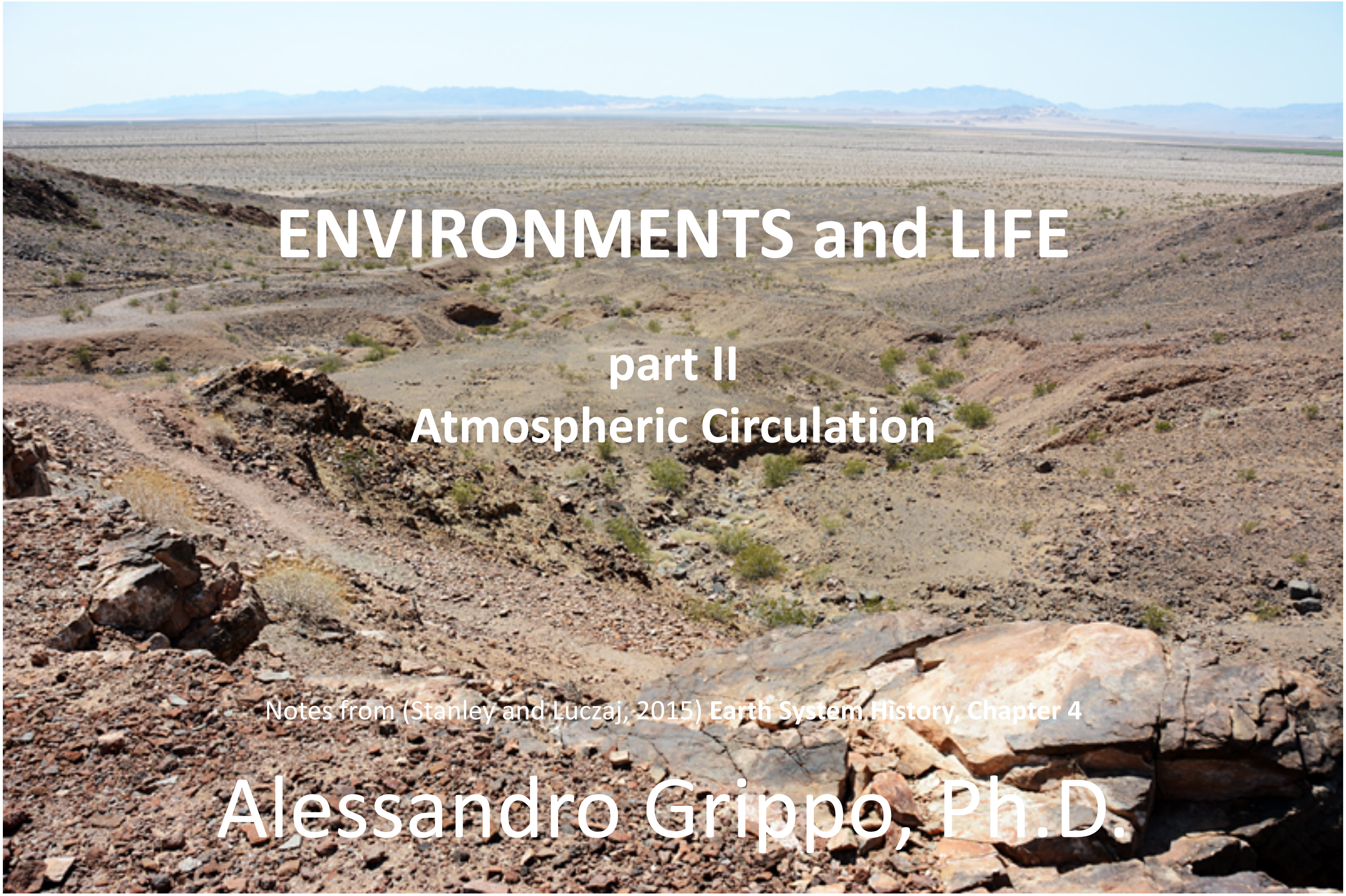


ENVIRONMENTS and LIFE

part II
Atmospheric Circulation

Notes from (Stanley and Luczaj, 2015) **Earth System History, Chapter 4**

Alessandro Grippo, Ph.D.

