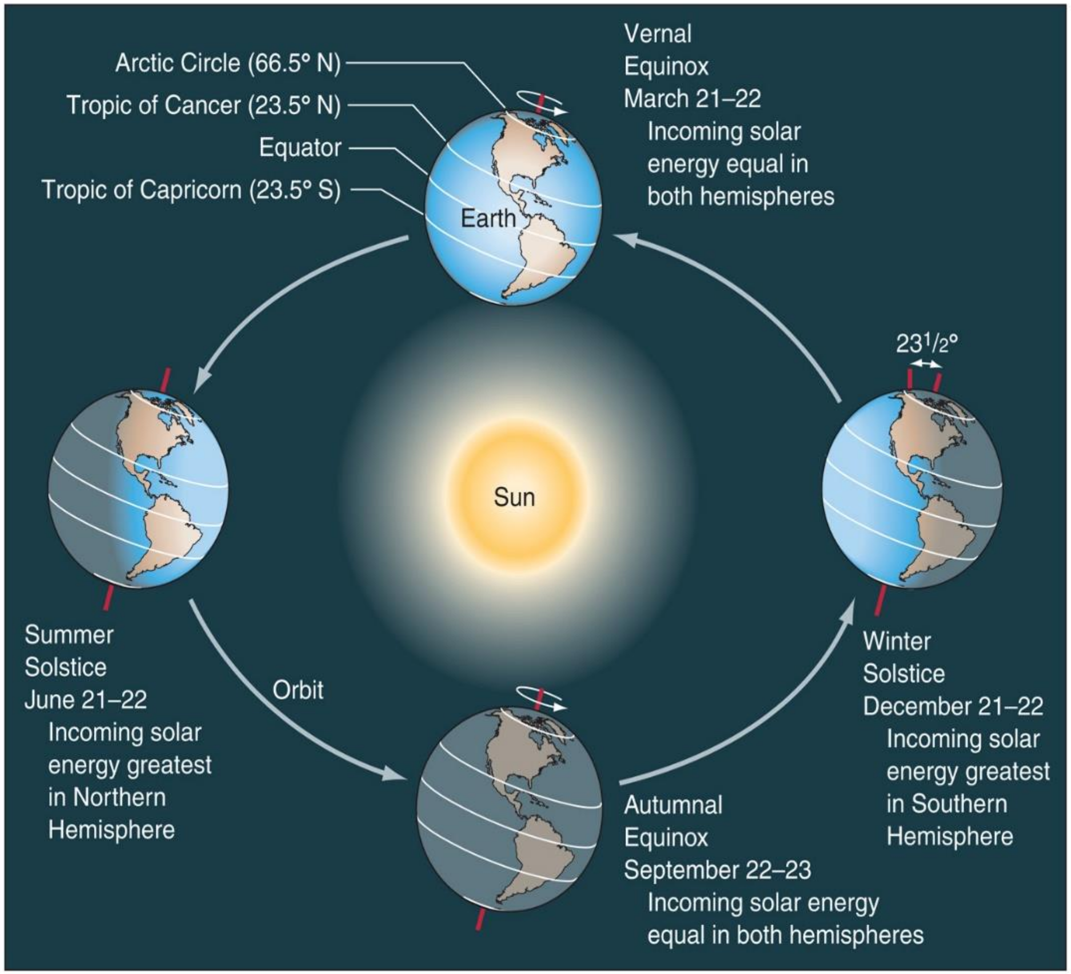
Solar Radiation and Environmental Biophysics

Geo 827, MSU
Jiquan Chen
Oct. 6, 2015

1) Solar radiation basics
2) Energy balance
3) Other relevant biophysics
4) A few selected applications of RS in ecosystem studies

1) Fundamental solar radiation



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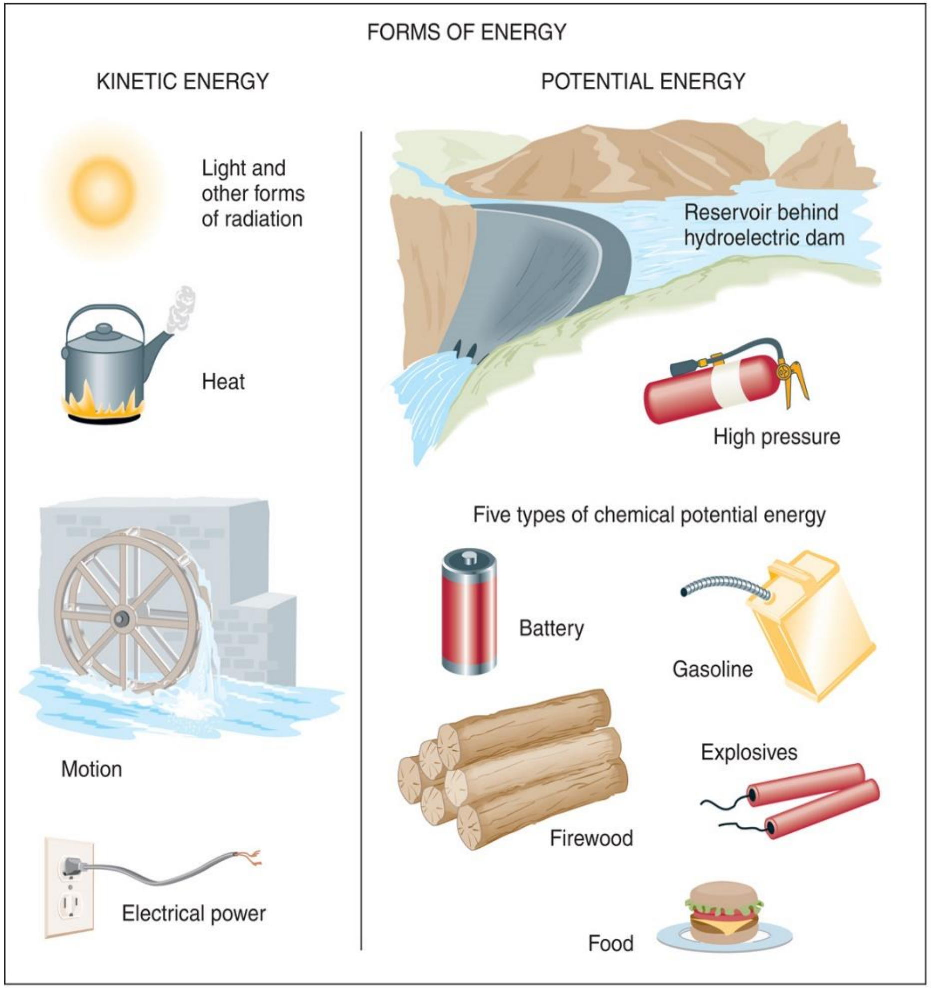
Atmospheric Science Group
Department of Geosciences
Texas Tech University

On Oct. 5, Slides 2-x were downloaded from http://www.atmo.ttu.edu/bancell/

1) Fundamental solar radiation

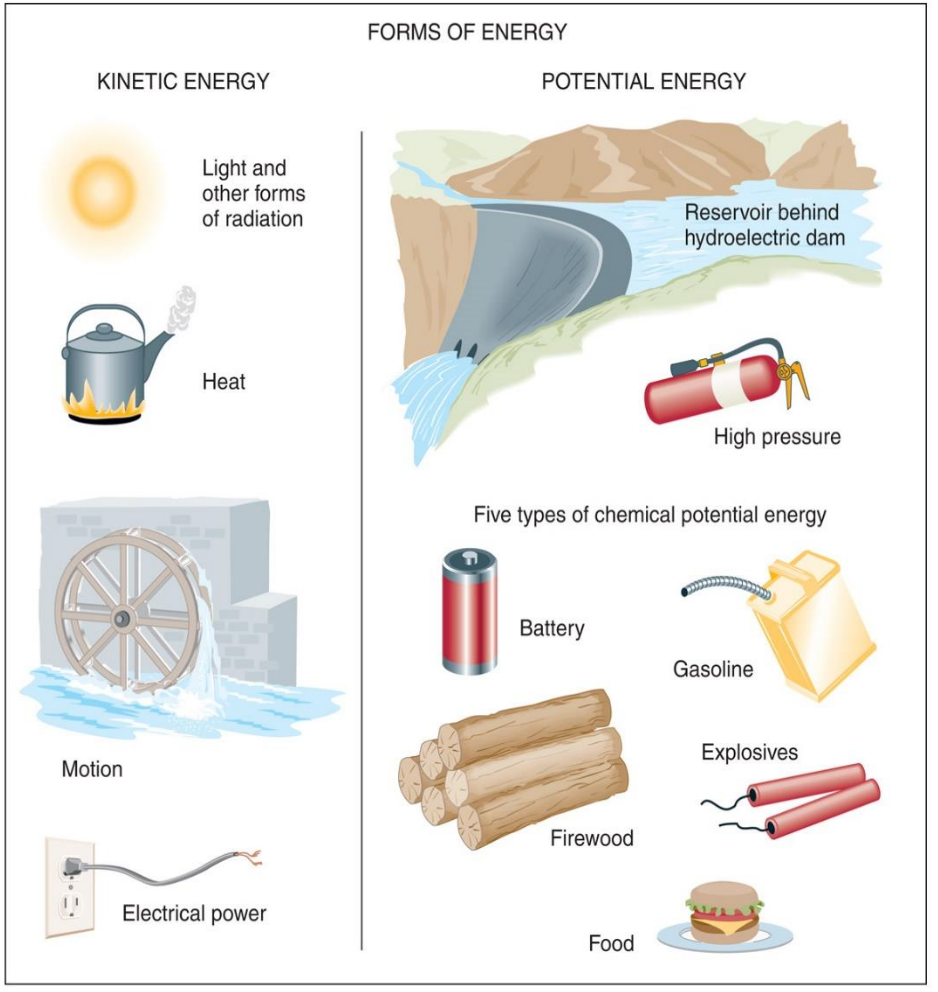
- **Energy** is defined as the ability to do work



