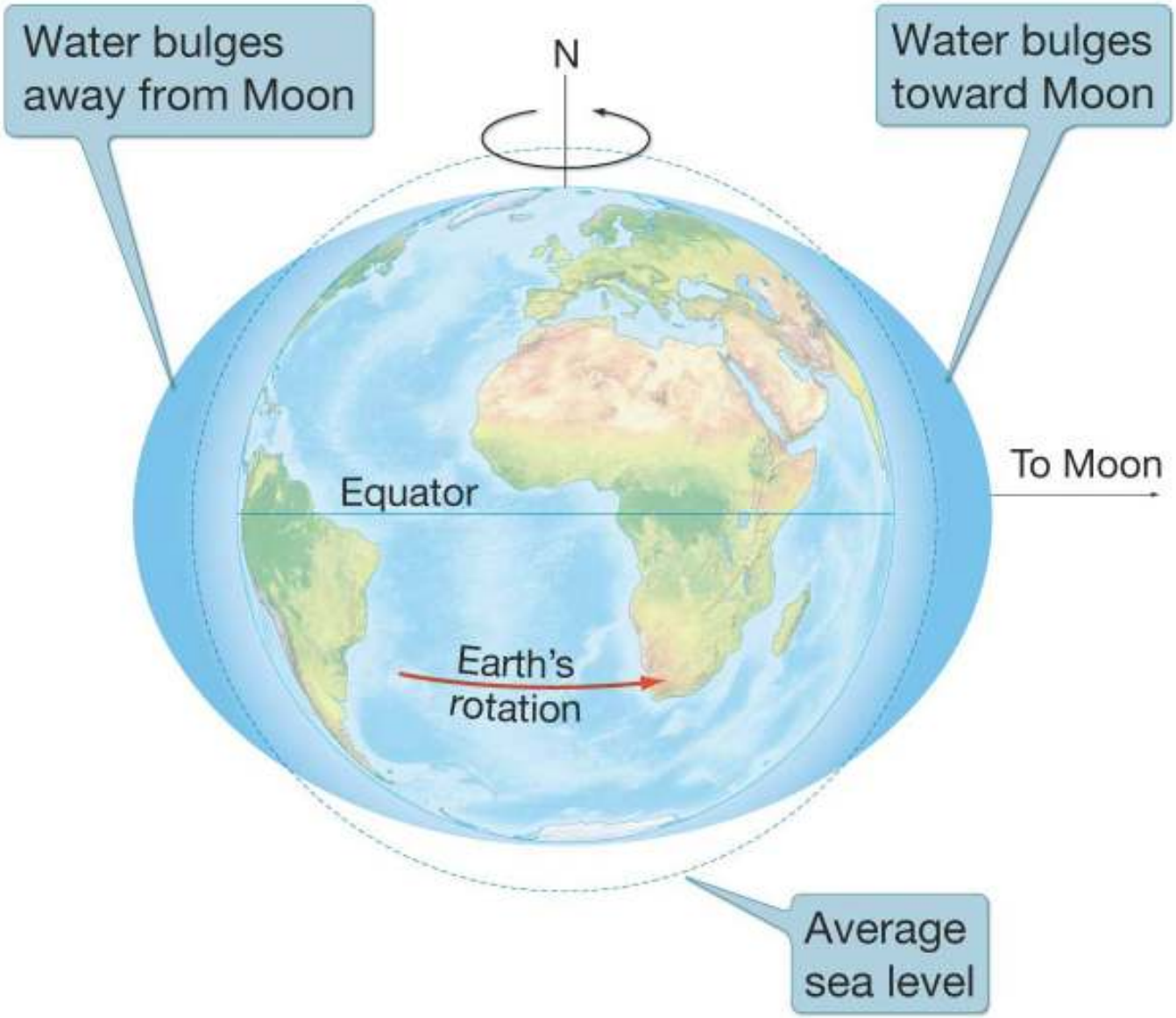


Tide-Generating Forces

- Resultant force has significant horizontal component
- Lunar bulges
  - Result when force pushes water into two simultaneous bulges
    - One toward Moon
    - One away from Moon



Idealized Tidal Bulges



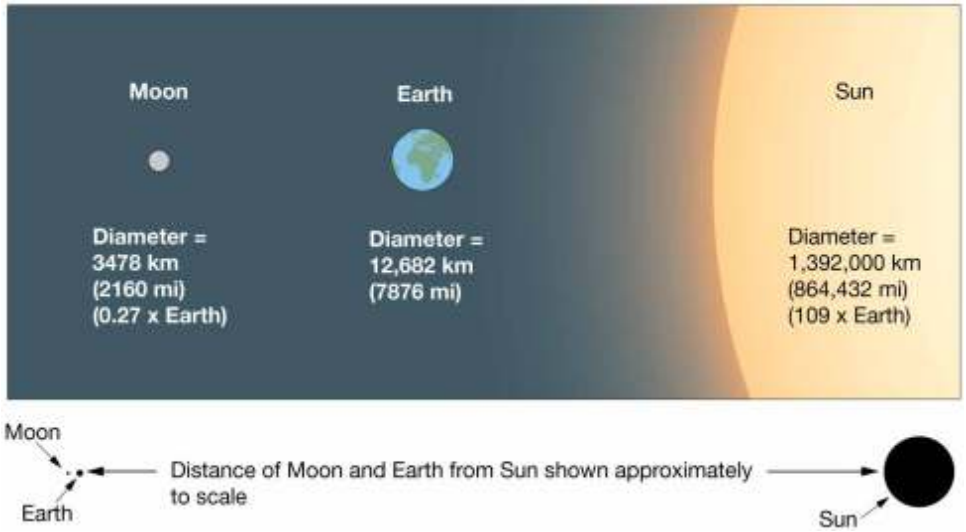
Tidal Phenomena

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

Lunar Day

Tidal Bulges – Sun's Effect

- Similar to lunar bulges but much smaller
- Moon closer to Earth, exerts greater gravitational force