The dry surface of the Mojave Desert in Cadiz, San Bernardino County, California

Introduction

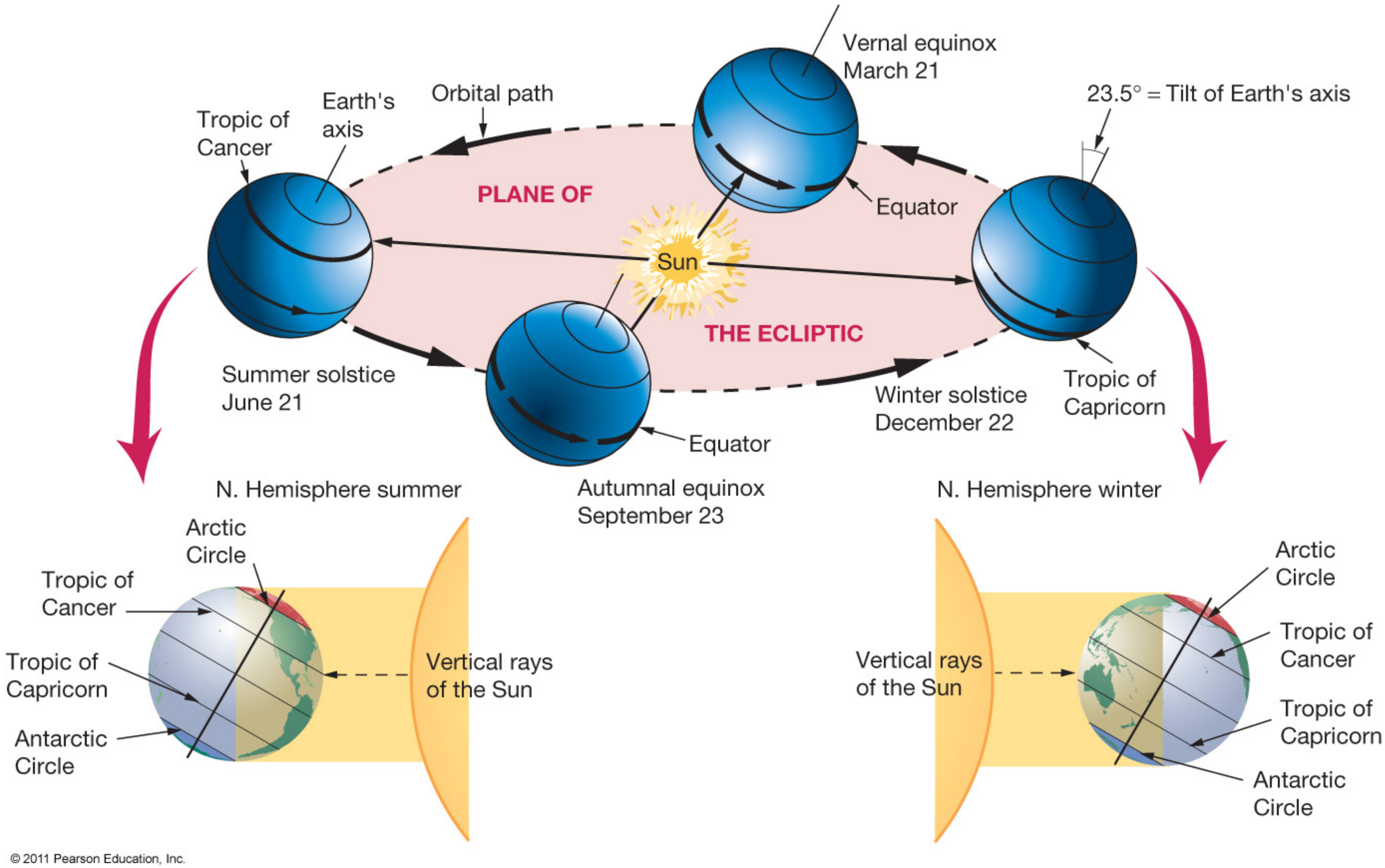
- The atmosphere and the ocean are one interdependent system
- There are complex feedbacks between the atmosphere and the ocean
- Energy from the Sun varies over time
- Energy from the Sun creates winds
- Winds create waves and ocean surface currents

Temperature variations and Earth's rotation govern circulation in the atmosphere

- Day/night cycles
- Seasons
  - Earth's seasons are NOT caused by its changing distance from the Sun
  - Earth's seasons are caused by the tilt of Earth's axis
  - Seasonal changes and Earth's rotation cause unequal solar heating of Earth's surface

- Earth's axis of rotation is tilted 23.5° with respect to the ecliptic
  - The ecliptic is the plane traced by Earth's solar orbit

- Vernal (spring) equinox
- Summer solstice
- Autumnal equinox
- Winter solstice



- Declination – angular distance of Sun from Earth's equatorial plane
  - Changes between 23.5° North and 23.5° South latitudes during one year

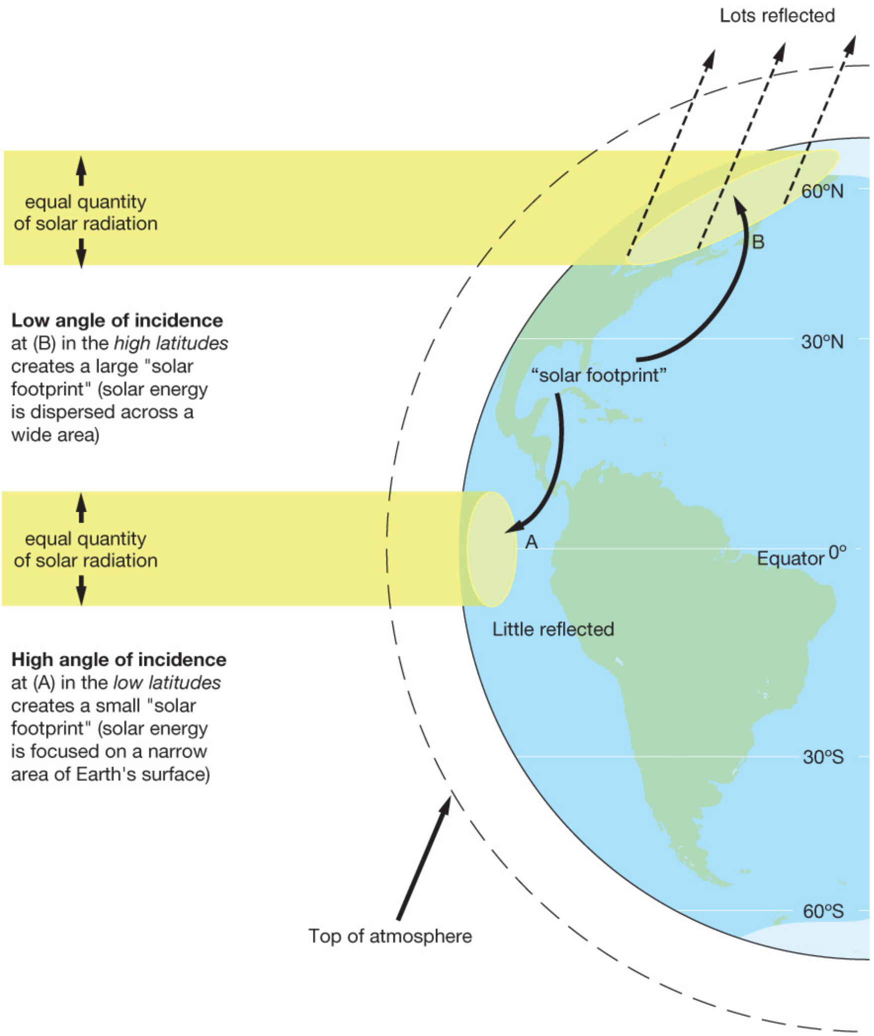
- Most radiation is received between these two latitudes (called tropics)
  - Tropic of Cancer
  - Tropic of Capricorn

