Climate and Vegetation

- Readings
  - E. Reserve – Chapter 3: The Physical Setting/Template (pp. 47-68)
  - Other sources: Strahler and Strahler. 1989. *Elements of Physical Geography*. Chapters 1-6.

Argyroxiphium sandwicense - Haleakala silversword

Climate and Vegetation

- **Goals**
  - Geographic competent (climate's role on vegetation)
  - Know where biomes are & why
  - Ecological factors on biomes & convergence
  - Floristic (faunistic) differences in biomes across Earth

Argyroxiphium sandwicense - Haleakala silversword

Climate and Vegetation

- Plants and animals are distributed over most of the surface of the earth

- Each species, though, has a smaller and unique distribution based on its own history and tolerance to environmental factors

- The Haleakala silversword is restricted to one high-elevation, cinder volcano in East Maui, Hawaii

Argyroxiphium sandwicense -
Haleakala silversword

Climate and Vegetation

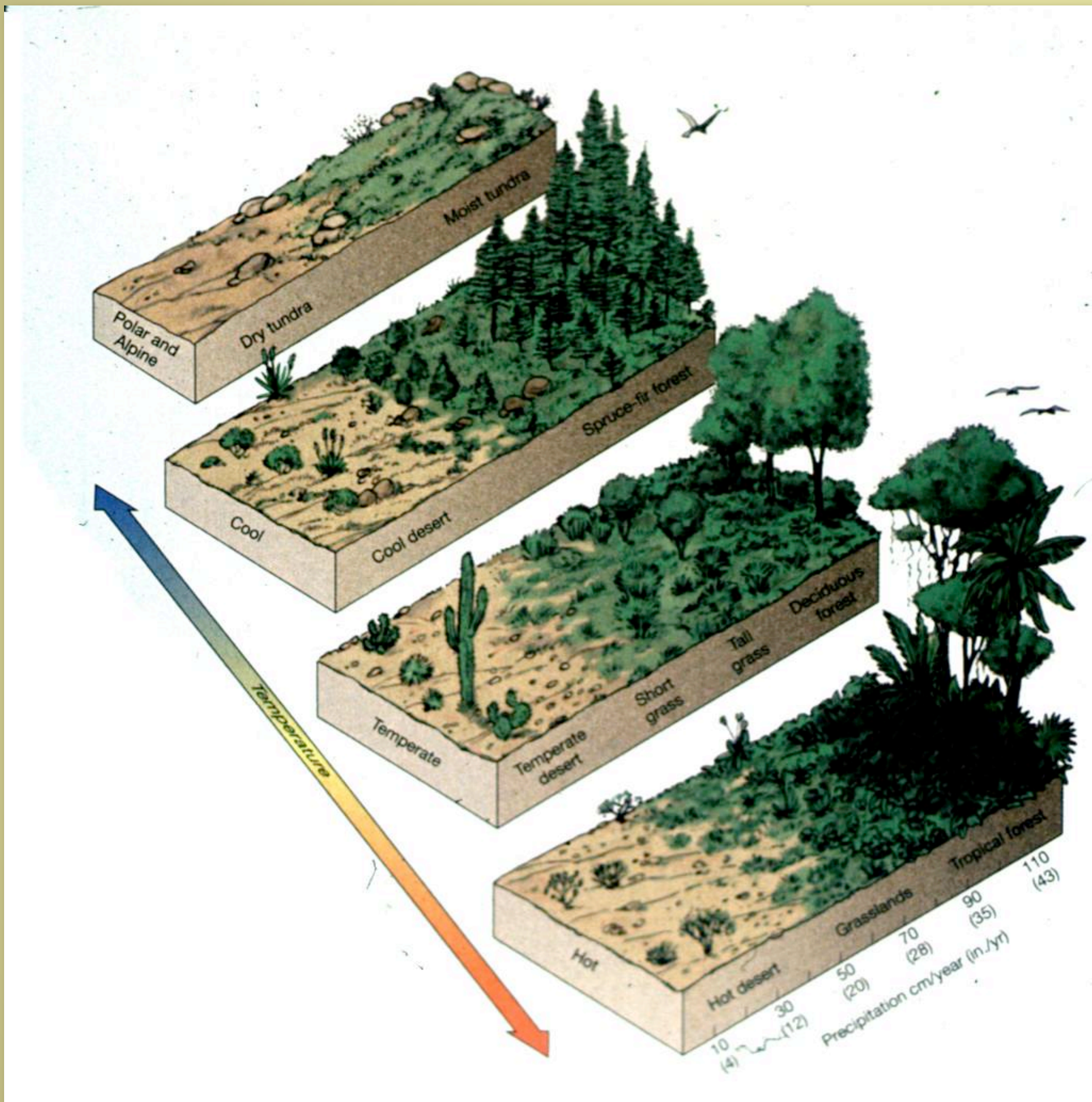
- Species with similar ecological tolerances develop into a plant formation (vegetation) that has similar structural (ecology) characteristics but with a distinctive floristic (flora) makeup in different regions

Puya
Andes

Lobelia
Mt. Kenya

Argyroxiphium sandwicense -
Haleakala silversword

Climate and Vegetation

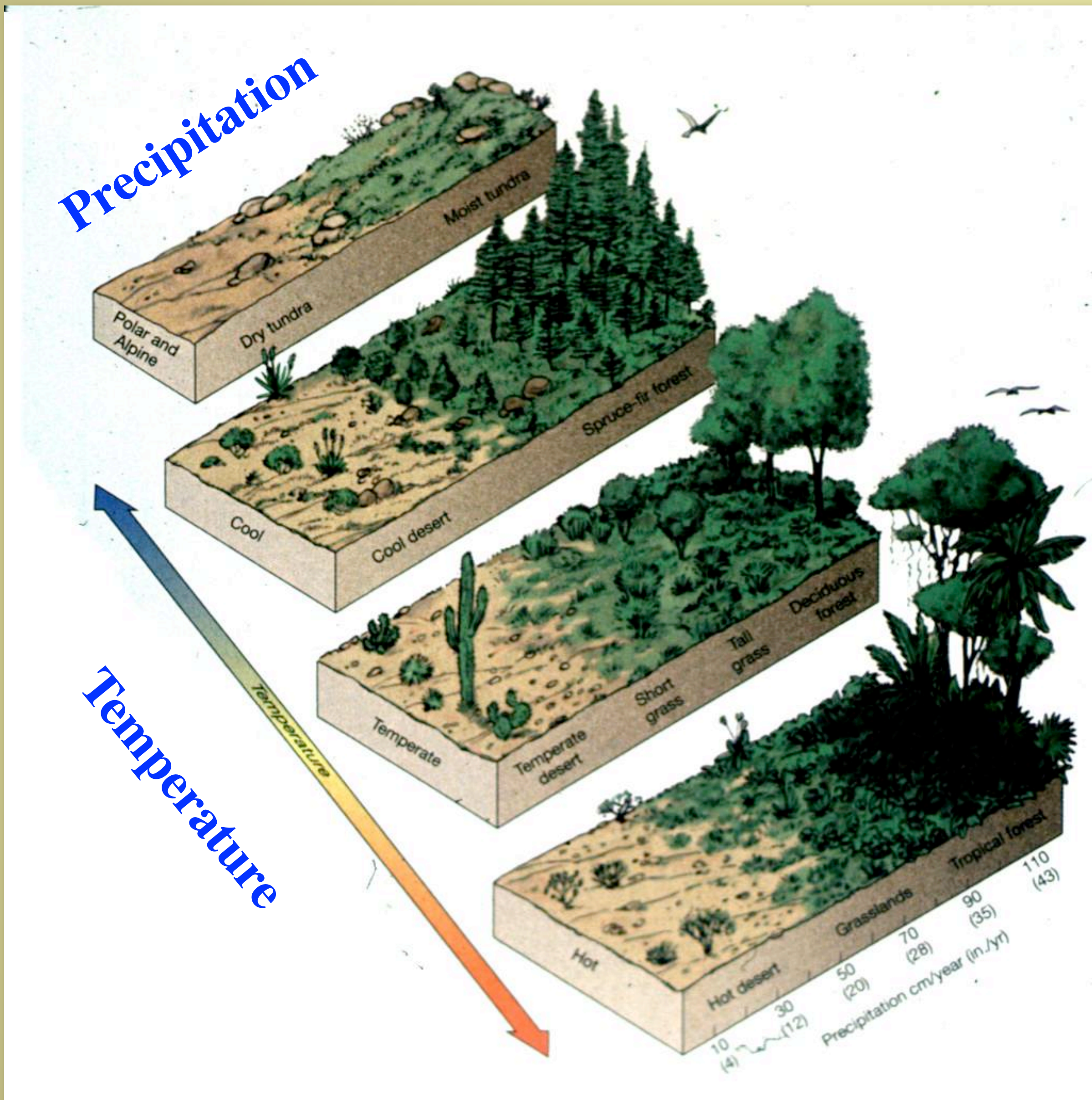


- Species with similar ecological tolerances develop into a plant formation (vegetation) that has similar structural (ecology) characteristics but with a distinctive floristic (flora) makeup in different regions

- At the broadest scale, these plant formations are the major biomes of the world

- The regional extent of each biome is primarily determined by climate, and thus climate is the basis for most plant vegetation systems

Climate and Vegetation

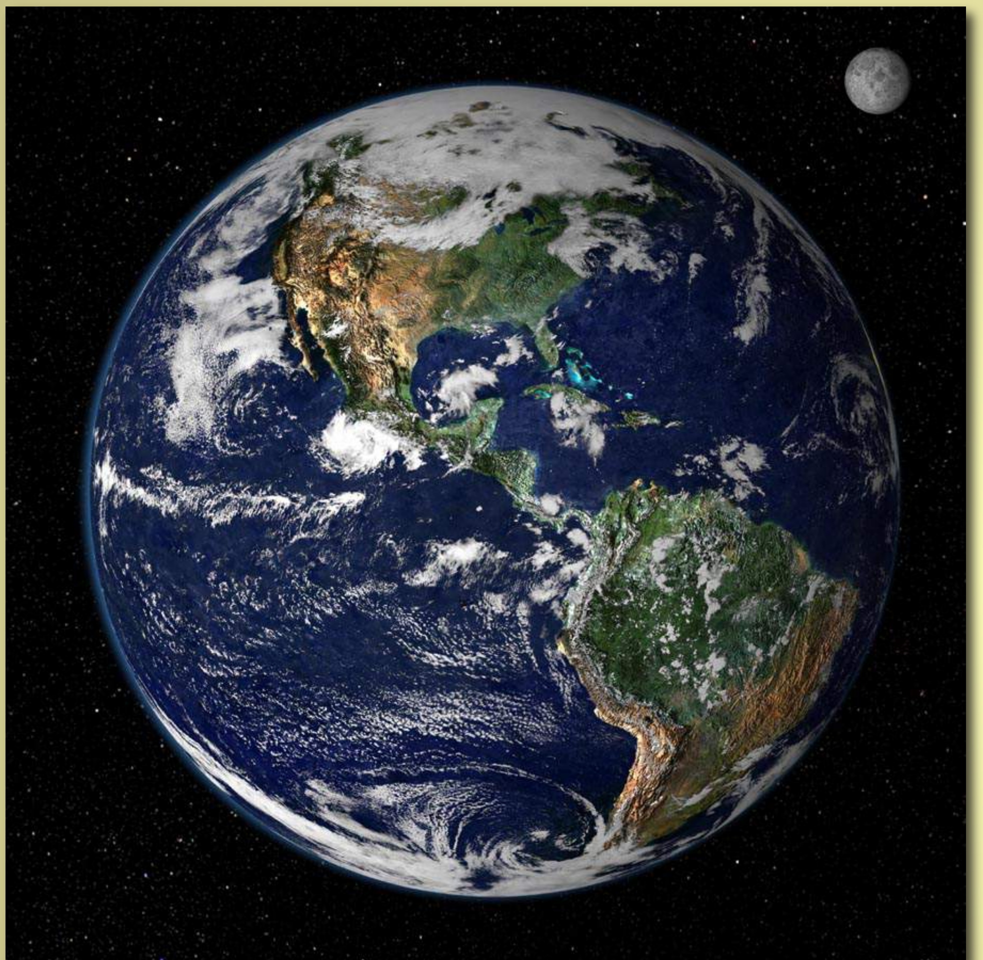


- Alphonse de Candolle in 1874 proposed that heat requirements and drought tolerance were the two major factors dictating the extent of plant formations

- although now more complicated, de Candolle's concept of temperature and precipitation and vegetation formed the basis of most modern classifications of vegetation and climate

- Köppen, Holdridge, Walter

Global Climate and Plant Distribution



- Plant and animal distributions are ultimately determined by **solar radiation** intercepting the atmosphere hydrosphere, lithosphere, and biosphere

- Some energy from sun intercepted by biosphere and converted by photosynthesis into chemical energy

- Most solar energy intercepted by all spheres is converted into or re-radiated as heat energy

Global Climate and Plant Distribution

• Atmosphere is critical for life on earth - only 120 miles high

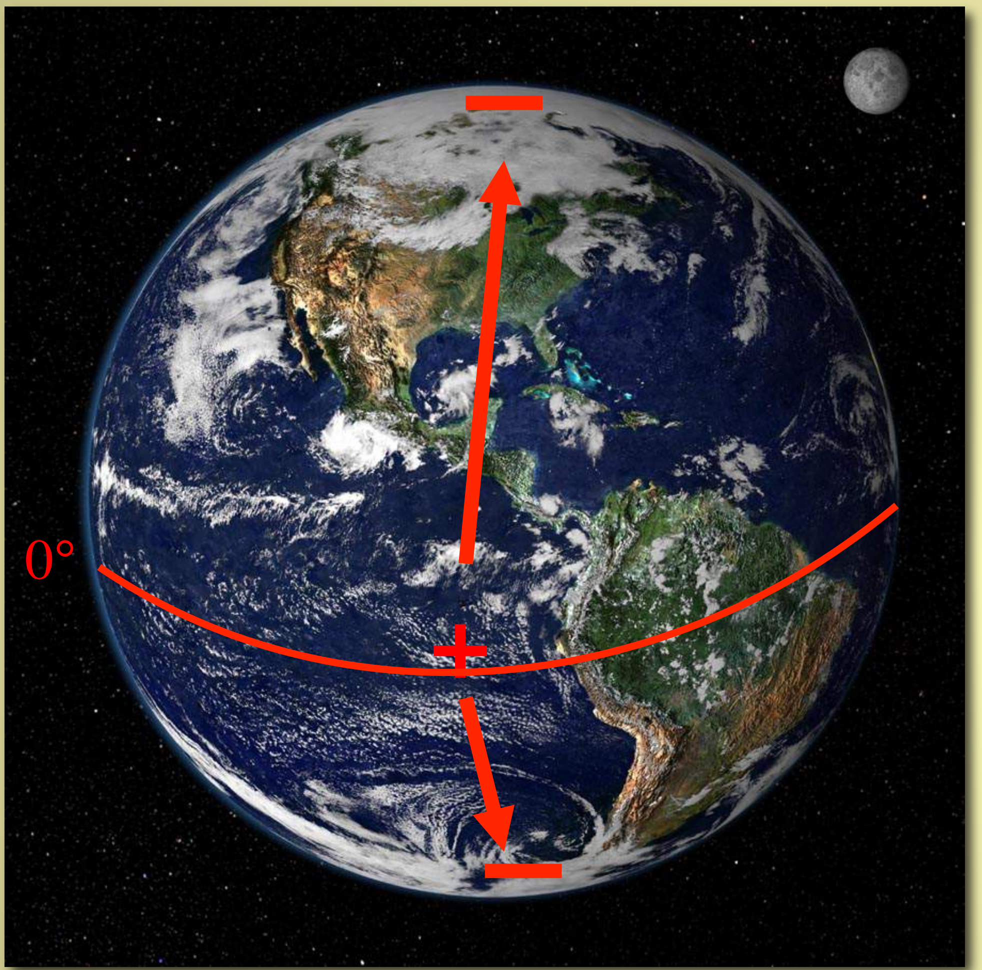
• Plant and animal distributions are ultimately determined by solar radiation intercepting the atmosphere, hydrosphere, lithosphere, and biosphere

• Some energy from sun intercepted by biosphere and converted by photosynthesis into chemical energy

• Most solar energy intercepted by all spheres is converted into or re-radiated as heat energy

For the first time in my life I saw the horizon as a curved line. It was accentuated by a thin seam of dark blue light – our atmosphere. Obviously this was not the ocean of air I had been told it was so many times in my life. I was terrified by its fragile appearance.
– Ulf Merbold

Global Climate and Plant Distribution

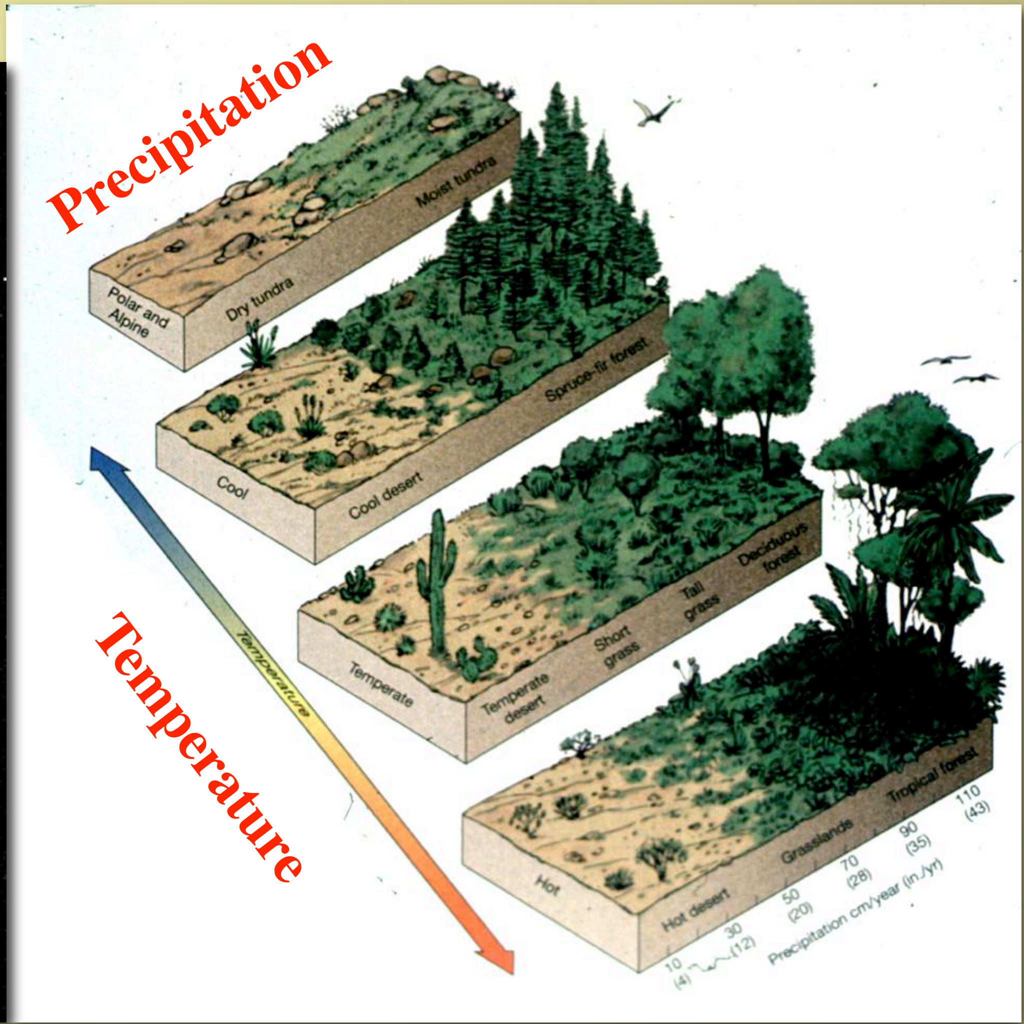


- Tropics or low latitudes show net energy gain or surplus; poles or high latitudes experience net-negative radiation balance

- Sets up energy or heat circulation from low to high latitudes by movement of atmosphere (air currents) and hydrosphere (water currents)

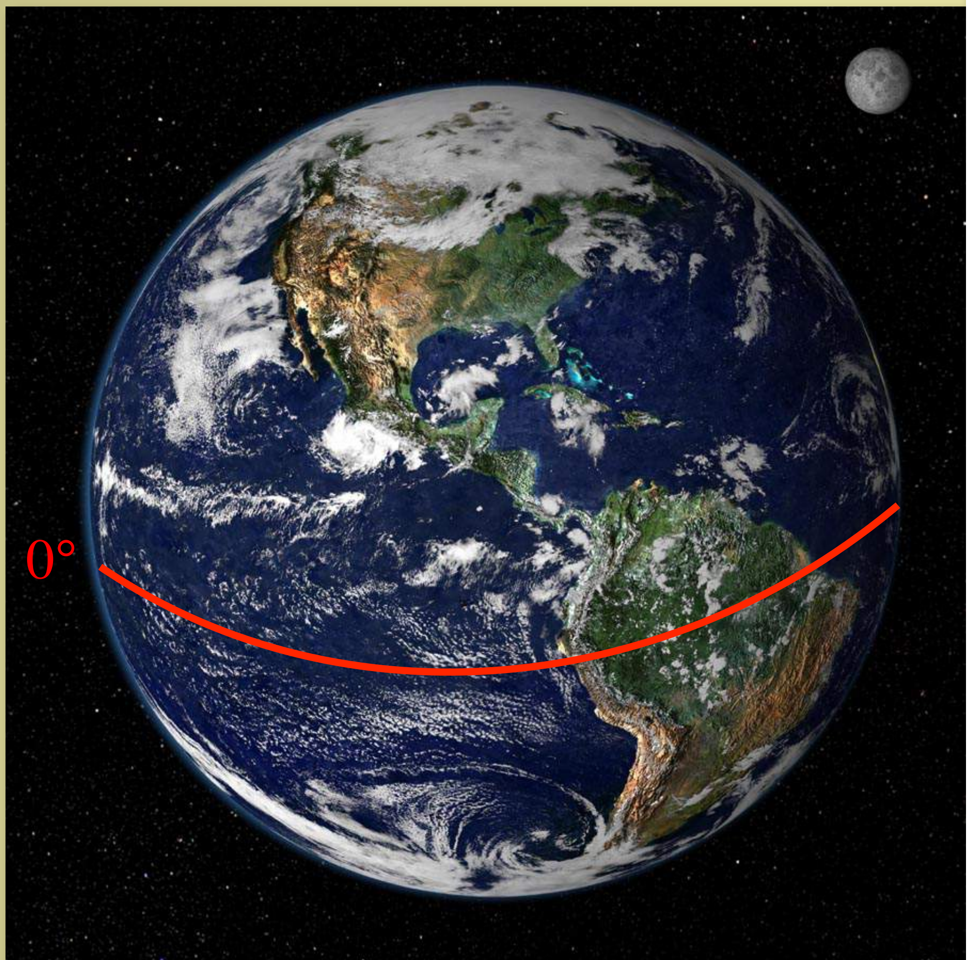
- Wind and ocean circulation patterns largely determine global temperature and precipitation that a given area experiences (climate)

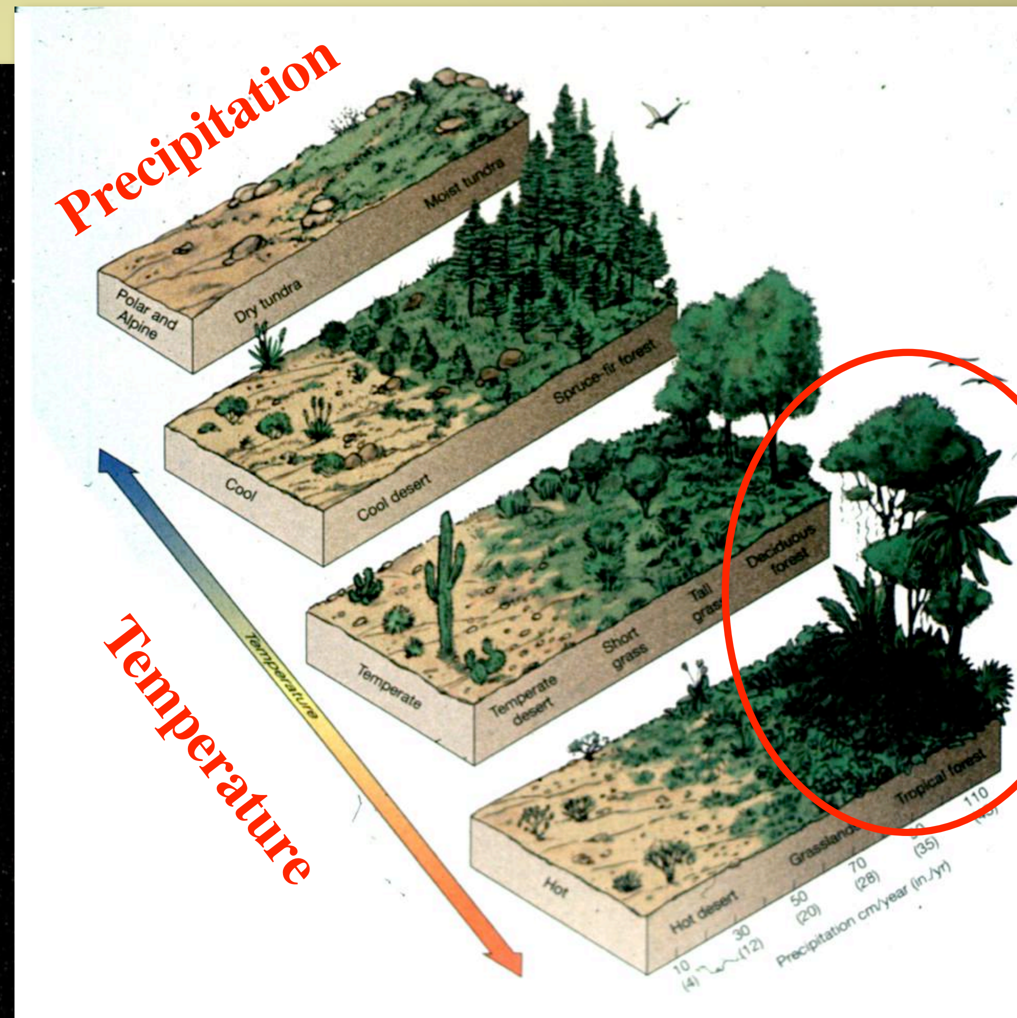
Global Climate and Plant Distribution



These broad patterns are responsible for specific climate and vegetation in specific areas

Global Climate and Plant Distribution

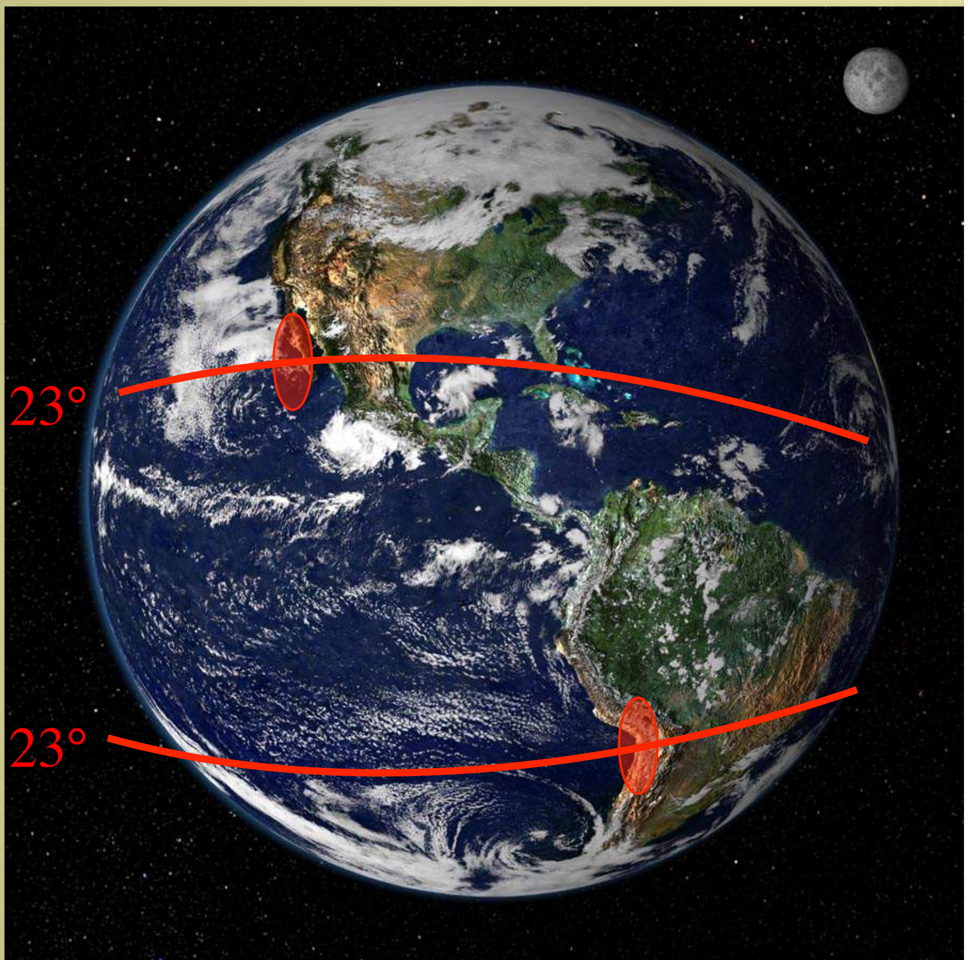


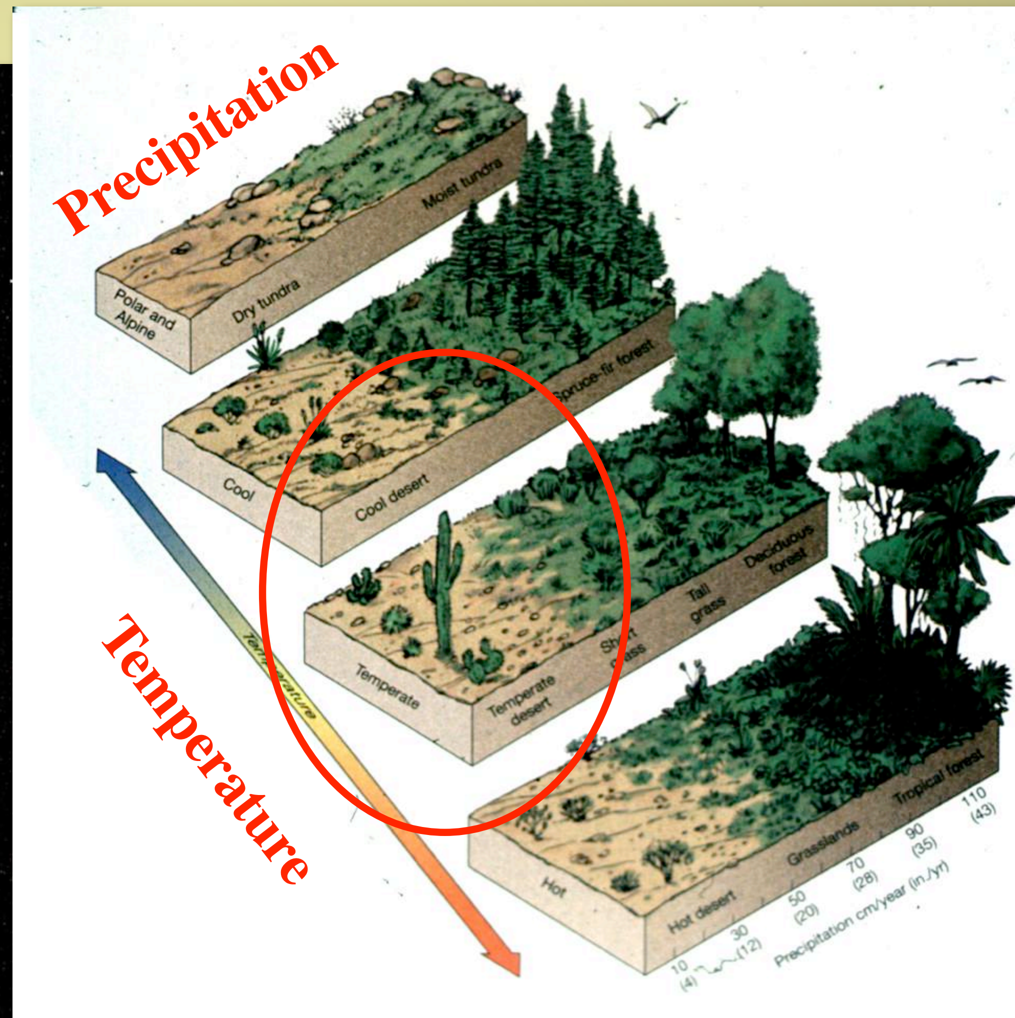


For example

- Wet, hot at equator → Tropical rain forests

Global Climate and Plant Distribution





• Dry, warm at 23° N & S → Deserts (Baja California & Atacama)

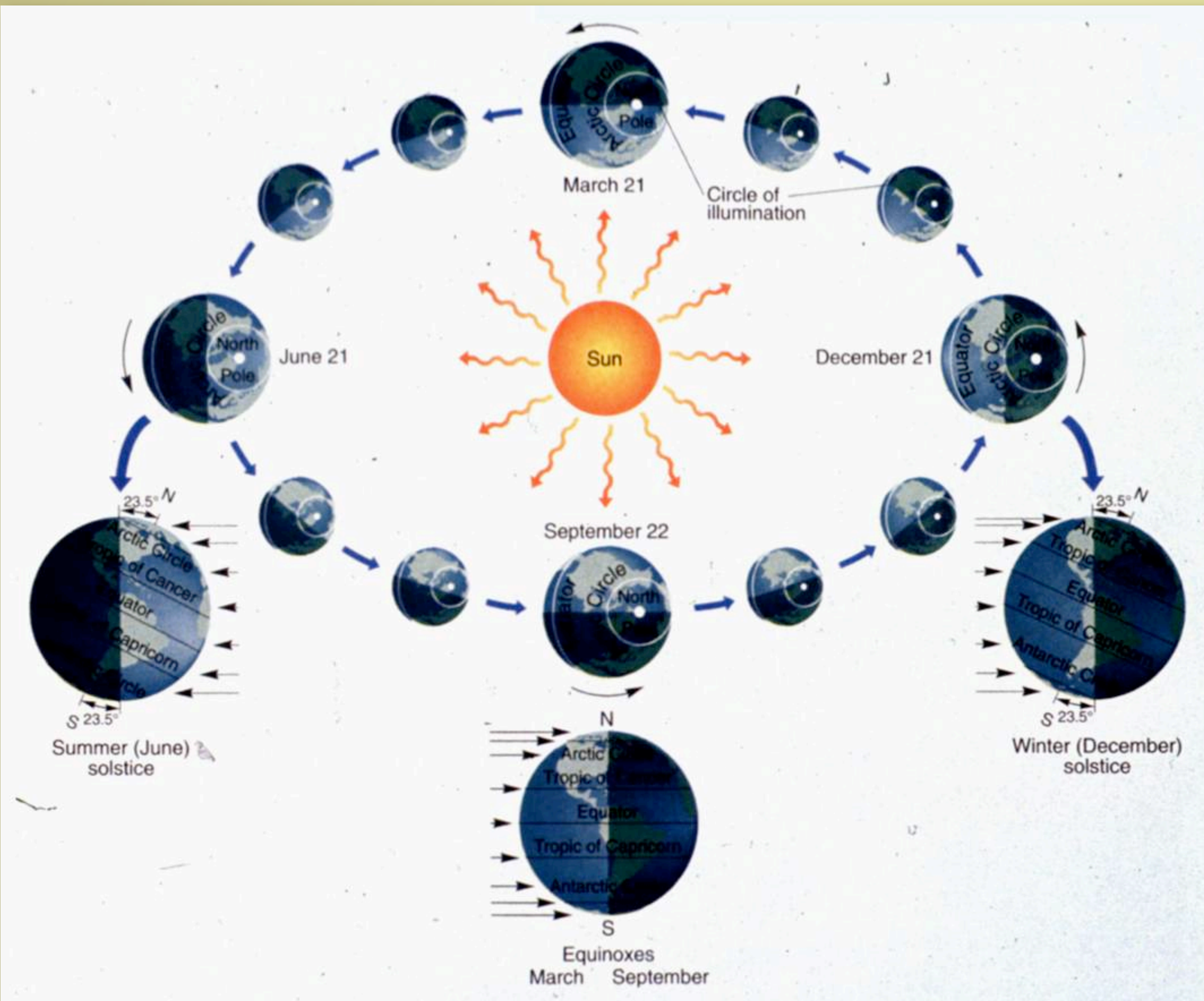
West sides of continents only

Earth's Spherical Habit

1. **Rotation on axis**

- Causes daily diurnal pattern that plants and animals can respond to
- Causes mysterious Coriolis effect that is so important in placement of plant biomes