Earth's Rotation and Tides

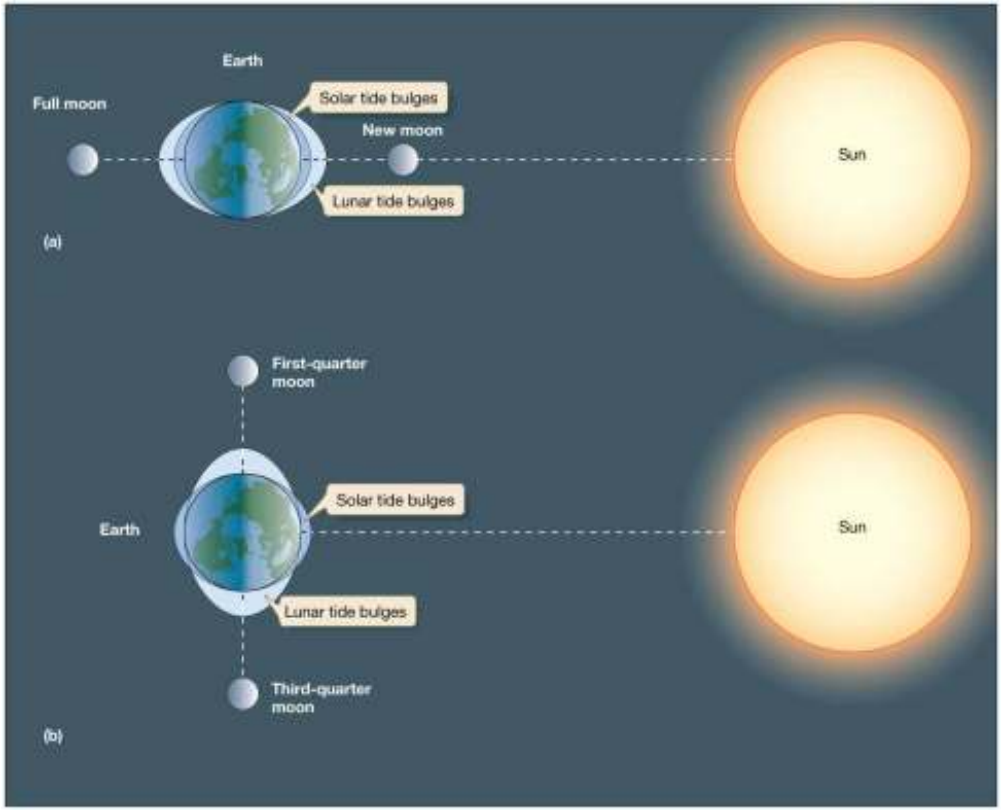
- Flood tide – water moves toward shore
- Ebb tide – water moves away from shore
- Tidal bulges are fixed relative to the Sun's and Moon's positions
  - Earth's rotation moves different geographic locations into bulges

Monthly Tidal Cycle

- Tidal range – difference between high and low tides
- Syzygy – Moon, Earth, and Sun aligned
- Quadrature – Moon in first or third quarter phase

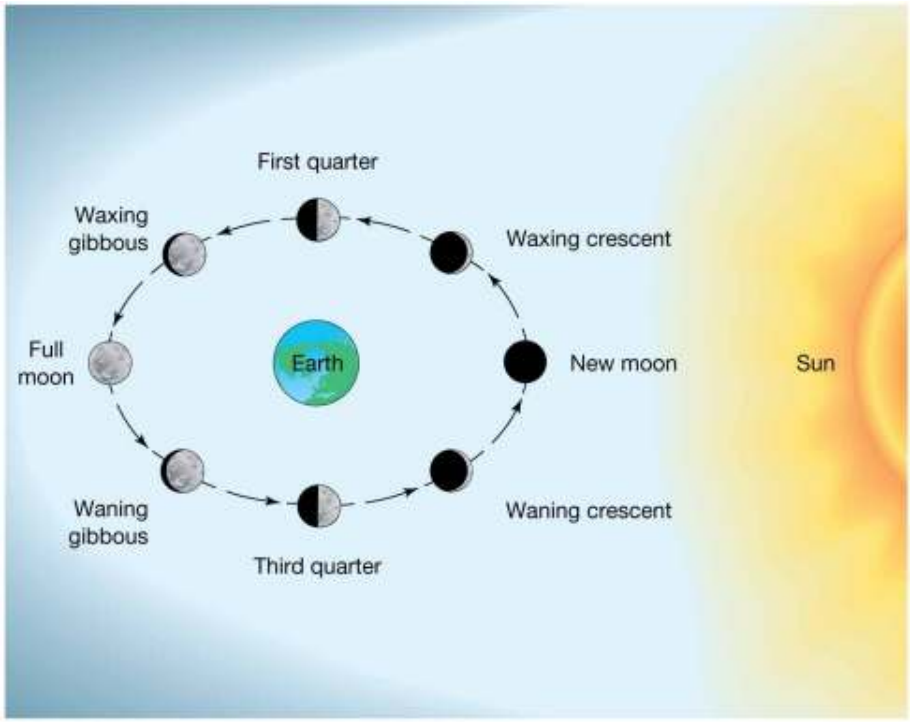
Monthly Tidal Cycle

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



Monthly Tidal Cycle

- New Moon – Moon between Earth and Sun, cannot be seen from Earth
- Full Moon – Moon and Sun opposite
- Quarter Moon – Moon appears half lit



