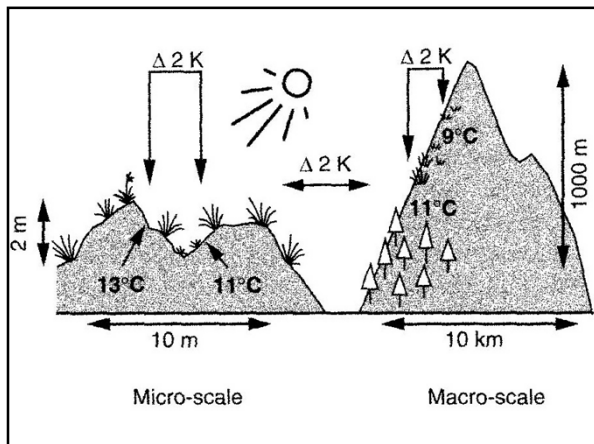


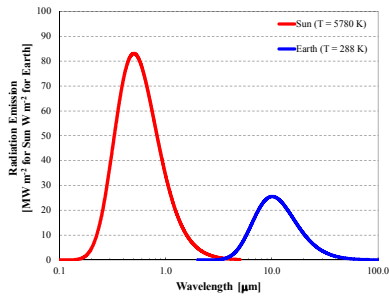
The biophysical environment has a significant impact on plant performance

- Biological microclimate is driven by solar and terrestrial energy inputs.
- Vegetation structure and distribution contributes to establishing microclimate heterogeneity.
- Microclimate profiles.
- Adaptations to microclimate.

- Incoming radiation (shortwave and longwave) is converted to heat and dissipated as radiation emission, convection, or evapotranspiration.

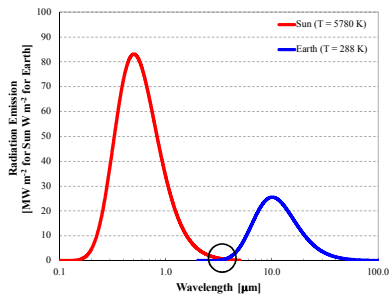


The biological microclimate is driven by solar radiation and terrestrial radiation inputs



The magnitude and wavelength range of radiation emission is dependent on to temperature.

The biological microclimate is driven by solar radiation and terrestrial radiation inputs

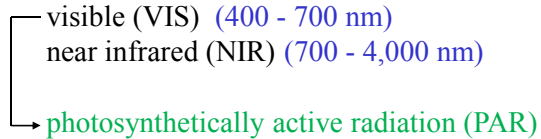


Due to temperature differences between Earth and sun, there is little to no overlap in spectral emission patterns.

Electromagnetic radiation

Shortwave (SW) radiation (sun):

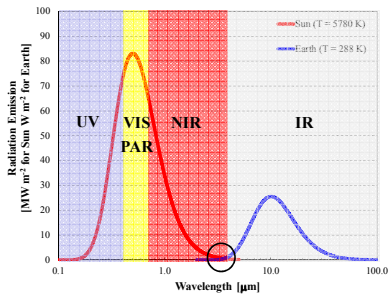
- ultraviolet (UV) (100 - 400 nm)
- visible (VIS) (400 - 700 nm)
- near infrared (NIR) (700 - 4,000 nm)



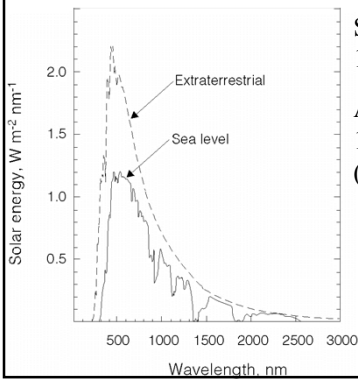
Longwave (LW) radiation (terrestrial objects):

- infrared (IR) (4,000 - 11,000 nm)

The biological microclimate is driven by solar radiation and terrestrial radiation inputs



Solar constant: Total solar radiation between 100 - 3,000 nm, incident at the top of Earth's atmosphere



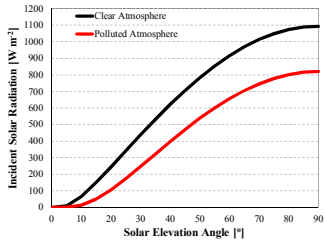
Solar constant:
1,367 W m⁻²
At Earth's surface:
1,000 W m⁻²
(summer, clear)

Solar radiation received at Earth's surface is less than that at the top of the atmosphere

