CHAPTER 6
Air-Sea Interaction

Chapter Overview

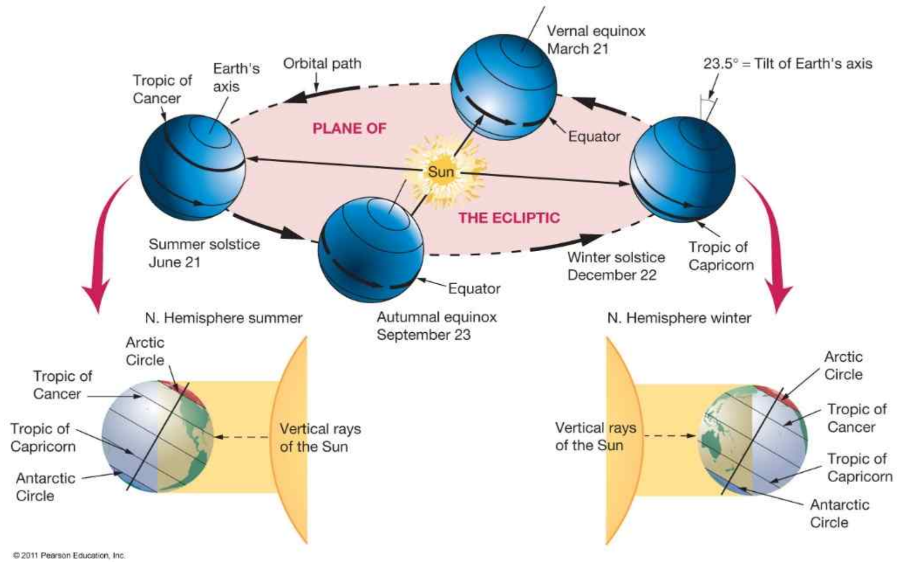
- The atmosphere and the ocean are one independent system.
- Earth has seasons because of the tilt on its axis.
- There are three major wind belts in each hemisphere.
- The coriolis effect influences atmosphere and ocean behavior.
- Oceanic climate patterns are related to solar energy distribution.

Earth's Seasons

- Earth's axis of rotation is tilted 23.5° with respect to ecliptic.
  - Ecliptic – plane traced by Earth's solar orbit
- Seasonal changes and Earth's rotation cause unequal solar heating of Earth's surface.

Seasons

- Tilt responsible for seasons
  - Vernal (spring) equinox
  - Summer solstice
  - Autumnal equinox
  - Winter solstice

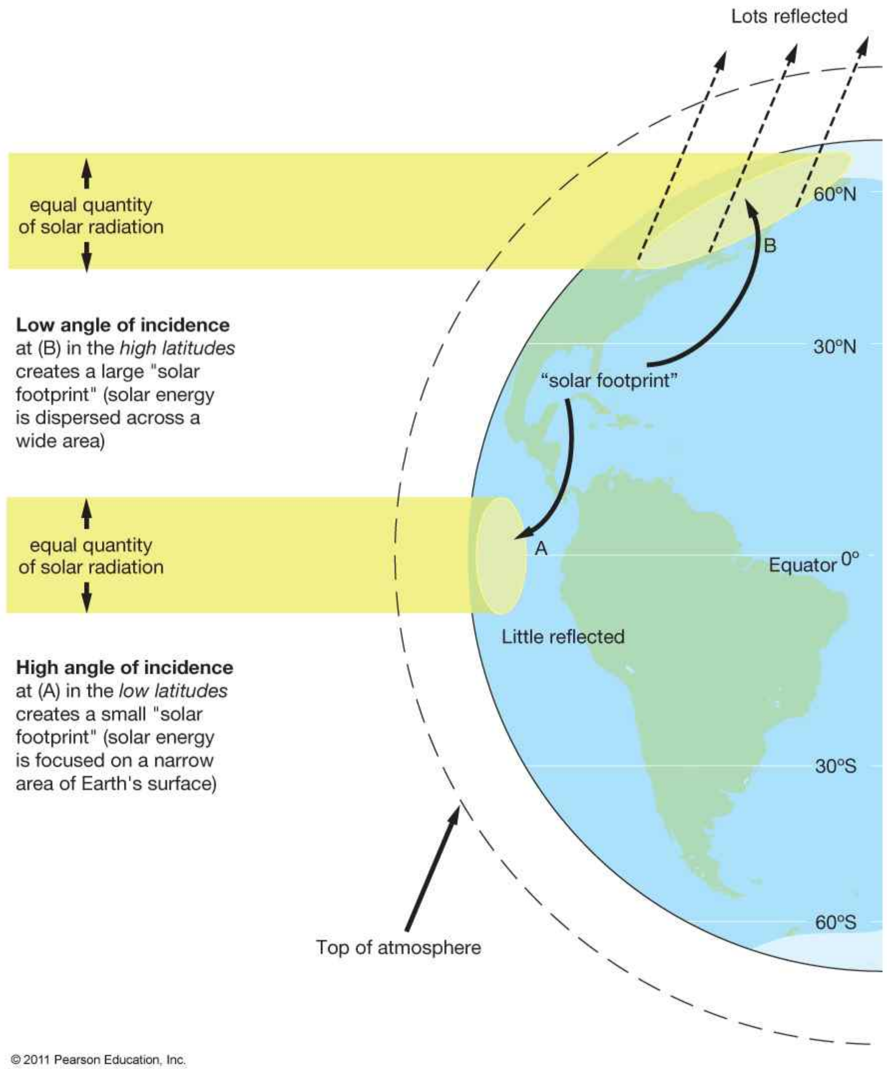


Solar Energy on Earth

- Declination – angular distance of Sun from equatorial plane
  - Varies between 23.5° North and 23.5° South latitudes
  - Tropics
- Arctic Circle – 66.5° North latitude
- Antarctic Circle – 66.5° South latitude

Distribution of Solar Energy

- Concentrated solar radiation at low latitudes
  - High angle of incidence
- Solar radiation more diffuse at high latitudes
  - Low angle of incidence



Distribution of Solar Energy

- Atmosphere absorbs radiation
  - Thickness varies with latitude
- Albedo: 0–100%
  - Reflectivity of a surface
  - Average for Earth is 30%
- Angle of sun on sea surface

Sun Elevation and Solar Absorption

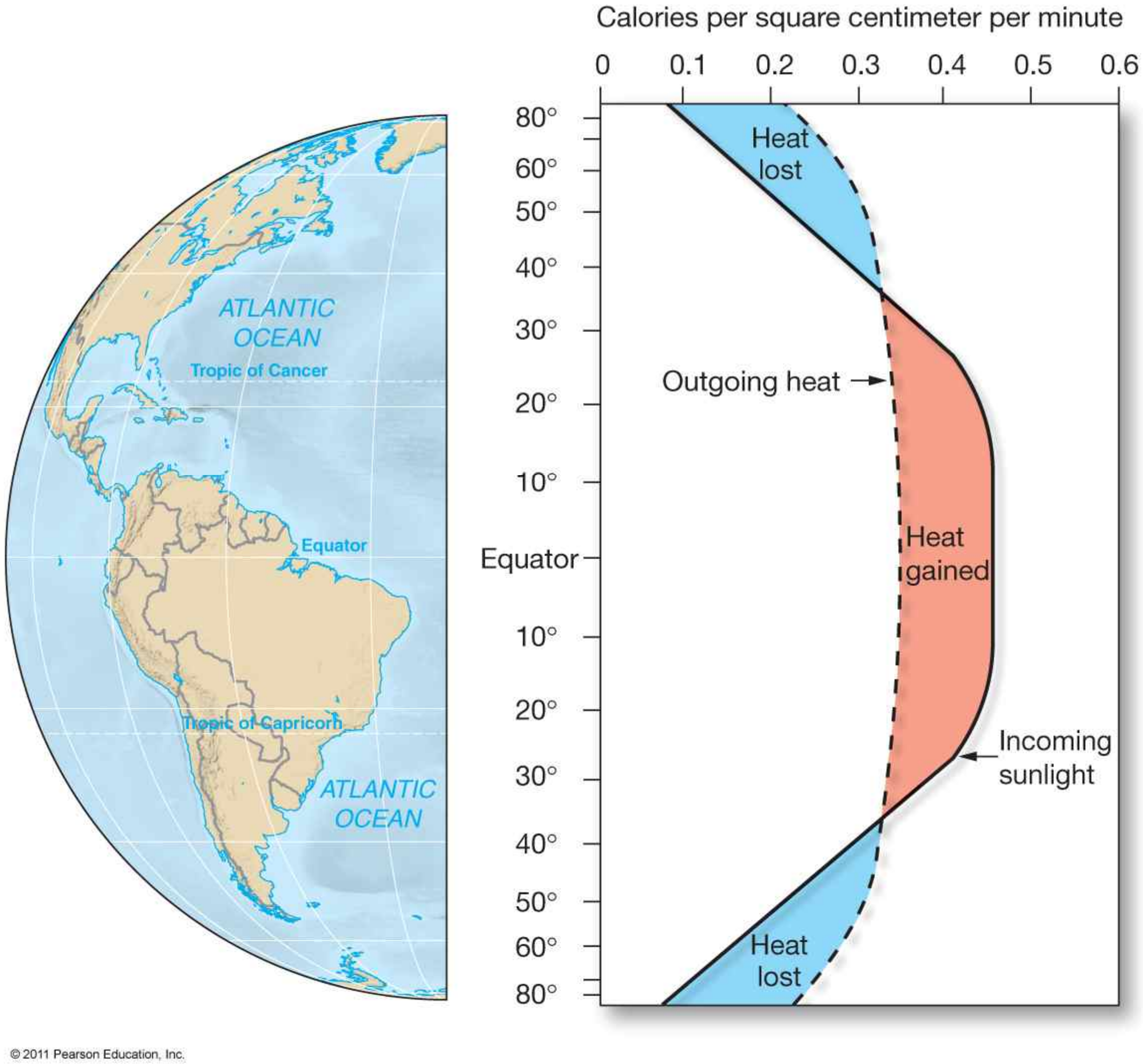
TABLE 6.1 REFLECTION AND ABSORPTION OF SOLAR ENERGY RELATIVE TO THE ANGLE OF INCIDENCE ON A FLAT SEA

Elevation of the Sun above the horizon	90°	60°	30°	15°	5°
Reflected radiation (%)	2	3	6	20	40
Absorbed radiation (%)	98	97	94	80	60