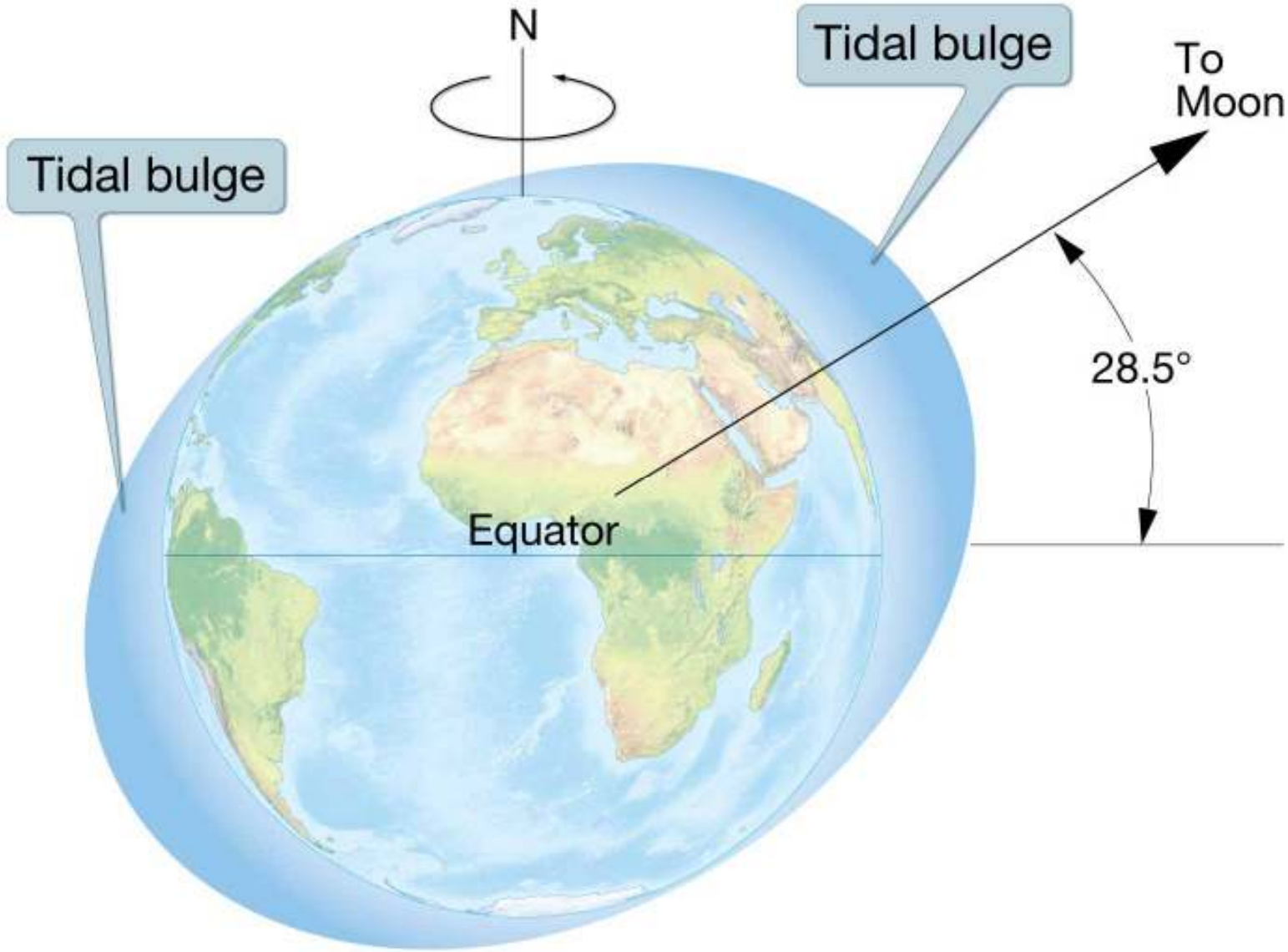
Monthly Tidal Cycle

- Other Moon phases
- Waxing crescent – Moon moving from new to first quarter
- Waxing gibbous – Moon moving from first quarter to full
- Waning gibbous – Moon moving from full to last quarter
- Waning crescent – Moon moving from last quarter to new 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



