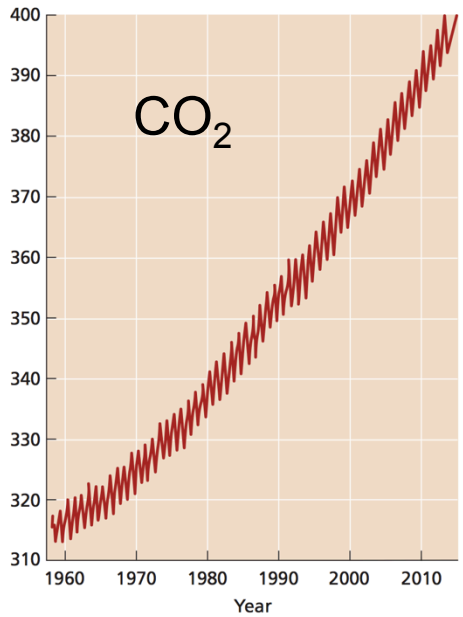


Climate Constrains Plant Distributions

Plant Ecology in a Changing World

Jim Ehleringer, University of Utah
http://plantecology.net

Part 1
A global overview

The potential distribution limits of plants are often related to two abiotic factors:

- water
- temperature

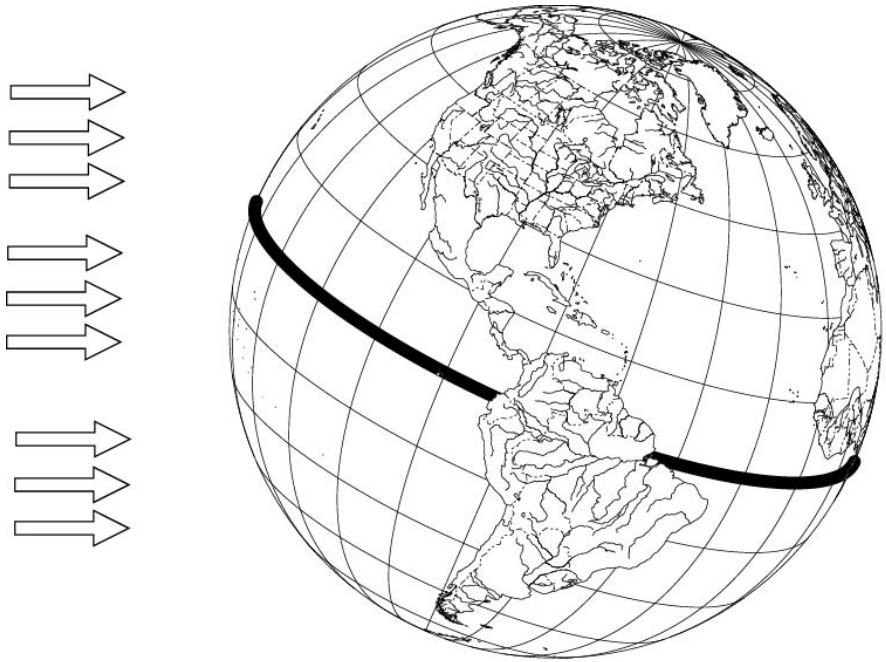
Abiotic controls over plant distribution:

- climate and microclimate
- role of water availability
- site water balance
- leaf area index - water, ecosystem
- constraints imposed by temperature

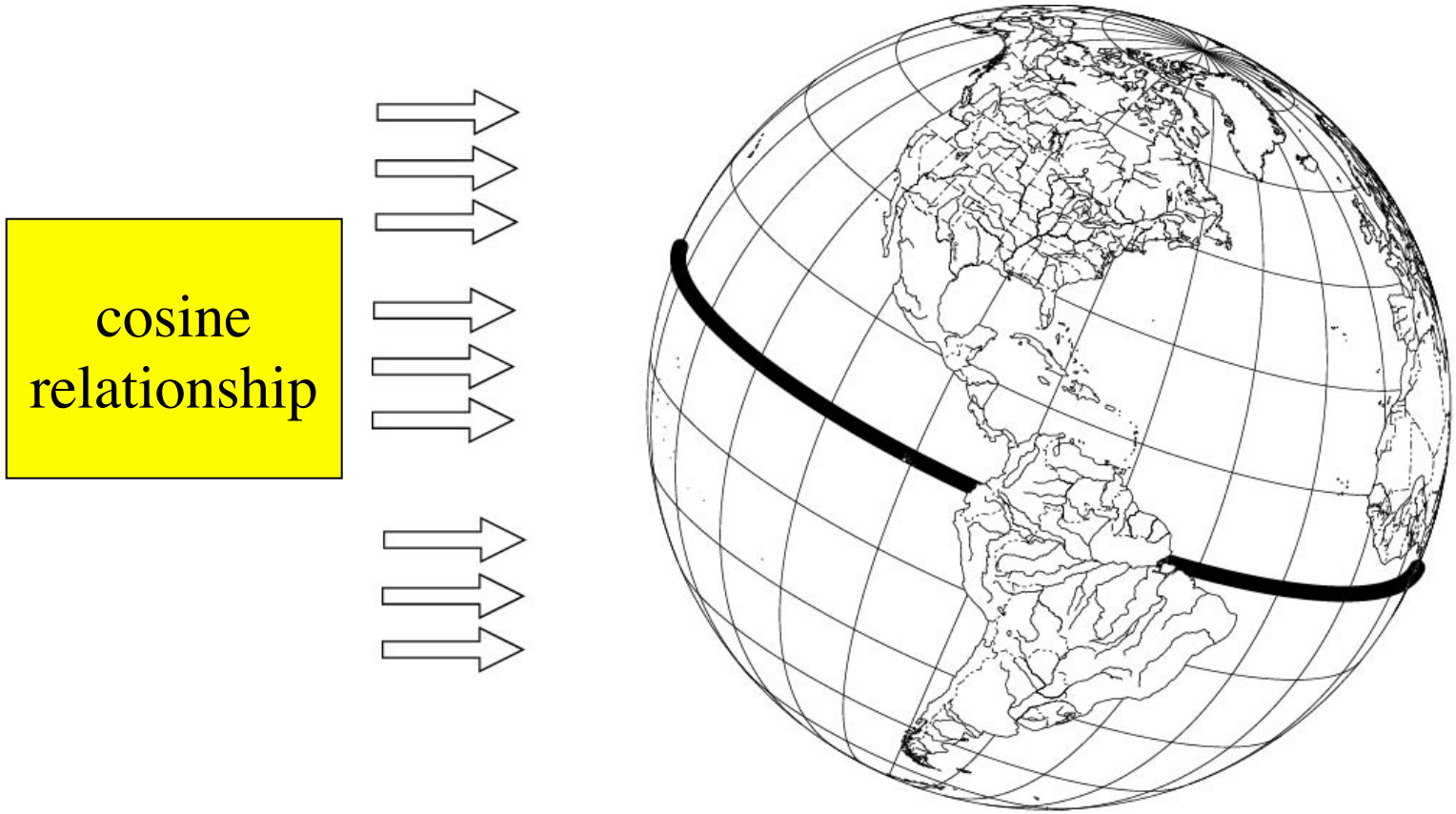
Let's review the basis for

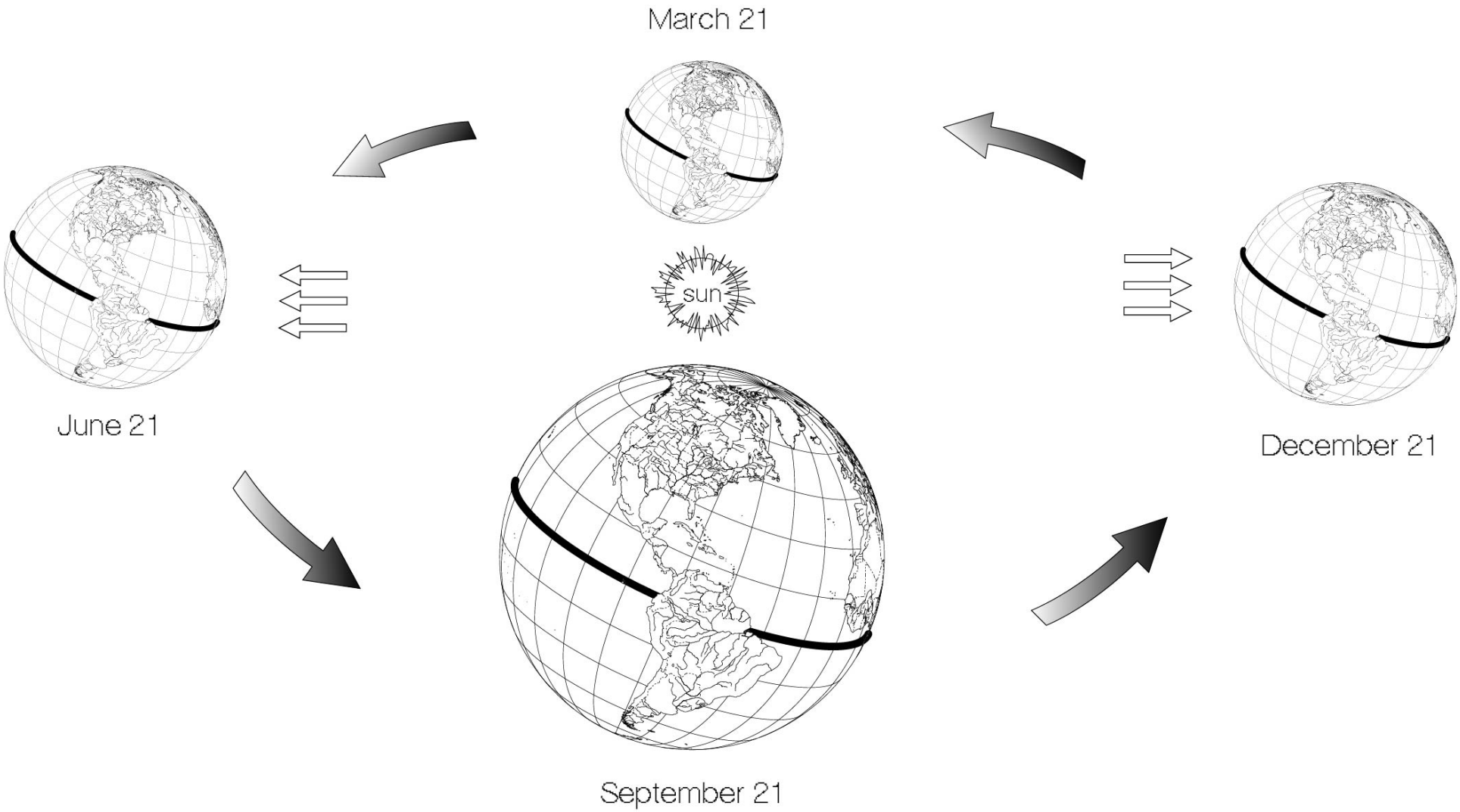
- geographic climate variation
- seasonality
- microclimate

The uneven latitudinal solar heating and axis tilt of the Earth result in predictable latitudinal gradients in climate.

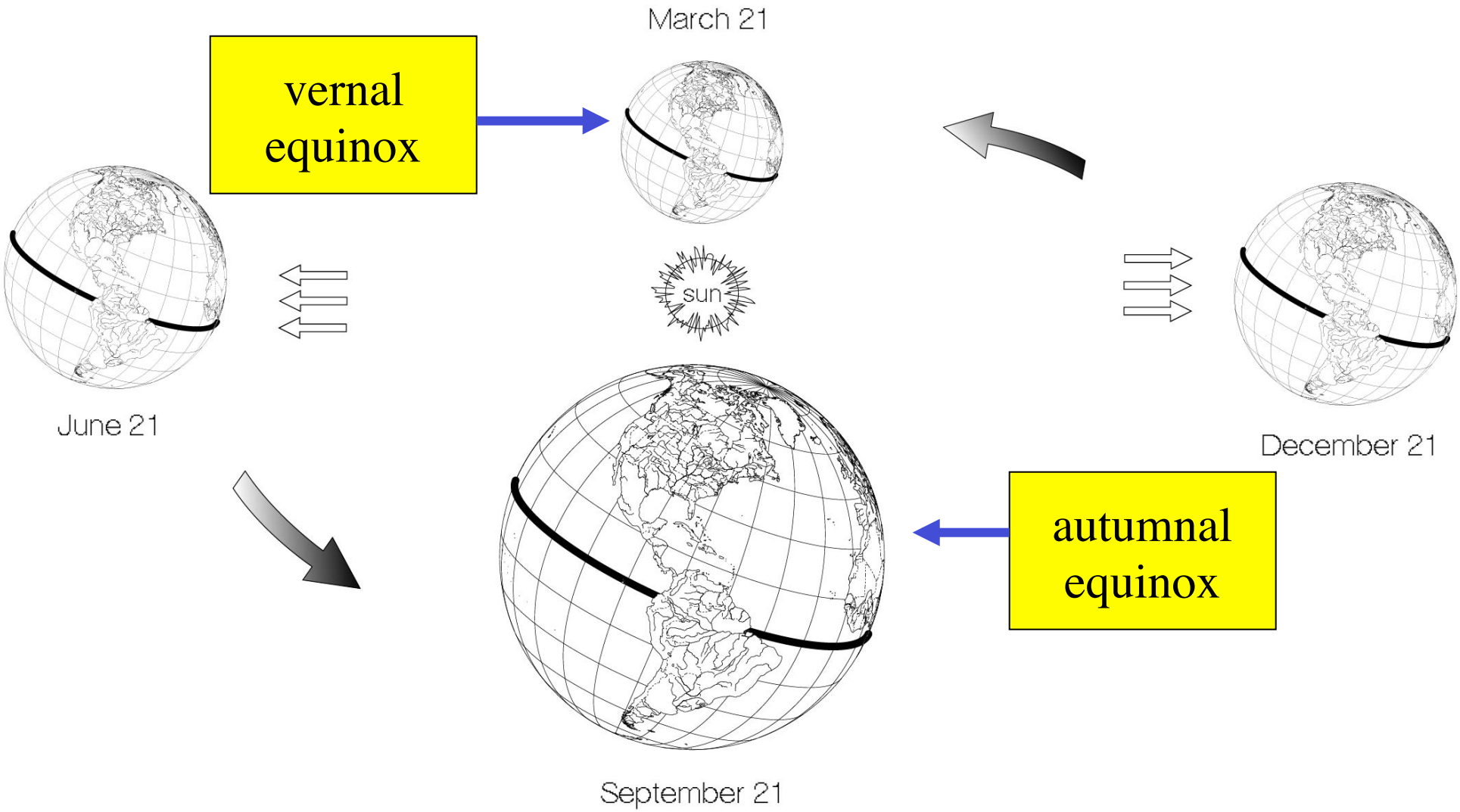


The uneven solar heating and axis tilt of the Earth result in predictable latitudinal gradients in climate