Oceanic Heat Flow

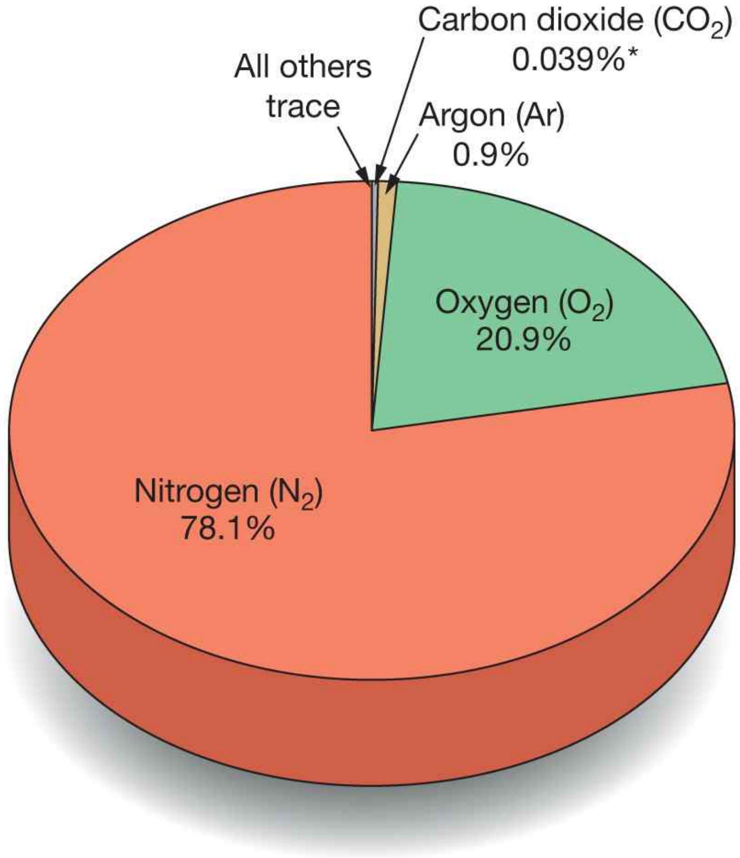
- High latitudes–more heat lost than gained
  - Ice has high albedo
  - Low solar ray incidence
- Low latitudes–more heat gained than lost

Heat Gained and Lost



Physical Properties of the Atmosphere

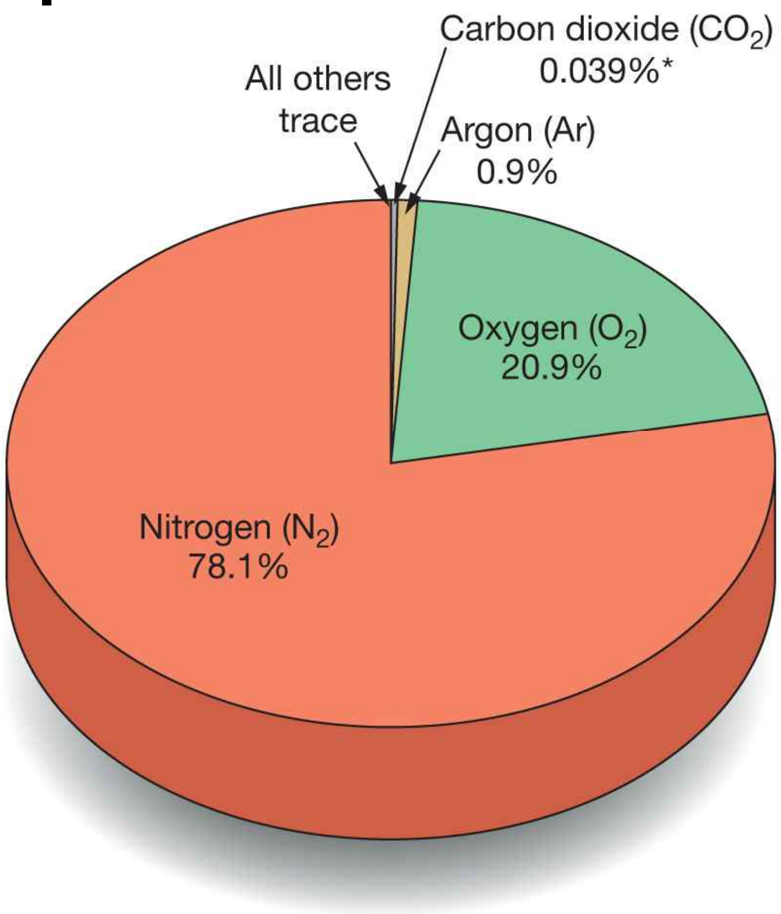
- Composition
- Mostly nitrogen (N_2) and Oxygen (O_2)
- Other gases significant for heat trapping properties



*Note that the concetration of carbon dioxide in the atmosphere is increasing by 0.5% per year due to human activities

Temperature Variation in the Atmosphere

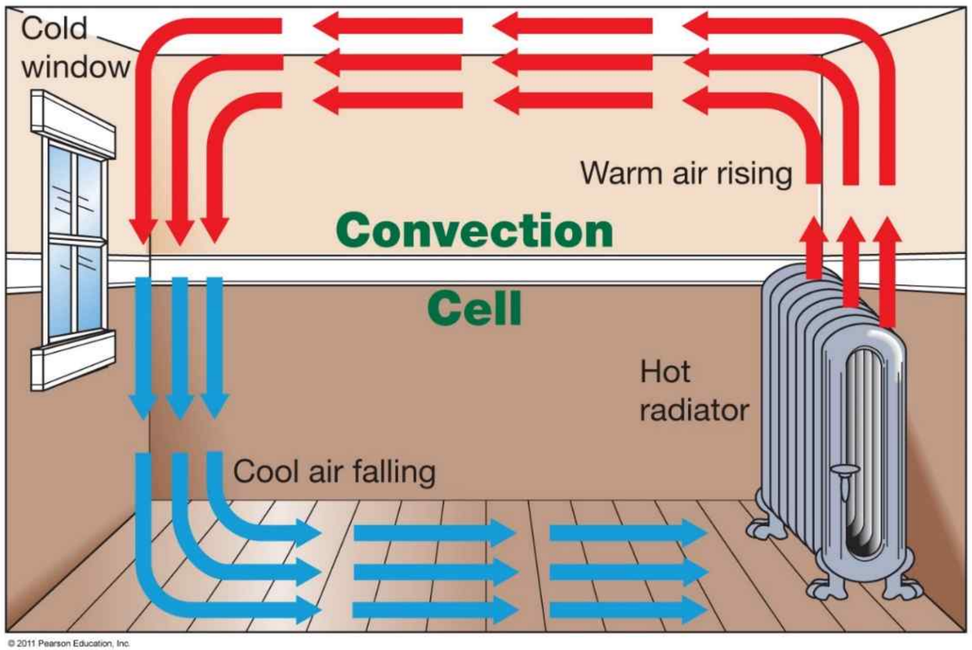
- Troposphere – lowest layer of atmosphere
  - Where all weather occurs
  - Temperature decreases with altitude



*Note that the concetration of carbon dioxide in the atmosphere is increasing by 0.5% per year due to human activities

Density Variations in the Atmosphere

- Convection cell – rising and sinking air
- Warm air rises
  - Less dense
- Cool air sinks
  - More dense
- Moist air (warm) rises
  - Less dense
- Dry air (cold) sinks
  - More dense

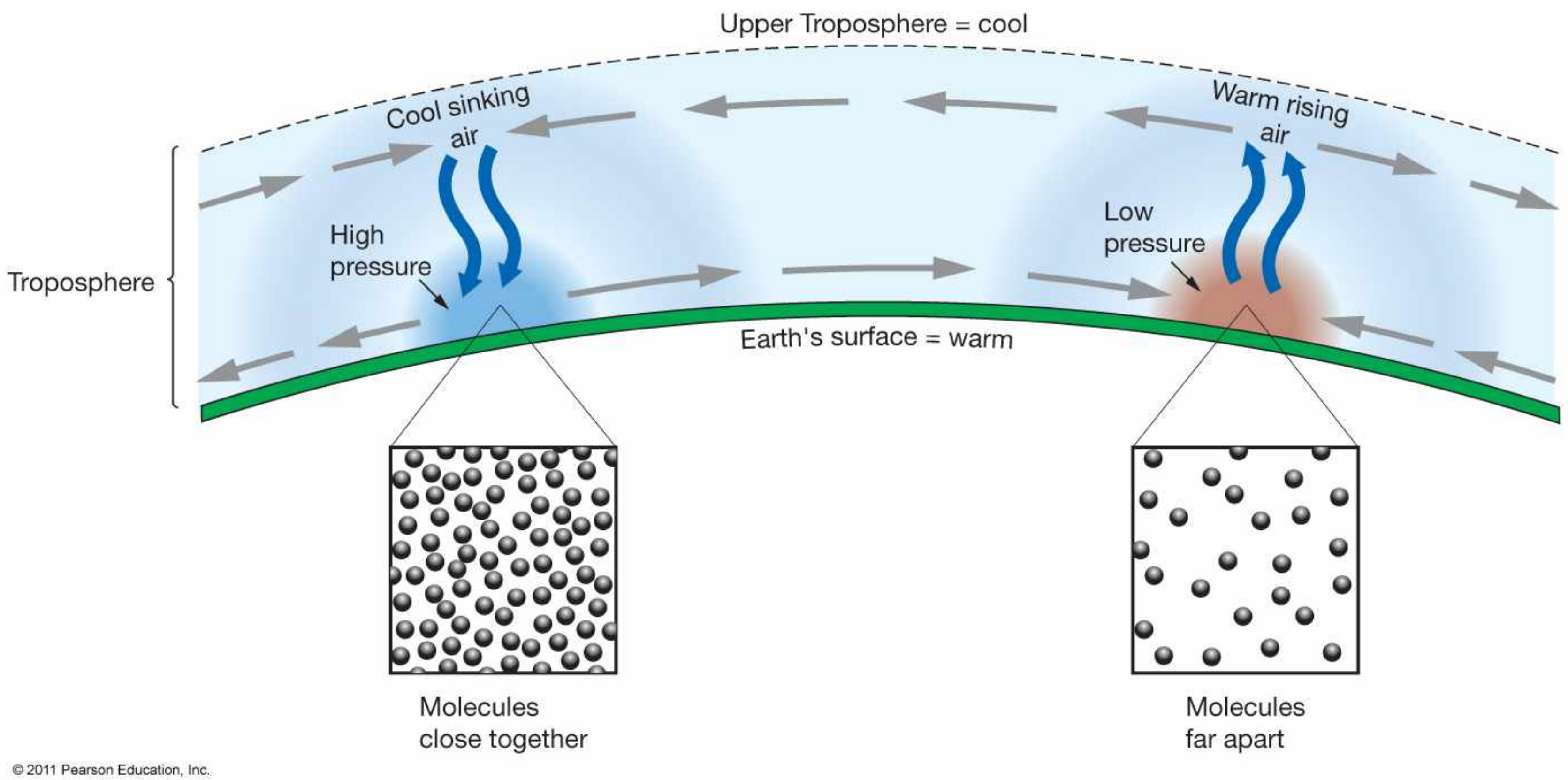


Atmospheric Pressure

- Thick column of air at sea level
  - High surface pressure equal to 1 atmosphere (14.7 pounds per square inch)
- Thin column of air means lower surface pressure
- Cool, dense air sinks
  - Higher surface pressure
- Warm, moist air rises
  - Lower surface pressure