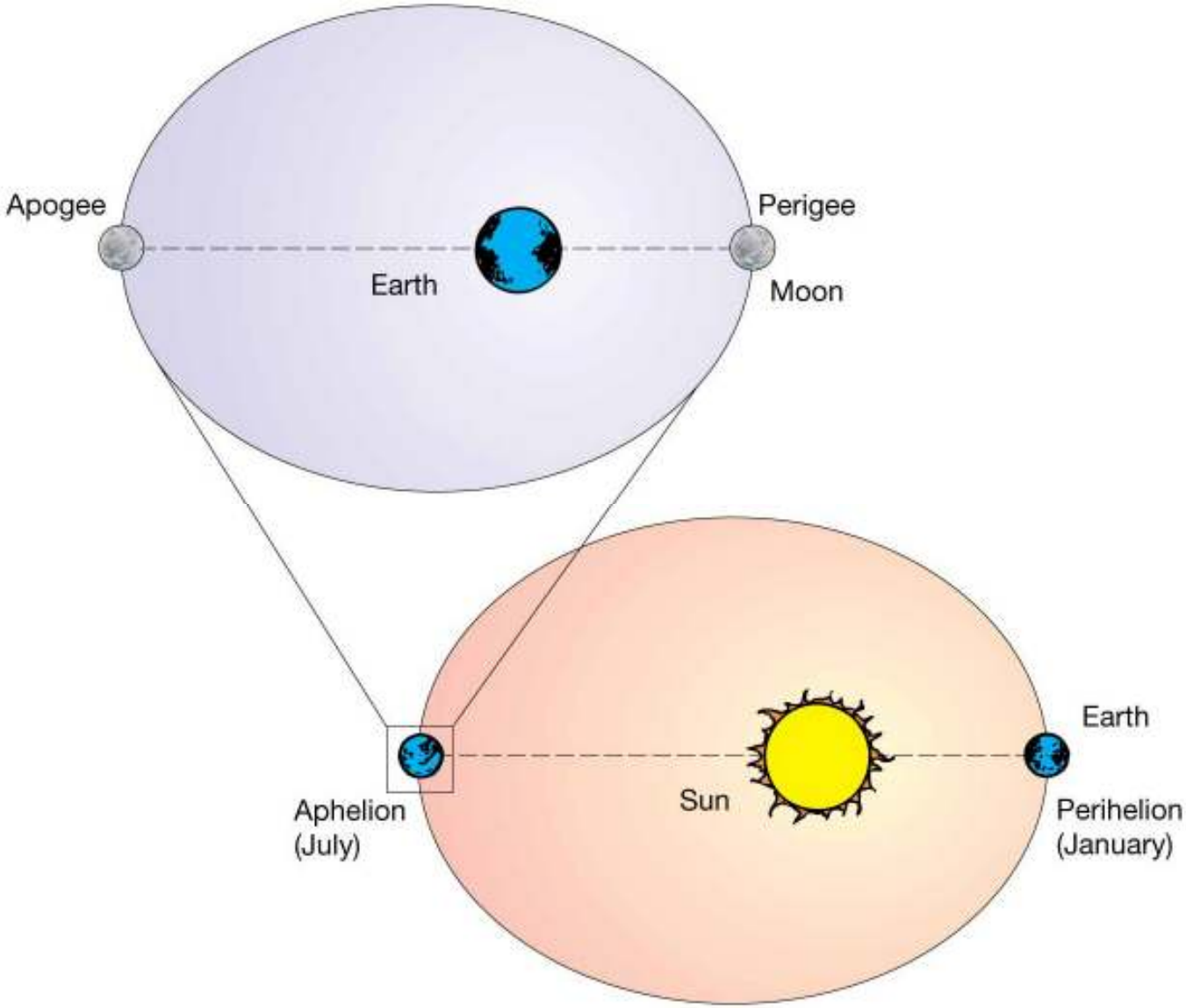
Complicating Factors

- Elliptical orbits
- Earth around Sun:
  - Tidal range greatest at perihelion (January)
  - Tidal range least at aphelion (July)

Complicating Factors

- 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
- Proxigean tides – spring tide + perigee
  - Exceptionally high tidal range
  - Every 1.5 years or so

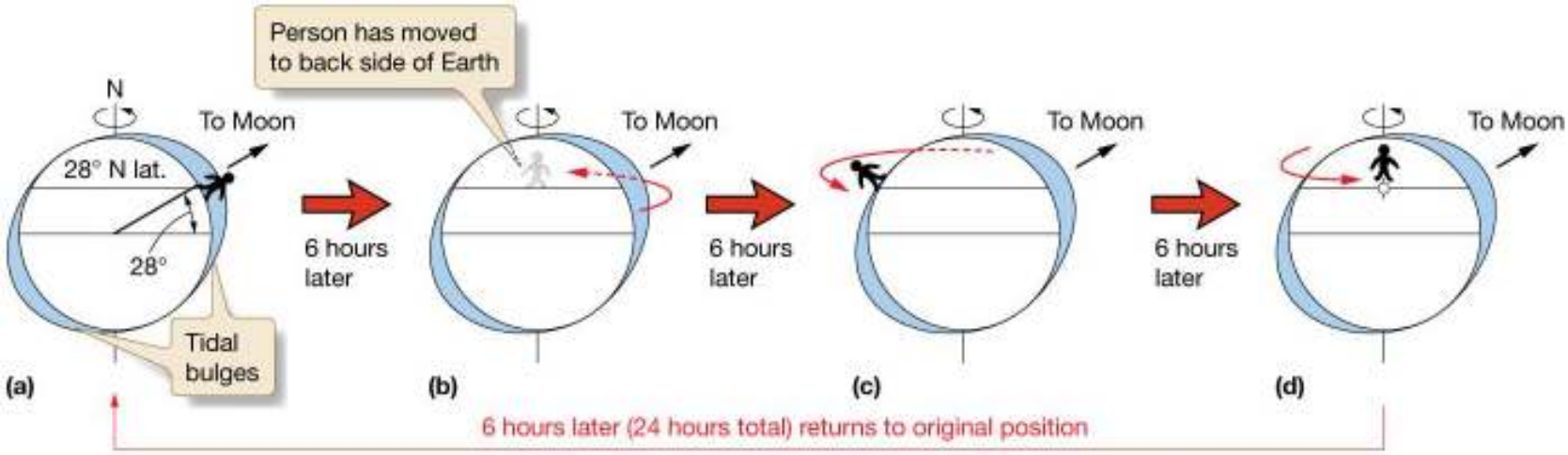
Effects of Elliptical Orbits

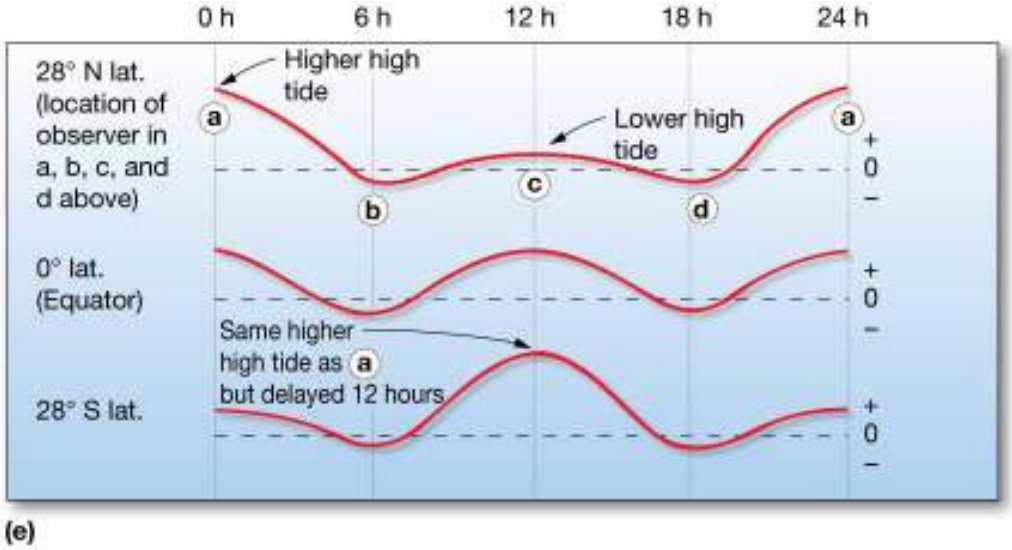


Idealized Tide Prediction

- Two high tides/two low tides per lunar day
- Six lunar hours between high and low tides