Energy

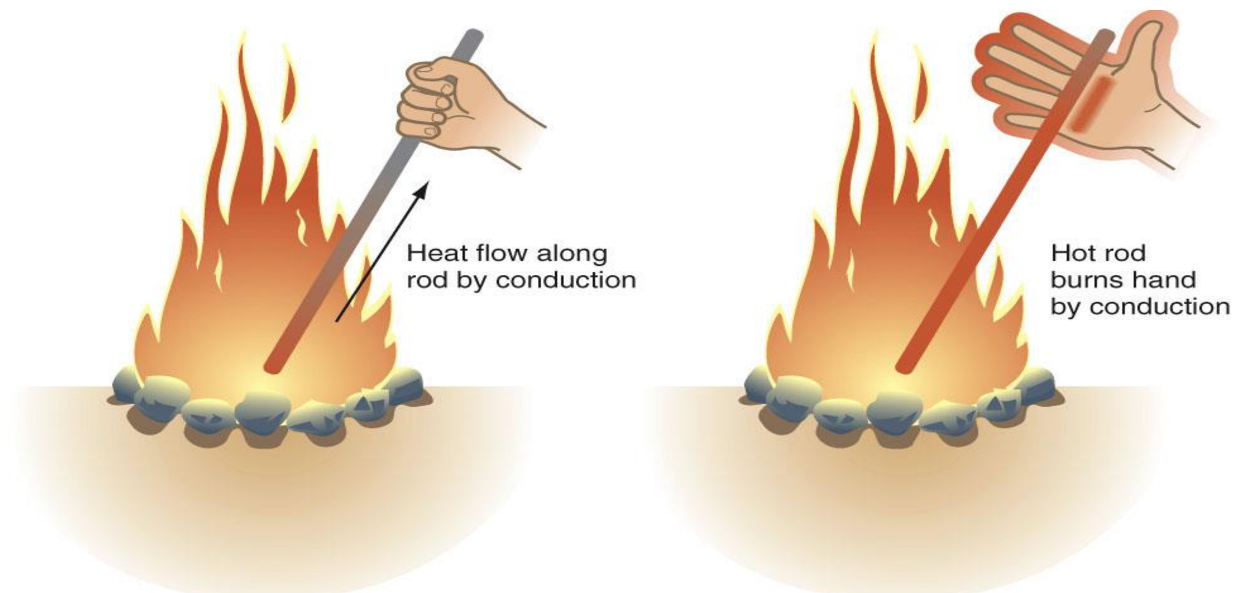
- **Energy** is defined as the ability to do work
  - **Kinetic energy** – the energy of motion
  - **Potential energy** – energy that can be used

- Energy is conserved!
(1st law of thermodynamics)



Energy Transfer

- Although energy is conserved, it can move through the following mechanisms:
  1) **Conduction** – heat transfer by physical contact, from higher to lower temperature



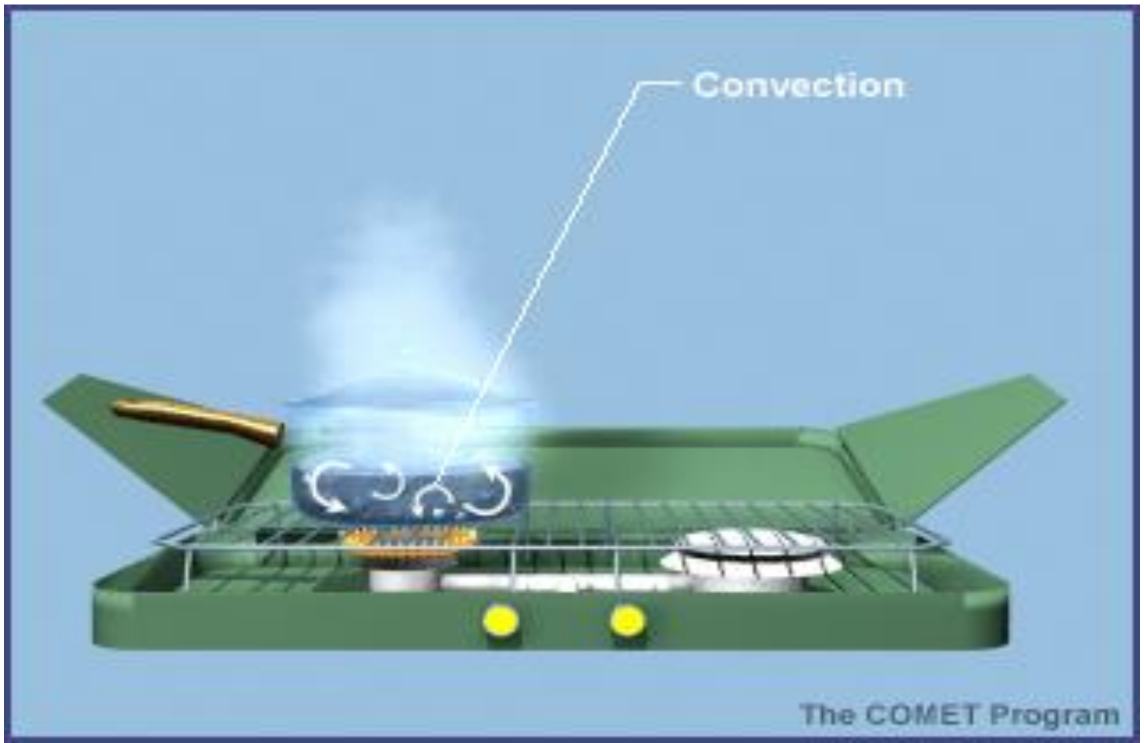
Conduction in the Atmosphere

- Occurs at the atmosphere/surface interface
    - Partly responsible for daytime heating/nighttime cooling! (The diurnal cycle)

Energy Transfer

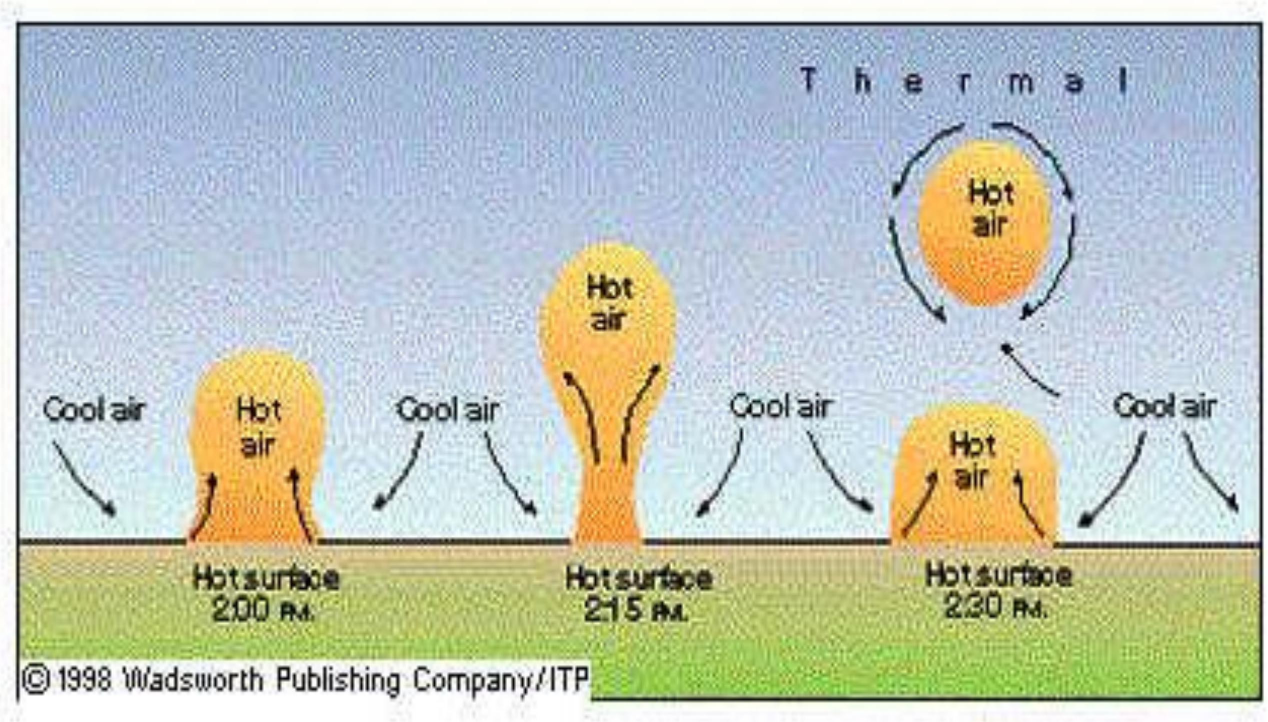
- Although energy is conserved, it can move through the following mechanisms:

2) **Convection** – heat transfer by movement



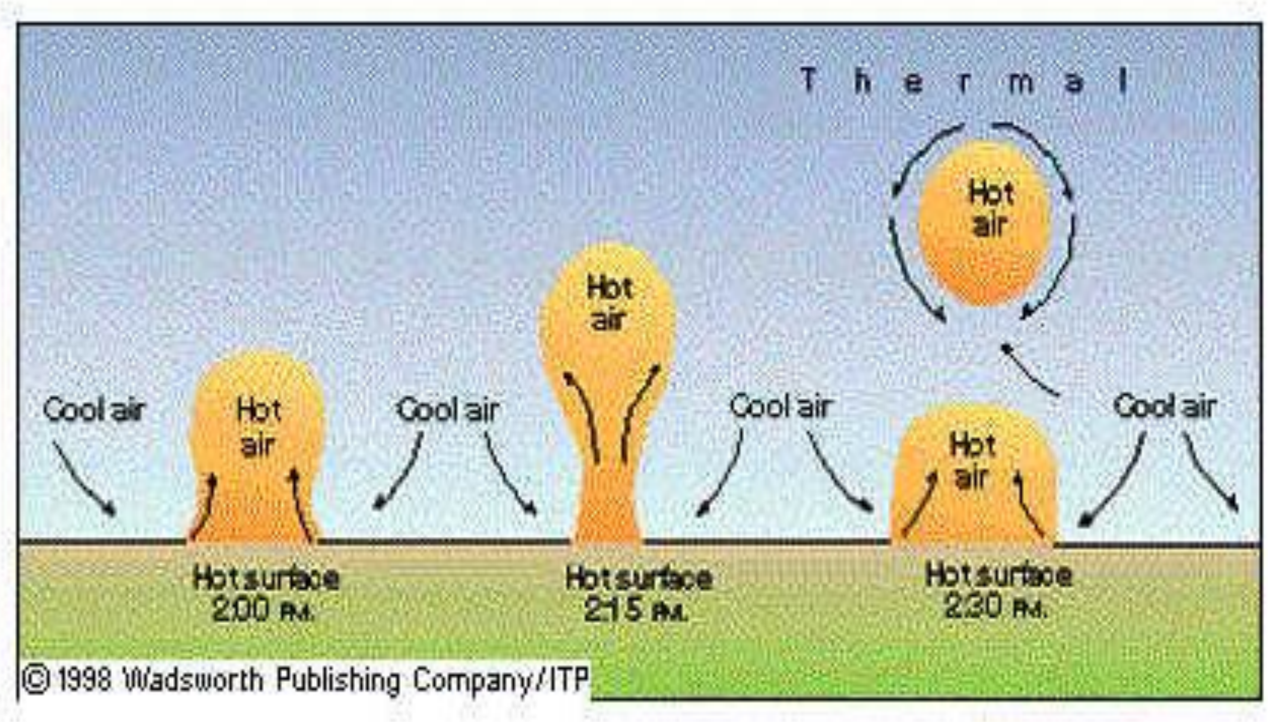
Convection in the Atmosphere

- Vertical transport of heat



Convection in the Atmosphere

- Vertical transport of heat



- Horizontal transport of heat = **advection**

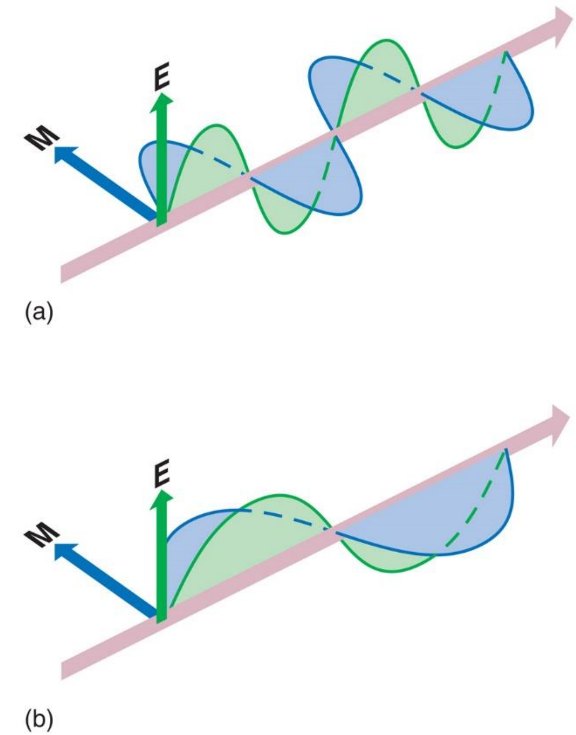
Convection in the Atmosphere

Courtesy maltaweather.info

Energy Transfer

- Although energy is conserved, it can move through the following mechanisms:

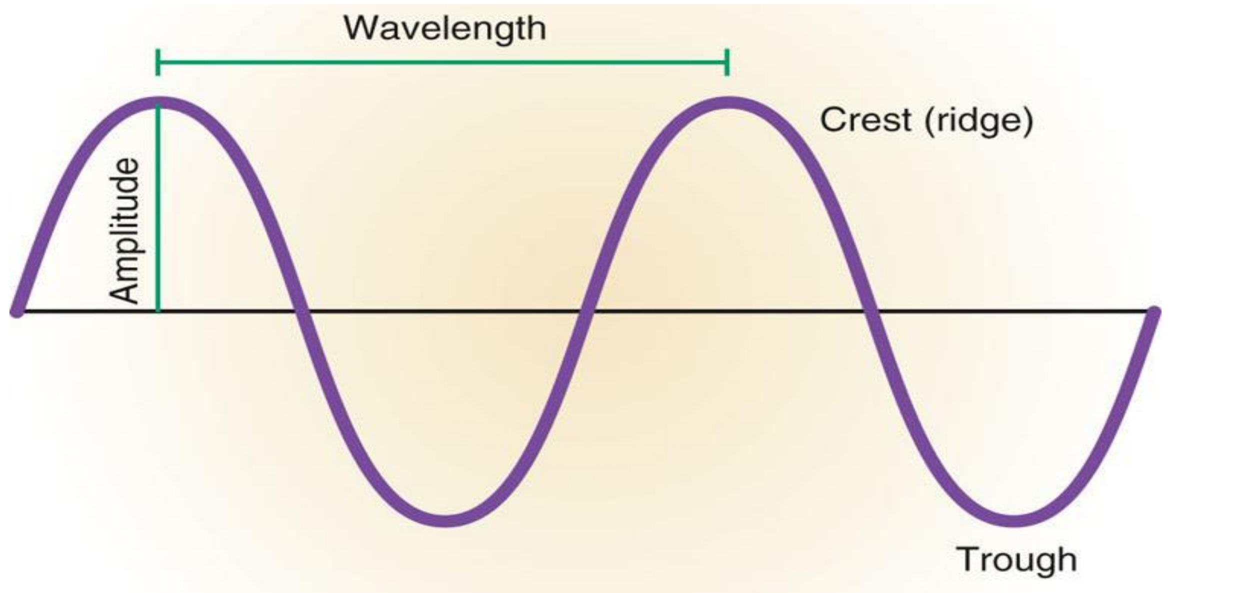
3) **Radiation** - transfer of energy by electromagnetic radiation (no medium required!)



Radiation

<u>Characteristics of radiation</u>

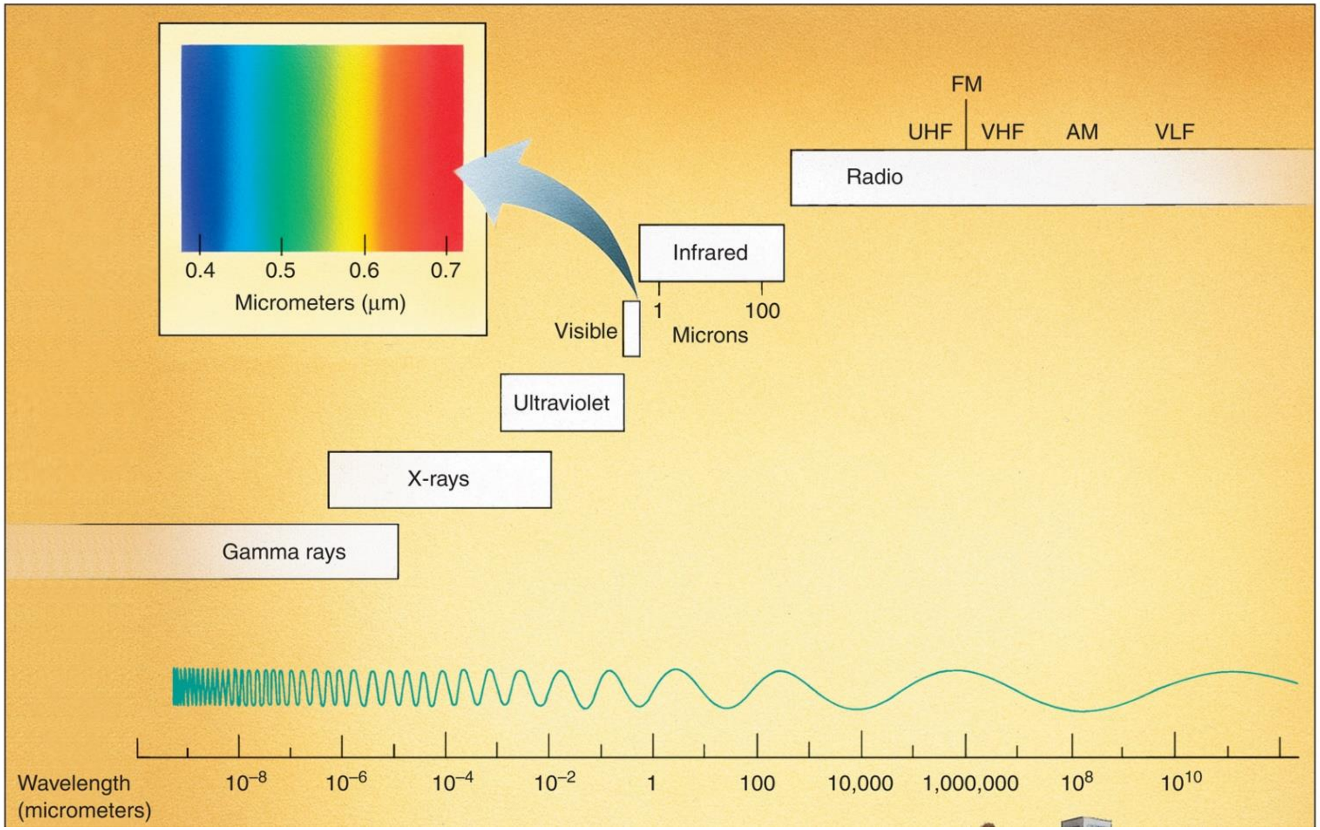
1) **Wavelength** – the distance between wave crests



2) **Amplitude** – the height of the wave
3) Wave speed – constant! (speed of light - 186,000 miles/second)

Radiation

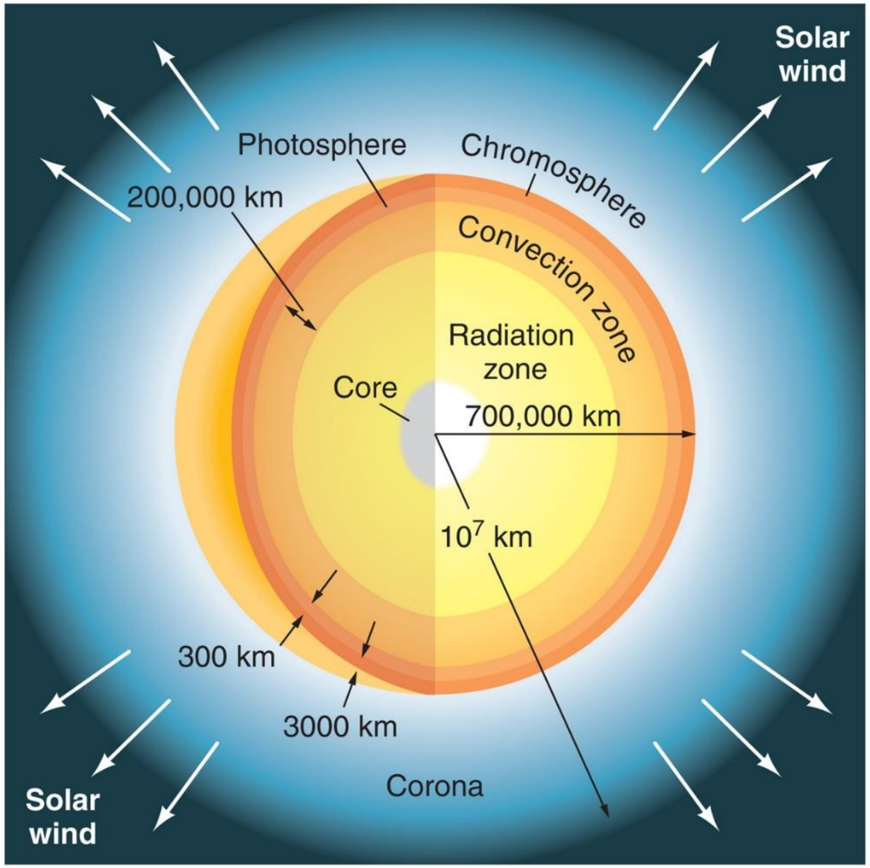
- The wavelength of radiation determines its type

