

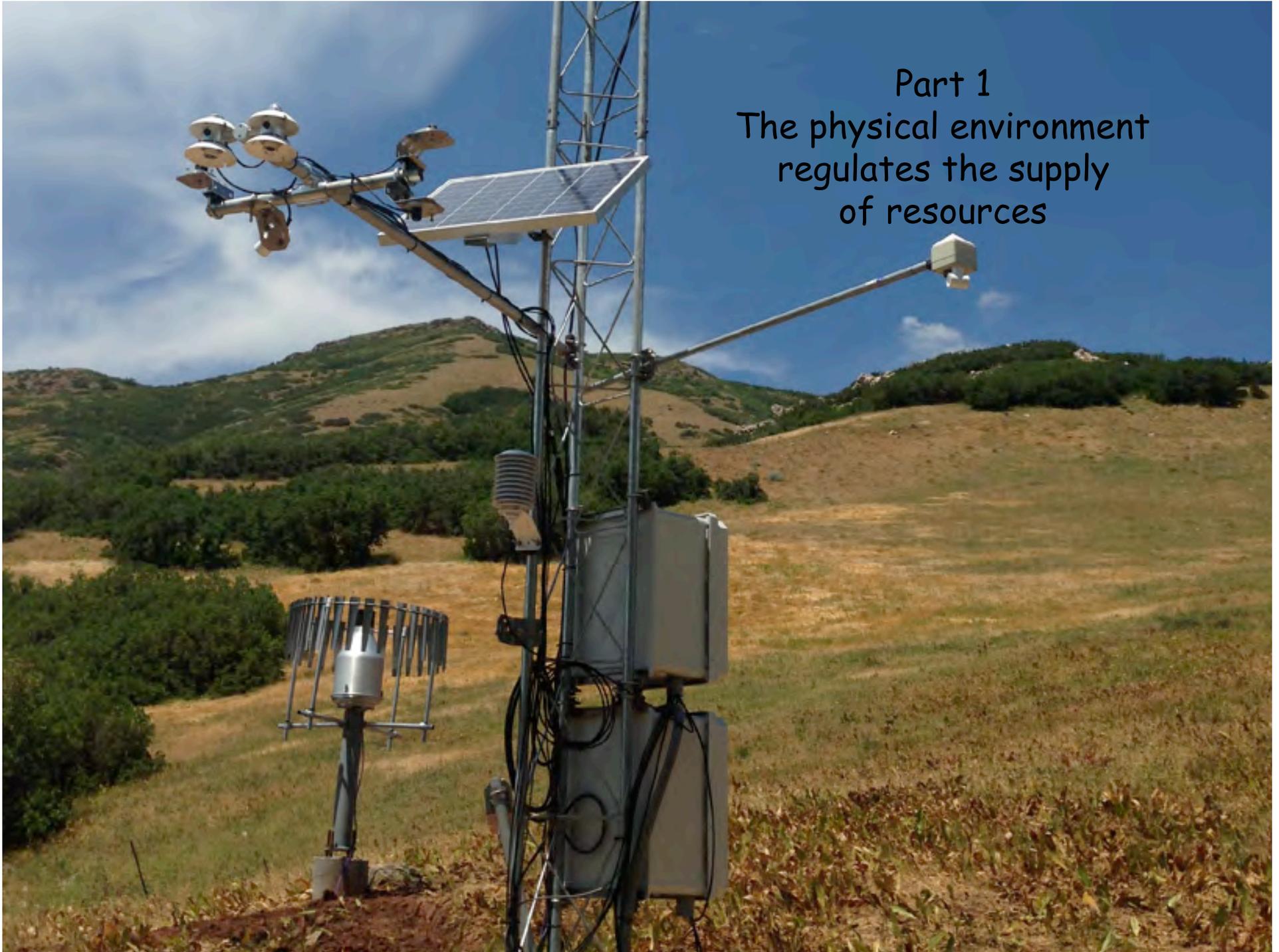
Macroclimates and microclimates

Plant Ecology in a Changing World

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<http://plantecology.net>



Part 1
The physical environment
regulates the supply
of resources

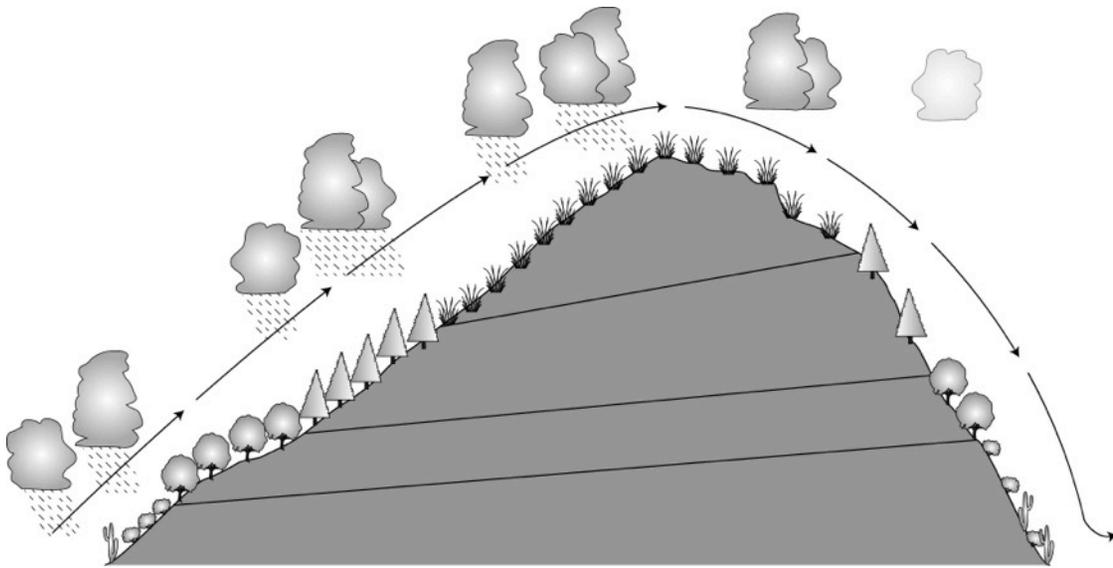


The physical environment regulates the supply of resources

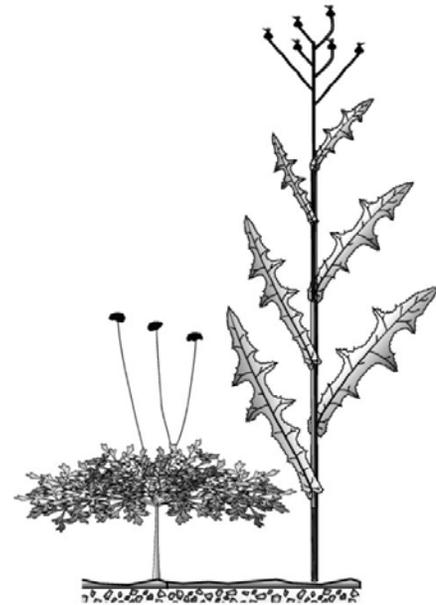
- macroclimate versus microclimate
- the biological microclimate is driven by solar and terrestrial energy inputs
- incoming solar energy is converted to heat and dissipated as reradiation, convection, or transpiration
- vegetative structure contributes to establishing microclimate heterogeneity

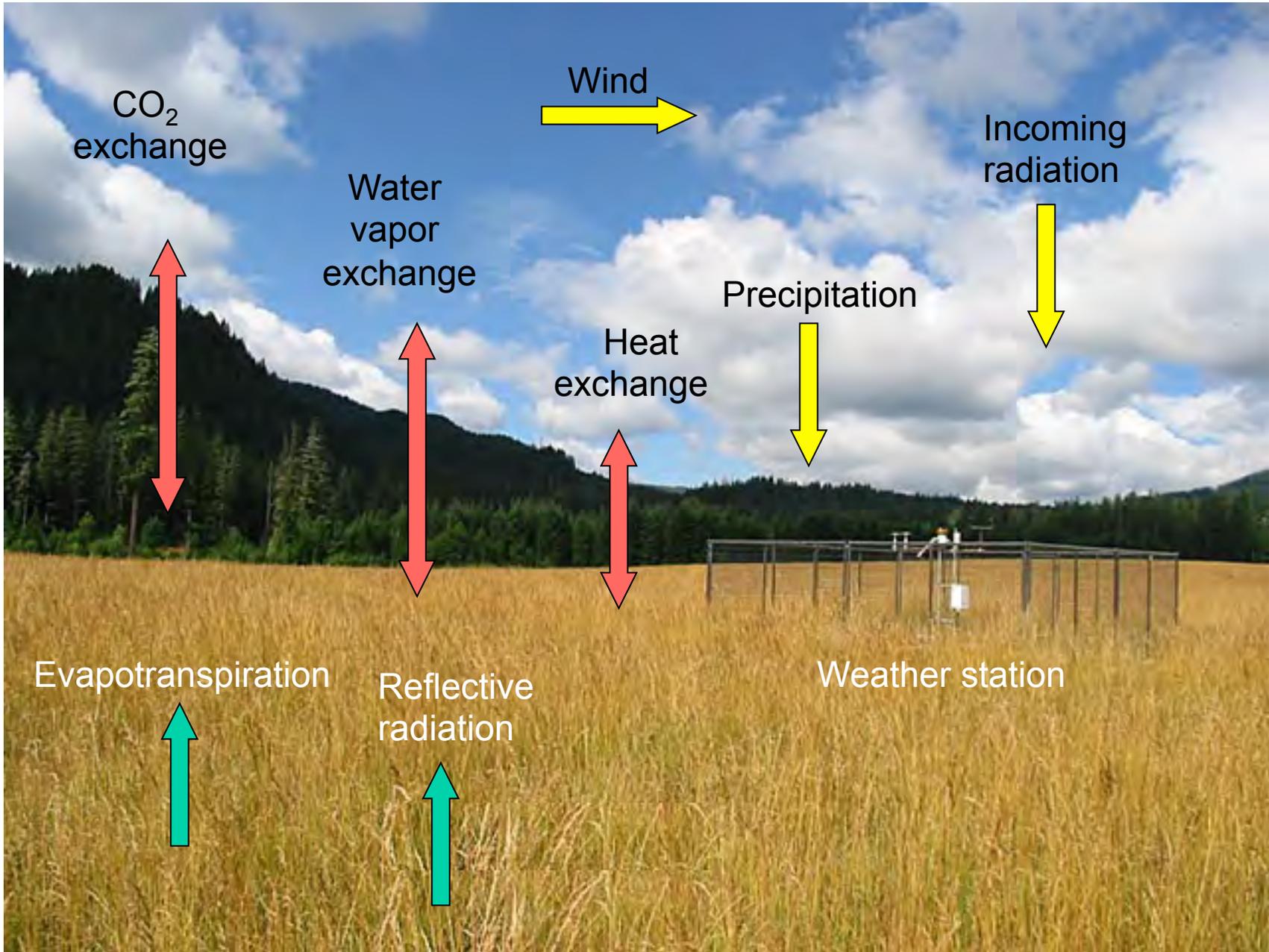
The distinction between macroclimate and microclimate is a matter of scale