Predicted Idealized Tides





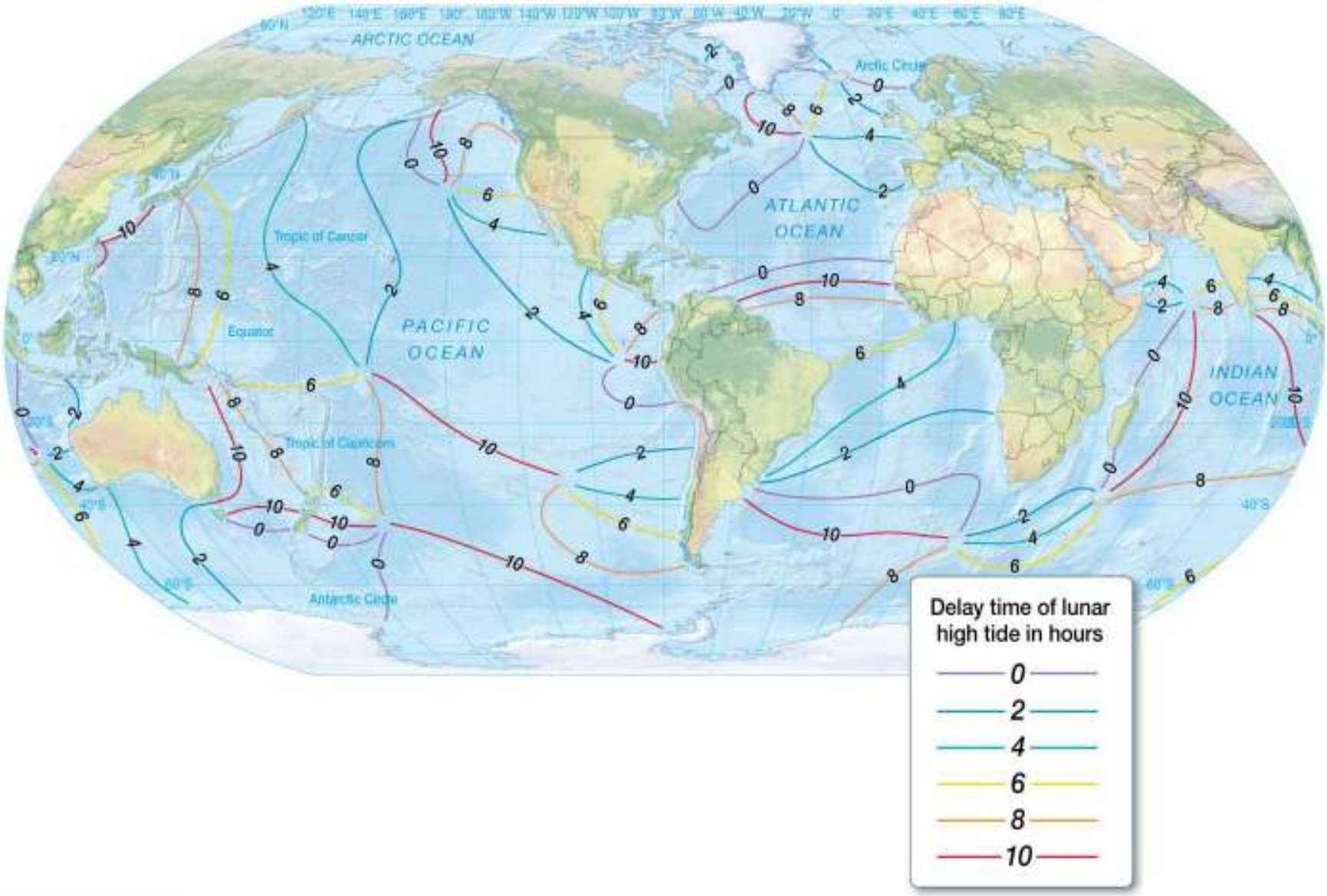
Real Tides

- 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.