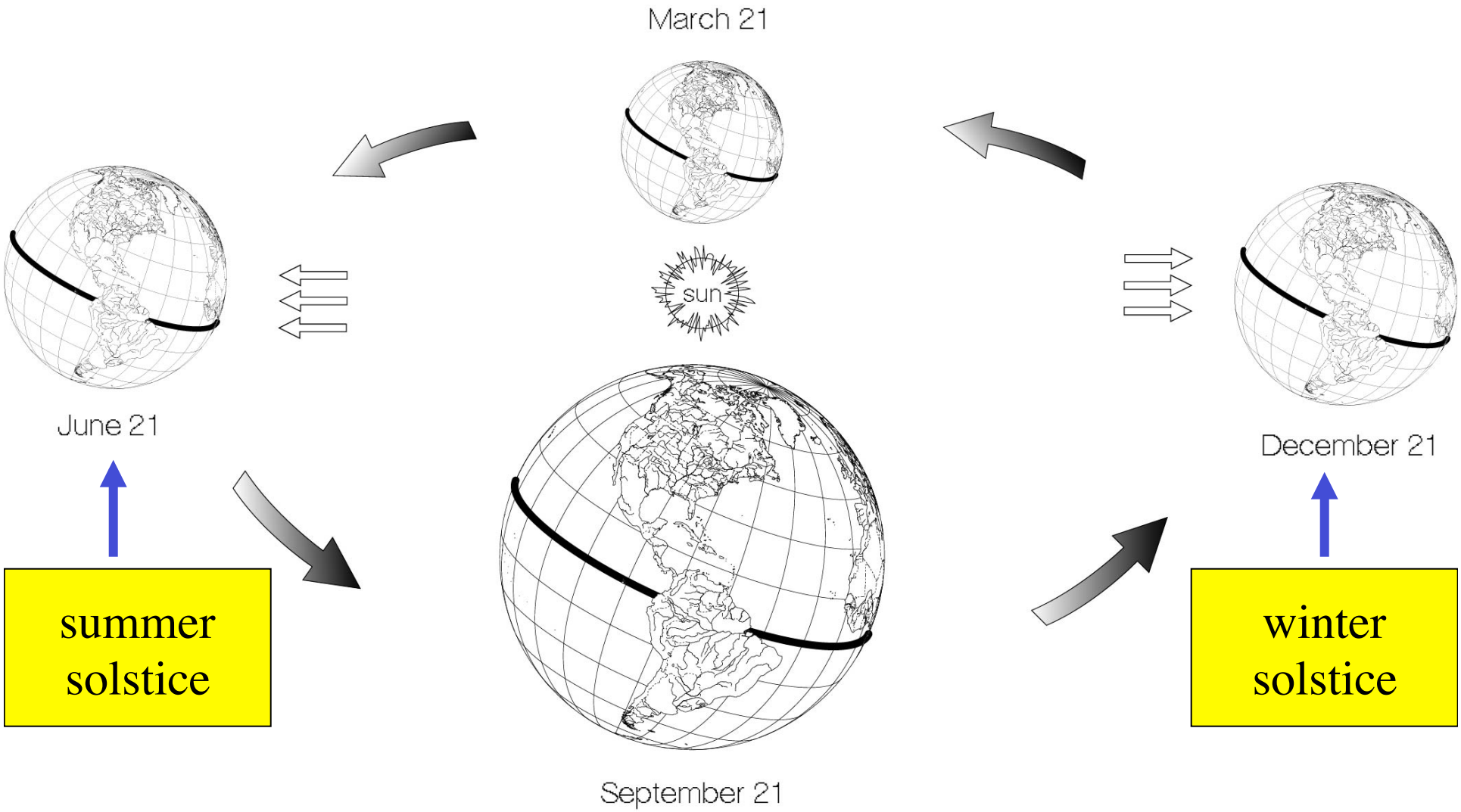




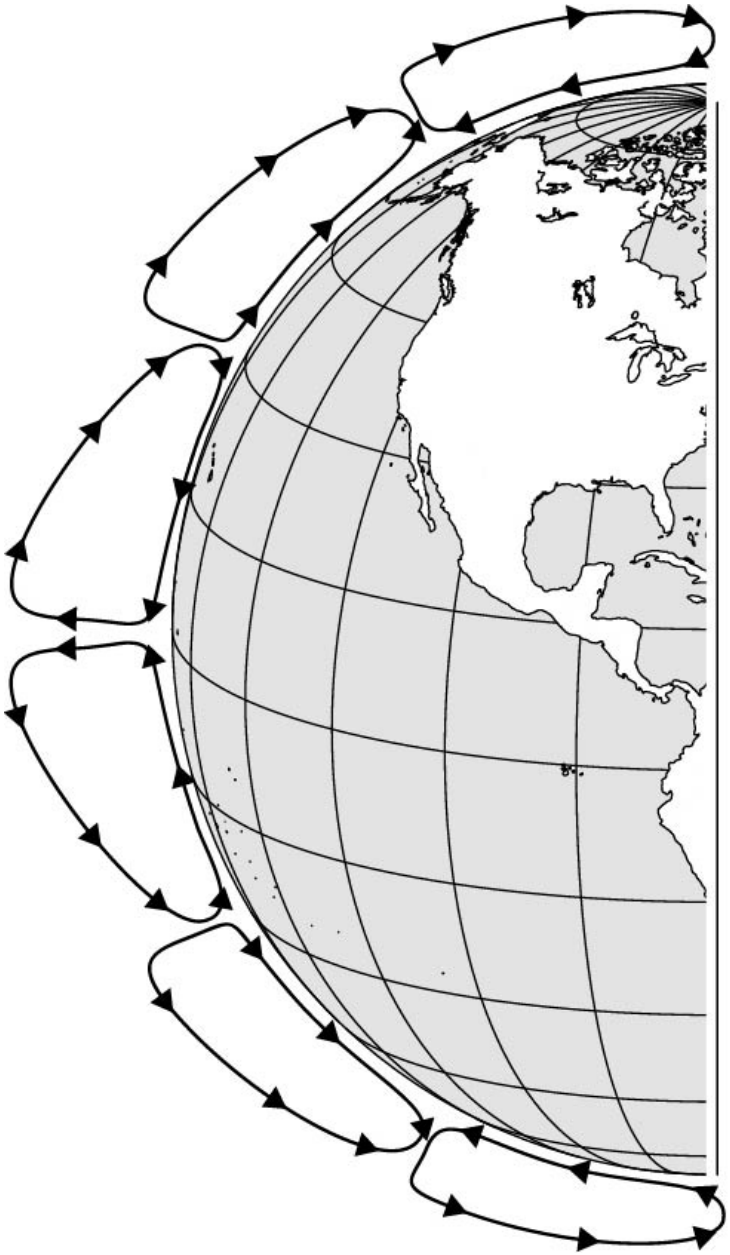
The Earth rotates around the sun with a current tilt of 23.5 °.