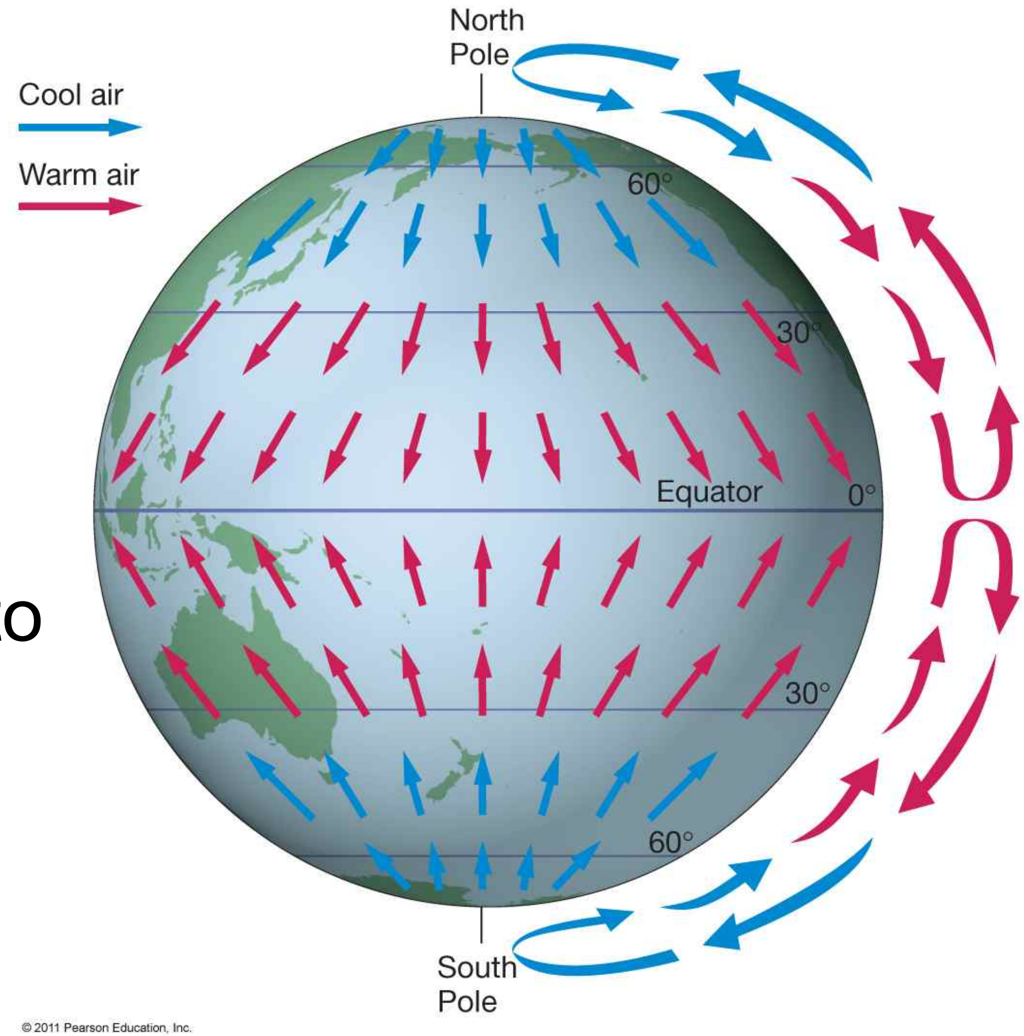
Movement of the Atmosphere

- Air *always* flows from high to low pressure.
- Wind – moving air



Movements in the Air

- Example: a non-rotating Earth
- Air rises at equator (low pressure)
- Air sinks at poles (high pressure)
- Air flows from high to low pressure
- One convection cell or circulation cell



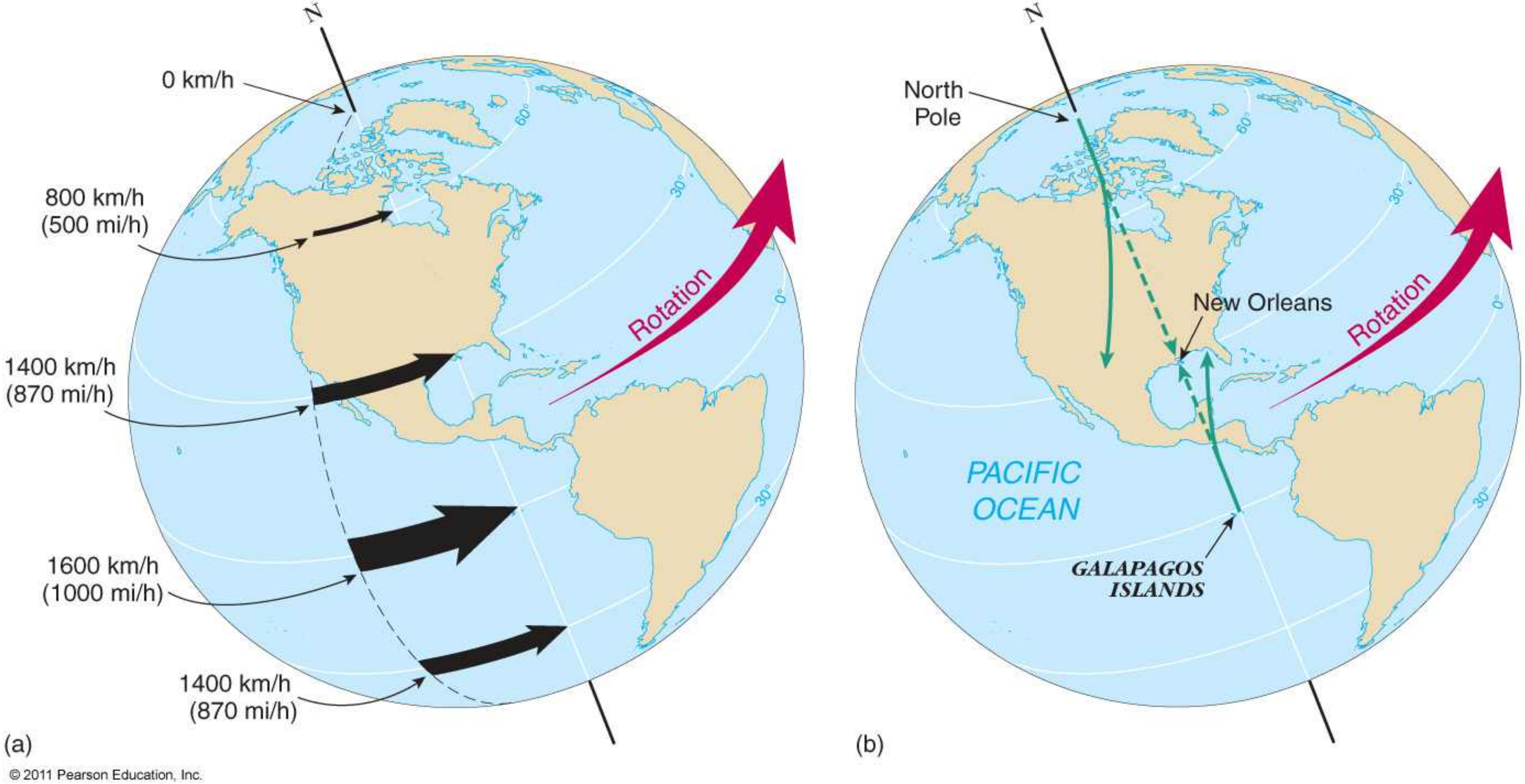
The Coriolis Effect

- Deflects path of moving object from viewer's perspective
  - To right in Northern Hemisphere
  - To left in Southern Hemisphere
- Due to Earth's rotation

The Coriolis Effect

- Zero at equator
- Greatest at poles
- Change in Earth's rotating velocity with latitude
  - 0 km/hour at poles
  - More than 1600 km/hour (1000 miles/hour) at equator (**How?**)
- Greatest effect on objects that move long distances across latitudes

The Coriolis Effect



Global Atmospheric Circulation

- Circulation Cells – one in each hemisphere
  - Hadley Cell: 0–30 degrees latitude
  - Ferrel Cell: 30–60 degrees latitude
  - Polar Cell: 60–90 degrees latitude

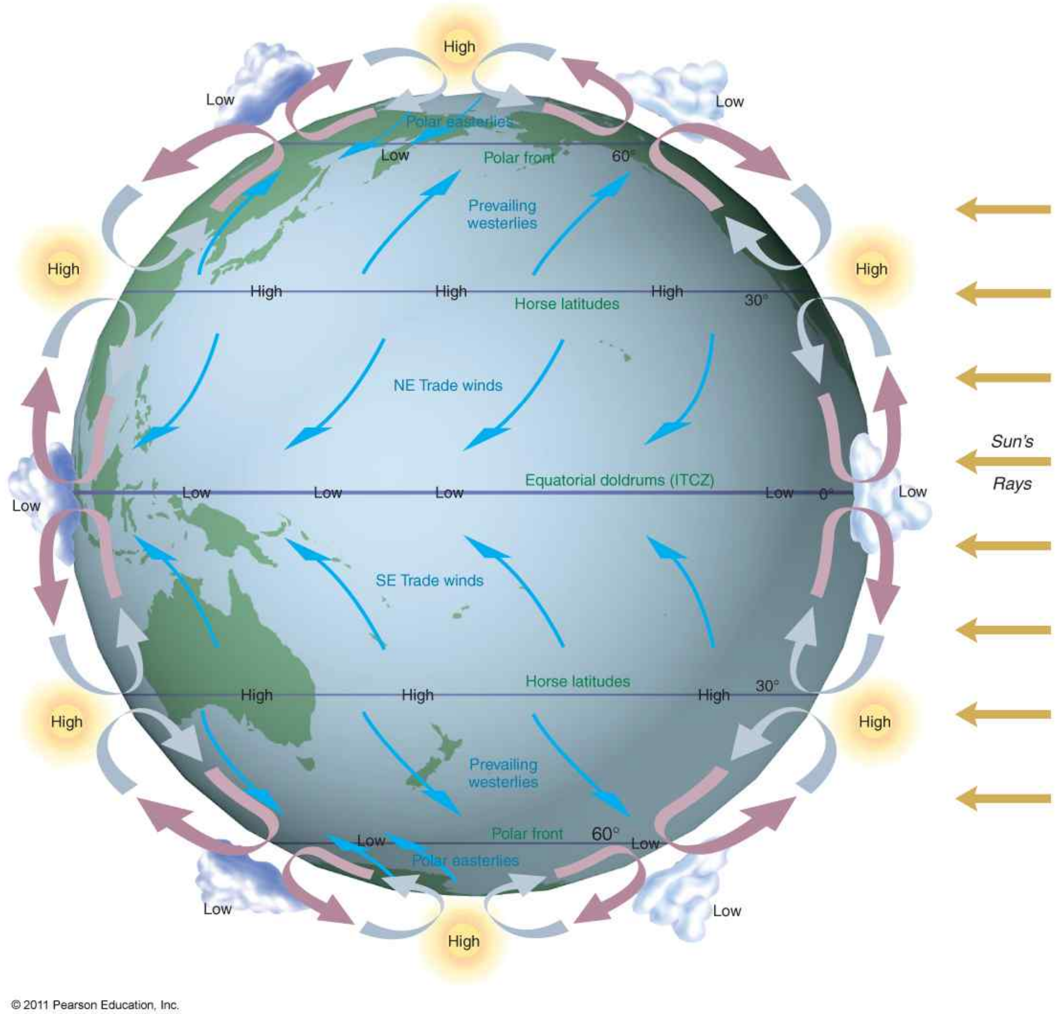
Global Atmospheric Circulation

- High pressure zones – descending air
  - Subtropical highs – 30 degrees latitude
  - Polar highs –90 degrees latitude
  - Clear skies
- Around 30 deg north and south latitude, the air cools off enough to become denser than the surrounding air.
- So it begins to descend, completing the loop.