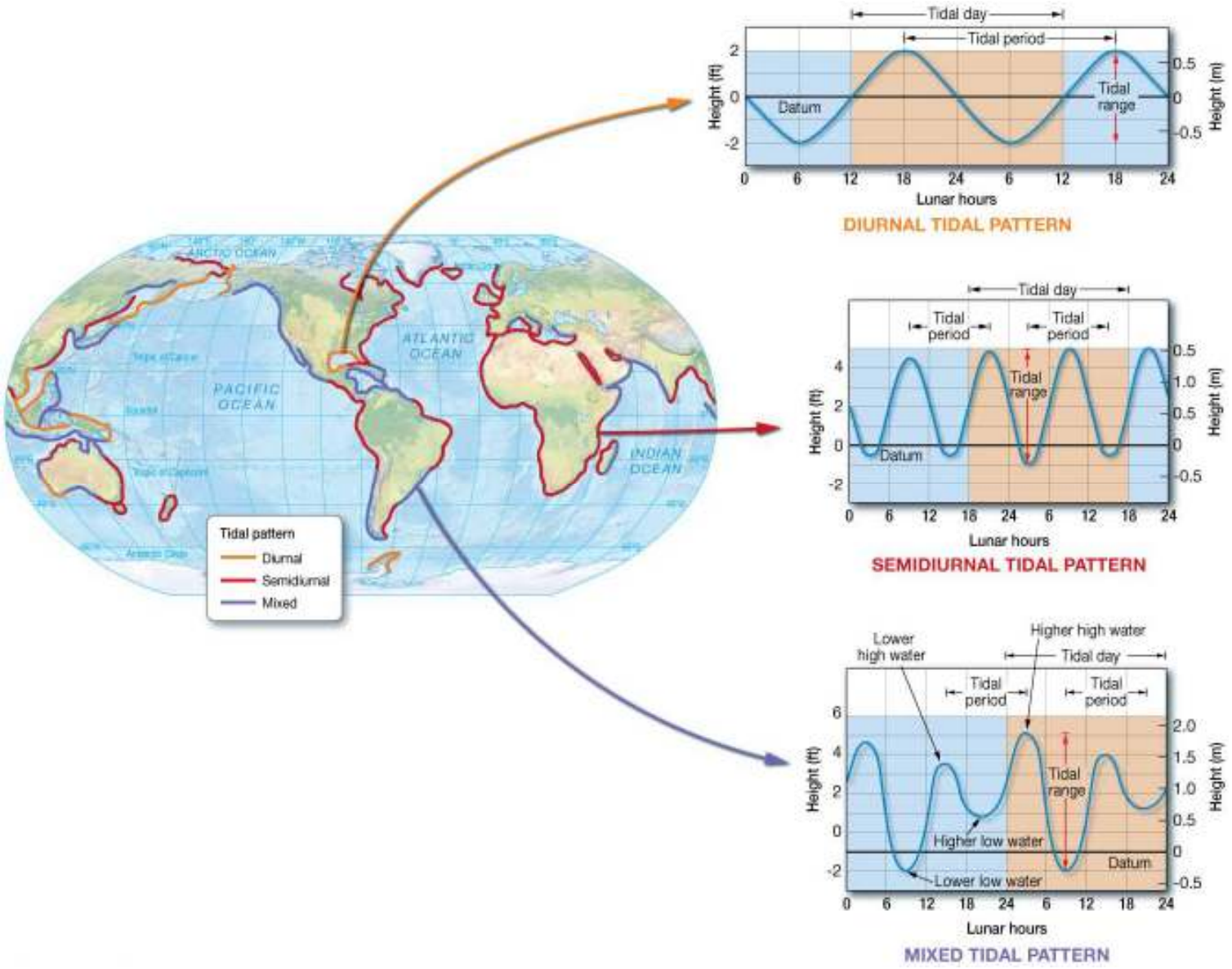
Cotidal Map



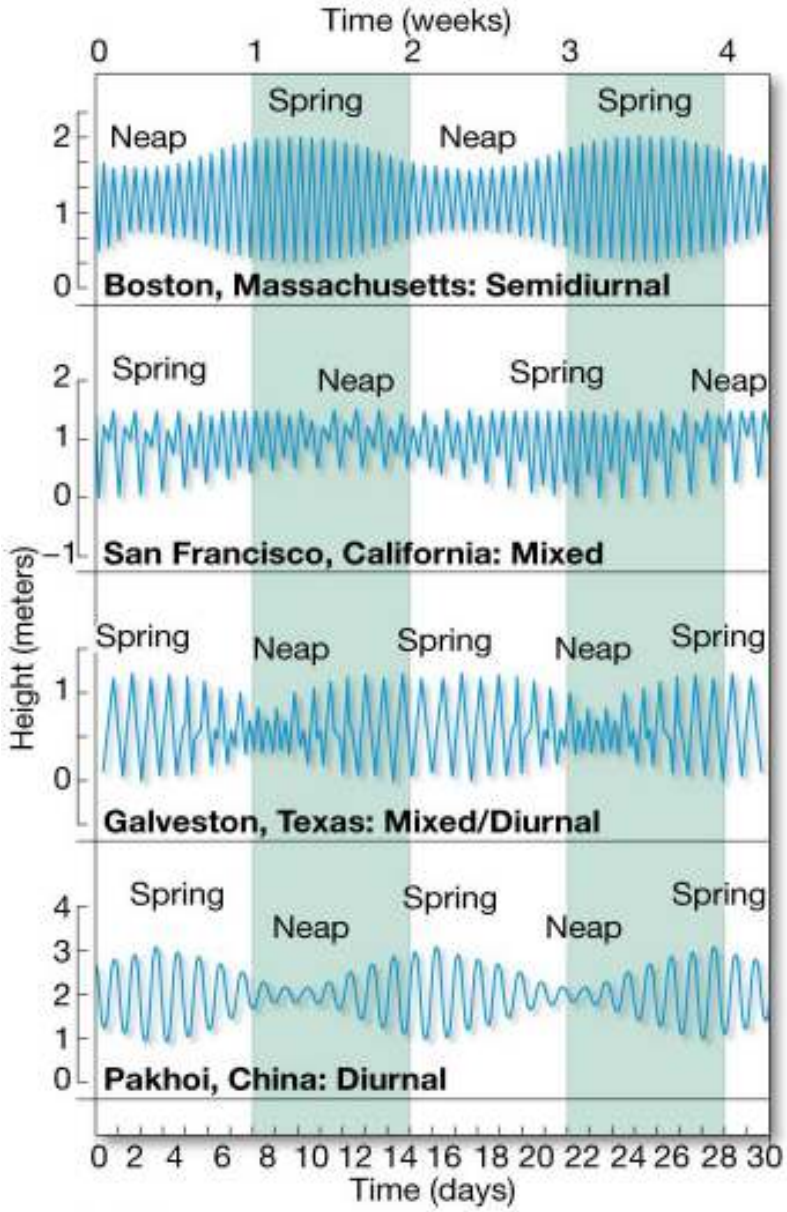
Tidal Patterns

- 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

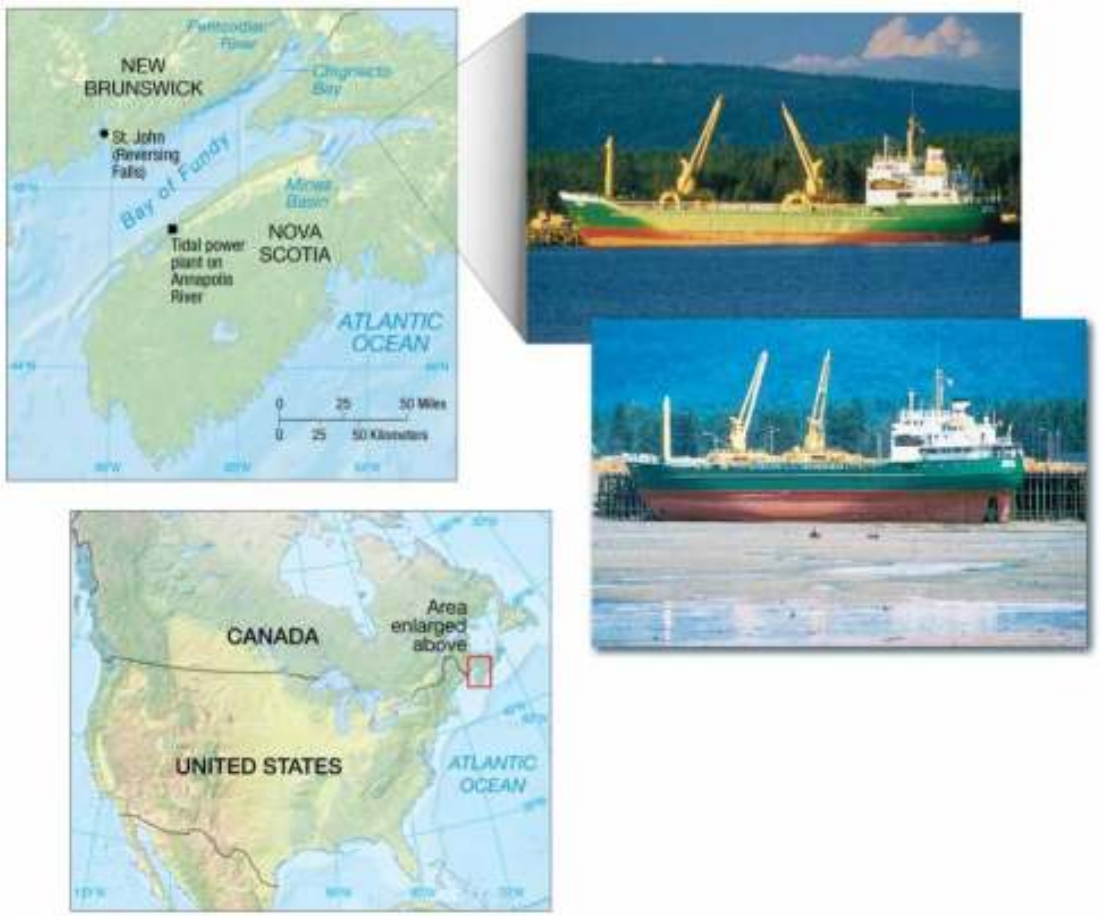


Tides in Coastal Waters

- Standing Waves
  - Tide waves reflected by coast
  - Amplification of tidal range

Tides in Coastal Waters

- Bay of Fundy in Nova Scotia
  - World's largest tidal range



Tides in Coastal Waters

- Tidal Bores
  - Tide-generated wall of water
  - Moves up certain rivers
- Conditions needed for tidal bores