- Absorption by atmospheric gases:
CO₂, H₂O, O₃
- Reflection by atmospheric gases (small molecules):
Rayleigh scattering
- Reflection by large particles and clouds:
Mie scattering

Atmospheric influence on solar radiation at the Earth's surface

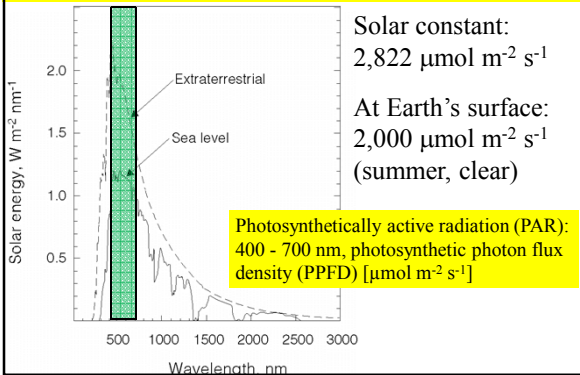
$I_0 = S_0 \sin(a) \tau^{1/\sin(a)}$
 I_0 = radiation at Earth's surface (perpendicular to direct beam) [$W m^{-2}$]
 S_0 = solar constant (1367 $W m^{-2}$)
 a = solar elevation angle (angle of the sun above the horizon) [$^\circ$]
 τ = atmospheric transmission coefficient
 (clear conditions: $\tau = 0.80$, polluted atmosphere: $\tau = 0.60$)



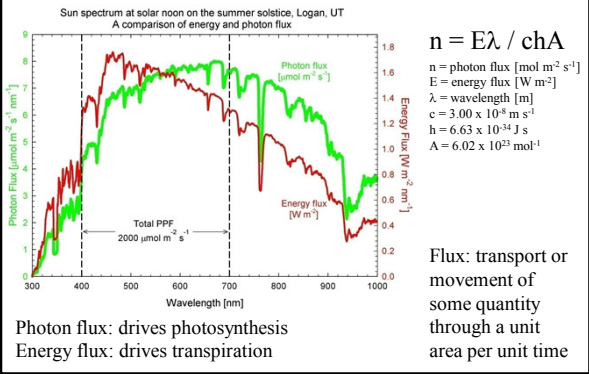
Solar elevation angle (a)

$\sin(a) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(h)$
 a = solar elevation angle (angle of the sun above the horizon) [$^\circ$]
 ϕ = latitude [$^\circ$]
 δ = solar declination (latitude where the sun is directly overhead) [$^\circ$]
 (range: -23.5° to 23.5°)
 h = hour angle (related to time of day) [$^\circ$]

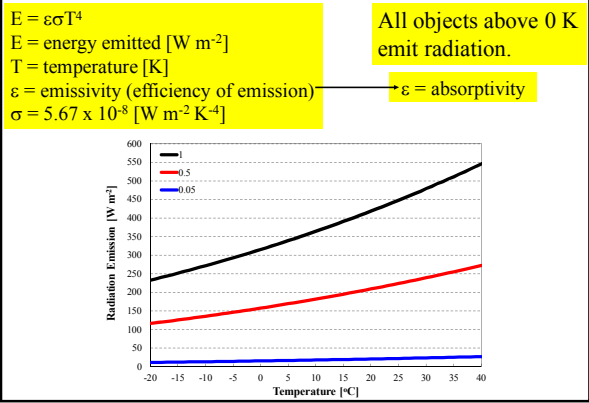
Solar radiation received at Earth's surface is less than that at the top of the atmosphere



Two ways to express radiation: Units of quantity (number of moles) and units of energy (intensity in Watts)



Stefan-Boltzmann radiation law: Energy emission



Many natural surfaces are nearly blackbodies

Emissivity values:

polished Al	0.04
polished Cu	0.05
fresh snow	0.82
dry sand	0.90
wet soil	0.94
water	0.96
human skin	0.98

Plants are nearly blackbodies

Emissivity values:

cotton leaves	0.97
oak leaf	0.97
sunflower leaf	0.97

Unlike biological organisms, the sky is not an efficient longwave radiation emitter

- Water vapor, CO₂, CH₄, N₂O, and O₃ are strong greenhouse gases.
- Dominant atmospheric gases (N₂, O₂, Ar) have limited influence on emissivity.
- $\epsilon_{\text{air}} = 0.06e_a^{0.5} + 0.53$ (e_a = air vapor pressure), range is approximately 0.53 - 0.68.