Global Atmospheric Circulation

- Low pressure zones – rising air
  - Equatorial low – equator
  - Subpolar lows – 60 degrees latitude
  - Overcast skies with lots of precipitation

Three-Cell Model of Atmospheric Circulation



Global Wind Belts

- Trade winds – From subtropical highs to equator
  - Northeast trades in Northern Hemisphere
  - Southeast trades in Southern Hemisphere
- Prevailing westerlies – from 30–60 degrees latitude
- Polar easterlies – 60–90 degrees latitude

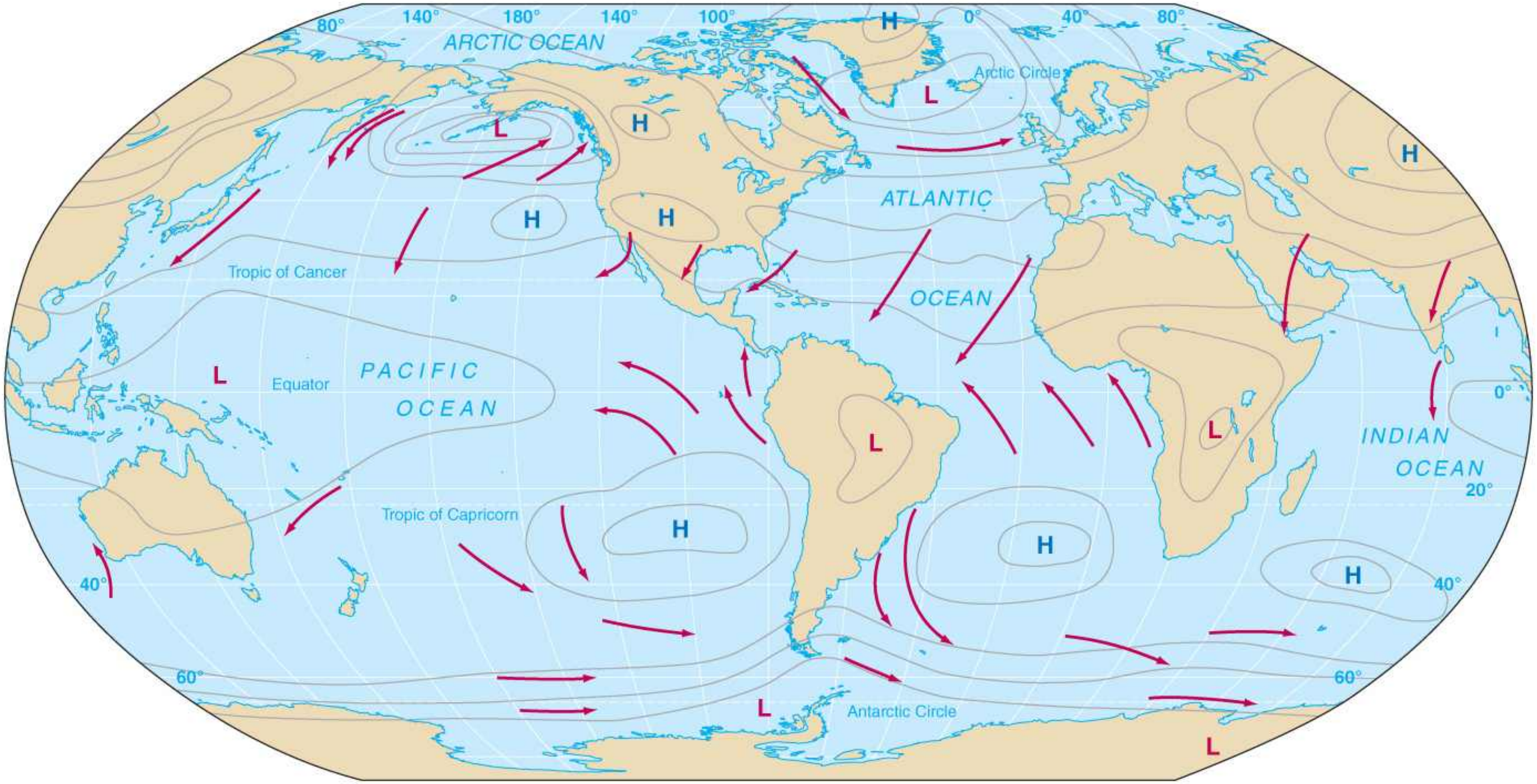
Global Wind Belts

- Boundaries between wind belts
  - Doldrums or Intertropical Convergence Zone (ITCZ) – at equator
  - Horse latitudes – 30 degrees
  - Polar fronts – 60 degrees latitude

Idealized Three-Cell Model

- More complex in reality due to
  - Seasonal changes
  - Distribution of continents and ocean
  - Differences in heat capacity between continents and ocean
    - Monsoon winds

January Atmospheric Pressures and Winds

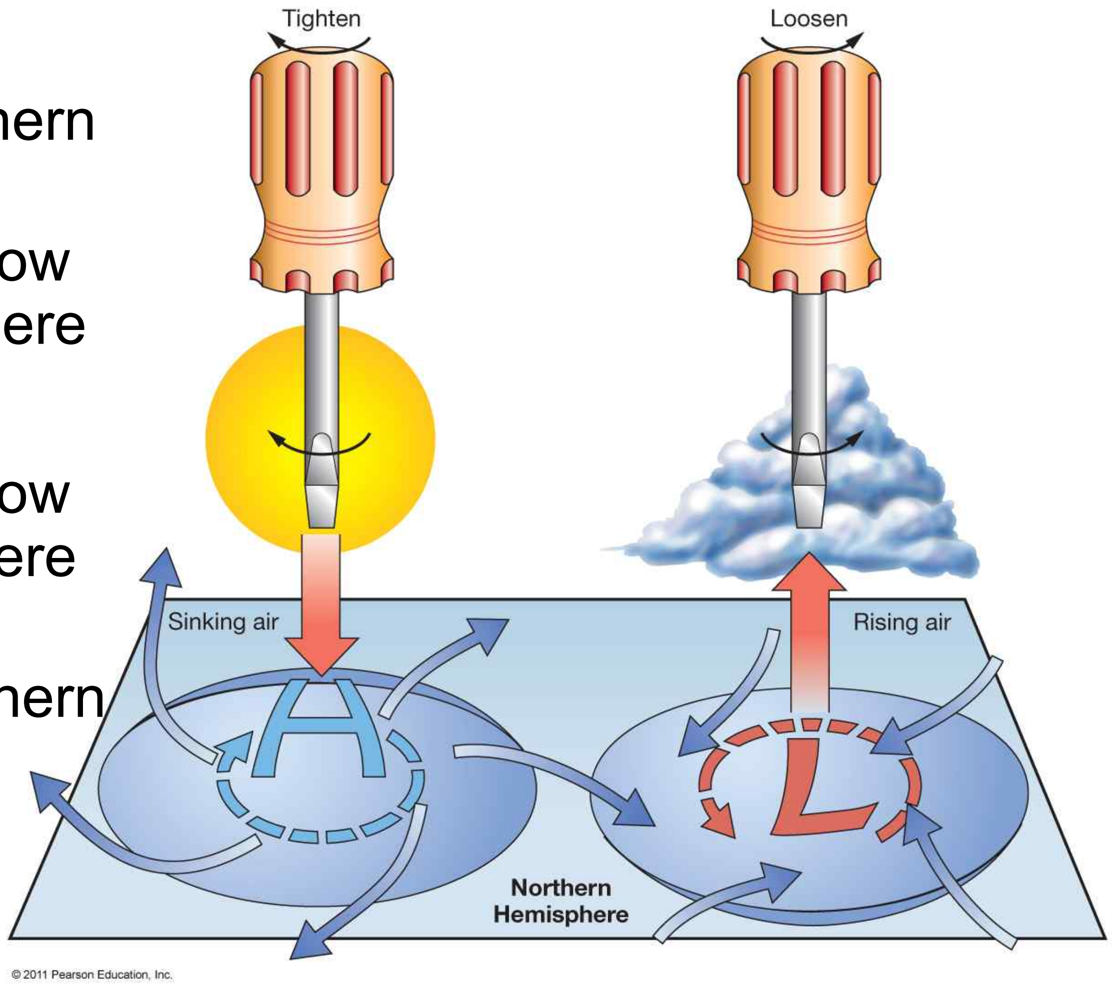


Weather vs. Climate

- Weather – conditions of atmosphere at particular time and place
- Climate – long-term average of weather
- Ocean influences Earth's weather and climate patterns.