  - Large spring tidal range of at least 6 m (20 ft)
  - Abrupt flood tide and short ebb tide phases
  - Low-lying river with seaward current
  - Shallowing of landward sea floor
  - Narrowing of basin in upper reaches

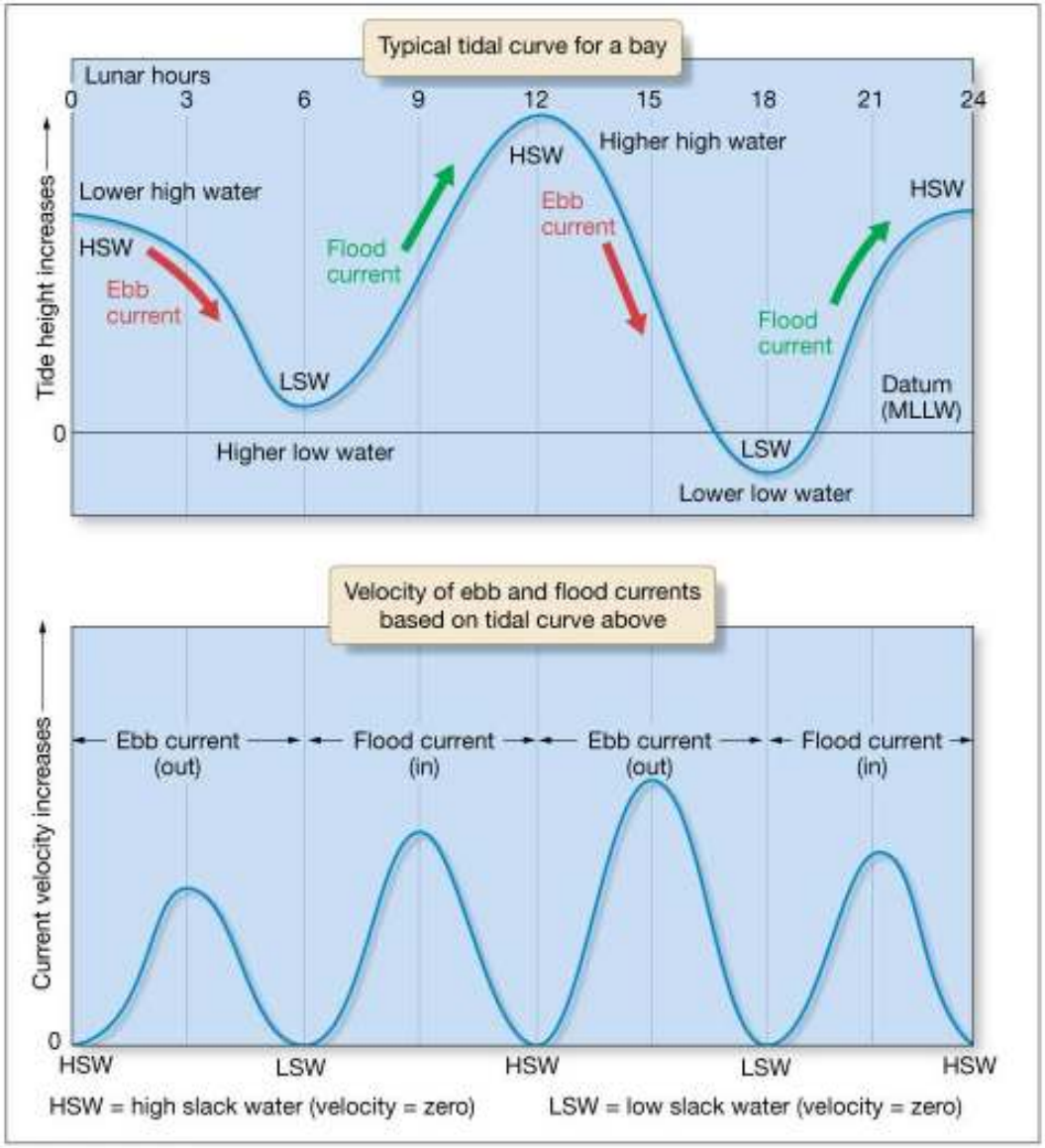
Coastal Tidal Currents

- Rotary Current
  - Current that accompanies the slowly turning tide crest in a Northern Hemisphere basin
  - Rotates counterclockwise
- Reversing current
  - Alternating current
  - Moves in and out of narrow coastal passages