Earth's Spherical Habit

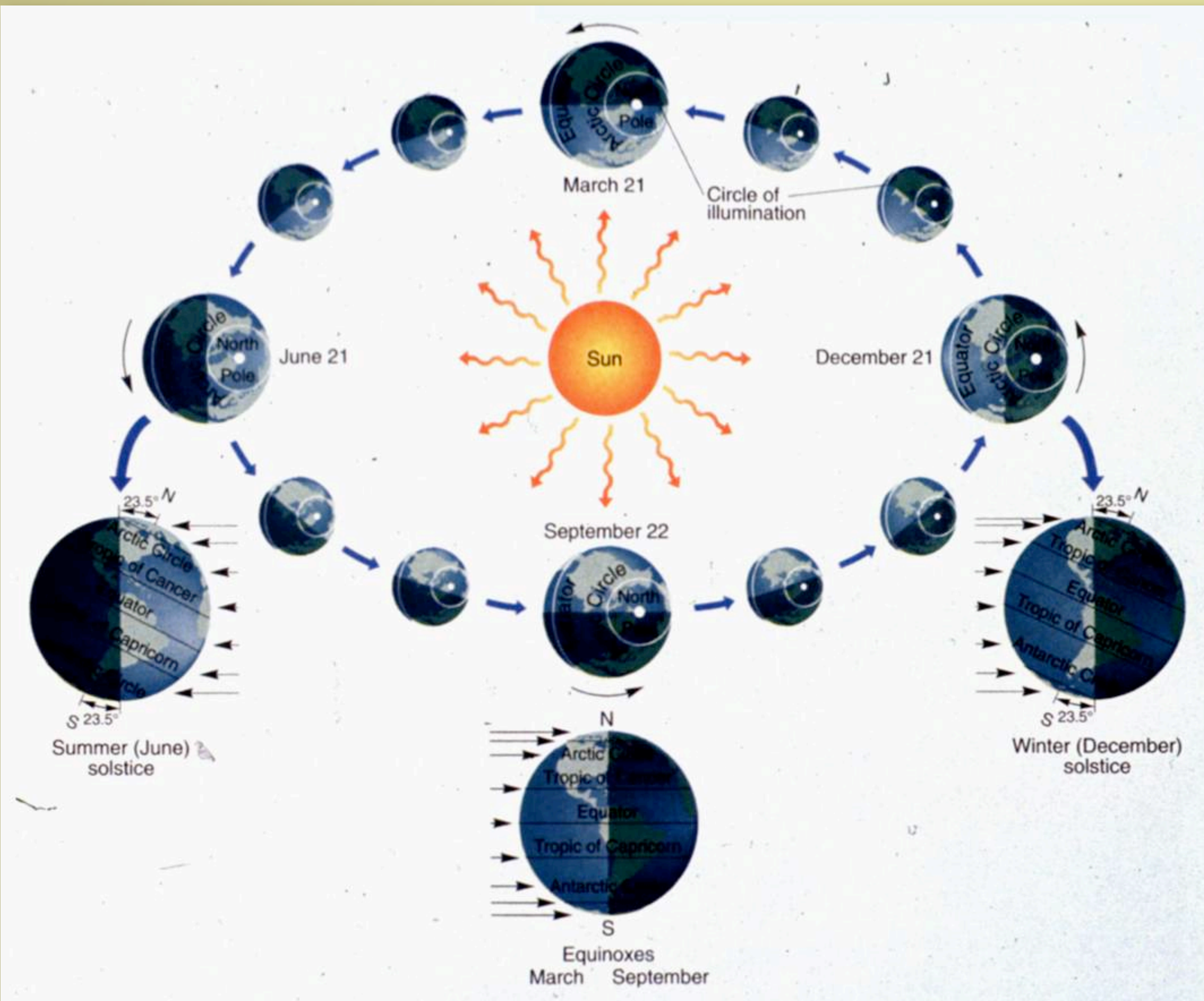


Annual march of the seasons as earth revolves around the sun. Shading indicates the changing position of the circle of illumination in the Northern Hemisphere.

2. **Revolution around sun**

- Sets tropical year = 365 days
- Sets the *timing* for climatic seasons that influence plant formations on earth

Earth's Spherical Habit



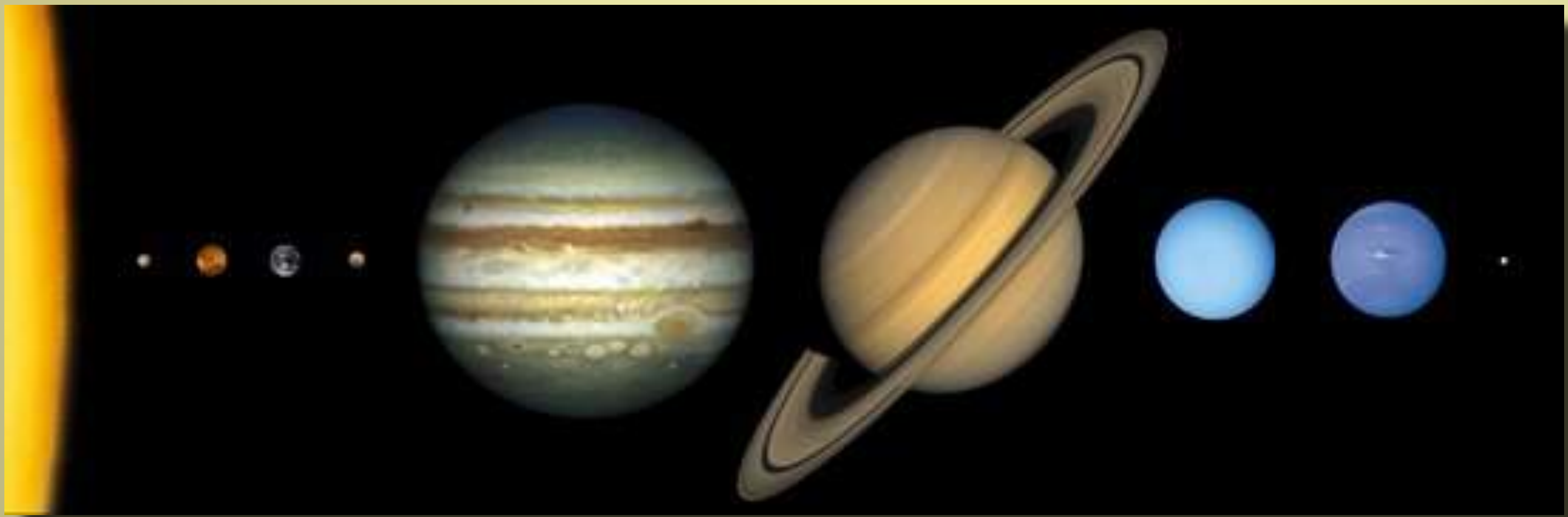
Annual march of the seasons as earth revolves around the sun. Shading indicates the changing position of the circle of illumination in the Northern Hemisphere.

3. **Tilt of earth's axis**

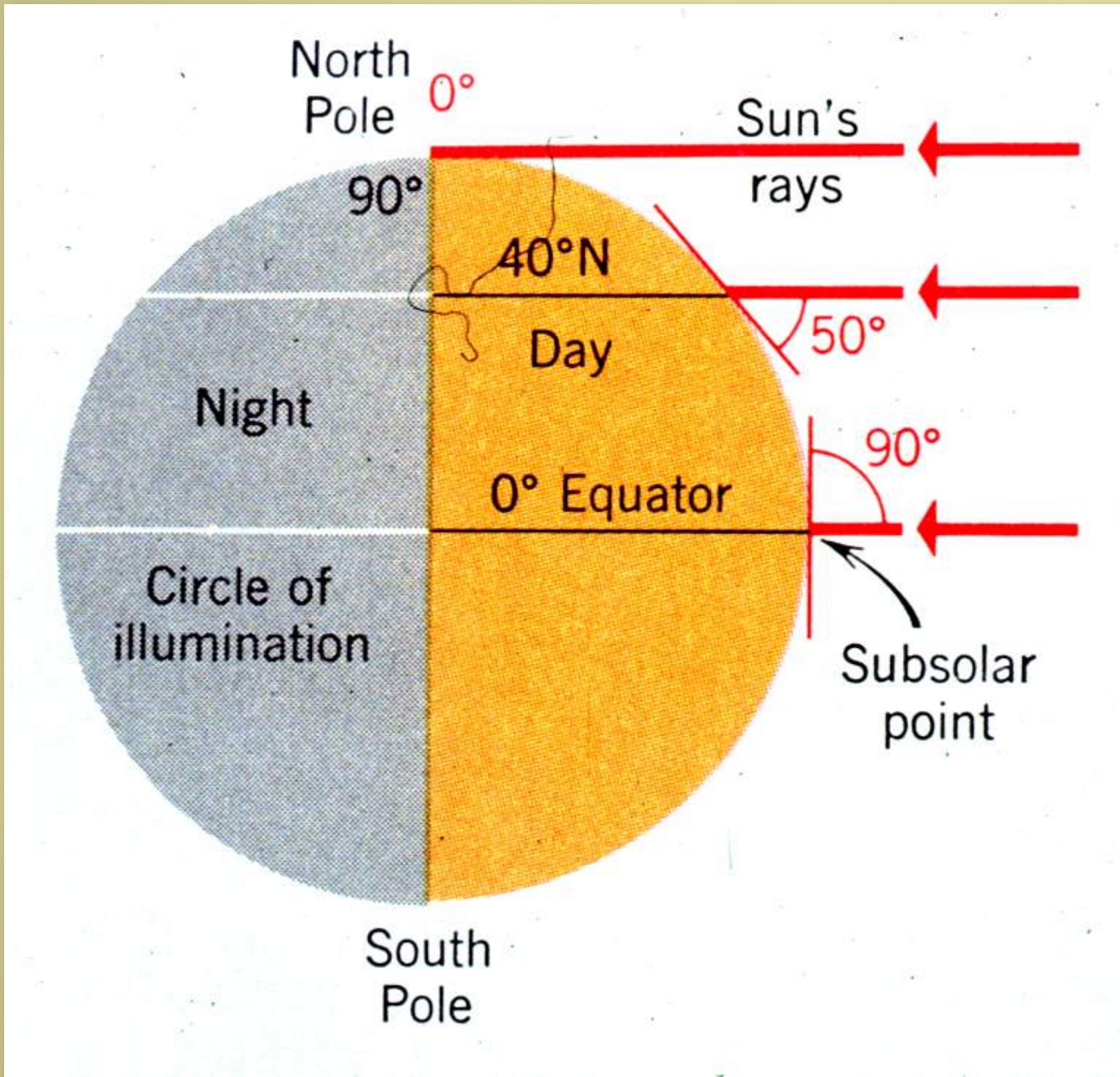
- The earth's axis is not perpendicular to the *plane of the ecliptic* - the plane on which the earth moves during a year
- Responsible for *causing climatic seasons*

Plane of the ecliptic

- All planets except Pluto lie on this plane [R to L: moon, sun, Saturn, Mars, Mercury]
- Like earth, some other planets show a tilt of their axis away from the perpendicular relative to the plane of the ecliptic



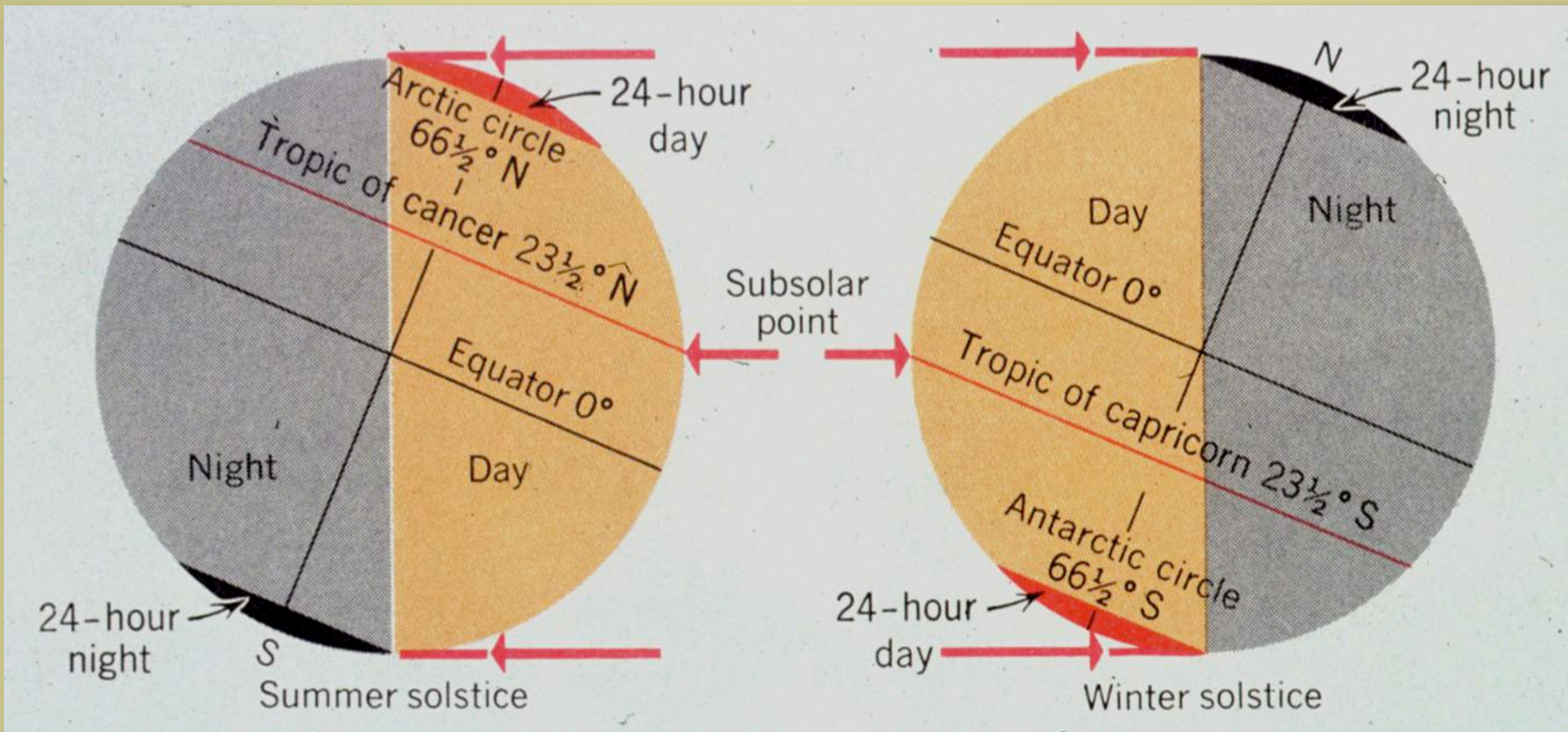
Earth's Spherical Habit



What if earth had no tilt?

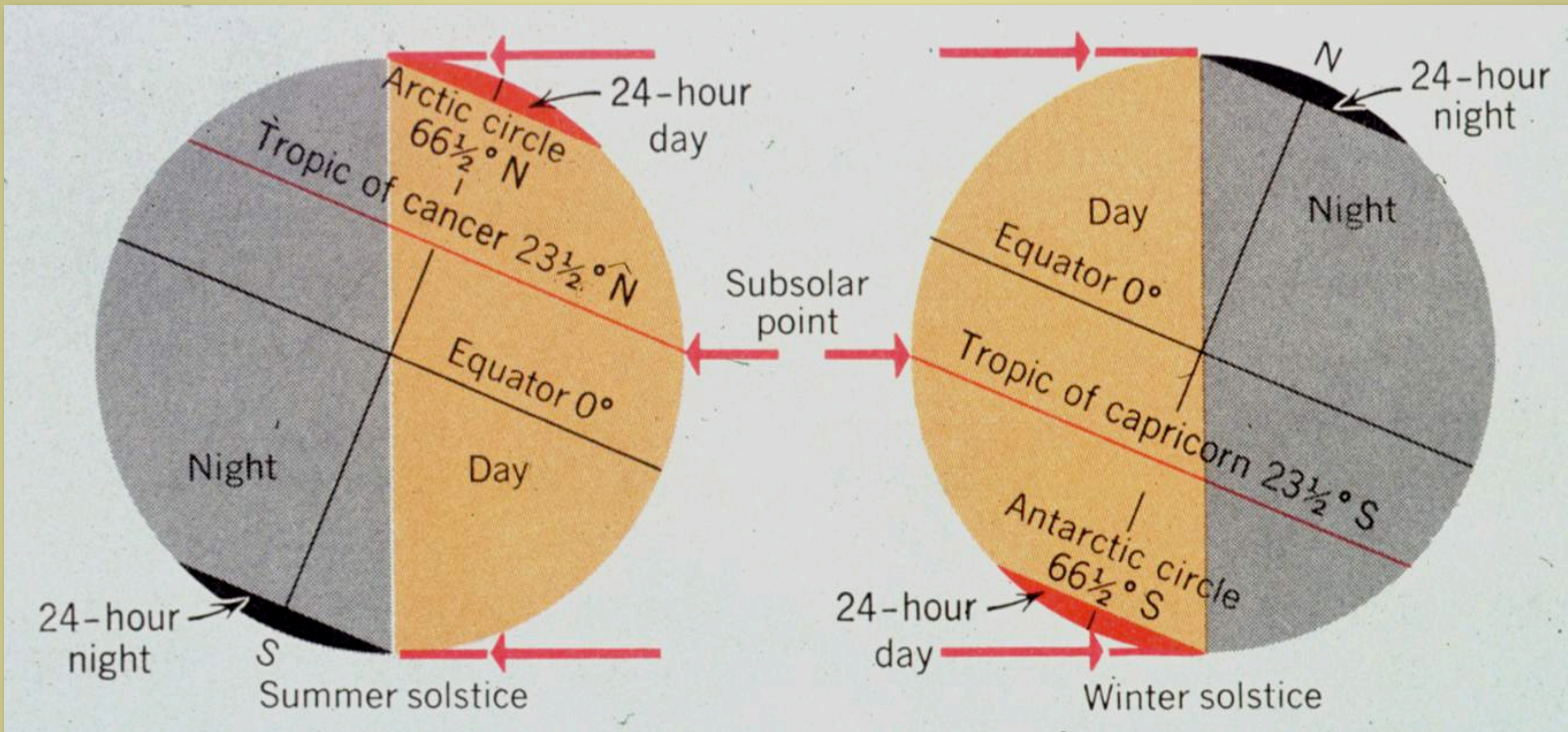
- Equator lies exactly on the plane of the ecliptic all the time
- Sun strikes the equator most directly (**subsolar point**) all the time
- Sun's rays just graze the North and South Poles all the time
- Every day would be the same; **there would be no seasons**; vegetation would be quite different!

Earth's Spherical Habit



- Earth's axis tilt is 23½° to the plane of the ecliptic
- Earth's axis maintains fixed orientation to the stars (Polaris)

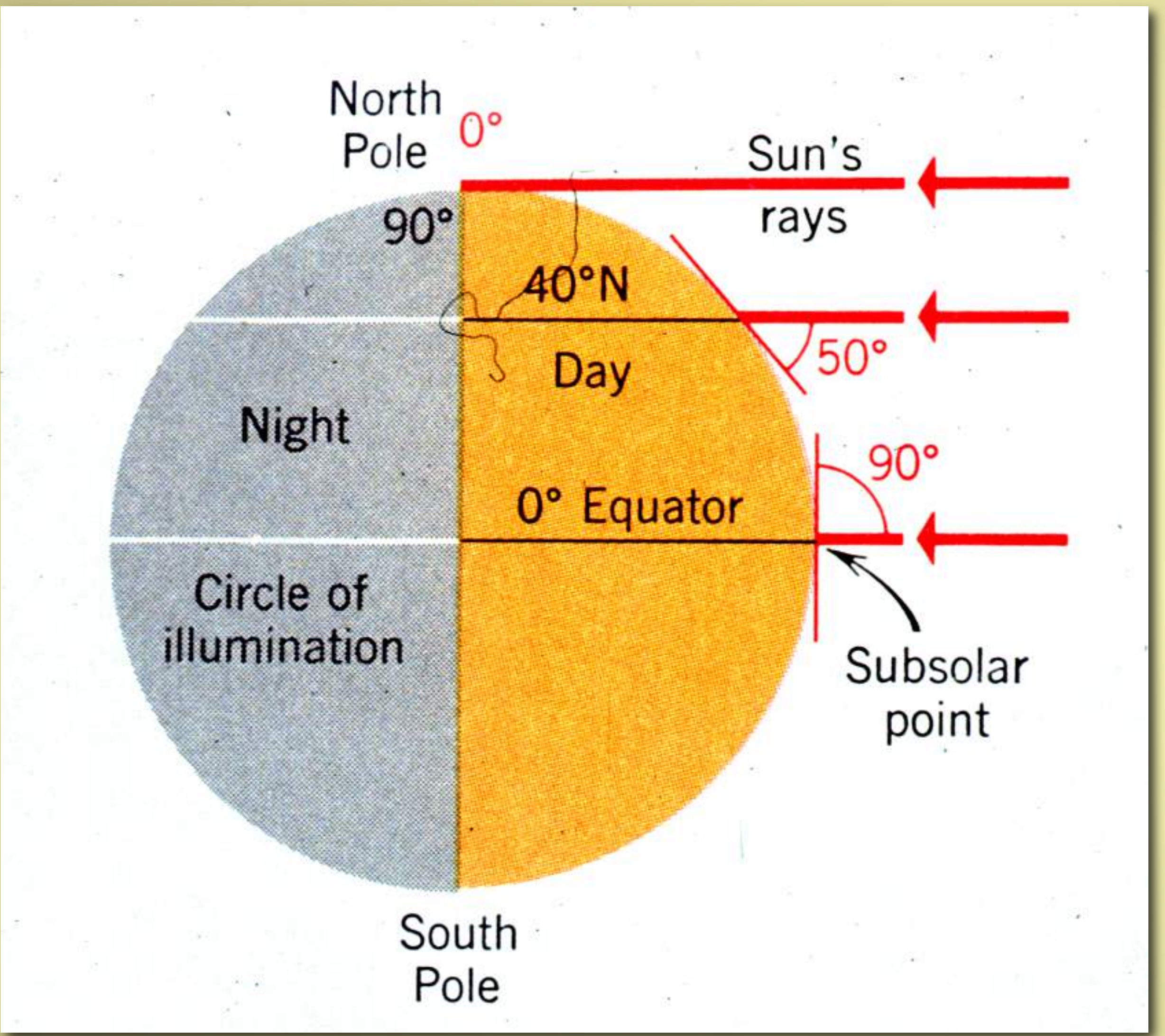
Earth's Spherical Habit



What are the consequences of these two features?

- **Solstice conditions** when poles point maximally towards or away from sun
    - In Northern Hemisphere, June 20 (summer solstice) and December 21 (winter solstice)
    - Subsolar point at the Tropic of Cancer or Capricorn (not equator)

Earth’s Spherical Habit

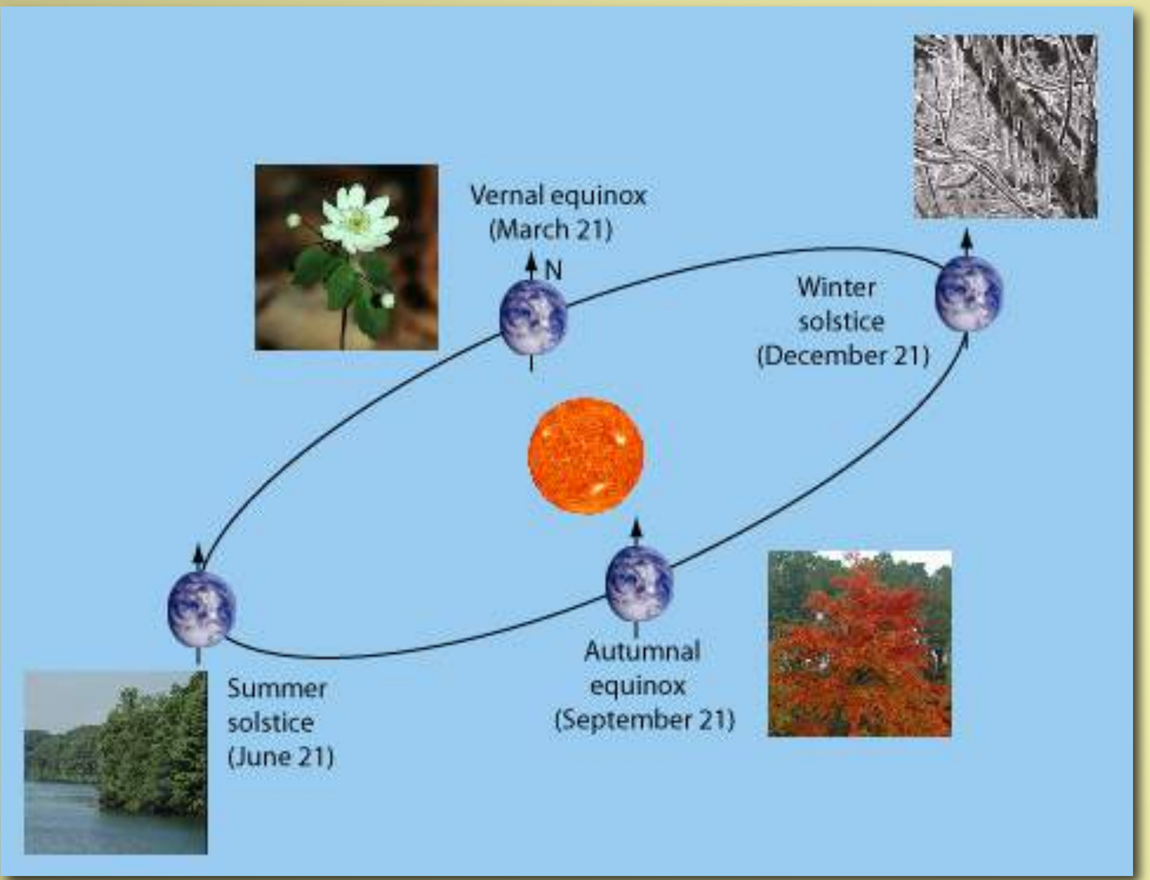


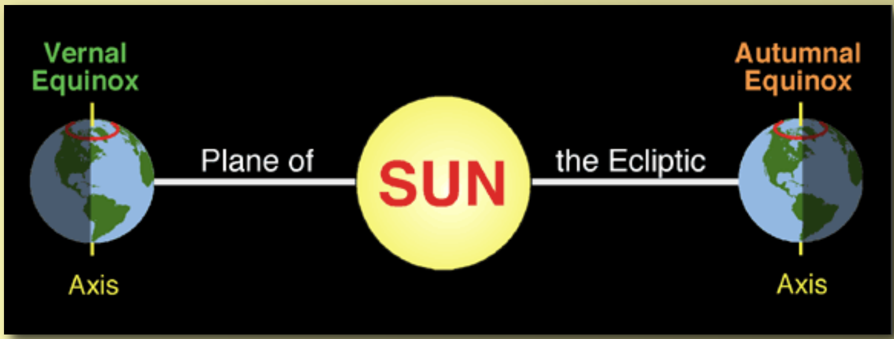
- **Equinox conditions** when neither pole has inclination to sun; subsolar point at equator

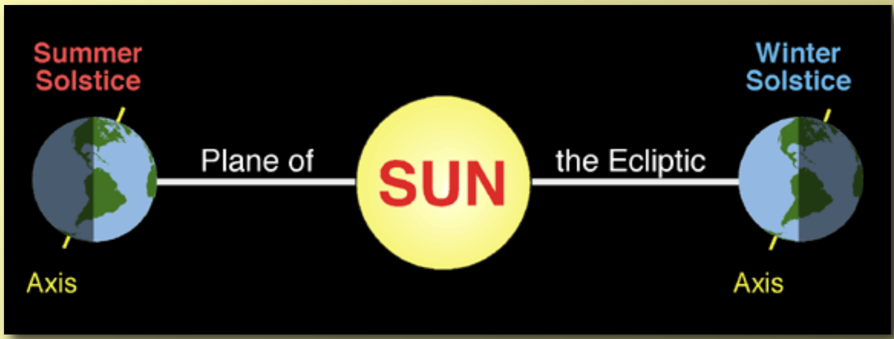
- Vernal (March 20)
- Autumnal (Sept. 22)

- Circle of illumination passes through poles; 12hr day, 12hr night worldwide

Earth's Spherical Habit

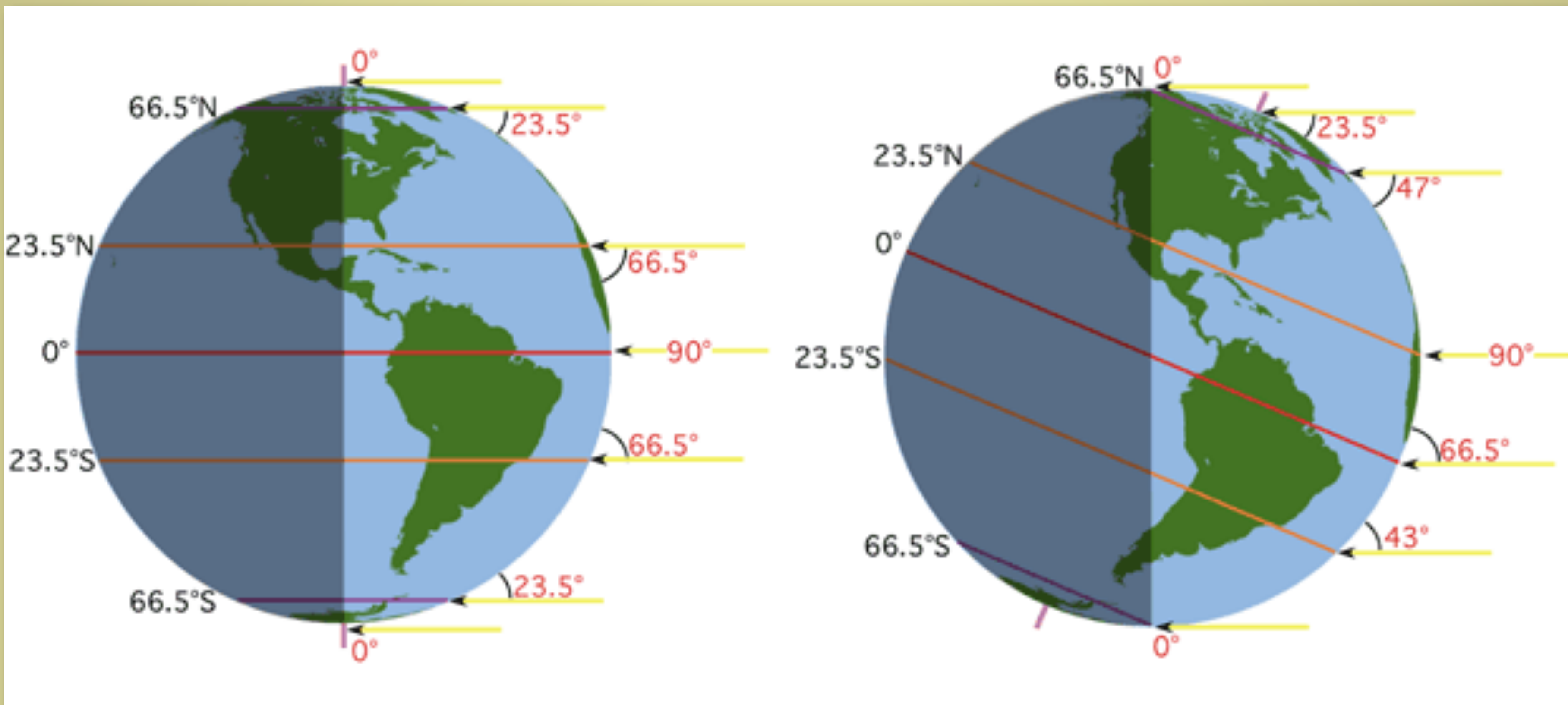






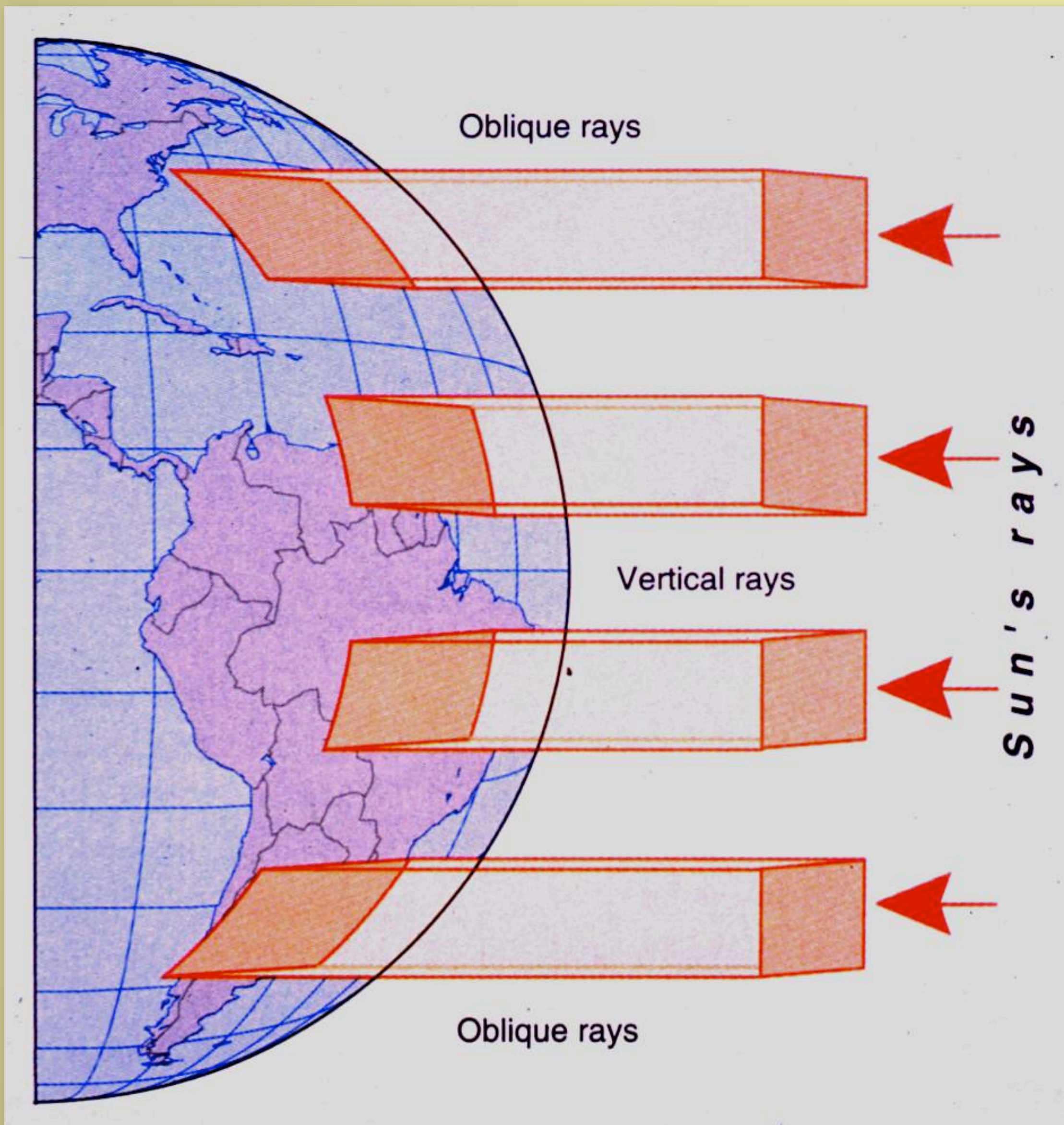
What are the consequences of these two features of earth's tilt? **Seasonality** that increases poleward and affects vegetation changes