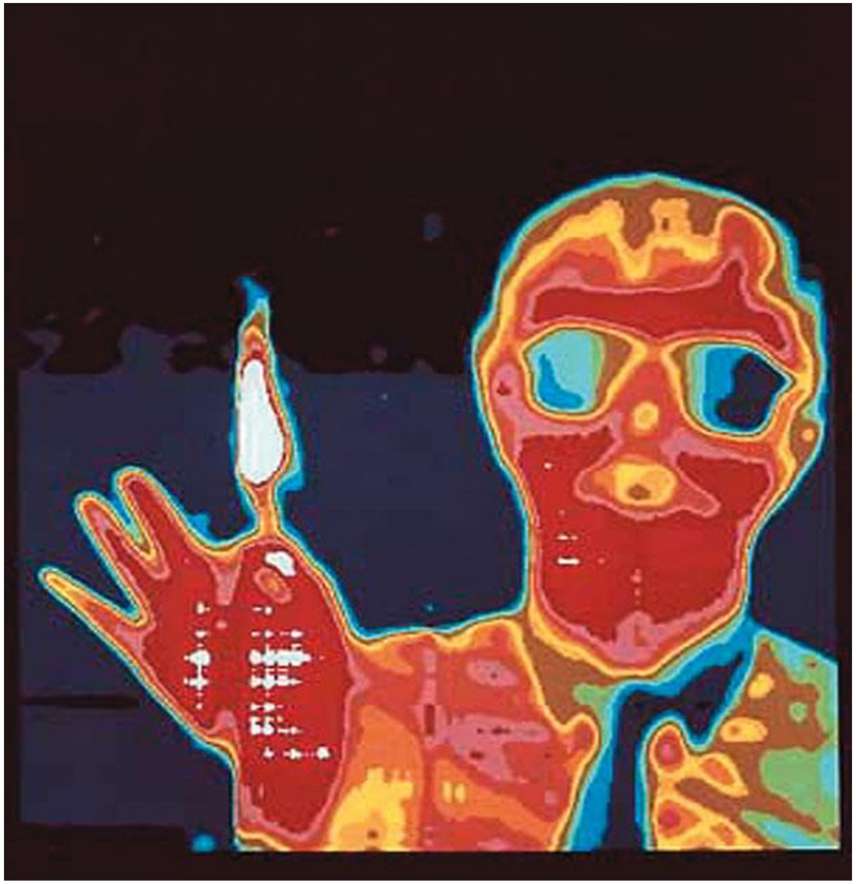


- The amplitude determines the intensity

Radiation

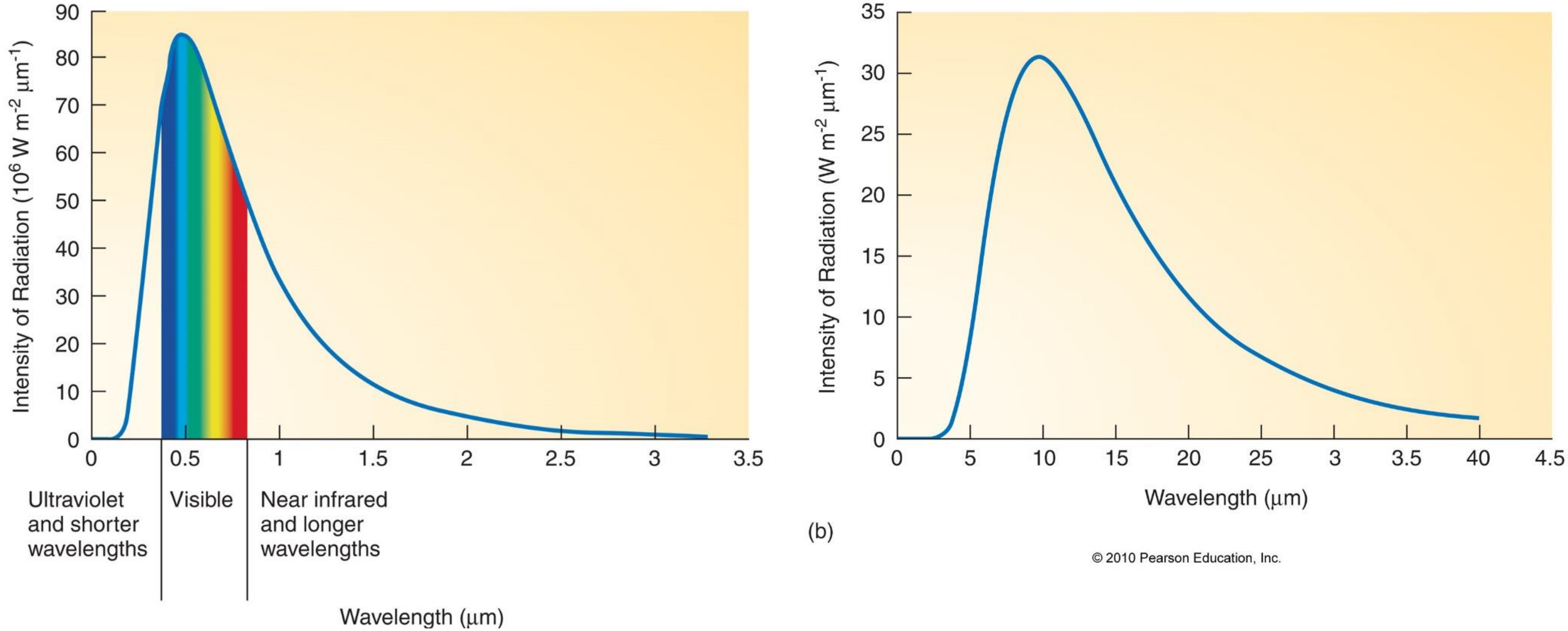
- What emits radiation? EVERYTHING!!





Radiation

- The types (wavelengths) and intensity (amplitudes) of radiation depend on temperature



Sun is HOT (~10,000ºF)

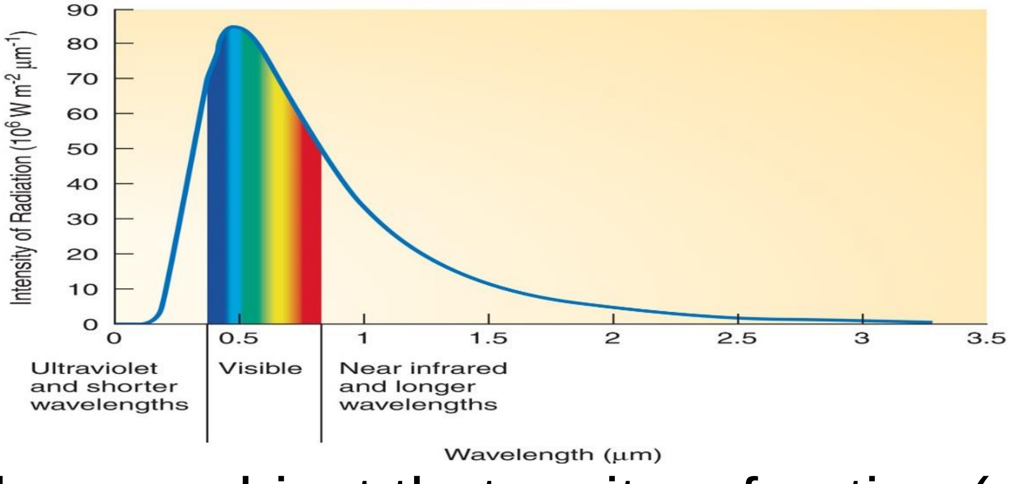
Shortwave radiation

Earth is NOT (~59ºF)

Longwave radiation

Radiation

- **Blackbody** – an object that absorbs all radiation and emits the maximum amount of radiation at every wavelength (not realistic)



- **Graybody** – an object that emits a fraction (**emissivity**) of blackbody radiation (more realistic)
- Total radiation emitted is equal to the sum over all wavelengths above

Radiation Laws

- **Stefan-Boltzmann Law** – the total amount of blackbody radiation emitted (I) is related to temperature:

$$\mathbf{I = \sigma T^4}$$

Radiation Laws

- **Stefan-Boltzmann Law** – the total amount of blackbody radiation emitted (I) is related to temperature:

$$\mathbf{I = \sigma T^4}$$

- For a graybody, this becomes:

$$\mathbf{I = \varepsilon\sigma T^4}$$

where ε is the emissivity

Radiation Laws

- **Wien's Law** – the wavelength of maximum blackbody emission is related to temperature:

$$\mathbf{\lambda_{max} = 2900/T}$$

Radiation Laws

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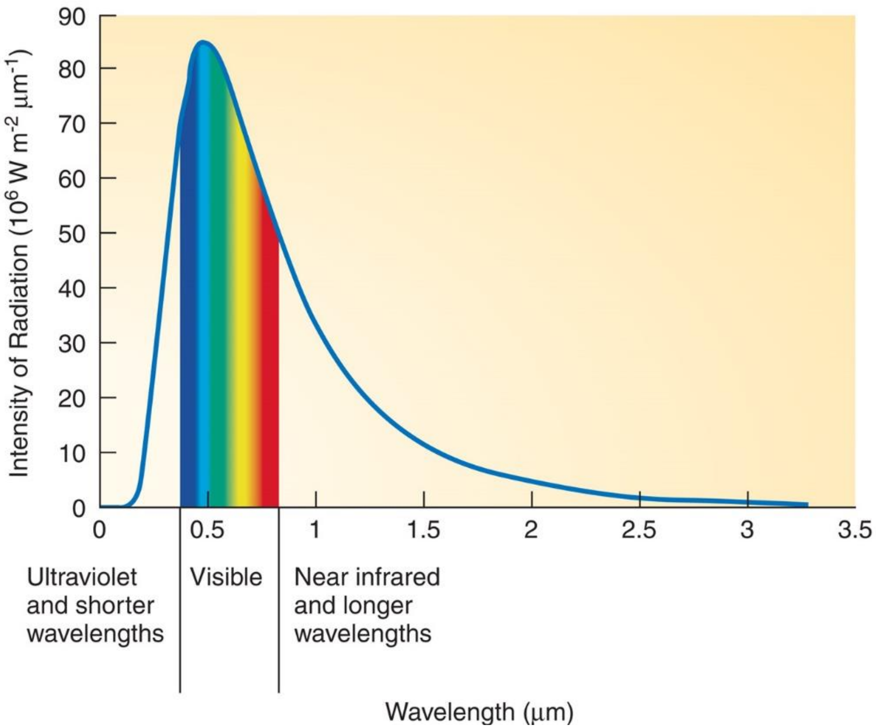
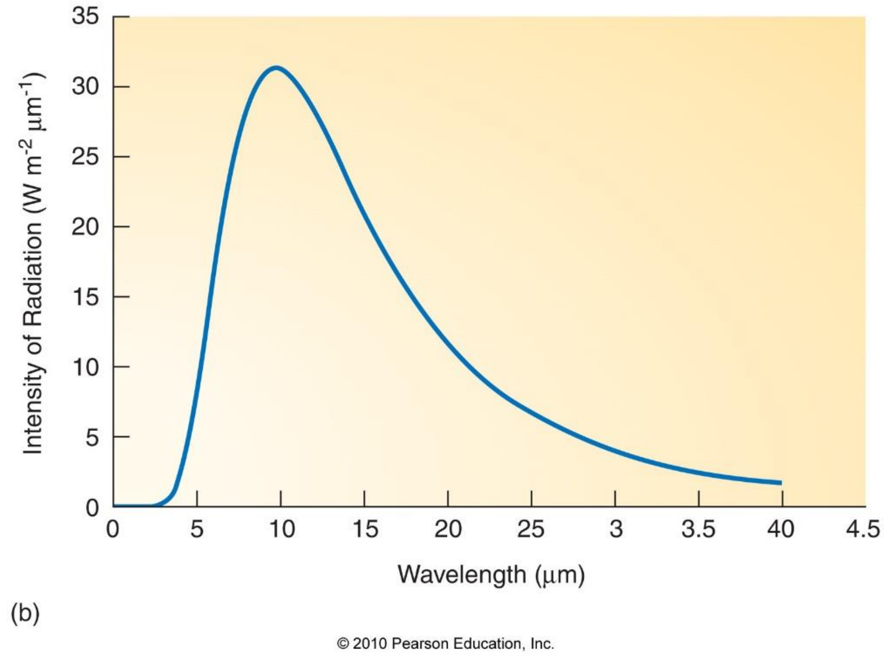
$$\lambda_{max} = 2900/T$$

