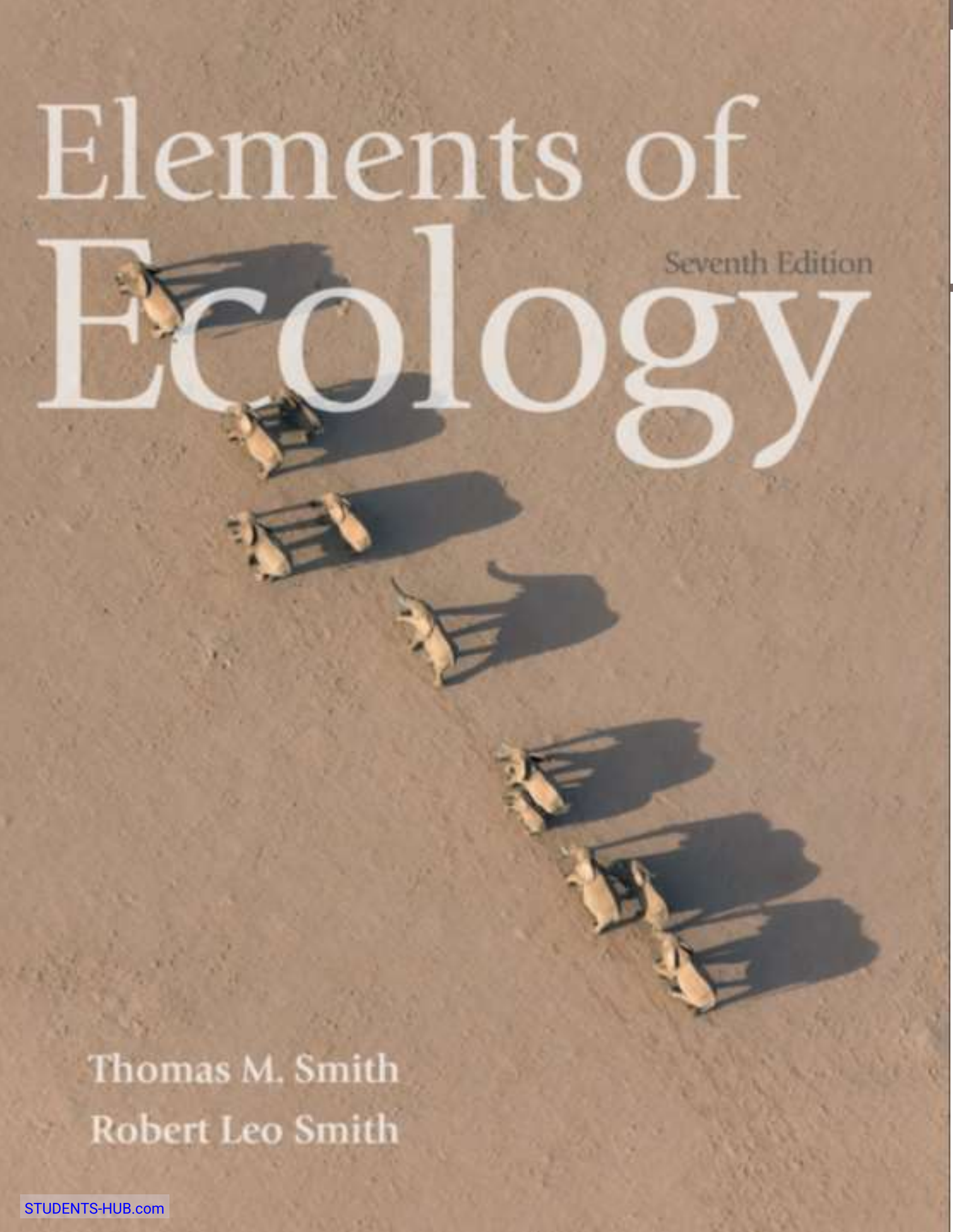


Chapter 2

Climate

Lecture prepared by
Aimee C. Wyrick

Part One: The Physical Environment

- Living organisms require certain **physical conditions to survive.**
- **Habitability** *is the ability of the* *physical environment* *to support life.*

- Organisms interact with the physical environment **over two very *different timescales*:**
  - **Over many generations (long periods)** the physical environment is a guiding force of natural selection.
  - **Over shorter periods** the physical environment influences an organism's physiology and resource availability.

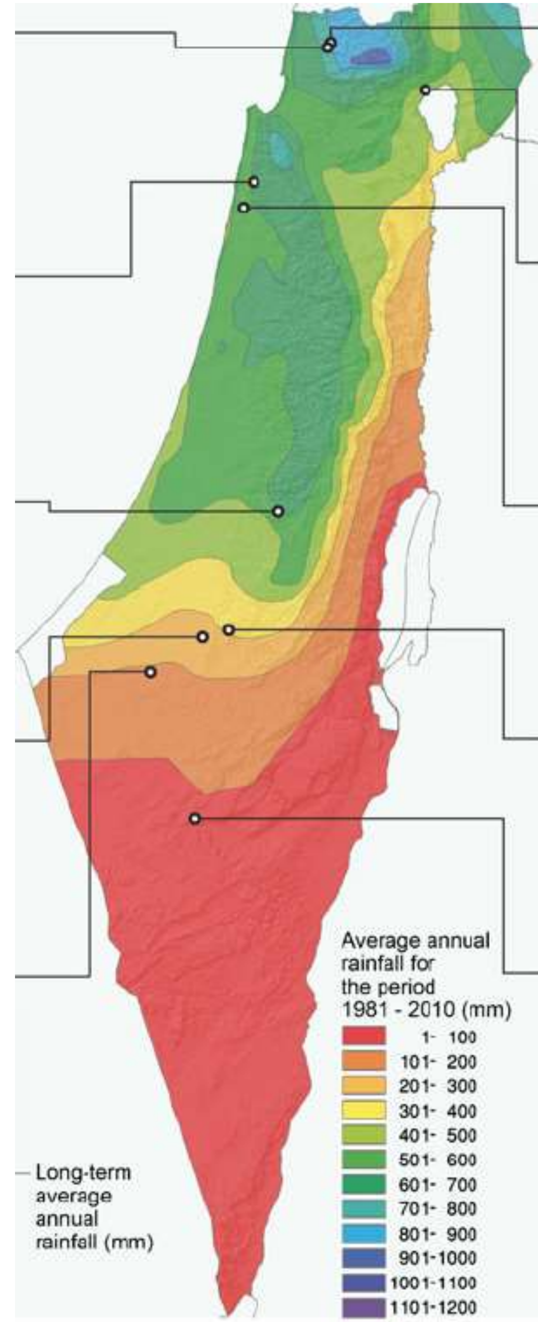
Climate

- **Weather** (الطقس) *is the combination of temperature, humidity, precipitation, wind, cloudiness, and other atmospheric conditions occurring at a specific place and time*.
- **Climate** (المناخ) *is the long-term average pattern of weather. Could vary:*
  - ***Locally***
  - ***Regionally***
  - ***Globally***

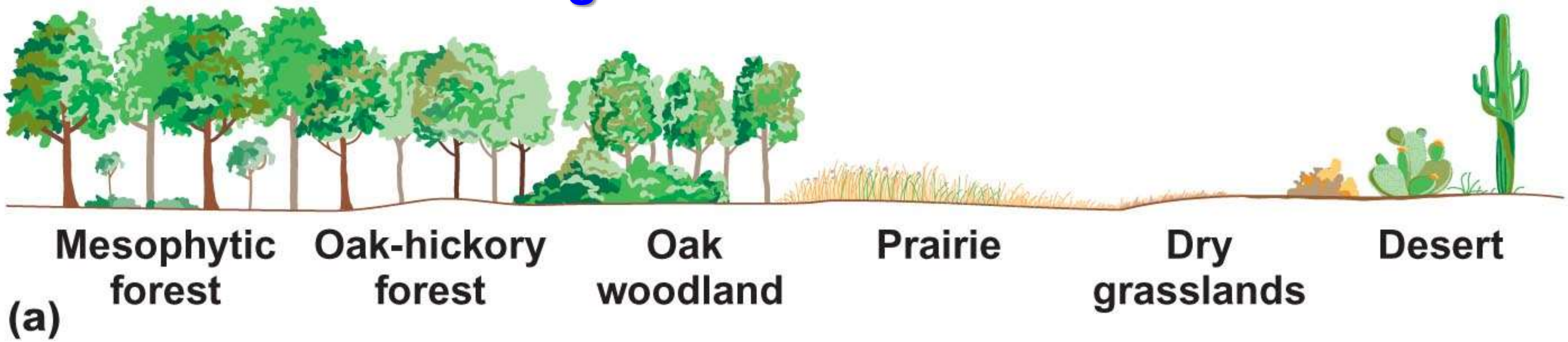
Example:

- ***Local***: **Climatic conditions gradients in Palestine:**

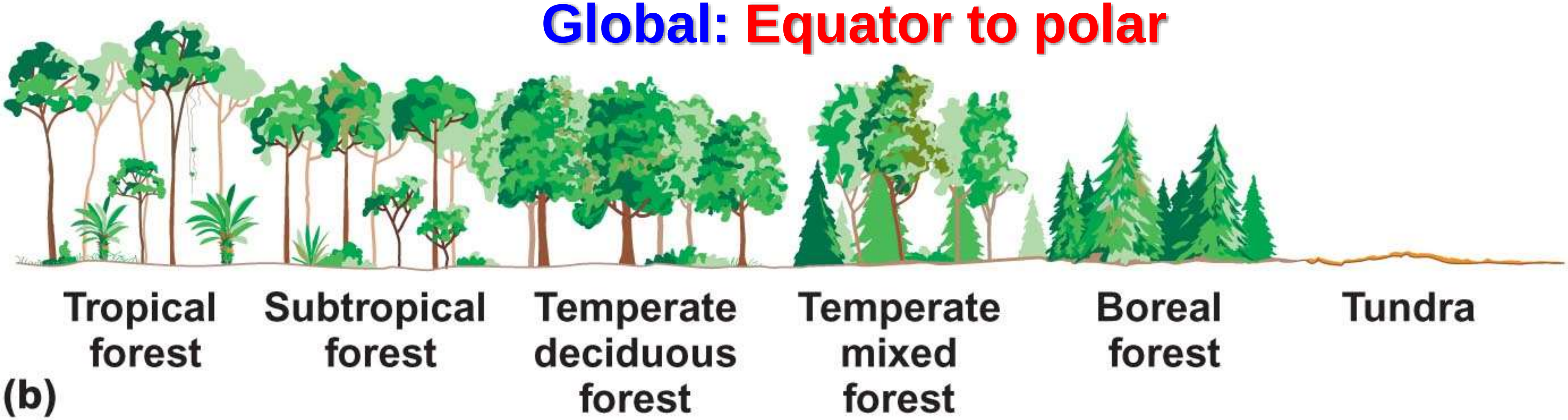
From North to south Rainfall decreases



Regional: East to West in the US



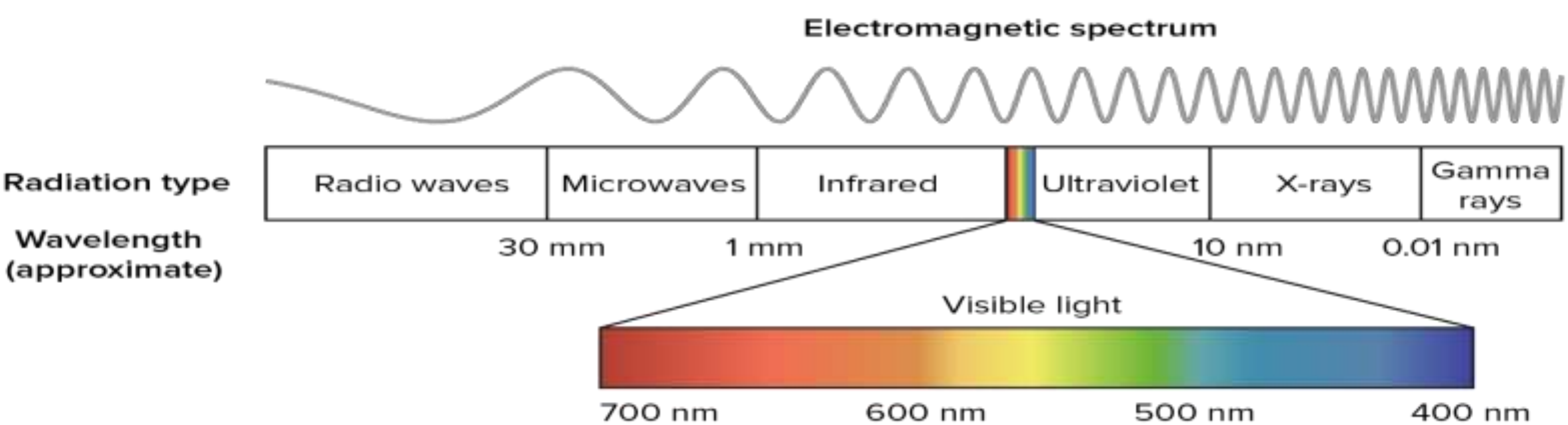
Global: Equator to polar



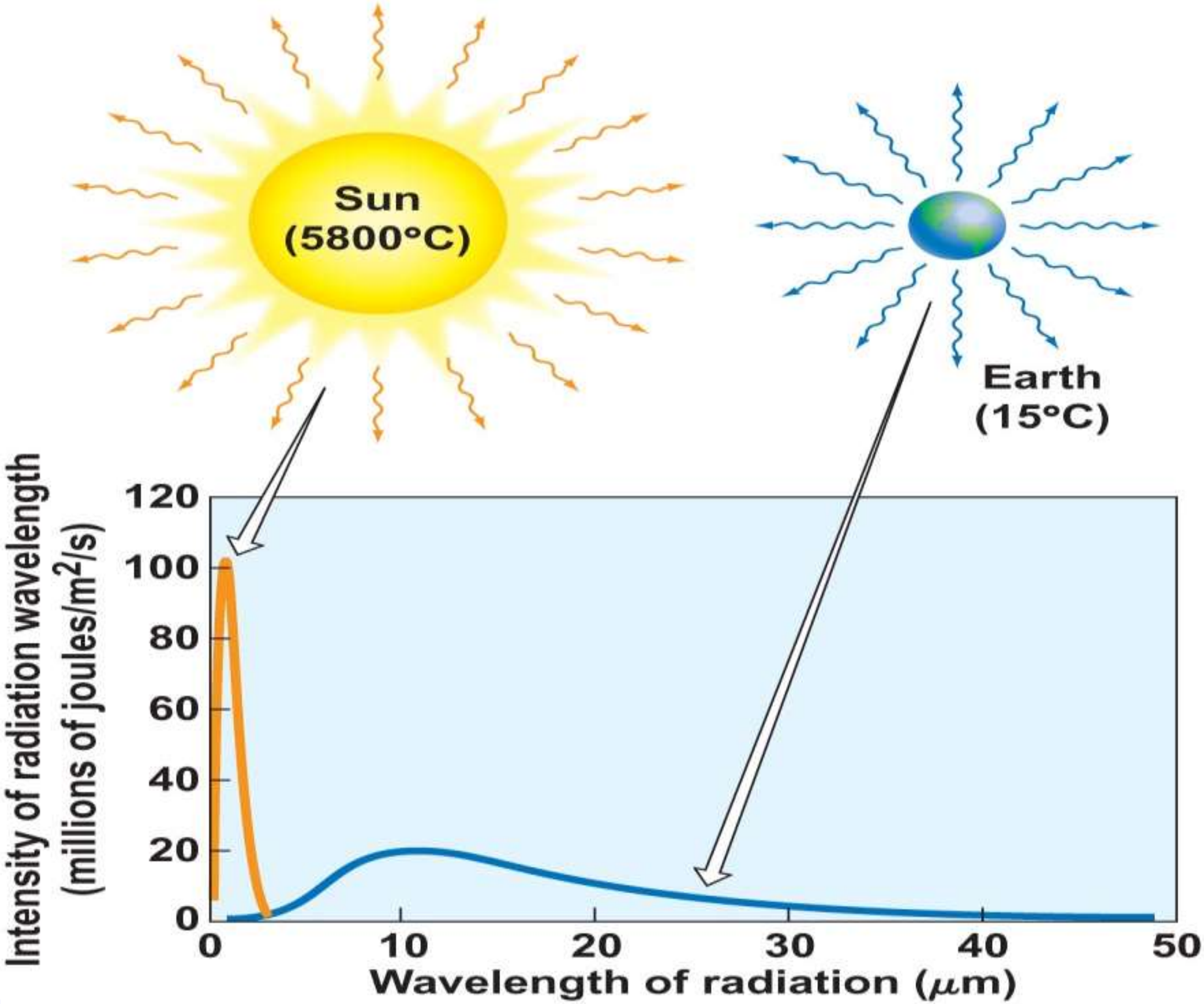
2.1 Earth Intercepts Solar Radiation

- Earth's weather patterns (e.g., distribution of rainfall) are influenced by the:
  - **solar radiation** intercepted by Earth's atmosphere.
  - **Earth's rotation and movement.**
- These create the **prevailing winds** and **ocean currents.**

- **Solar radiation** *is the* *electromagnetic energy* *or stream of* *photons* *produced by the sun.*
- Electromagnetic energy is measured in terms of
  - **Wavelength** (λ): *the physical distance between successive wave crests*
  - **Frequency** (*ν*): *the number of crests that pass a given point per second*

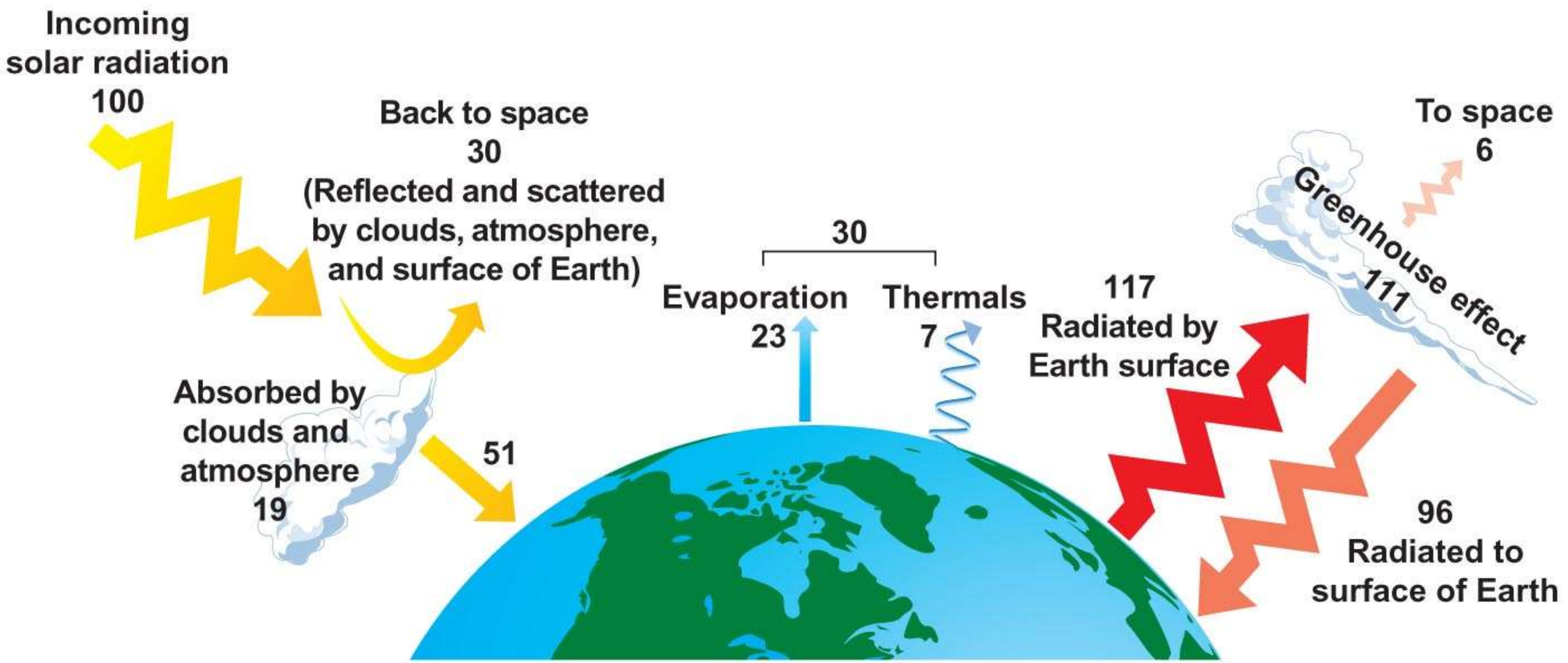


- All objects **emit radiant energy.**
- The energy emitted **depends on** the **temperature** of the object it is coming from.
- **The hotter the object is, the more energetic the photons and the shorter the λ:**
  - **Shortwave radiation**: emitted by a very hot surface (e.g., Sun = 5800°C)
  - **Longwave radiation**: emitted by a cooler object (e.g., average Earth's surface = 15°C)



Sun
(5800°C)
Earth
(15°C)
Intensity of radiation wavelength
(millions of joules/m2/s)
120
100
80
60
40
20
0
0
10
20
30
40
50
Wavelength of radiation (μm)

- **Only 51%** of the solar radiation that reaches the top of the Earth's atmosphere is actually **absorbed by Earth's surface.**
- The remaining solar radiation is primarily **reflected** and **scattered** by the atmosphere and clouds.

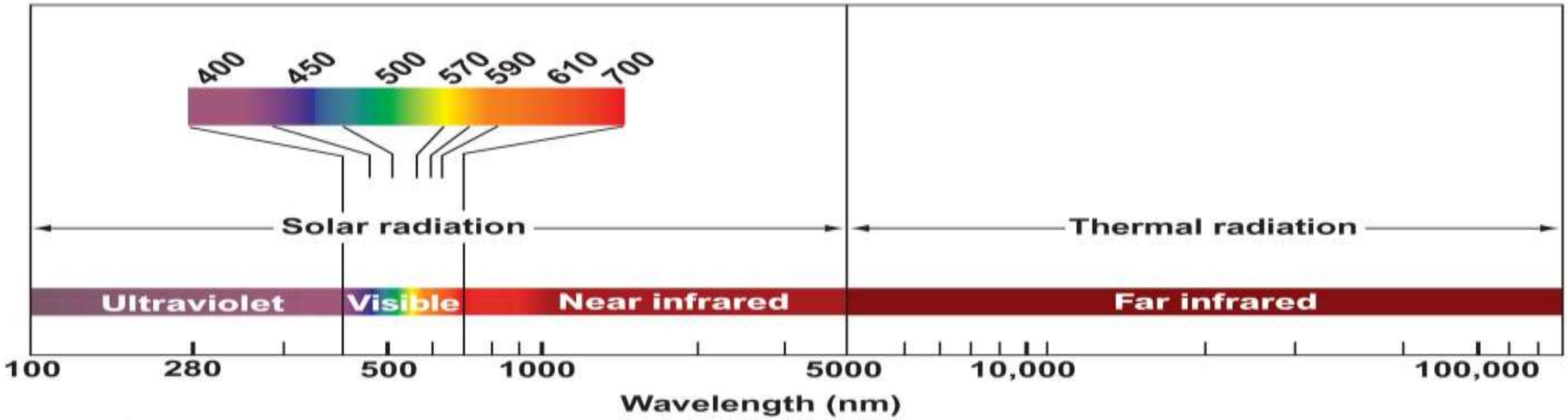


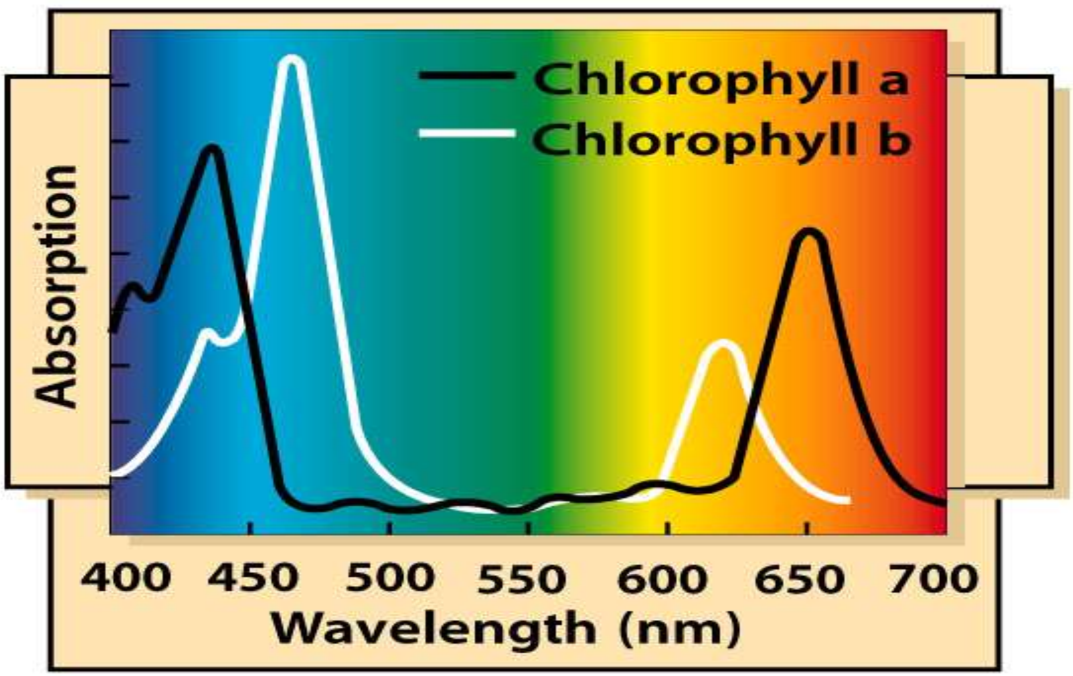
Inputs = 51 units + 96 units = 147 units
Outputs = 30 units + 117 units = 147 units

- Earth not only receives solar radiation but **emits its own longwave radiation.**
- The energy emitted by Earth’s surface exceeds the solar radiation absorbed. Why?:
  - *Solar radiation is received during the day but Earth radiates energy both day and night*
  - Earth’s atmosphere captures most of the radiation emitted by the Earth and this energy is radiated back to Earth. This is called the **greenhouse effect**