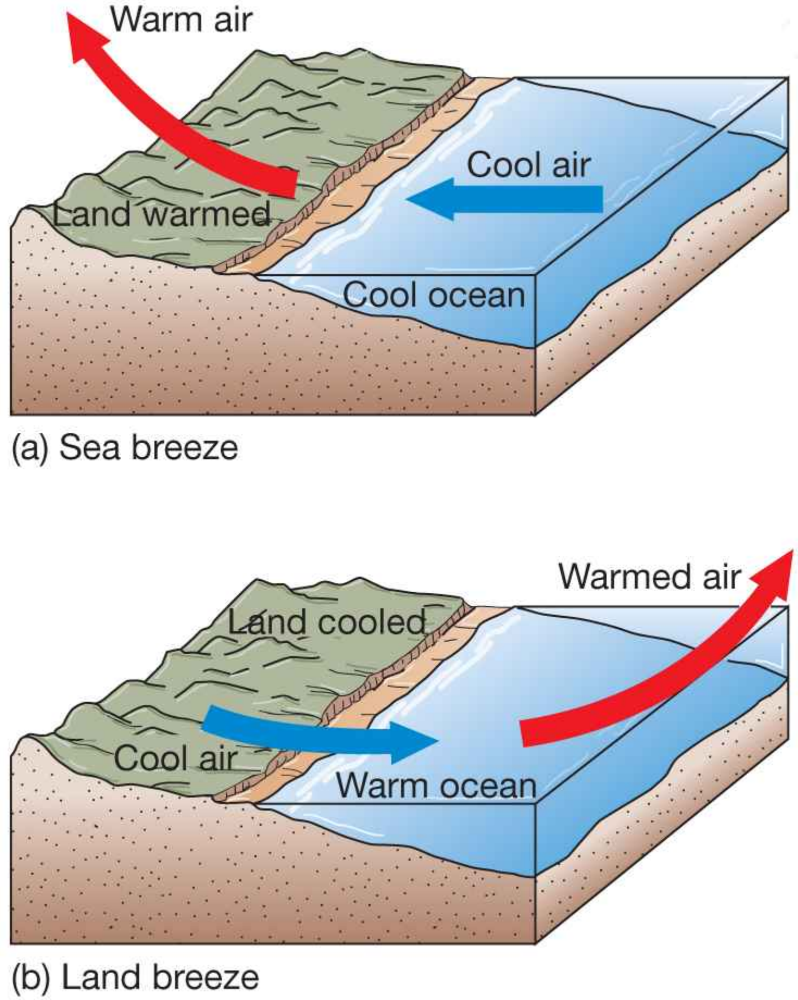
Winds

- Cyclonic flow
  - Counterclockwise around a low in Northern Hemisphere
  - Clockwise around a low in Southern Hemisphere
- Anticyclonic flow
  - Clockwise around a low in Northern Hemisphere
  - Counterclockwise around a low in Southern Hemisphere



Sea and Land Breezes

- Differential solar heating is due to different heat capacities of land and water.
- Sea breeze
  - From ocean to land
- Land breeze
  - From land to ocean

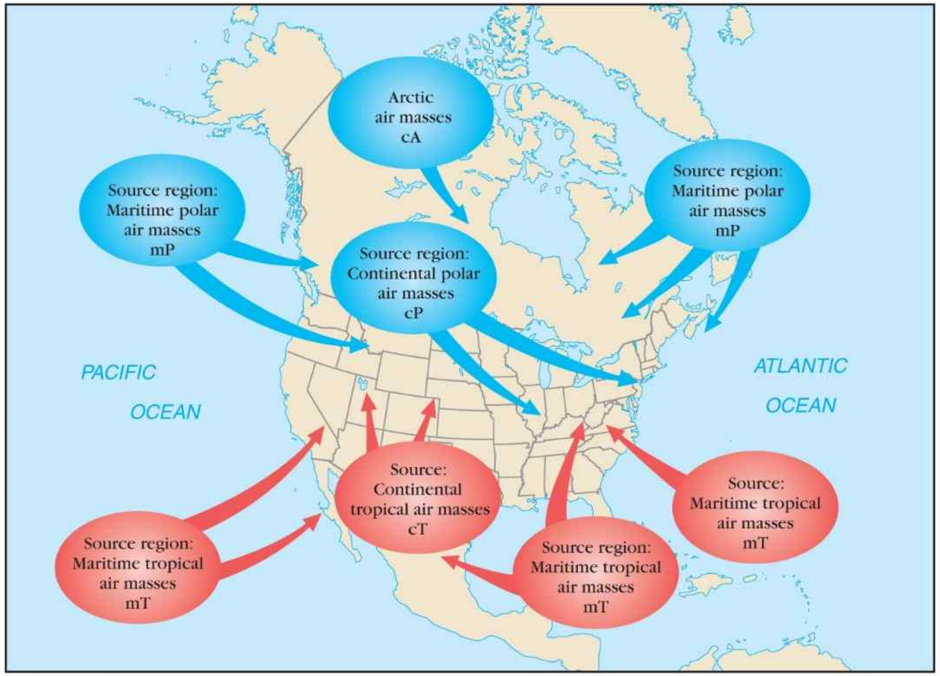


(a) Sea breeze

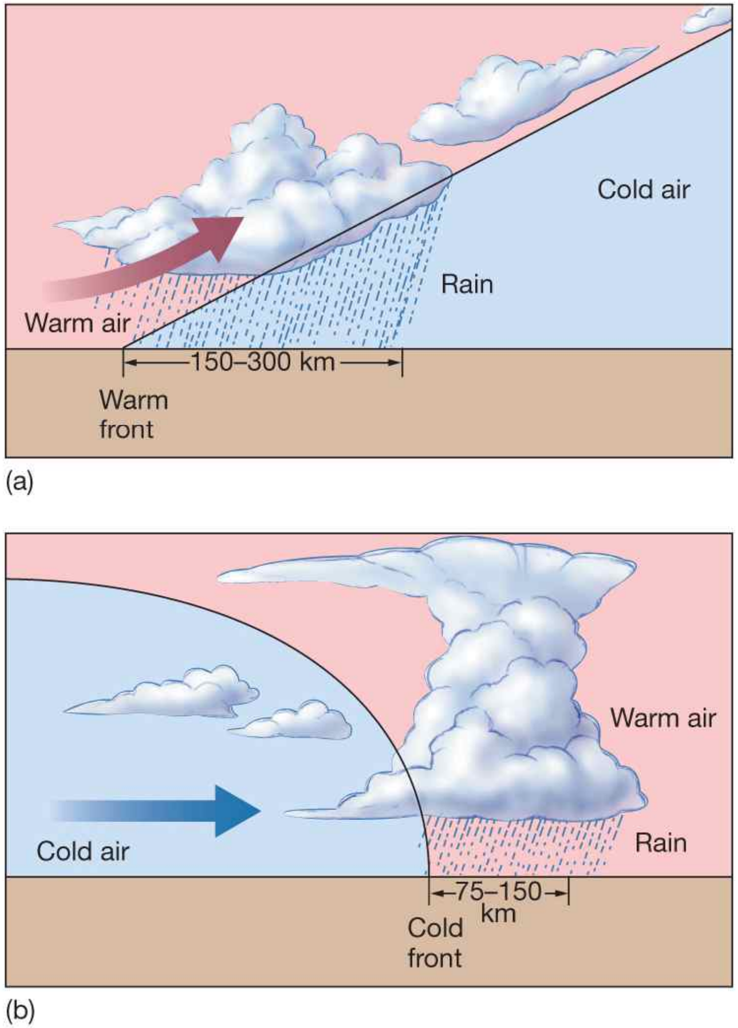
(b) Land breeze

Storms and Air Masses

- Storms – disturbances with strong winds and precipitation
- Air masses – large volumes of air with distinct properties



Fronts



- Fronts – boundaries between air masses
  - Warm front
  - Cold front
- Storms typically develop at fronts.
- Jet Stream – may cause unusual weather by steering air masses.

Tropical Cyclones (Hurricanes)

- Large rotating masses of low pressure
- Strong winds, torrential rain
- Classified by maximum sustained wind speed
- Typhoons (called in the Pacific)
- Cyclones (called in the Indian)

Hurricane Origins

- Low pressure cell
- Winds feed water vapor – latent heat of condensation
- Air rises, low pressure deepens
- Storm develops
  - Winds less than 61 km/hour (38 miles/hour) – tropical depression
  - Winds 61–120 km/hour (38–74 miles/hour) – tropical storm
  - Winds above 120 km/hour (74 miles/hour) – tropical cyclone or hurricane