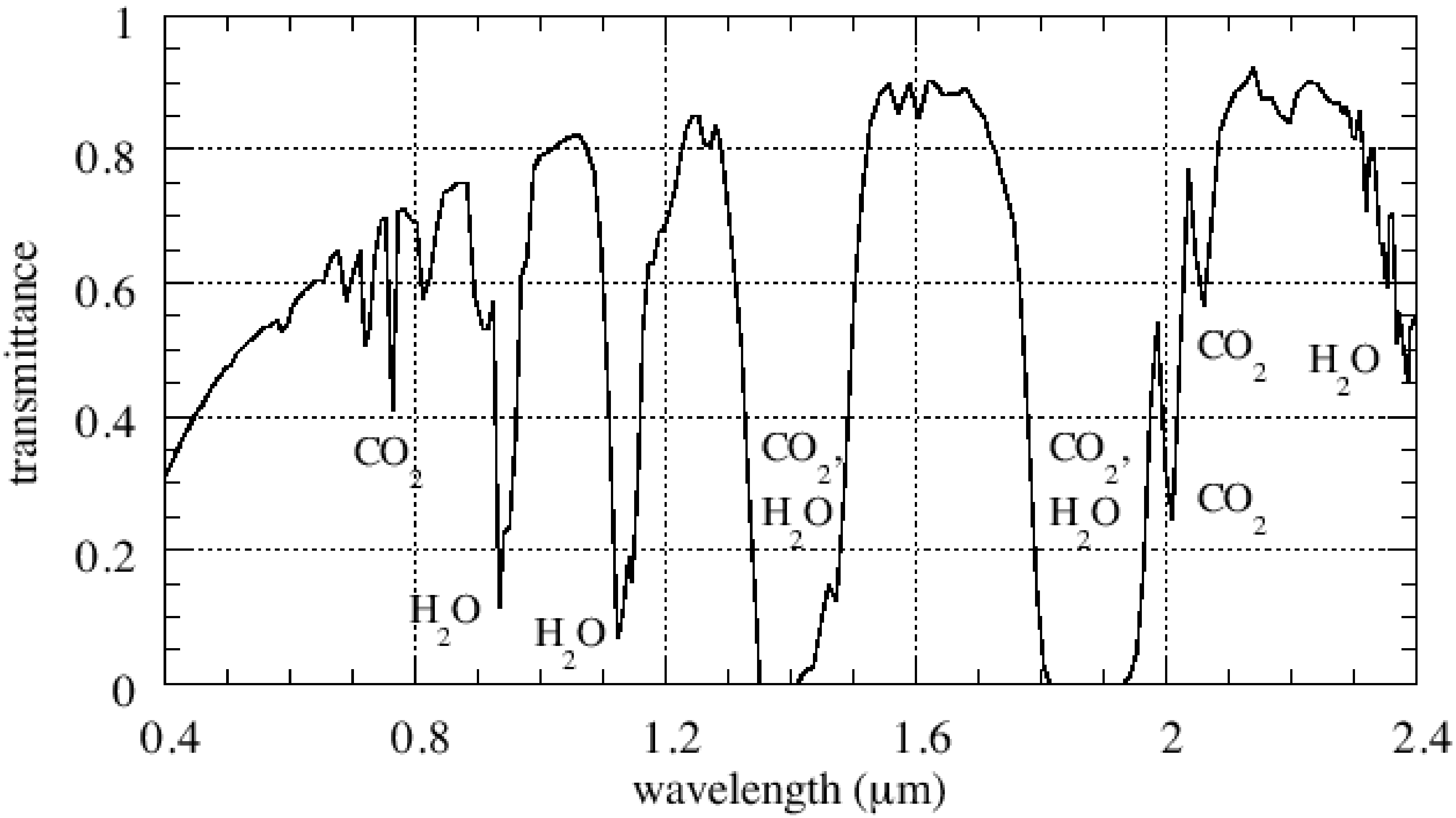


Sun is HOT (~6000K)



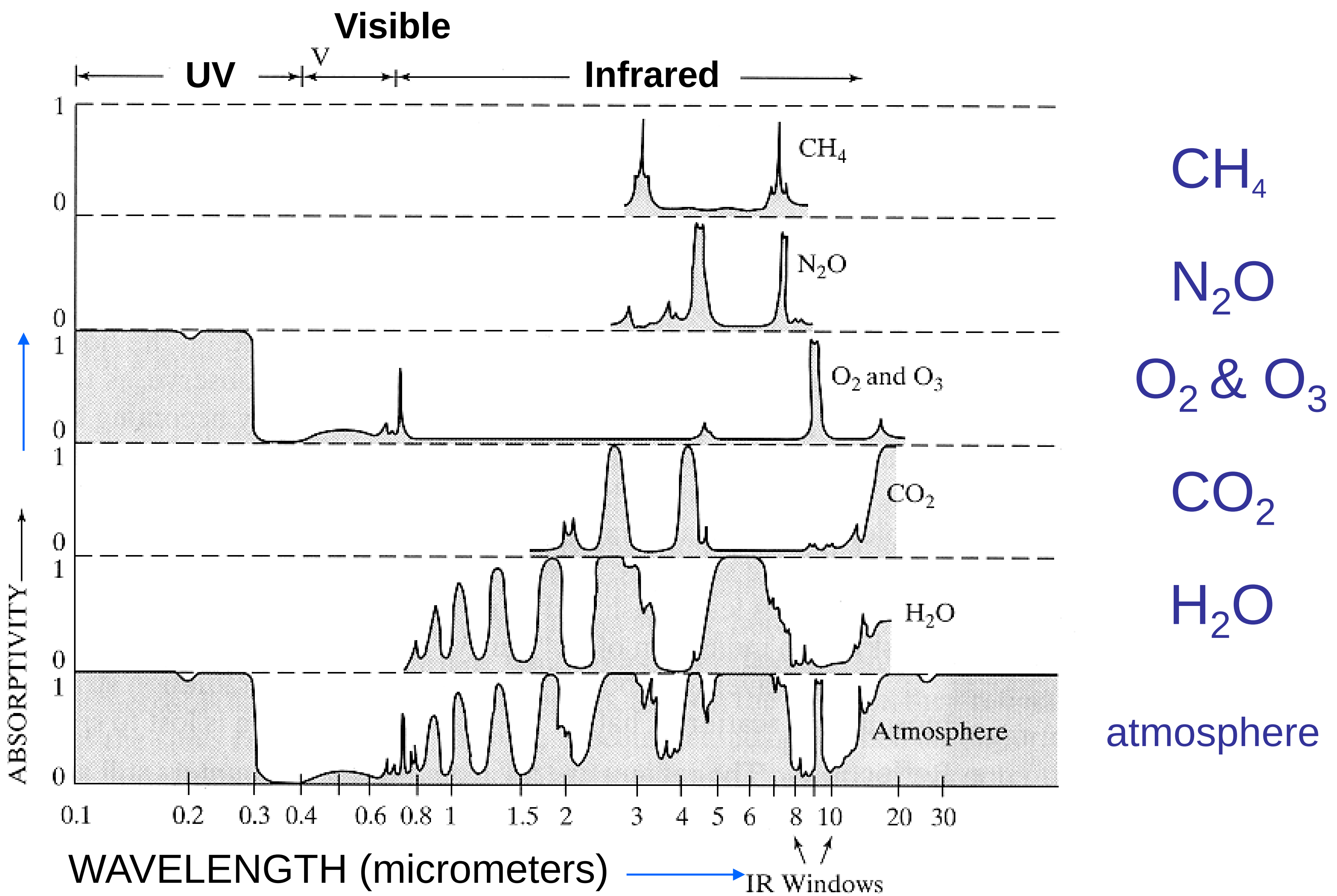
Earth is NOT (~290 K)