The sun is a point source:

Orientation has a large influence on the amount of sunlight received.

Terrestrial objects are not point sources:

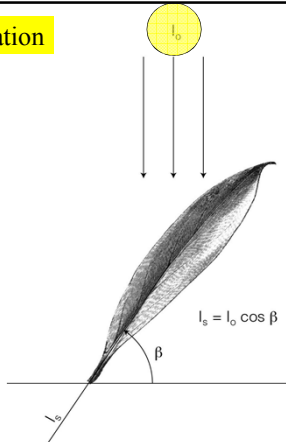
Orientation does not have a large influence on the amount of infrared received.

Cosine law of illumination

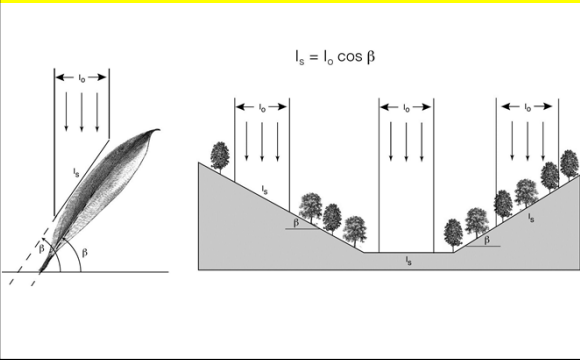
$$I_s = I_0 \cos \beta$$

β	$\cos \beta$
0	1.00
10	0.98
20	0.94
30	0.87
40	0.77
50	0.64
60	0.50
70	0.34
80	0.17
90	0.00

Orientation of the object matters!!



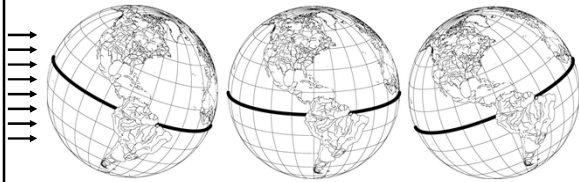
This same cosine relationship applies to hillsides as well as to leaves



Since the sun is not often directly overhead, a more complex equation is required

$\cos(i) = \cos(\beta)\sin(a) + \sin(\beta)\cos(a)\cos(z_{\text{sun}} - z_{\text{slope}})$
 β = angle of leaf or slope [°]
 a = solar elevation angle (angle of the sun above the horizon) [°]
 z_{sun} = azimuth of the sun (compass direction) [°]
 (south: 0°, east: -90° west: 90°)
 z_{slope} = azimuth of leaf or slope (compass direction) [°]
 (south: 0°, east: -90° west: 90° north: 180° or -180°)

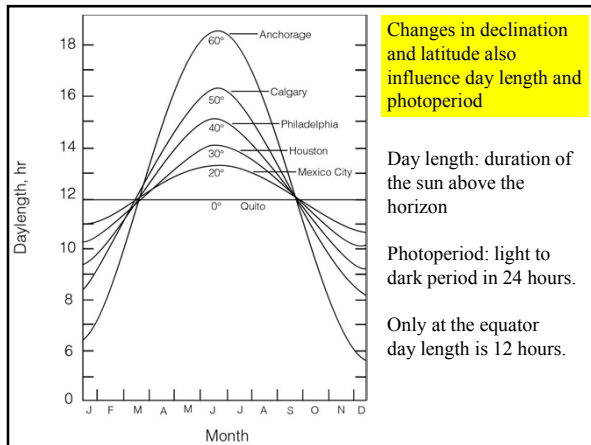
The interplay of declination and surface slope influence the incident solar radiation levels and energy balance of specific locations



For any given time, latitude, declination, time of day, and angle of leaf or slope combine to determine incident radiation.

From solar radiation measured on a horizontal plane at Earth's surface (S_h), incident solar radiation on a leaf or slope (S_s) is:

$$S_s = S_h \cos(i) / \sin(a)$$



Changes in declination and latitude also influence day length and photoperiod

Day length: duration of the sun above the horizon

Photoperiod: light to dark period in 24 hours.