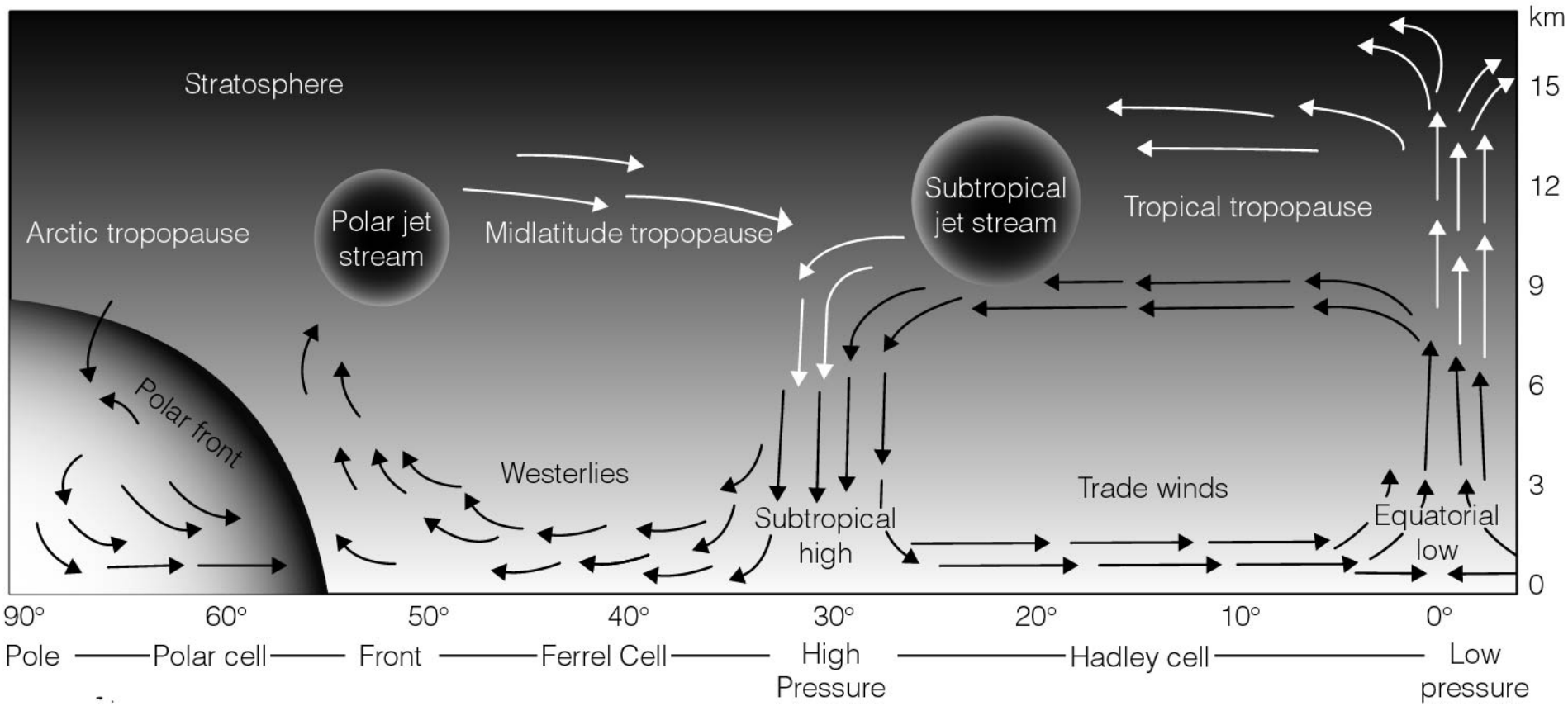
Equinox - March 21, September 21



Solstice - June 21, December 21

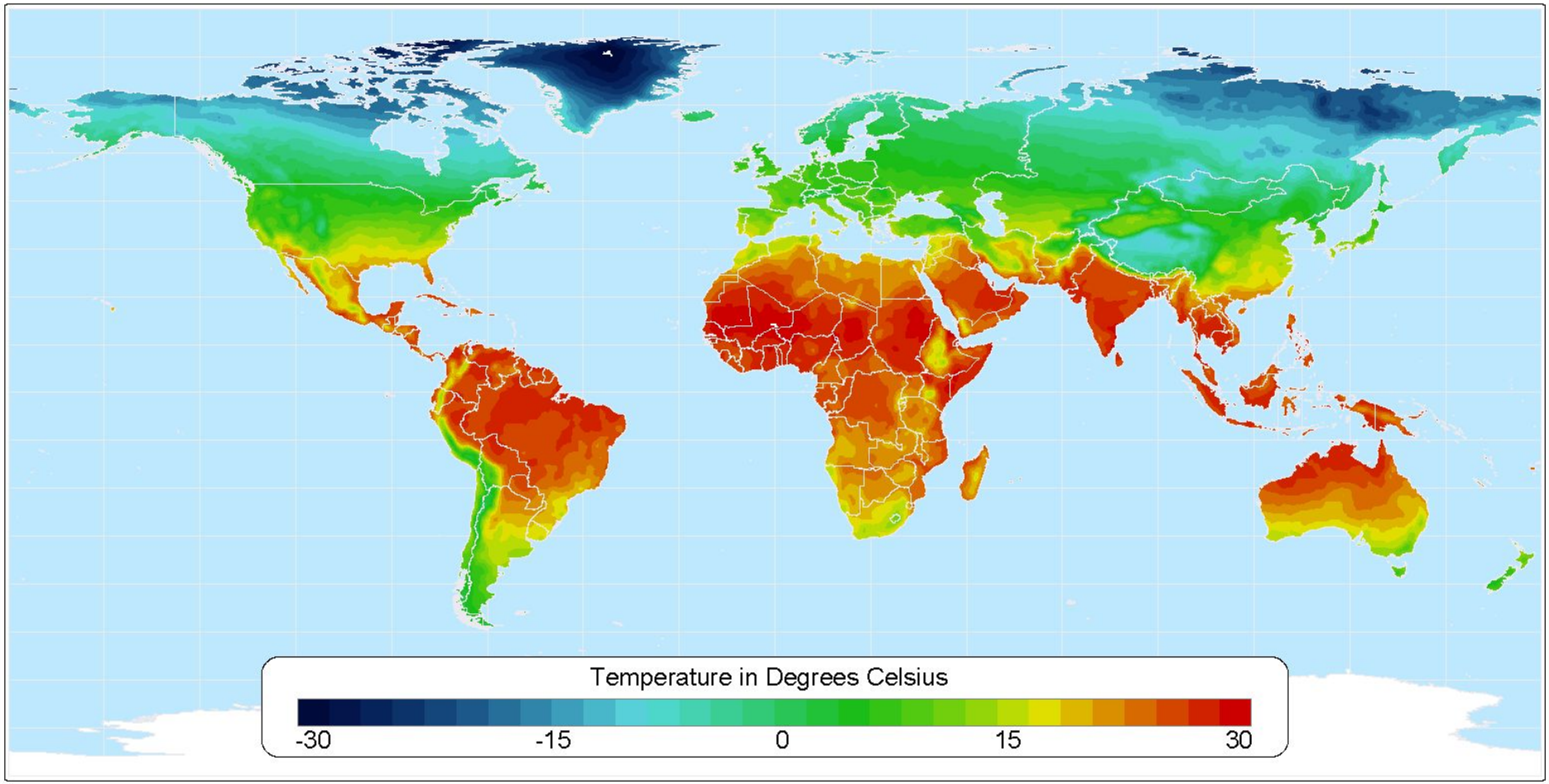


The uneven solar heating and axis tilt of the Earth result in predictable latitudinal gradients in climate



The differential heating results in the establishment of cells and wind patterns.

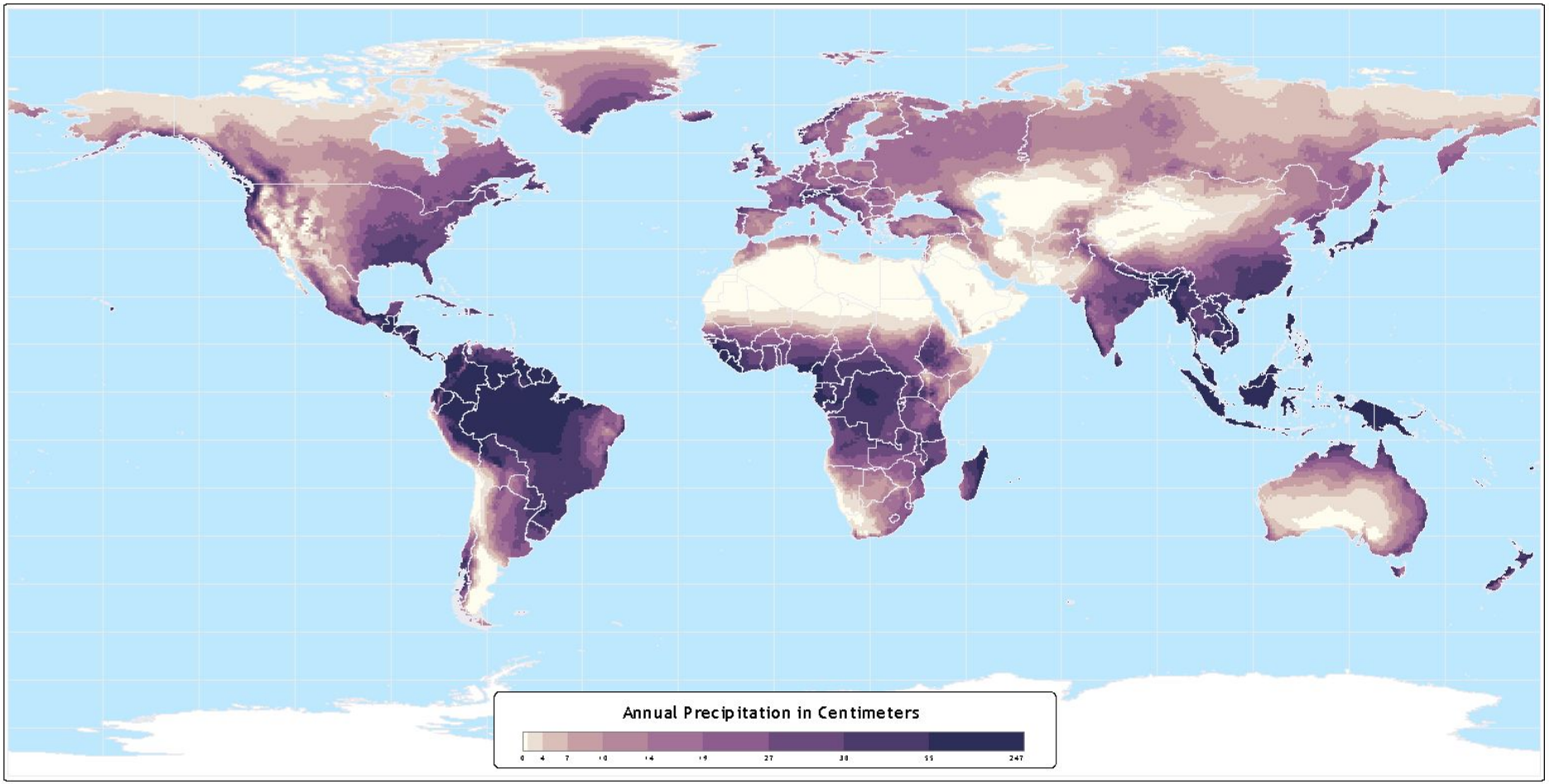
Average Annual Temperature



Data taken from: CRU 0.5 Degree Dataset (New, et al.)

Atlas of the Biosphere
Center for Sustainability and the Global Environment
University of Wisconsin - Madison

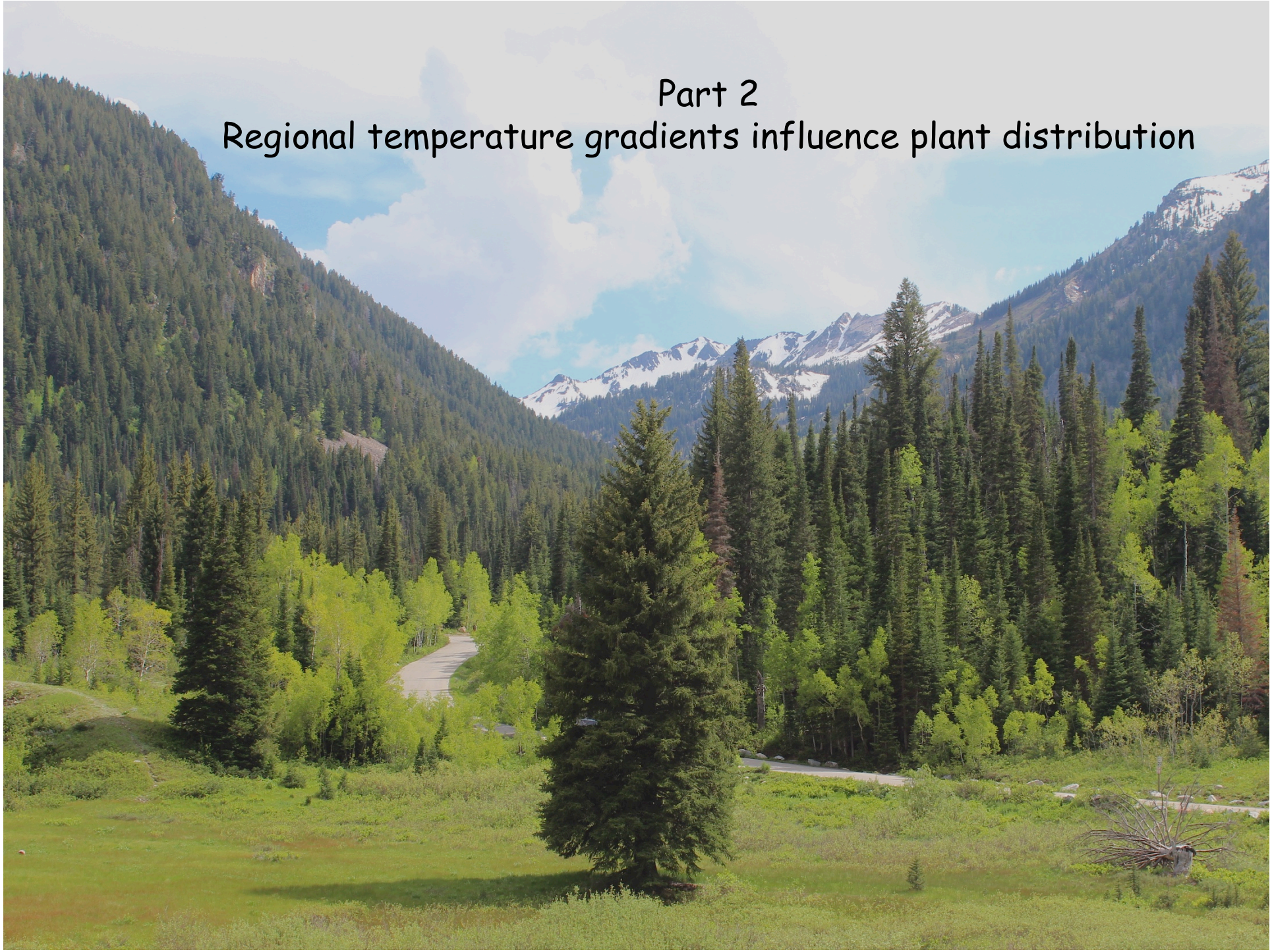
Annual Total Precipitation



Data taken from: CRU 0.5 Degree Dataset (New et al)

Atlas of the Biosphere

Center for Sustainability and the Global Environment
University of Wisconsin - Madison


Part 2
Regional temperature gradients influence plant distribution

Temperature and Elevation

On average the atmosphere cools 6.5°C for each 1 km increase in elevation (lapse rate)

- a dry atmosphere has a lapse rate of 9.8°C per km
- the lapse rate in a moist atmosphere is nonlinear and depends on the total amount of water in the atmosphere.

Thus, mountain tops (in general) tend to be cooler than low lying areas.