Typical atmospheric transmittance in VIS-SWIR



From Schowengerdt book

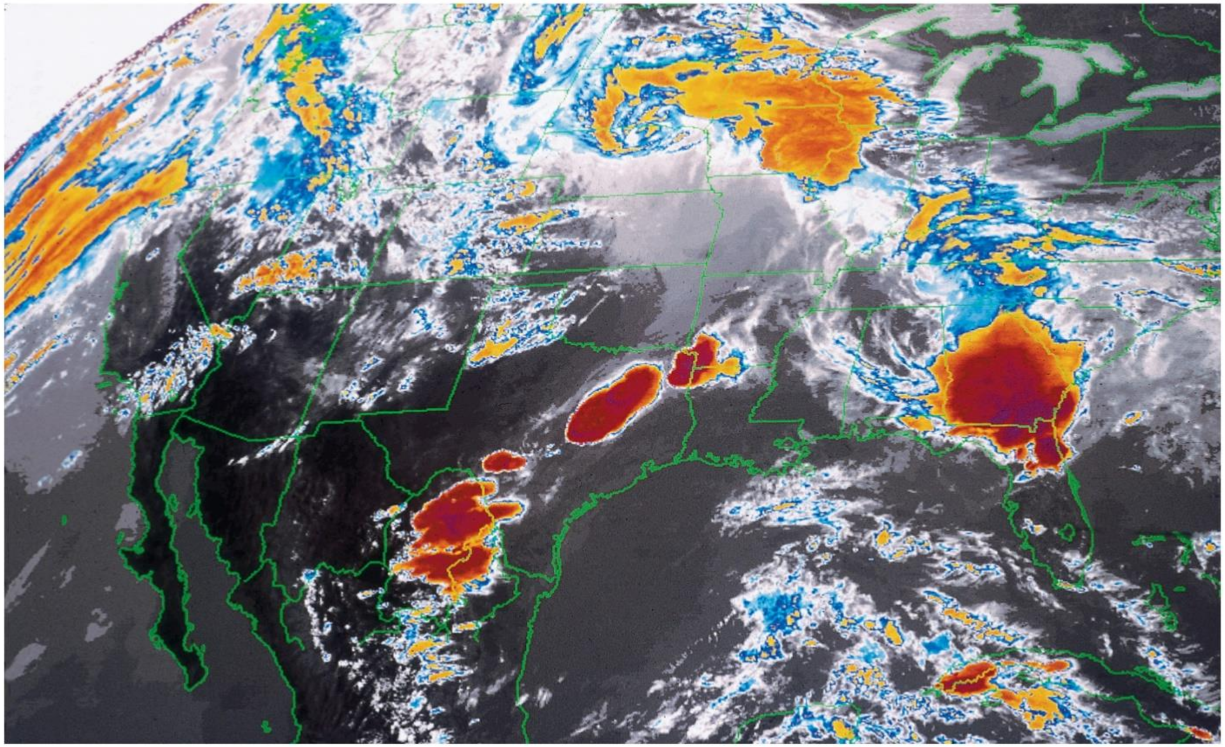
Absorption Spectra of Atmospheric Gases



Anthes, p. 55

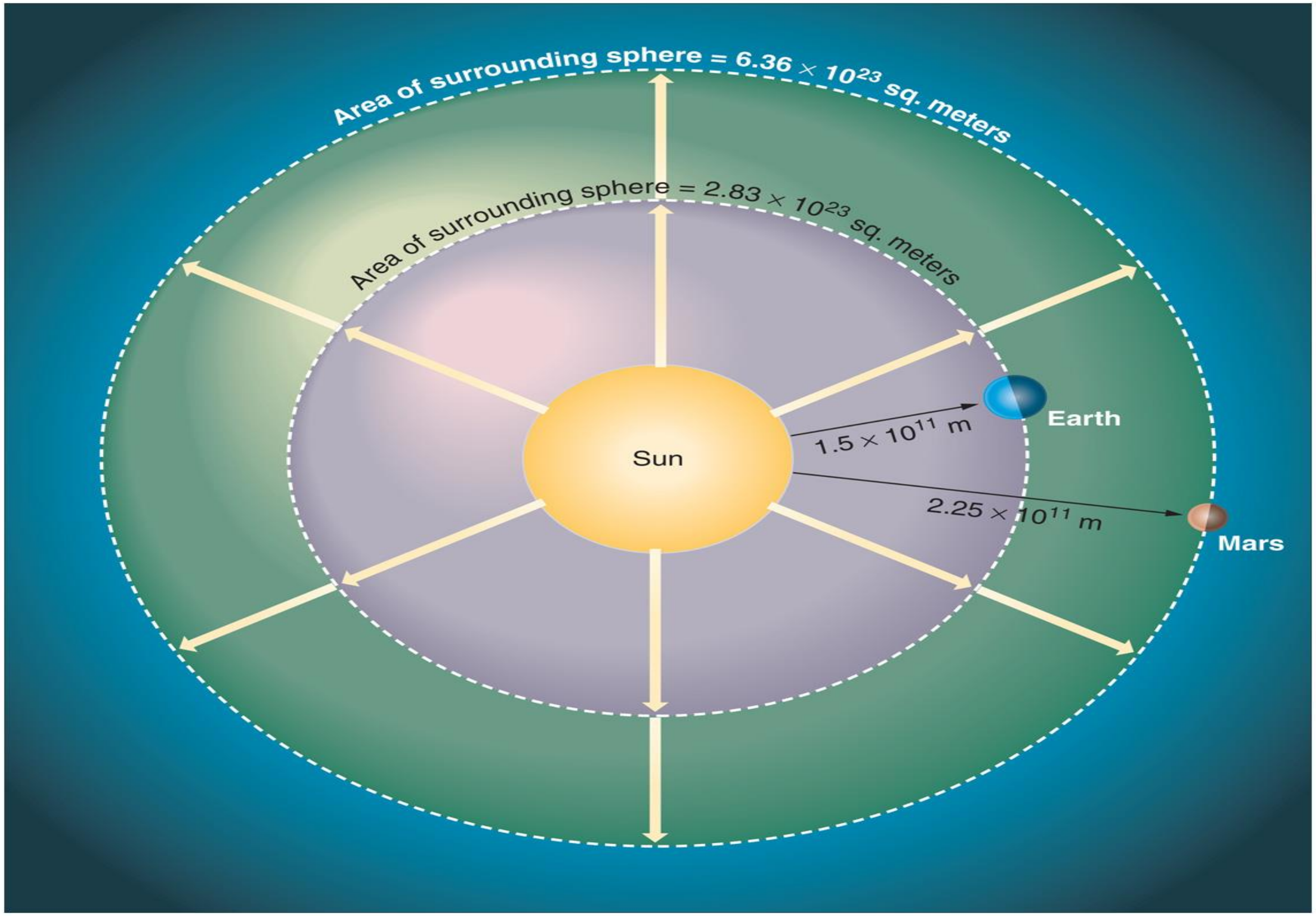
Practical use of Radiation Properties

- Visible satellite imagery doesn't work in the dark
- Infrared (longwave) radiation occurs always – use infrared satellite imagery!



Solar Radiation and the Earth

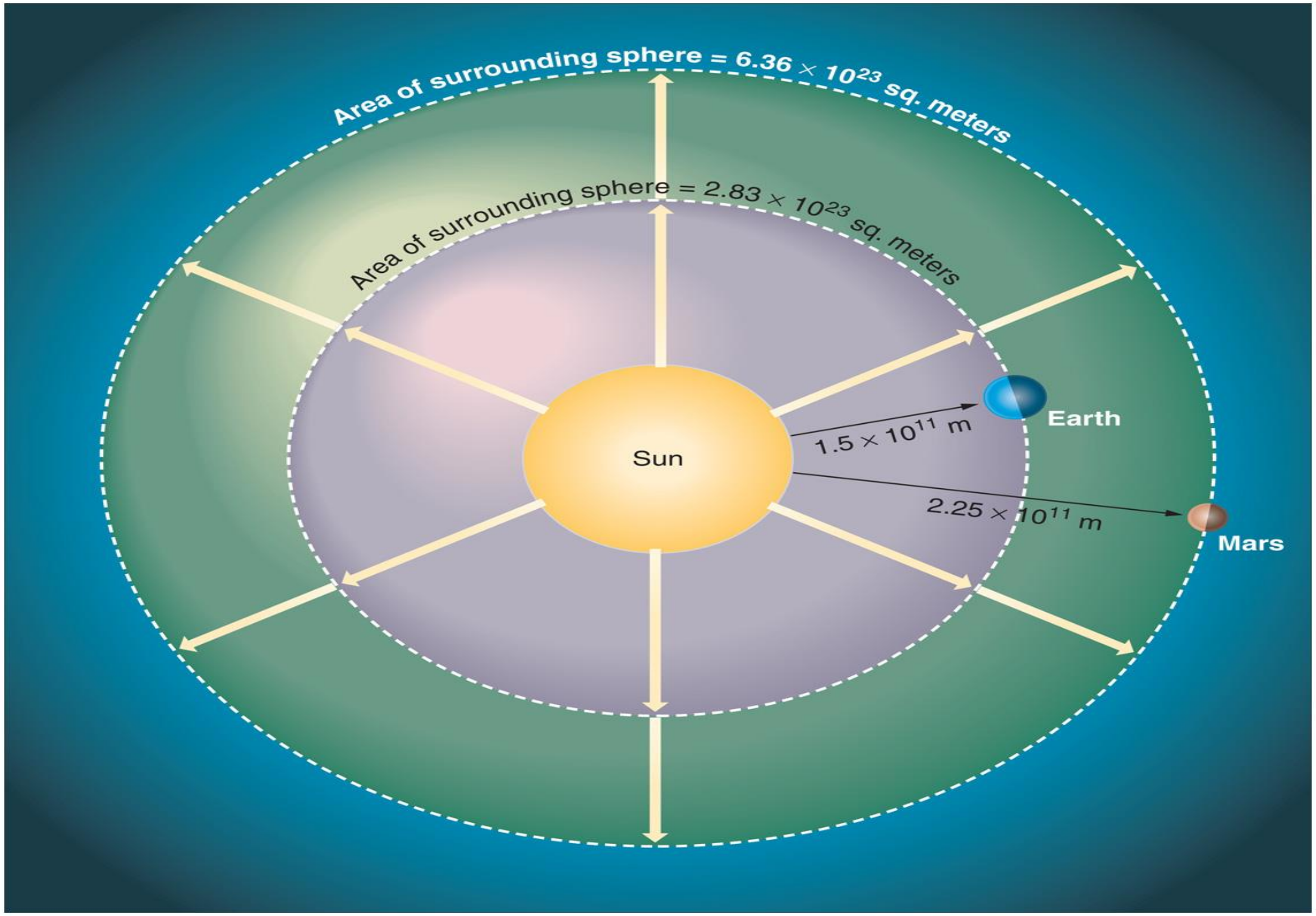
- The solar constant – the amount of solar radiation hitting the earth



Solar Radiation and the Earth

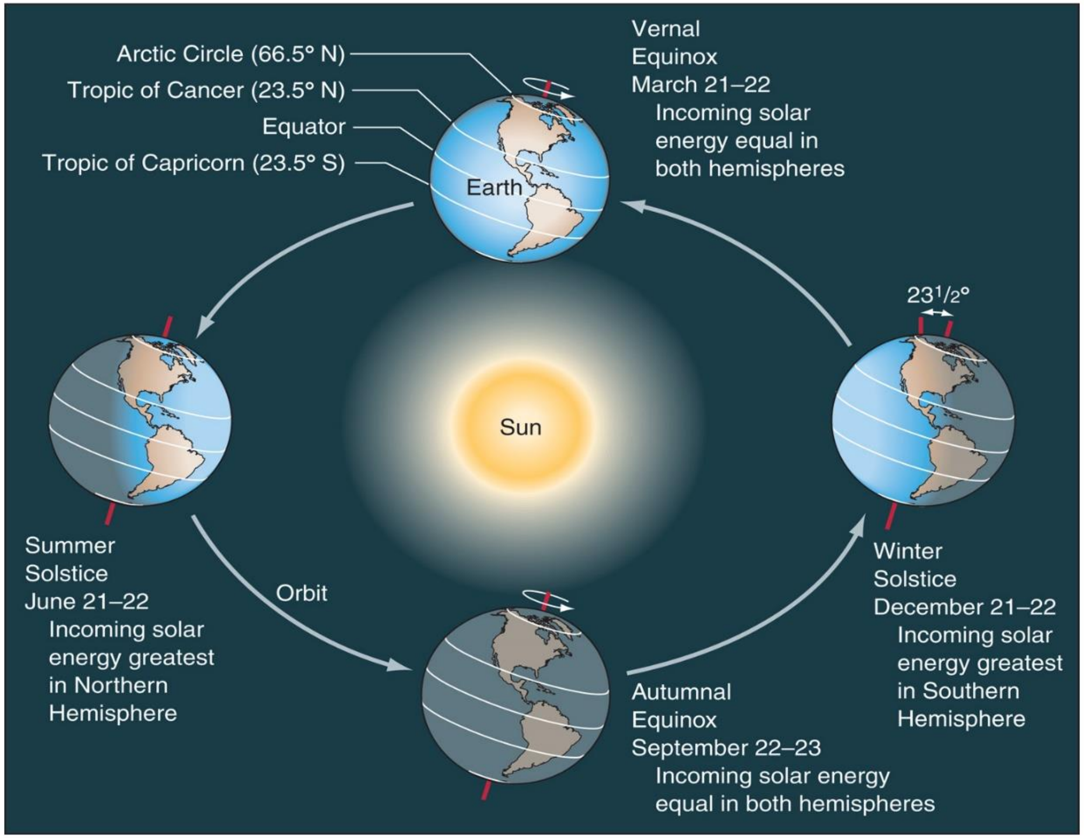
Earth – 1367 W/m^2

Mars – 445 W/m^2



Solar Radiation and the Earth

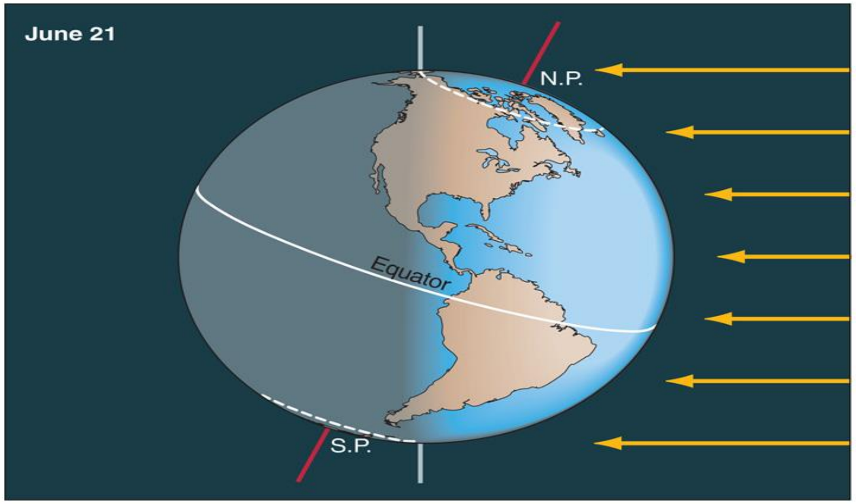
- Earth's tilt is the true cause of the seasons!
  - Earth's axis is tilted 23.5^o