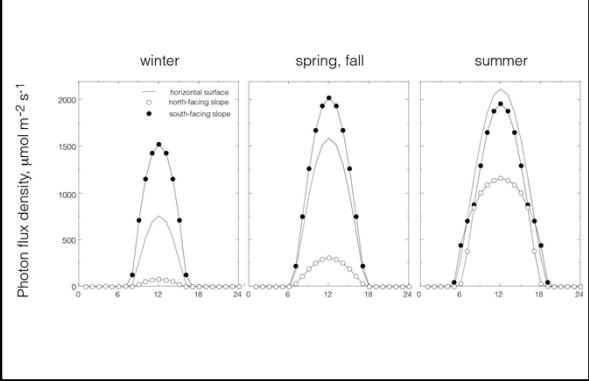
Only at the equator day length is 12 hours.

Day length calculation

$$\Lambda = 2 \arccos(-\tan(\phi)\tan(\delta)) / 15$$

↑
day length
[hours]

Slope orientation has a significant influence on incident solar radiation, and therefore: heating, evapotranspiration, photosynthesis, growing season



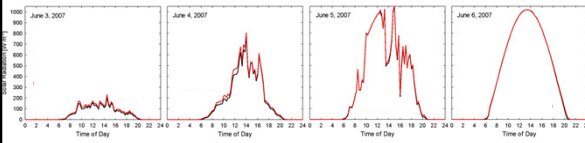
Daily total PPFD (400-700 nm) [mol m⁻² d⁻¹] received on different slopes in Salt Lake City during different seasons

	Winter Solstice	Equinox	Summer Solstice
Horizontal surface	13.1	39.2	63.7
South-facing: 45°	29.6	50.0	52.0
North-facing: 45°	1.3	7.7	42.5
East-facing: 45°	11.3	32.8	51.4
West-facing: 45°	11.3	32.8	51.4

Flowering times: days after March 1

Species	South-facing slope	North-facing slope
<i>Dentaria laciniata</i>	33	39
<i>Dicentra cucullaria</i>	34	40
<i>Arisaema triphyllum</i>	44	51
<i>Arabis laevigata</i>	51	57
<i>Phacelia bipinnatifida</i>	52	63

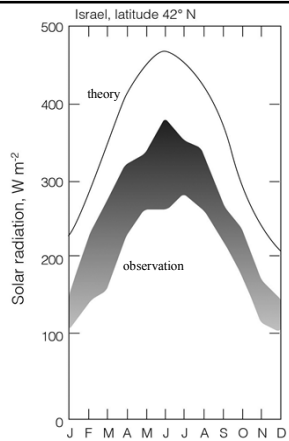
Influence of clouds



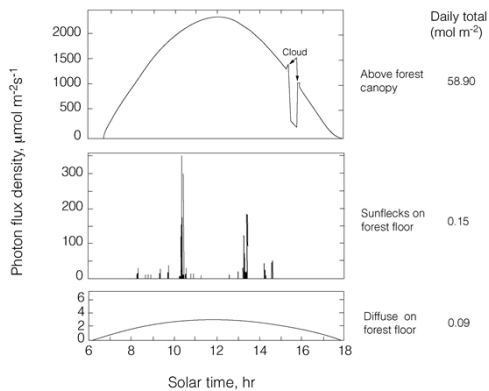
- Cloudiness in any month can reduce incident radiation by 10-30 % in arid regions and 40-60 % in humid regions.
- On cloudy days, most incident radiation at the surface is diffuse radiation scattered from all portions of the sky; little, if any, radiation strikes the surface as direct beam.
- On cloudy days, when most or all radiation is diffuse, angular orientation of leaves or slopes with respect to the sun has little influence on incident PPFD, assuming the fraction of visible sky is not appreciably decreased.

Influence of clouds

Most regions of the world experience cloudiness, reducing incident solar radiation below the theoretical maximum.

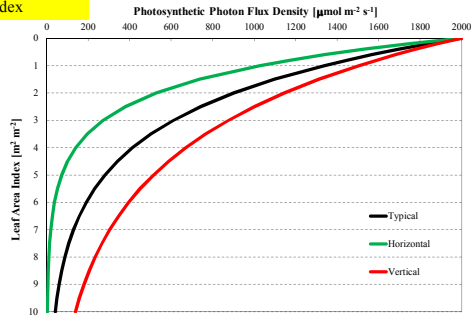


Solar radiation at the top and bottom of a forest canopy

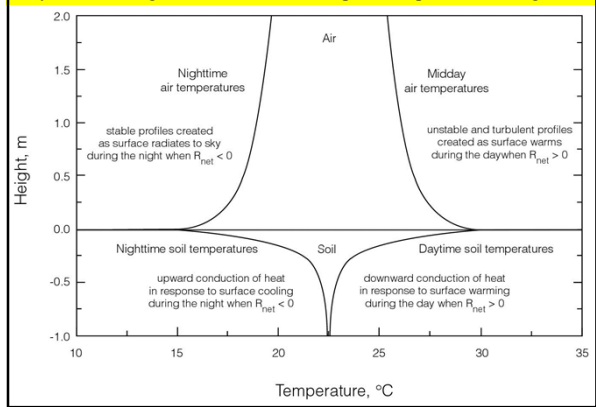


Photosynthetic Radiation Under Three Different Plant Canopies:

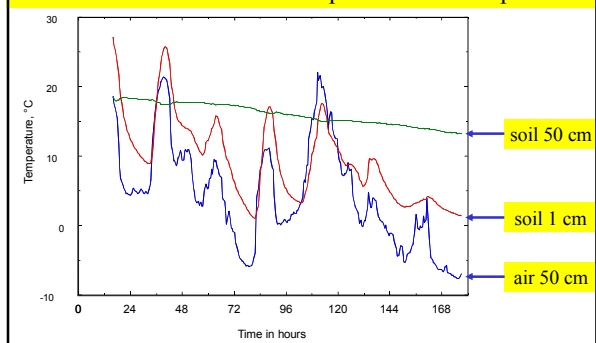
$I = I_0 e^{-K \cdot F}$
 I = radiation in canopy
 I_0 = radiation above canopy
 K = attenuation coefficient
 F = leaf area index



Daytime and Nighttime air and soil temperature profiles: bare ground



Observations of soil temperature with depth



Many roots experience a much smaller temperature range than stems and leaves above-ground.

Soil temperatures fluctuations decrease with depth in the soil profile according to soil damping depth

Damping depth: depth in soil required to see a $1/e$ (0.37) reduction in daily or annual soil temperature amplitude.

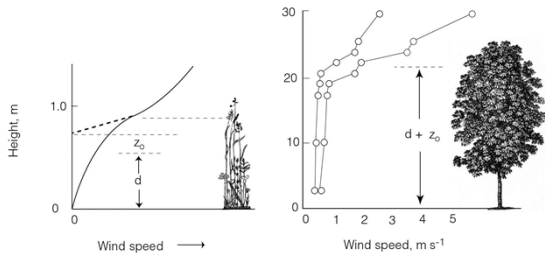
0 x damping depth	$1/e^0$	1.00
1 x damping depth	$1/e^1$	0.37
2 x damping depth	$1/e^2$	0.14
3 x damping depth	$1/e^3$	0.05

Typical daily damping depths = 0.06-0.15 m
Annual damping depths = 19 x daily depth

Damping depth on an annual basis is approximately 19 times higher than on a daily basis.

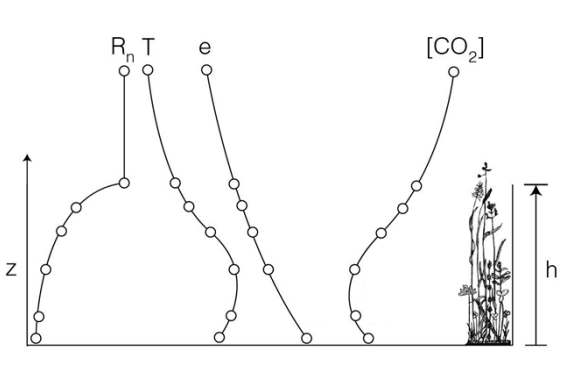
At some depth, depending on damping depth, soil will remain sufficiently warm for roots to be active.

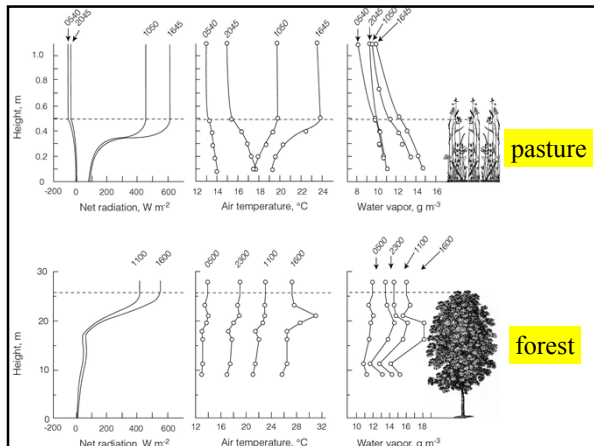
Wind speed decreases logarithmically above vegetation