Hurricane Intensity

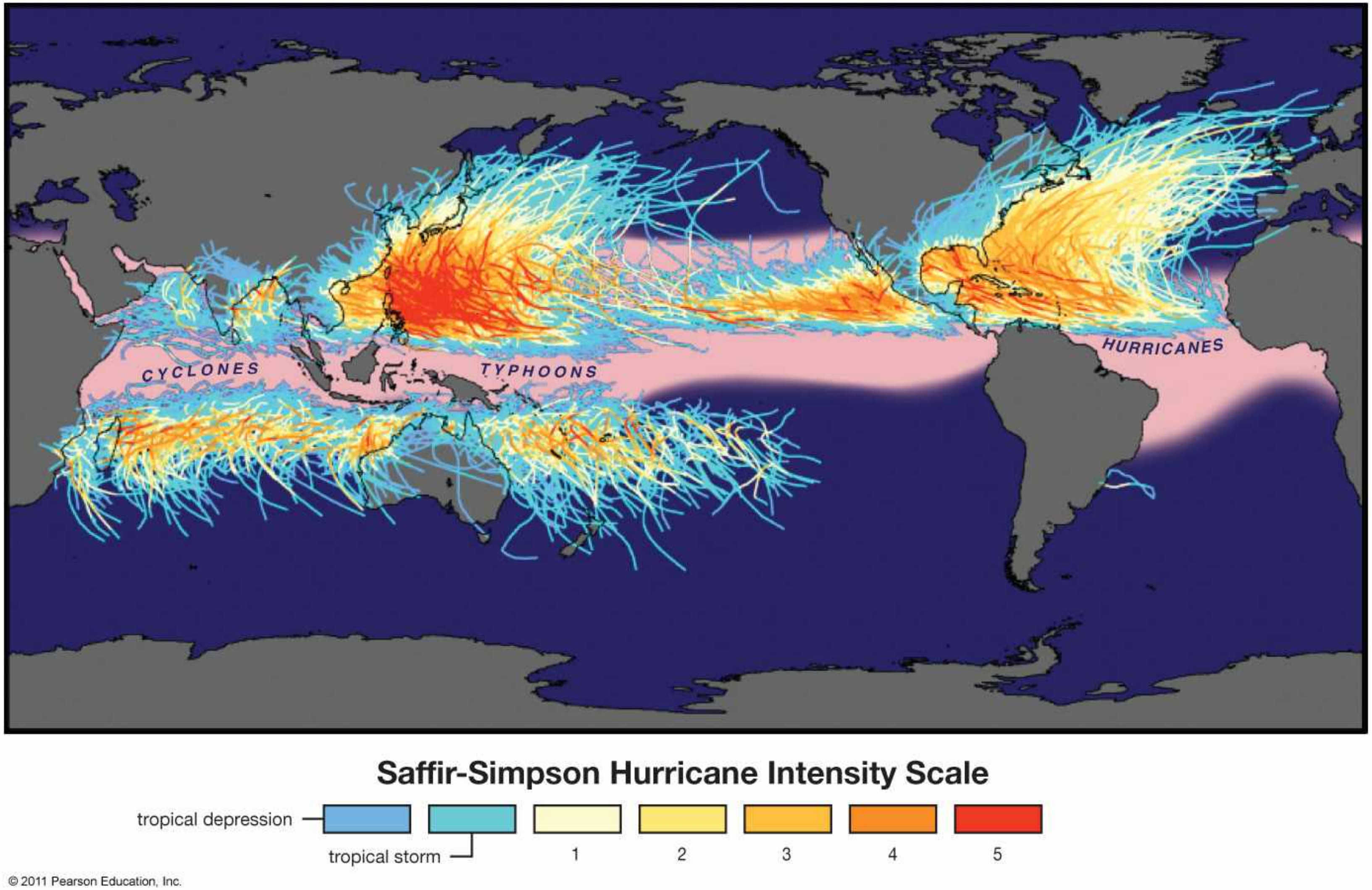
TABLE 6.3 THE SAFFIR-SIMPSON SCALE OF HURRICANE INTENSITY

Category	Wind speed (km/hr)	Wind speed (mi/hr)	Typical storm surge (sea level height above normal) (meters)	Typical storm surge (sea level height above normal) (feet)	Damage
1	120–153	74–95	1.2–1.5	4–5	Minimal: Minor damage to buildings
2	154–177	96–110	1.8–2.4	6–8	Moderate: Some roofing material, door, and window damage; some trees blown down
3	178–209	111–130	2.7–3.7	9–12	Extensive: Some structural damage and wall failures; foliage blown off trees and large trees blown down
4	210–249	131–155	4.0–5.5	13–18	Extreme: More extensive structural damage and wall failures; most shrubs, trees, and signs blown down
5	>250	>155	>5.8	>19	Catastrophic: Complete roof failures and entire building failures common; all shrubs, trees, and signs blown down; flooding of lower floors of coastal structures

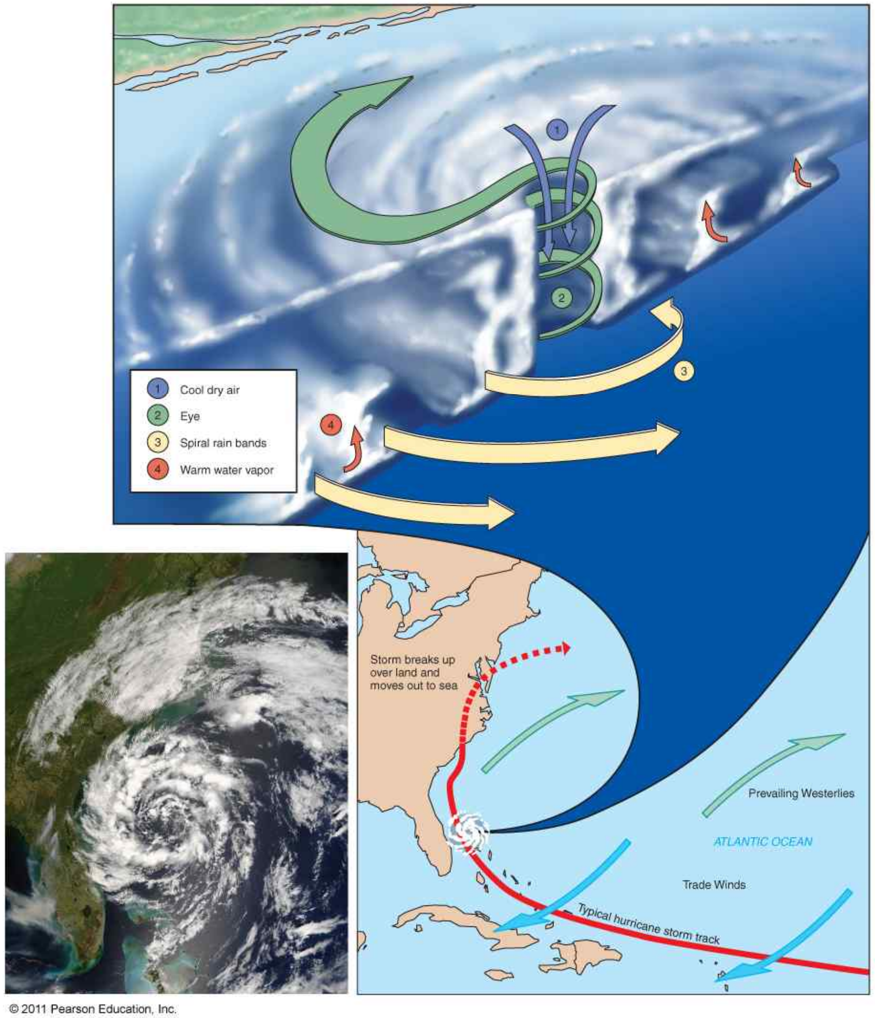
Hurricanes

- About 100 worldwide per year
- Require
  - Ocean water warmer than° 25°C (77°F)
  - Warm, moist air
  - The Coriolis Effect
- Hurricane season is June 1 – November 30