macroclimate



microclimate





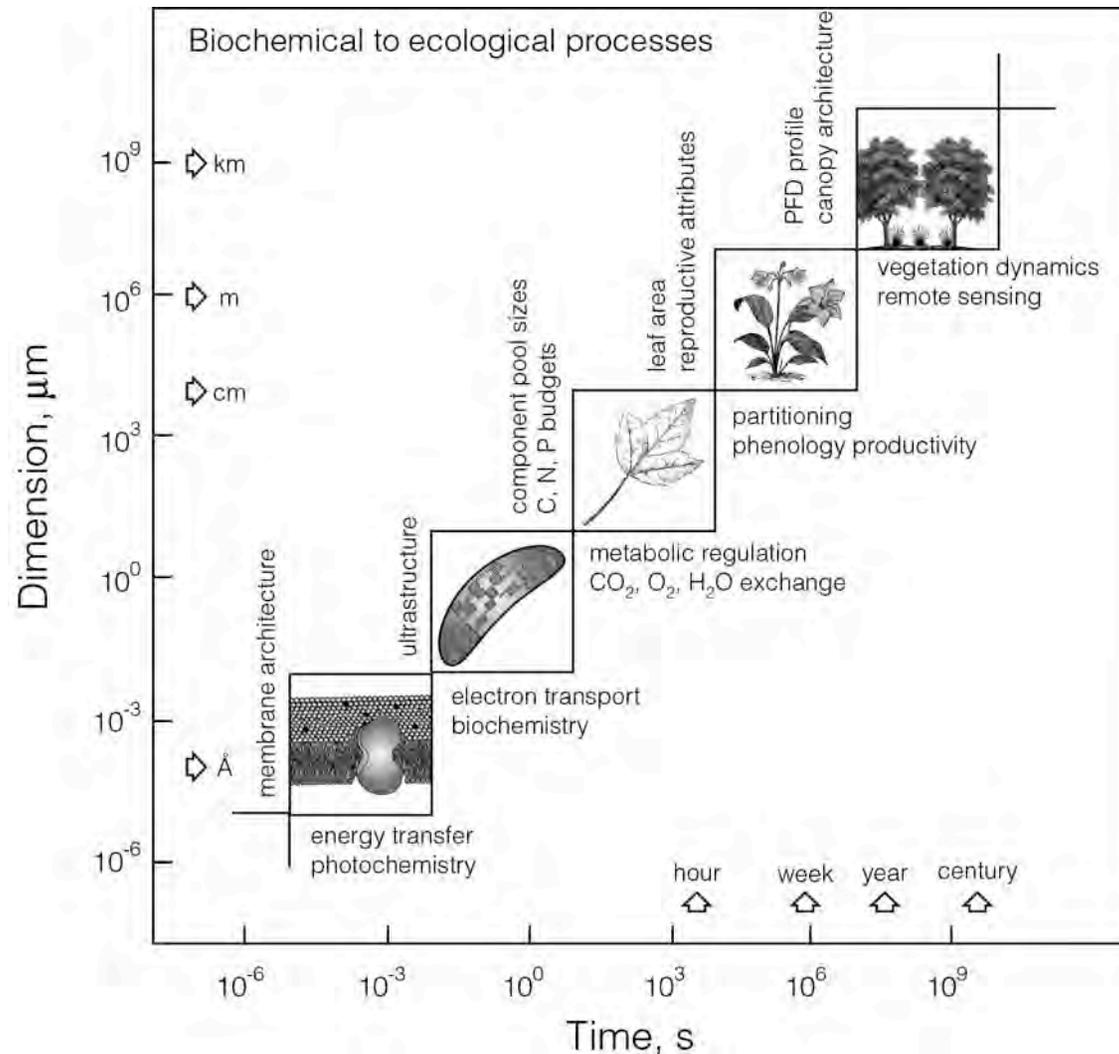
The physical environment impacts plant performance

- physical environment supplies resources (water, nutrients, temperature, humidity, sunlight)
- physical environment temporally modulates plant activities (temperature, sunlight, daylength)
- physical environment imposes stresses (water, nutrients, temperature, humidity, sunlight)



Recognizing the temporal scales of environmental measurements is critical

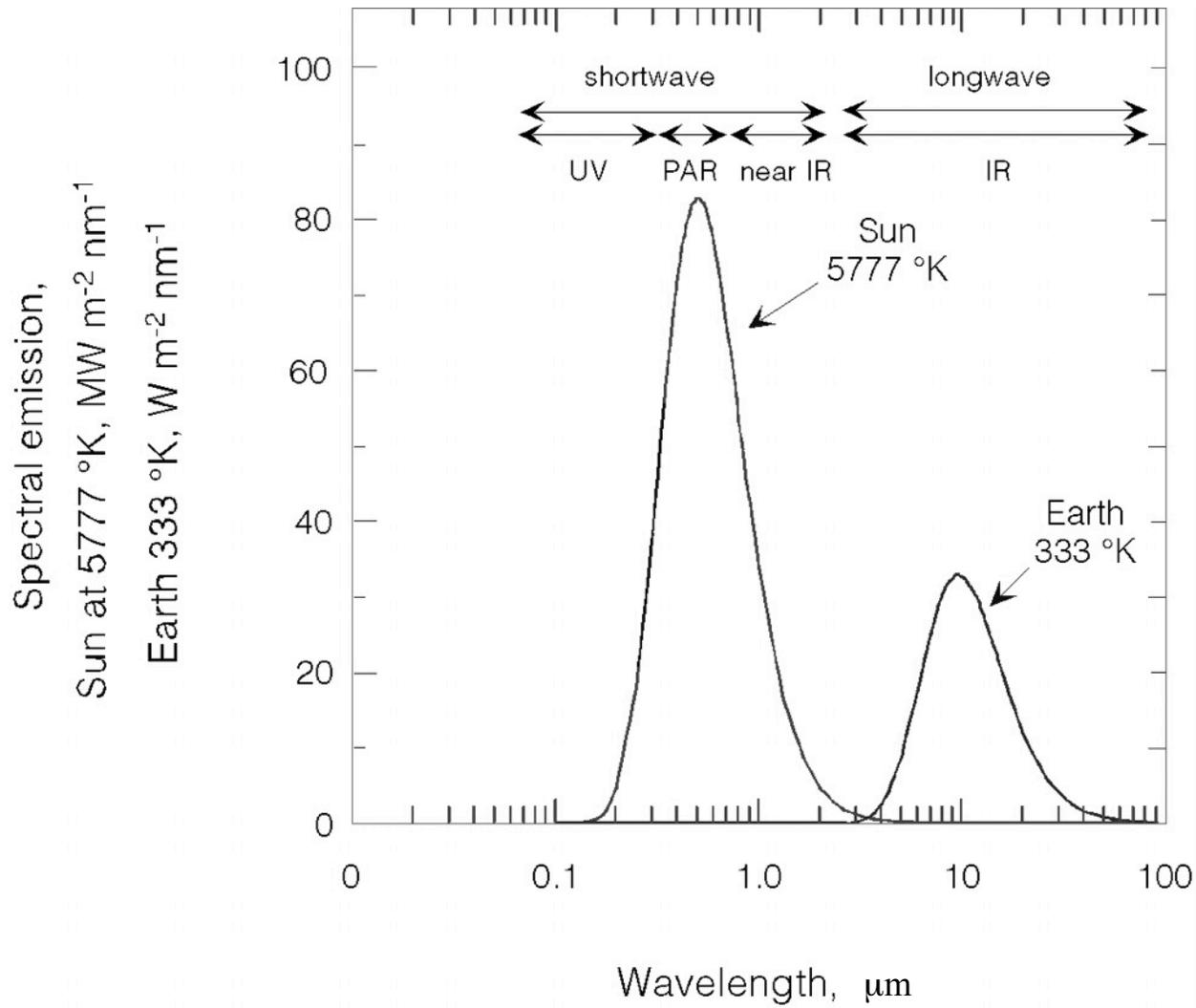
We must recognize that dynamics and variations in the physical environment and their impacts on plants occur over different time scales.