However, at night, colder, denser air sinks into valleys (cold air sink or temperature inversion)

Consider how temperature might place limits on plant distribution

low freezing temperatures

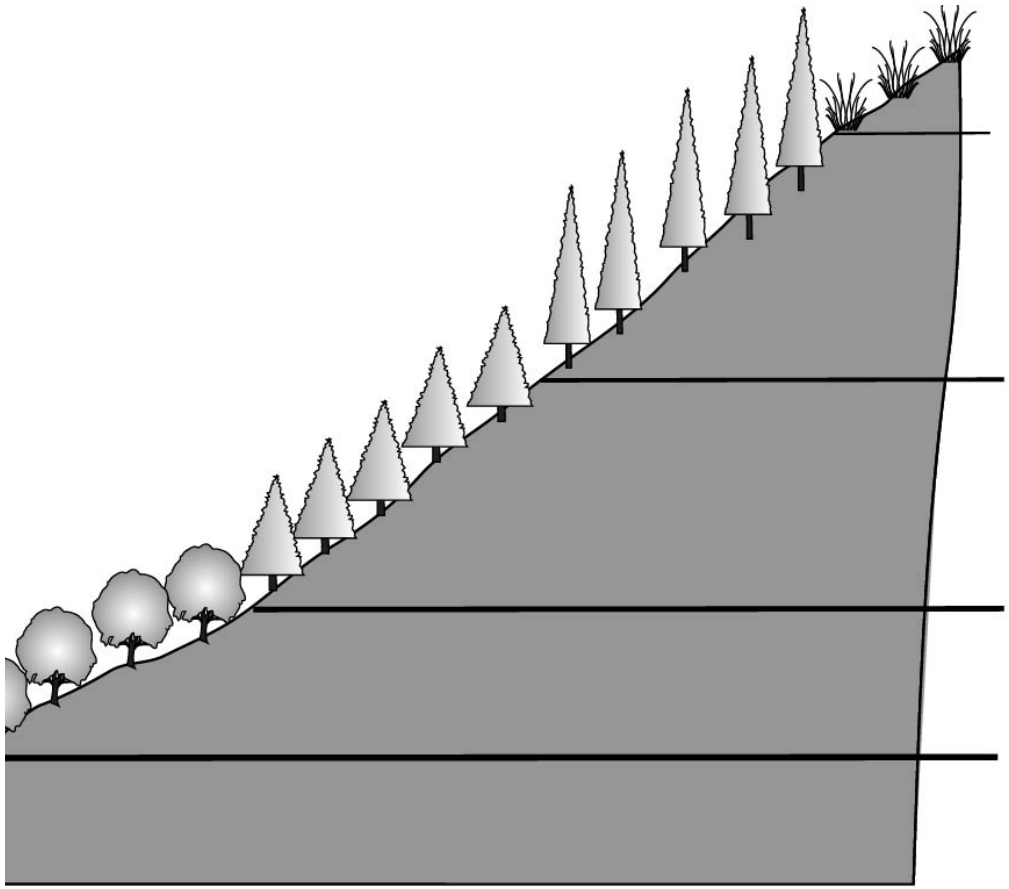
- tree lines
- freezing tolerance

high temperatures

- high temperature tolerance
- transpirational water loss

Temperature influences

- transpiration by virtue of the potential evaporative gradient
- capacity to metabolize and maintain growth activities



Trees along the Wasatch Front

Picea pungens

Picea engelmannii

Abies lasiocarpa

Pseudtosuga menziesii

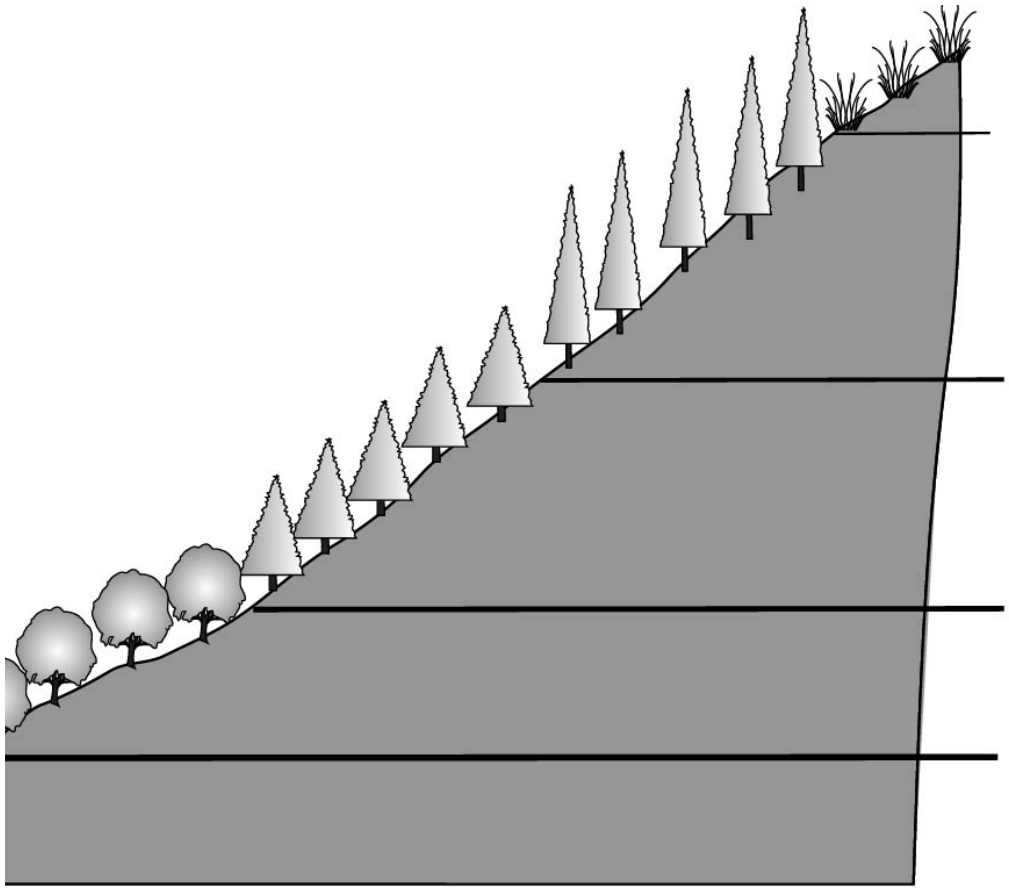
Abies concolor

Acer grandidentata

Quercus gambelii

Juniperus osteosperma

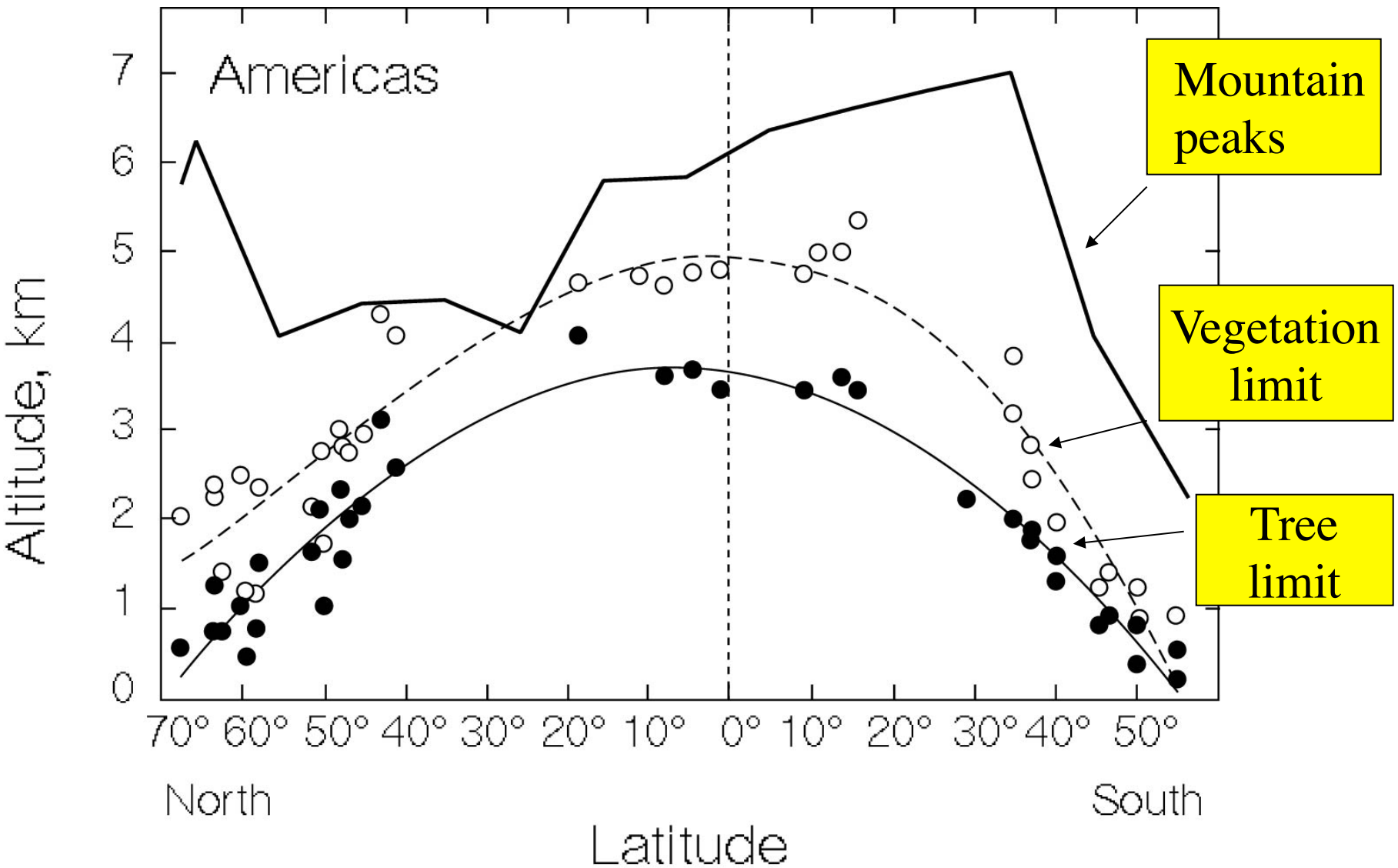
Elevational species replacements reflect both water (lower) and temperature (upper) constraints.



Freezing resistance of buds (°C)	
Picea pungens	-60 °
Picea engelmannii	-60 °
Abies lasiocarpa	-40 °
Pseudotseuga menziesii	-30 °
Abies concolor	-30 °

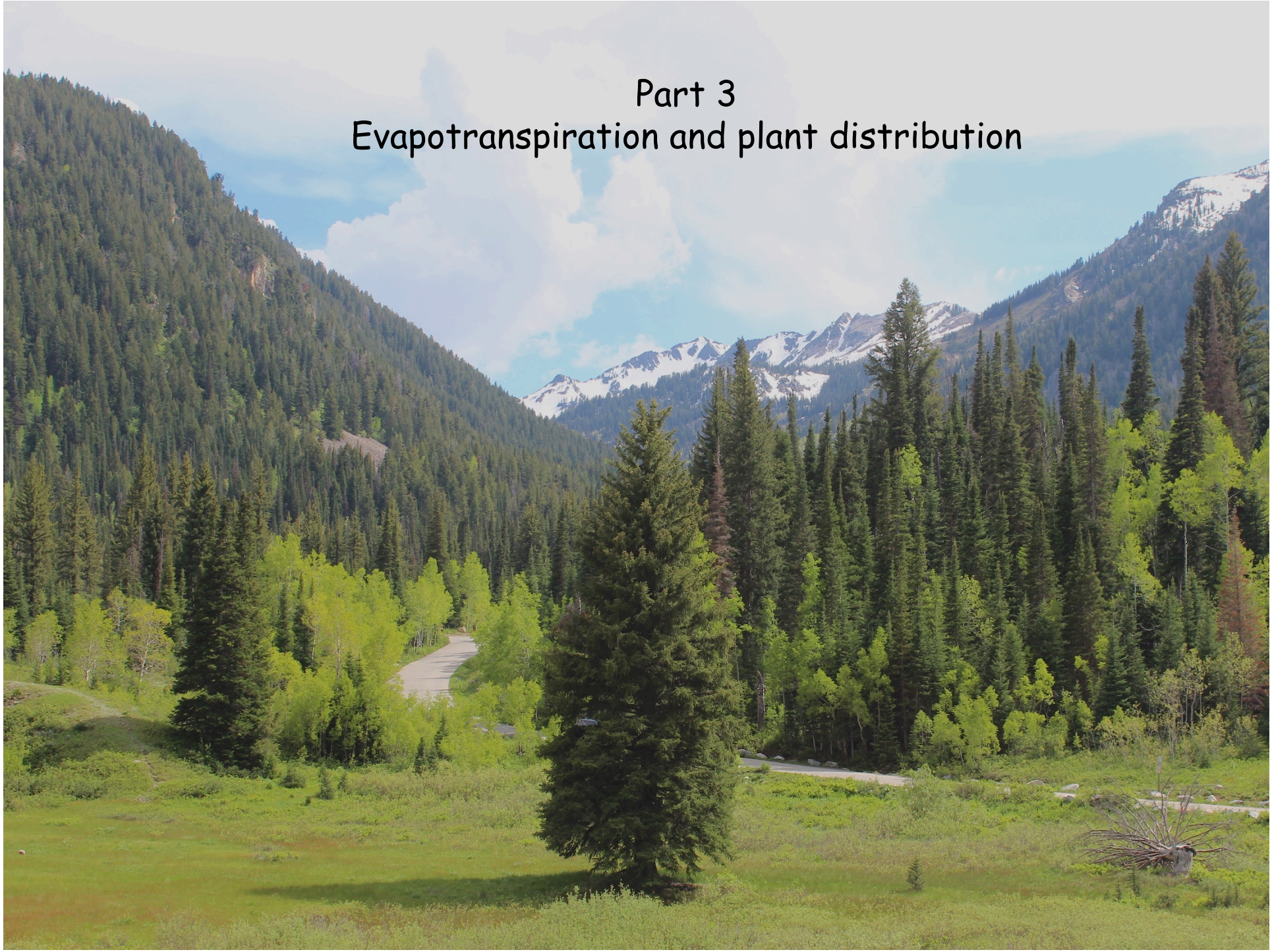
Species occurring at higher elevations have more freezing-resistant buds.