Earth's Spherical Habit

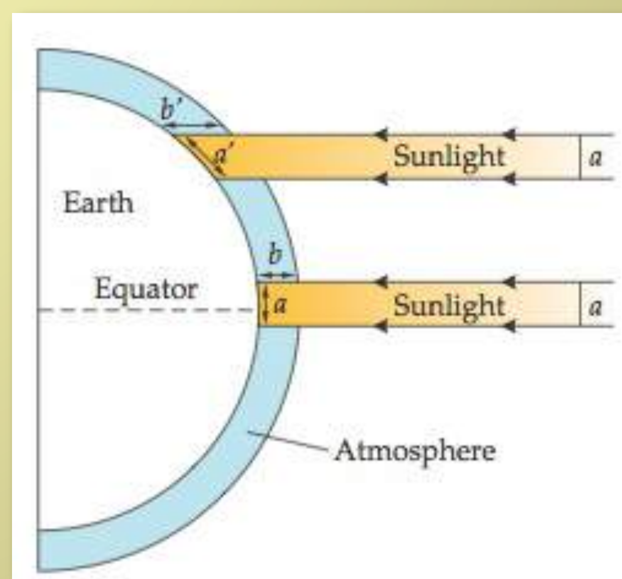


arctic circle	66½° N	24 hr light in N.H. summer solstice
antarctic circle	66½° S	24 hr dark in N.H. summer solstice
tropic of cancer	23½° N	subsolar point in N.H. summer solstice
tropic of capricorn	23½° S	subsolar point in S.H. summer solstice

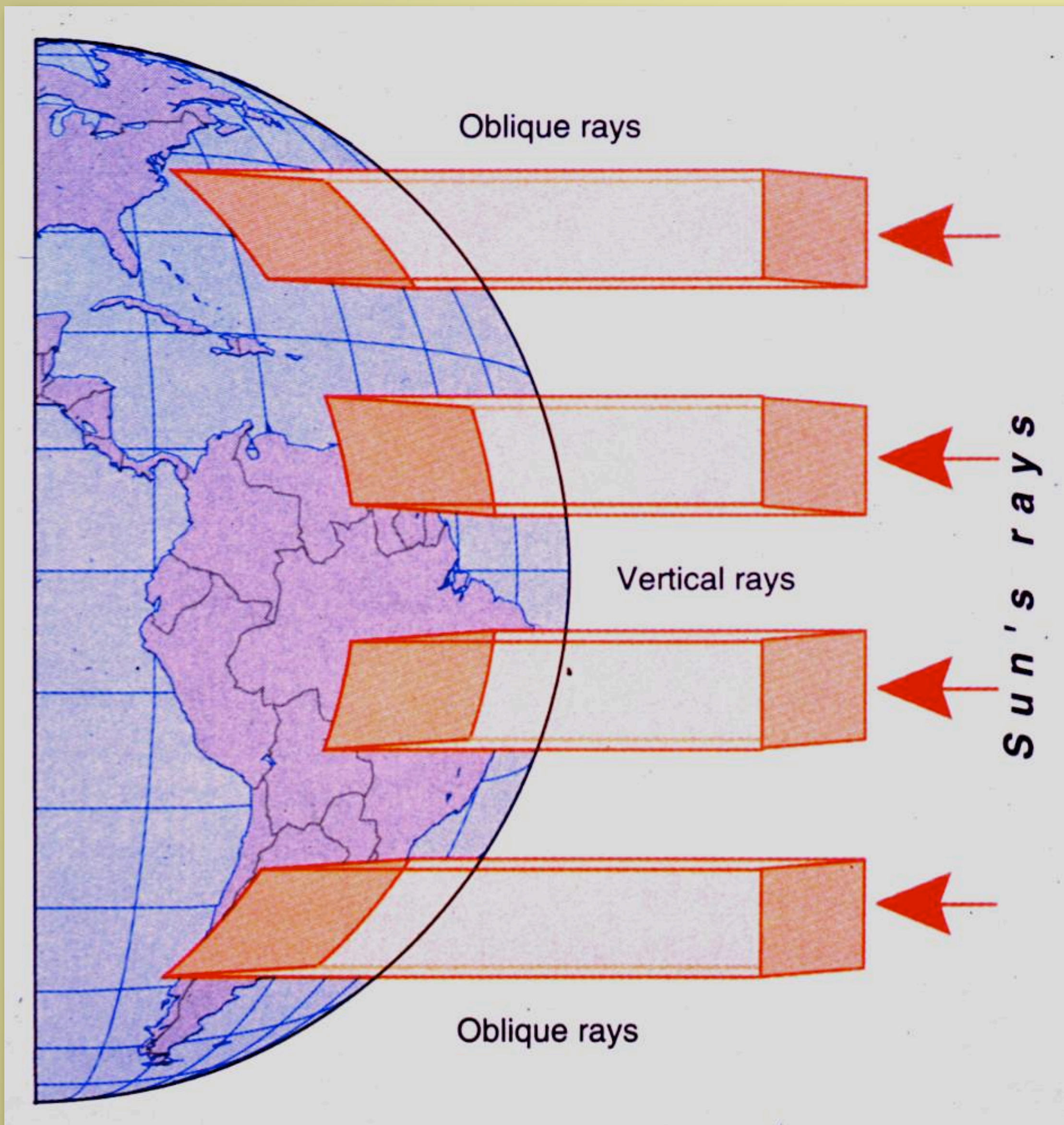
Insolation Over the Globe



- All points on earth receive the *same hours* of light averaged over the year
- **Insolation** - amount of solar energy intercepted by an exposed surface - is *not* constant over time or place
- Only at subsolar point will solar energy be intercepted at the full value of the solar constant



Insolation Over the Globe



- **solar constant**

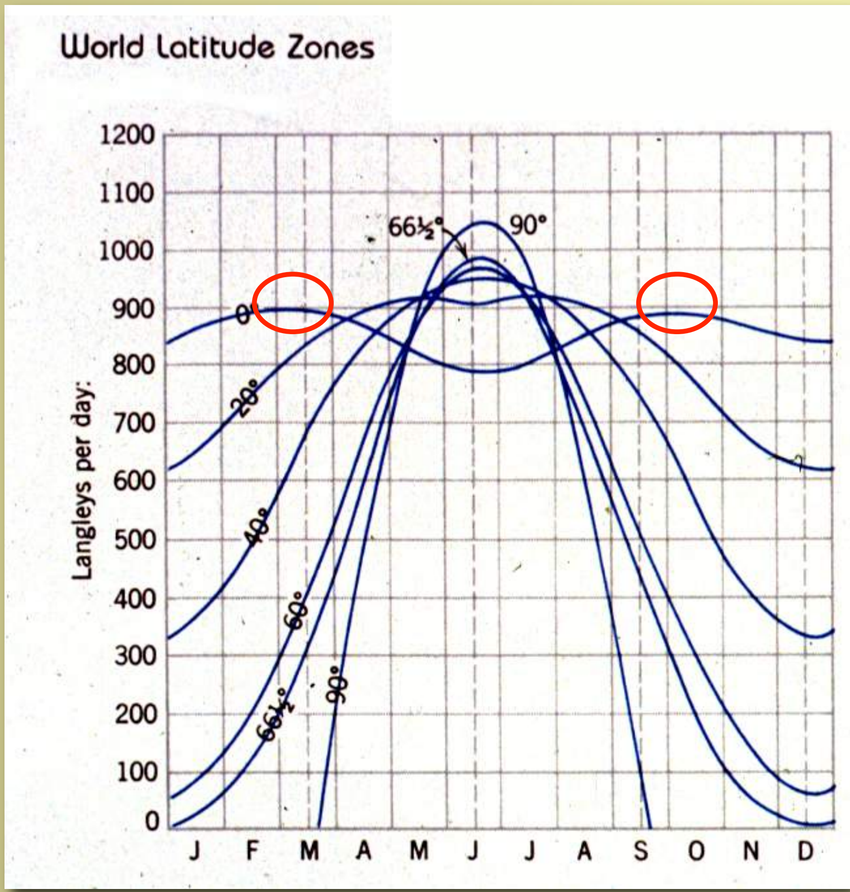
= 2 langley (ly) / min
= 2 g calories / cm^2 / min

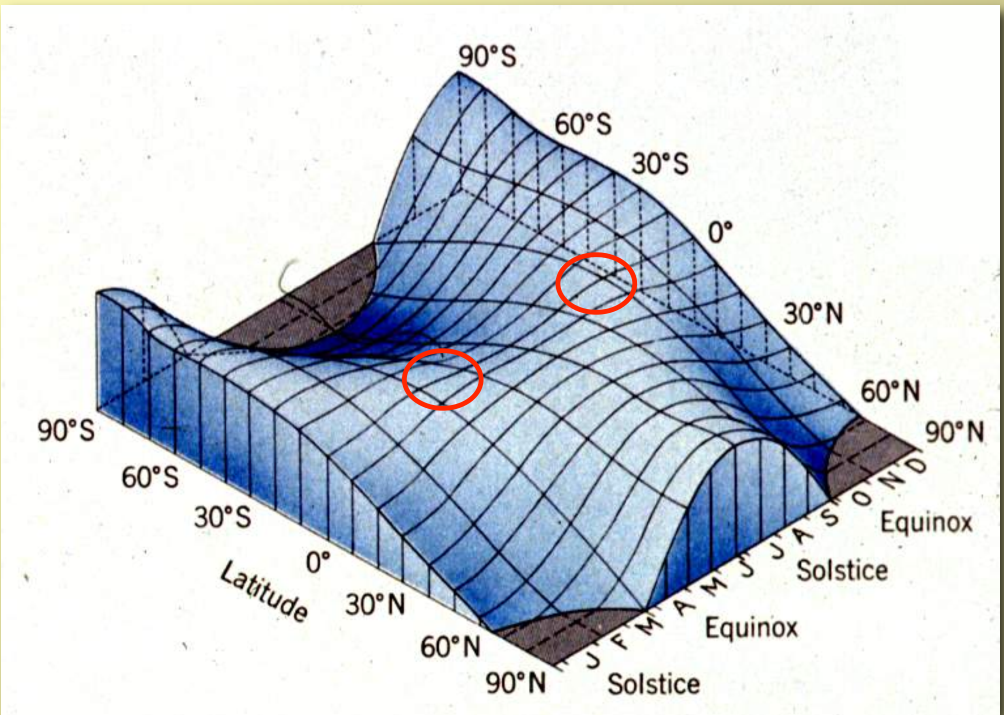
[langley or gram calorie / cm^2 is the amount of heat to raise 1g water by 1°C]

- Insolation received at any place on earth depends on 2 factors:
  - angle at which sun's rays strike earth
  - length of time of exposure to the sun's rays

Insolation Over the Globe
3 Important Results

1. Equator gets a little less than "no tilt" model; only at equinoxes is it at subsolar point; therefore two humps or seasonality in energy

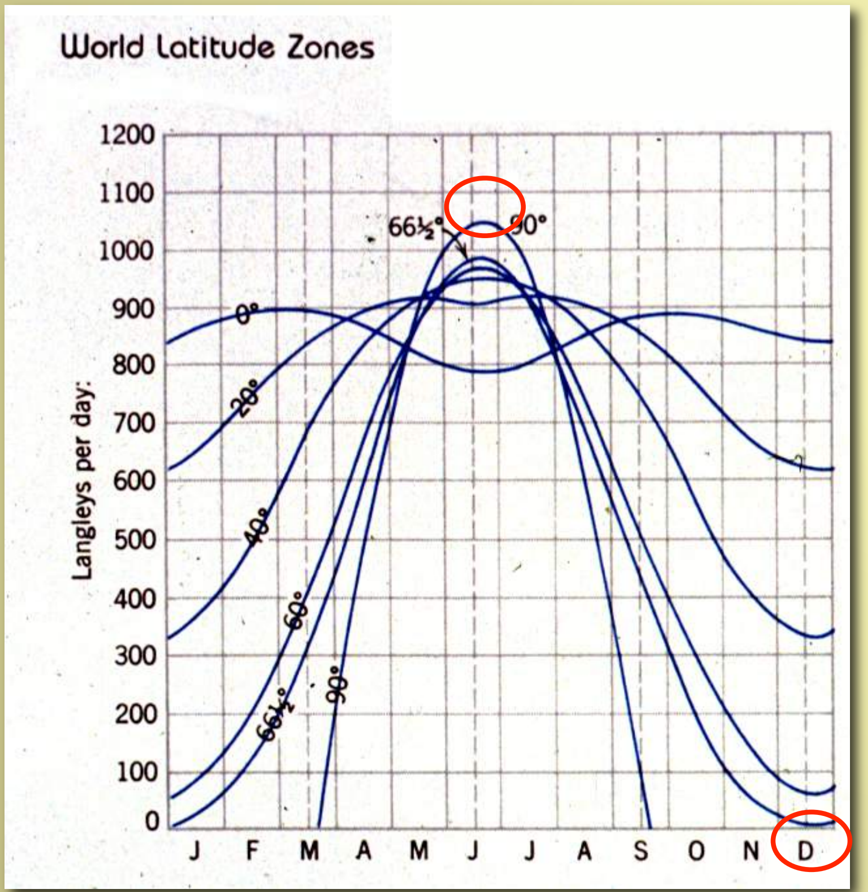


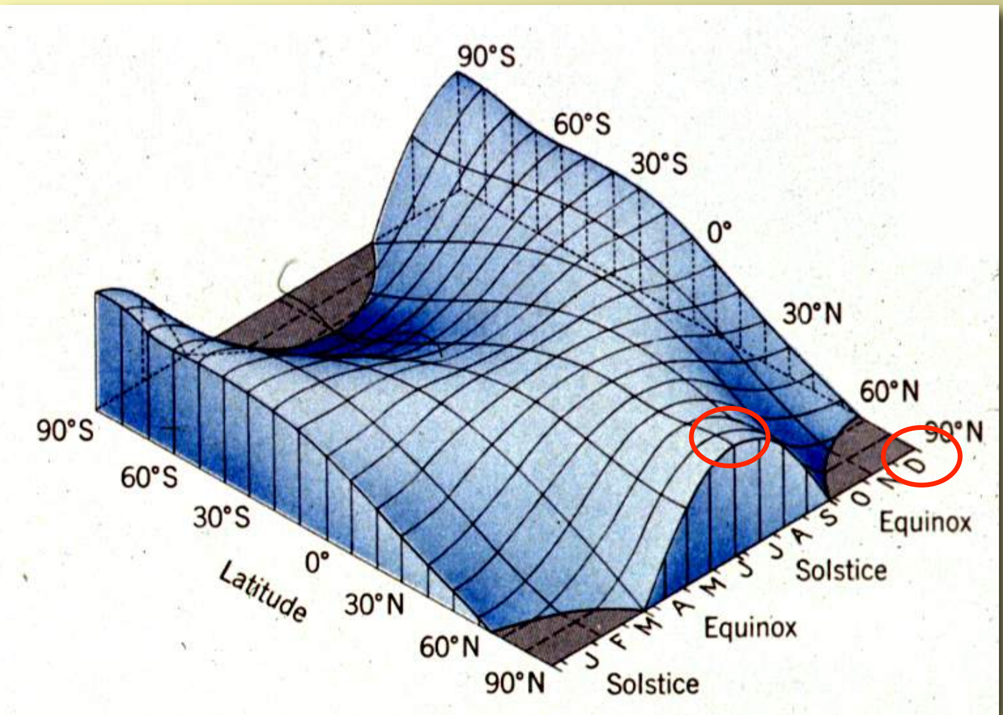


Insolation curves at different latitudes and different times

Insolation Over the Globe
3 Important Results

2. Insolation amount on longest days increases poleward in respective summer, but so does contrast between 2 solstices

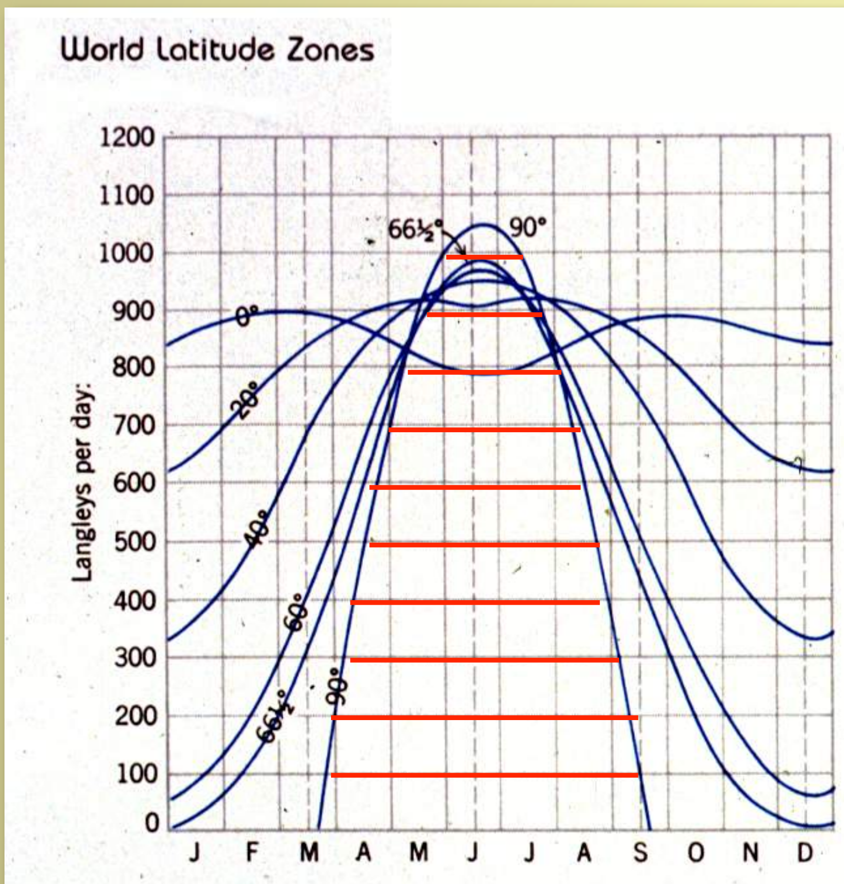


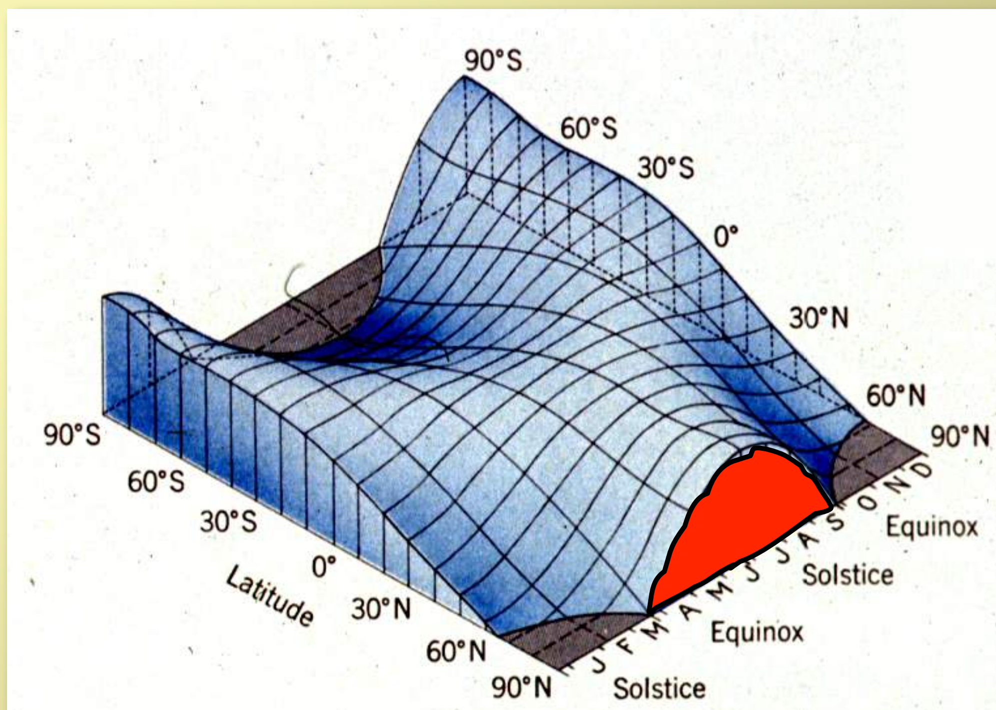


Insolation curves at different latitudes and different times

Insolation Over the Globe
3 Important Results

3. Polar regions receive over 40% of equatorial insolation - major impact on plant distributions and adaptations

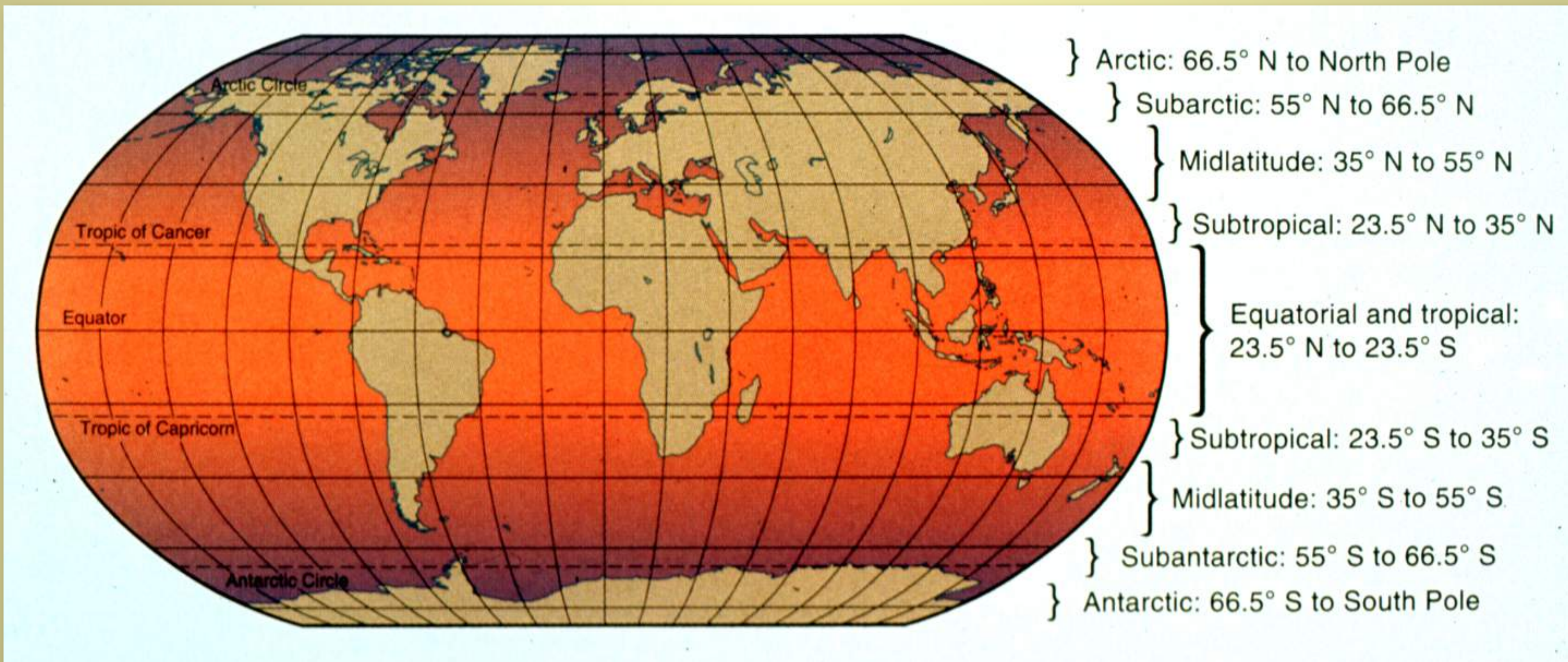




Insolation curves at different latitudes and different times

World Latitudinal Geographic Zones

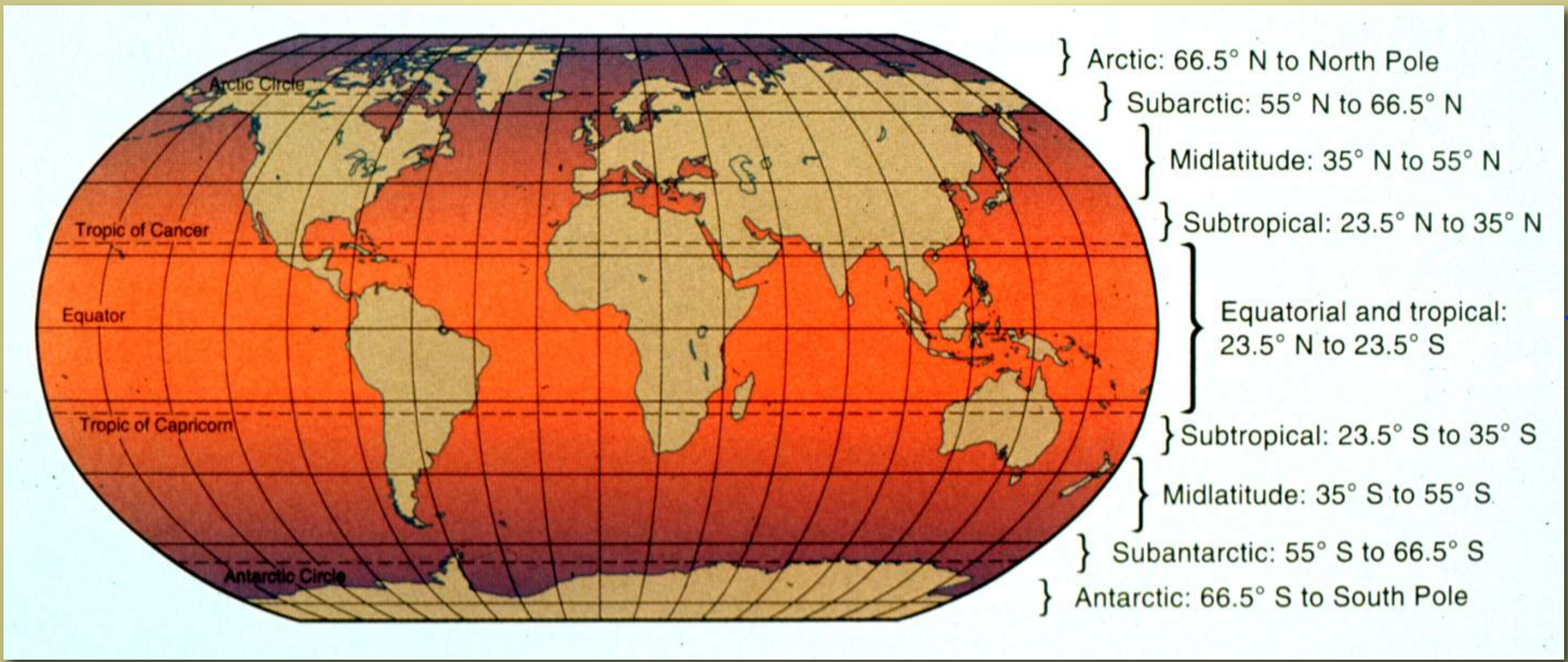
The angle of attack of sun's rays and length of day determines the flow of solar energy reaching a given unit of earth's environment and therefore governs the thermal environment of life in the biosphere — basis for **latitudinal zones**



World Latitudinal Geographic Zones

Equatorial zone: 10° N - 10° S

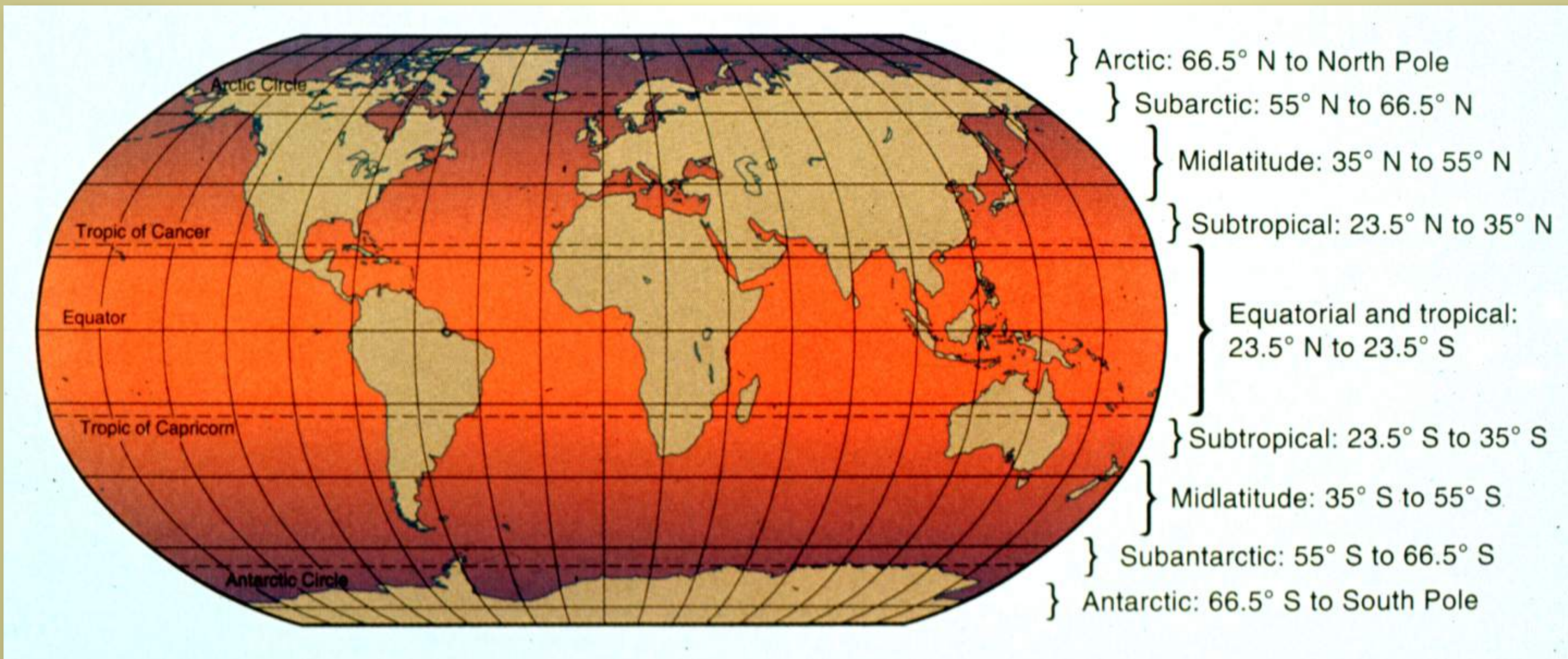
- intense insolation
- day and night roughly equal in duration
- aseasonal



World Latitudinal Geographic Zones

Tropical zone: 10° - 23.5° N & S

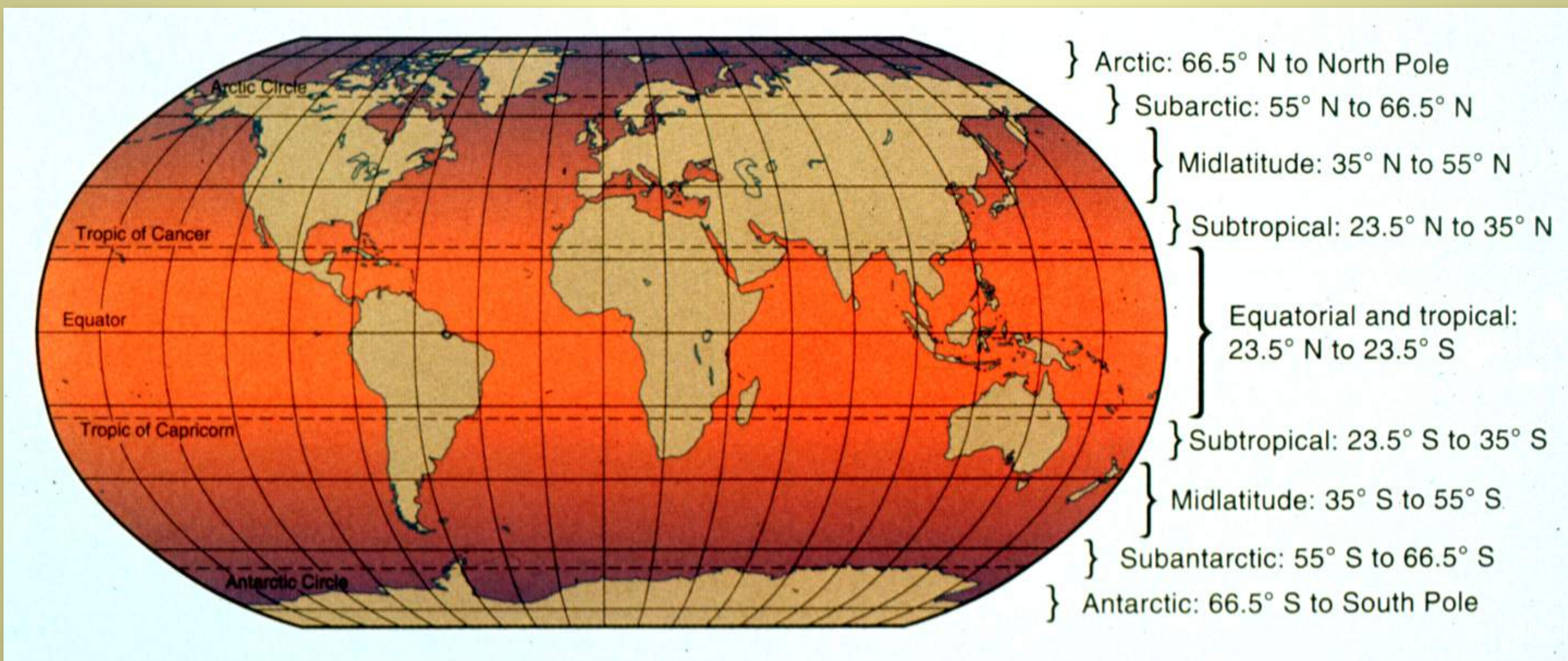
- large total insolation
- marked seasonal cycle