- Arctic Circle – 66.5° North latitude
- Antarctic Circle – 66.5° South latitude
  - for part of the year, the areas between these circles and the poles do not experience daily lights of daylight an darkness

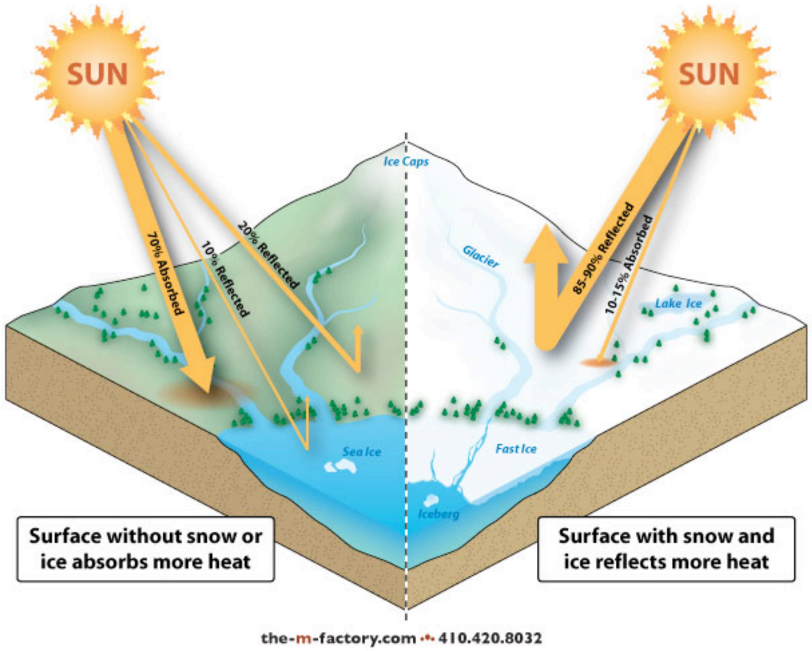
How Latitude Affects the Distribution of Solar Radiation

- Earth as a disk vs. Earth as a sphere
  - amount and intensity of solar radiation received at high latitudes are much less than at lower latitudes

- Besides daily and seasonal variations, *four factors* affect the amount of radiation received at high and low latitudes



- Four factors that affect amount of radiation received at different latitudes:
  - **Solar footprint**: the same amount of radiation is spread over a wider area at high latitudes
  - **Atmospheric absorption**: atmosphere absorbs radiation, and at high latitudes radiation crosses more atmosphere than at lower latitudes
  - **Albedo**: ratio reflected radiation/incident radiation. Depends on materials, white ice has a higher value
  - **Reflection of incoming sunlight**: angle at which sunlight strikes the ocean surface determines how much is absorbed and how much is reflected



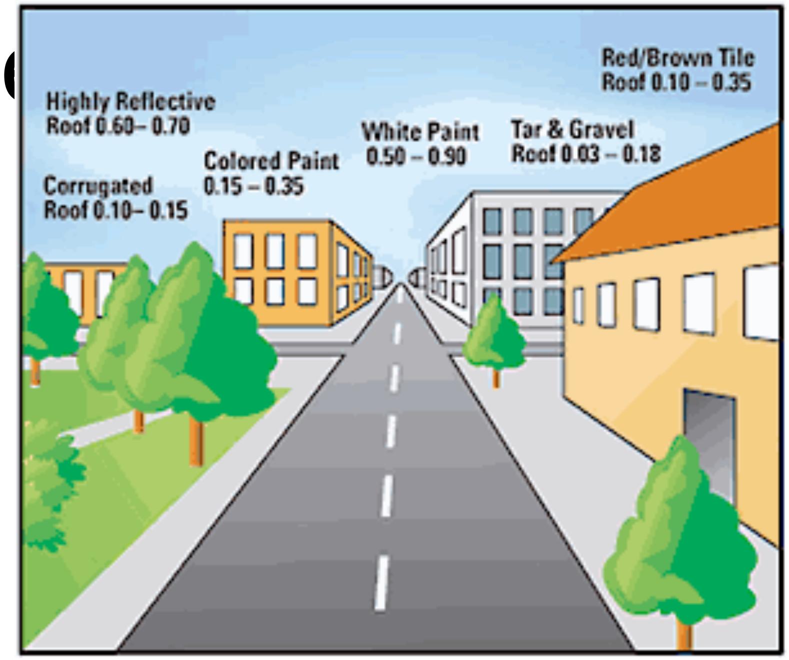


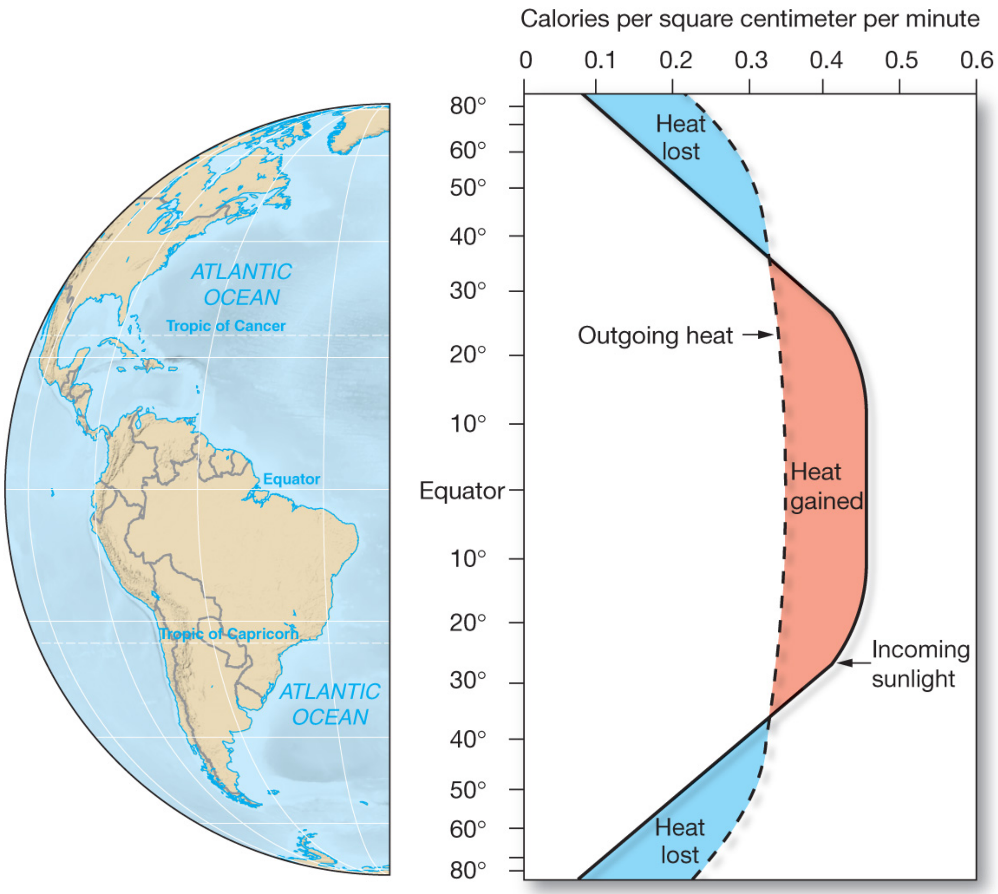
TABLE 6.1 REFLECTION AND ABSORPTION OF SOLAR ENERGY RELATIVE TO THE ANGLE OF INCIDENCE ON A FLAT SEA