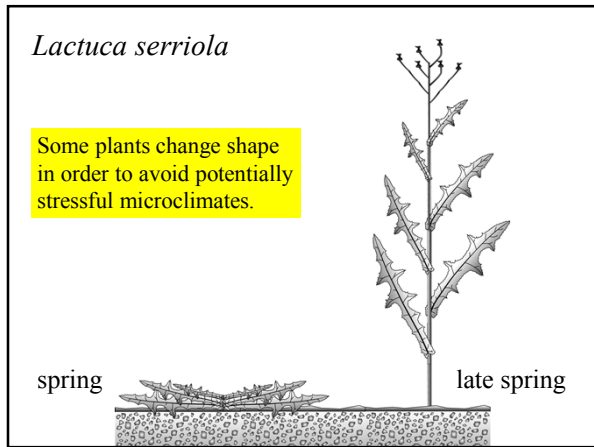


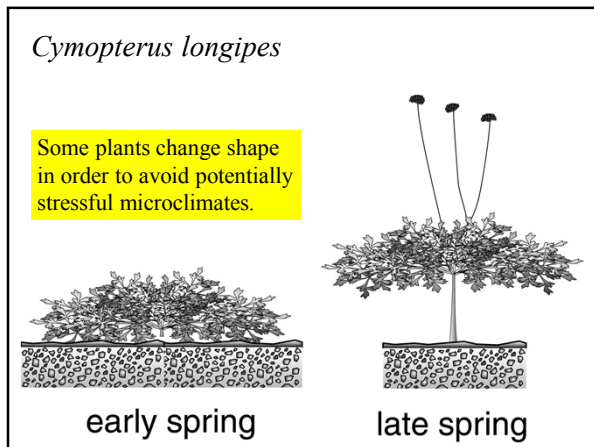
- As wind blows across a surface, layers or packets of air close to the surface are slowed down due to drag exerted by the surface.
- Features at the surface, such as vegetation, interrupts the logarithmic decrease in wind speed, imposing surface roughness and changing the shape of the wind profile within the canopy.

Vegetation alters microclimate profiles near the surface

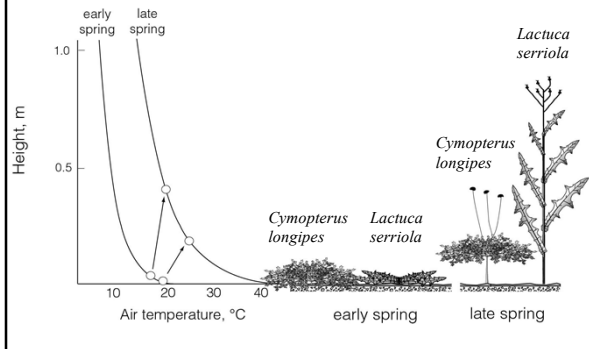




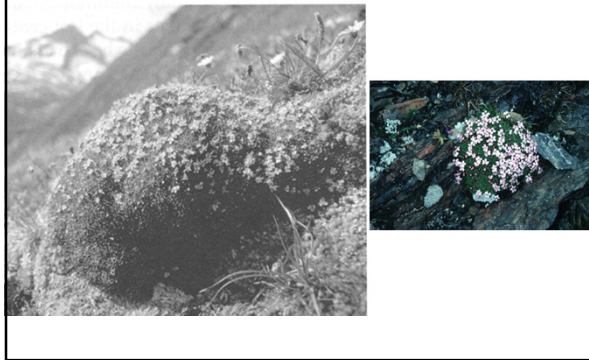




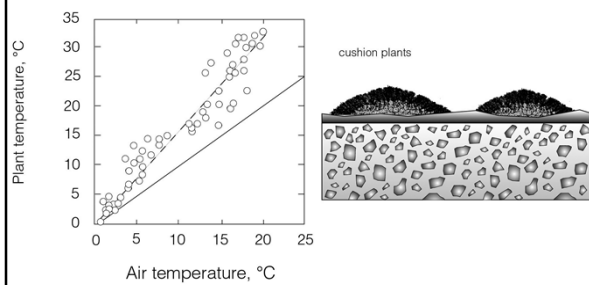
Vegetative structures are within or elevated out of the warmest part of the air temperature profile, depending on season



Cushion plants in alpine tundra



Tightly-packed plants in the alpine tundra have reduced wind speeds and elevated temperatures



Tightly-packed plants in the alpine tundra have reduced wind speeds and elevated temperatures