World Latitudinal Geographic Zones

Subtropical zone: 23.5° - 35° N & S

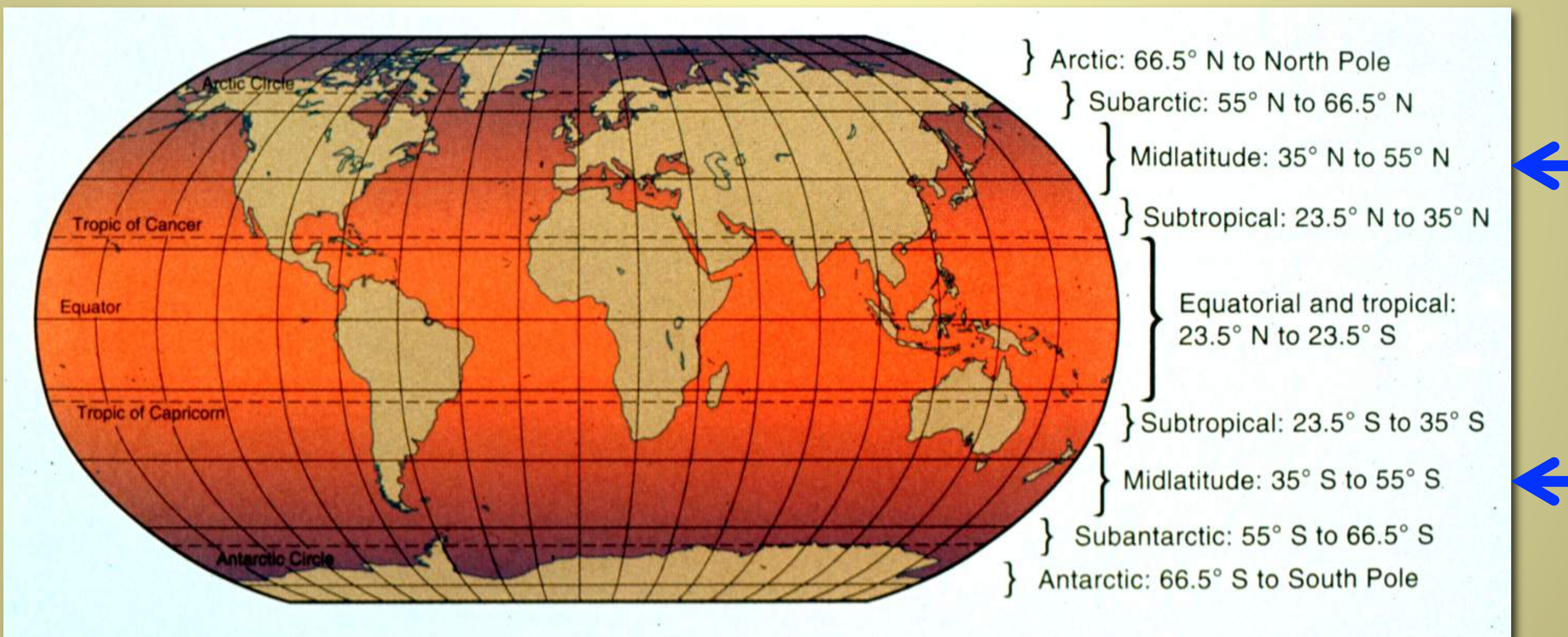
- transitional between tropical and temperate
- East/West sides of continents different in vegetation



World Latitudinal Geographic Zones

Midlatitude zone: 35° - 55° N & S [Madison, WI = 43° N]

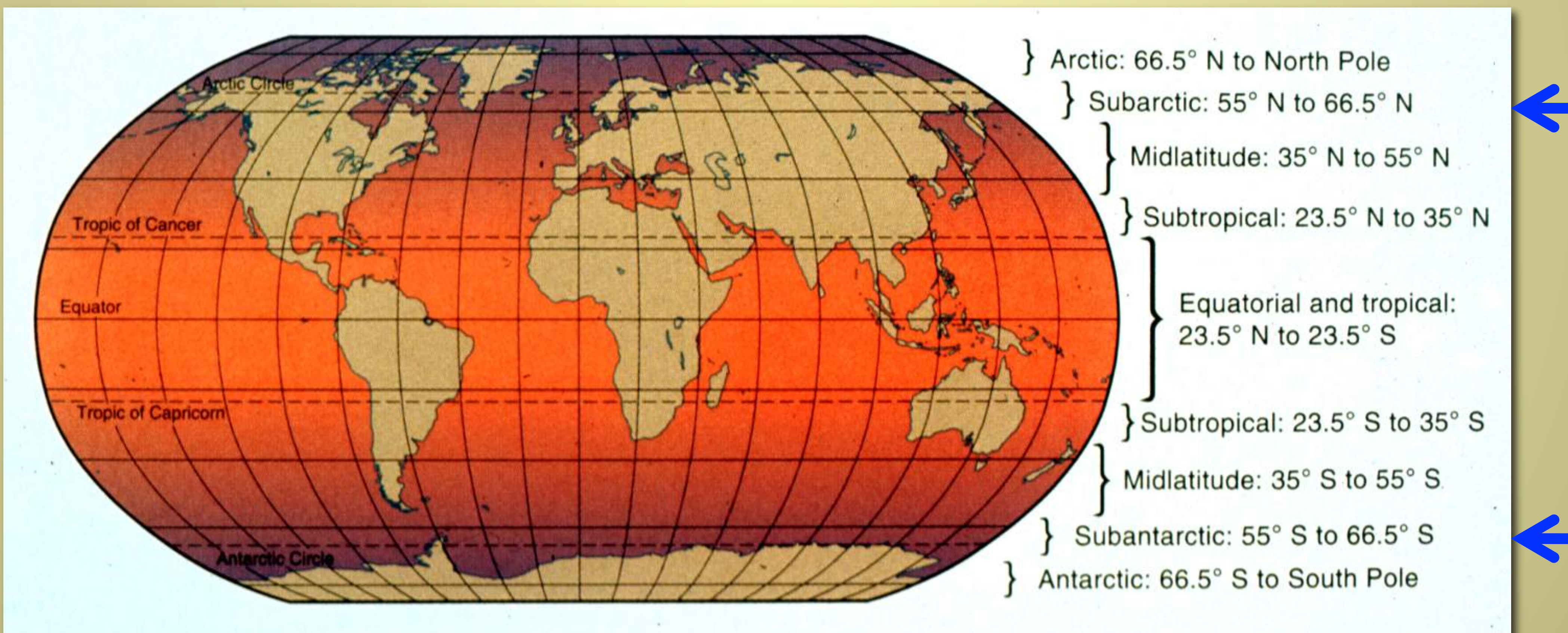
- strong seasonal contrast in insolation
- strong seasonal contrast in day/night lengths
- East/West sides of continents different in vegetation



World Latitudinal Geographic Zones

Subarctic/Subantarctic zone: 55° - 66.5° N & S

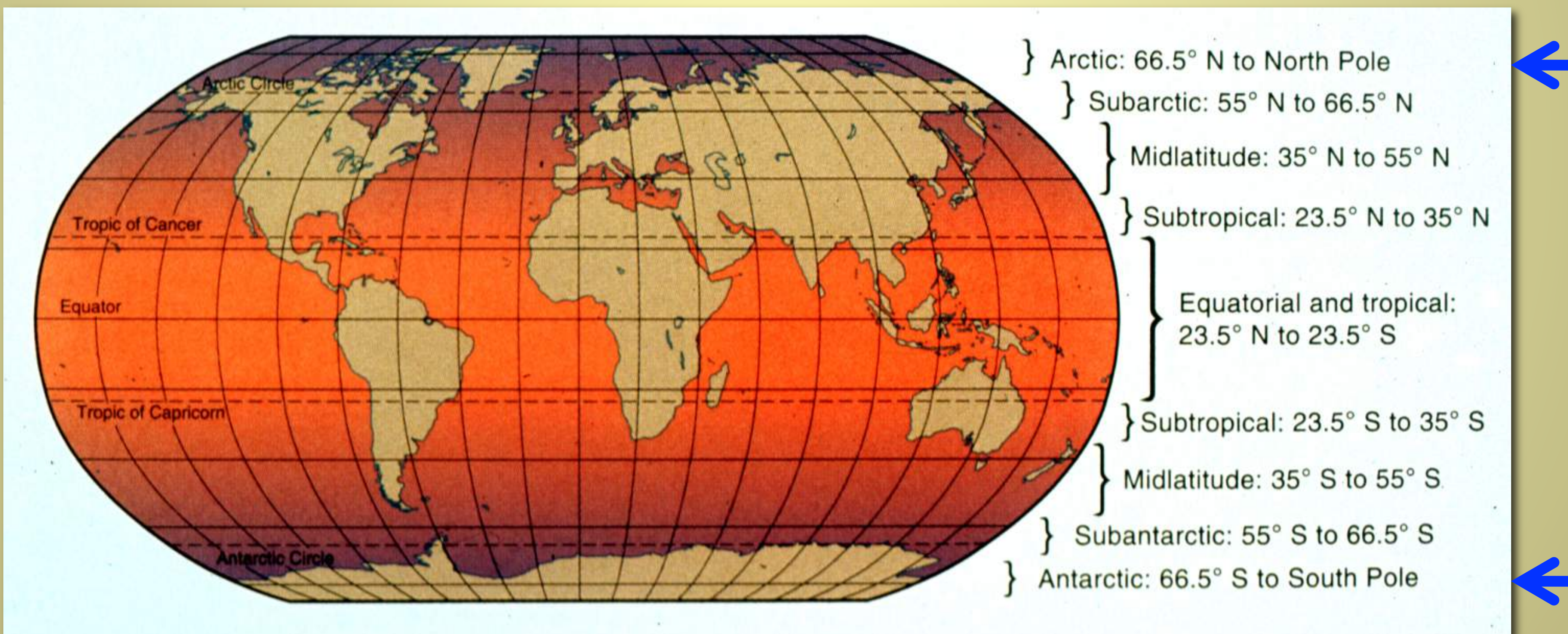
- enormous seasonality in insolation and day length



World Latitudinal Geographic Zones

Arctic/Antarctic zone: 66.5° - 90° N & S

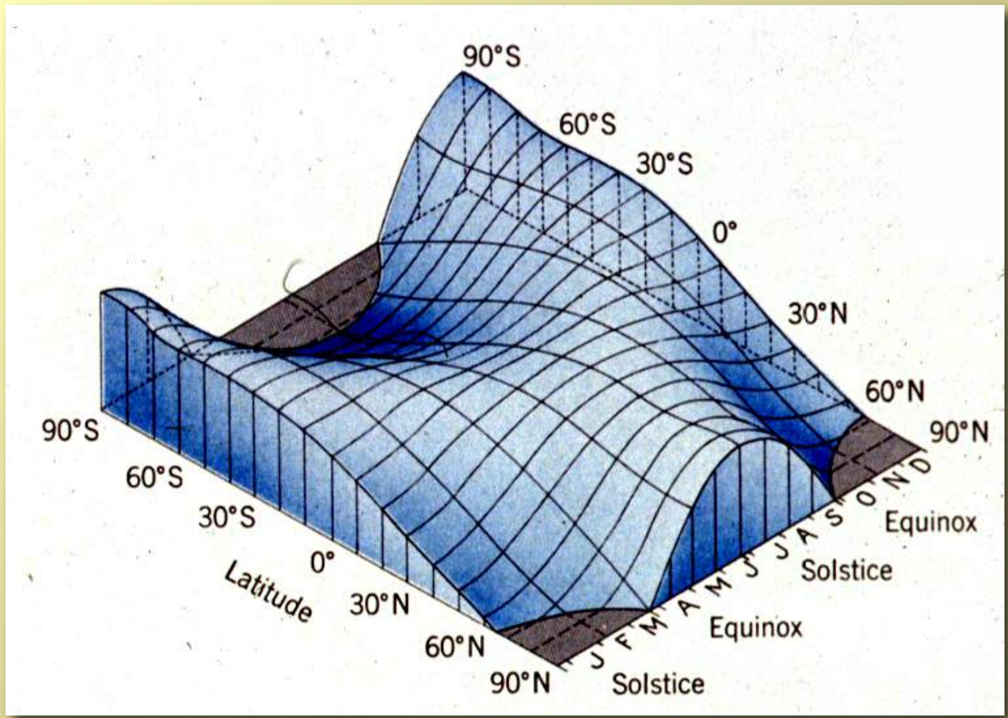
- ultimate in seasonal contrasts of insolation and day length
- 6 months of day and 6 months of night



Temperature and Precipitation

The spherical nature of the earth accounts for seasonal and latitudinal variations in insolation

These patterns are critical factors for where vegetation biomes exist and set the parameters for why species can tolerate the local environment



The energy input of the sun is also instrumental in setting the global pressure system and the very important patterns of **temperature**, **precipitation** and **wind/ocean currents**

Temperature and Elevation

Look first at the perhaps counter-intuitive fact that air gets colder as you ascend to higher elevations

The downfall of Icarus - son of Daedalus

Temperature and Elevation

Look first at the perhaps counter-intuitive fact that air gets colder as you ascend to higher elevations

Why are there arctic-like conditions (paramo, puna, etc.) as you near the tops of high mountains in the tropics and in fact snow cover on Mt. Kenya in tropical East Africa?

Answer lies in the thermal properties of air. Density and air pressure decrease with increasing elevation. Less energy stored in gas molecules at lower densities.

Lobelia telekii - Mt. Kenya [0^oS]

Temperature and Elevation

Environmental Temperature Lapse Rate
(Normal lapse rate)

= decrease of temperature with altitude in still air

6.4°C per 1,000 m (1 km) or 3.5°F per 1,000 ft

Mt. Kenya (with perpetual snow at summit)

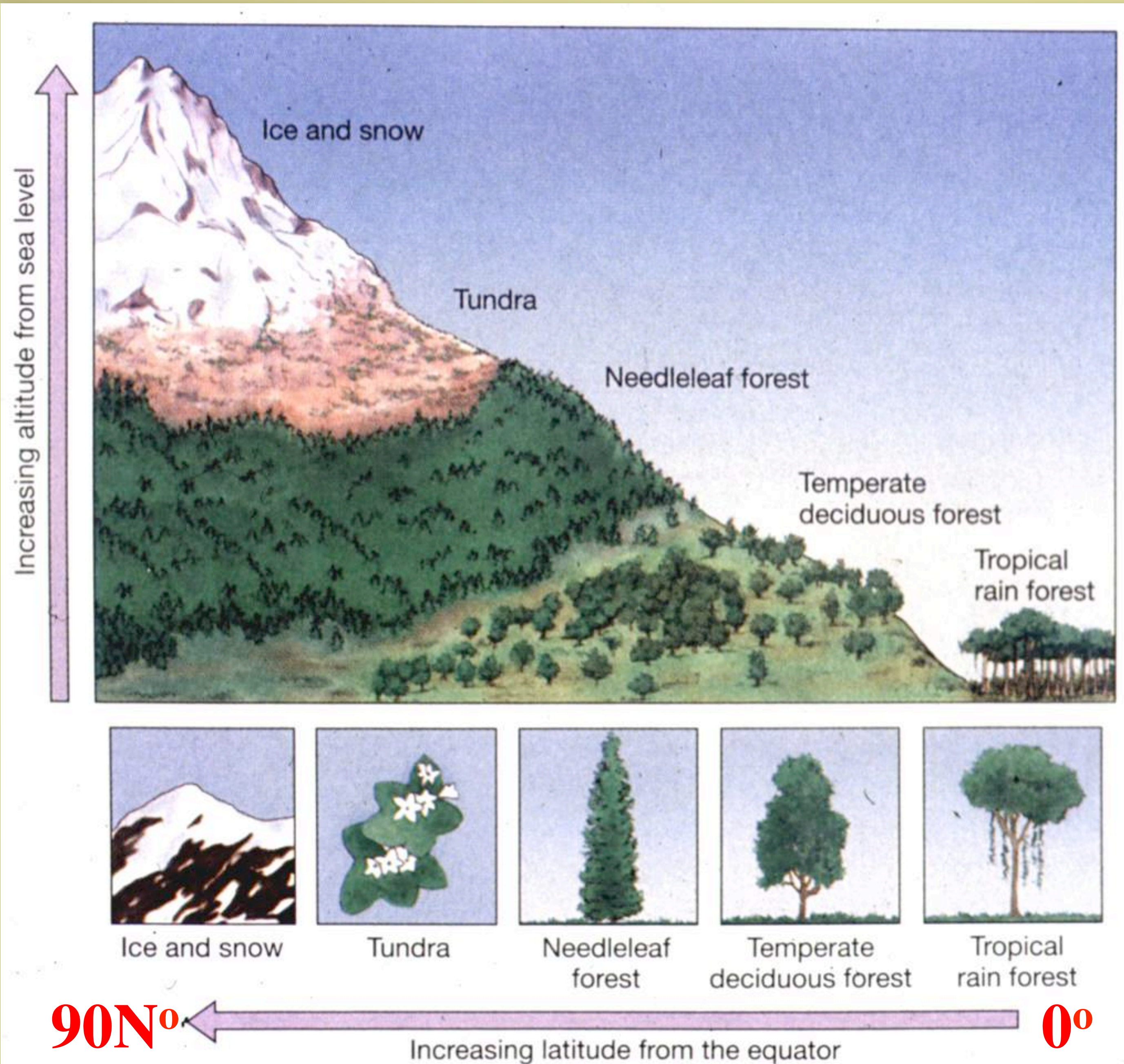
32°C (90°F) at sea level
0°C (32°F) at 5,000 m (5 km) or 16,250 ft

Mt. Kenya is 5,895 m or 19,160 ft

How about other mountains?

Lobelia telekii - Mt. Kenya [0°S]

Temperature and Elevation



Hopkins' Bioclimatic Law

Temperature lapse with increasing elevation is reflected in temperature lapse with increasing latitude

1,000 feet of altitude = 100 miles of latitude = - 3.5°F

Andrew Hopkins, 1918

Temperature and Elevation

Hopkins' Bioclimatic Law

"Spring Time Law"

Hopkins discovered that spring advances:

- 1 day for every 15 minutes of latitude northward
- 1.25 days for each degree of longitude westward
- 1 day for every 100 feet higher in elevation

Temperature lapse with increasing elevation is reflected in temperature lapse with increasing latitude

1,000 feet of altitude = 100 miles of latitude = - 3.5°F

Anemone patens
pasque flower

Andrew Hopkins, 1918

Temperature and Elevation

"Spring Time Law"

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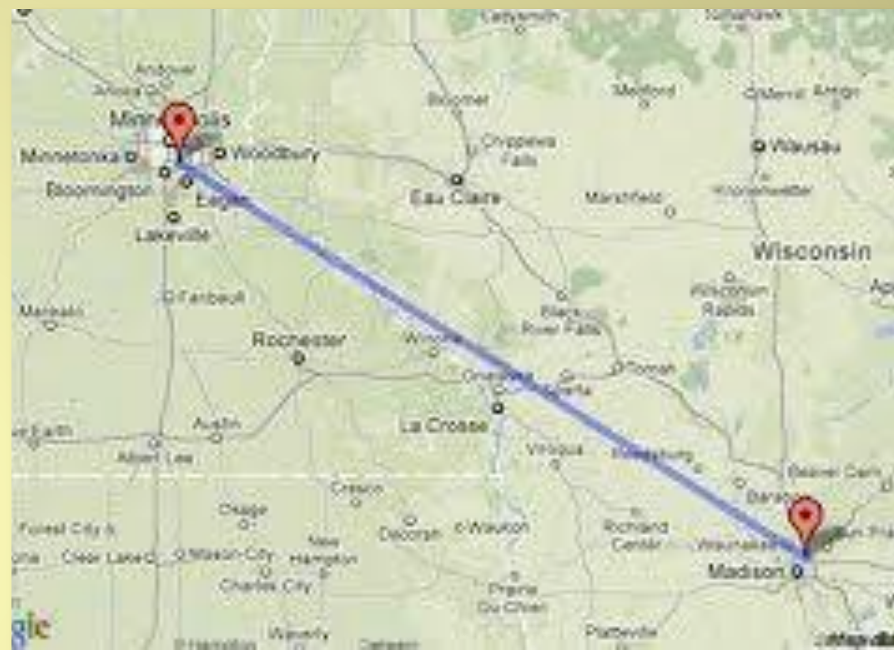


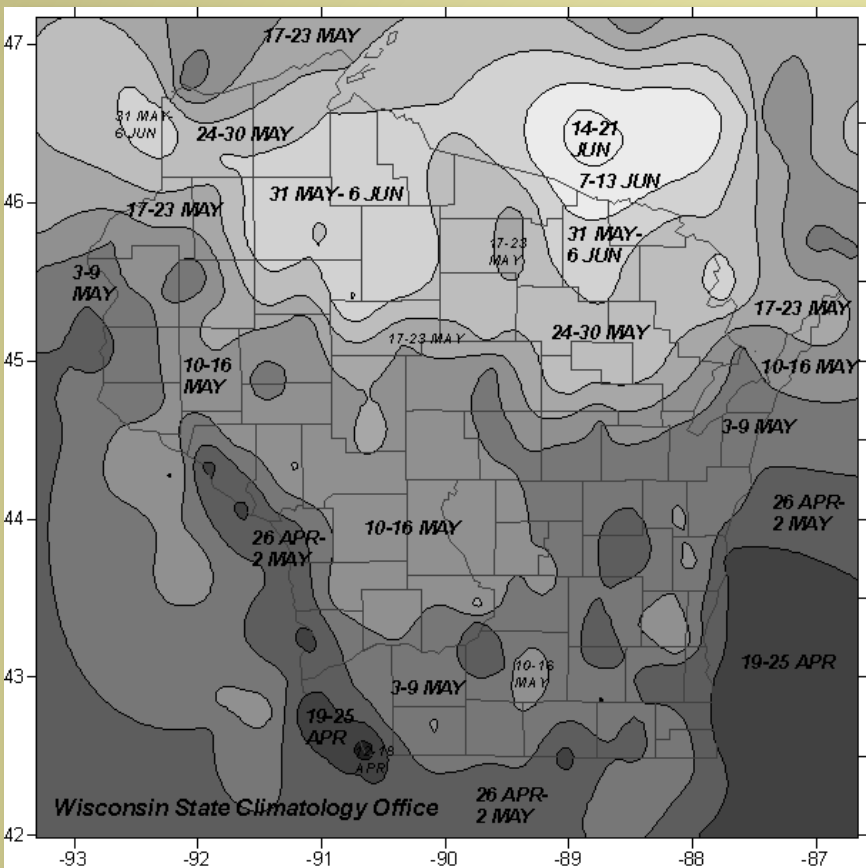
Madison vs. Minneapolis spring date?

115 min N, 4 degrees W, 100 ft higher

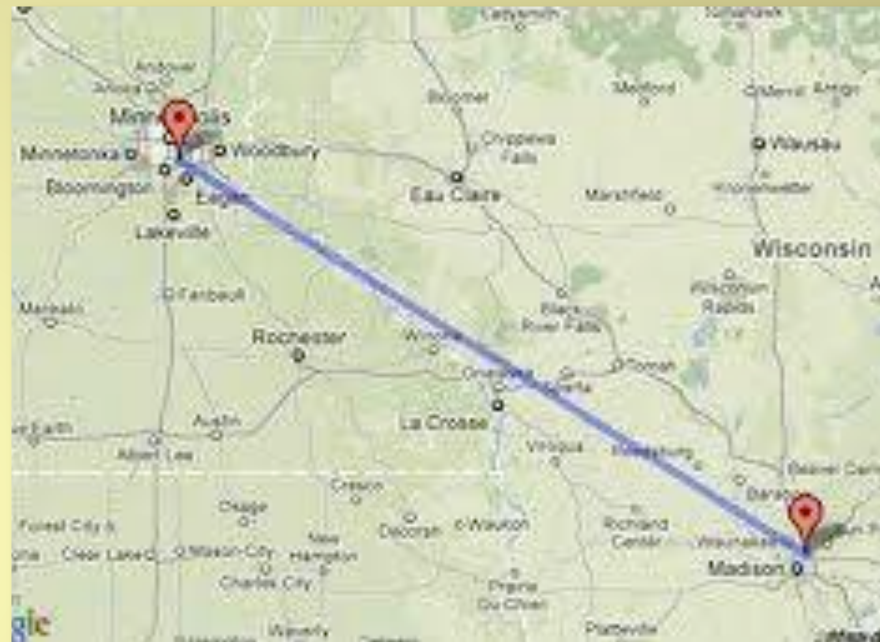
or 11-12 days later

Andrew Hopkins, 1918

Temperature and Elevation



Median date of last occurence of 32 deg F temperature in spring (1971-2000 average)



Madison vs. Minneapolis spring date?

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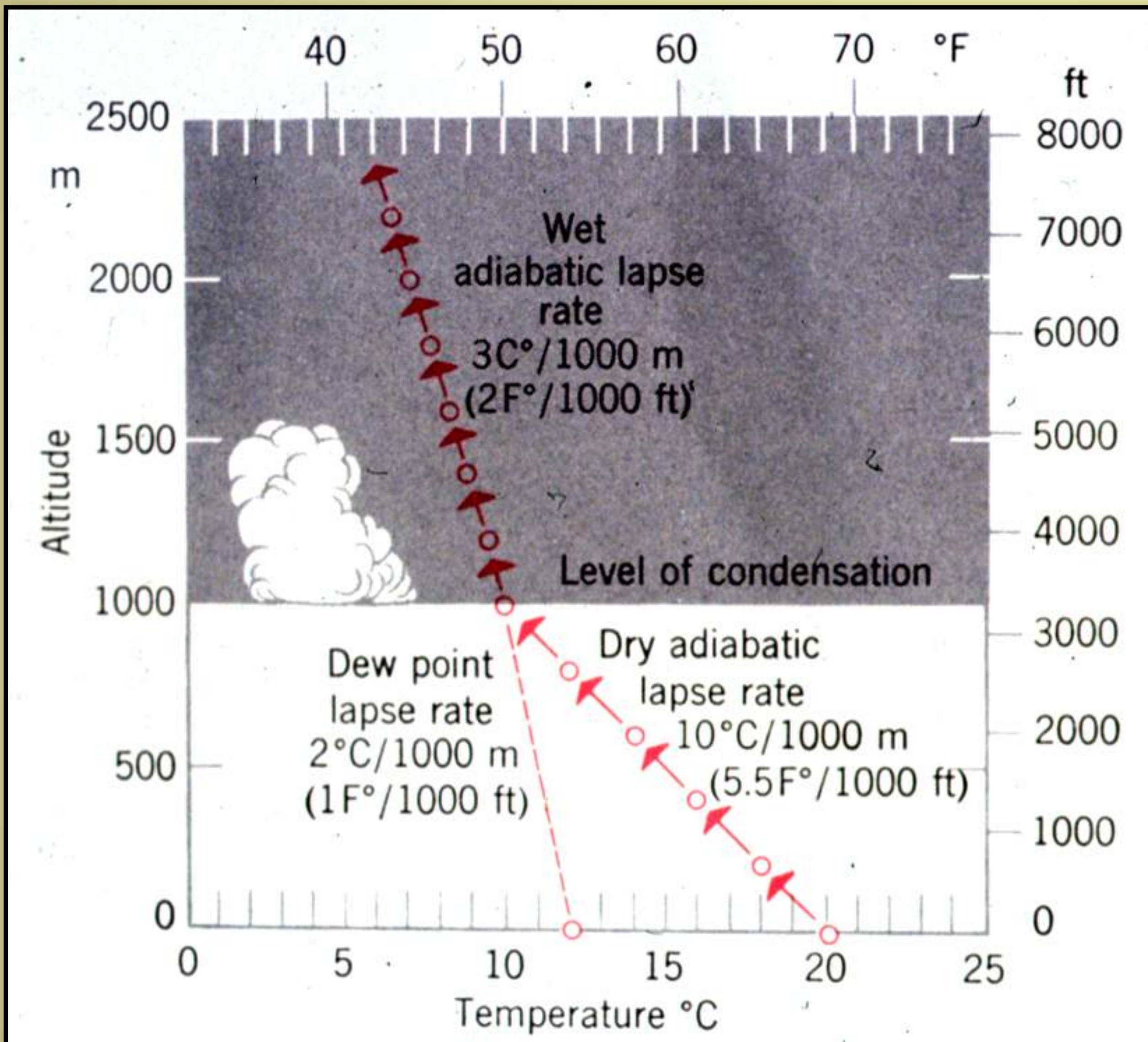
Andrew Hopkins, 1918

Adiabatic Cooling and Warming



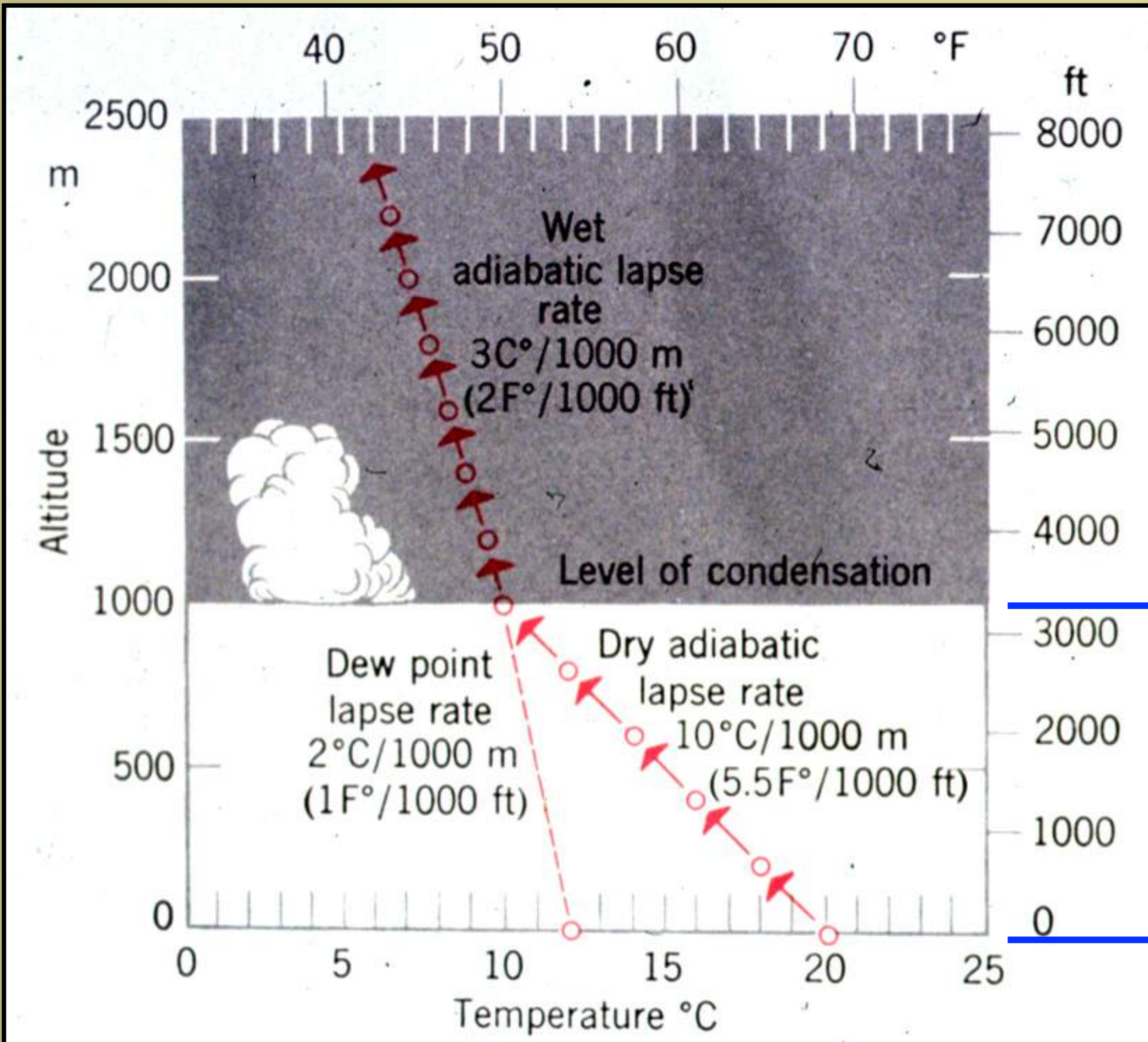
Instead of still air, consider what happens when a body of air (a bubble) rises:

• the body of air will drop in temperature as a result of the decrease in air pressure at higher elevations — even though no heat energy is lost to the outside