- The sun emits **electromagnetic radiation** of a wide range of wavelengths.
- The wavelengths of **400 to 700 nanometers** (nm) make up **visible light.**

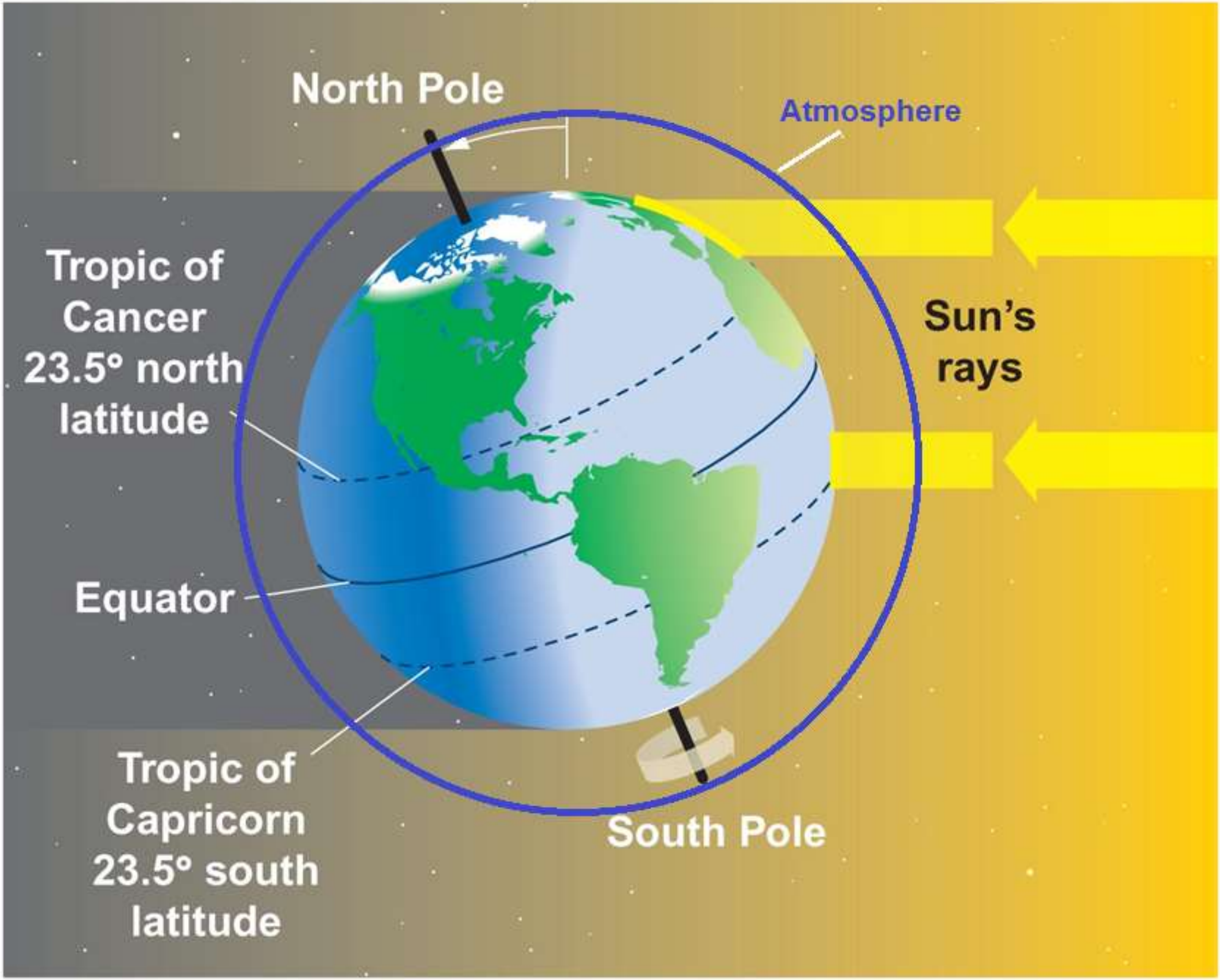
  [One nanometer is *one-billionth of a meter* (1 nm = 0.000000001 m)].
- These same wavelengths are also called **photosynthetically active radiation** (**PAR**):
  - Used by plants to power photosynthesis (Activates chlorophyll molecules)


400
450
500
570
590
610
700
Solar radiation
Thermal radiation
Ultraviolet
Visible
Near infrared
Far infrared
100
280
500
1000
5000
10,000
100,000
Wavelength (nm)


Chlorophyll a
Chlorophyll b
Absorption
400
450
500
550
600
650
700
Wavelength (nm)

2.2 Intercepted Solar Radiation Varies Seasonally

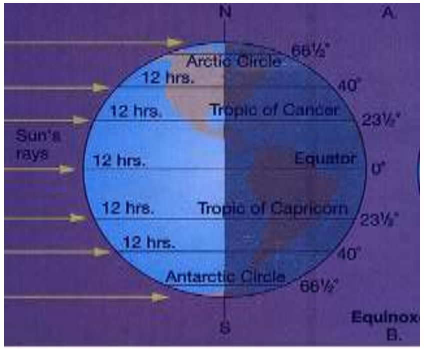
- The **amount of solar radiation** intercepted at any point on Earth's surface **varies by latitude;** with a **gradient of decreasing temperature from the equator to the poles because:**
- **A) At higher latitudes**, solar radiation hits Earth's surface **at a steeper angle. Therefore,** Sunlight is spread over a larger area**.**
- **B) Radiation must pass through a deeper layer of air** and so it encounters more particles in the atmosphere and is reflected back into space


North Pole
Atmosphere
Tropic of Cancer 23.5° north latitude
Sun's rays
Equator
Tropic of Capricorn 23.5° south latitude
South Pole

- **Seasons are the result of**:
  - **1) Earth's tilt (inclination) of 23.5°.**
  - **2) Earth's movement:** Yearly movement around the Sun in a plane called the ecliptic.
- **In addition, the Earth exhibits a 24-hour rotation (around its axis) resulting in the day and night (diurnal cycle).**

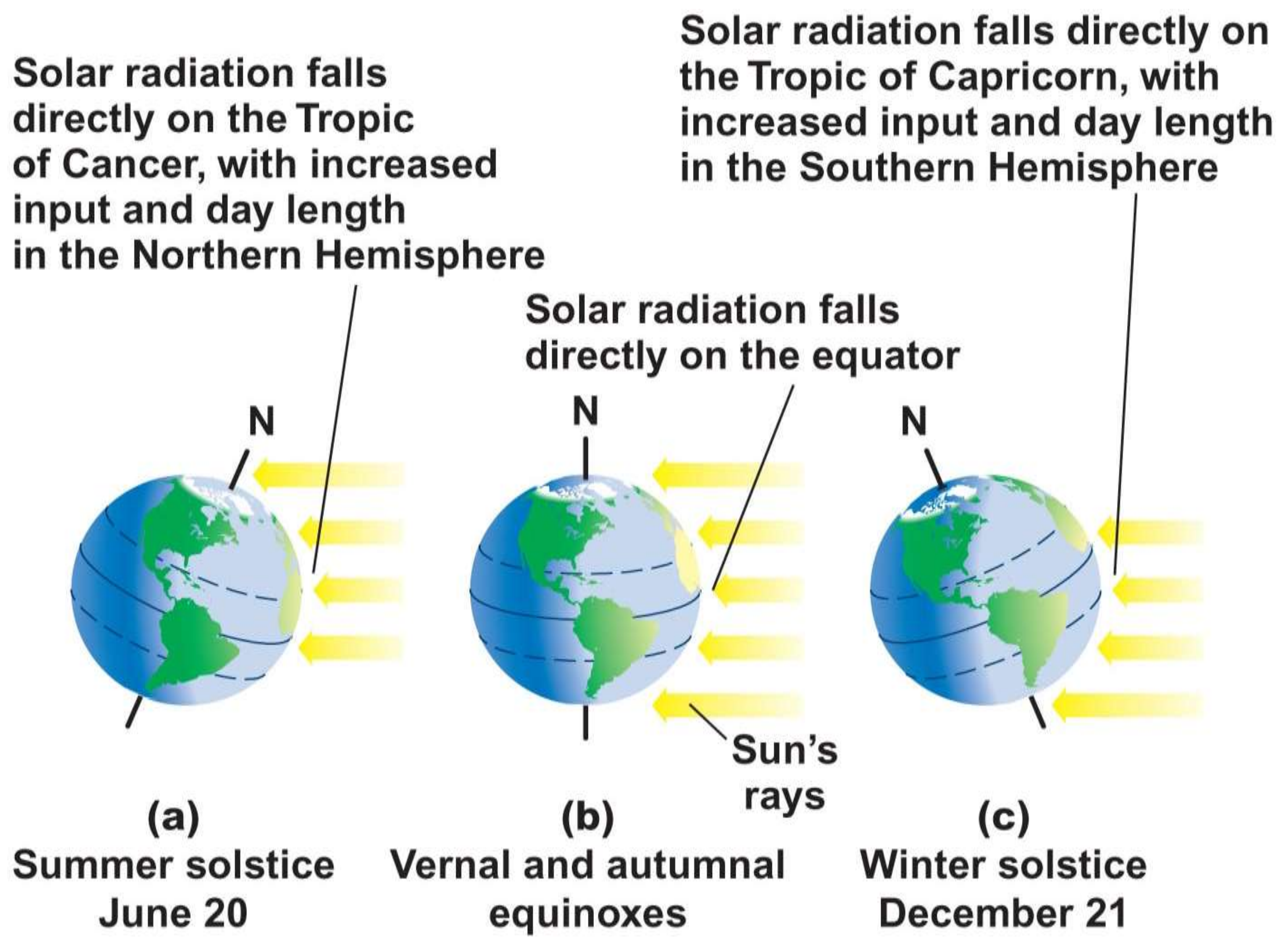
- The **diurnal cycle** (hours of daylight and darkness) varies with the season everywhere on Earth ***except*** at the equator.
  - Only the equator receives 12 hours of daylight and night throughout the year.

- Solar radiation **falls directly** on the **Equator:** during the **vernal equinox (الاعتدال الربيعي) =21 March** and **autumnal equinox (الاعتدال الخريفي)=22 September.**
  - Equatorial region is heated most intensely.
  - Every place on Earth receives the same day length.

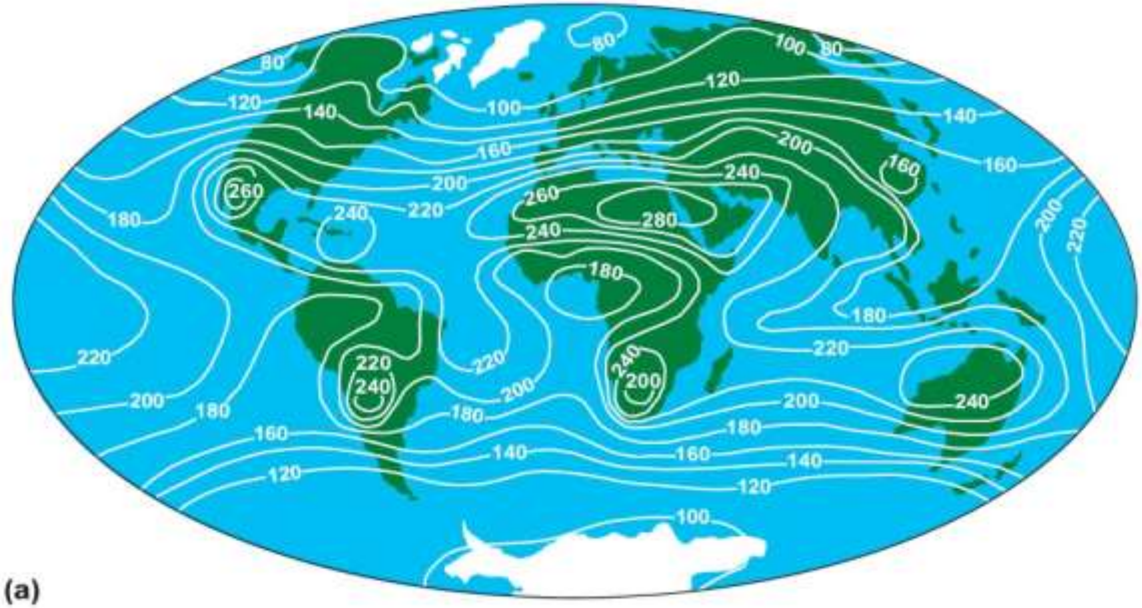


Solar radiation **falls directly** on the:

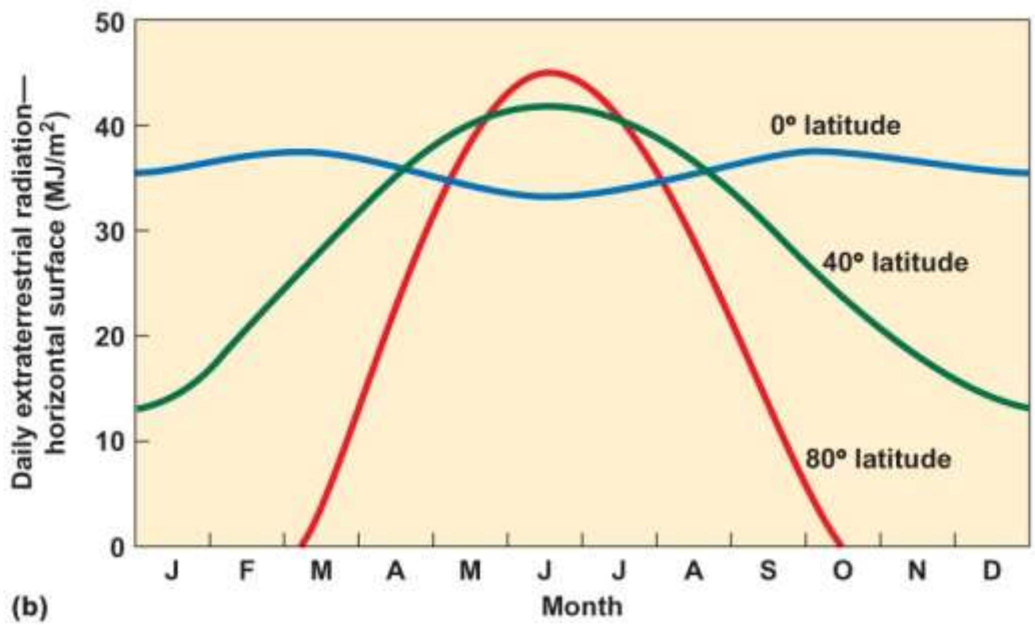
- **Tropic of Cancer (23.5°C north latitude):** during the **summer solstice (June 22) (انقلاب صيفي):** *The Northern Hemisphere is heated most intensely. Day length is at its longest.*
- **Tropic of Capricorn (23.5°C south latitude):** during the **winter solstice (December 22) (انقلاب شتوي):**
  - *Northern Hemisphere experiences winter.*
  - *Day length is at its shortest.*


Solar radiation falls directly on the Tropic of Cancer, with increased input and day length in the Northern Hemisphere
Solar radiation falls directly on the equator
Solar radiation falls directly on the Tropic of Capricorn, with increased input and day length in the Southern Hemisphere
N
N
N
Sun's rays
(a)
Summer solstice
June 20
(b)
Vernal and autumnal equinoxes
(c)
Winter solstice
December 21

- The **seasonality** of **solar radiation, temperature, and day length** increases with latitude.
- At the **Arctic and Antarctic circles** (66.5° north and south latitudes, respectively) day length varies from **zero to 24 hours** over the course of the year!

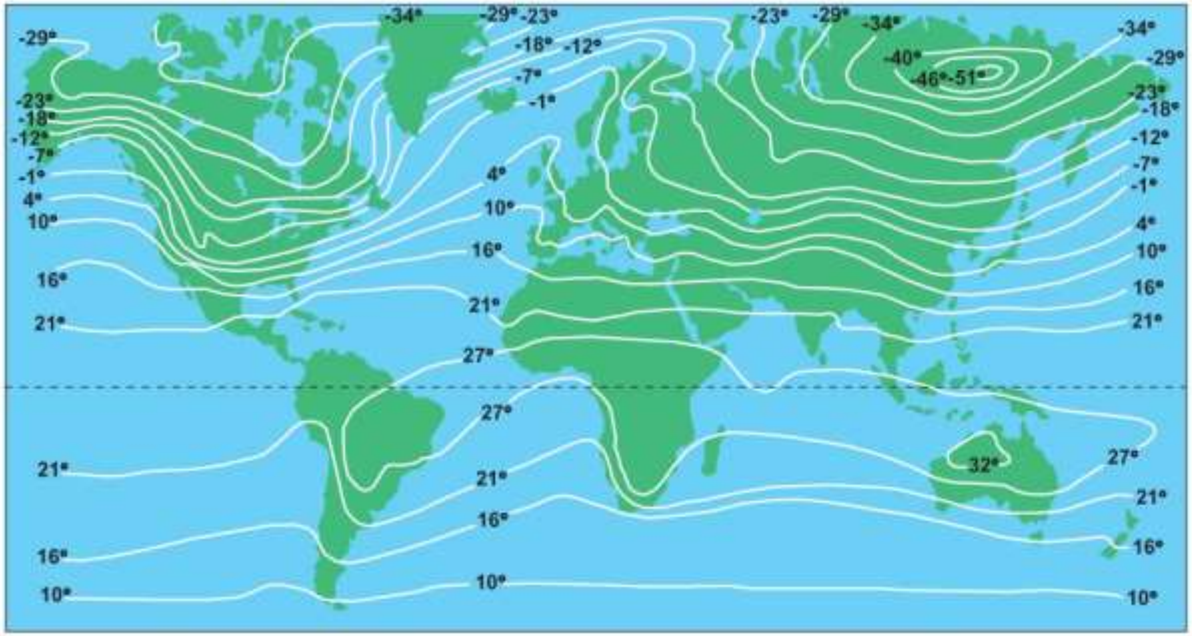


(a)

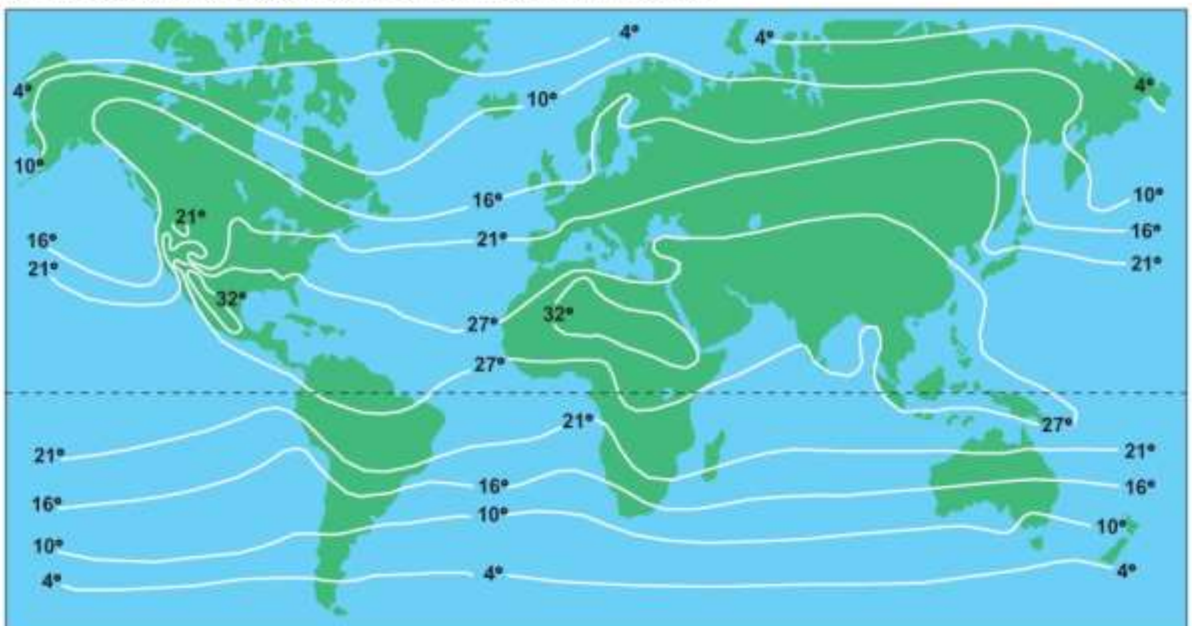

Daily extraterrestrial radiation—horizontal surface (MJ/m^2)
50
40
30
20
10
0
0° latitude
40° latitude
80° latitude
J F M A M J J A S O N D
Month

(b)

- The variation in the exposure of different latitudes to solar radiation **controls mean annual temperature around the globe**



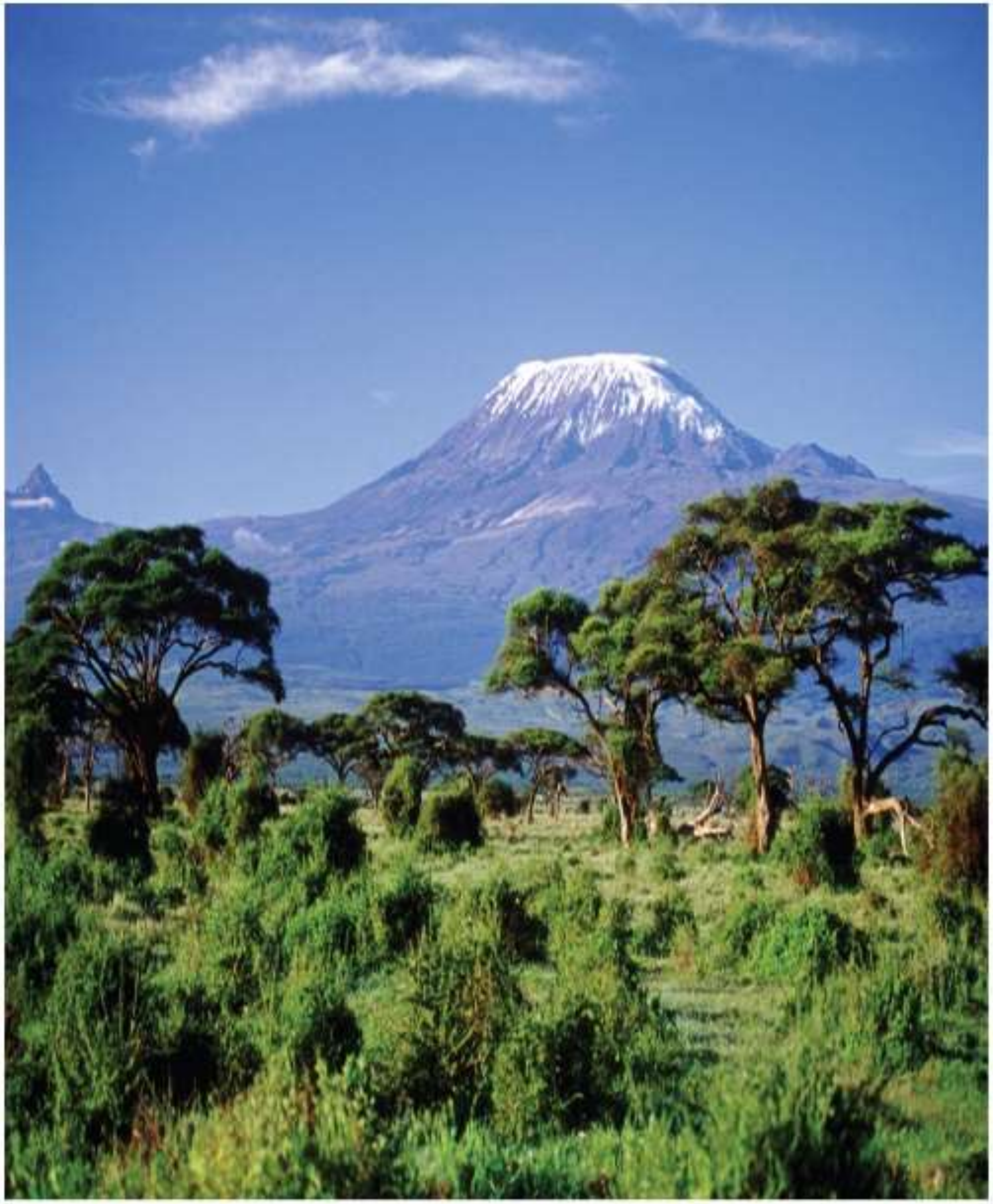
(a) January isotherms (lines of equal temperature) around the Earth



(b) July isotherms (lines of equal temperature) around the Earth

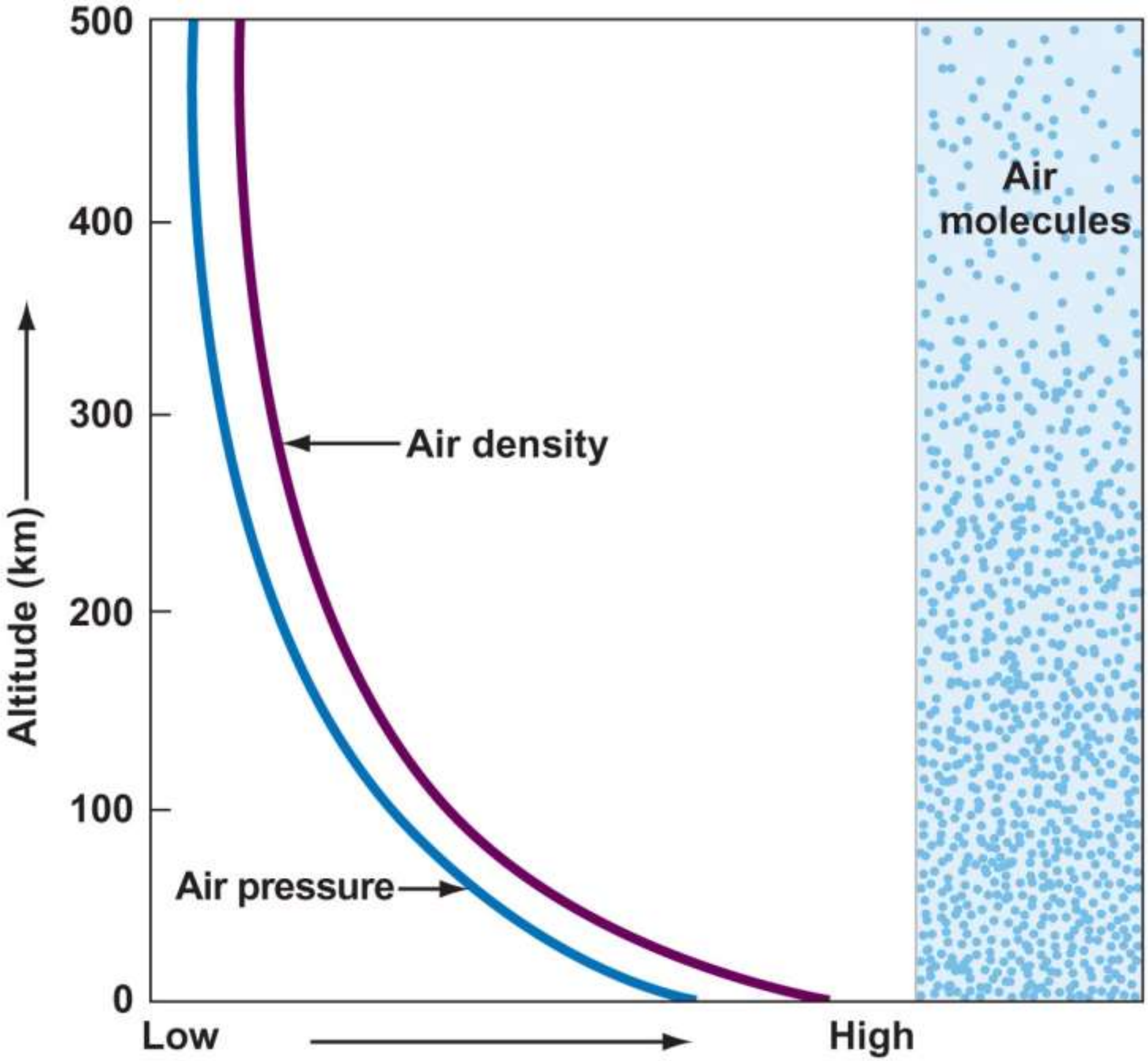
2.3 Air Temperature Decreases with Altitude