Sakai and Weiser (1973)

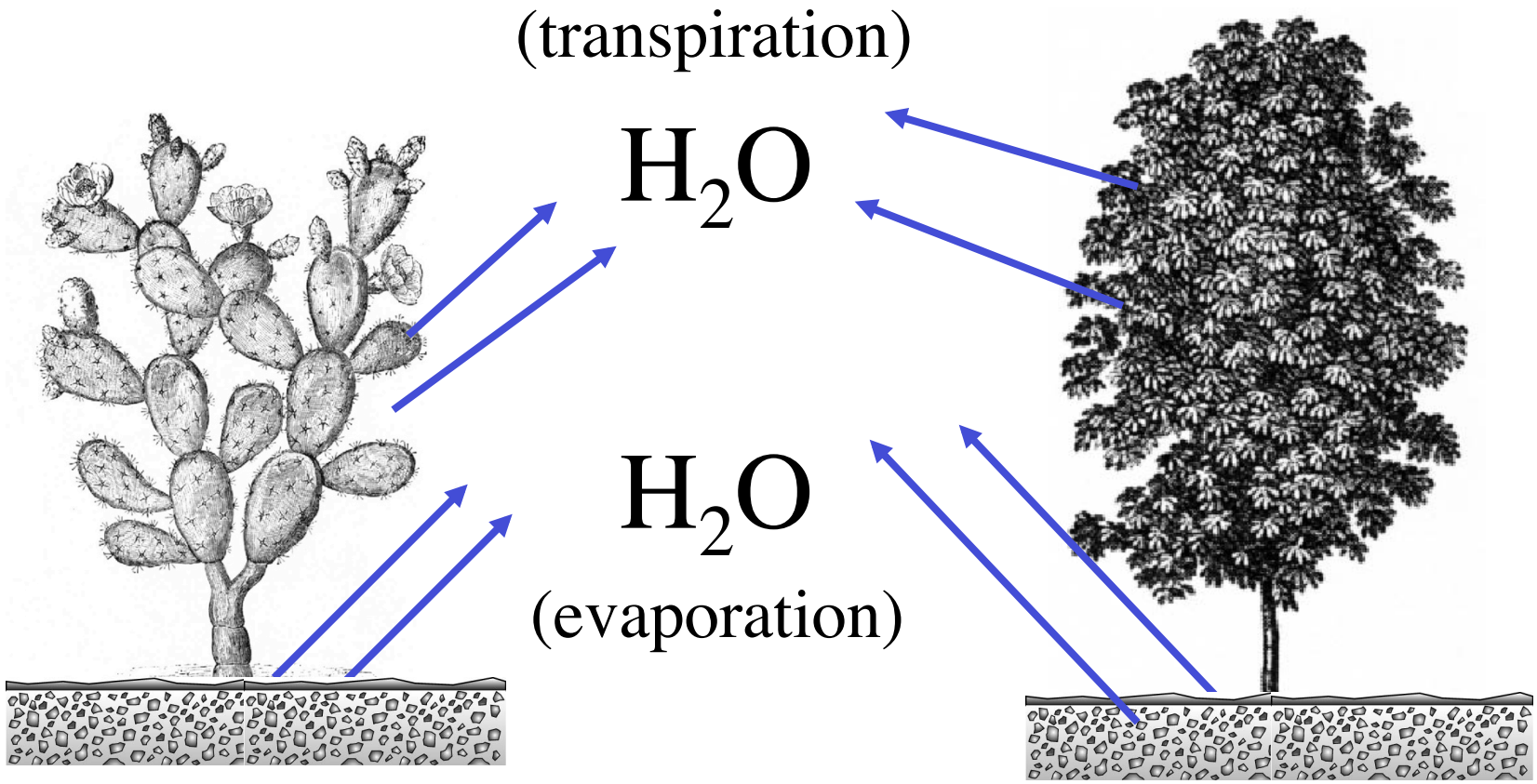


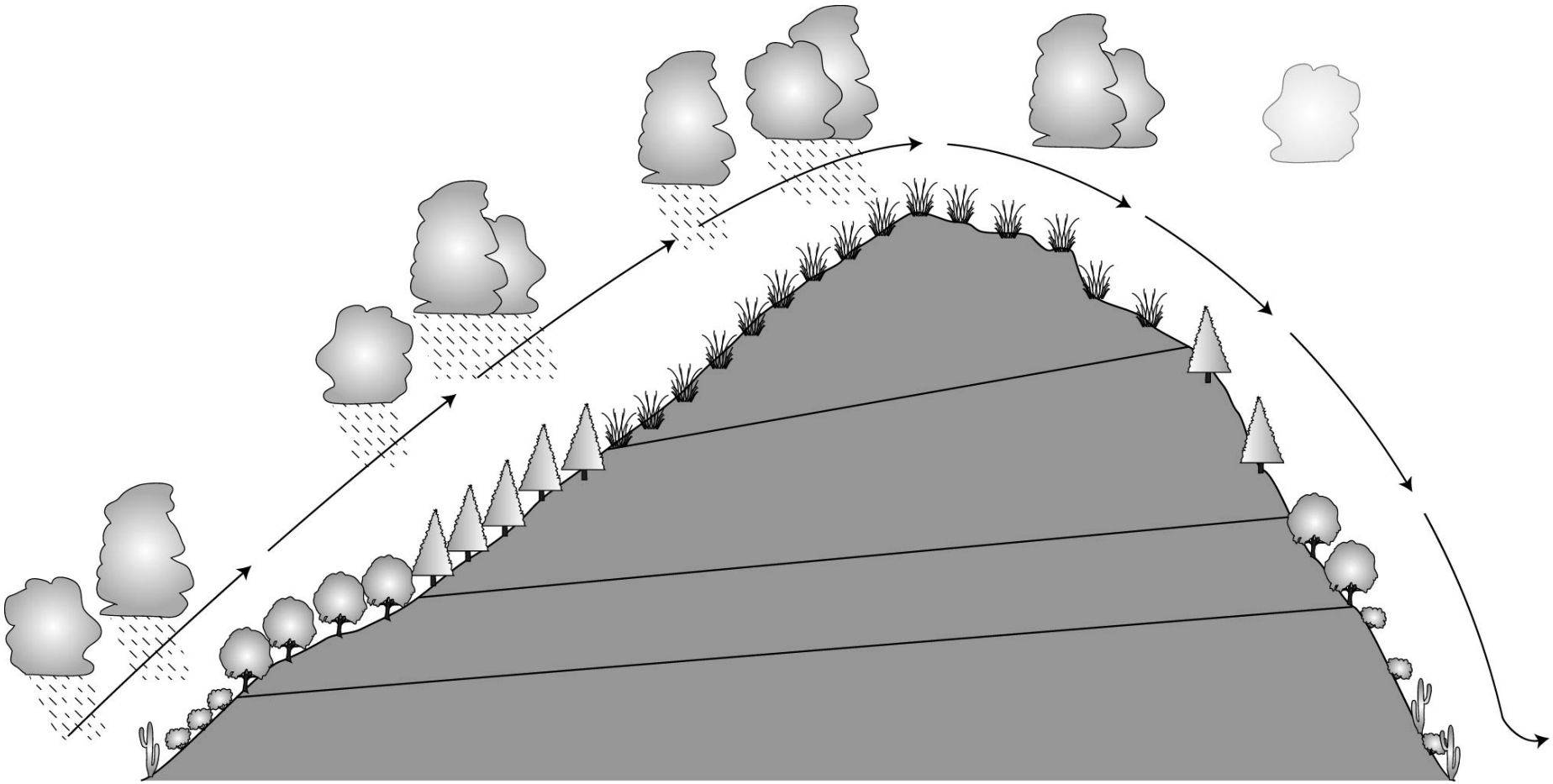
Tree line becomes lower as one moves poleward.

Part 3
Evapotranspiration and plant distribution

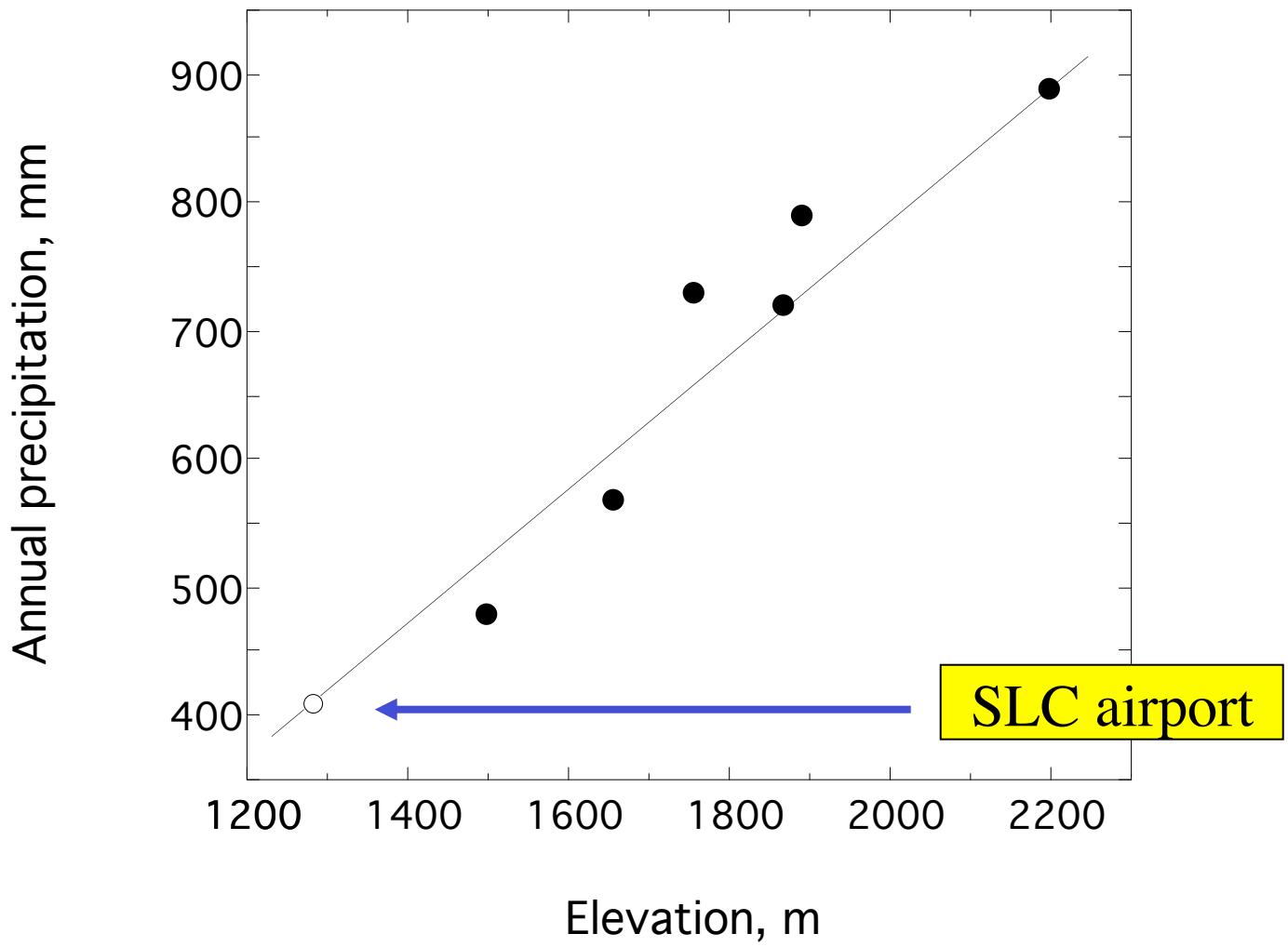


Evapotranspiration is the sum of **transpiration** from plants and **evaporation** from soils.

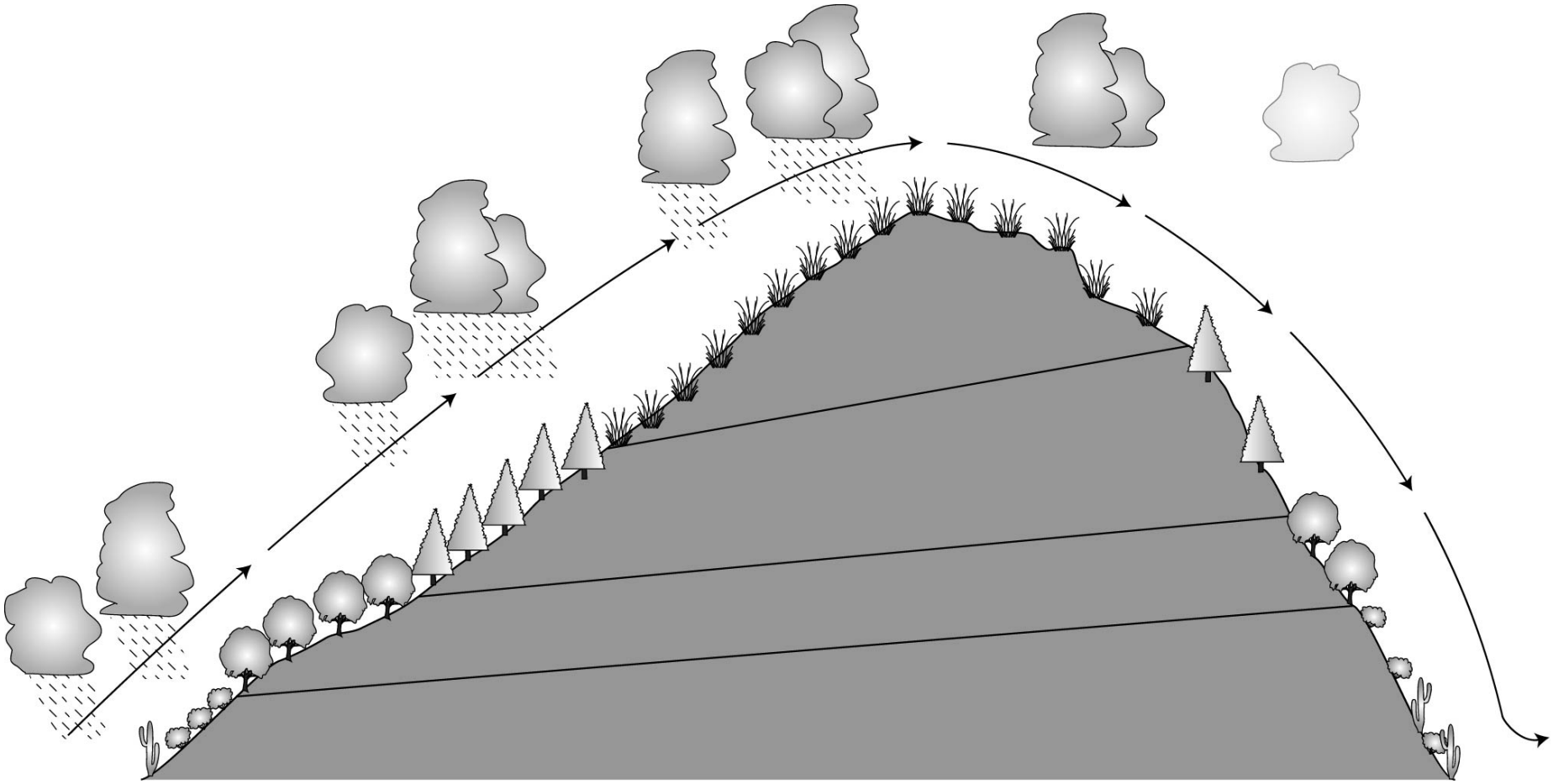




Precipitation increases with elevation, resulting in the presence of more mesic vegetation at higher elevations. This replacement occurs until one reaches the tree line, the upper limits of tree distribution.