• process is reversible; warms as it descends

= adiabatic process

Adiabatic Cooling and Warming



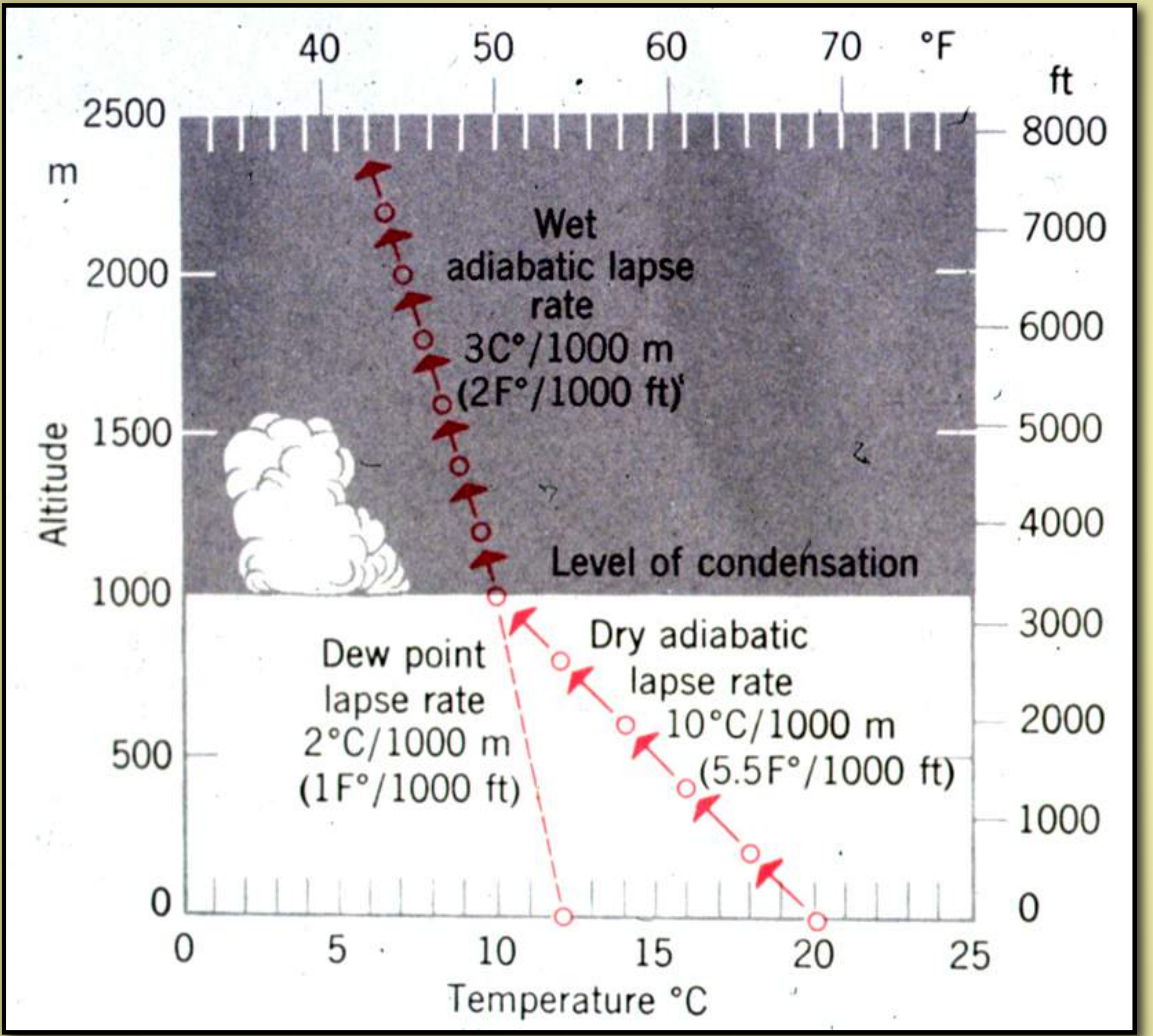
Adiabatic cooling not to be confused with normal lapse rate which applies to non-moving air

Dry adiabatic rate:

10°C per 1,000 m vertical rise (5.5°F per 1,000 ft)

Dry adiabatic rate occurs only when water in air is in gas phase

Adiabatic Cooling and Warming

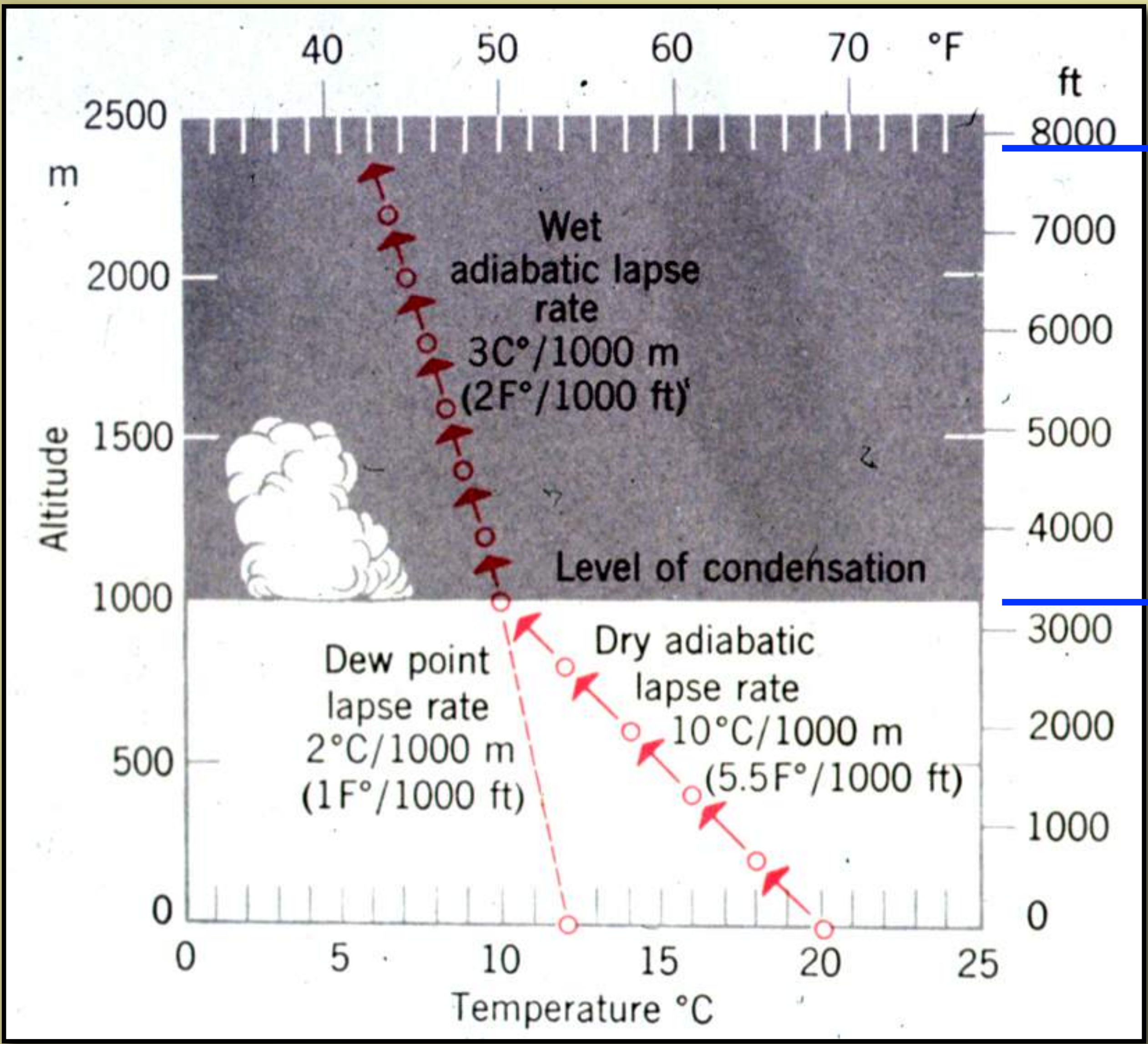


At altitude of about 1,000 m (3,300 ft) air temperature meets dew point (saturation) and **condensation** of water vapor into liquid water occurs (clouds)

Going from high energy water vapor to low energy liquid water (condensation) releases 600 calories / gram of H_2O

This **latent heat** liberated by condensation causes adiabatic lapse rate to slow down in further rising air

Adiabatic Cooling and Warming



Wet adiabatic rate:

3°C per 1,000 m vertical rise
(2°F per 1,000 ft)

Convectional Precipitation

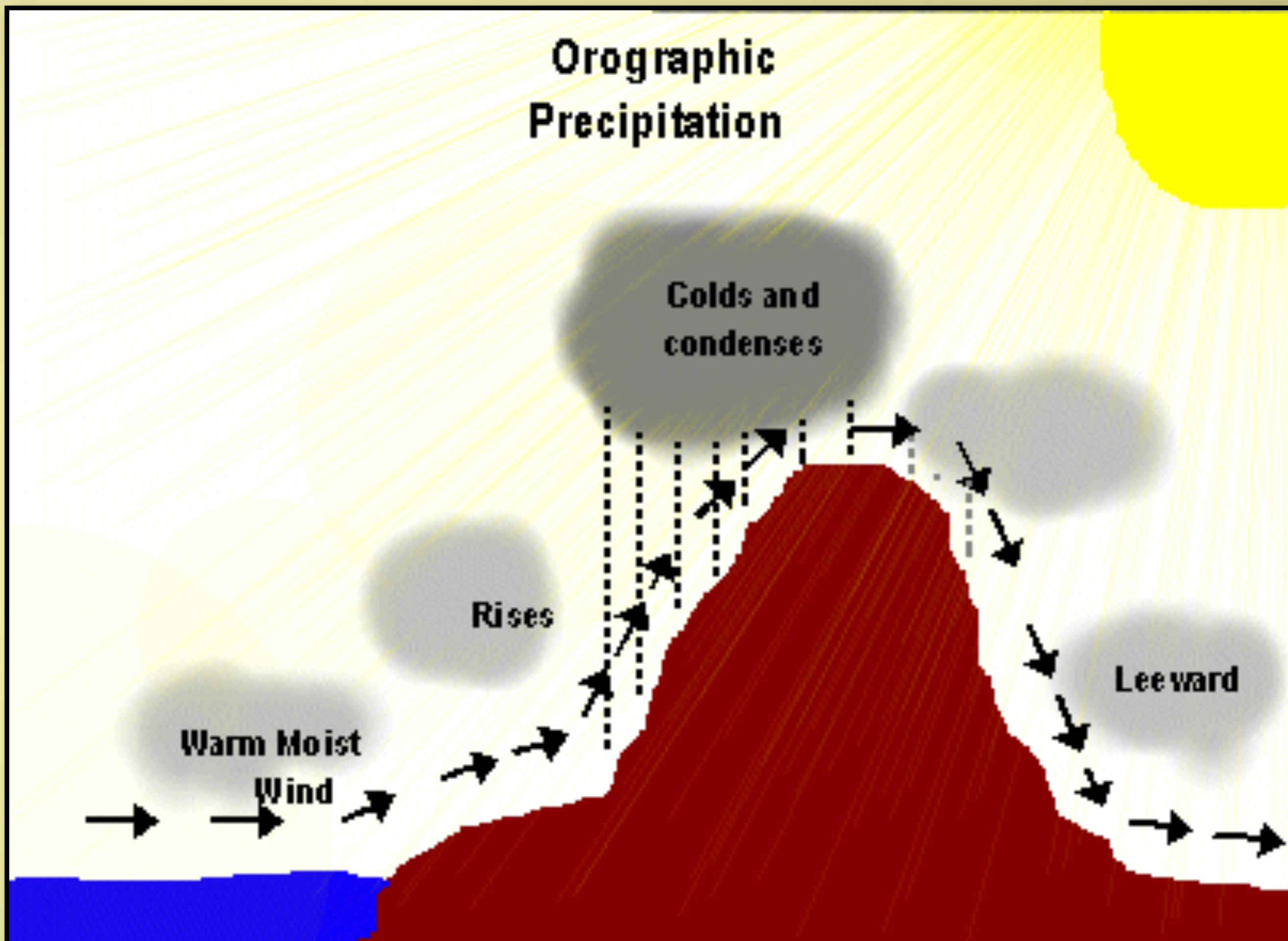
Further rising causes **convectional precipitation**; like a bonfire — the latent heat pushes the air even higher, causing more condensation

The tropical rainforests ("*firebox of the globe*") exhibit greatest latent heat budget coupled with abundant water source and thus greatest convectional precipitation

Brazil near Parana River from ground and spac

Orographic Precipitation

Orographic precipitation generated by the forced ascent of moist air over a mountain barrier



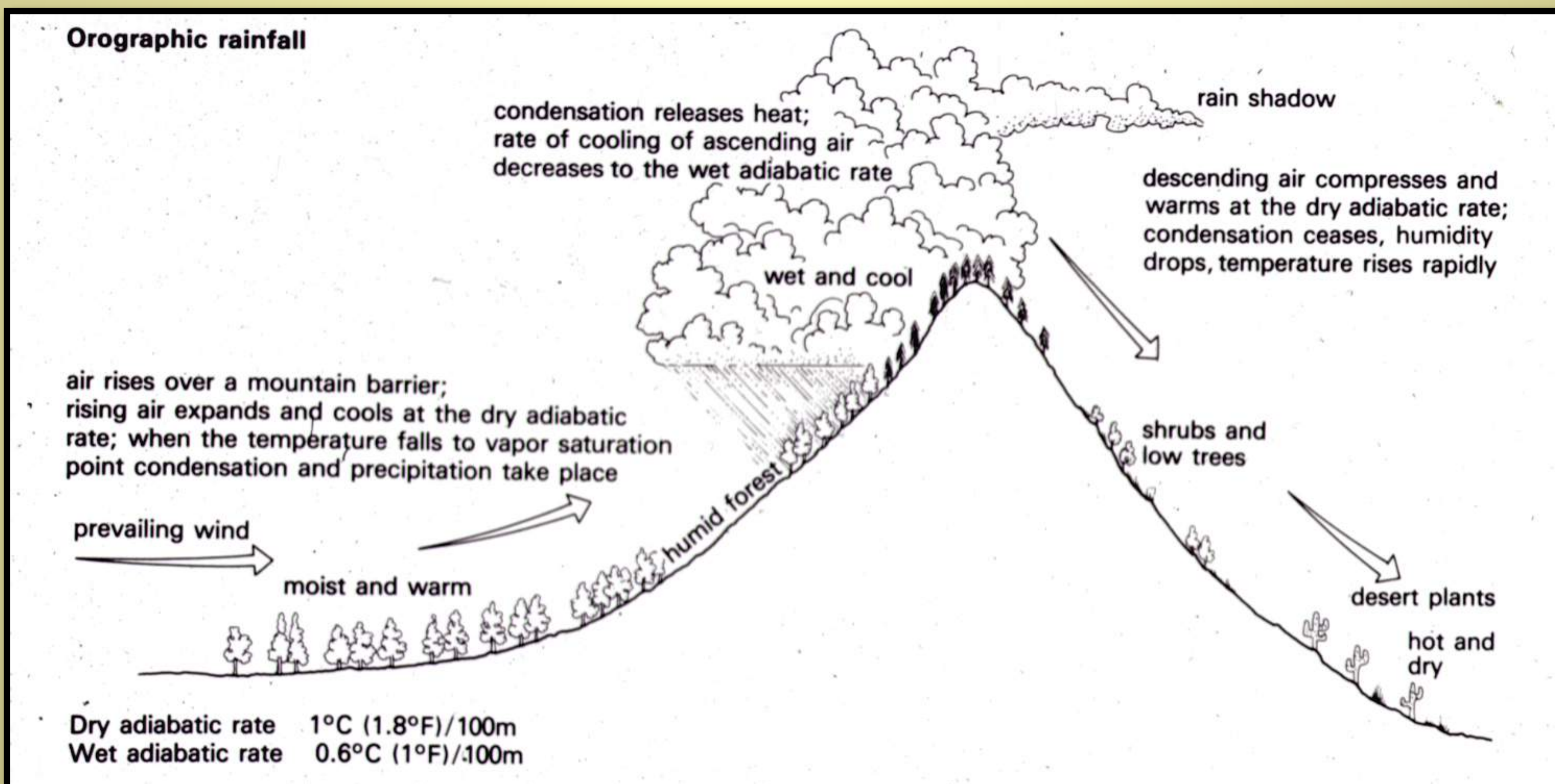
"Orogeny" = mountain building

Orographic Precipitation

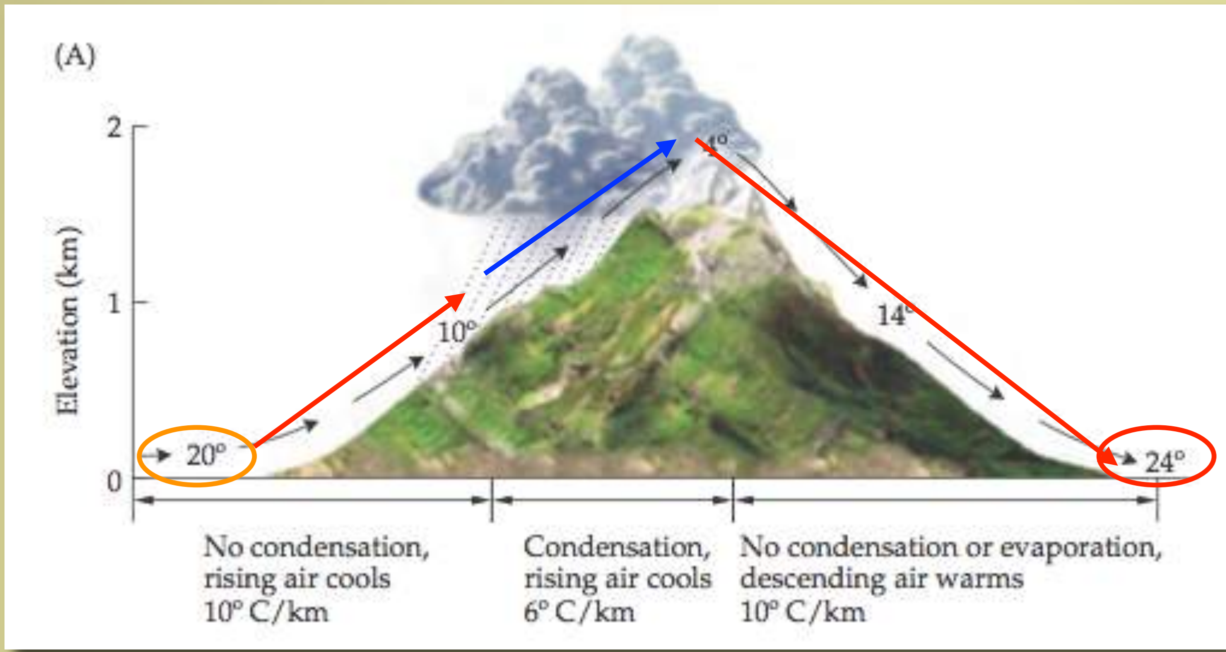
Orographic precipitation generated by the forced ascent of moist air over a mountain barrier

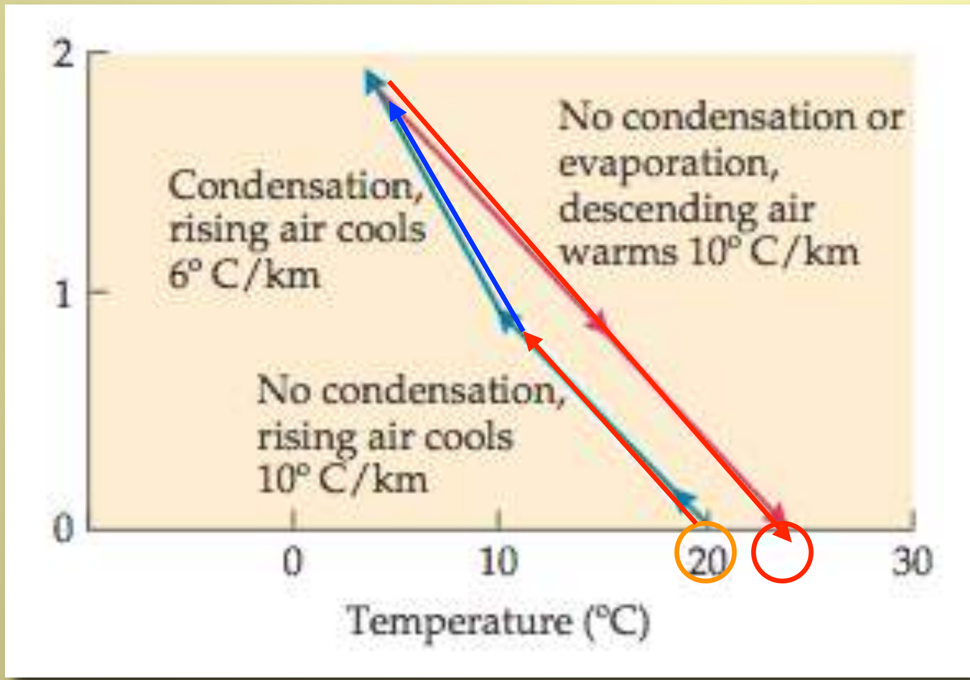
Air rises windward, cools adiabatically, precipitation occurs at vapor saturation point

Air descends leeward, now dry, and warms up adiabatically



Orographic Precipitation





1. Windward side adiabatic cooling first at dry rate and then at slower wet rate

2. Leeward side adiabatic warming only at fast dry rate

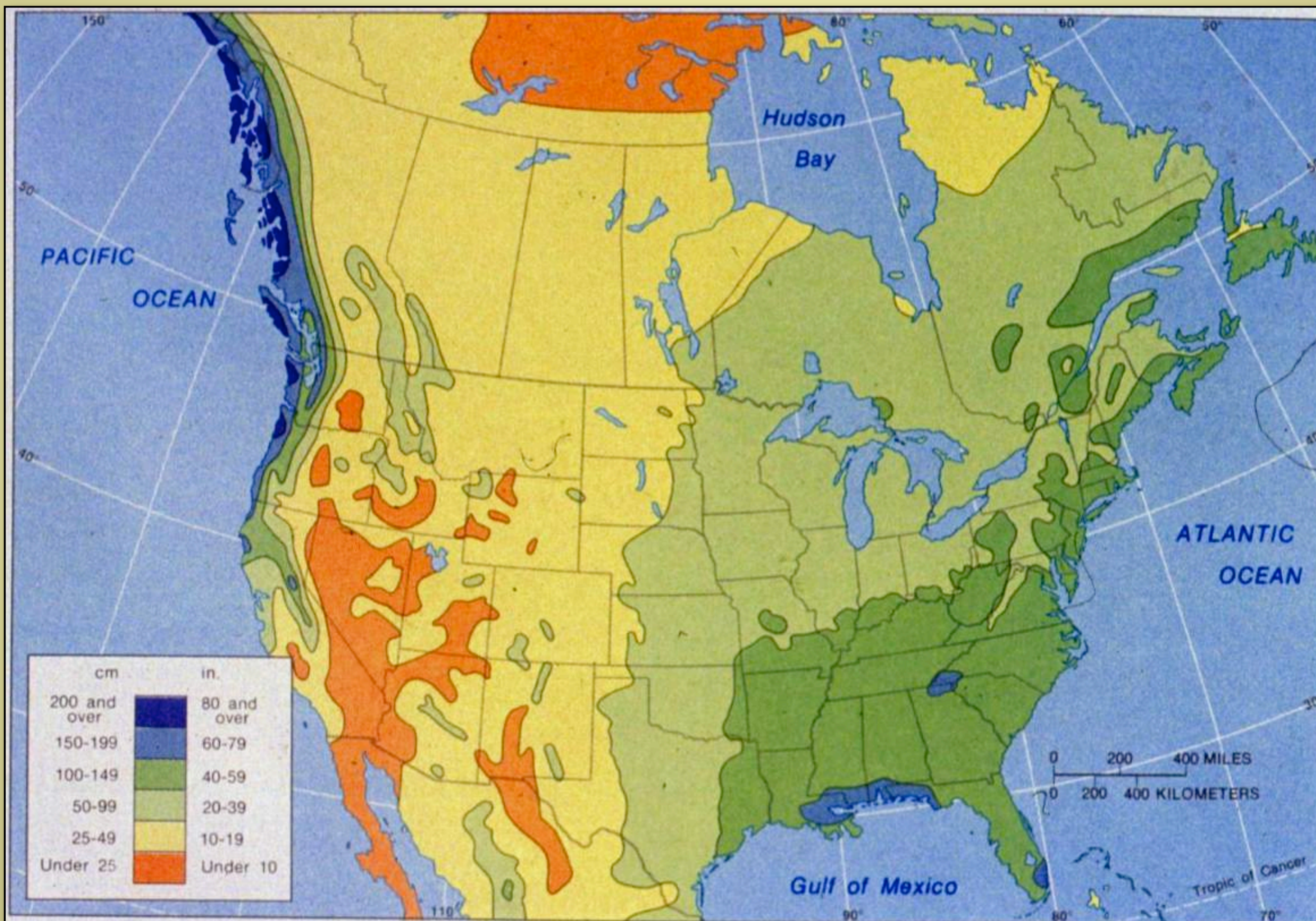
3. Air mass at same elevation on leeward side drier and hotter than when first started — **hot, dry rainshadow**

Orographic Precipitation

November temperature map shows adiabatic warming on leeward side of Rockies

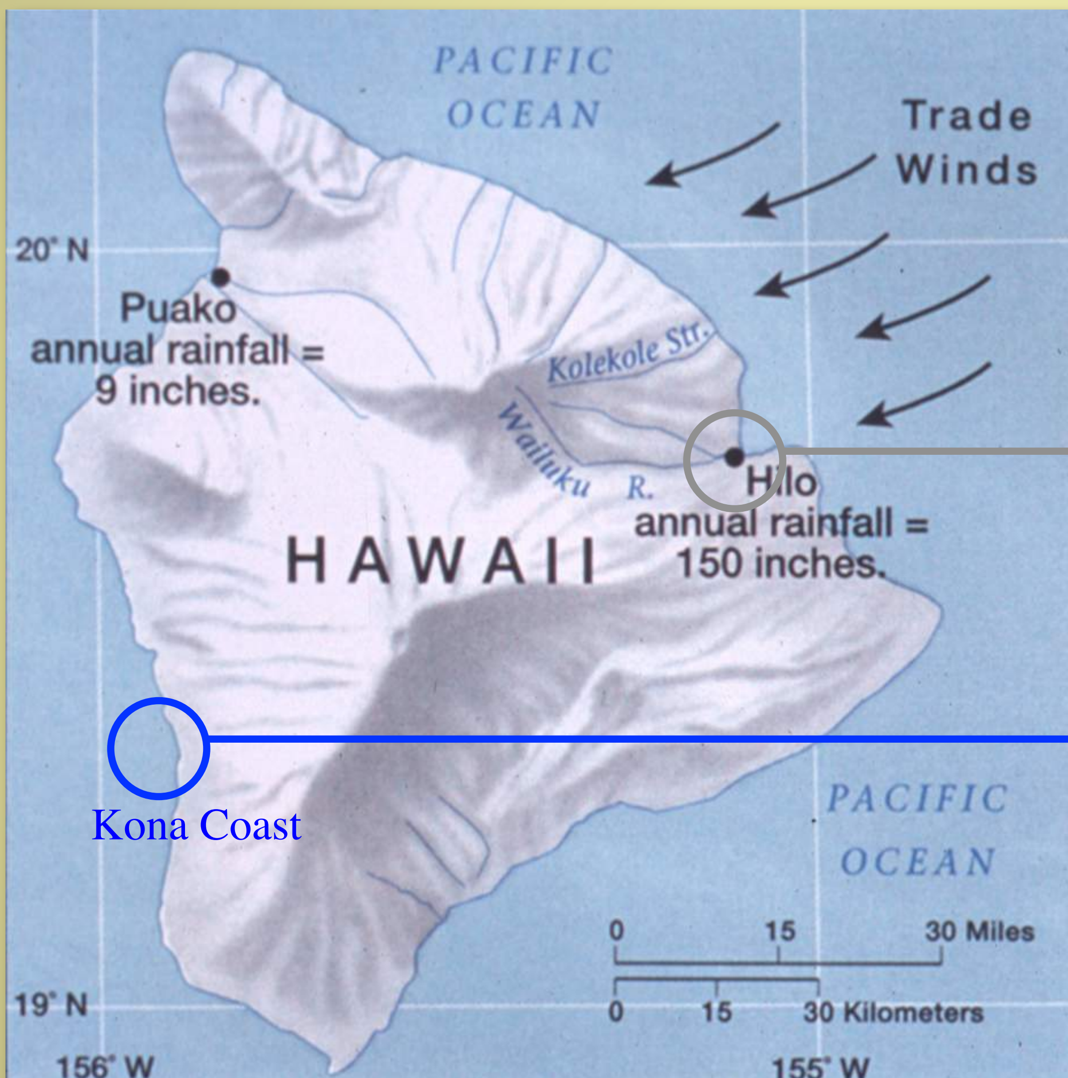
Orographic Precipitation

Precipitation map shows rainshadow deserts/grasslands E of Rockies & Sierra Nevada

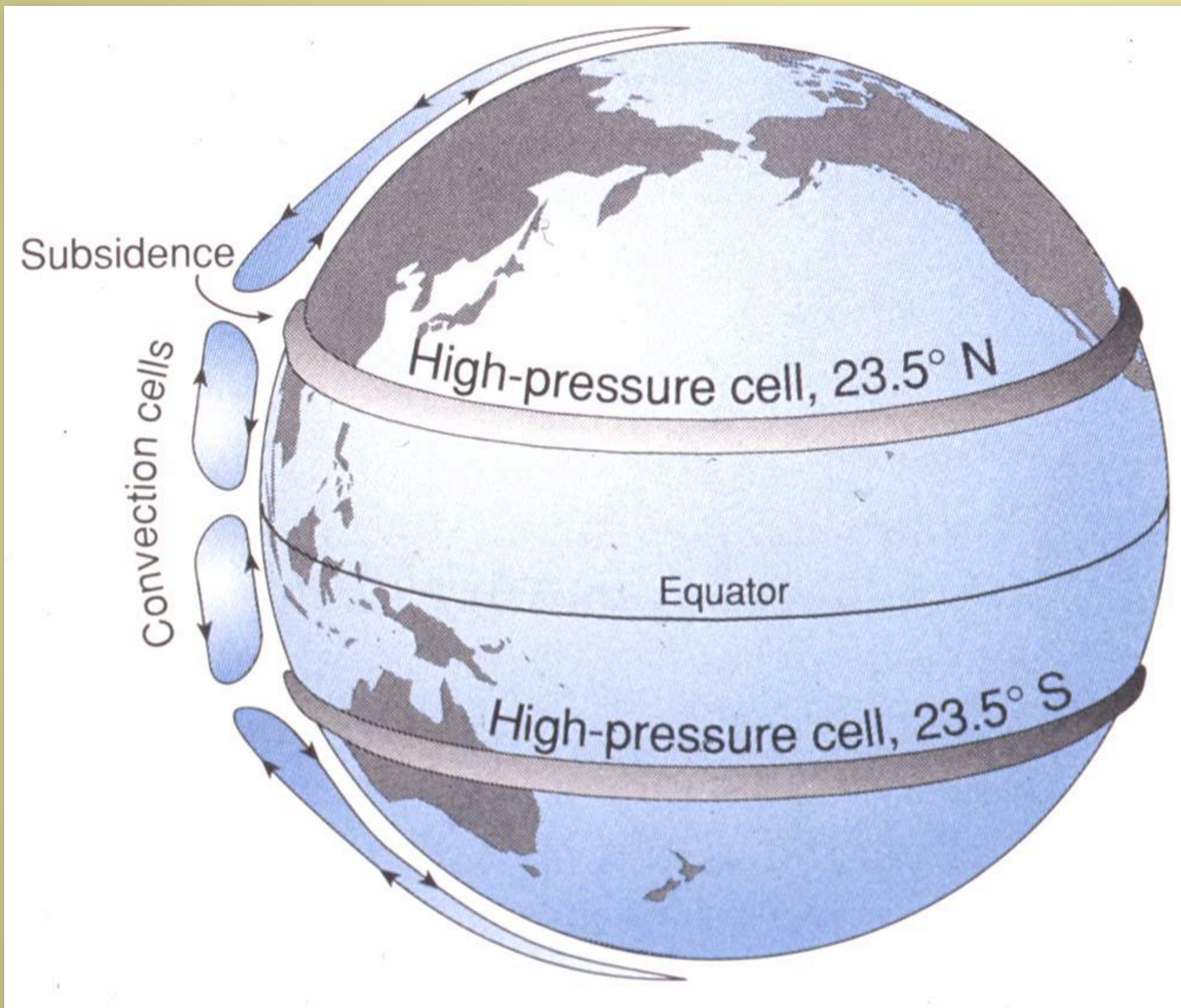


Orographic Precipitation

Hilo (windward and wet) vs. Kona Coast in Hawaii (leeward and dry)



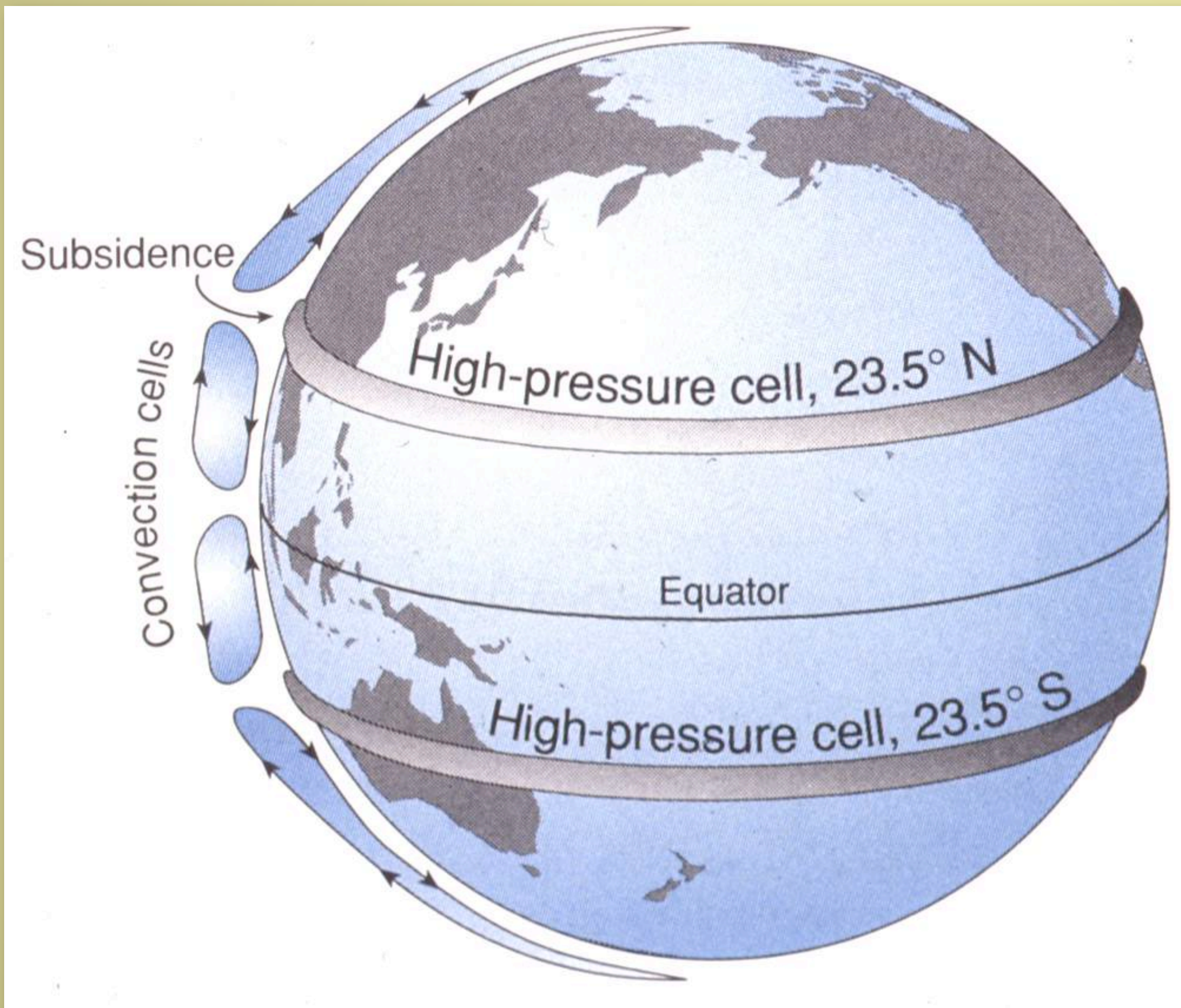
Global Pressure Systems, Precipitation, & Wind



Link insolation of sun, latitude, precipitation and wind by examining global atmospheric pressure systems