Coastal Tidal Currents

- Flood current
  - Water rushes up a bay or river with incoming tide
- Ebb current
  - Water drains from bay or river as tide goes out
- High slack water
  - Peak of each high tide with no current motion
- Low slack water
  - Peak of each low tide with no current motion

Coastal Tidal Currents

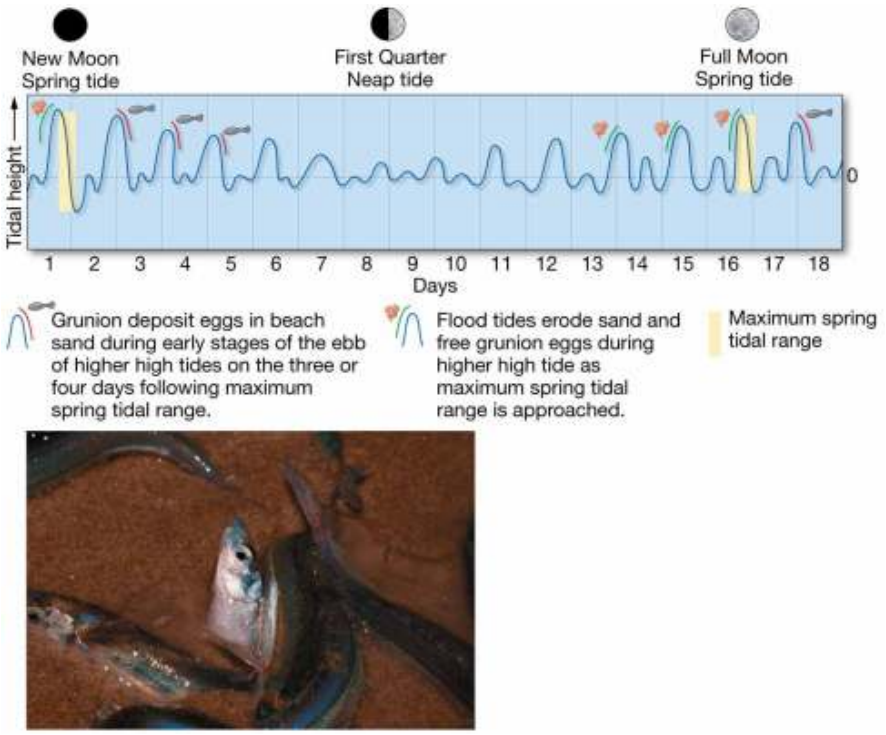


Coastal Tidal Currents

- Whirlpool
  - Rapidly spinning seawater
  - Restricted channel connecting two basins with different tidal cycles
  - *Maelstrom* near Arctic Norway

Tides and Marine Life

- Grunion spawning
  - Small silvery fish
  - Come out of water in California to spawn
  - Spawn only after each night's higher high tide has peaked on the three or four nights following the night of the highest spring high tide



Tide-Generated Power

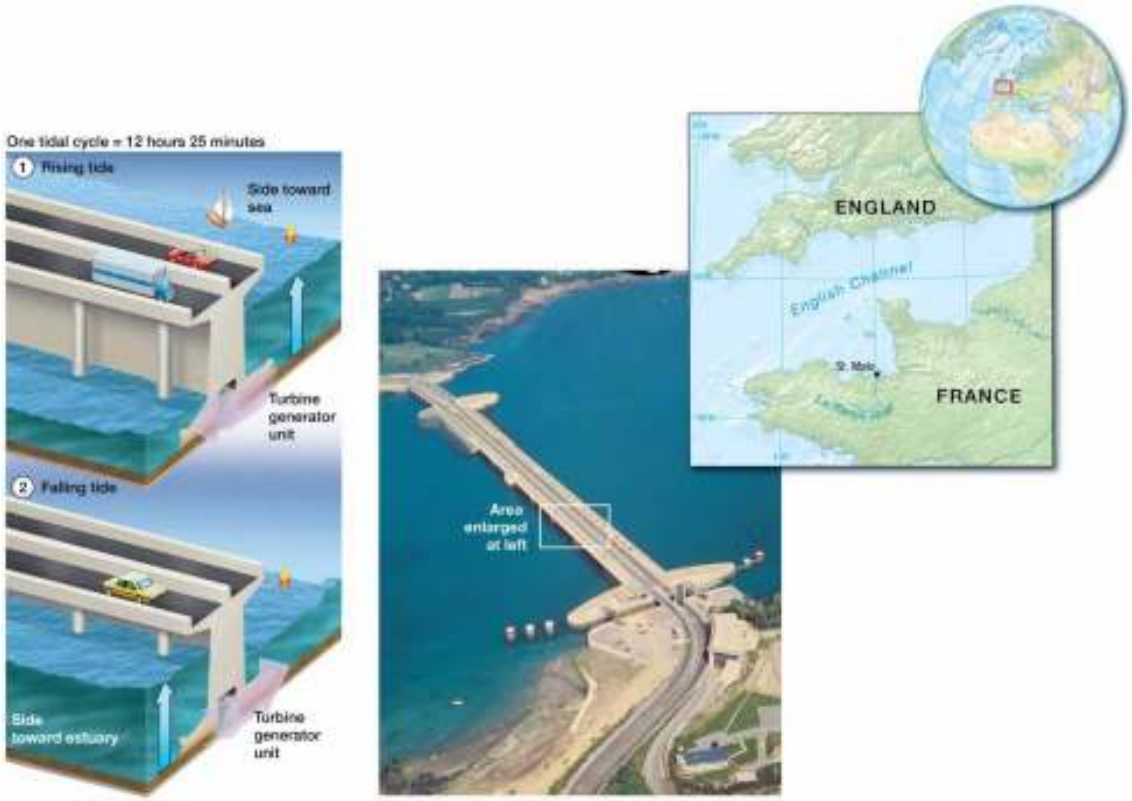
- Tides can be trapped one of 2 ways
  - Tidal water trapped behind coastal barriers in bays and estuaries turns electrical turbines
  - Tidal currents in narrow channels turn underwater turbines

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
- Potential usable tidal energy increases with increasing tidal range.



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Tides