The relationship between precipitation and elevation is often linear. Note that there are even strong differences in precipitation between the Salt Lake City airport and the mouth of Red Butte Canyon.



Rain shadows are associated with directionality in precipitation events. Note the vertical displacement of vegetation types on rain-shadow side of the mountain.

Slope aspect will influence water balance

In the northern hemisphere, south-facing slopes receive greater sun exposure

In the southern hemisphere, north-facing slopes receive greater sun exposure

Potential evapotranspiration (PE/T)

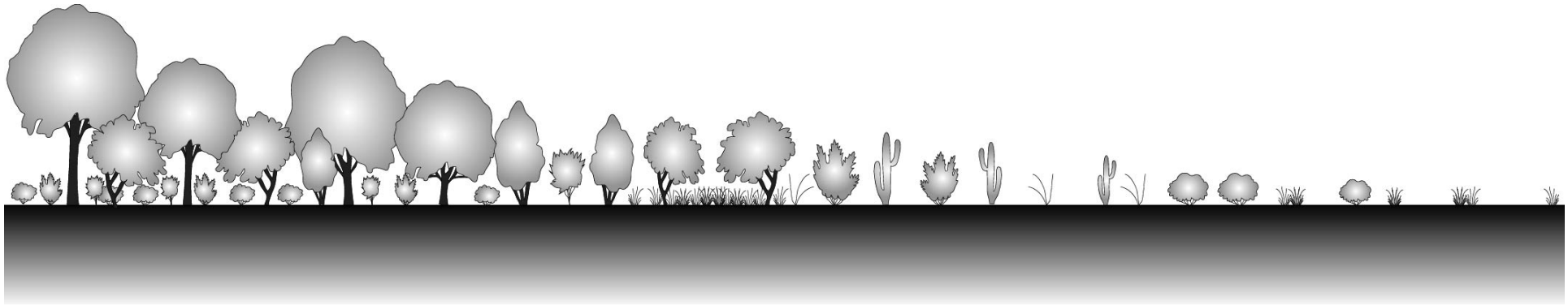
Potential evapotranspiration or PE/T is an estimate of the amount of water that would be lost to the atmosphere through the processes of evaporation and transpiration, assuming no control on water supply.

Actual evapotranspiration or AE/T is the amount of water that is actually removed from a surface due to the processes of evaporation and transpiration.

In **arid** climates, precipitation is less than PE/T.

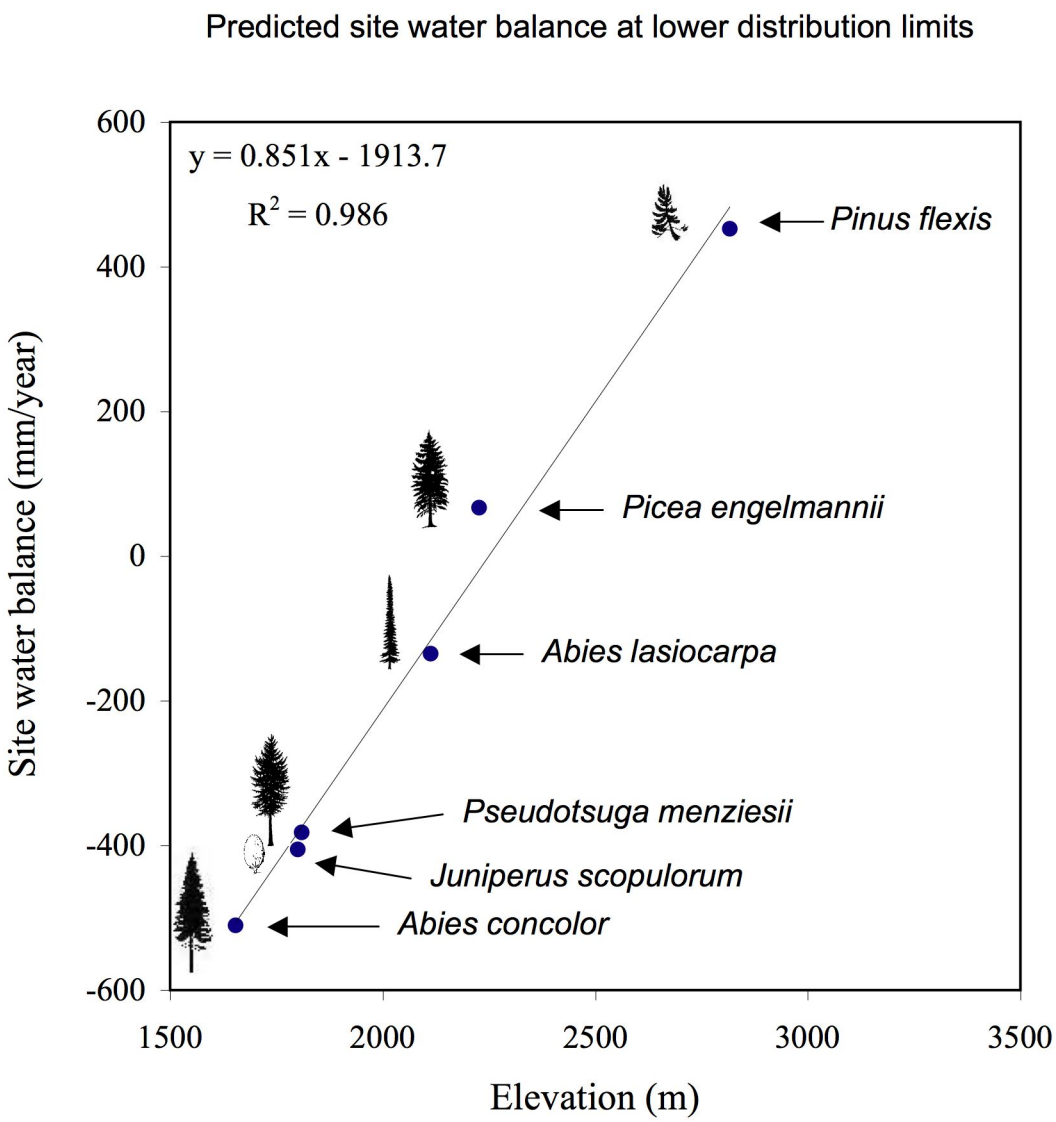
In **humid** climates, precipitation exceeds PE/T.

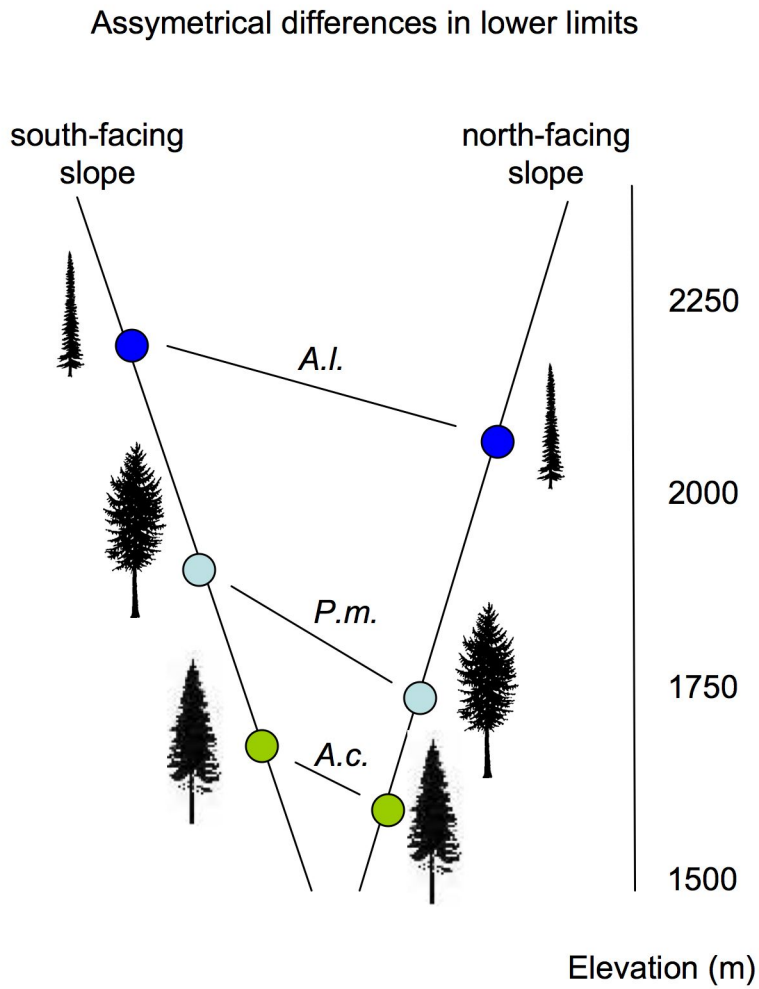
Evapotranspiration correlates with plant distribution



Forest-to-desert gradients follow precipitation gradients.

Gradients may be abrupt whenever rain shadows appear.


Predicted site water balance at lower distribution limits
y = 0.851x - 1913.7
R2 = 0.986
Pinus flexis
Picea engelmannii
Abies lasiocarpa
Pseudotsuga menziesii
Juniperus scopulorum
Abies concolor
Site water balance (mm/year)
600
400
200
0
-200
-400
-600
1500
2000
2500
3000
3500
Elevation (m)


Assymetrical differences in lower limits
south-facing slope
north-facing slope
A.l.
P.m.
A.c.
2250
2000
1750
1500
Elevation (m)