This linkage will have the most dramatic affects on plant distributions and largely determines where plant biomes will form

Global Pressure Systems, Precipitation, & Wind

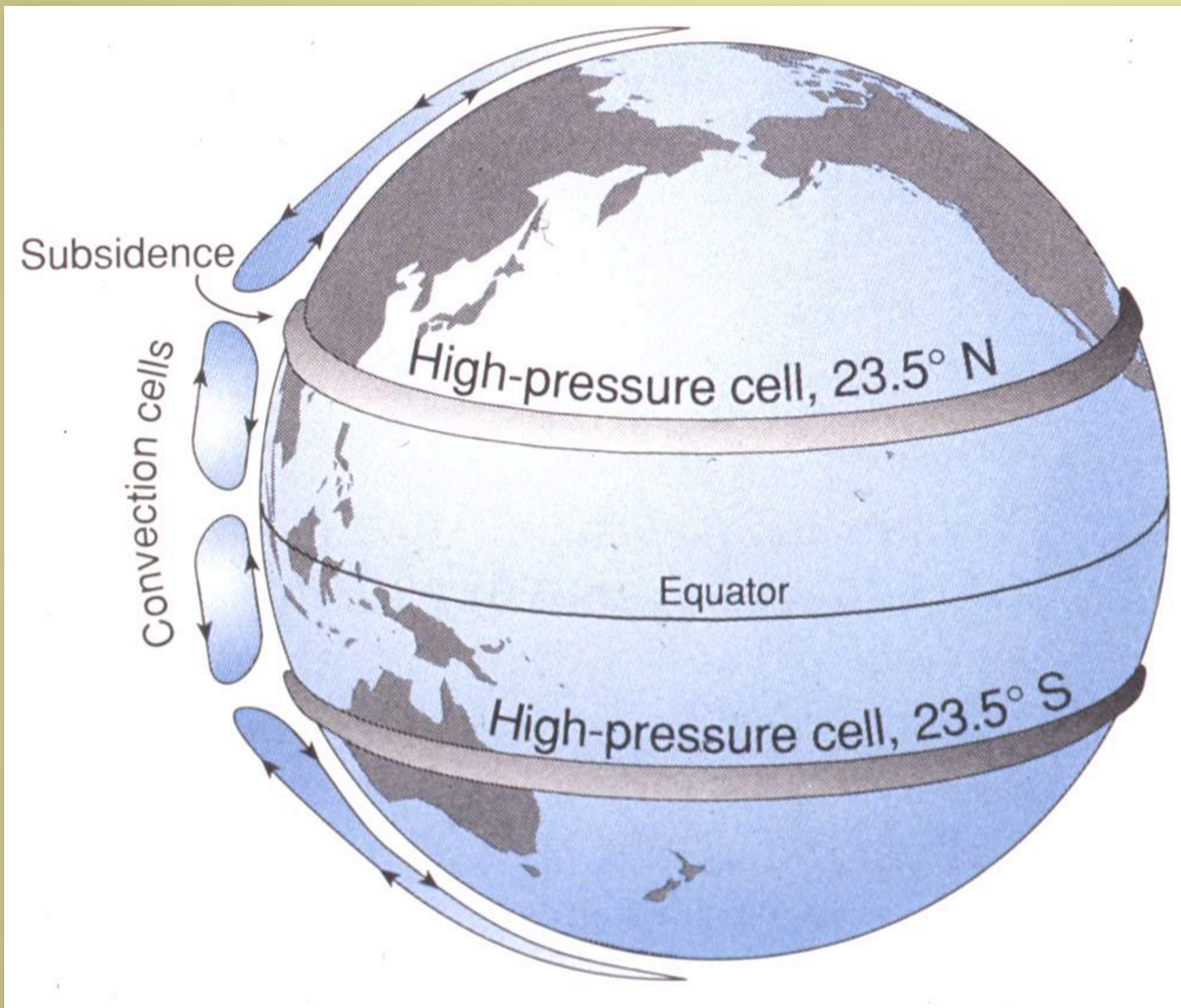


Equatorial trough

- high insolation over the equatorial zone causes warming of air and rising of air bubbles in convective cells

- rising air causes low air pressure (trough) over the equator

Global Pressure Systems, Precipitation, & Wind

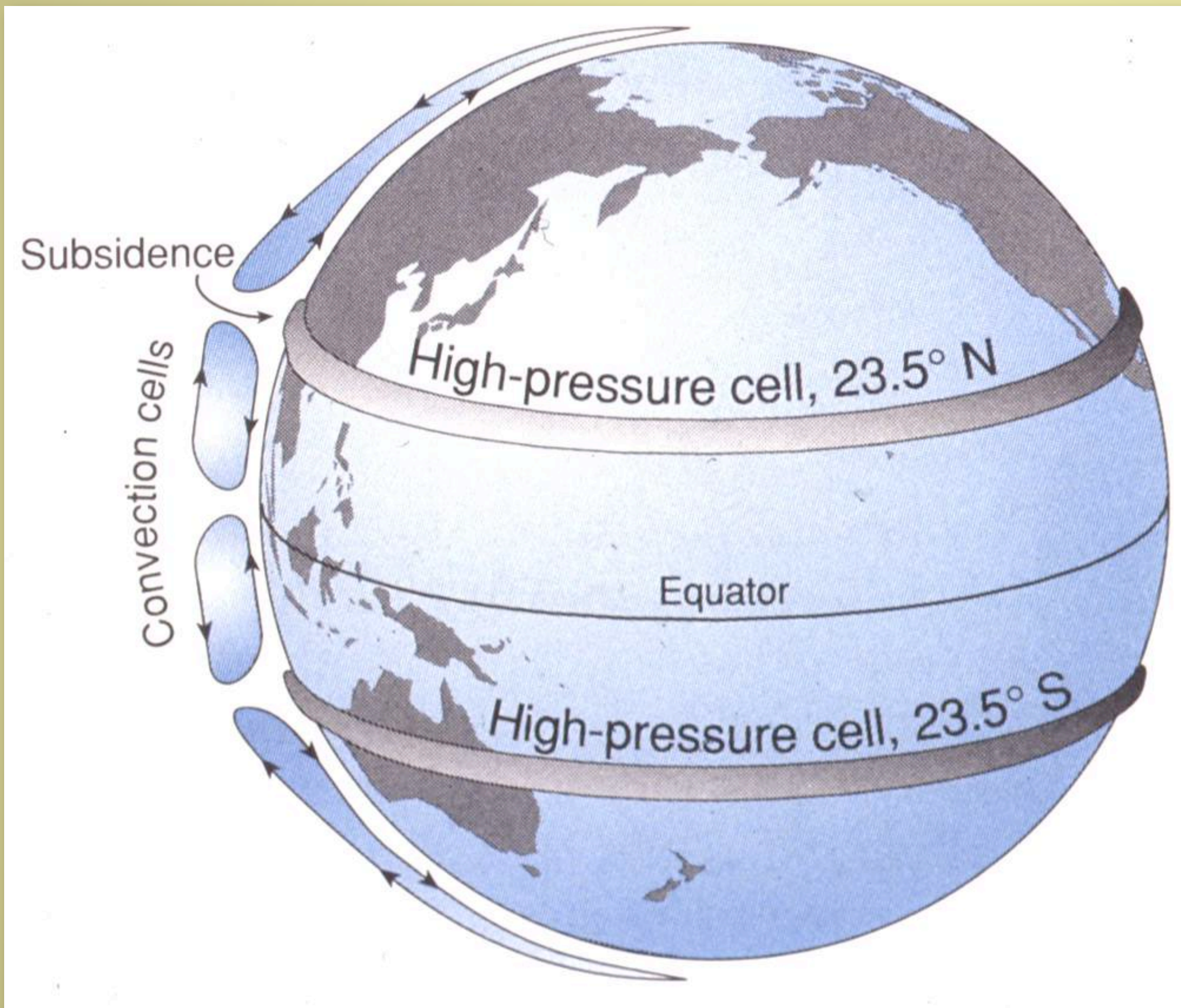


Equatorial trough

• convectional precipitation occurs, enormous amounts of latent heat liberated, updrafts continue to increase, more rain

Tropical forests: firebox of the globe

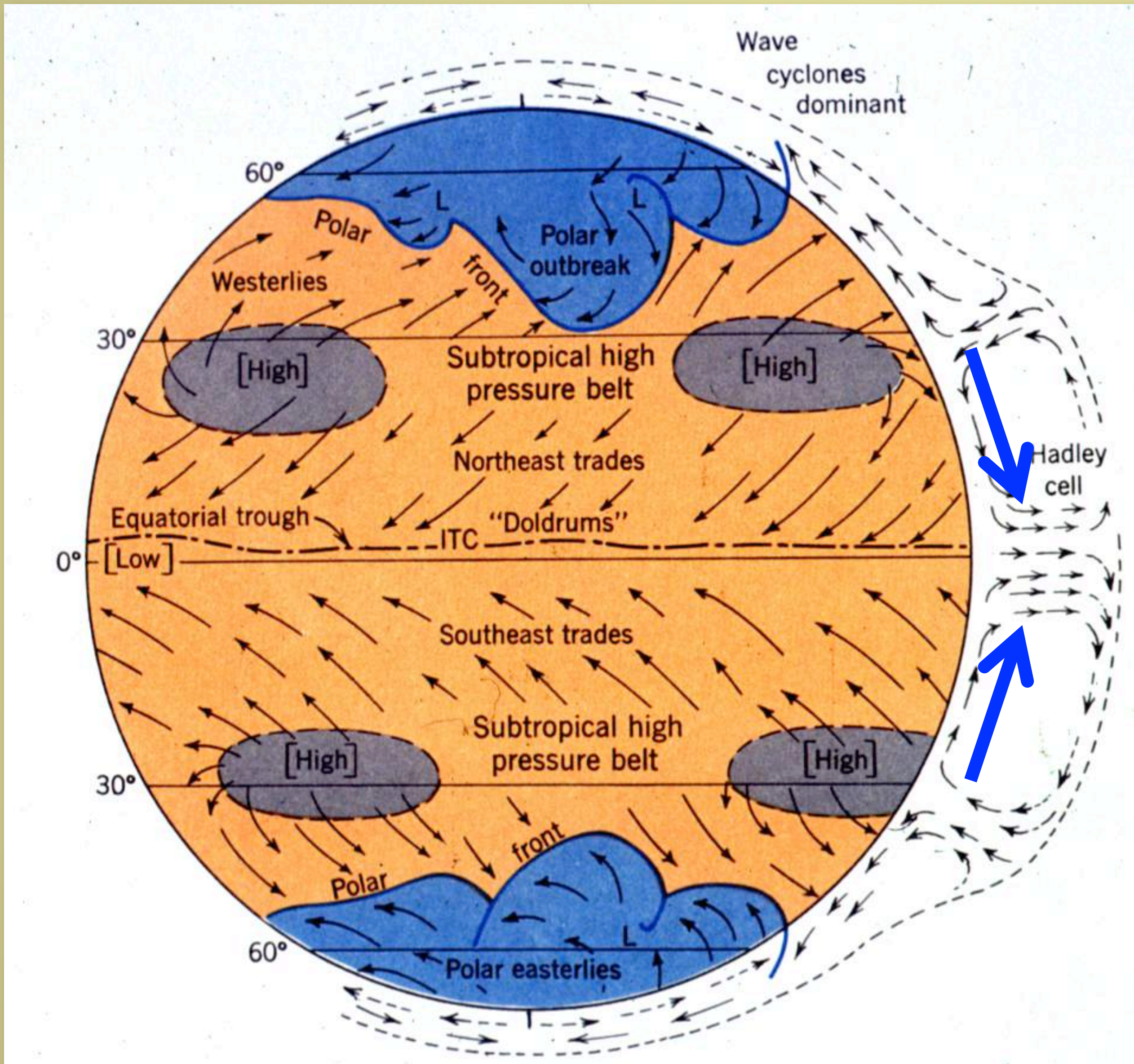
Global Pressure Systems, Precipitation, & Wind



Subtropical high pressure belt

- at higher altitudes, water depleted air cools, becomes denser, stops rising
- cooled, denser, drier air cell sinks at 23-30° latitude — "horse latitudes"
- sinking air causes high pressure system; usually dry and hot (dry adiabatic warming rate!)

Global Pressure Systems, Precipitation, & Wind



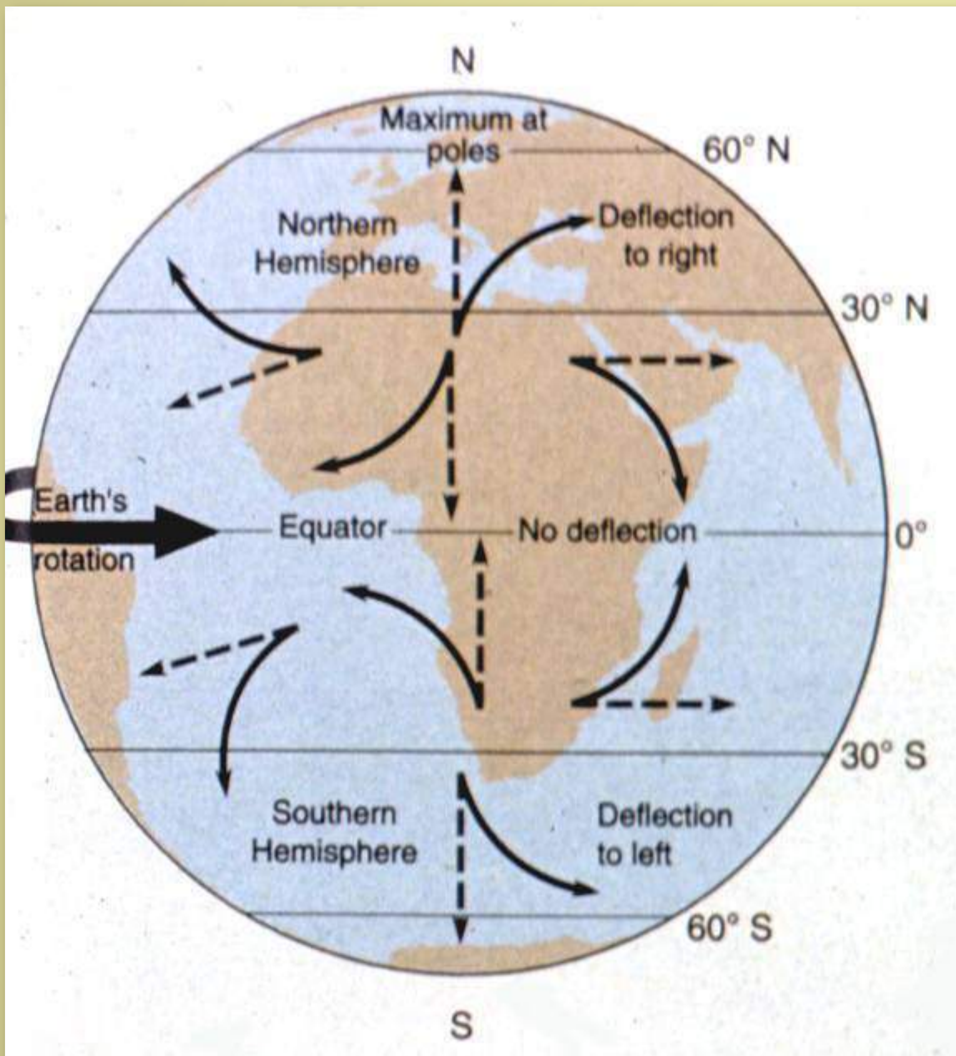
Hadley Cells

- circular flow of air set up; air moves from these subtropical high belts and rushes towards equator to replace rising air
- this dry air mass picks up water vapor from oceans/land to further feed the equatorial convection
- these winds moving from Subropical high to Equatorial low are the **trade winds**

Geography Illiteracy

https://www.youtube.com/watch?v=7_pw8duzGUg

Global Pressure Systems, Precipitation, & Wind



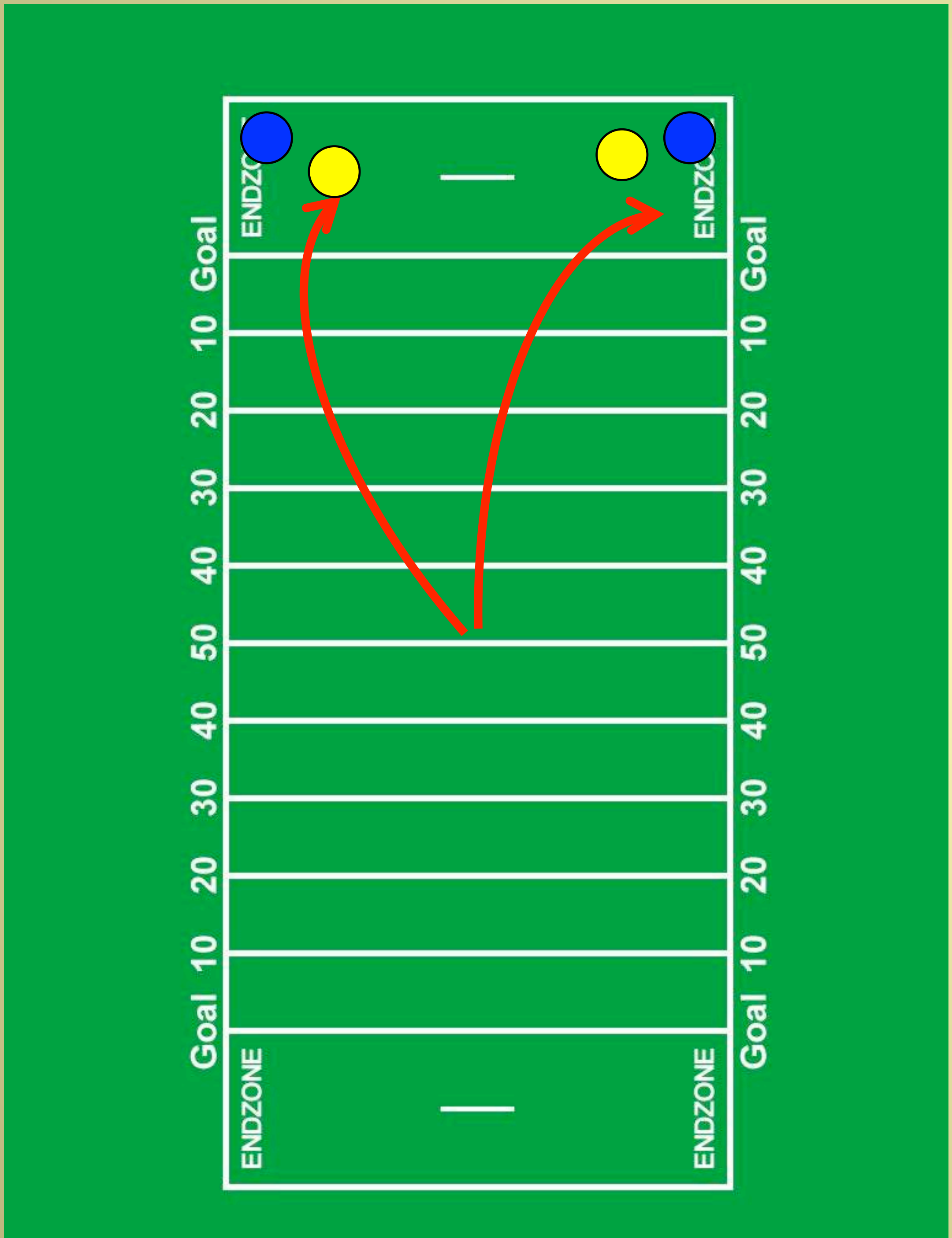
Coriolis effect

• these winds do not blow exactly in N-S direction, but appear to be deflected by rotation of the earth

• rotational velocity:
  equator 40,000 km / day
  other latitudes slower
[Madison = 28,320 km / day]

• in northern hemisphere, winds are deflected to the right — clockwise
  in southern hemisphere, to the left — counterclockwise

Global Pressure Systems, Precipitation, & Wind



Coriolis effect

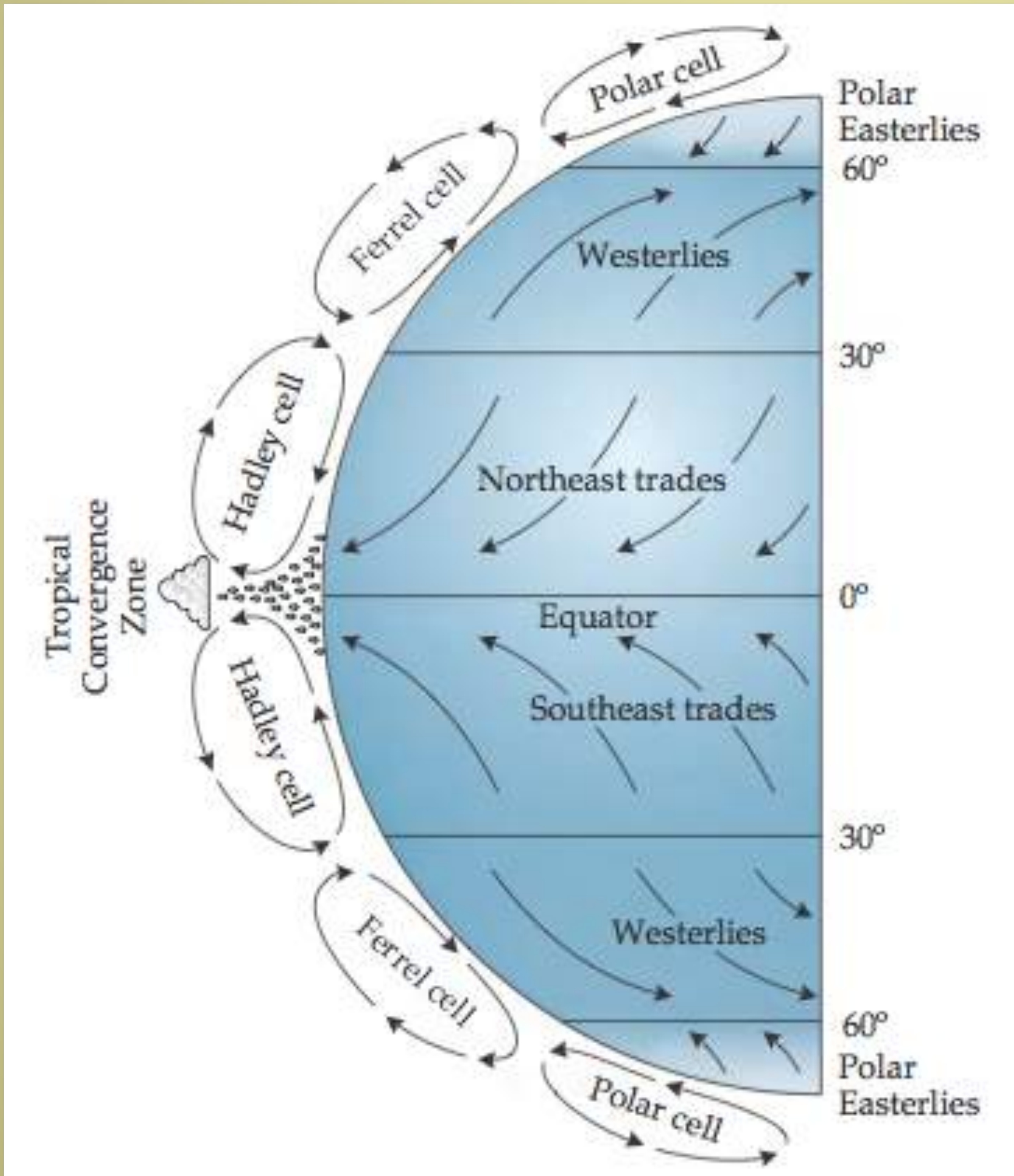
- Does the Coriolis effect affect endzone passes in the Super Bowl?

- Is it harder to intercept a pass to the right corner of either end zone?

wide- receiver

corner/safety

Global Pressure Systems, Precipitation, & Wind



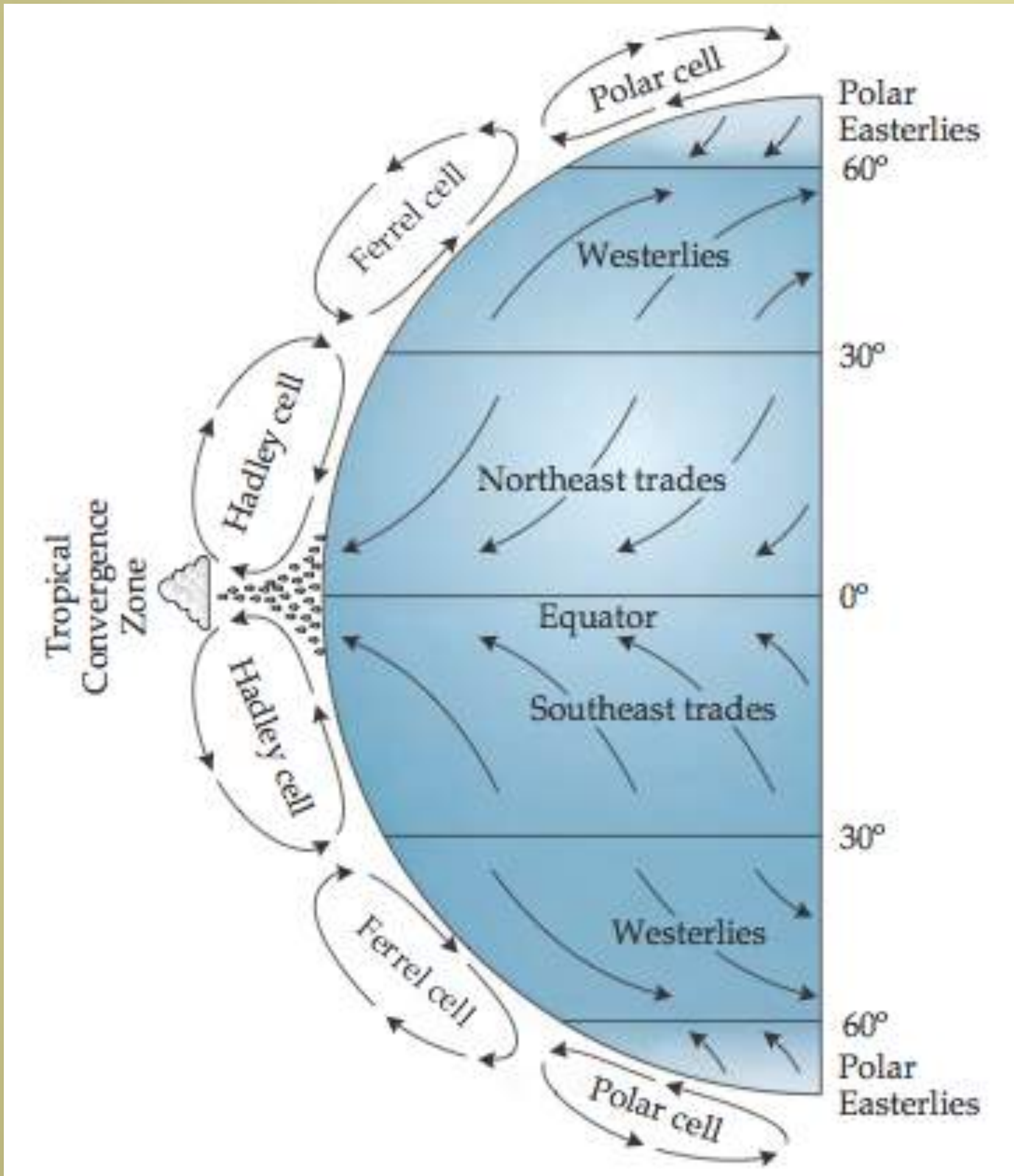
Easterlies

- trade winds are called the "**easterlies**" as they approach the equator from the east in both hemispheres

- Northeast trade winds
  Southeast trade winds

- trade winds converge at the narrow **intertropical convergence zone** (doldrums)

Global Pressure Systems, Precipitation, & Wind



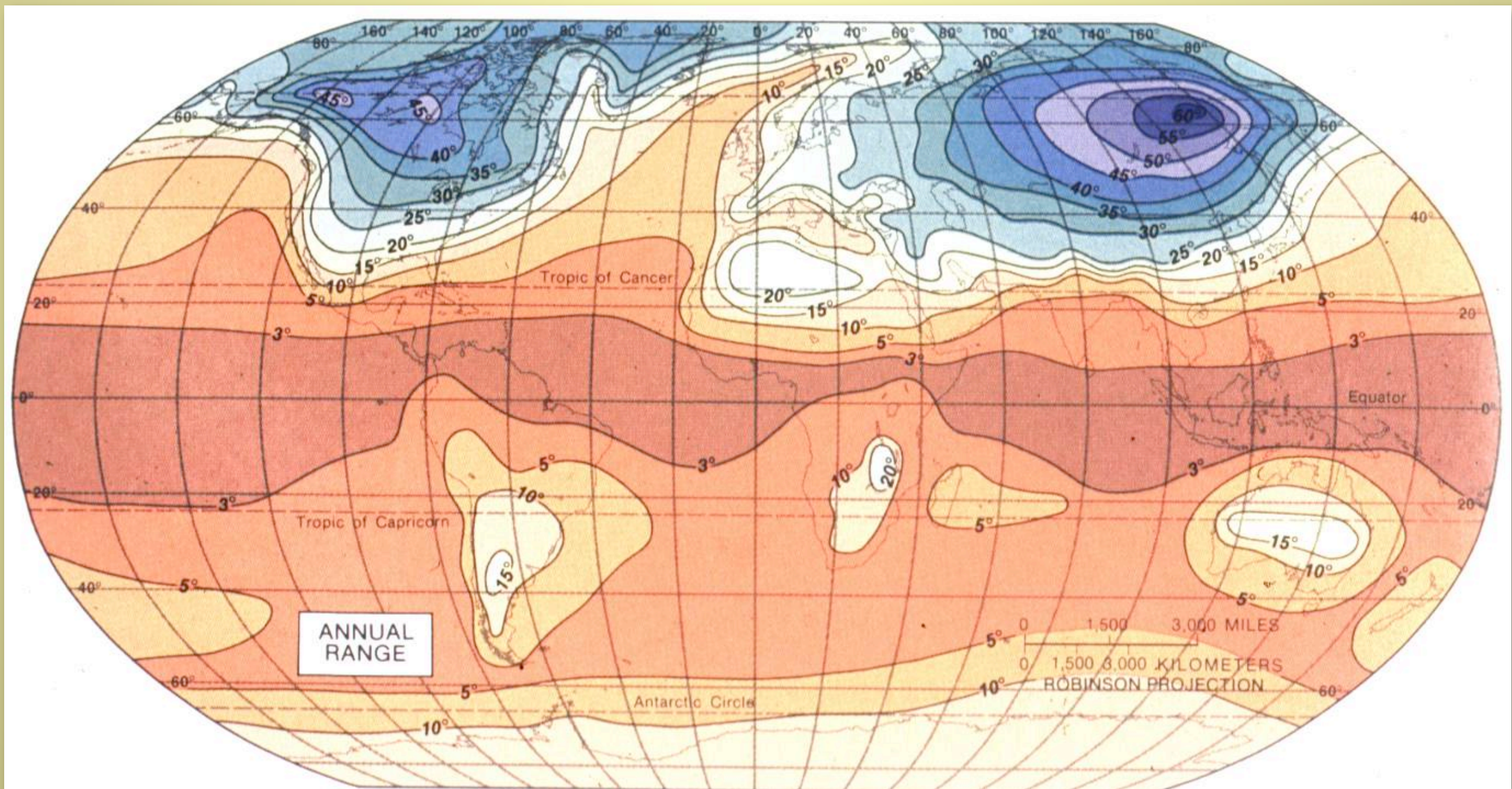
Westerlies

- winds and moisture carried to subarctic and subantarctic low pressure belts at 60° latitude are called the "**westerlies**"
- westerlies disrupted somewhat in northern hemisphere by large continents
- in the great "Southern Ocean" more pronounced:
  - "roaring 40s"
  - "furious 50s"
  - "screaming 60s"

Global Pressure Systems, Precipitation, & Wind

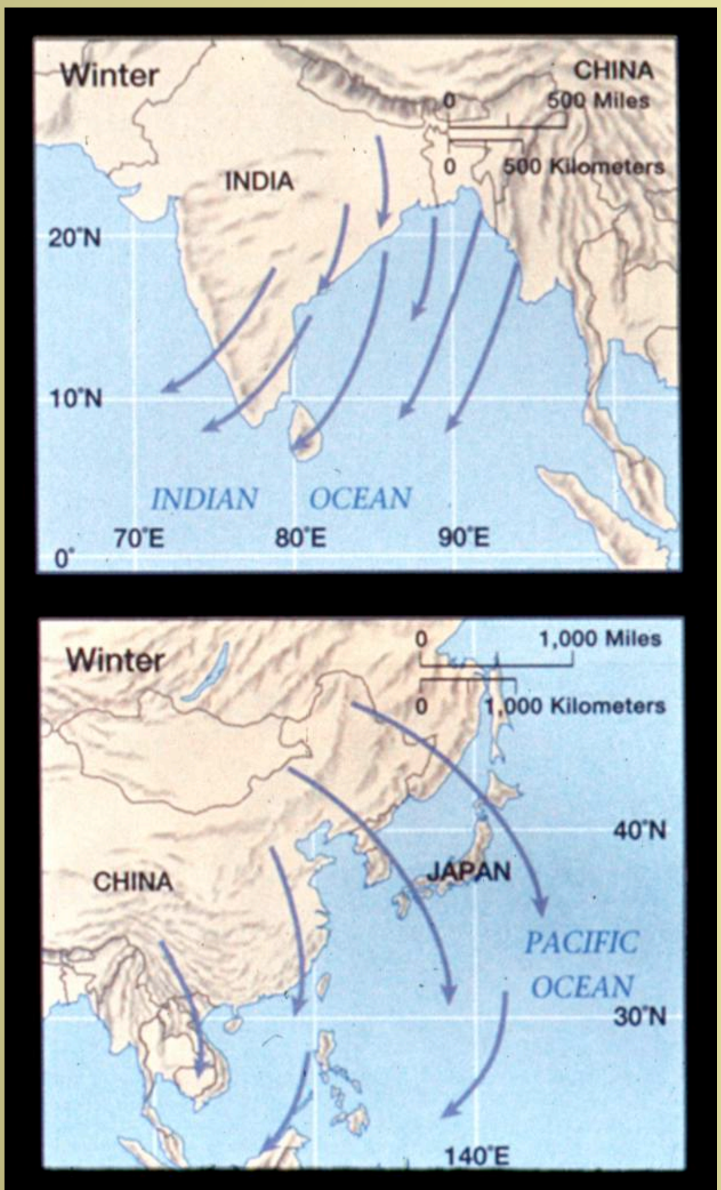
Northern Hemisphere Pressure System

- vast continents of northern hemisphere exert powerful control over pressure systems and climate
- note the **extreme** annual range in temperature over North America and Eurasia



Global Pressure Systems, Precipitation, & Wind

Northern Hemisphere Pressure System



Winter

High pressure (cold, dry, dense air) develops over very cold continents (Siberian/Canadian highs)