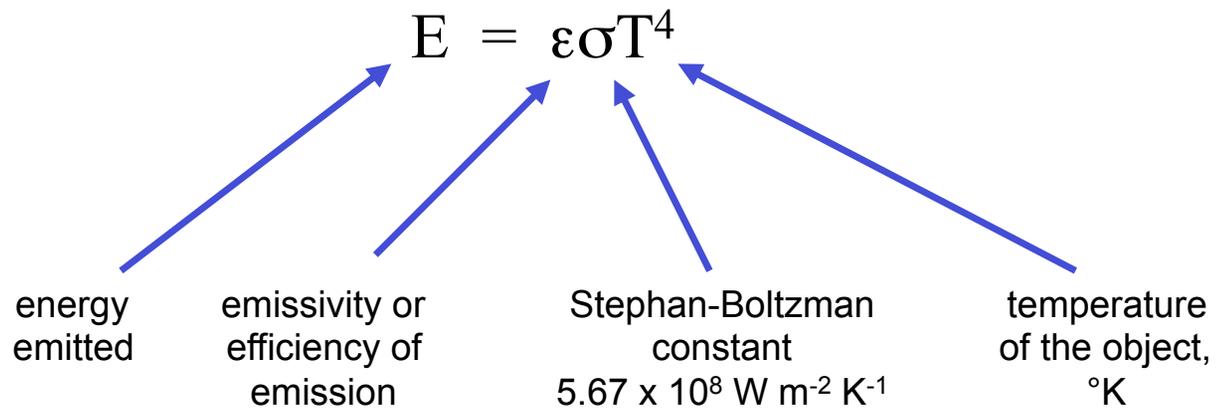
Part 2
Short- and long-wave
radiation



Variations in the biological microclimate are driven by differences in the inputs of both solar radiation and terrestrial radiation



Blackbody Radiation Law - all objects above 0°K emit radiation



The emissivity of biological materials and of O-containing materials is high

Oxidized **inorganic** materials
are strong blackbodies

emissivity values, %

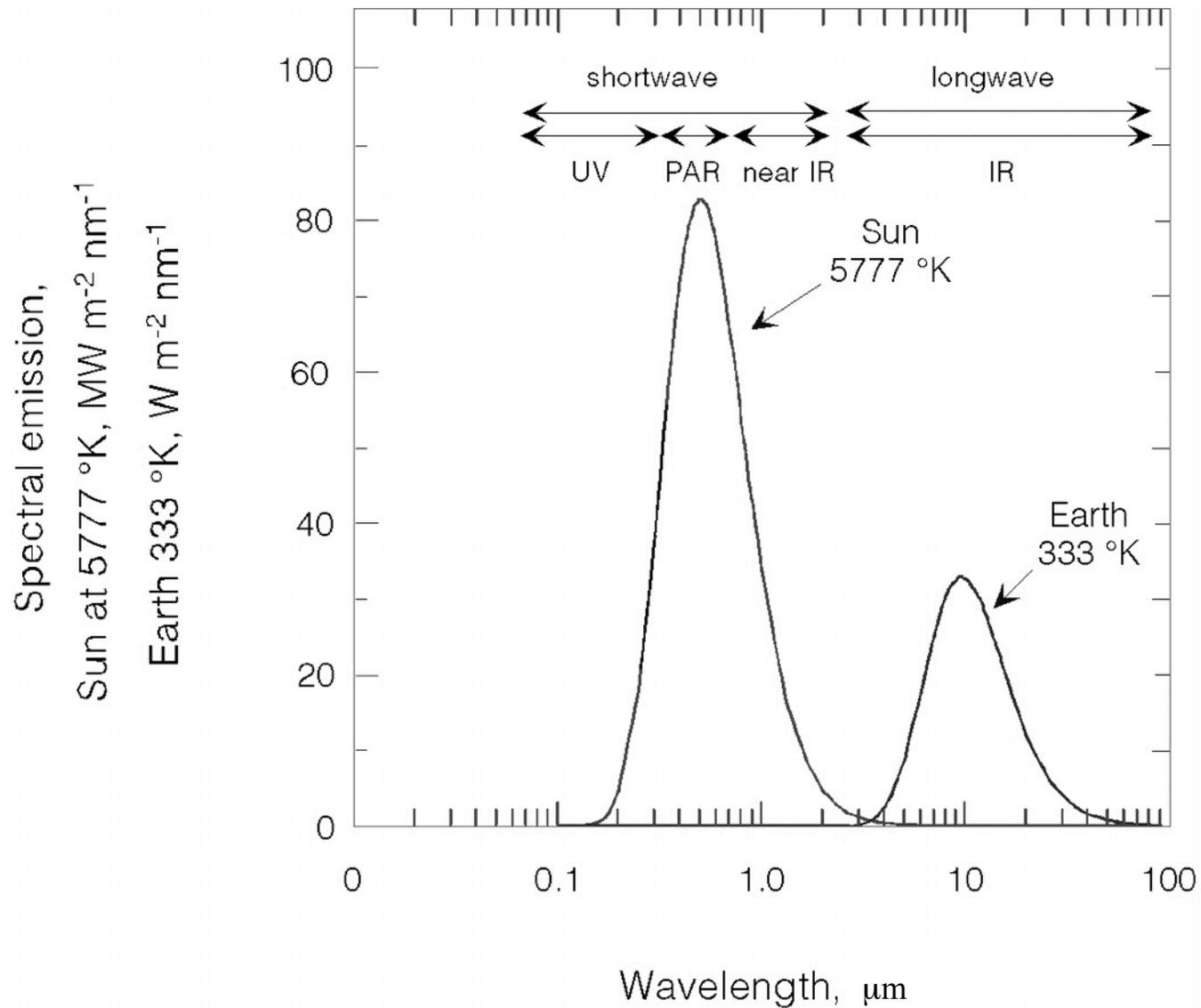
polished Al	4
polished Cu	5
copper oxide	78
cast iron	65
brick	93
quartz	93
water	95

Biological materials are
strong blackbodies

emissivity values, %

cotton leaves	97
oak leaf	97
sunflower leaf	97

Because of surface temperature differences between the Earth and sun, there is no overlap in the spectral emission patterns



The sun is a point source

.. therefore orientation influences the amount of sunlight received

Terrestrial objects are not point sources

.. therefore orientation has limited influence on the amount of infrared received