- Temperature decreases with an increase in **altitude (elevation)**
- **Example:** **Mount Kilimanjaro** (Tanzania, tropical Africa): height= 5,895 meters, top is permanently capped with ice.
  - **Mount Hermon** (جبل الشيخ) height 2814 m.




- **Atmospheric pressure** or **air pressure** *is the amount of force exerted over a given surface area.*
- The **atmospheric pressure** at any point is measured in terms of the **total mass of air above that point.**
- **Atmospheric pressure** decreases with an increase in altitude.

- The **density of air** (the number of air particles per unit volume) is directly related to atmospheric or air pressure
- Atmospheric (air) pressure and air density **decrease** systematically and continuously with height above sea level (altitude):
  - At an altitude of 50 km, air pressure is only 0.1% of that measured at sea level.


500
400
300
200
100
0
Altitude (km)
Air density
Air pressure
Low
High
Air
molecules

- Air temperature normally decreases from Earth's surface up to an altitude of 11 km
- The **environmental lapse rate** *is the rate at which temperature decreases with altitude*
- Air temperature has a **complicated vertical profile**, and the temperature at different altitudes is influenced by **two factors:**

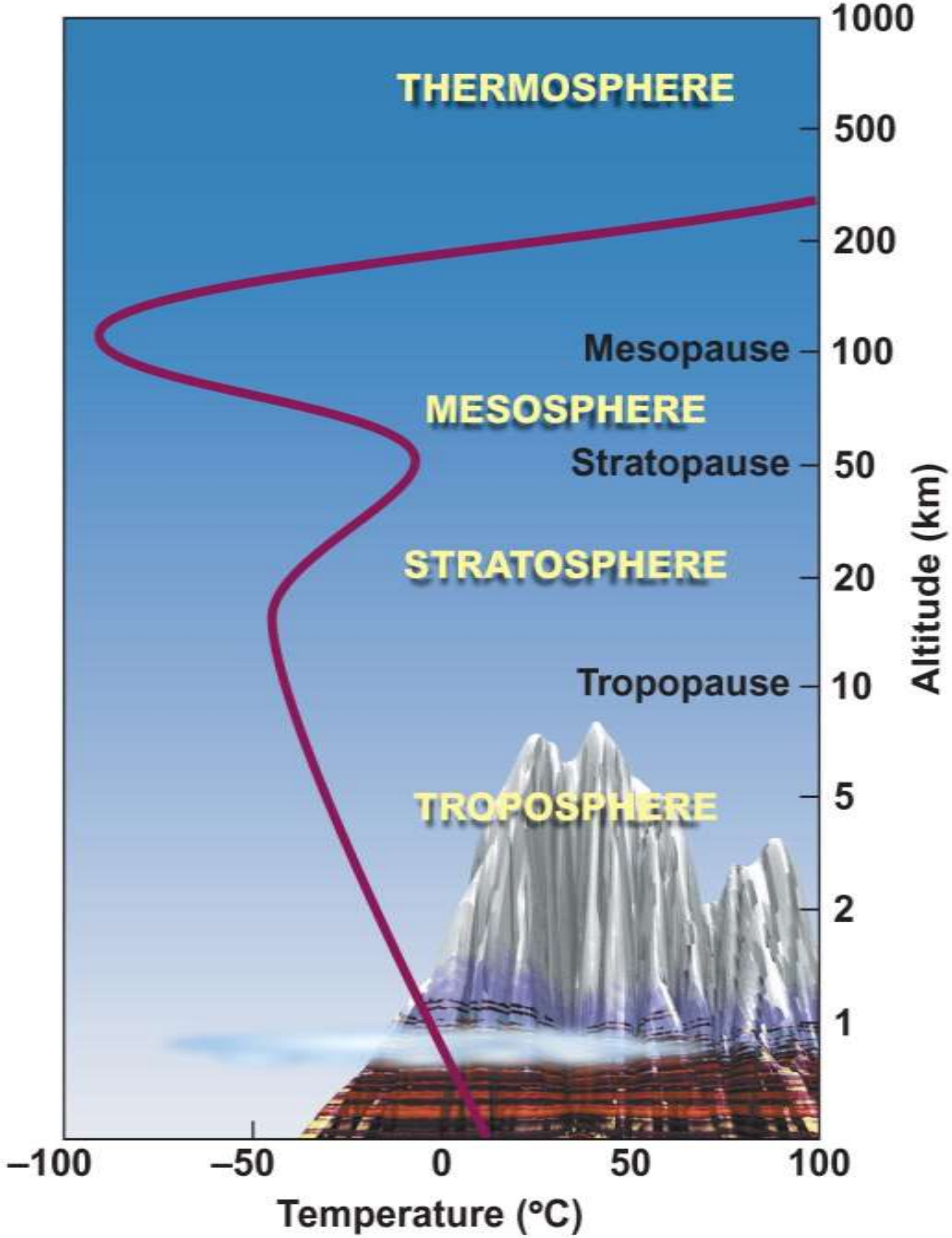
1) **Air molecules move more quickly with a greater pressure**. Temperature is a measurement of the average speed of air molecules:

- Atmospheric pressure, air movement and temperature are highest at sea level.

2) The "**warming effect**" of Earth's surface decreases with an increase in altitude:

- The long wave radiation emitted from Earth's surface is dissipated as it moves from the Earth's surface to higher altitude.

- Air temperature does not decline continuously with increasing height above Earth’s surface.
- Atmospheric regions (Layers):
  - **Troposphere (the layer around us)**
  - **Stratosphere (The layer that contains ozone)**
  - **Mesosphere**
  - **Thermosphere**
- Boundary zones between regions of the atmosphere:
  - **Tropopause**
  - **Stratopause**
  - **Mesopause**


THERMOSPHERE
MESOSPHERE
STRATOSPHERE
TROPOSPHERE
Mesopause
Stratopause
Tropopause
1000
500
200
100
50
20
10
5
2
1
Altitude (km)
–100
–50
0
50
100
Temperature (°C)

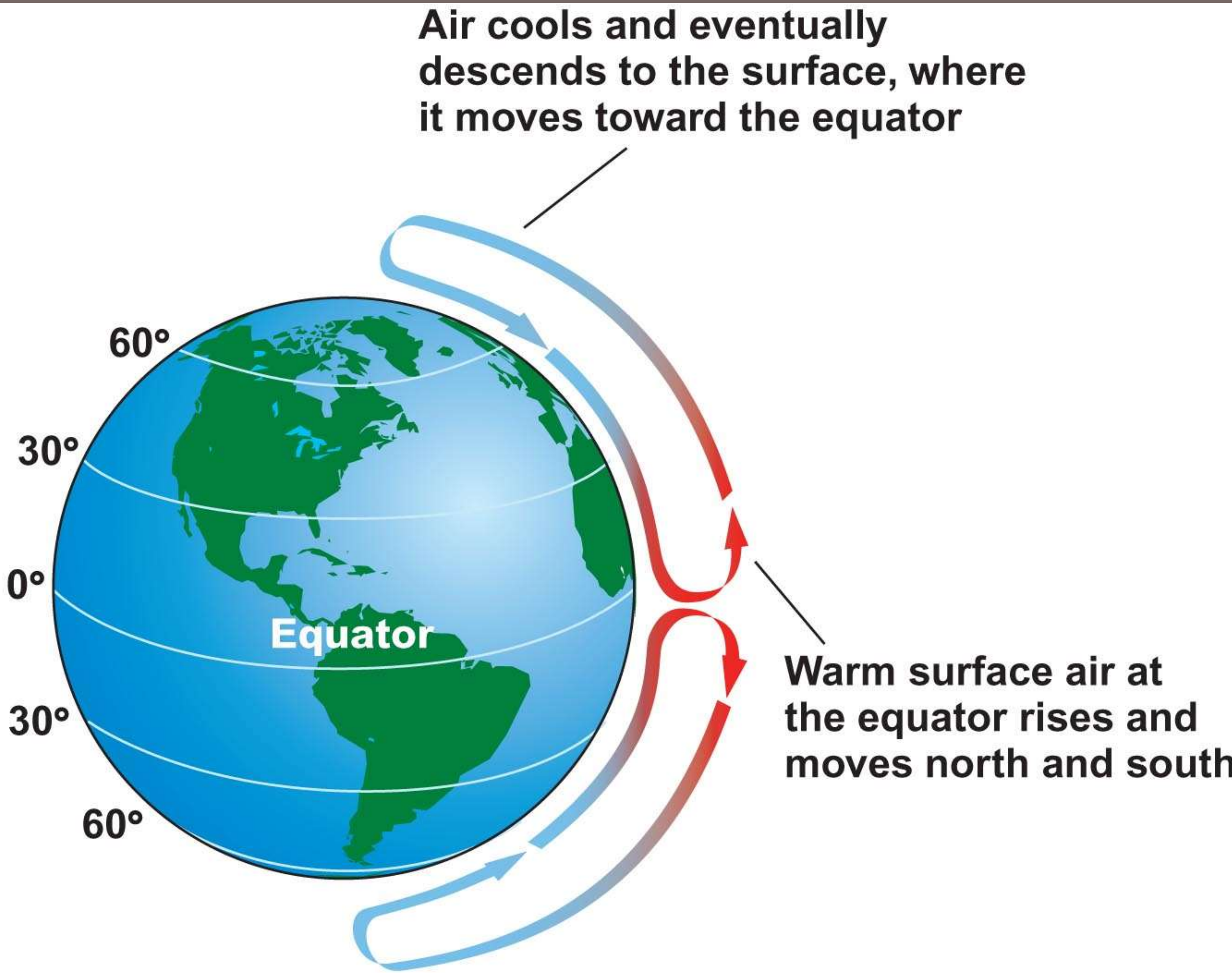
- There is **vertical movement of air** which affects air temperature at a particular altitude
- As a warm, buoyant parcel of air rises, it experiences decreasing atmospheric pressure which allows it to expand and cool.
- **Adiabatic cooling** *is a decrease in air temperature through expansion rather than through heat loss*

- The rate of **adiabatic cooling** depends on the **moisture** in the air and slows with an increase in moisture:
  - **Dry air: 10°C per 1000 m elevation**
  - **Moist air: approximately 6°C per 1000 m elevation**
- The **adiabatic lapse rate** *is the rate of temperature change with altitude*