Low pressure (warm, mois air) develops over warmer oceans

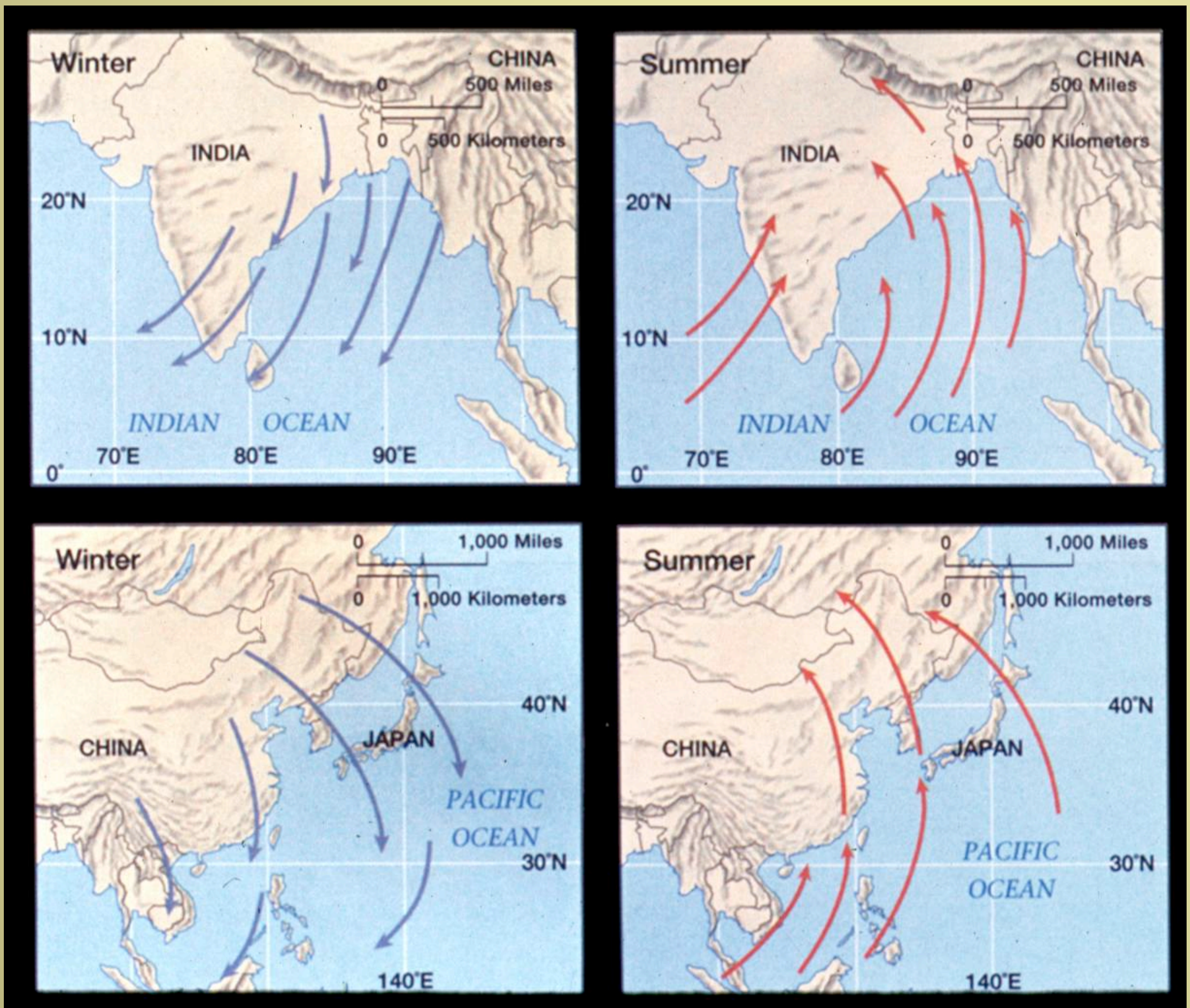
Winter exhibits a southwar flow of air toward equator

- winter monsoon = dry weather

Global Pressure Systems, Precipitation, & Wind

Northern Hemisphere Pressure System

Summer



Low pressure develops ove
very hot continents

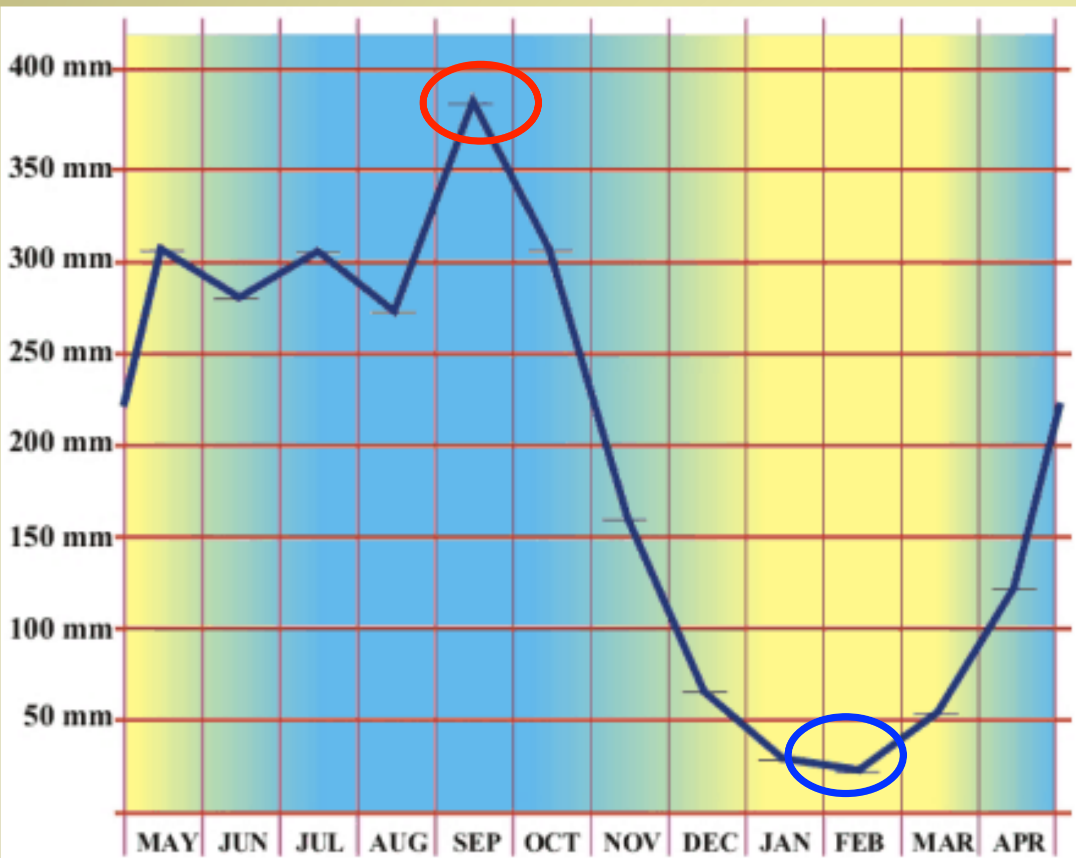
Oceans develop high
pressure systems

Summer exhibits a
northward flow of very
moist oceanic air toward
continents

- summer monsoon =
  very wet weather

Global Pressure Systems, Precipitation, & Wind

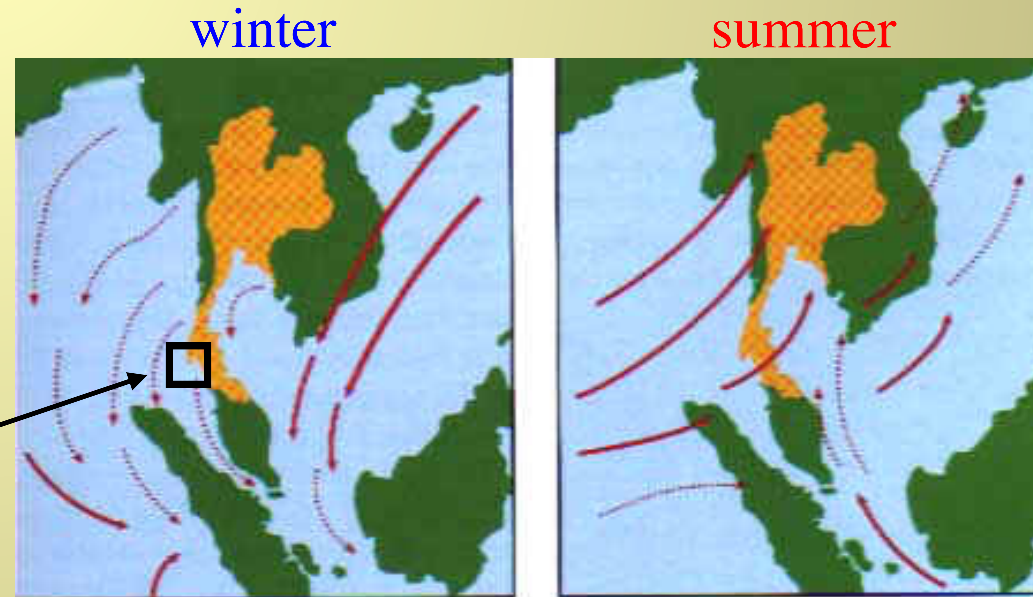
Northern Hemisphere Pressure System



Annual precipitation in Phuket, Thailand

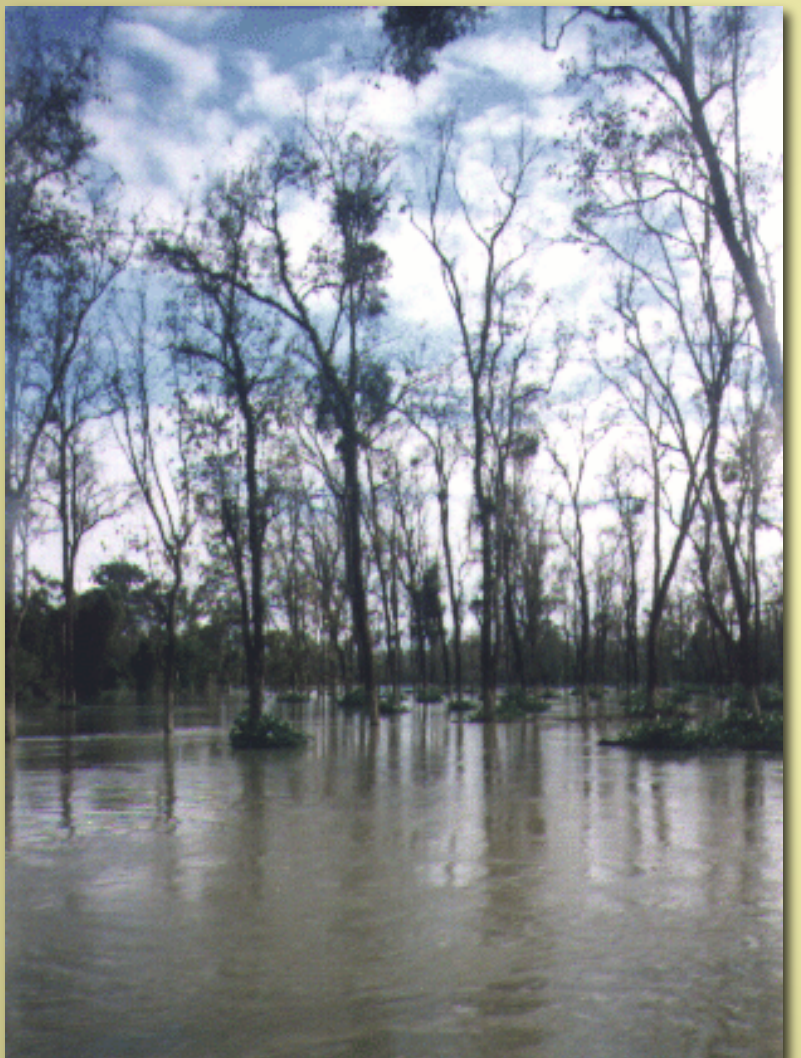
Monsoon climate

Asian monsoon areas experience drastic differences in moisture between winter and summer



Global Pressure Systems, Precipitation, & Wind

Northern Hemisphere Pressure System

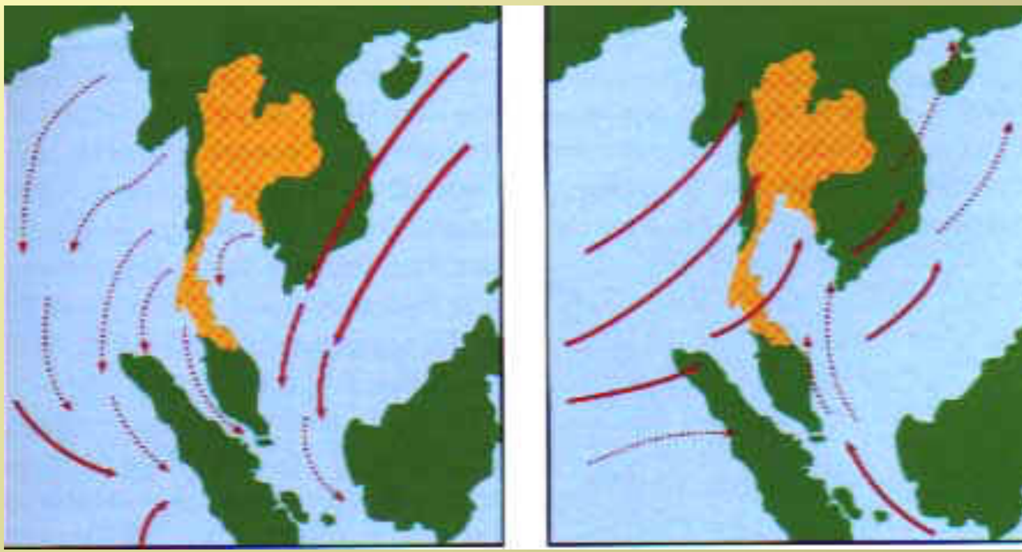


Monsoon forest in Phuket, Thailand

Monsoon climate

Asian monsoon areas experience drastic differences in moisture between winter and summer

Monsoon forests must adapt to alternating flooding and drying



Global Pressure Systems, Precipitation, & Wind

Northern Hemisphere Pressure System

Monsoon climate

Asian monsoon areas experience drastic differences in moisture between winter and summer

Monsoon forests must adapt to alternating flooding and drying

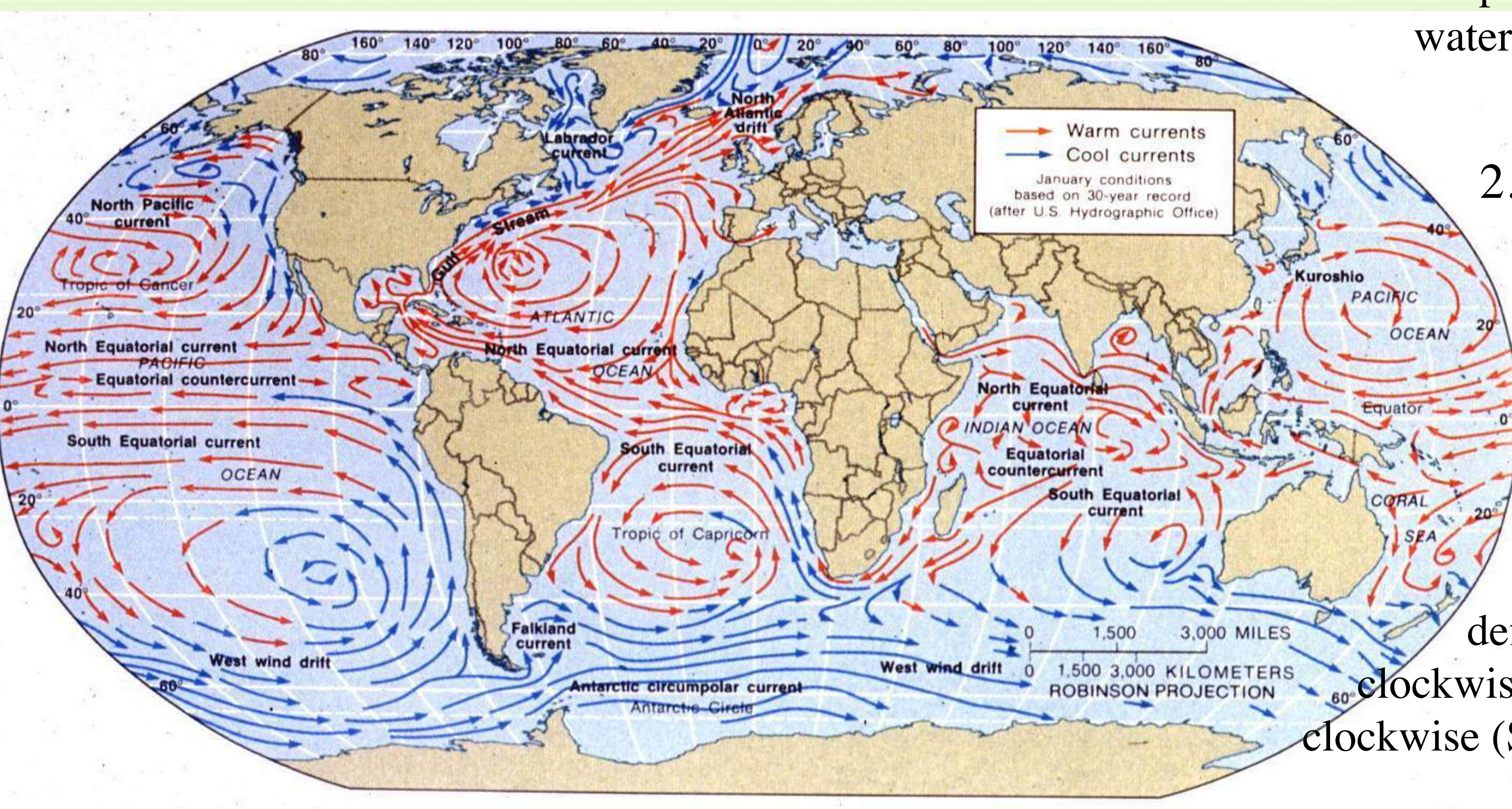
The remarkable extremes of monsoon conditions not as prevalent in the Americas thus less monsoon forest

Global Pressure Systems, Precipitation, & Wind

Ocean Currents

- patterns of global pressure belts and subsequent air/wind movements greatly influence the movement of water in the hydrosphere

- winds influenced by the Coriolis effect initiate the major ocean currents



1.easterlies push surface water to equator

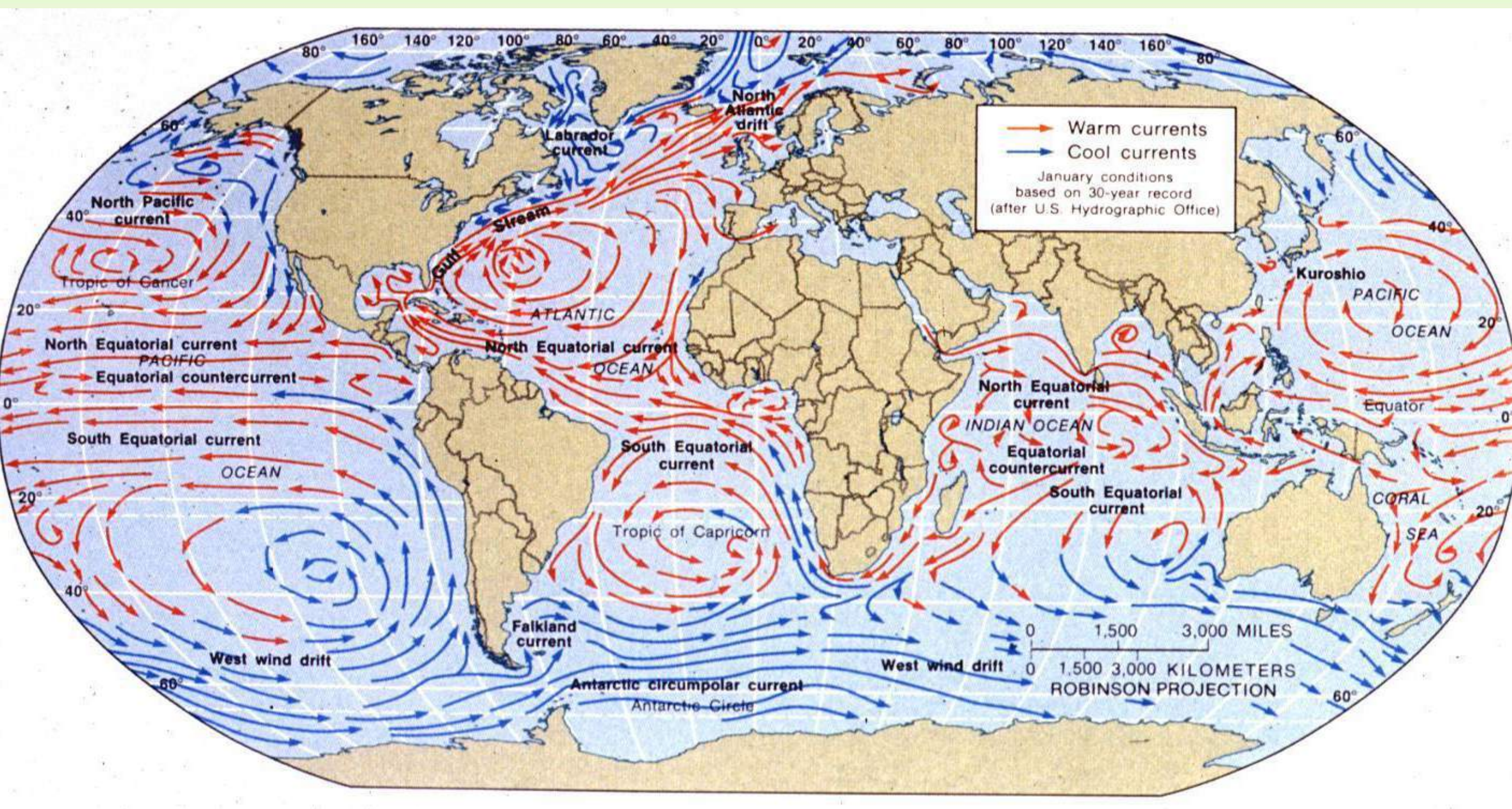
2.westerlies produc eastward movin currents at highe latitude

3.water masses responding to Coriolis effect deflect water masses clockwise (NH) or counter clockwise (SH) to form **gyres**

Global Pressure Systems, Precipitation, & Wind

Ocean Currents

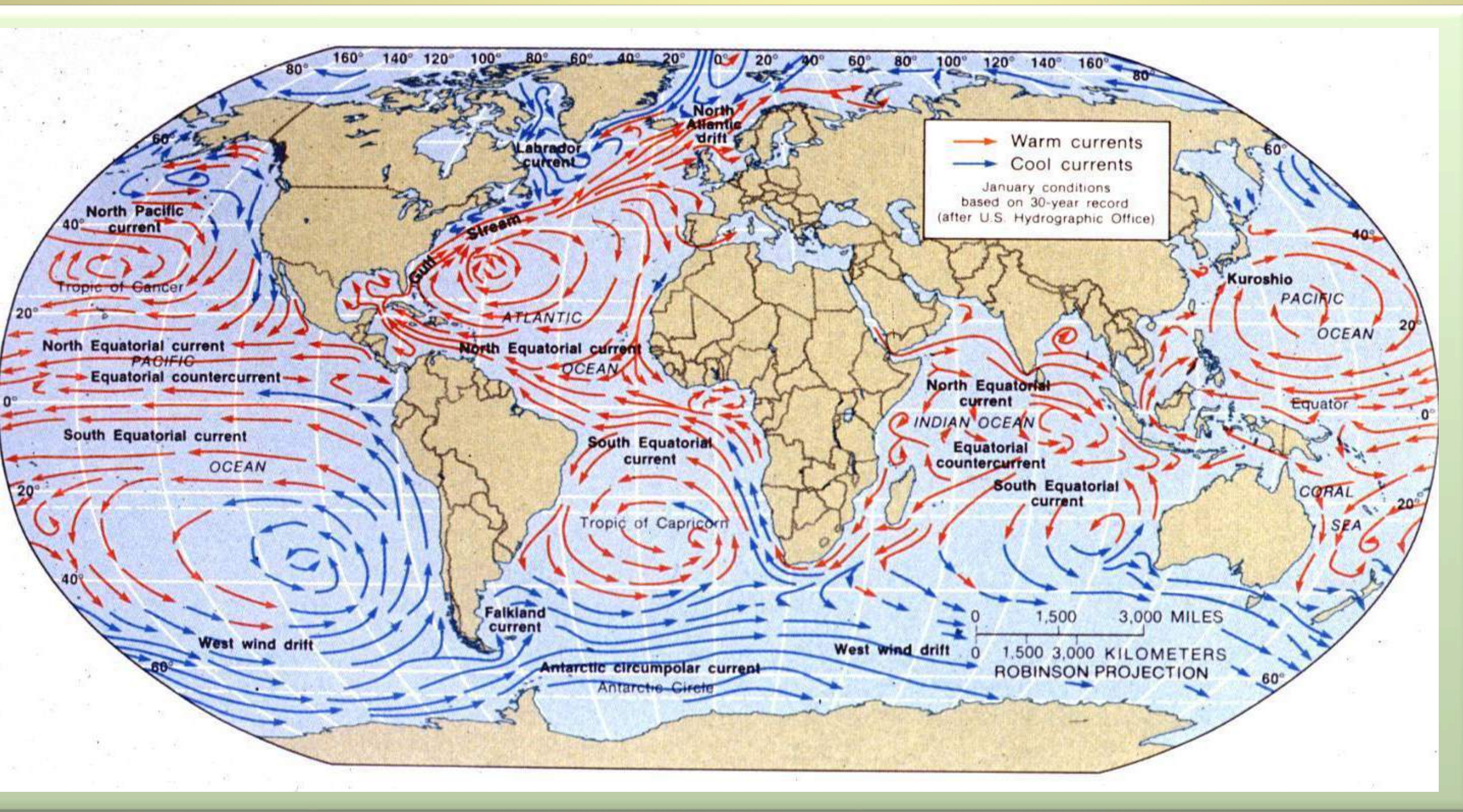
- equatorial current - westward flow
- westwind drift - slow eastward flow at 35- 45° N & 30- 60° S latitudes



Global Pressure Systems, Precipitation, & Wind

Ocean Currents

- warm currents flow from the tropics along *eastern continental margins*
- Gulf (Florida, Caribbean) stream
- Kuroshio current

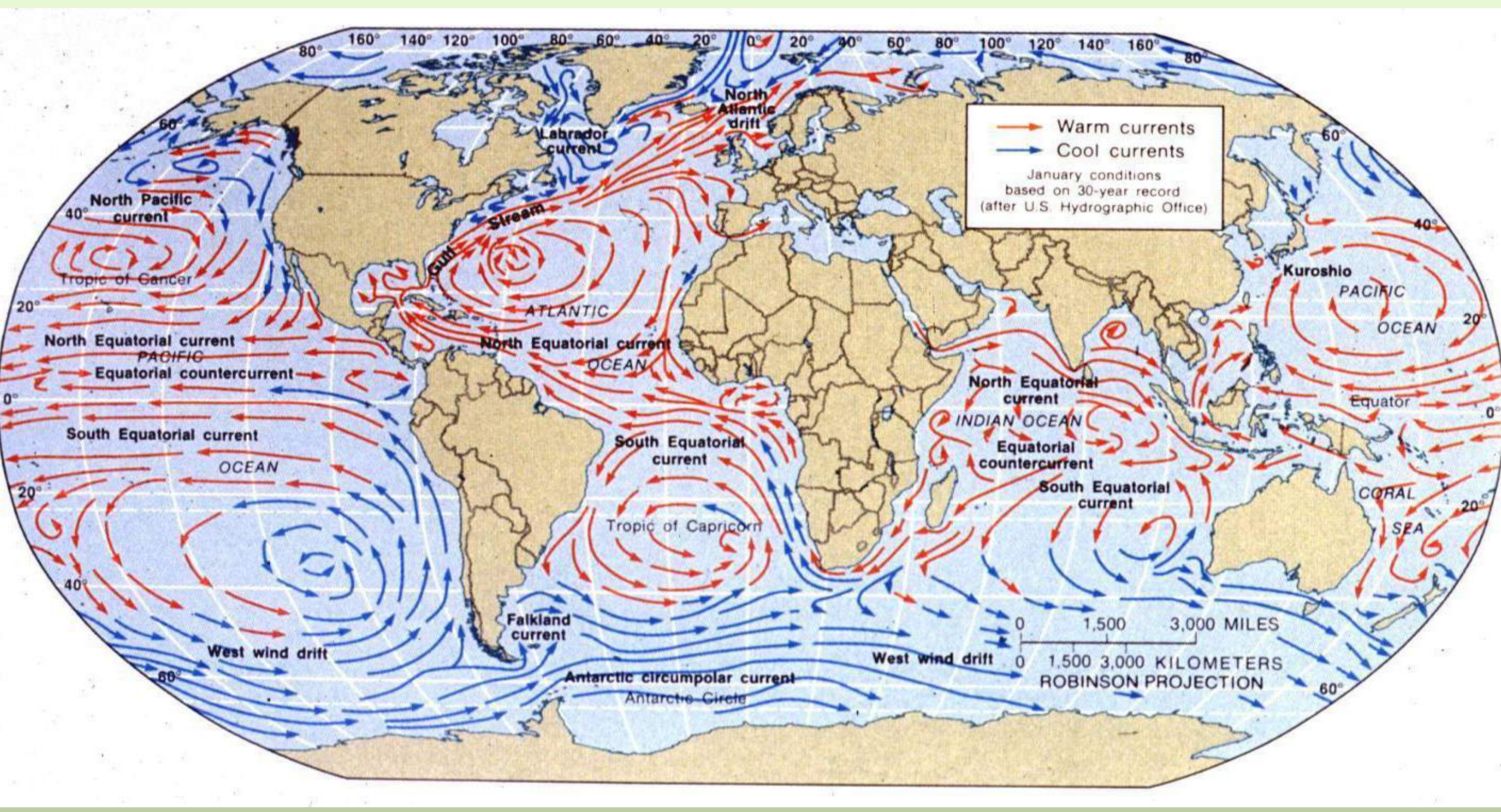


Global Pressure Systems, Precipitation, & Wind

Ocean Currents

- cold currents flow from the high latitudes down along *western continental margins*

- California current (western N. Amer.)
- Humboldt (Peru) current (Chile, Peru)
- Benguela current (SW Africa)
- Canaries current (Spain, N. Africa)



Global Pressure Systems, Precipitation, & Wind

Ocean Currents

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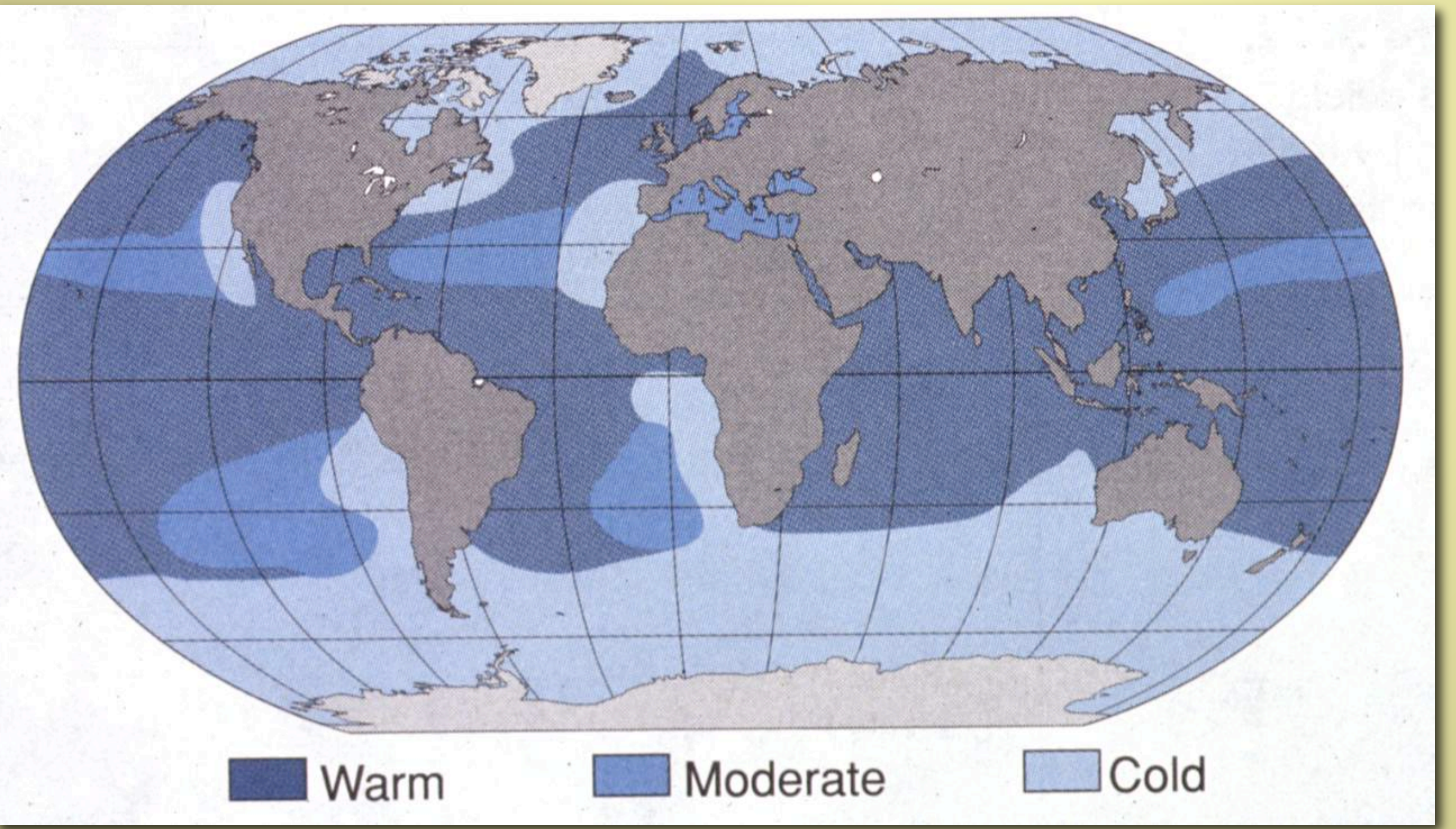
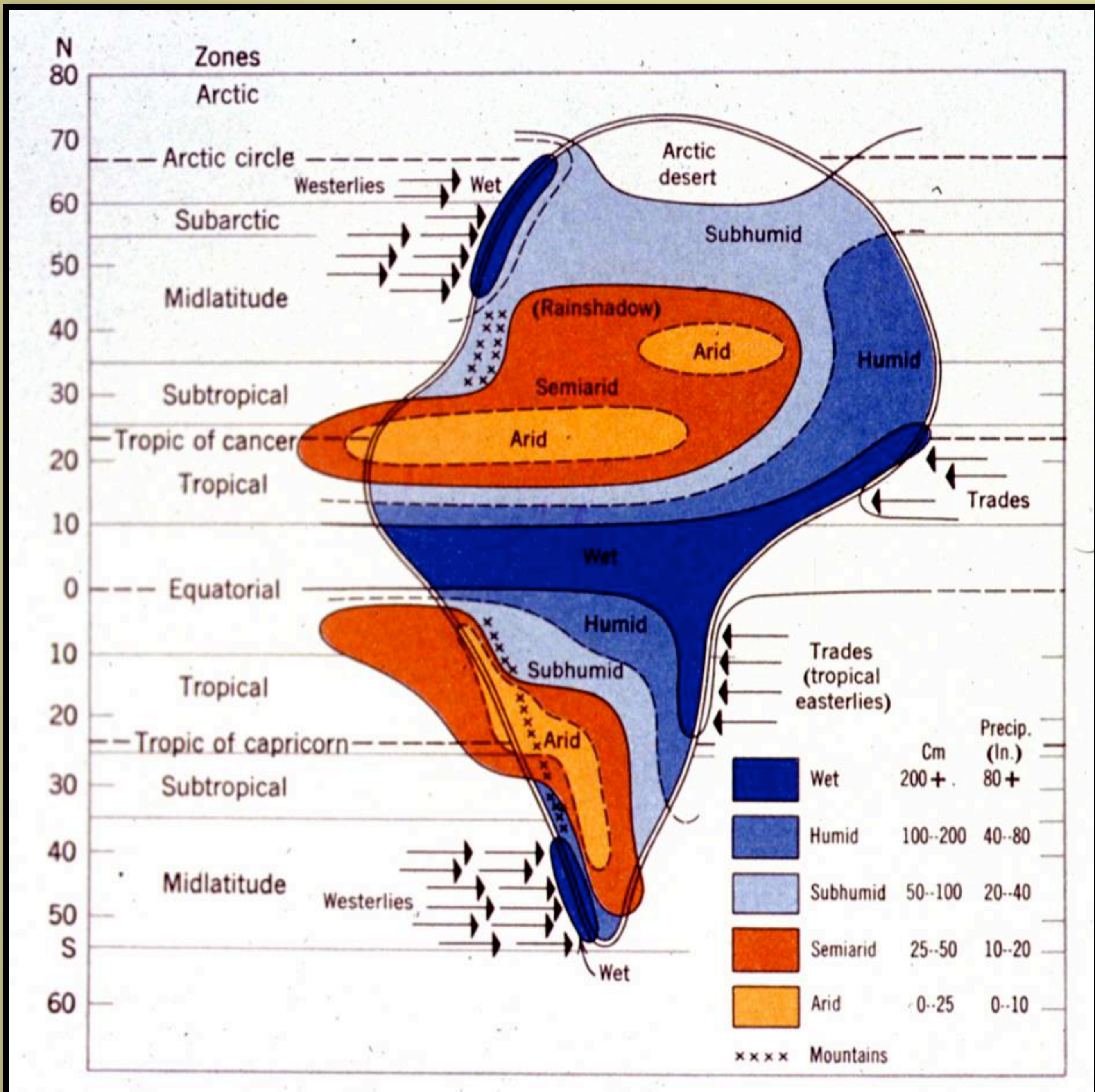