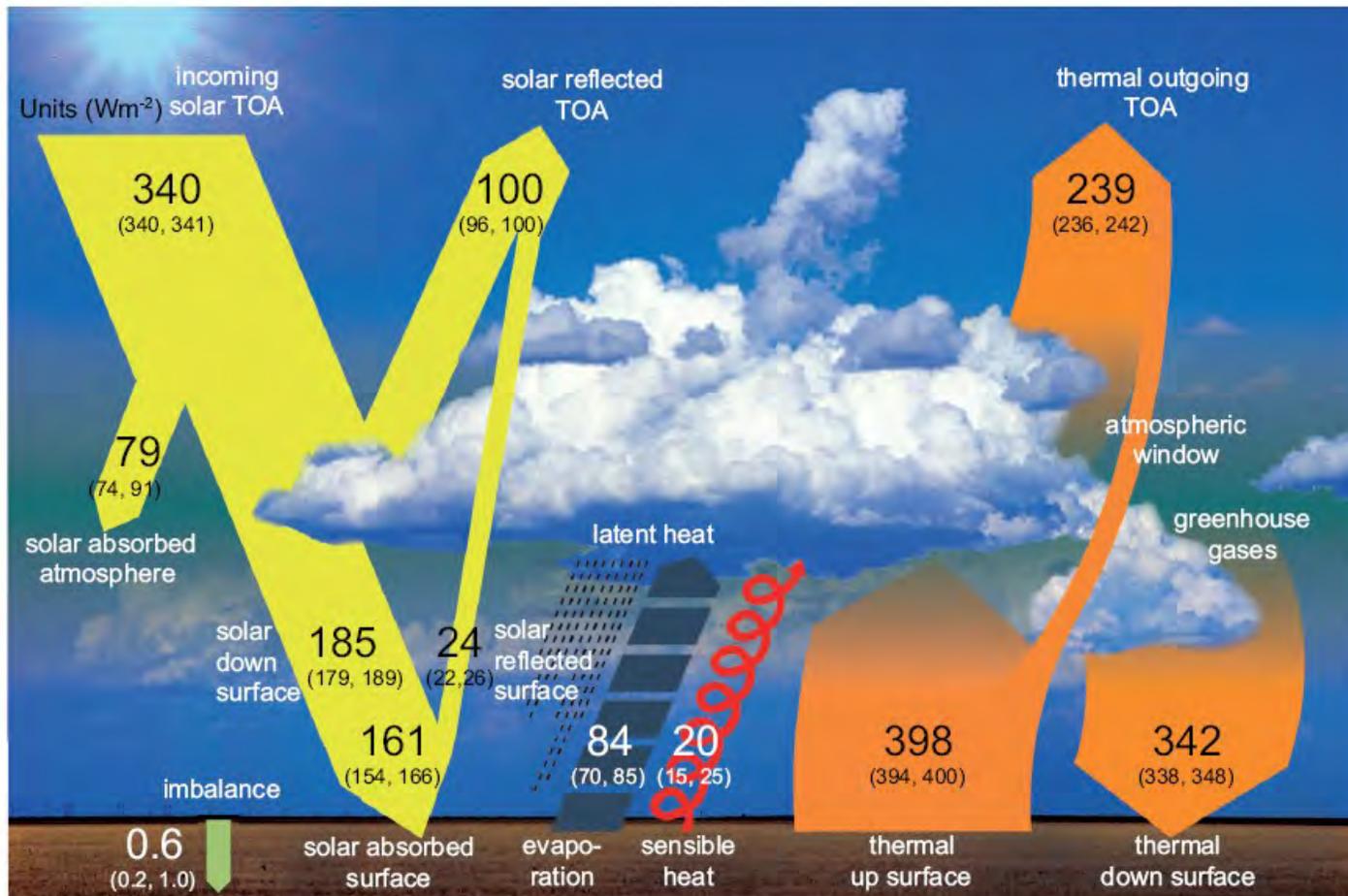
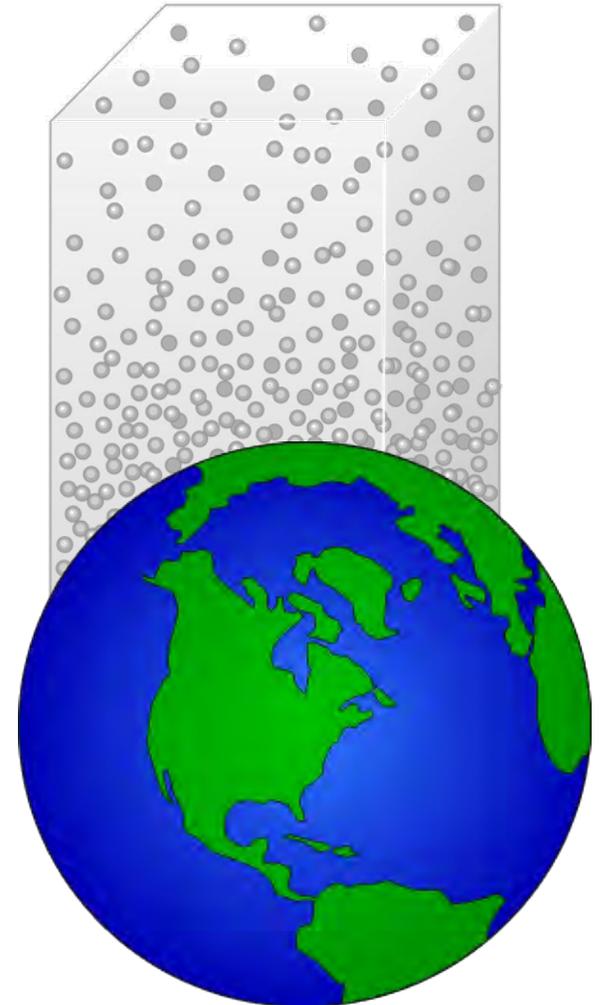


Figure 2.11: | Global mean energy budget under present-day climate conditions. Numbers state magnitudes of the individual energy fluxes in $W m^{-2}$, adjusted within their uncertainty ranges to close the energy budgets. Numbers in parentheses attached to the energy fluxes cover the range of values in line with observational constraints. (Adapted from Wild et al., 2013.)

Unlike biological organisms, the atmosphere (sky) is not a strong blackbody

- the density of absorbing molecules is less than that of the soil
- the dominant atmospheric gases (N_2 , O_2 , Ar) have limited influence on increasing emissivity
- largest component influencing the emissivity of air are the greenhouse gases (CO_2 , CH_4 , N_2O , and H_2O)
- $\epsilon_{air} = 0.06e^{0.5} + 0.53$ (e = vapor pressure)



Short- and long-wave radiation originates from different sources

short-wave radiation (sun)

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

Solar constant:

energy units

1,367 W m⁻²
(100 - 3,000 nm)

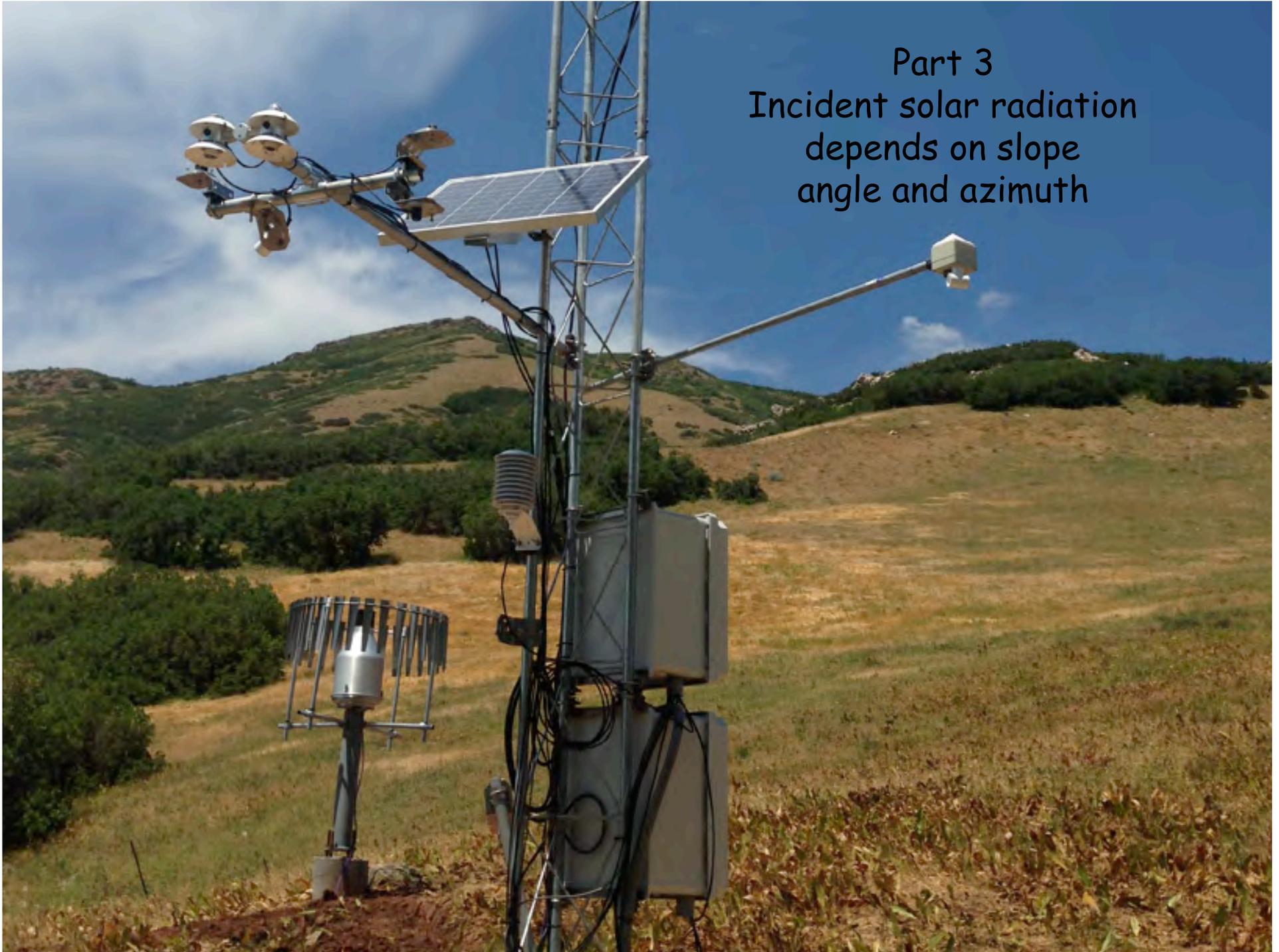
photosynthesis units

2,830 μmol m⁻² s⁻¹
(400 - 700 nm)