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



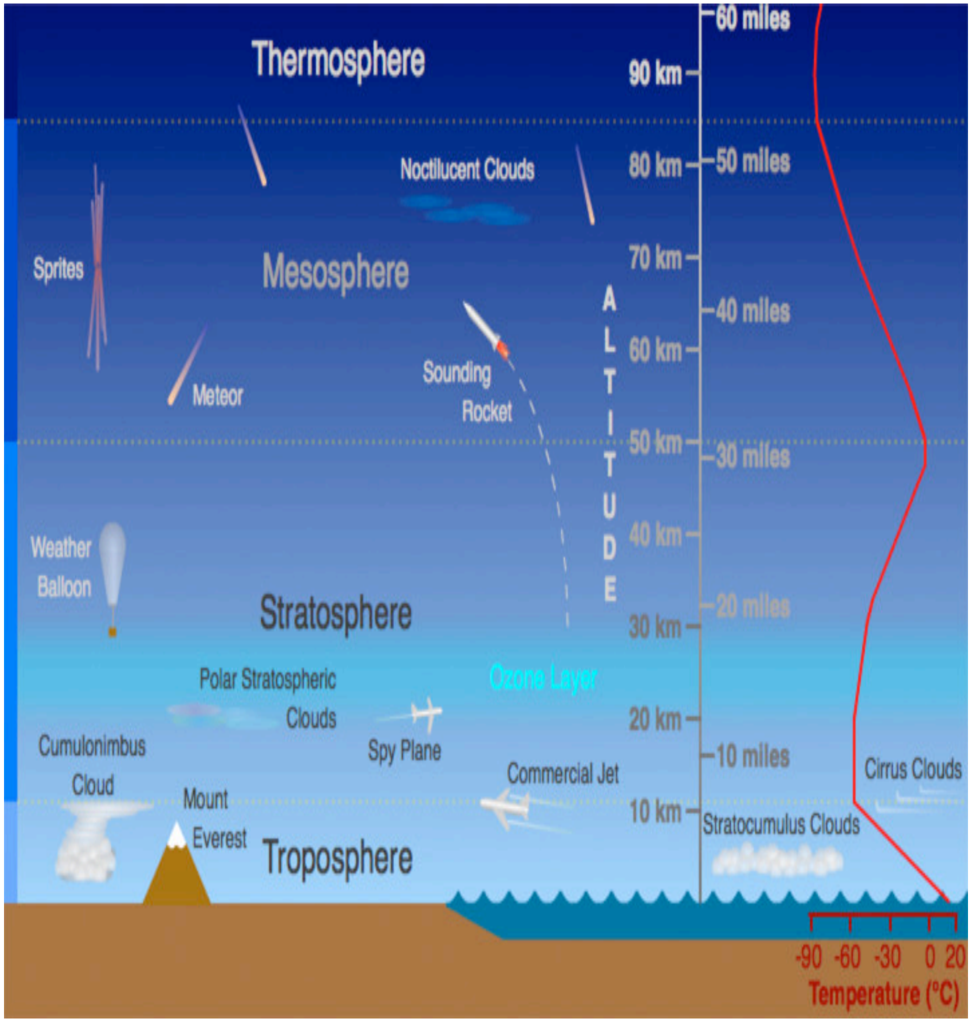
- If equatorial areas gain heat and polar areas lose heat continuously, then the first should be overheating and the second should be freezing

- What happens is that the excess heat from the equator travels towards polar areas, warming them up

- This excess heat is transferred via:
  - air circulation in the atmosphere
  - water circulation in the oceans