The effect of these currents on biome placement and plant vegetation can be dramatic - deserts and Mediterranean regions

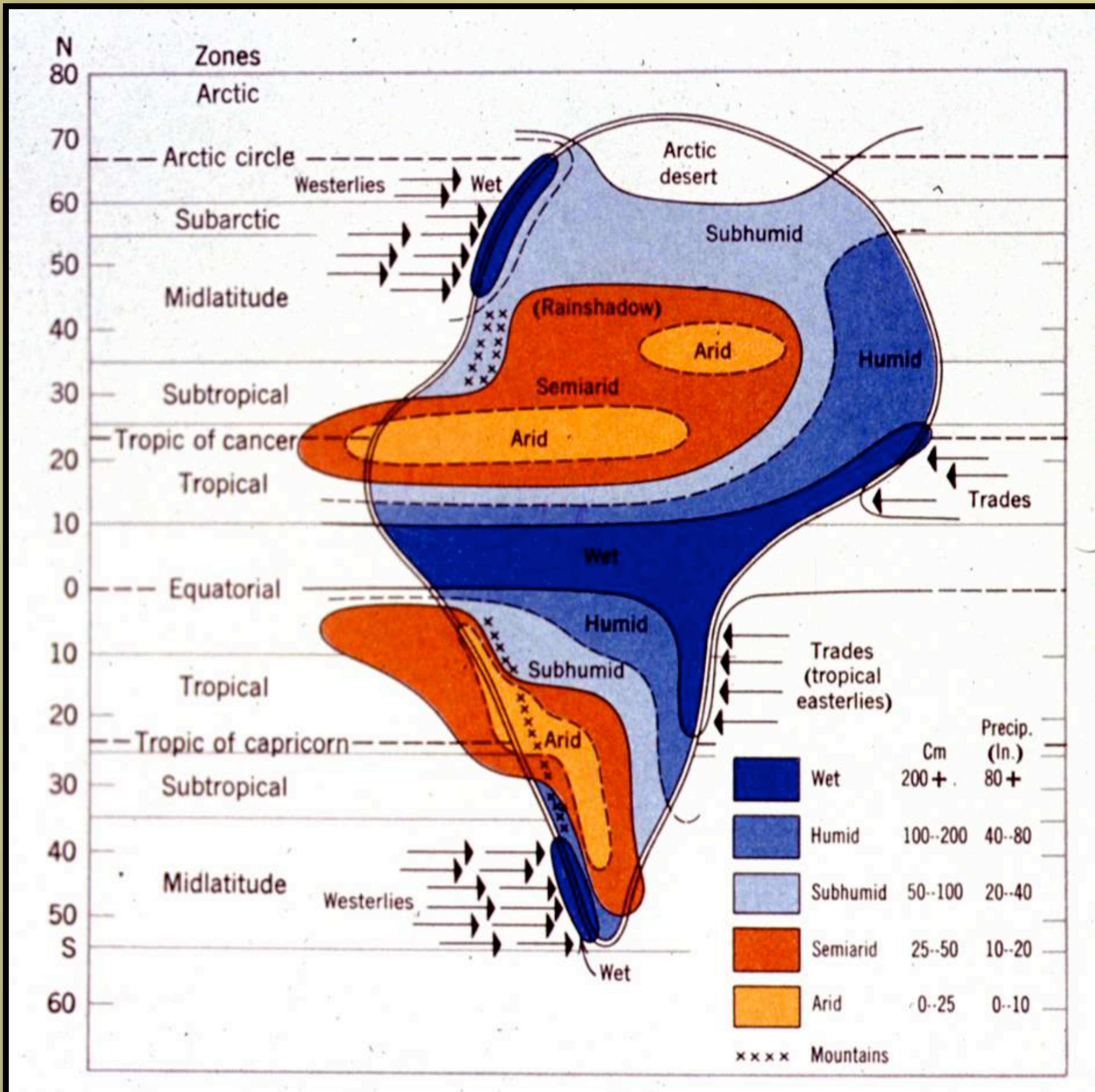
World Precipitation Patterns & Climates



Interplay of all these patterns in insolation, wind, ocean currents to form worldwide precipitation and climate patterns on idealized continent

1. Equatorial wet belt
   200 cm+ (80in) per year
2. Trade wind coasts
   to 25° latitudes N&S
   east side of continents
   150-200 cm per year
3. Humid coasts further poleward of trade wind coasts; moist winds from warm currents

World Precipitation Patterns & Climates



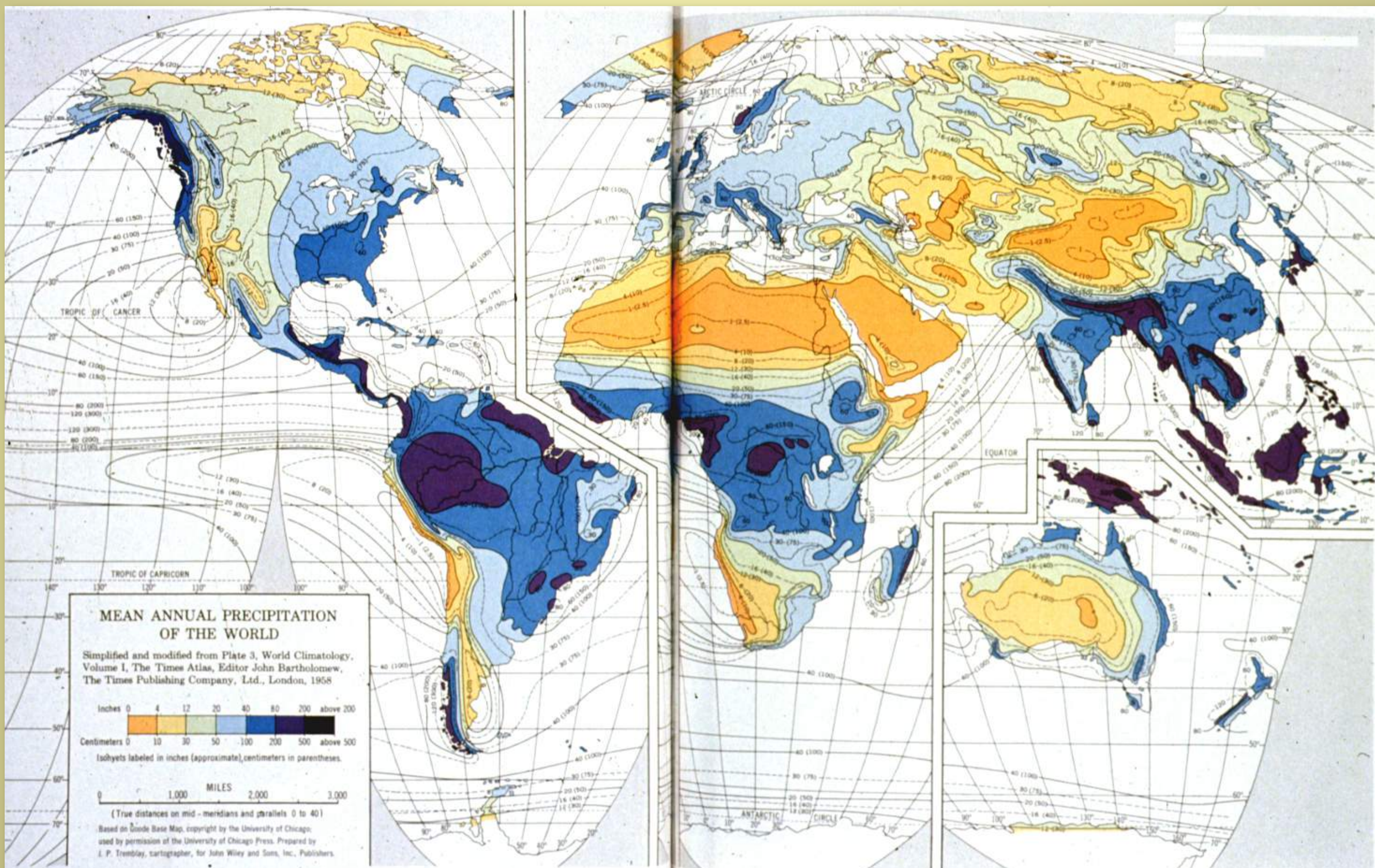
4. Subtropical deserts
straddle Tropics of cancer
and capricorn under hot, dry
high pressure areas,
and west side of continents
(no trade winds & cold
currents from high latitudes

5. Mid-latitude steppes or
grasslands in "continental"
interiors (and mountain
rainshadows)

6. Temperate rain forests
west coasts at 40-65° due to
moist westerlies

World Climate and Vegetation Classifications

Actual rainfall patterns are far more complex



World Climate and Vegetation Classifications

Köppen-Geiger Climate Classification largely based on precipitation patterns

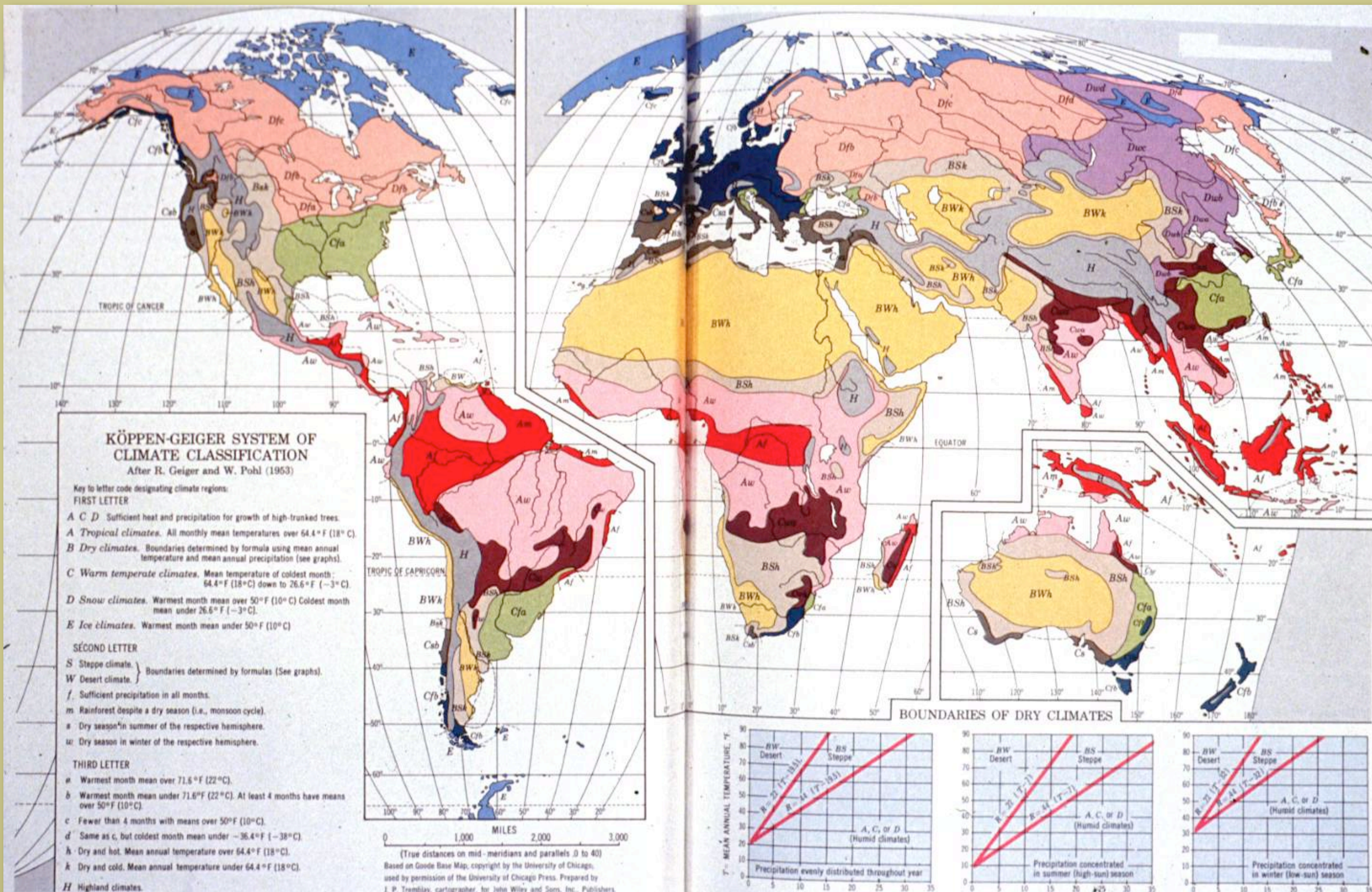


FIGURE 7.17 World map of climates according to the Köppen–Geiger–Pohl system.

World Climate and Vegetation Classifications

Vegetation types (here Eyre 1968) correlate with these climate features

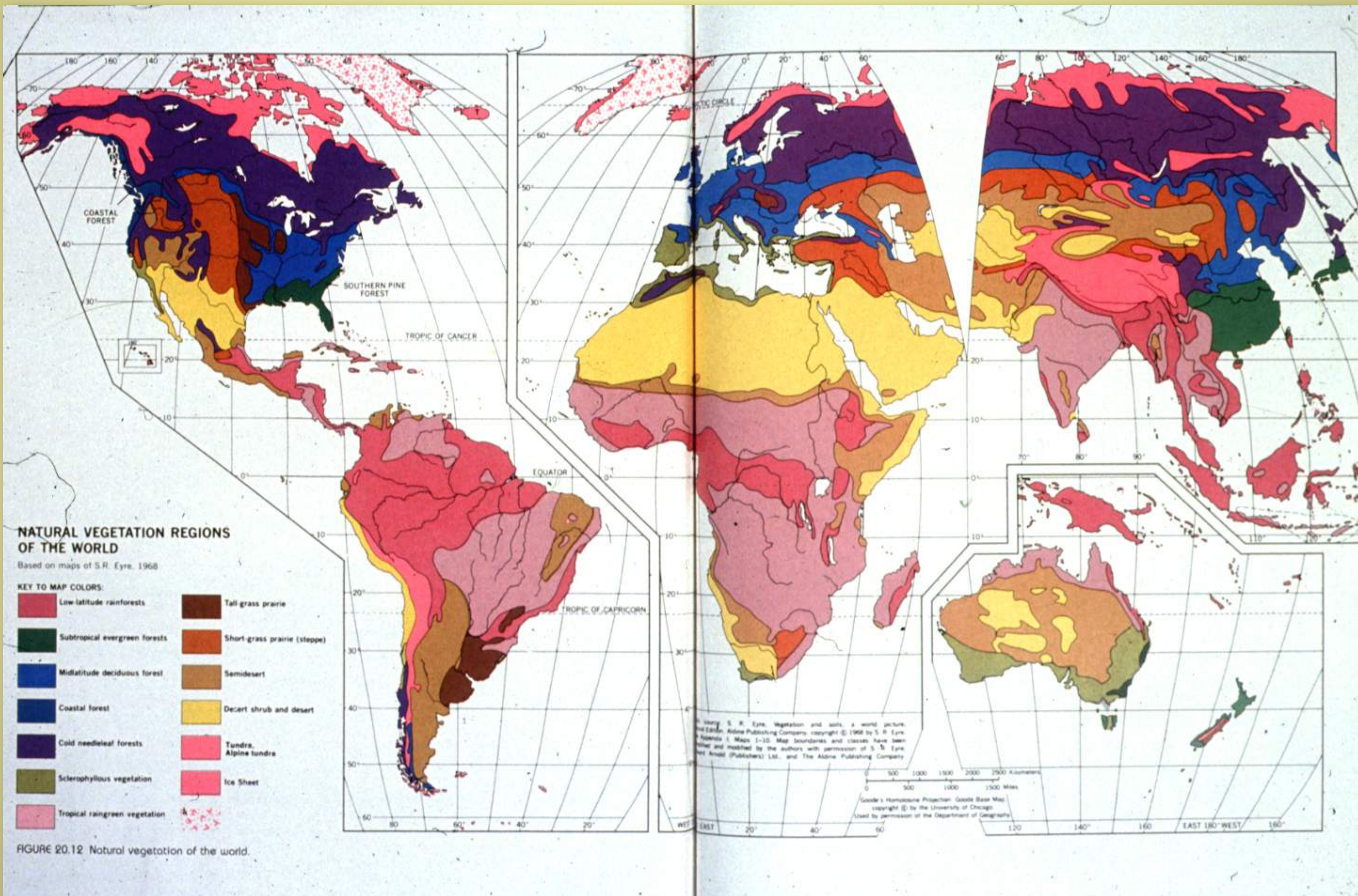
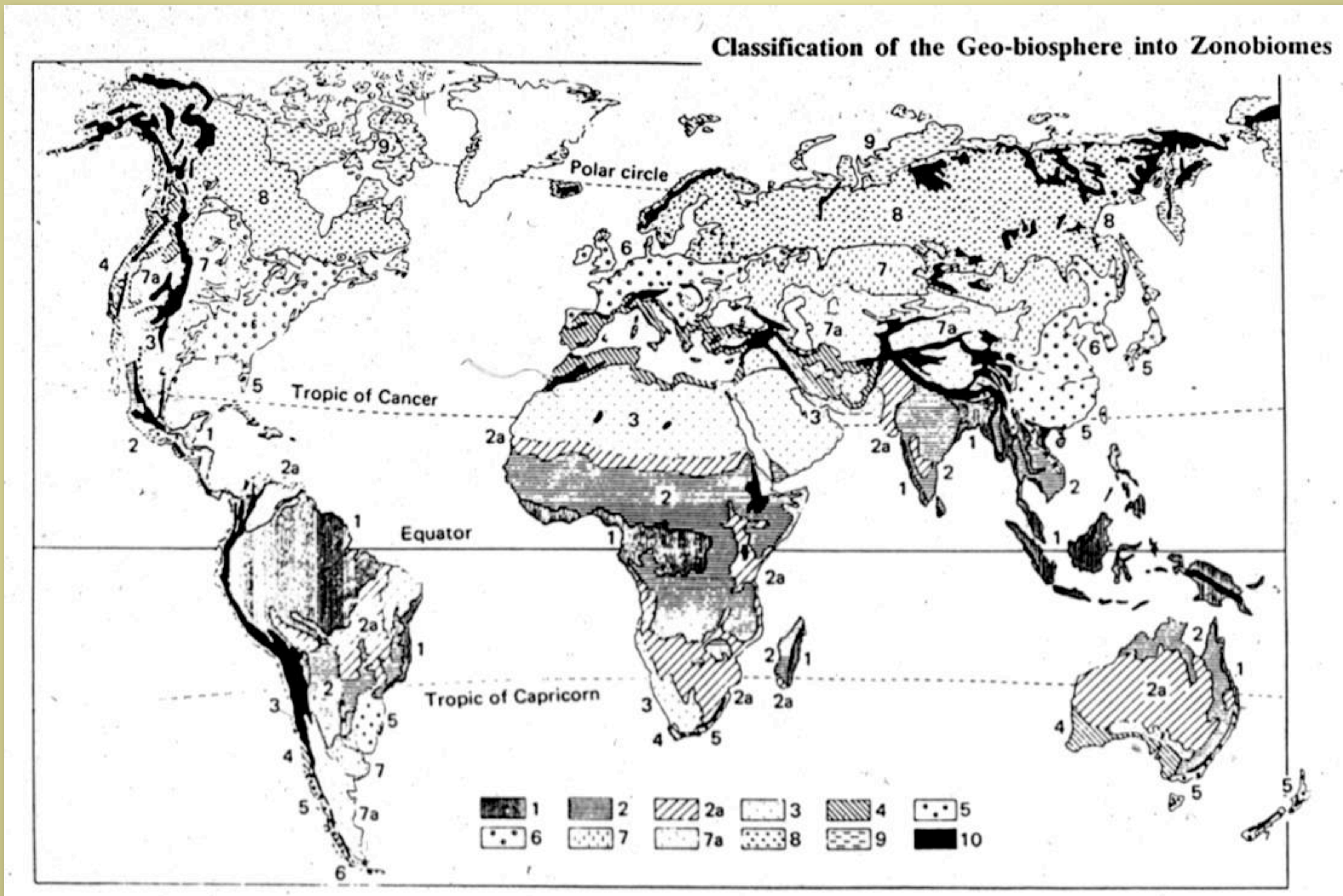


FIGURE 20.12 Natural vegetation of the world.

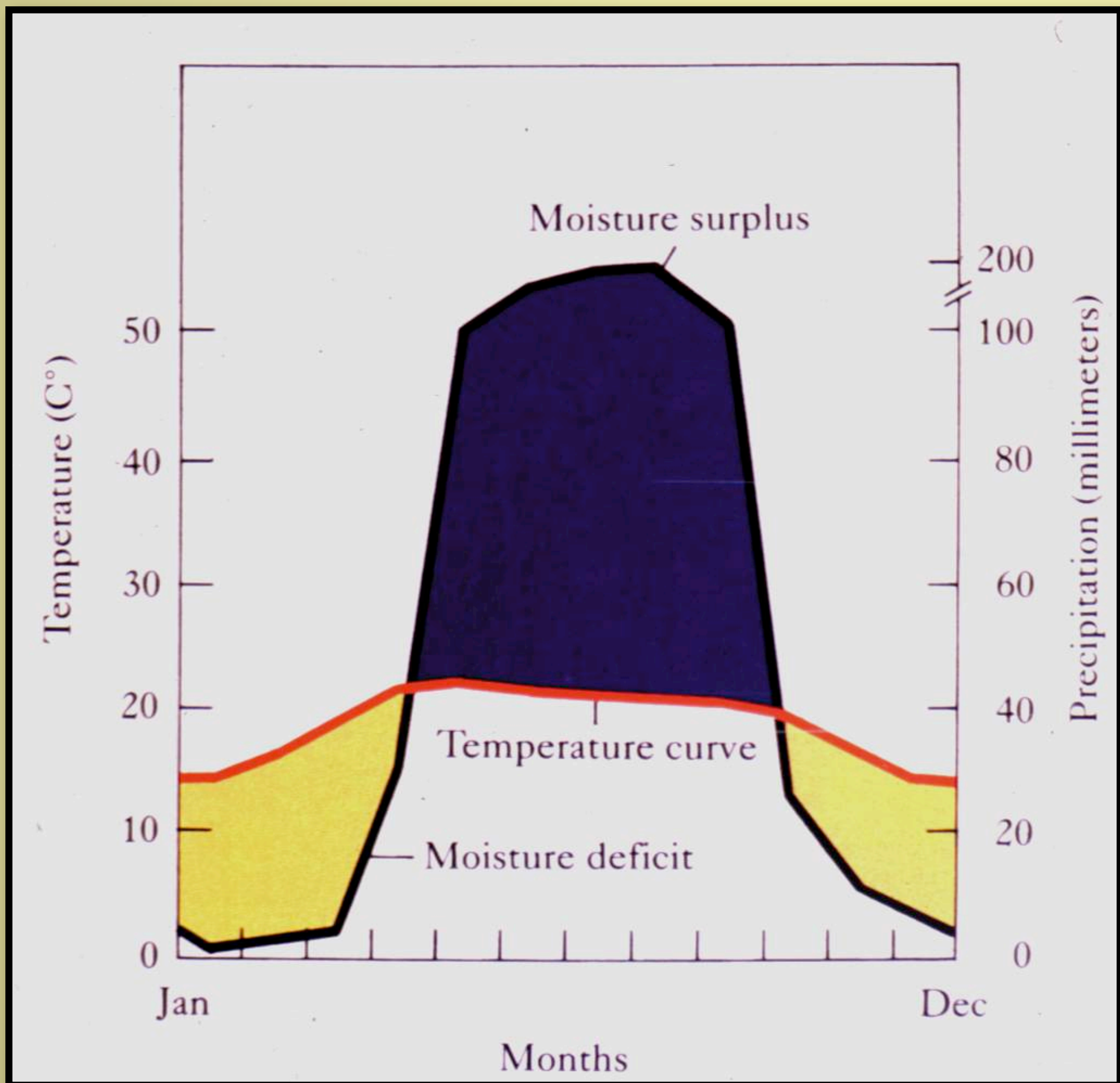
World Climate and Vegetation Classifications

Heinrich Walter's Zonobiome Classification is often used in biogeography



World Climate and Vegetation Classifications

Heinrich Walter's Climate Diagrams



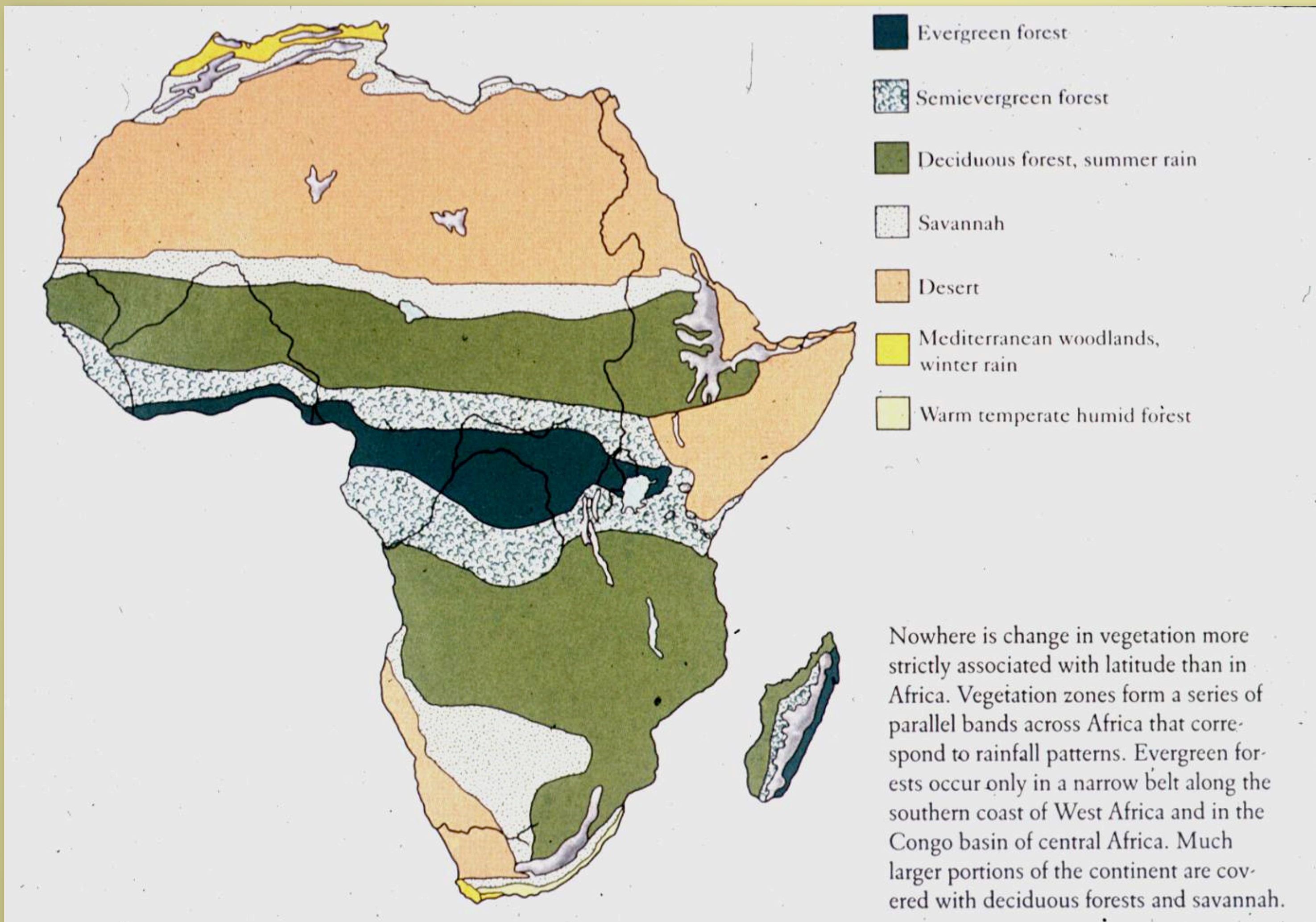
Climate diagrams are useful in encapsulating major climate features for each biome

- Depict moisture and temperature curves by month
- Show relative moisture deficit or surplus

This climate diagram could be:

- Monsoon forest
- Tropical dry forest
- Summer-rain forest
- Summer-green forest

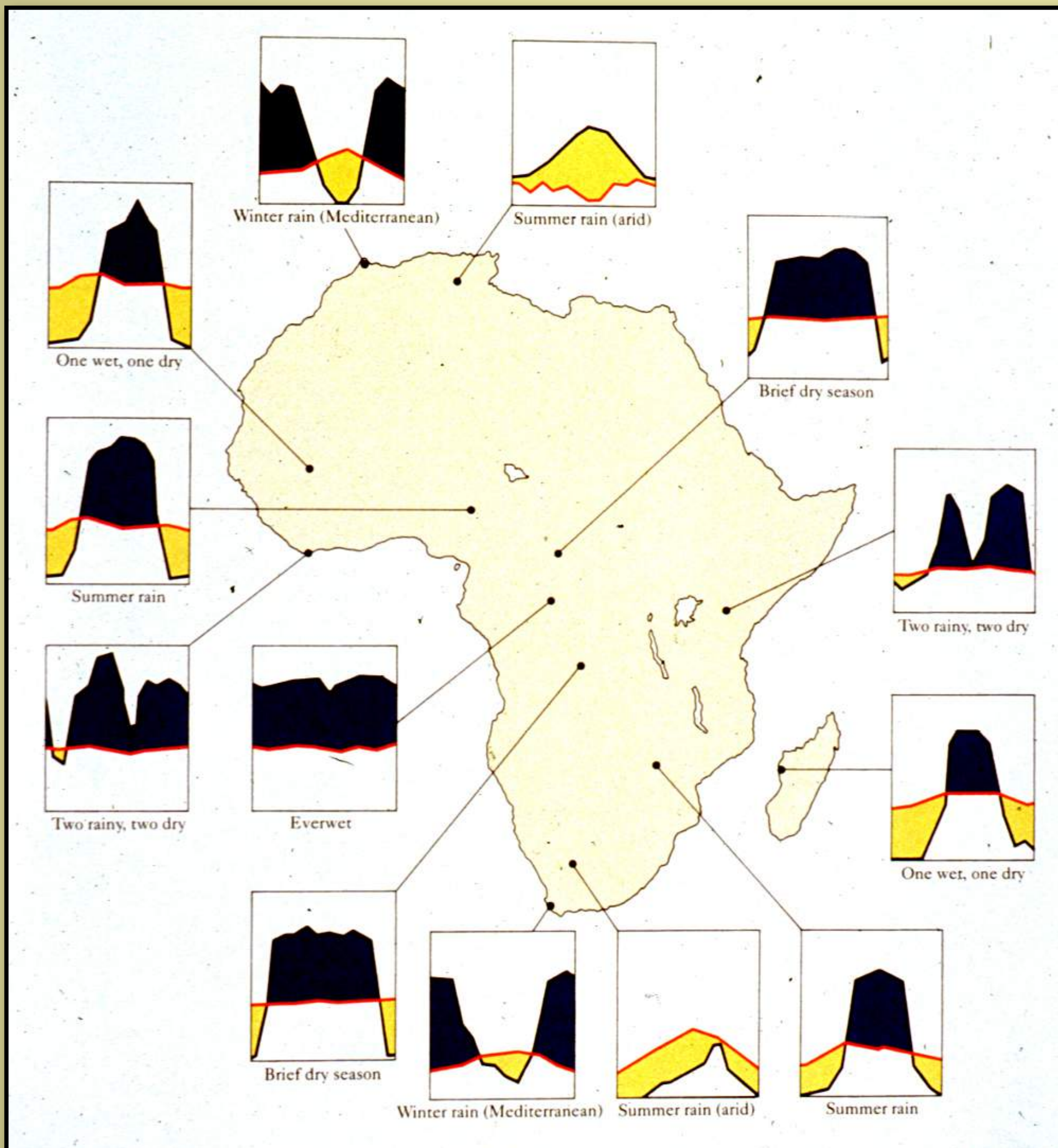
World Climate and Vegetation Classifications



The African continent i
illustrative of the utility
of climate diagrams

As the continent
straddles the equator,
biome types are
replicated in north and
south latitudes

World Climate and Vegetation Classifications



Climate diagrams for tropical dry forest, Mediterranean biome, and desert are easily recognized and appear on both sides of the equatorial rainforest diagrams

Note: by convention, summer months for both hemispheres are placed in the middle of the diagram to allow direct comparison