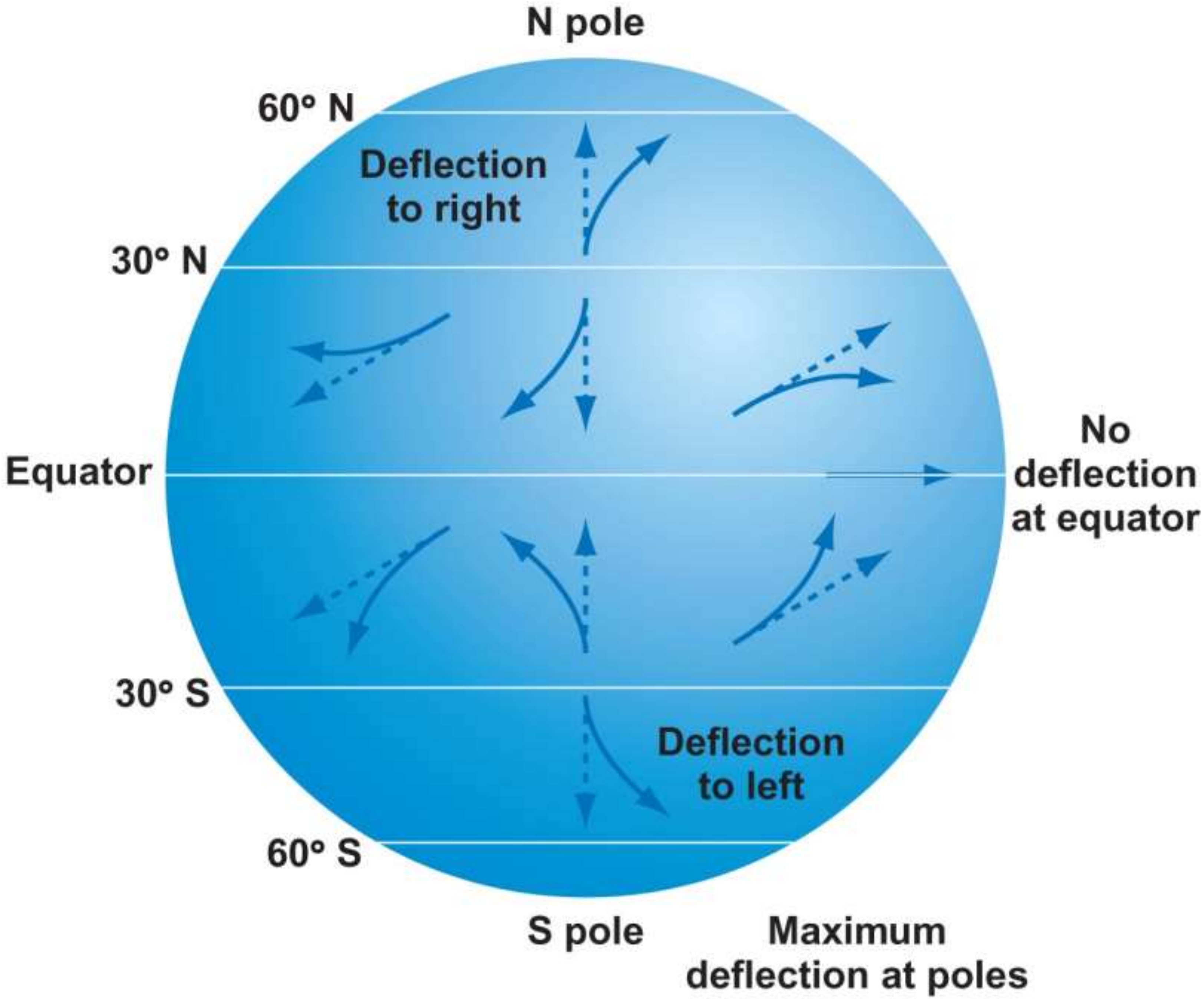
2.4 Air Masses Circulate Globally

- The atmosphere is in a constant state of movement that is driven by **rising** and **sinking** air masses and **by Earth's rotation** on its axis.
- **Air heated in the equatorial region rises to the top of the troposphere**
- As this air rises away from the Earth, an area of **low pressure** establishes at the surface
- More air rises beneath and causes the air in the troposphere to spread toward the north and south poles

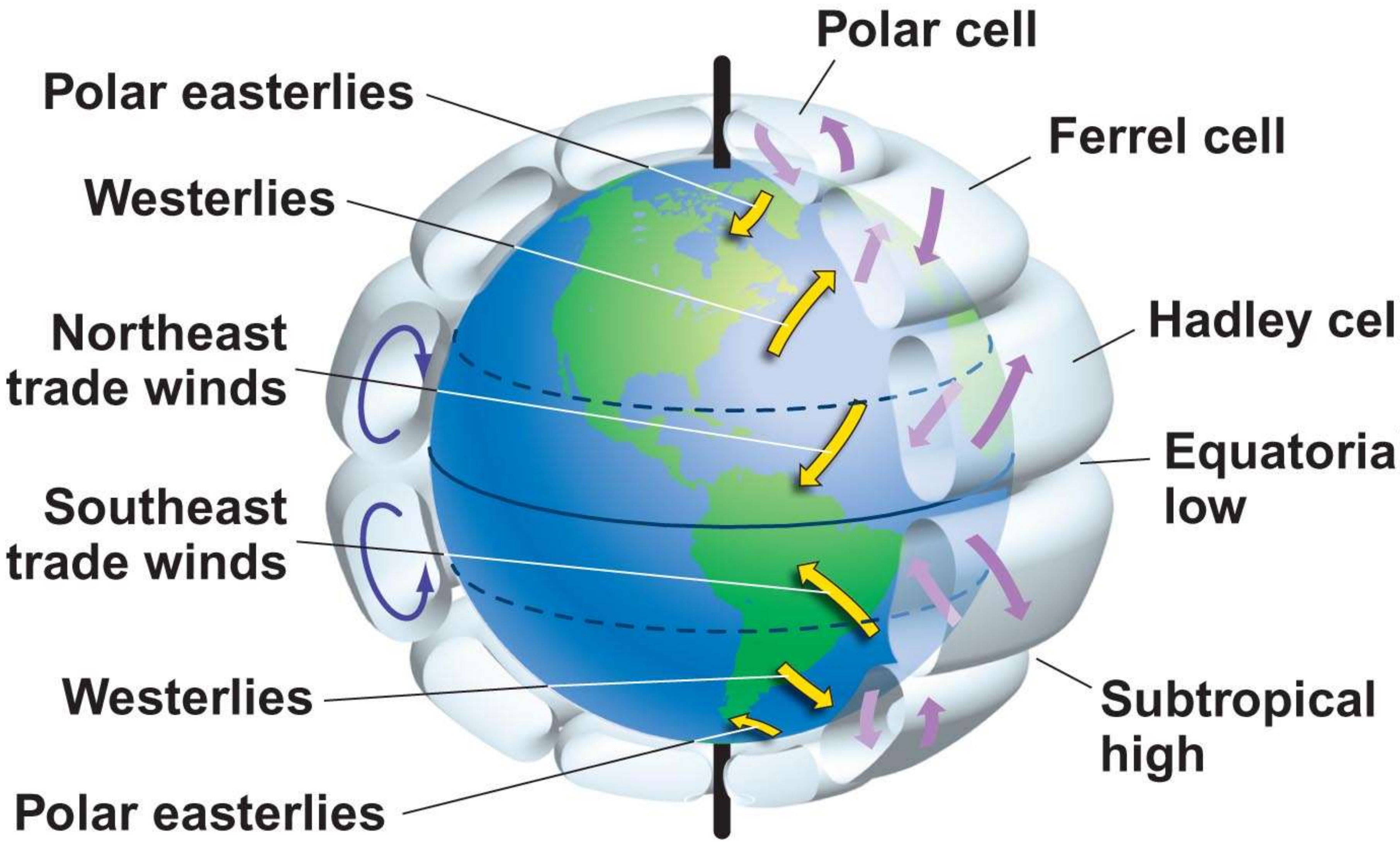
- Air that reaches the **polar areas** cools and sinks to the Earth's surface
- The sinking air **raises surface air pressure**
- The cooled, heavier air then flows toward the low pressure zone at the equator


Air cools and eventually descends to the surface, where it moves toward the equator
60°
30°
0°
Equator
30°
60°
Warm surface air at the equator rises and moves north and south

- The **speed of rotation** at different latitudes on Earth and **irregular topography** further affect air circulation in the atmosphere
- The **Coriolis effect** *is the deflection in the pattern of air flow due to differences in rotation speed*


N pole
60° N
Deflection to right
30° N
Equator
No deflection at equator
30° S
Deflection to left
60° S
S pole
Maximum deflection at poles

- The **Coriolis effect** creates a **series of belts of prevailing winds** and *breaks up the simple flow of surface of air from the equator to the poles*
- The belts and cells of air are formed in the **Northern Hemisphere** and the **Southern Hemisphere** at the same latitudes



Polar cell
Polar easterlies
Ferrel cell
Westerlies
Northeast trade winds
Hadley cell
Equatorial low
Southeast trade winds
Westerlies
Subtropical high
Polar easterlies

- The **equatorial low** is the low-pressure zone created near the surface as heated air rises upward
- The **subtropical high** is created by the descending air cooled at 30° north (**Hadley cells)**

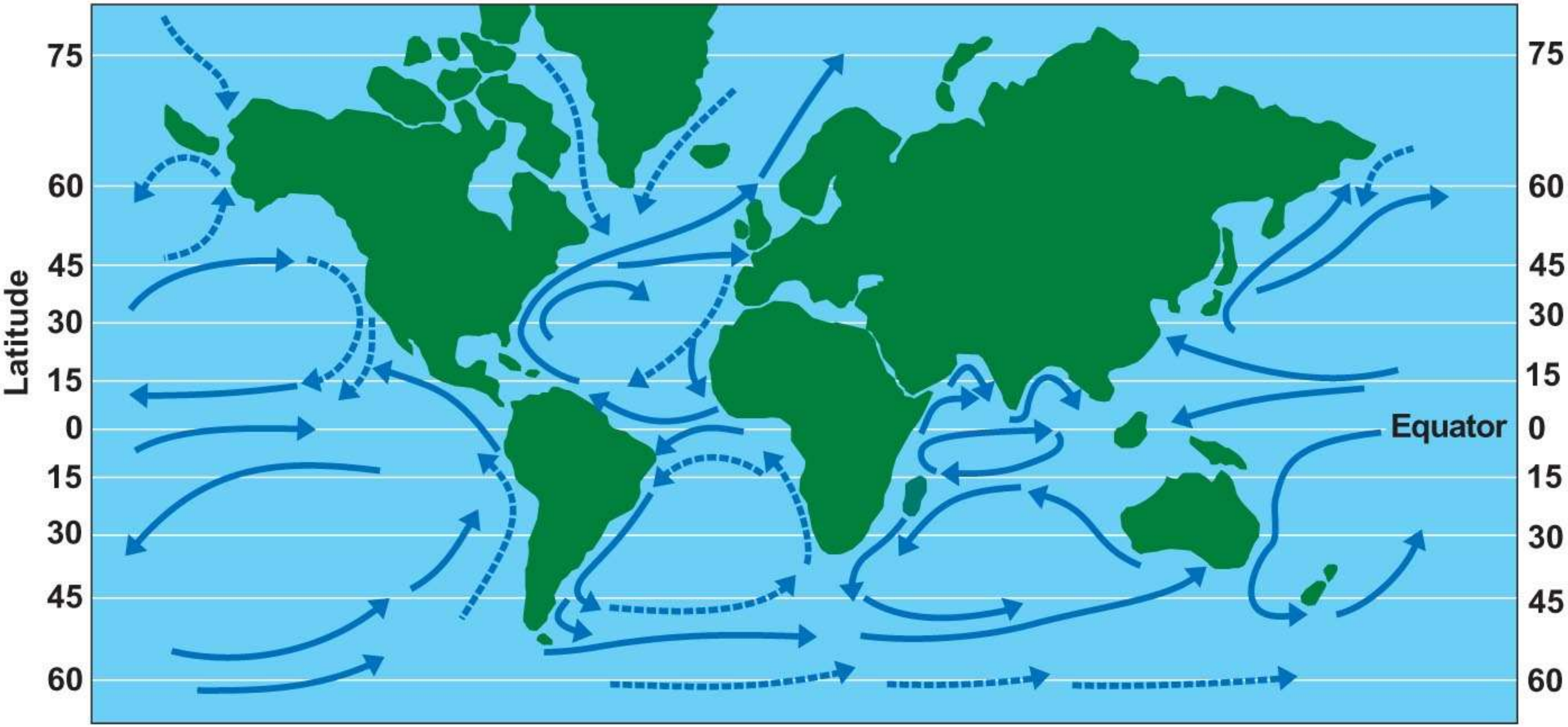
- **Westerlies** are the currents that move toward the poles (away from the Hadley cells) and are diverted to the right by the Coriolis effect
- The **trade winds** are the currents that move toward the equator (away from the Hadley cells) and are deflected to the right by the Coriolis effect

- The **subpolar low** is a zone of low pressure where the westerlies converge with cold air moving down from the poles
- The westerlies and polar air do not readily mix and thus close the loop to form **Ferrel cells**

- As the northward moving air reaches the pole, it slowly sinks and flows back toward lower latitudes to form the **polar cells**
- The **polar easterlies** are formed as air moves away from the poles and this air is deflected to the right by the Coriolis effect

2.5 Solar Energy, Wind, and Earth's Rotation Create Ocean(اوشن) Currents

- *The systematic pattern of water movement, or* **currents**, is determined by the global pattern of prevailing winds
- Two circular water motions (**gyres**) occur in each ocean
  - The ocean current moves **clockwise in the Northern Hemisphere**
  - The ocean current **moves counterclockwise in the Southern Hemisphere**