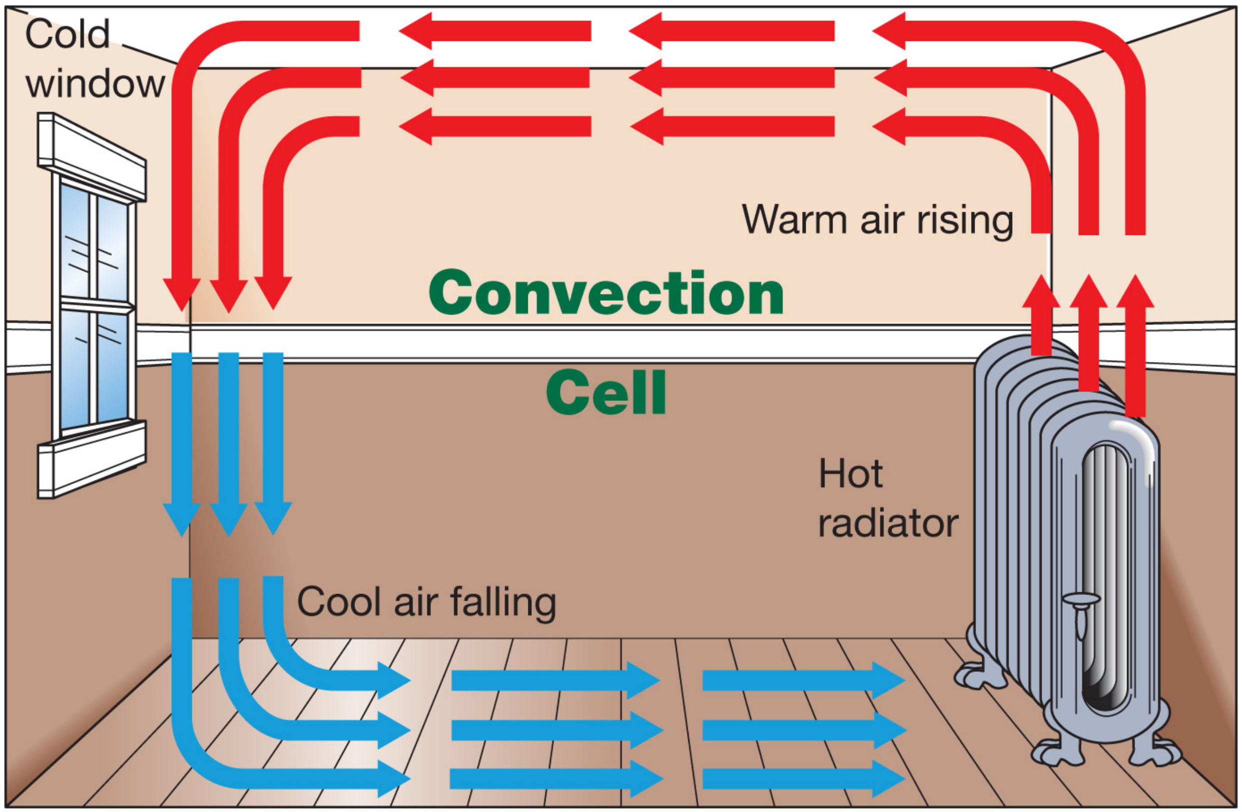
Temperature Variation in the Atmosphere

- The heat we feel at the surface is not directly from the Sun but from Earth radiating Sun's energy back
- Because of this, in the Troposphere (mixed layer) temperatures drop with altitude (away from the source, Earth's surface)
- The Troposphere is where all weather occurs



Density Variation in the Atmosphere

- Warm air is less dense, so it rises
- Cool air is more dense, so it sinks



Atmospheric Water Vapor Content

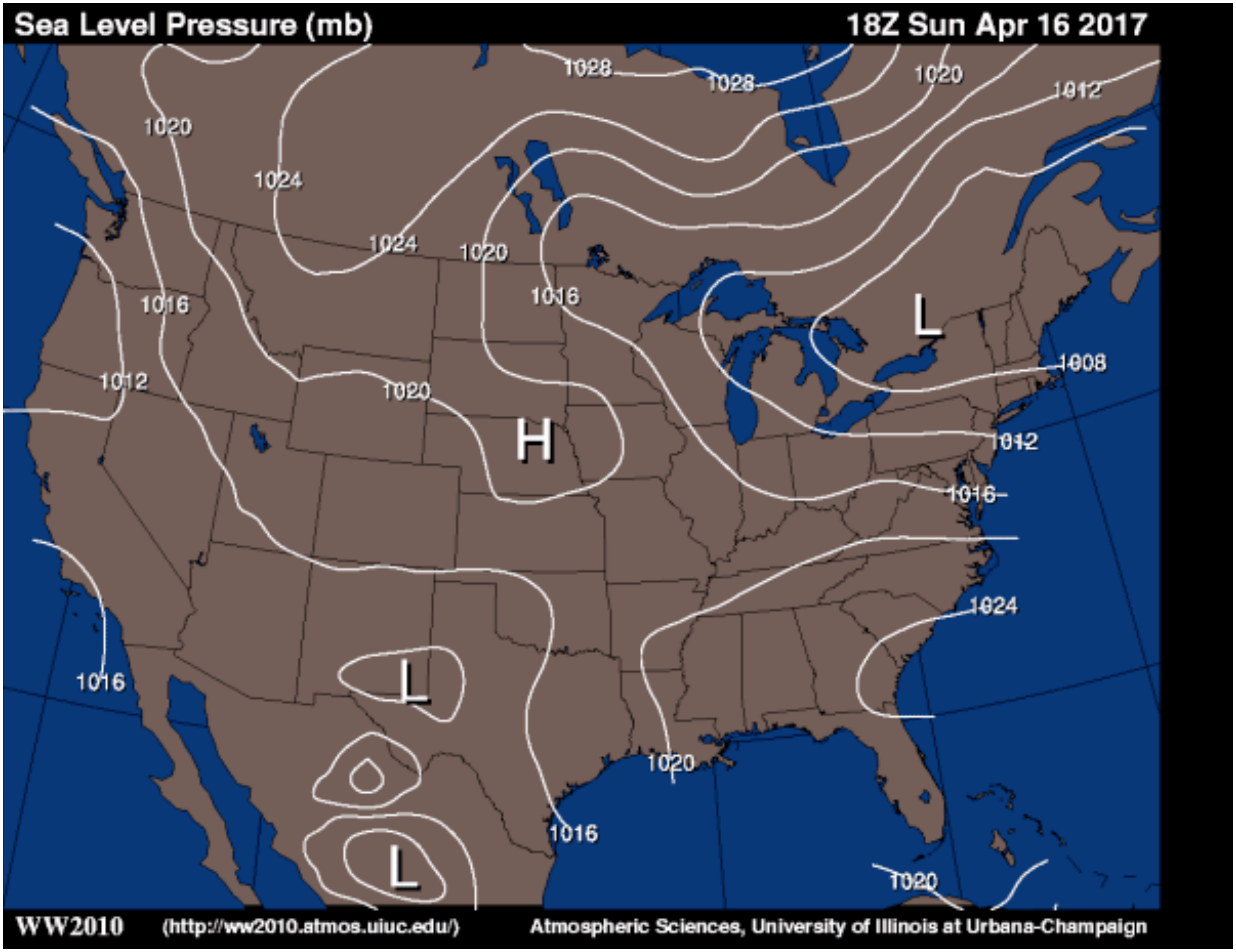
- Warm air can hold more moisture than cold air
  - Air molecules moving at higher speed come into contact with more water vapor