Historical Storm Tracks

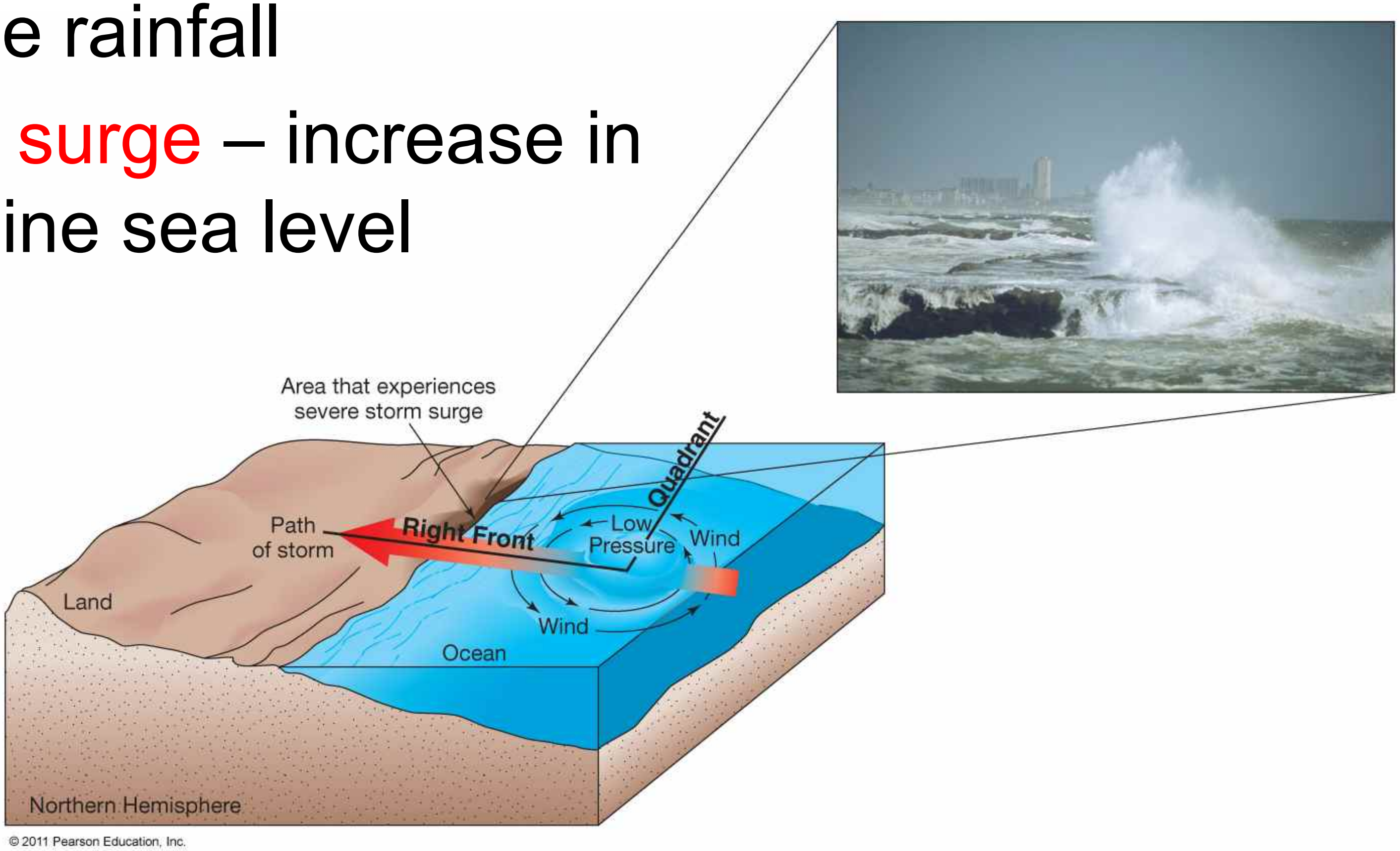


Hurricane Anatomy and Movement



Hurricane Destruction

- High winds
- Intense rainfall
- Storm surge – increase in shoreline sea level



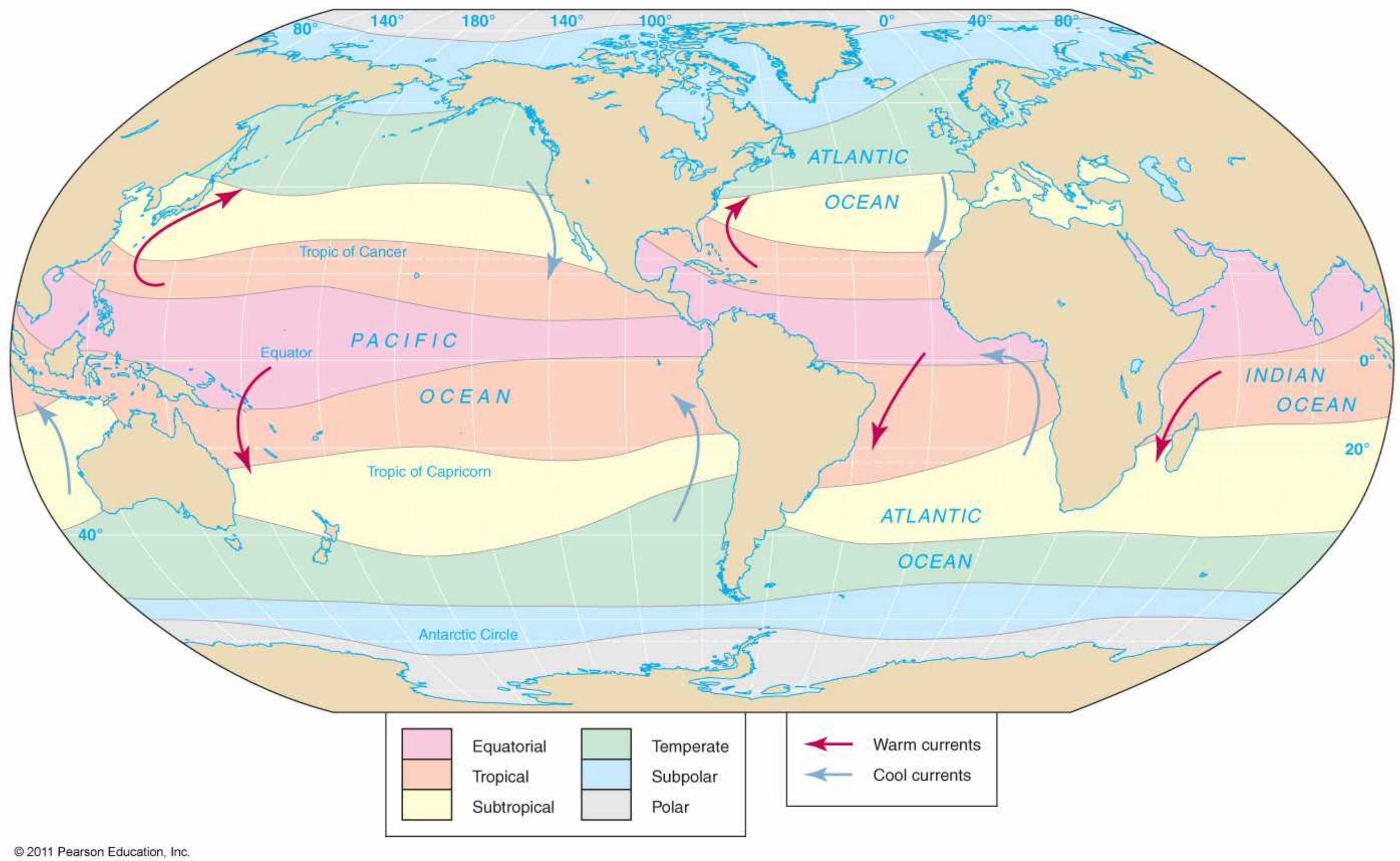
Storm Destruction

- Historically destructive storms
  - Galveston, TX, 1900
  - Andrew, 1992
  - Mitch, 1998
  - Katrina, 2005
  - Ike, 2008

Ocean's Climate Patterns

- Open ocean's climate regions are parallel to latitude lines.
- These regions may be modified by surface ocean currents.

Ocean's Climate Patterns



Ocean's Climate Zones

- Equatorial
  - Rising air
  - Weak winds
  - Doldrums
- Tropical
  - North and south of equatorial zone
  - Extend to Tropics of Cancer and Capricorn
  - Strong winds, little precipitation, rough seas
- Subtropical
  - High pressure, descending air
  - Weak winds, sluggish currents

Ocean’s Climate Zones

- Temperate
  - Strong westerly winds
  - Severe storms common
- Subpolar
  - Extensive precipitation
  - Summer sea ice
- Polar
  - High pressure
  - Sea ice most of the year

Sea Ice Formation

- Needle like crystals
- Become slush
- Slush becomes pancake ice
- Pancakes coalesce to ice floes
- Rate of formation depends on temperature
- Self-perpetuating

(a)

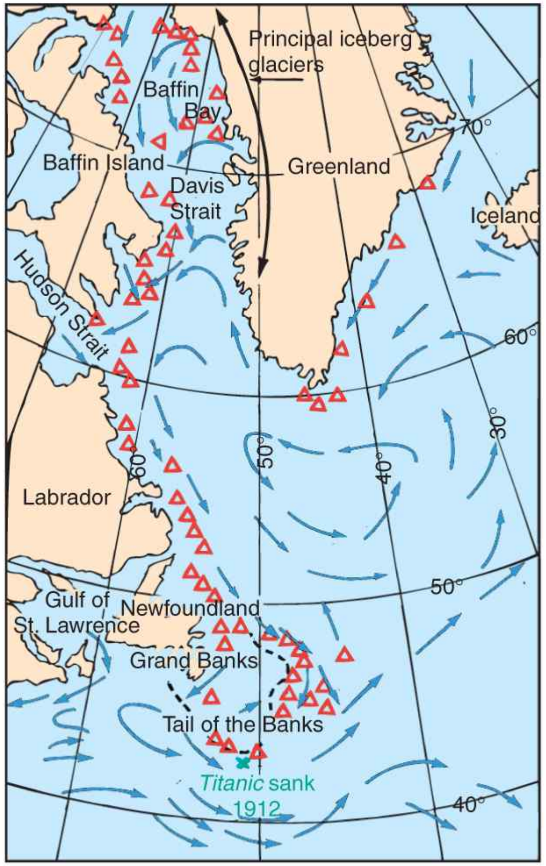
Sea Ice

(b)

Iceberg Formation

- Icebergs break off of glaciers.

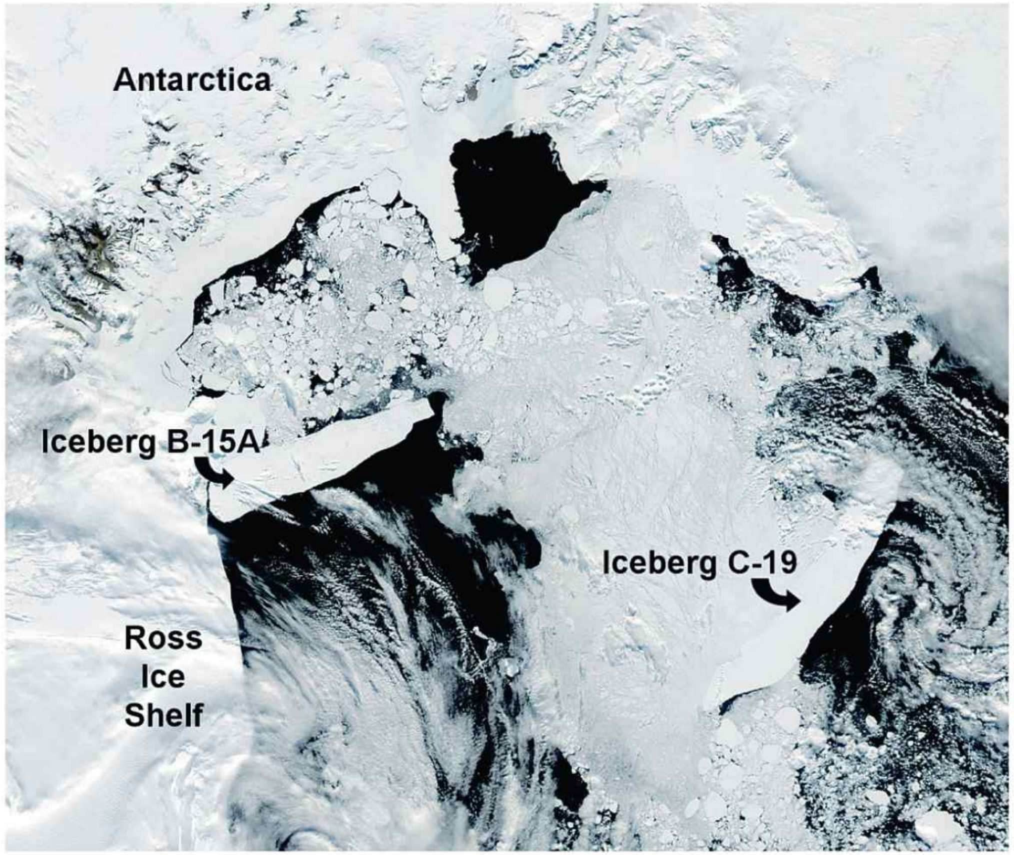
(a)



(b)

Shelf Ice

- Antarctica – glaciers cover continent
  - Edges break off



(d)

Wind Power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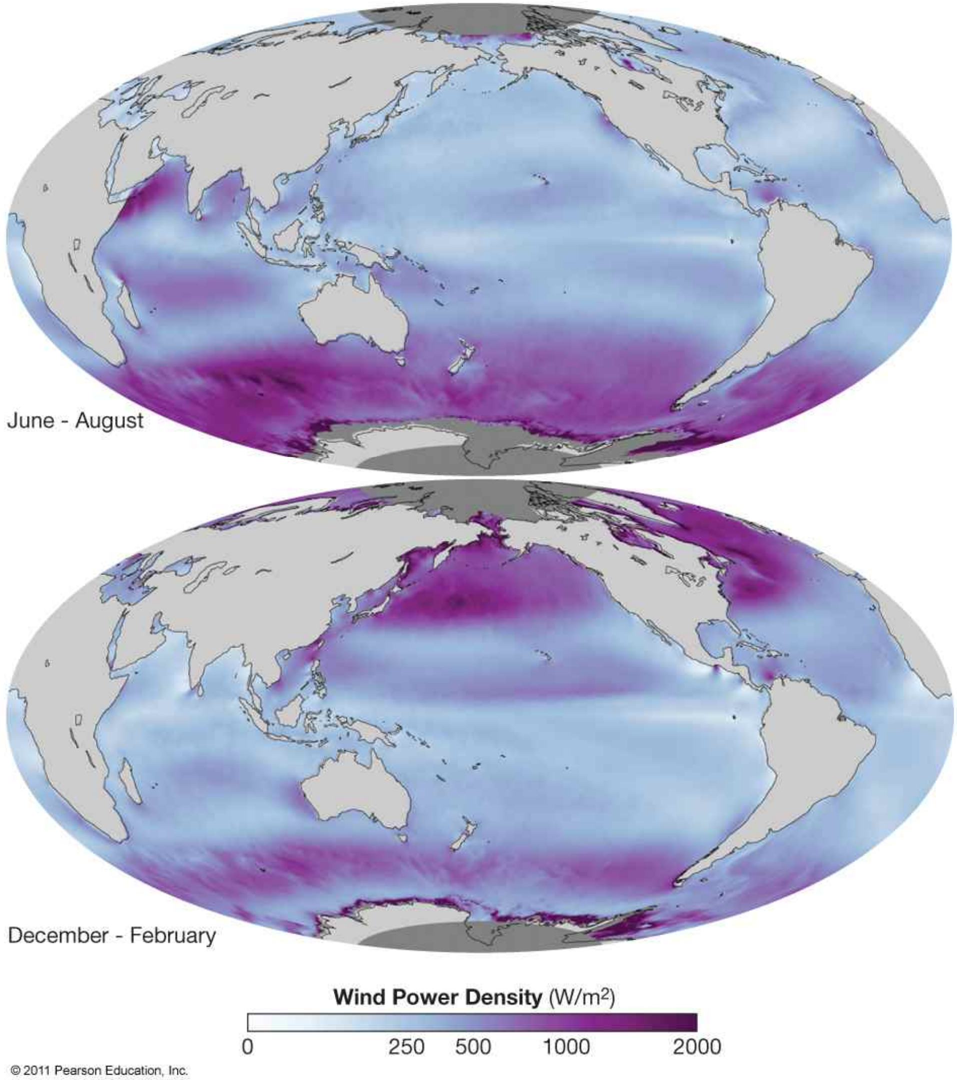
- Uneven solar heating of Earth generates winds
- Turbines harness wind energy
- Offshore wind farms generate electricity