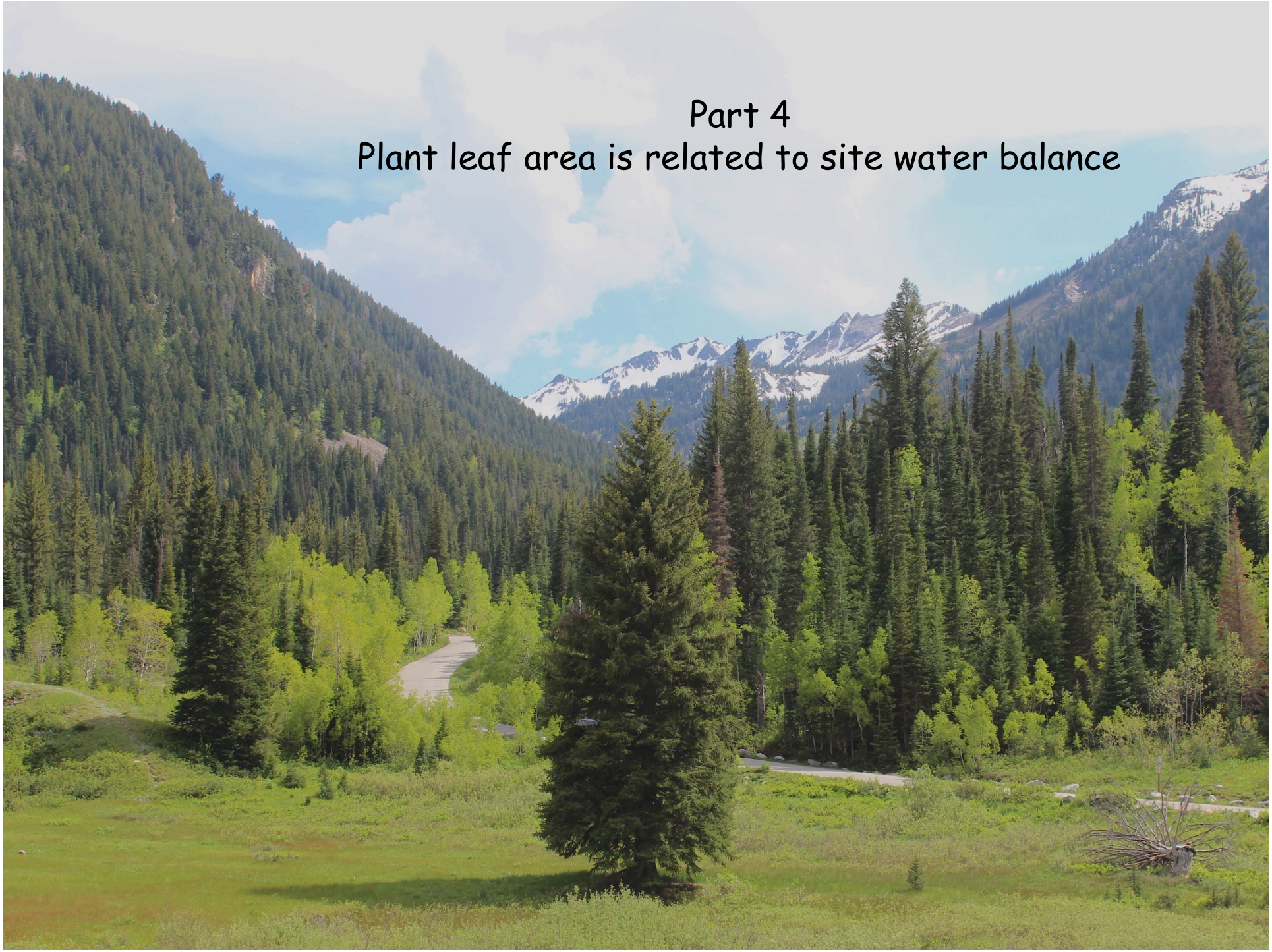
Drought effects on seedlings versus adults

The establishment phase of a plant's life cycle is often the critical stage where drought effects impose their highest mortality rates and prevent a plant from establishing at a site, even though mature individuals can persist at that site.

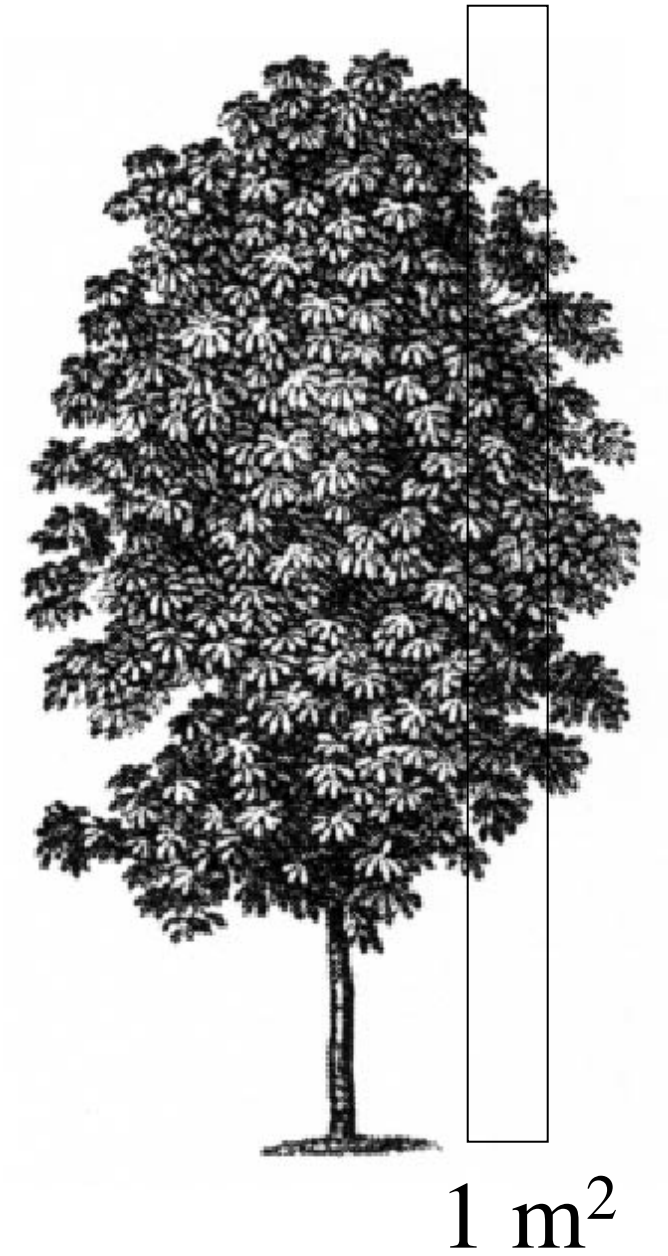
The length of the year that plants can remain active (growing season) is influenced by both

- temperature
  (active versus inactive)

- water availability
  (potential evapotranspiration)



Part 4
Plant leaf area is related to site water balance

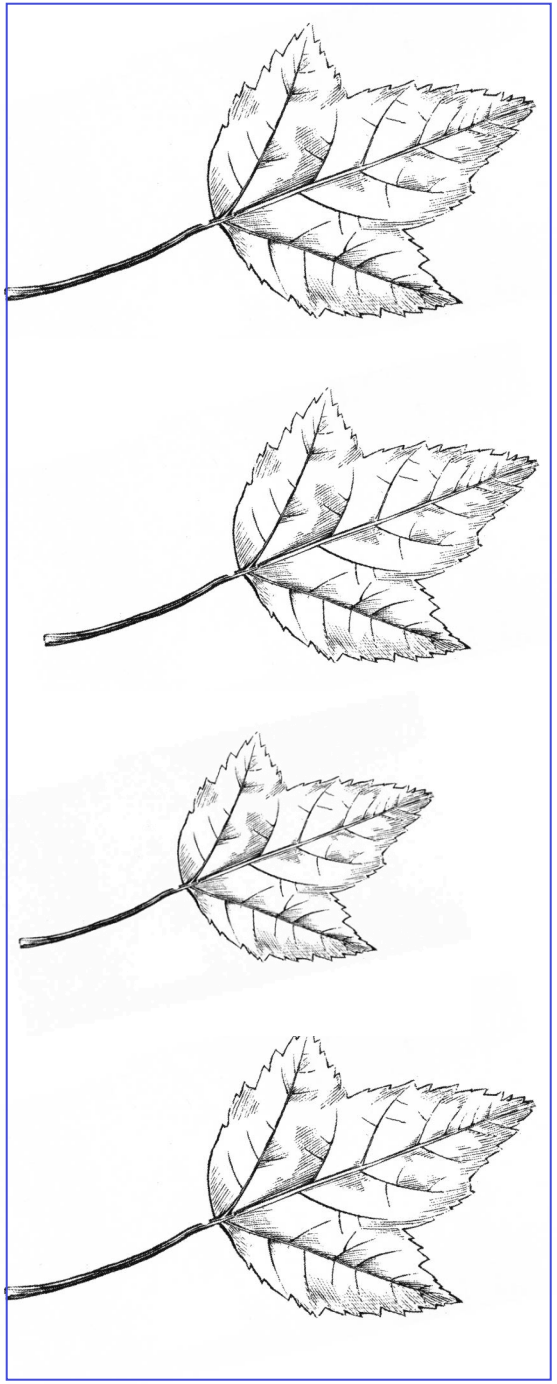


Leaf area index (LAI) is the m^2 leaf area per m^2 ground area

$$LAI = \frac{m^2 \text{ leaf area}}{m^2 \text{ ground area}}$$

LAI is the sum of the areas of all leaves within a column above 1 m^2 ground area.

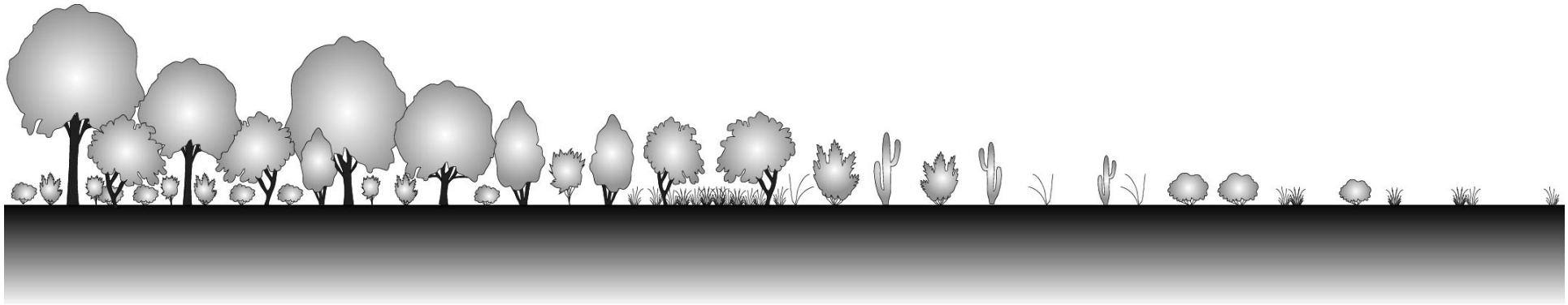
LAI is not a constant, but may vary with plant water availability.



LAI and vegetation type

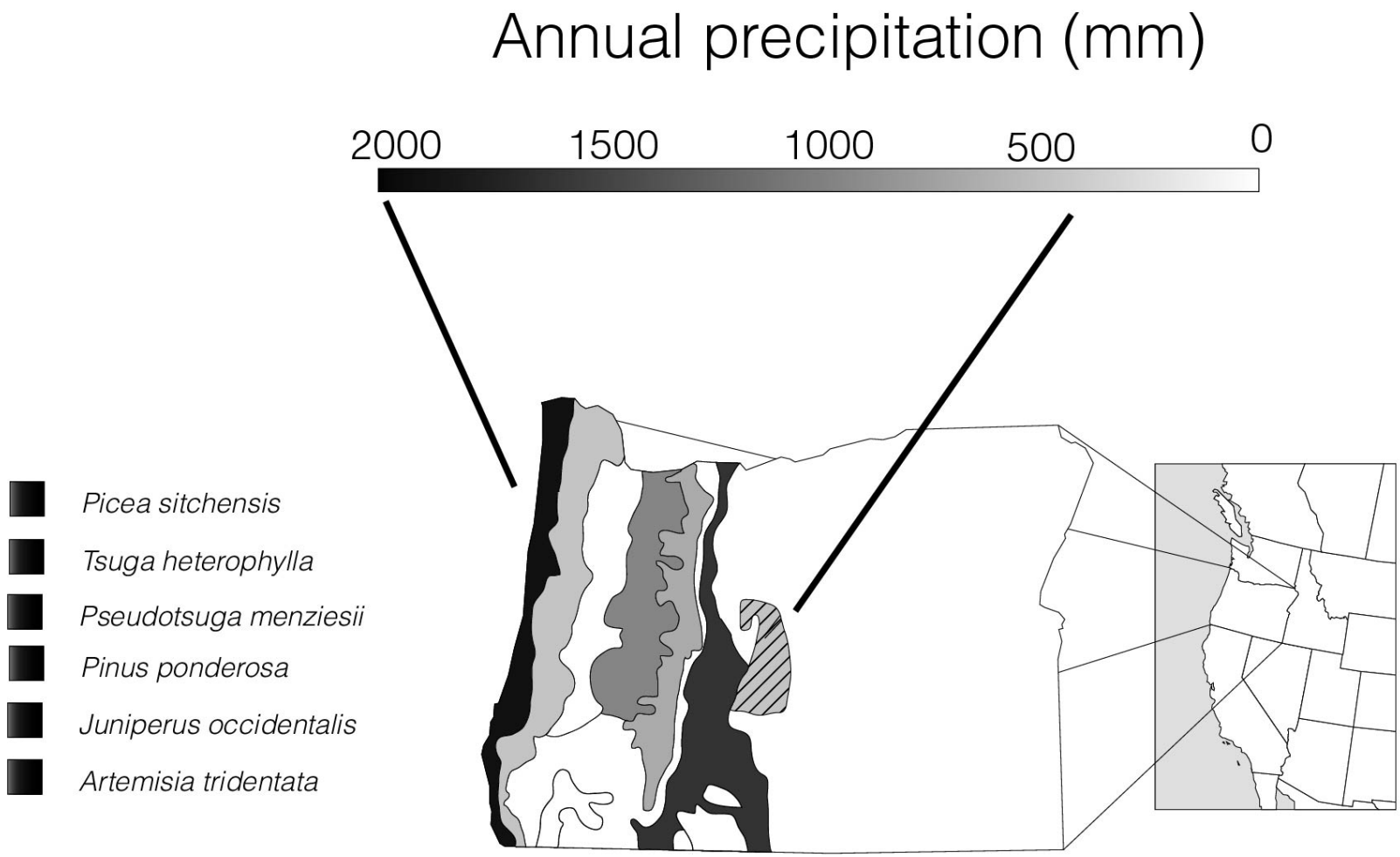
LAI < 1	deserts
LAI $= 1\text{-}3$	shrublands
LAI > 3	forests