- Warming air would "absorb" moisture (dry conditions in a desert, for instance)
- Cooling air would "lose" moisture (precipitation)

- Water vapor also influences the density of air:
  - Water vapor is less dense than air, so:
    - Moist air rises because it is less dense
    - Dry air sinks because it is more dense

Atmospheric Pressure

- Atmospheric pressure depends on the weight of the column of air above
- This means that atmospheric pressure decreases with elevation (it is higher on the ground)
- The atmospheric unit of pressure is the **standard atmosphere** (atm), defined as 101,325 Pascals, or 1.01325 bars
    - 1.033 kg/cm^2
    - 14.7 lb/in^2



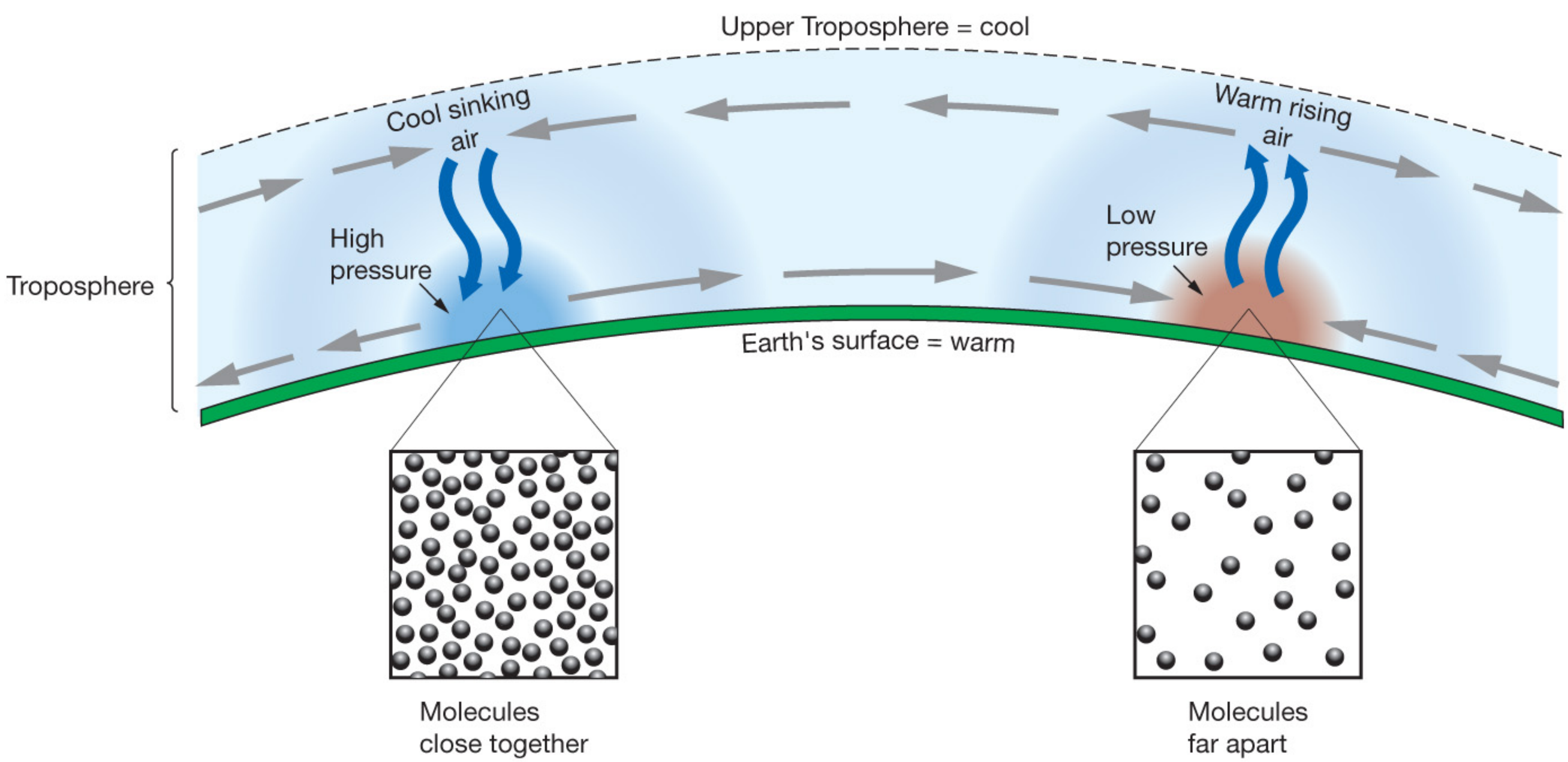
A map showing atmospheric pressure in millibars (mb)

- Temperature affects pressure:
  - Cool temperatures cause air molecules to be closer to each other, and vice versa

- Cool air sinks (high pressure on the surface)
  - sinking cool air warms up in the process: compression
- Warm air rises (low pressure on the surface)
  - rising warm air cools down in the process: expansion