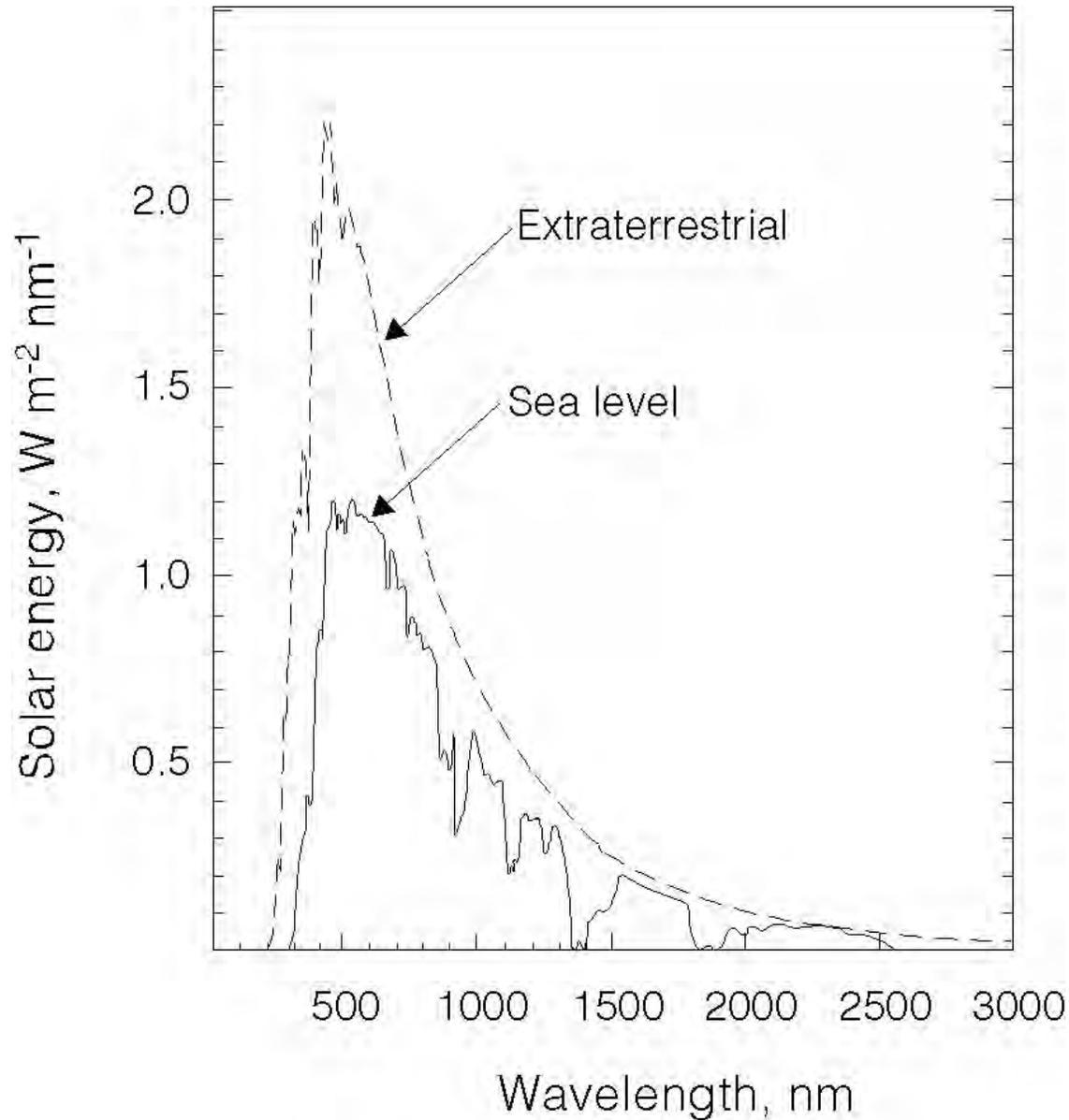
long-wave radiation (terrestrial objects)

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

Part 3
Incident solar radiation
depends on slope
angle and azimuth

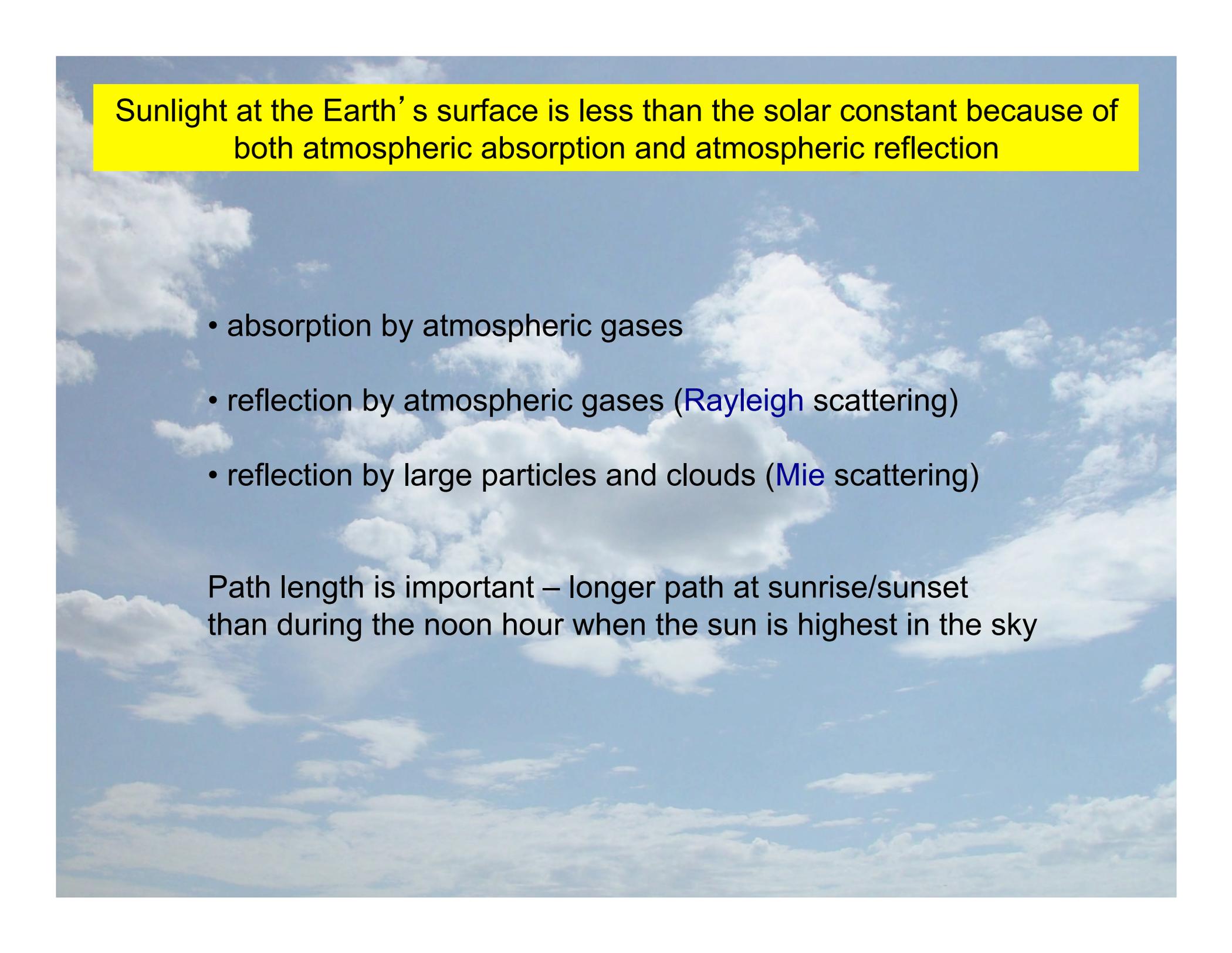


Some solar wavelengths are **absorbed** as photons penetrate the atmosphere



PAR = 400 – 700 nm
photosynthetically active radiation

PPFD =
photosynthetic photon flux density



Sunlight at the Earth's surface is less than the solar constant because of both atmospheric absorption and atmospheric reflection

- absorption by atmospheric gases
- reflection by atmospheric gases (**Rayleigh** scattering)
- reflection by large particles and clouds (**Mie** scattering)

Path length is important – longer path at sunrise/sunset than during the noon hour when the sun is highest in the sky