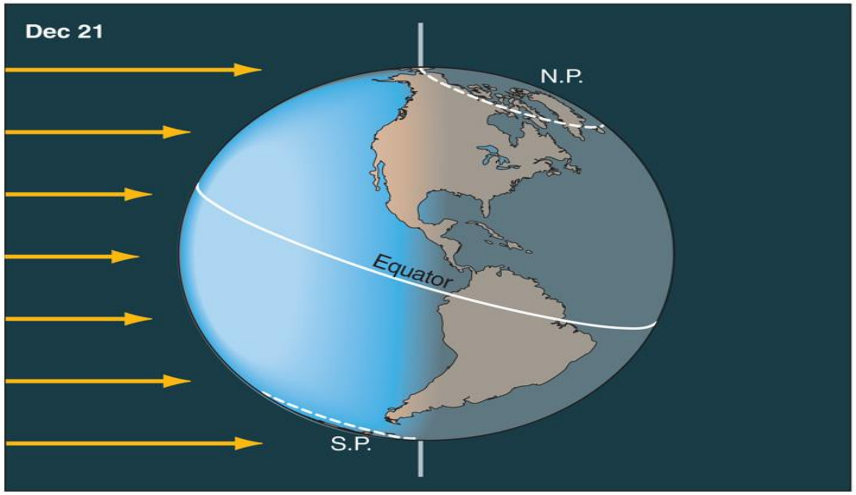


Solar Radiation and the Earth

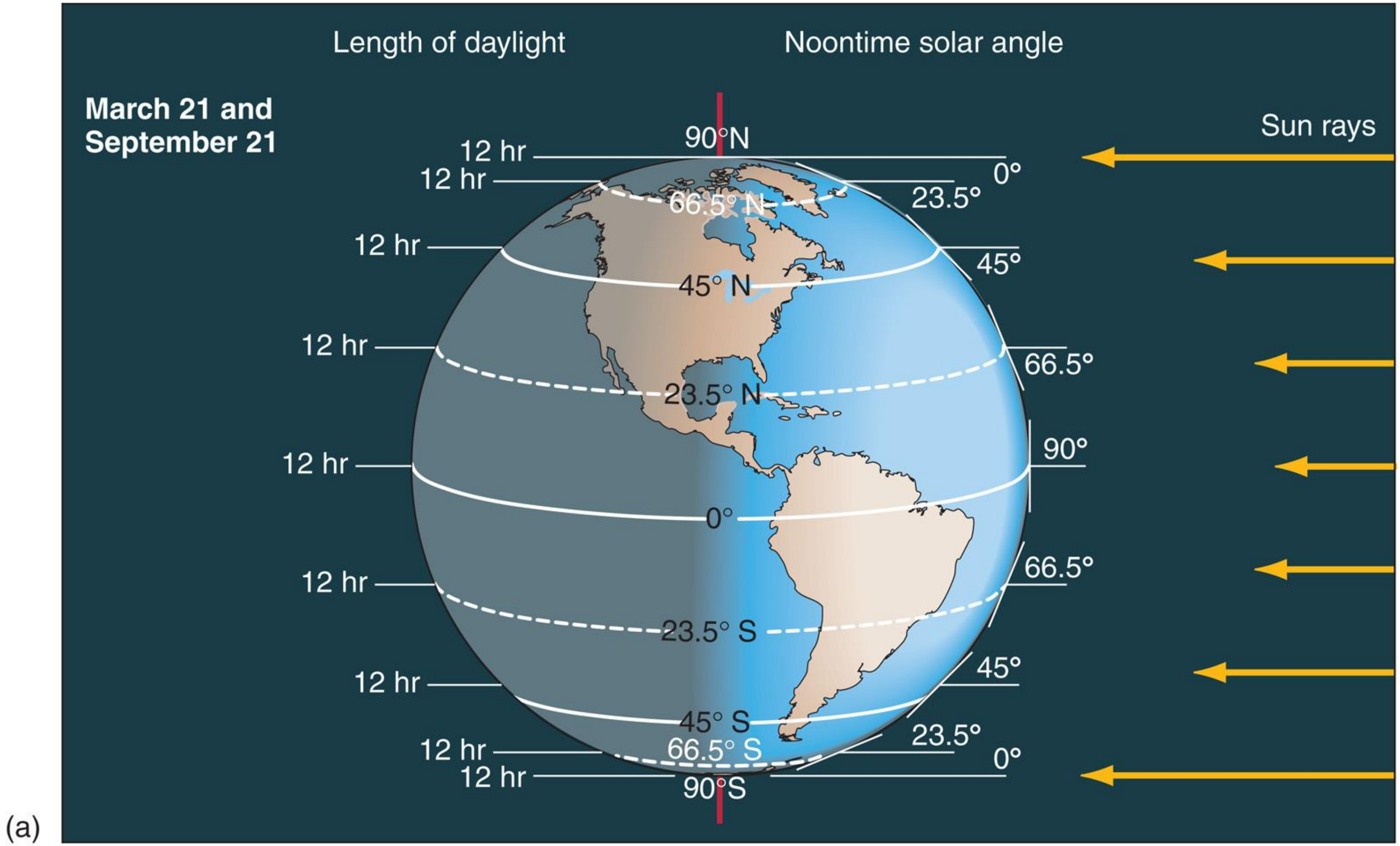
- 3 factors contribute to the amount of incoming solar radiation (**insolation**):