75
60
45
30
15
0
15
30
45
60
Latitude
75
60
45
30
15
Equator
0
15
30
45
60

2.6 Temperature Influences the Moisture(موسيتشر) Content of Air

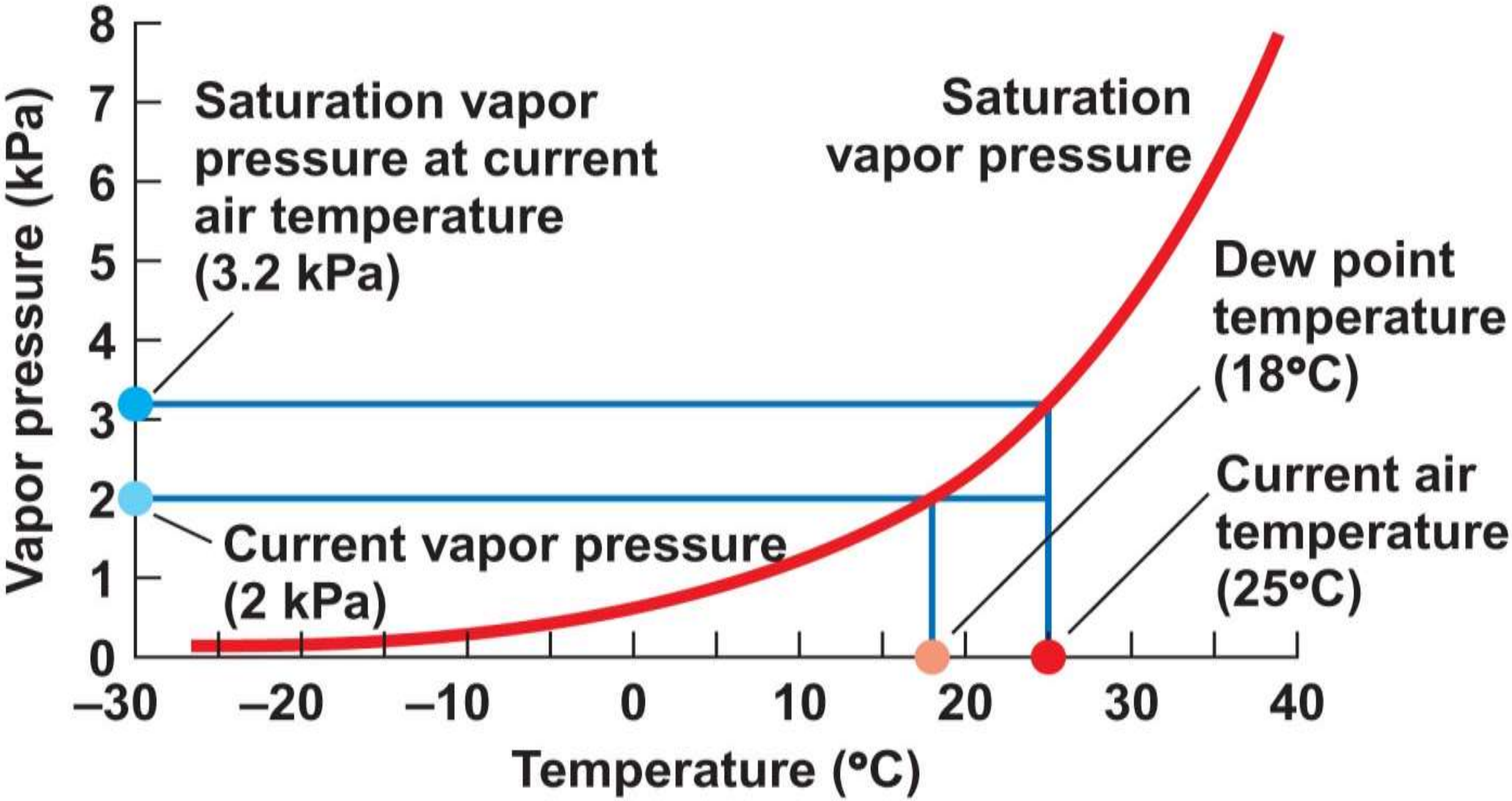
- **Latent heat** is a *measure of the amount of energy released or absorbed (per gram) during a change of state*
  - In going from a more ordered state (liquid) to a less ordered state (gas), **energy is absorbed**.

- **Evaporation** *is the transformation of water from a liquid to a gaseous state*
- **Condensation** *is the transformation of water vapor to a liquid state*
- When the evaporation rate equals the condensation rate, **the air is saturated**

- Water vapor is an independent gas that has weight and exerts pressure in the air
- **Vapor pressure** is the amount of pressure water vapor exerts
- The water vapor content of air at saturation is the **saturation vapor pressure**
  - If this is exceeded, then water condenses

$$\text{Relative humidity} = \frac{\text{Current vapor pressure}}{\text{Saturation vapor pressure}} \times 100$$

$$\text{Relative humidity} = \frac{2\text{kPa}}{3.2\ \text{kPa}} \times 100 = 62.5\%$$

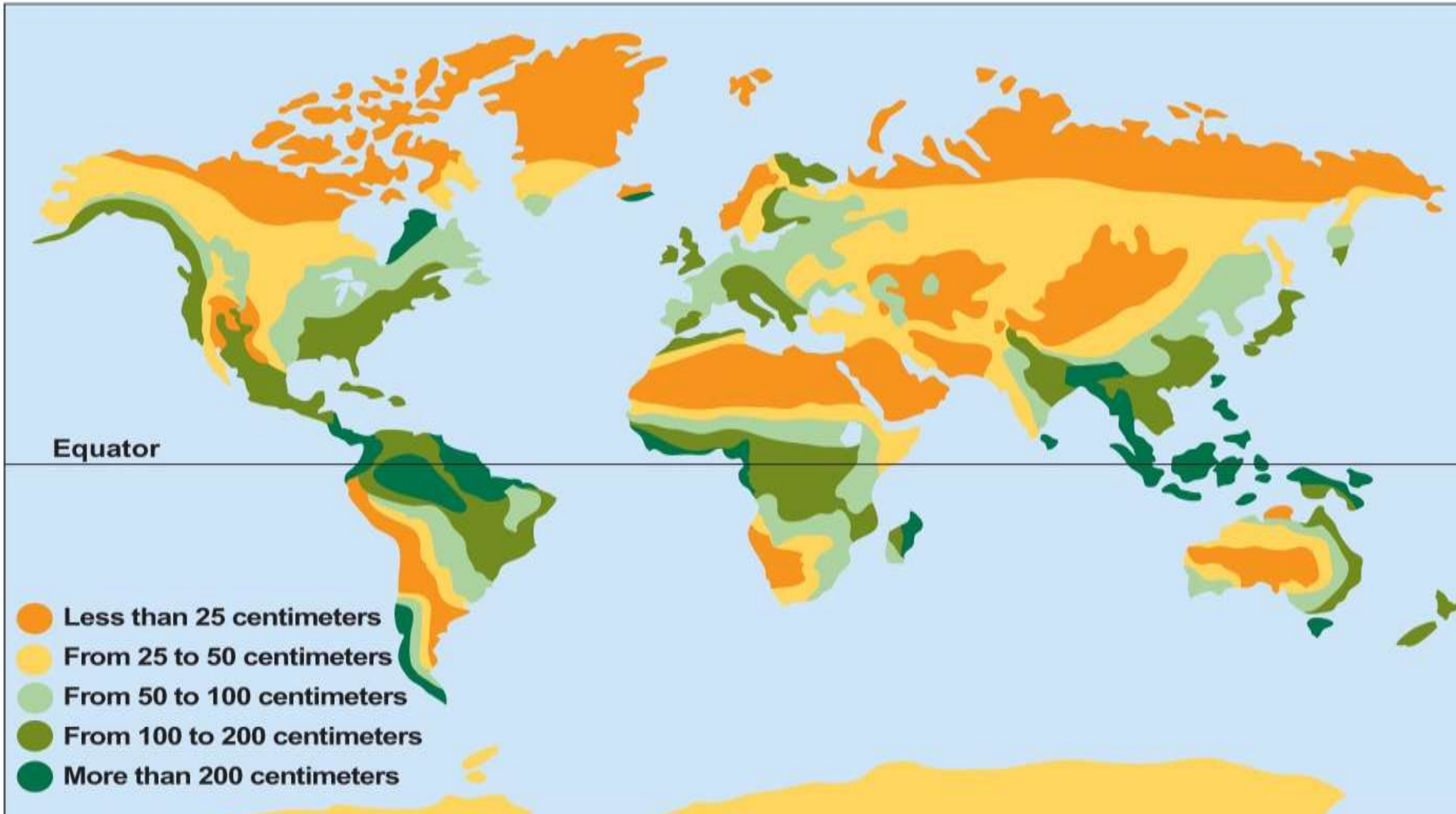


- **Relative humidity** *is the amount of water vapor in the air expressed as the percentage of the saturation vapor pressure*
- At the saturation vapor pressure, the **relative humidity is 100%**
  - If air cools while the water vapor pressure remains constant, **then relative humidity increases** as the saturation vapor pressure declines

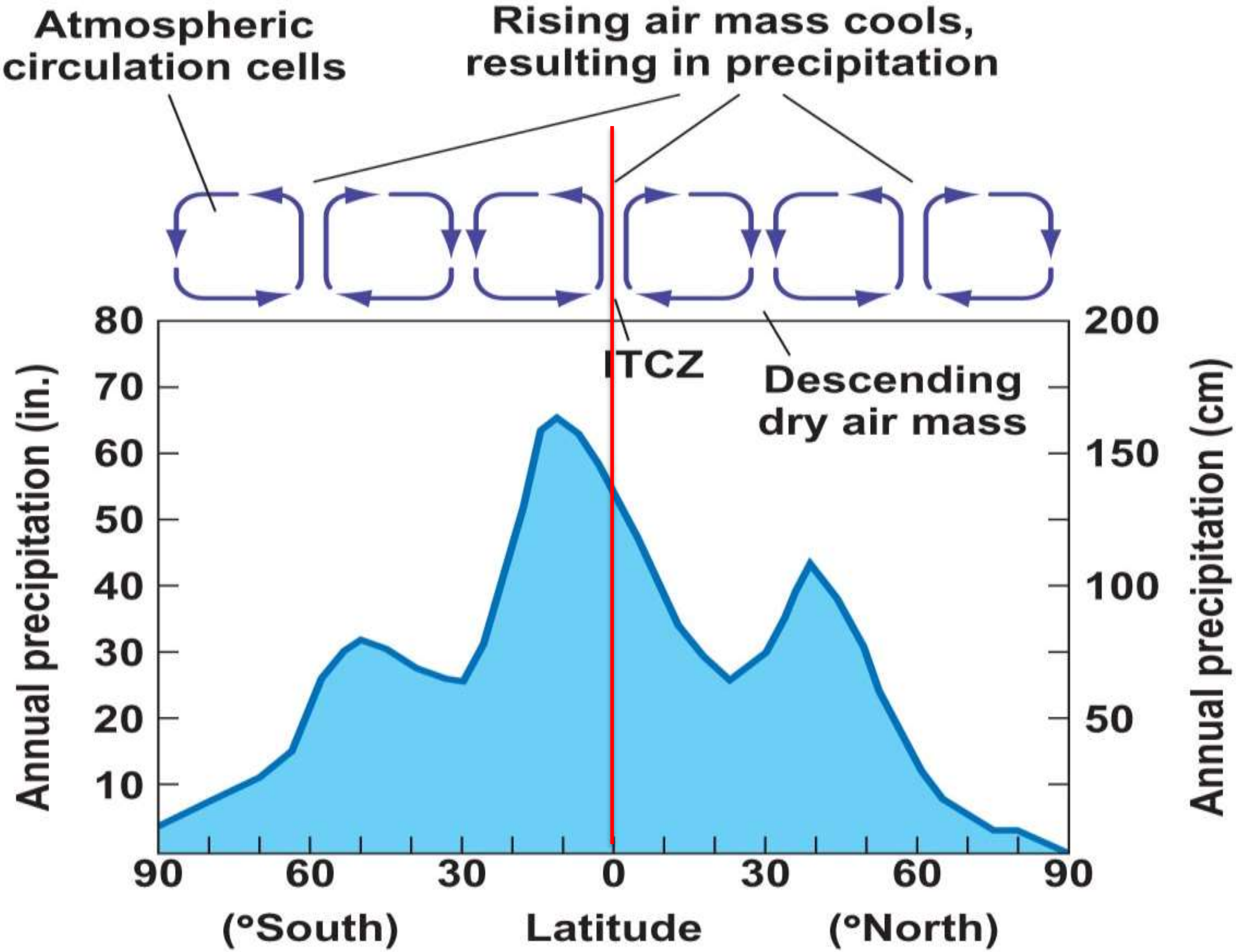
- The temperature at which saturation pressure is achieved is the **dew point temperature**