high LAI values --> --> --> --> low LAI values

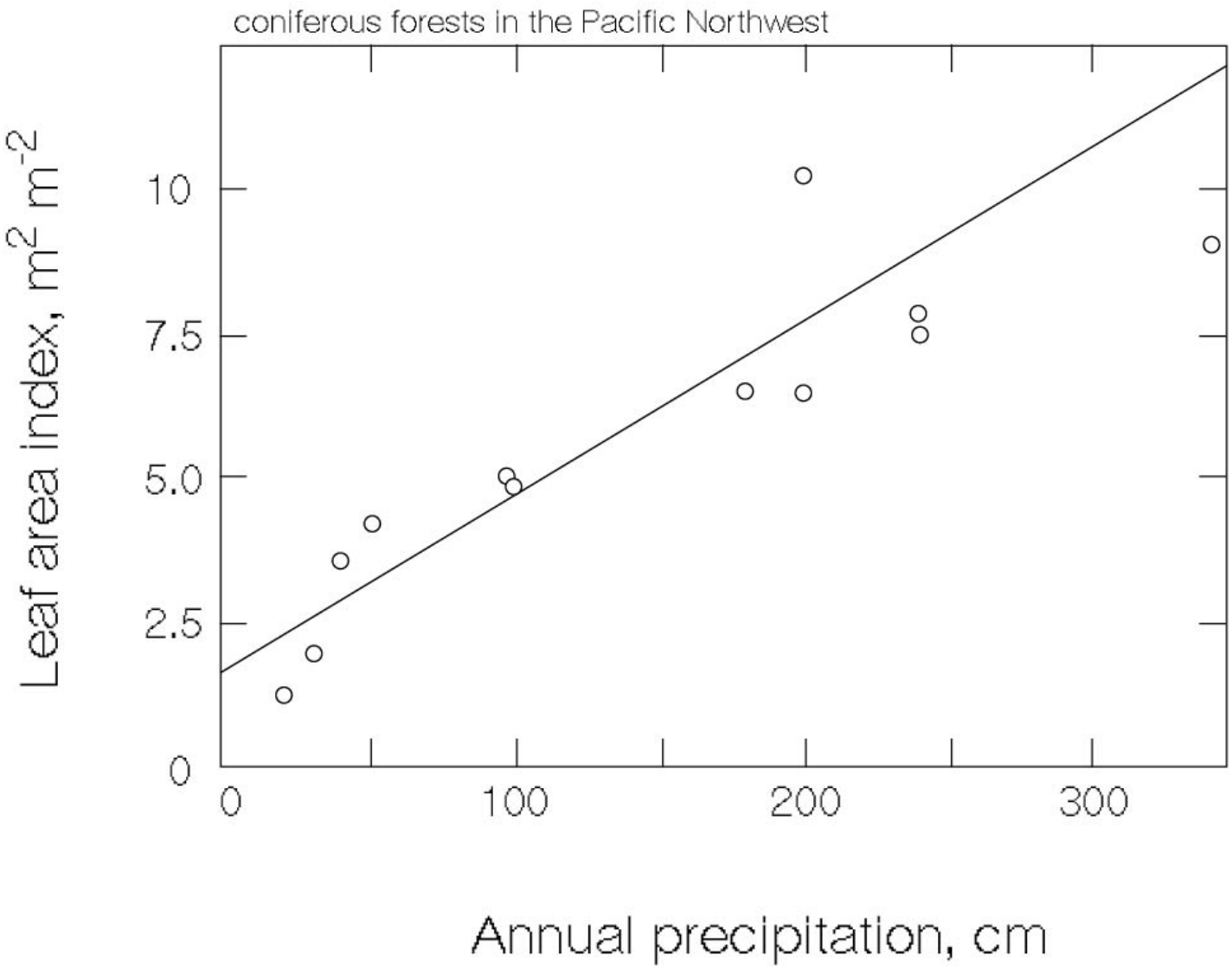


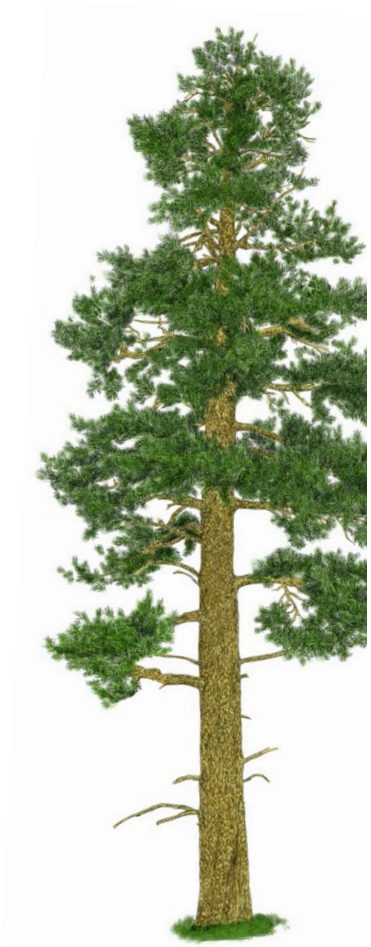
Forest-to-desert gradients follow precipitation gradients.

Gradients may be abrupt whenever rain shadows appear.



A coniferous tree replacement series occurs along precipitation gradients in Oregon.

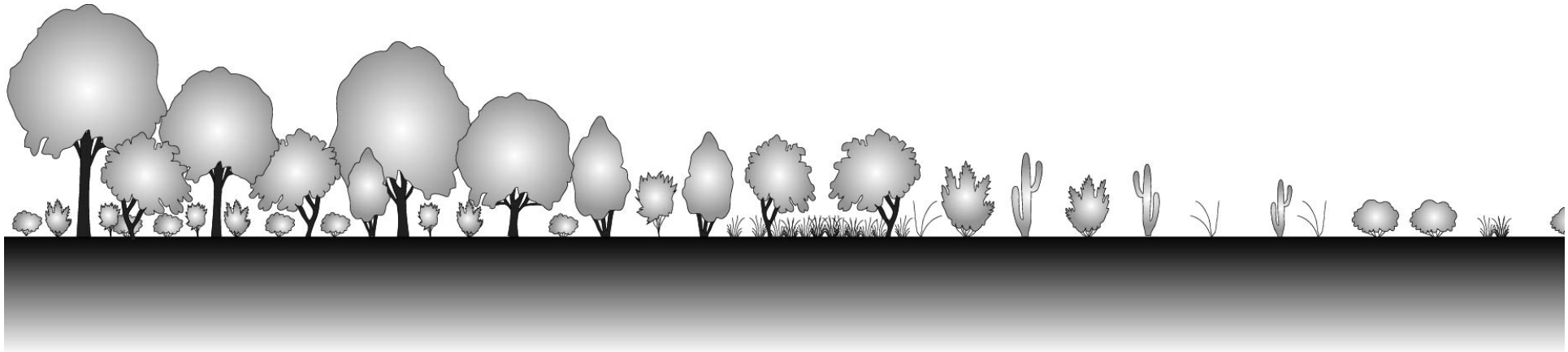




Supportable LAI increases with increasing rainfall in the Pacific Northwest.

Yet, the dry-end limits of tree distributions need not follow absolute precipitation patterns

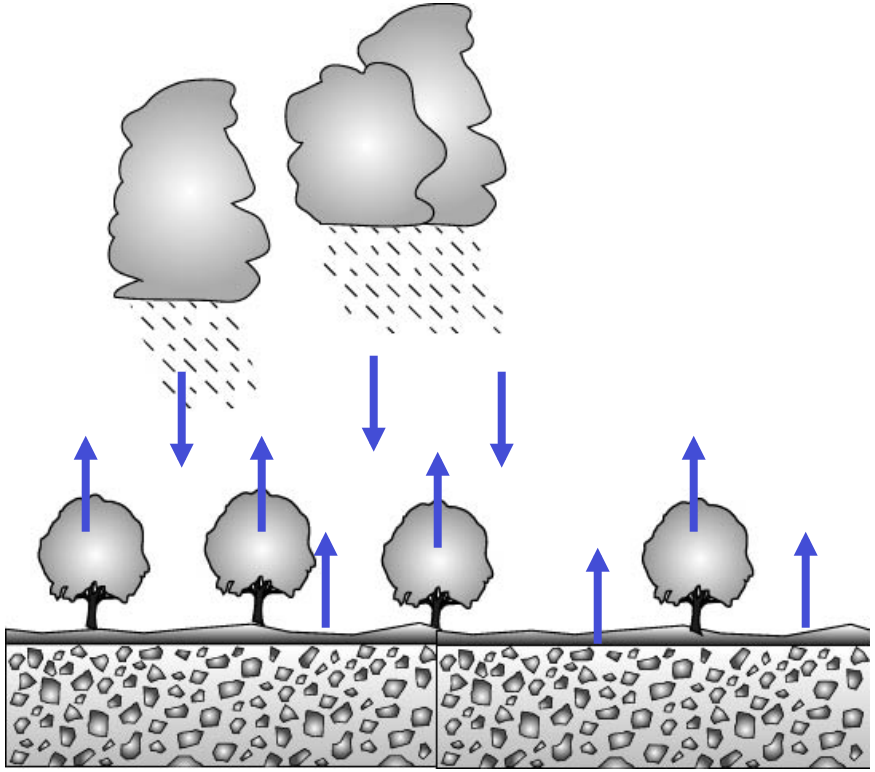
250 mm	lower limits for trees in Oregon
180 mm	lower limits for trees in Alaska

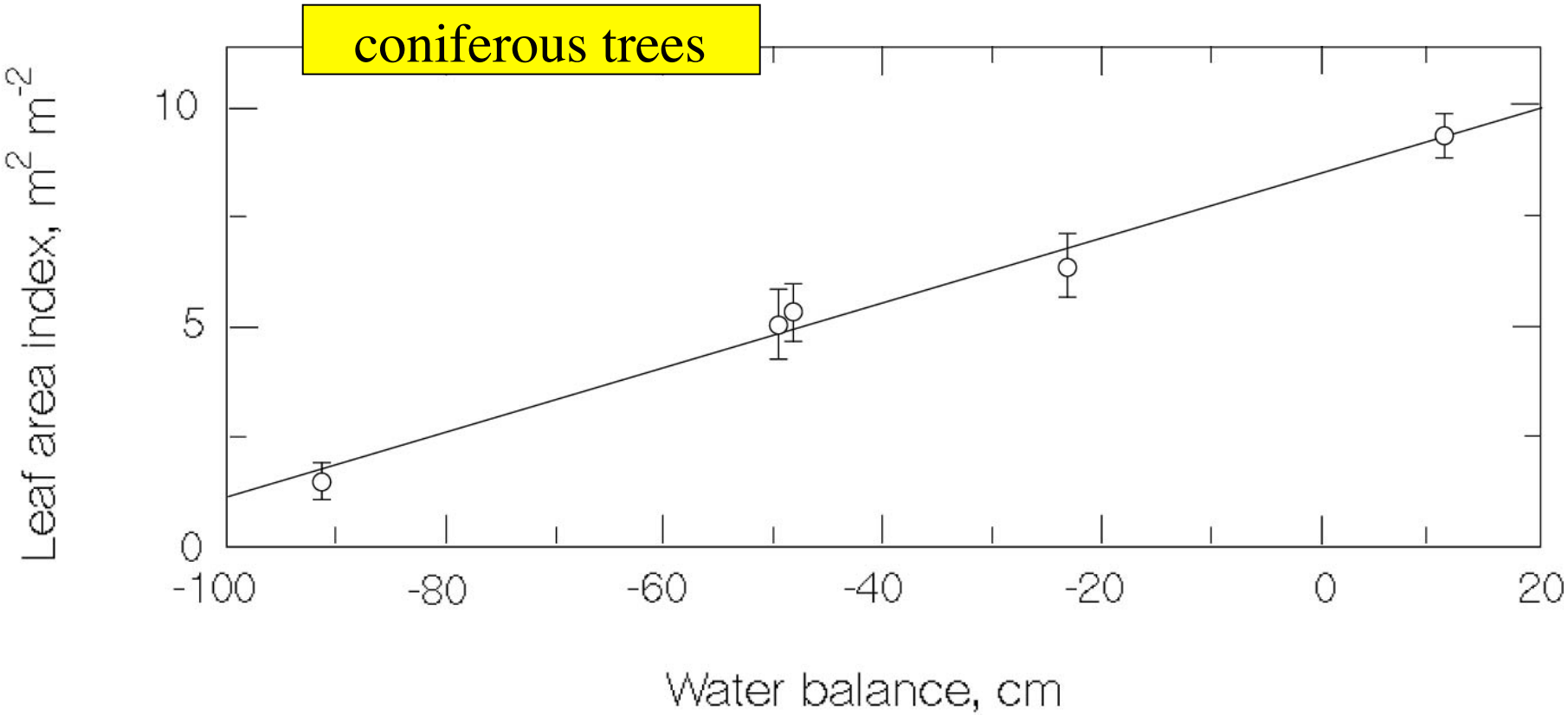


Water balance controls the amount of leaf area in a canopy.

water balance = **soil availability** - evapotranspiration

soil availability = precipitation - (interception + runoff + percolation)





The LAI maintained by vegetation is proportional to site water balance.