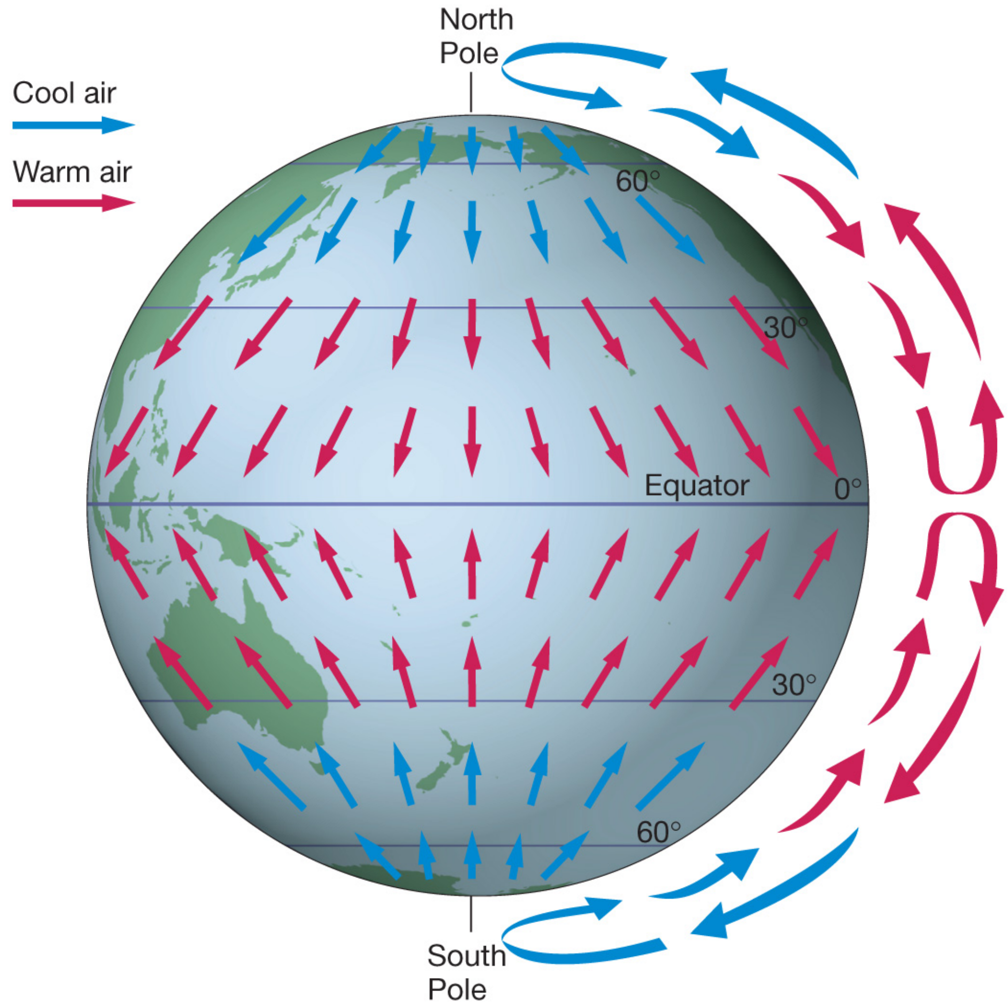
Movement of the Atmosphere

- Air *always* moves from high-pressure regions to low pressure regions
- Movement of air on the ground is called **wind**



Movements in the Air: an example from a non-spinning Earth

- Warm air rises at equator (low pressure)
  - it cools down and releases moisture → precipitation
- Air sinks at poles (high pressure)
  - it warms up and absorbs moisture → dry condition
- Air flows from high to low pressure
- One giant convection cell or circulation cell



Was that model a good approximation? No

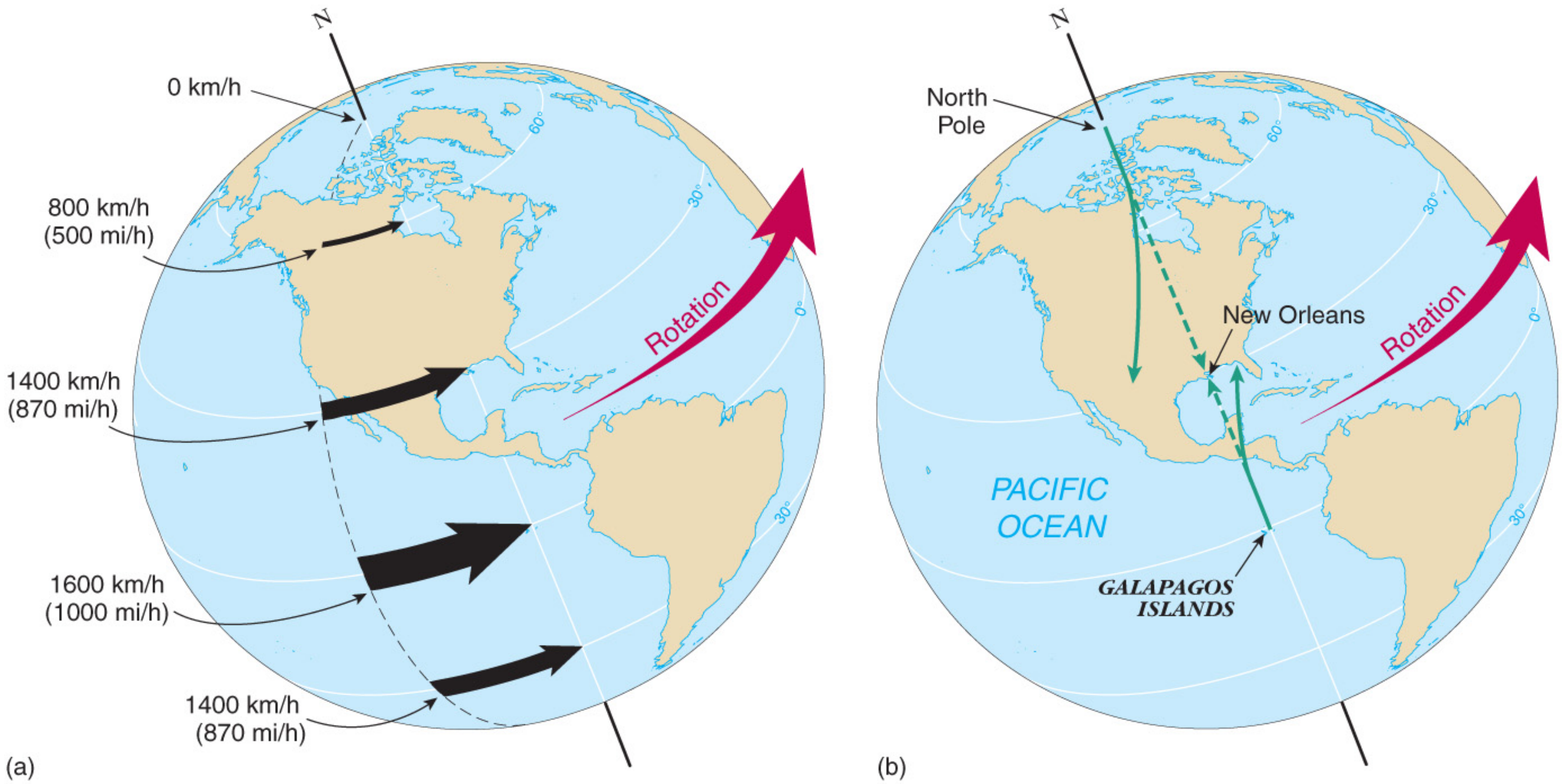
- The previous model used the correct principles that drive air circulation