We calculate the atmospheric influence on sunlight at the Earth's surface

$$I_o = S \cdot \sin(\alpha) \cdot \tau^{1/\sin(\alpha)}$$

I_o = direct sunlight on Earth's surface

S = solar constant

α = solar angle above surface

τ = atmospheric transmission coefficient

First we need to calculate the elevation of the sun above the horizon

latitude

declination

$$\sin(\alpha) = \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\cos(h)$$

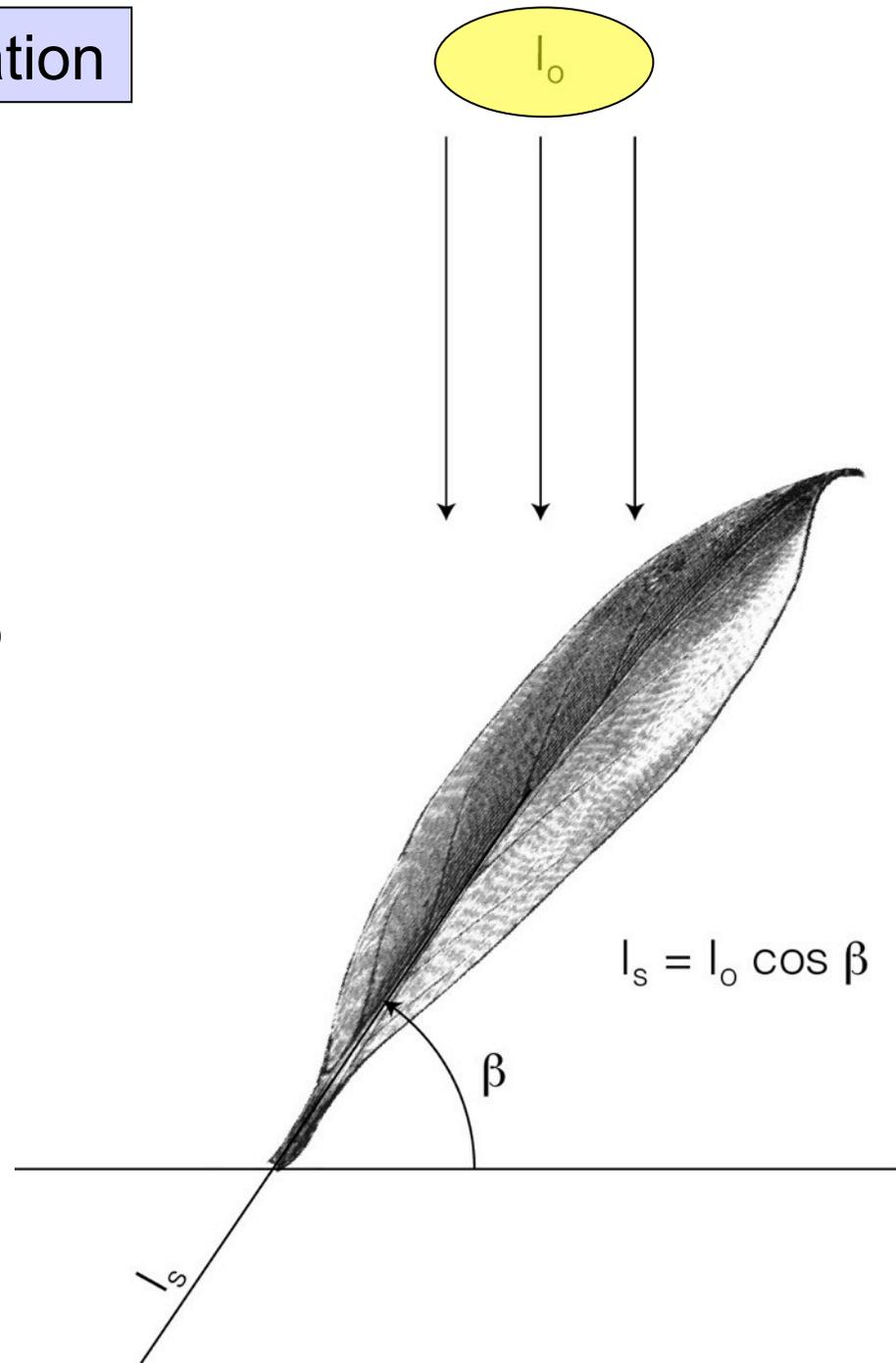
angle of the sun
above horizon

hour angle
during the day

Cosine Law of Illumination

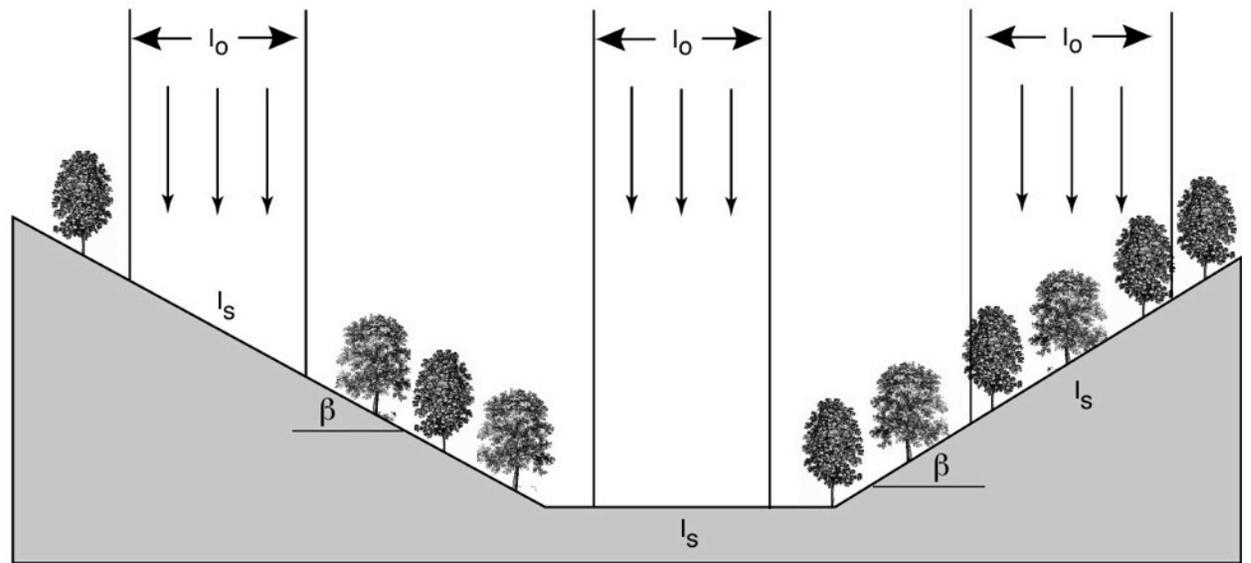
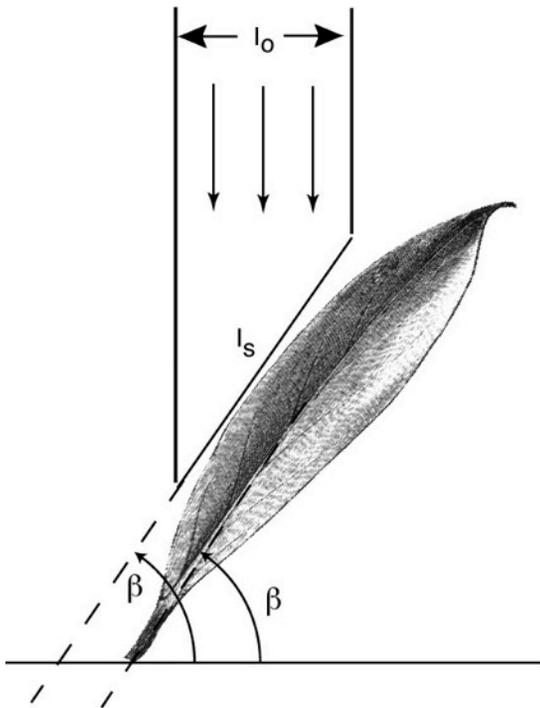
$$I_s = I_o \cos \beta$$

orientation of the
object matters !



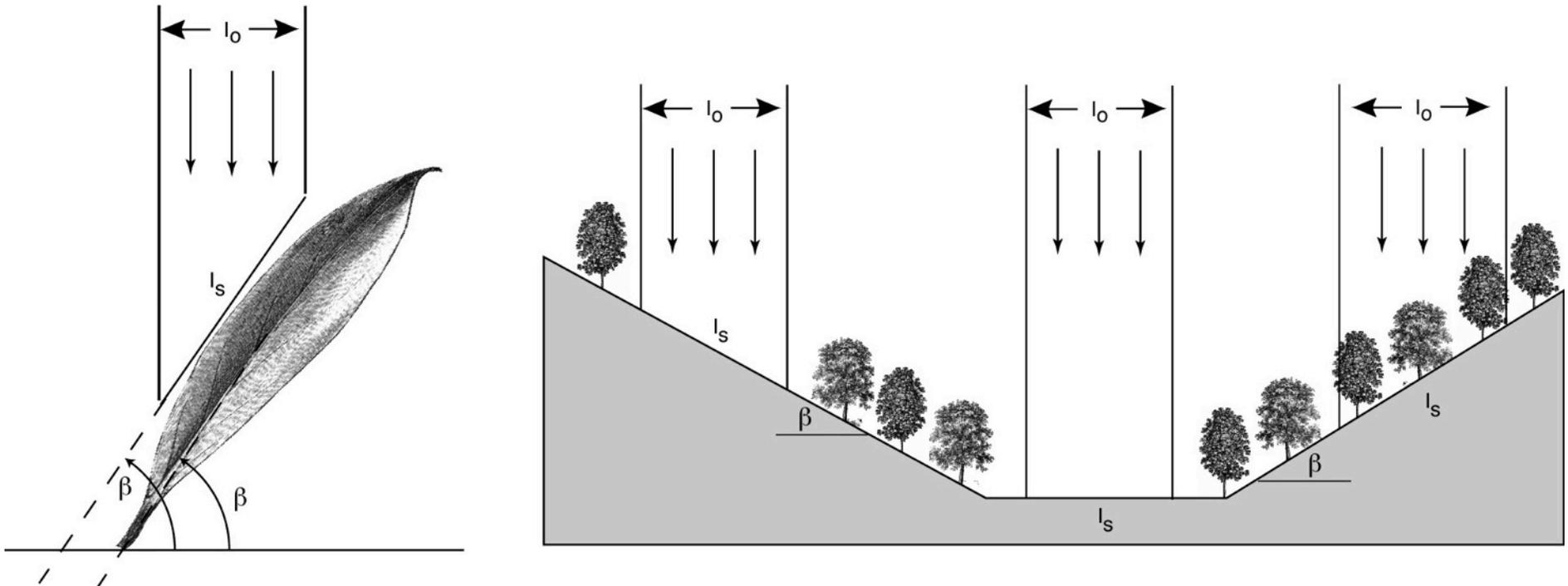
This same cosine relationship applies to hillsides as well as to leaves