2.7 Precipitation Has a Distinctive Global Pattern

- Precipitation is not evenly distributed across Earth



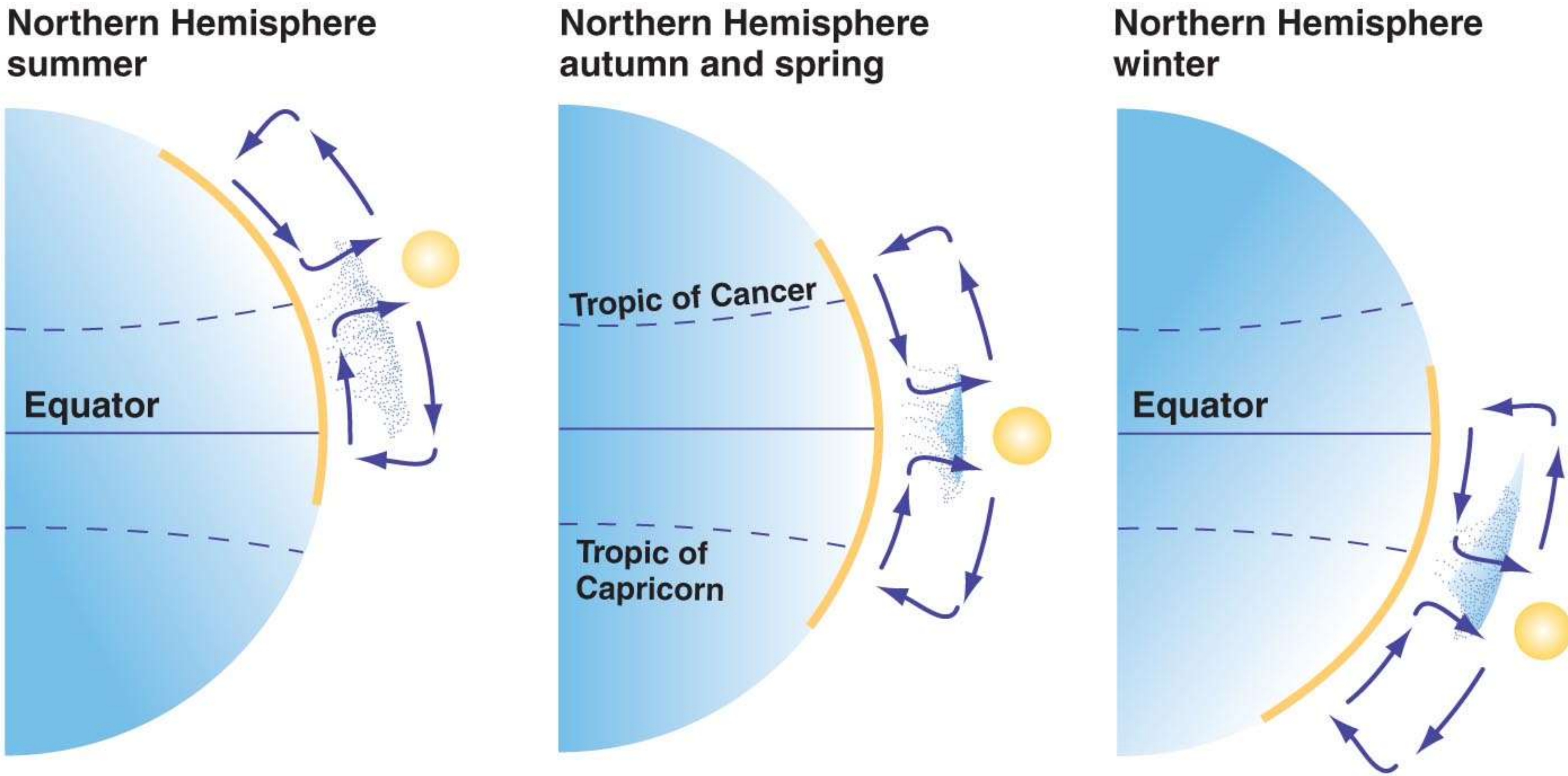
- A **general rainfall pattern exists** on Earth
  - *Precipitation is highest in equatorial regions and declines as you move north and south*
- The declines of precipitation are not continuous because of prevailing wind effects.

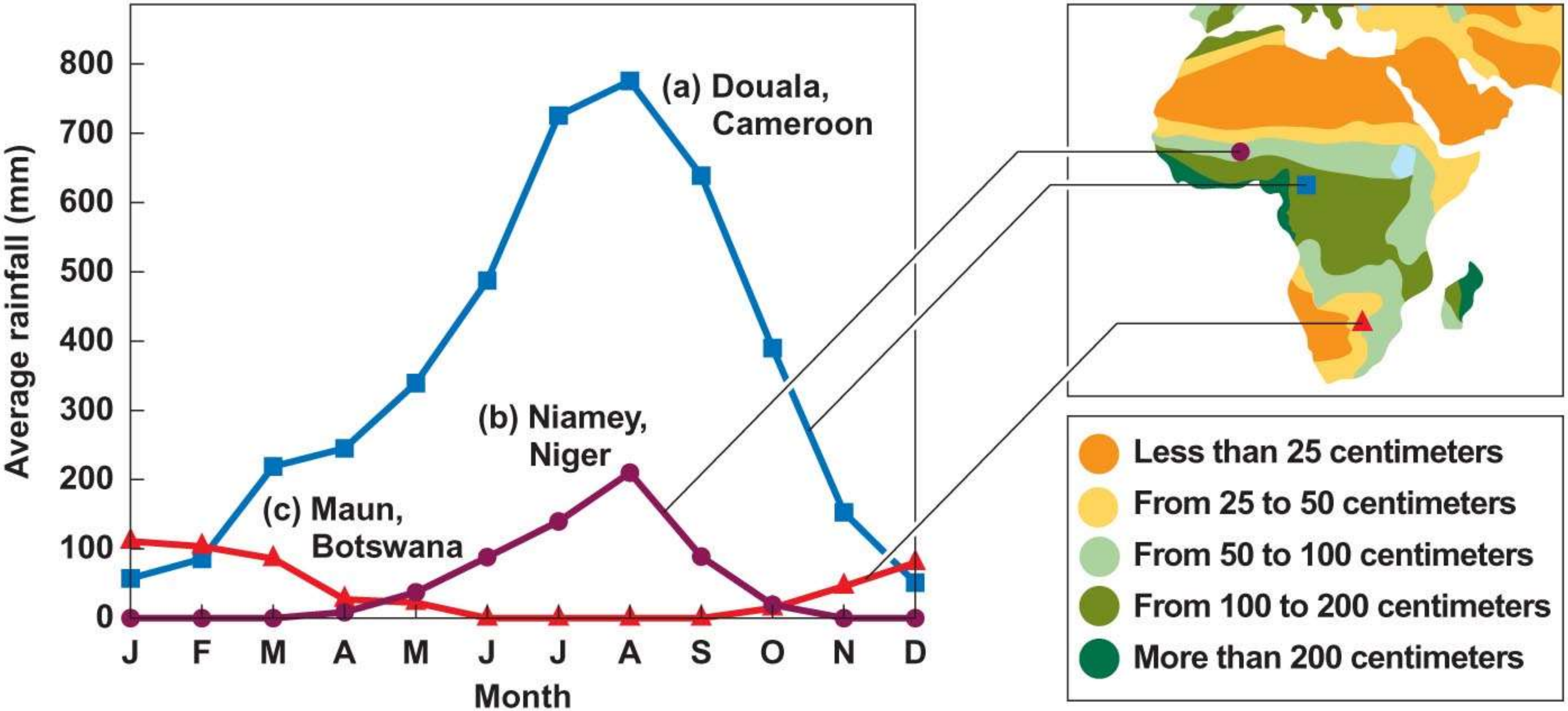


Atmospheric circulation cells
Rising air mass cools, resulting in precipitation
ITCZ
Descending dry air mass
80
70
60
50
40
30
20
10
200
150
100
50
Annual precipitation (in.)
Annual precipitation (cm)
90
60
30
0
30
60
90
(°South)
Latitude
(°North)

- The **intertropical convergence zone (ITCZ)** *is the region that forms where the trade winds meet and is characterized by high amounts of precipitation.*
- Rainfall is generally greater in the Southern Hemisphere because the oceans cover a greater proportion of the Southern Hemisphere.
  - Water evaporates more readily from the water's surface than from terrestrial areas

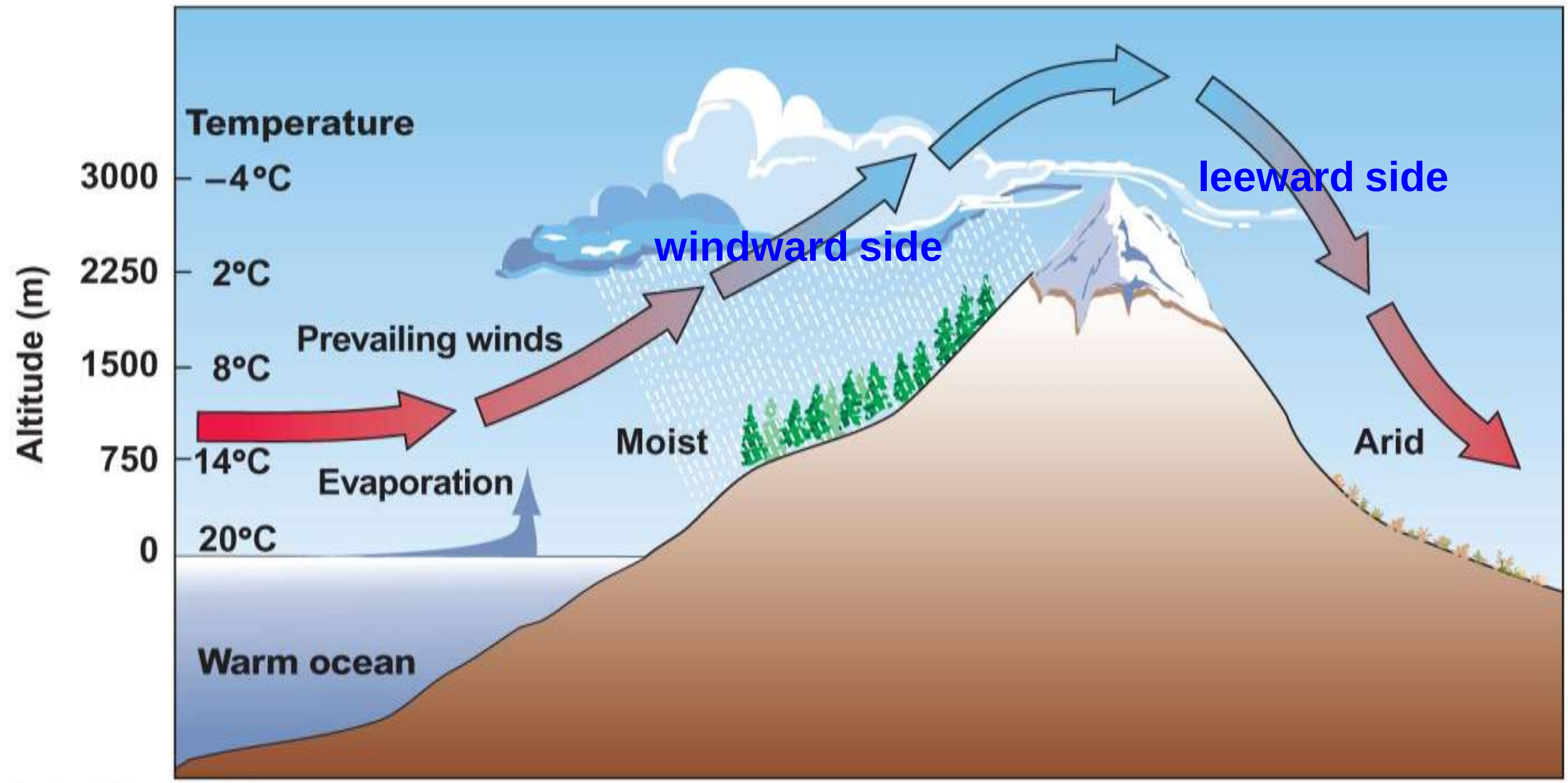
- The **ITCZ** migrates toward regions of the globe with the warmest surface temperature.
- The migration of the ITCZ is responsible for weather conditions as seasons change in the northern and southern latitudes
  - The ITCZ is positioned directly over the equator during the spring and fall equinoxes
  - The ITCZ shifts to northern latitudes during the summer solstice
  - The ITCZ shifts to southern latitudes during the winter solstice


Northern Hemisphere summer
Equator
Northern Hemisphere autumn and spring
Tropic of Cancer
Tropic of Capricorn
Northern Hemisphere winter
Equator


800
700
600
500
400
300
200
100
0
Average rainfall (mm)
(a) Douala, Cameroon
(b) Niamey, Niger
(c) Maun, Botswana
J F M A M J J A S O N D
Month
Less than 25 centimeters
From 25 to 50 centimeters
From 50 to 100 centimeters
From 100 to 200 centimeters
More than 200 centimeters

2.8 Topography Influences Regional and Local Patterns of Precipitation

- Mountainous topography influences local and regional precipitation patterns.
- A **rain shadow** forms on the leeward side of a mountain (or mountain range) due to the loss of moisture from air as it travels up and over the mountains from the windward side.



Temperature
3000
–4°C
2250
2°C
1500
8°C
750
14°C
0
20°C
Altitude (m)
Prevailing winds
Evaporation
Warm ocean
Moist
windward side
leeward side
Arid

(a)

windward side

(b)

leeward side

2.10 Most Organisms Live in Microclimates

- Most organisms live in **local conditions** that do not match the general climate profile of the larger region surrounding them.
- **Microclimates** *define the conditions (e.g., light, heat) organisms live in.*
  - Compare the conditions experienced by an insect at the ground's surface to one at the top of a tree on a windy day

- **Topography** influences the local climatic conditions.
- **Aspect**, the direction that a slope faces, is of particular importance to microclimate conditions.
- In the Northern Hemisphere, because of differences in the exposure to solar radiation:
  - South-facing slopes experience warm, dry, and variable conditions
  - North-facing slopes experience cool, moist, and more uniform conditions.
- The **opposite** is true of south- and north-facing slopes in the Southern Hemisphere.

- ***End of Chapter***