- Reality is more complicated than this because Earth is spinning and because the angle of incidence of Sun’s radiation varies during seasons

Coriolis Effect

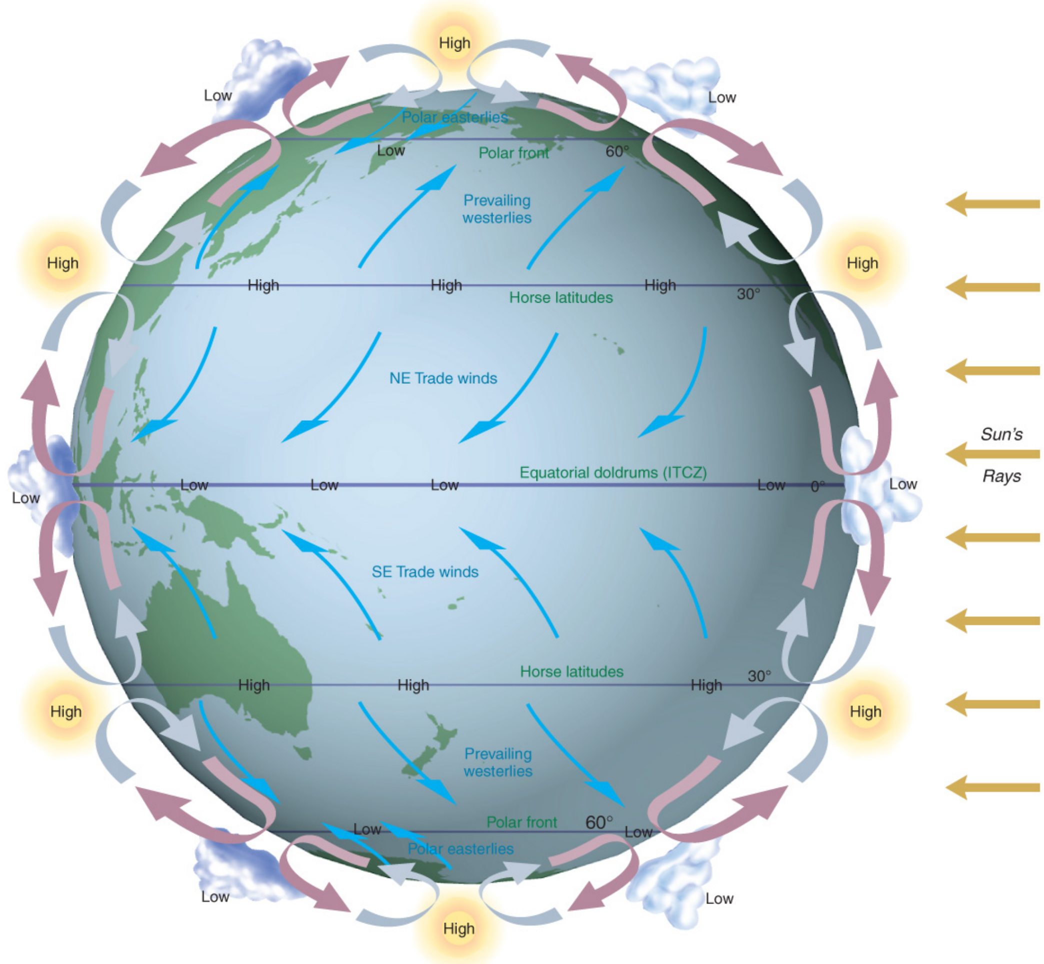
- Objects moving on Earth follow a curved path
  - deflected to the right in the Northern Hemisphere
  - deflected to the left in the Southern Hemisphere
- This is due to Earth's rotation

- The Coriolis effect is greatest at the poles
- Change in Earth's rotating velocity with latitude
  - 0 km/hour at poles
  - More than 1600 km/hr (1000 mi/hr) at equator
- The greatest effect is on objects that move long distances across latitudes



A slightly more realistic model for air circulation

- Circulation cells
- Pressure
- Wind belts
- Boundaries



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

- High pressure zones – descending air
  - Subtropical highs – 30 degrees latitude
  - Polar highs –90 degrees latitude
  - Clear skies
- Low pressure zones – rising air
  - Equatorial low – equator
  - Subpolar lows – 60 degrees latitude
  - Overcast skies with lots of precipitation

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

- Boundaries between wind belts
  - Doldrums or Intertropical Convergence Zone (ITCZ) – at equator
  - Horse latitudes – 30° N/S
  - Polar fronts – 60° N/S

Circulation Cells: Idealized or Real?

- While basically correct, the 3-cells model is idealized
- That is particularly true for location and direction of motion of the Hadley and Polar Cells
- Complexity also comes from:
  - tilt of Earth's axis, producing seasons
  - uneven distribution of land masses and ocean basins (particularly in the Northern Hemisphere)
  - differences in heat capacity between continents and oceans
    - air over continents is warmer in summer and colder in winter, when compared to air over adjacent oceans. This difference triggers local changes to the general circulation pattern
      - examples: Monsoons in the Indian Ocean

Part II

The end