$$I_s = I_o \cos \beta$$

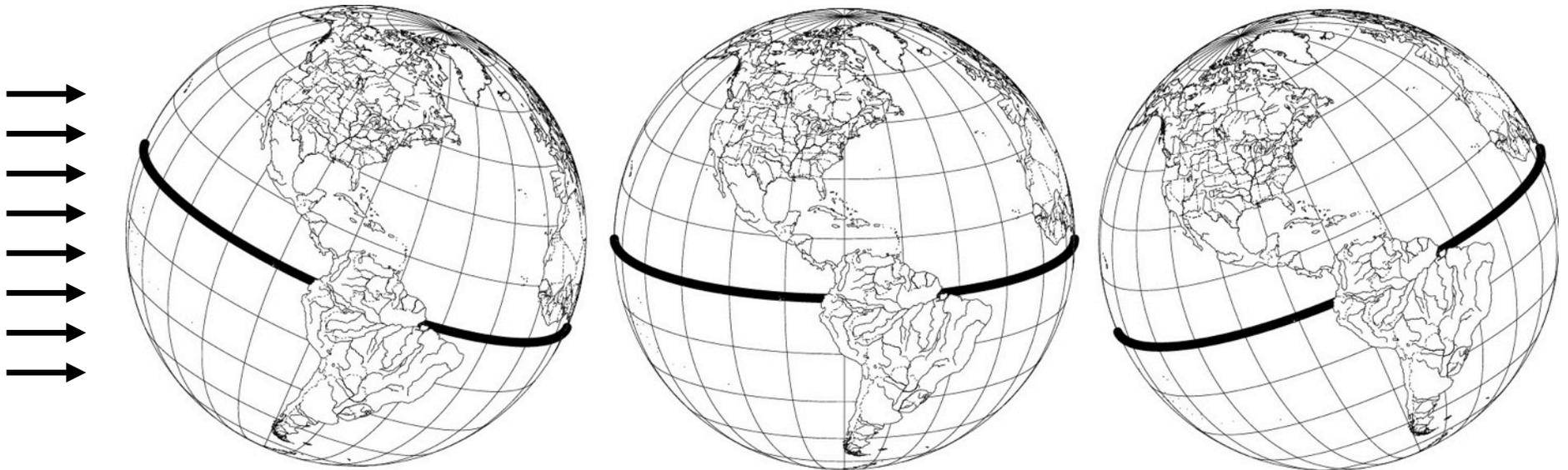


If you are supplied with the flux density of solar radiation measured on a horizontal surface (S_h) (which is how meteorologists report these data), then the flux density incident on a leaf or slope (S_s) will be

$$S_s = S_h \cdot \cos(i) / \sin(\alpha)$$

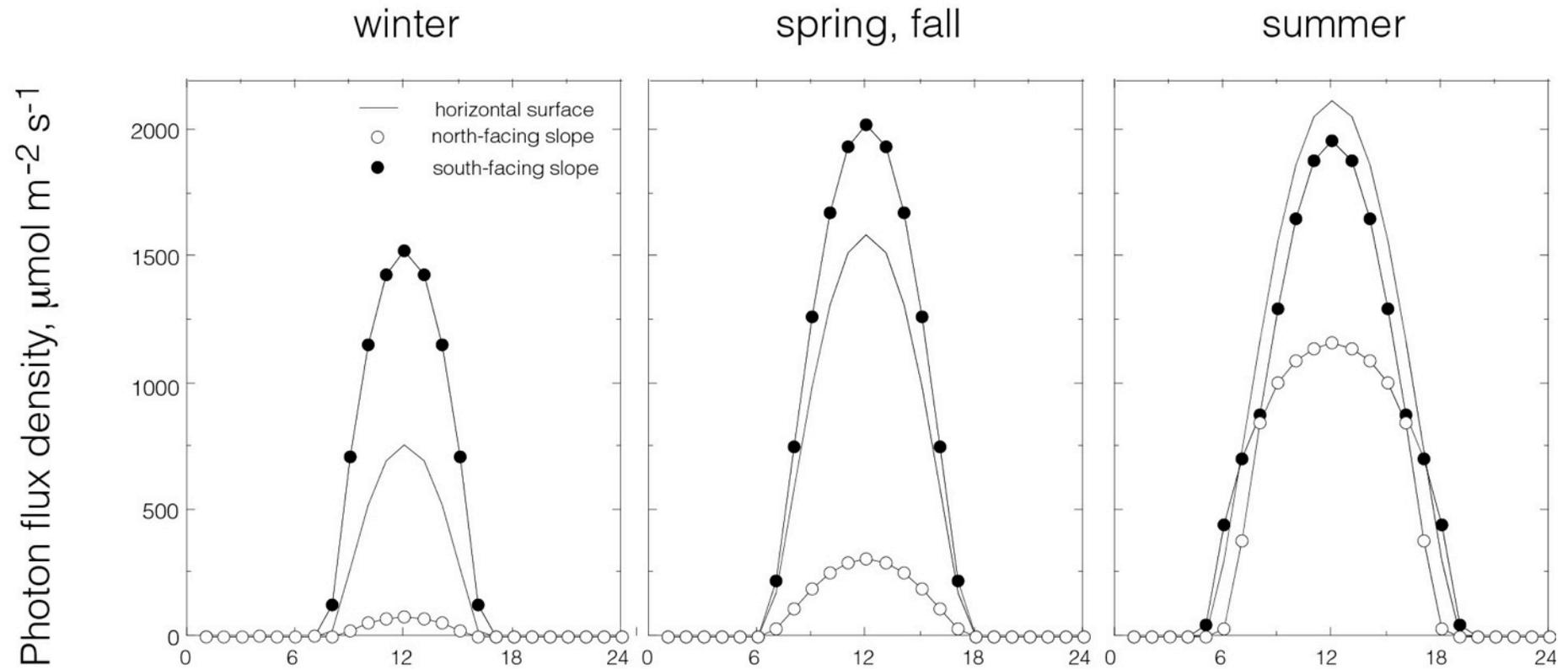


The interplay of surface and declination influence the incident solar radiation levels and energy balance of specific locations



Recall that declination varies from -23.5° to $+23.5^\circ$

Slope orientation has a significant influence on incident sun light
... and many other processes (incl. heating and evaporation)



Total daily photons (400-700 nm) in mol m⁻² day⁻¹ received on different slopes in Salt Lake City during different seasons

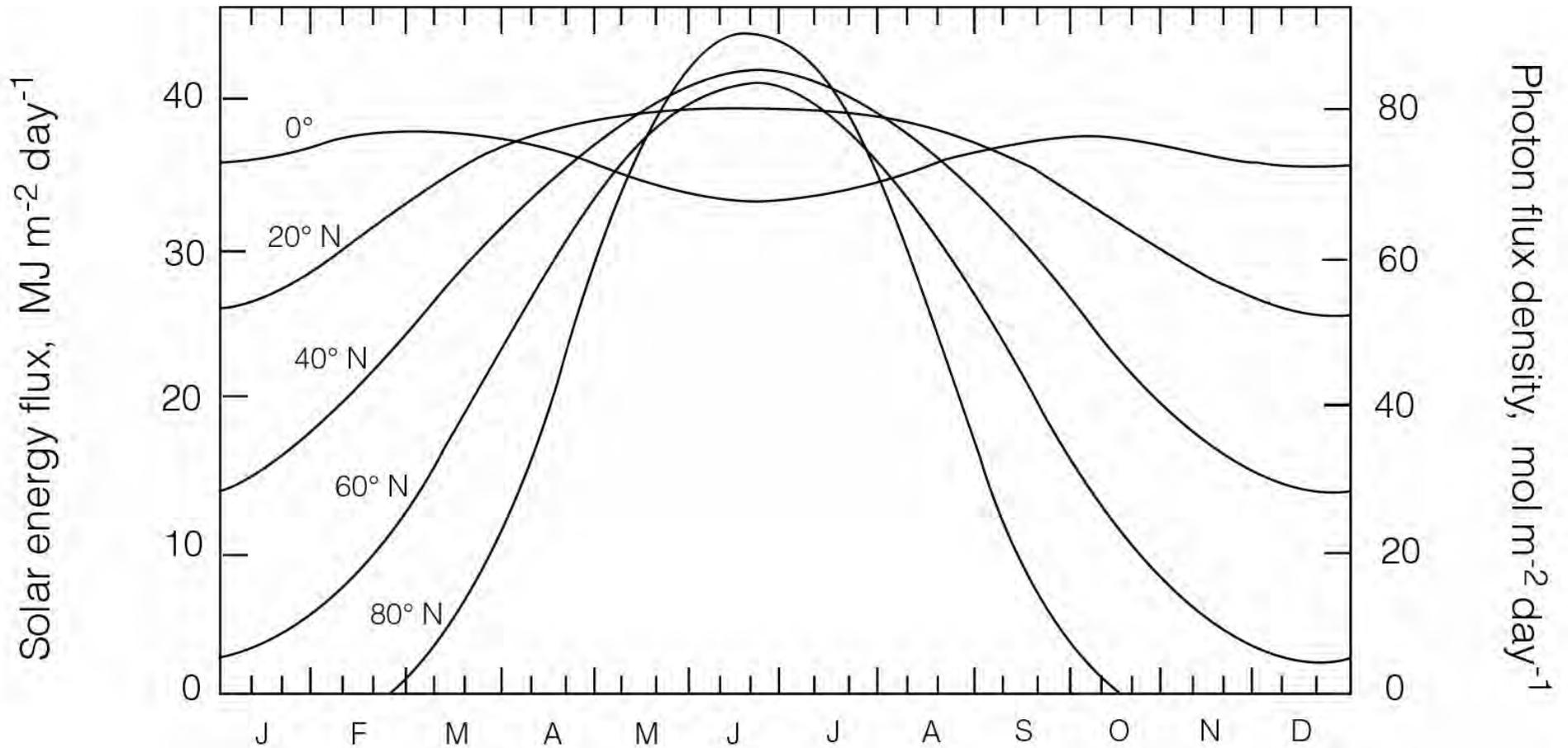
	winter solstice	equinox	summer solstice
horizontal surface	16.2	43.5	68.9
south facing, 45°	38.4	56.6	61.9
north facing, 45°	0.0	4.9	36.5
east facing, 45°	14.3	36.3	55.1
west facing, 45°	14.3	36.3	55.1