Global Ocean Wind Energy



Greenhouse effect

- Energy from Sun shorter wavelengths
- Energy reradiated from Earth longer wavelengths

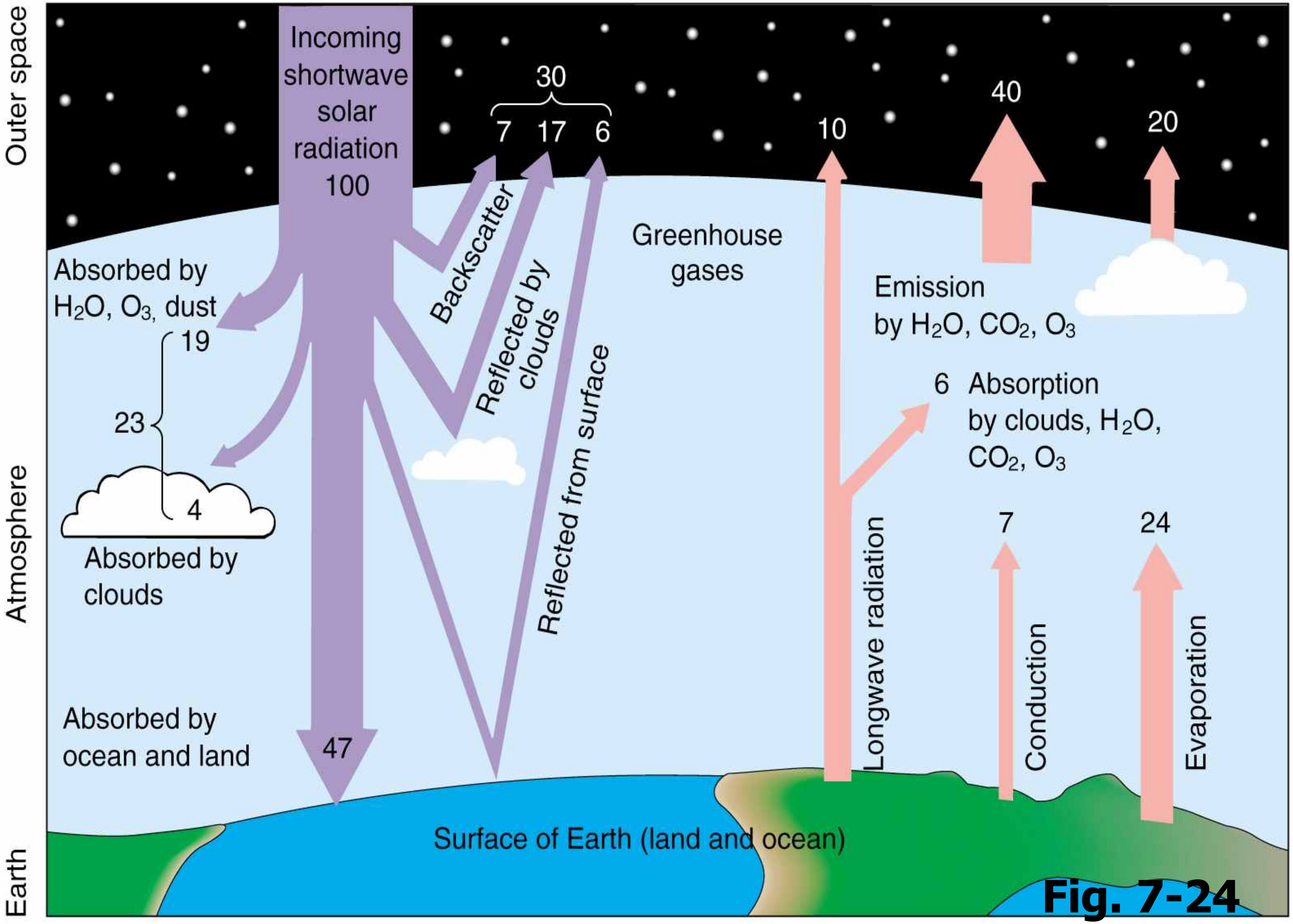
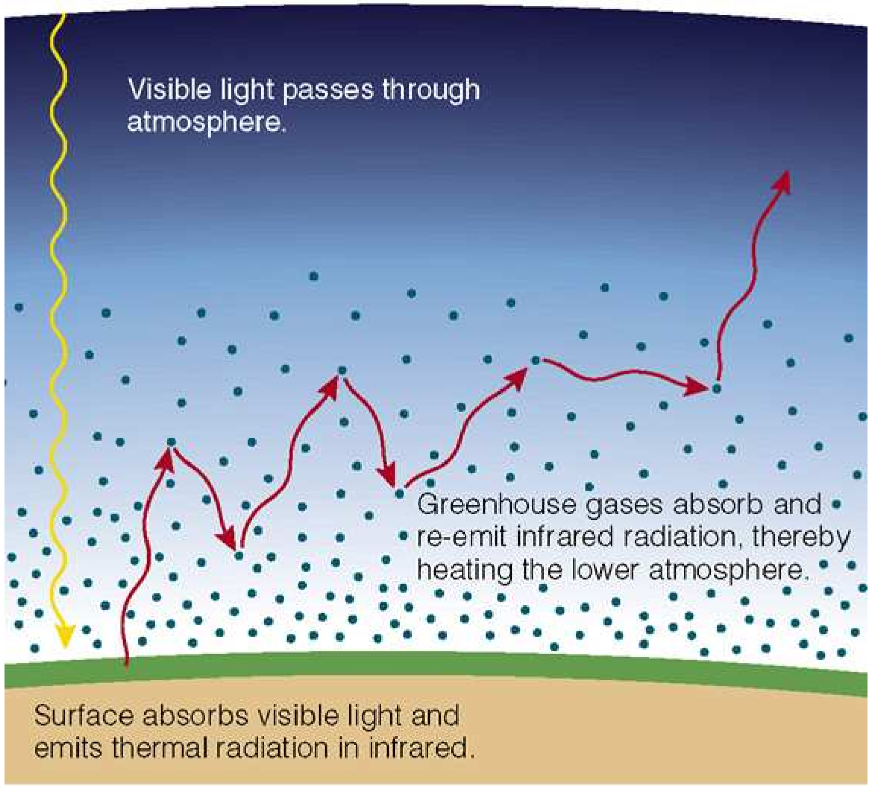

Outer space
Atmosphere
Earth
Incoming shortwave solar radiation 100
30
7 17 6
Backscatter
Reflected by clouds
Reflected from surface
Absorbed by H2O, O3, dust
19
23
4
Absorbed by clouds
Absorbed by ocean and land
47
Greenhouse gases
10
40
20
Emission by H2O, CO2, O3
6 Absorption by clouds, H2O, CO2, O3
7
24
Longwave radiation
Conduction
Evaporation
Surface of Earth (land and ocean)

Fig. 7-24

The Greenhouse Effect on Earth

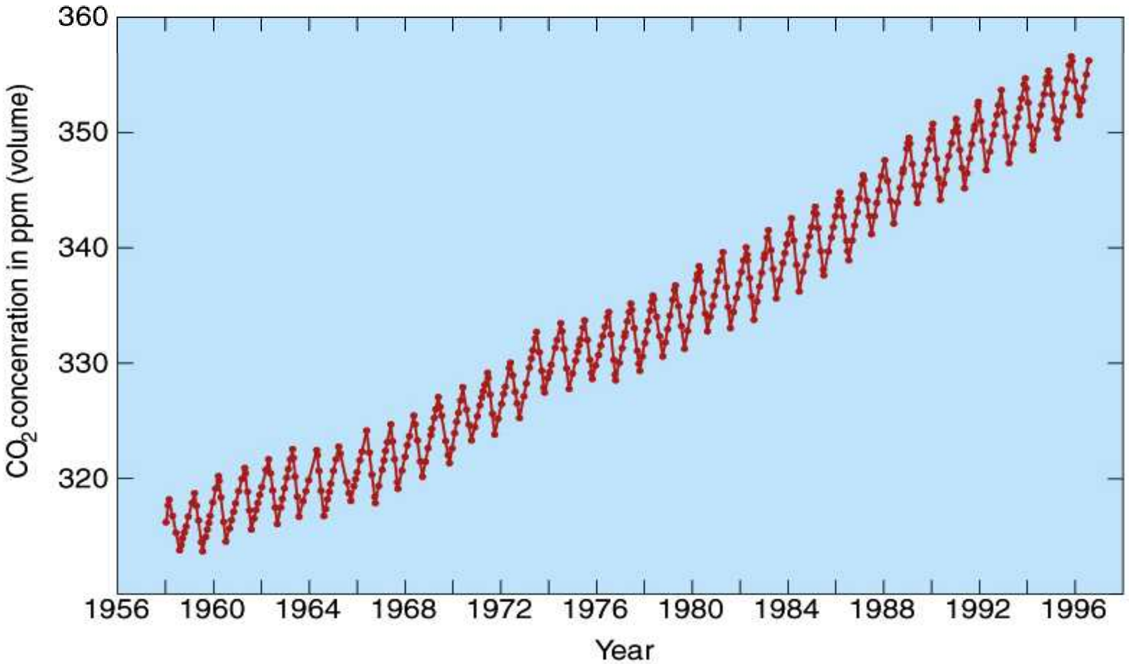
Earth's atmosphere is slightly warmer than what it should be due to direct solar heating because of a ***mild case of greenhouse effect…***

- The ground is heated by visible and (some) infrared light from the Sun.
- The heated surface emits infrared light.
- The majority of Earth's atmosphere (N_2 and O_2) are not good greenhouse gas.
- The small amount of greenhouse gases (H_2O, CO_2) traps (absorb and re-emit) the infrared radiation, increasing the temperature of the atmosphere…



Greenhouse gases

- Absorb infrared radiation from Earth
- Mainly H_2O and CO_2



Other greenhouse gases

- Minor gases: methane, nitrous oxides, ozone, chlorofluorocarbons
- Anthropogenic sources of greenhouse gases contribute to global warming
  - Increase in global temperature
  - Some natural
  - Most artificial

CO_2 in oceans

- CO_2 high solubility in seawater
- Excess CO_2 in atmosphere locked up in oceans
  - $CaCO_3$ biogenic sediments
- Stimulate growth of phytoplankton to use up CO_2 in ocean

End of CHAPTER 6
Air-Sea Interaction