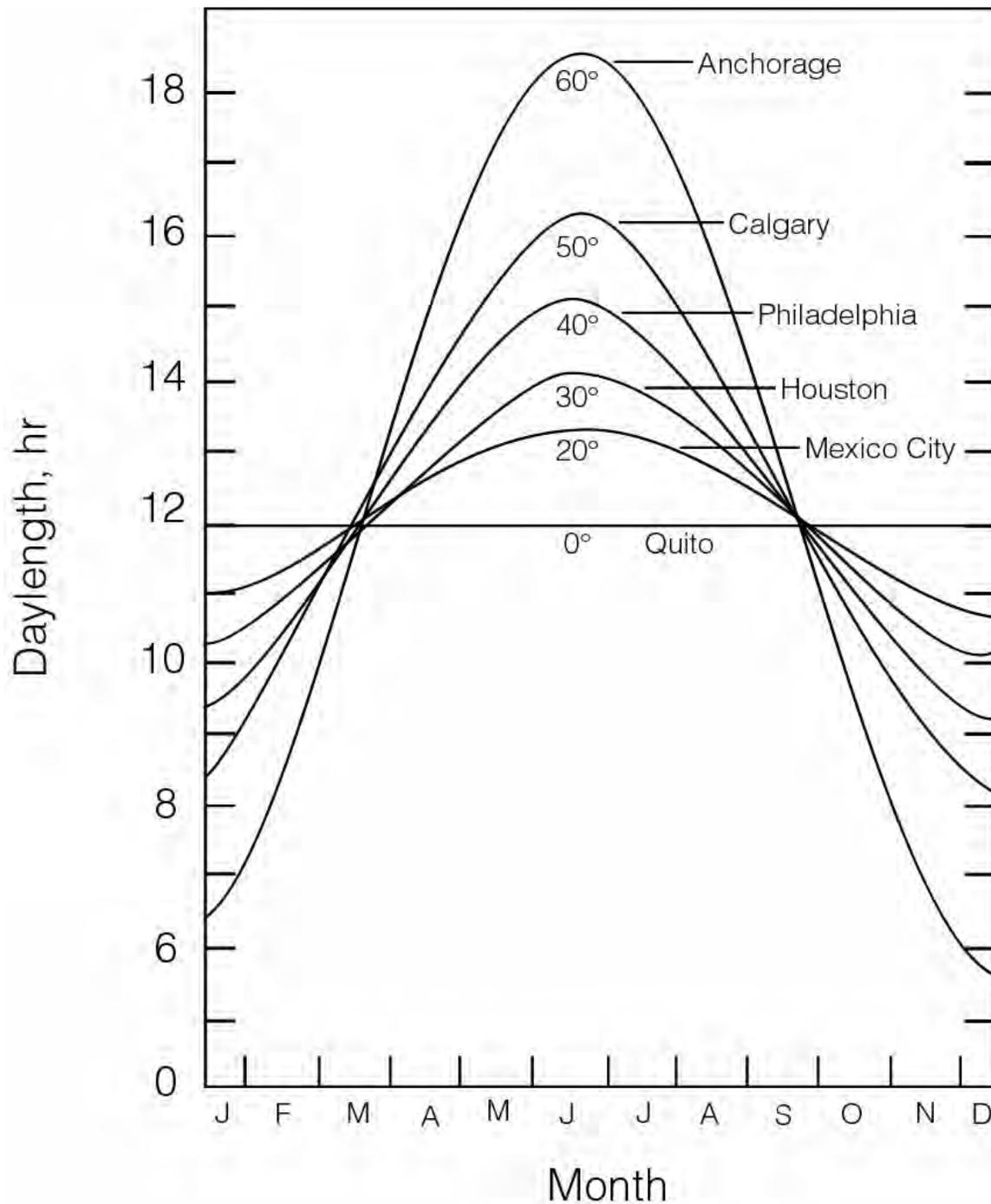


These changes in slope orientation influence soil heating and also influence flowering times (days after March 1)

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

If we integrate the total solar energy flux incident at specific latitudes, we see strong annual patterns and latitudinal differences





Changes in solar declination also influences:

day length - duration of the sun above the horizon

photoperiod - light to dark period in 24 h

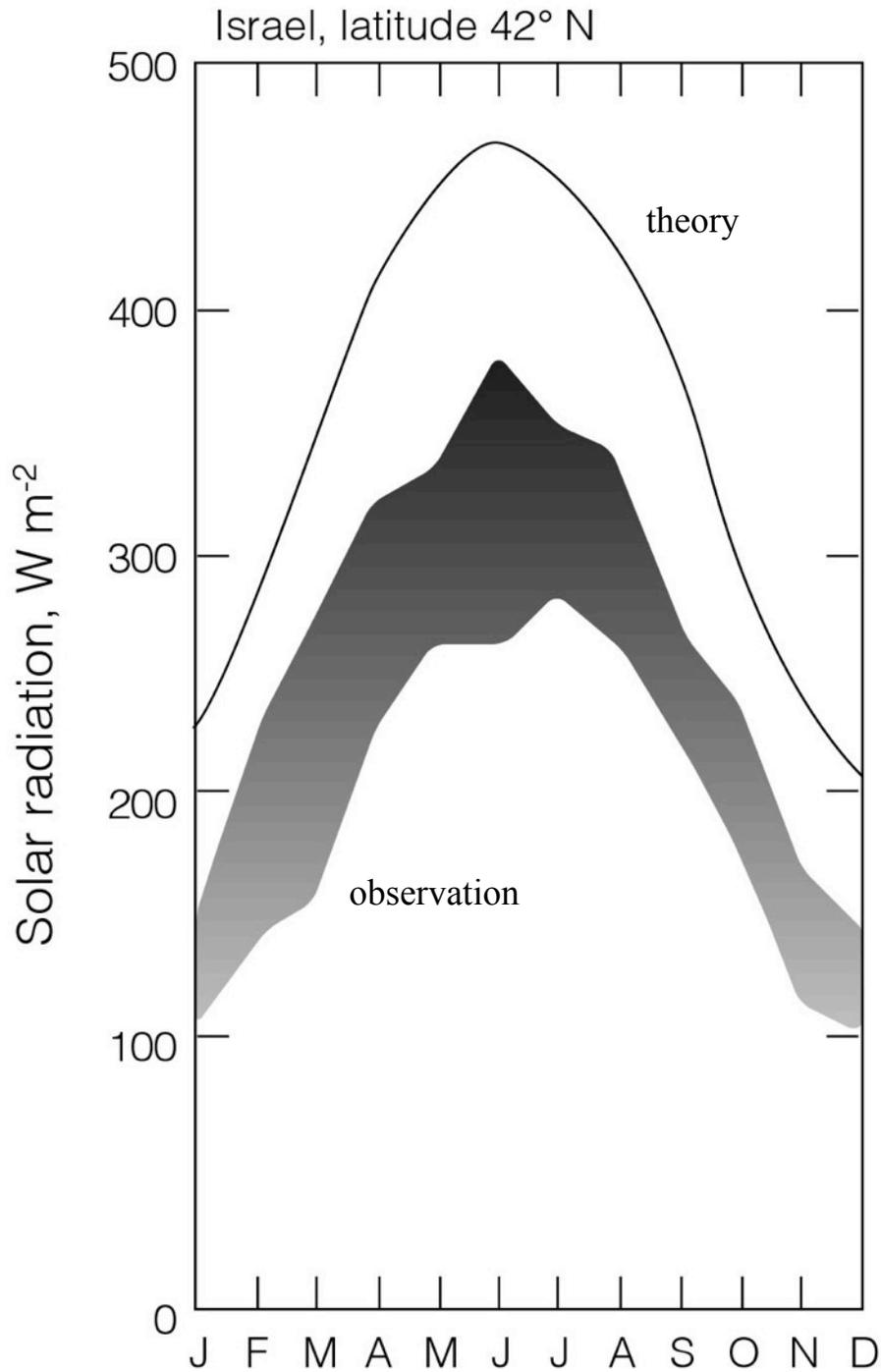
Note: only at the equator day length is 12 h

For those interested in the calculation ...

$$\Lambda = 2 \cos^{-1}(-\tan(\phi) \tan(\delta)) / 15$$



day length
in hours



Most regions of the world experience cloudiness, reducing the incident sun light below the theoretical values

... including Israel which is largely desert

“Compass” plants



Lactuca serriola



Silphium laciniatum

Notice that some leaf orientations might actually reduce the incident sun light received during the midday period

winter
declination = -23°
 $0^\circ = 14.5 \text{ mol m}^{-2}$
 $75^\circ = 23.4 \text{ mol m}^{-2}$

spring
declination = 0°
 $0^\circ = 42.0 \text{ mol m}^{-2}$
 $75^\circ = 37.5 \text{ mol m}^{-2}$

summer
declination = 23°
 $0^\circ = 68.9 \text{ mol m}^{-2}$
 $75^\circ = 43.5 \text{ mol m}^{-2}$