1) Period of daylight



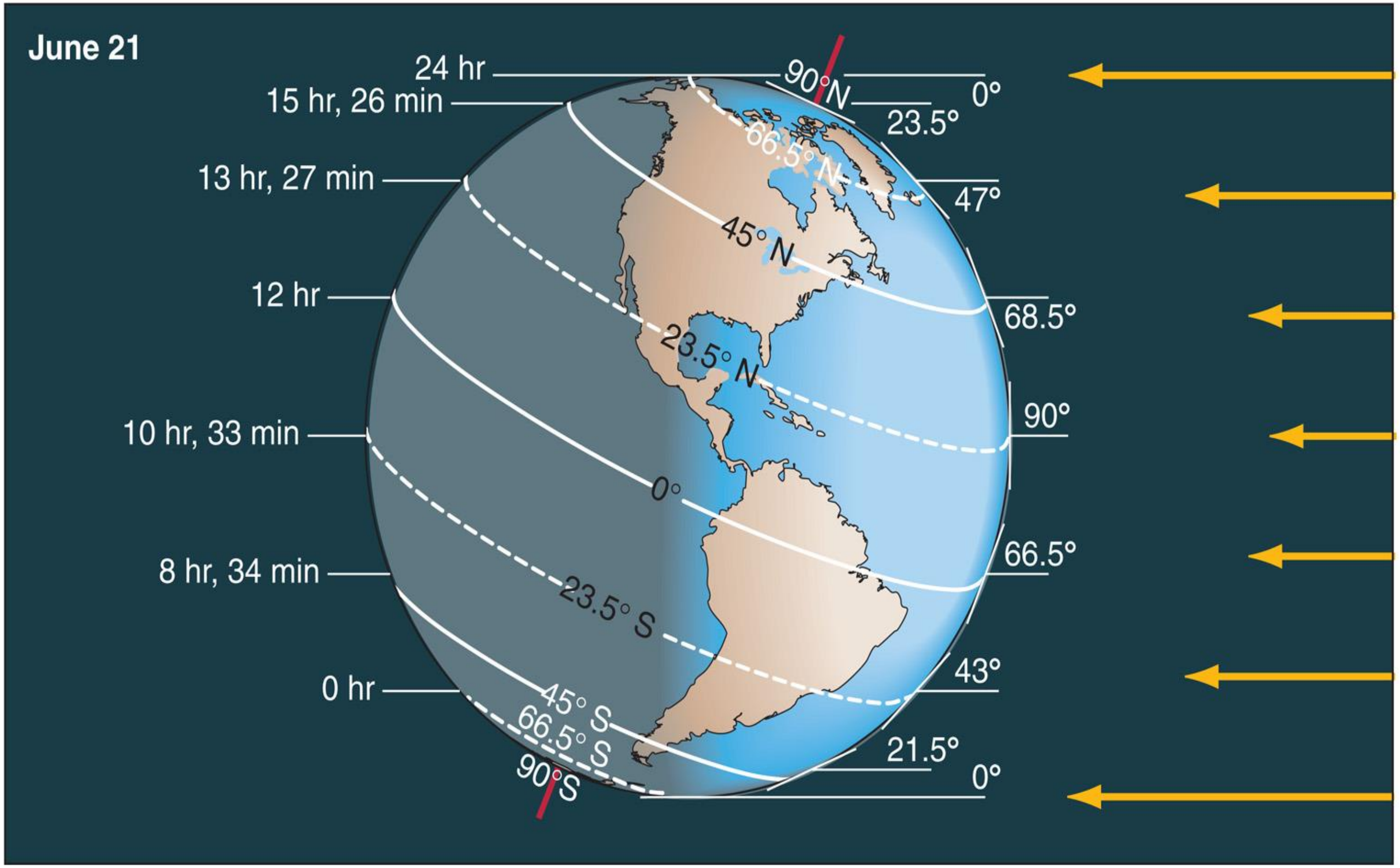


Period of Daylight



Vernal and autumnal equinox

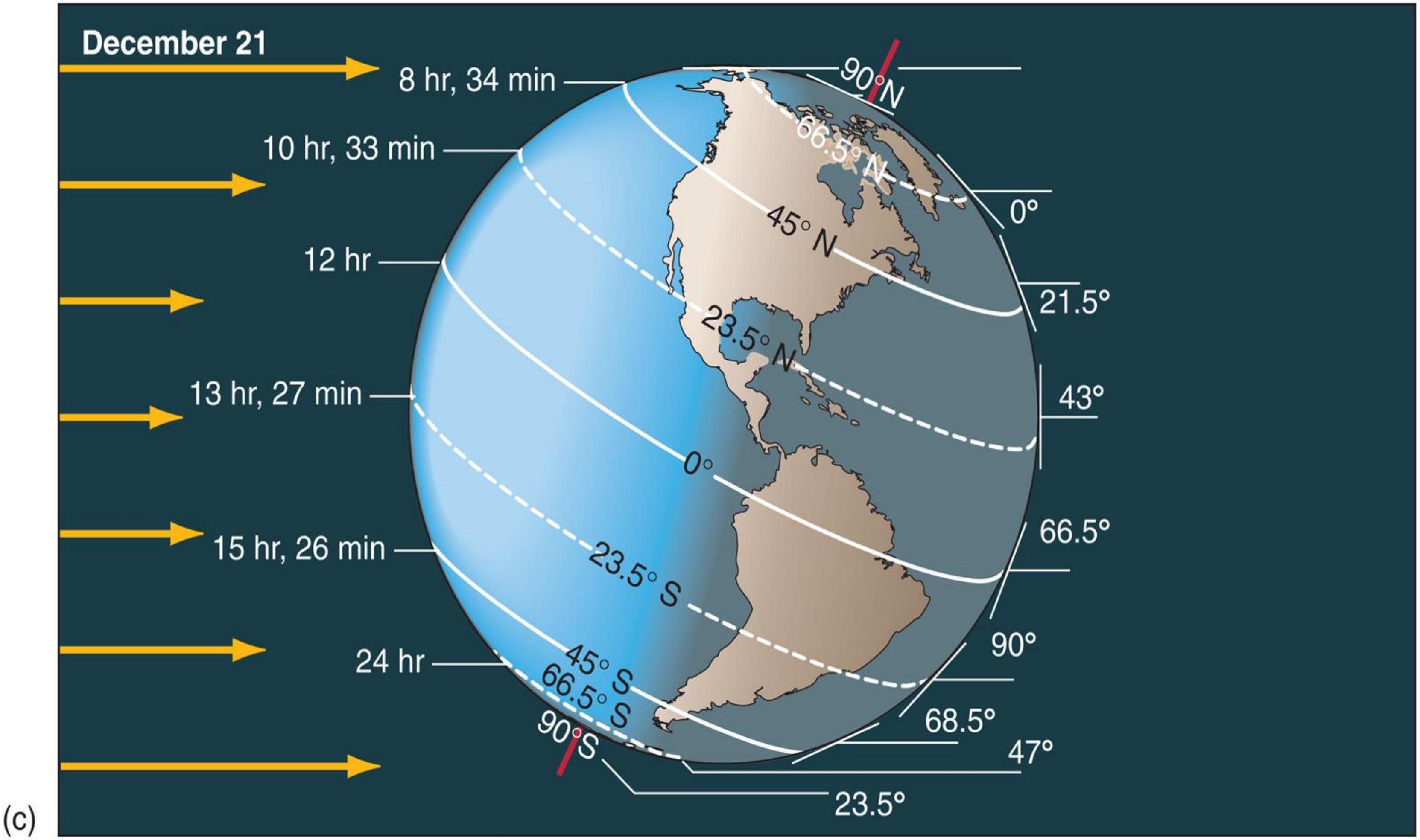
Period of Daylight



(b)

Summer solstice

Period of Daylight

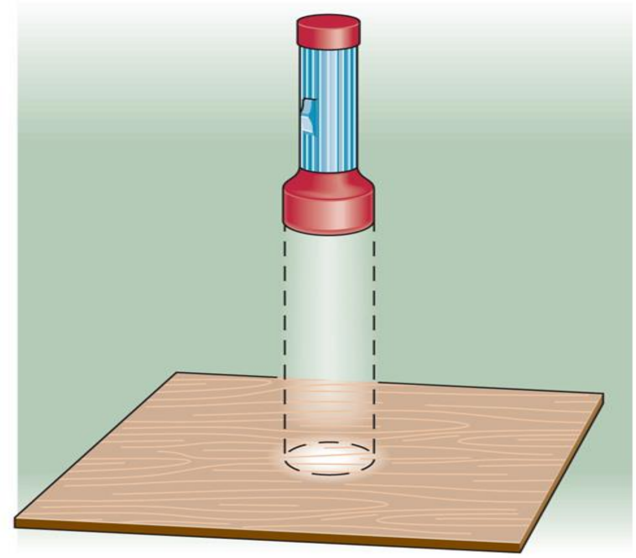


Winter solstice

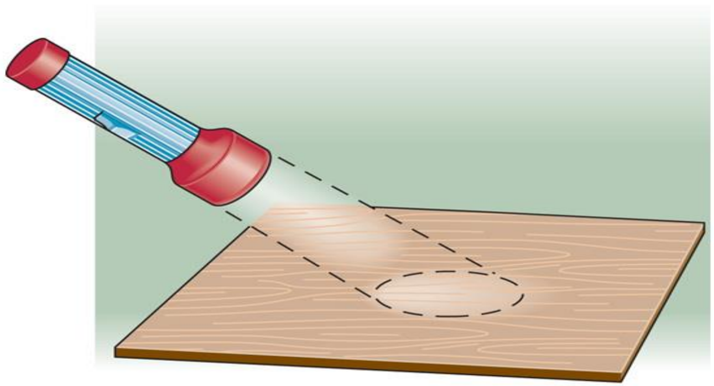
Solar Radiation and the Earth

- 3 factors contribute to the amount of incoming solar radiation (**insolation**):

2) Solar angle

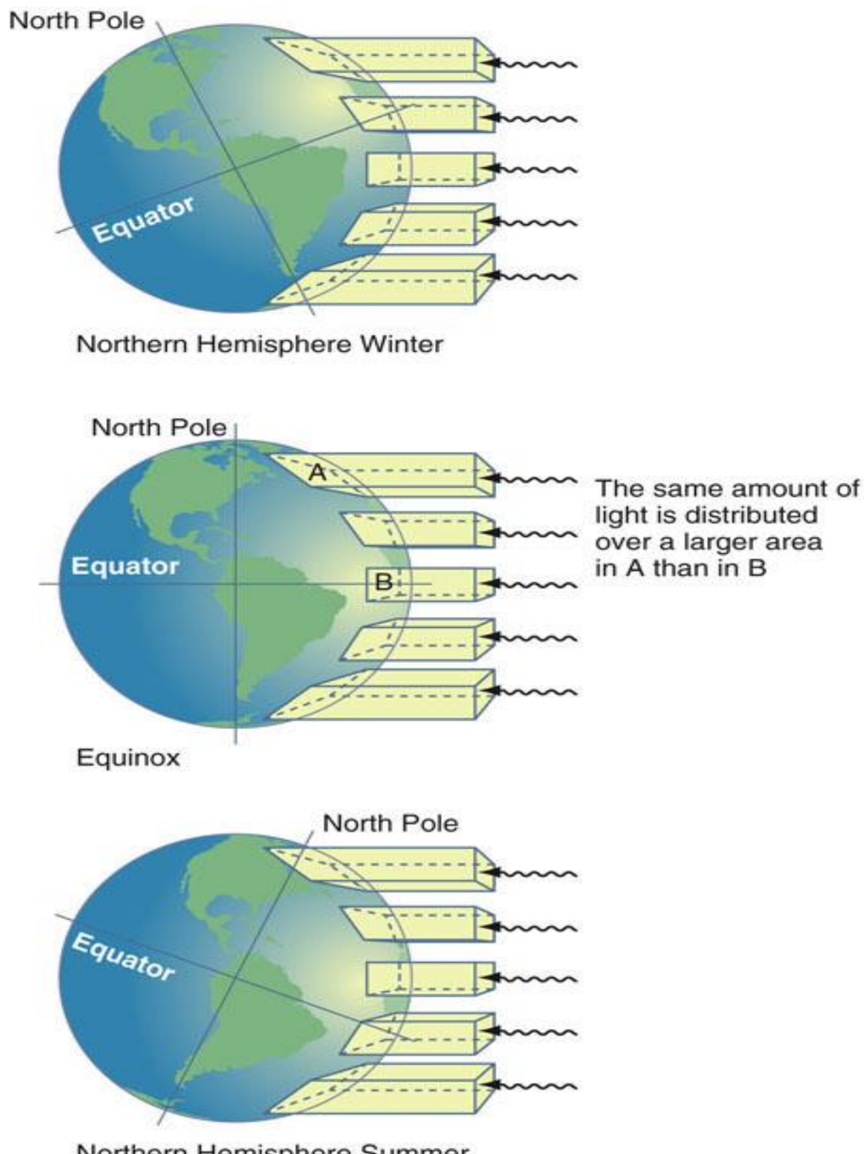


(a)



(b)

Solar Angle

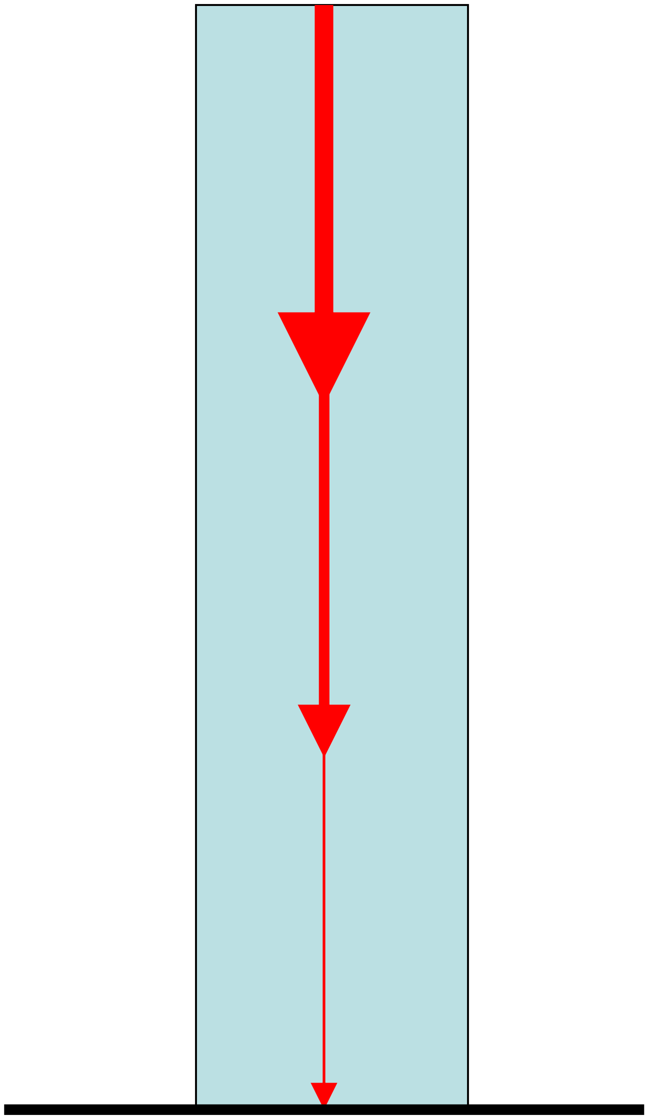


North Pole
Equator
Northern Hemisphere Winter
North Pole
A
Equator
B
The same amount of light is distributed over a larger area in A than in B
Equinox
North Pole
Equator
Northern Hemisphere Summer

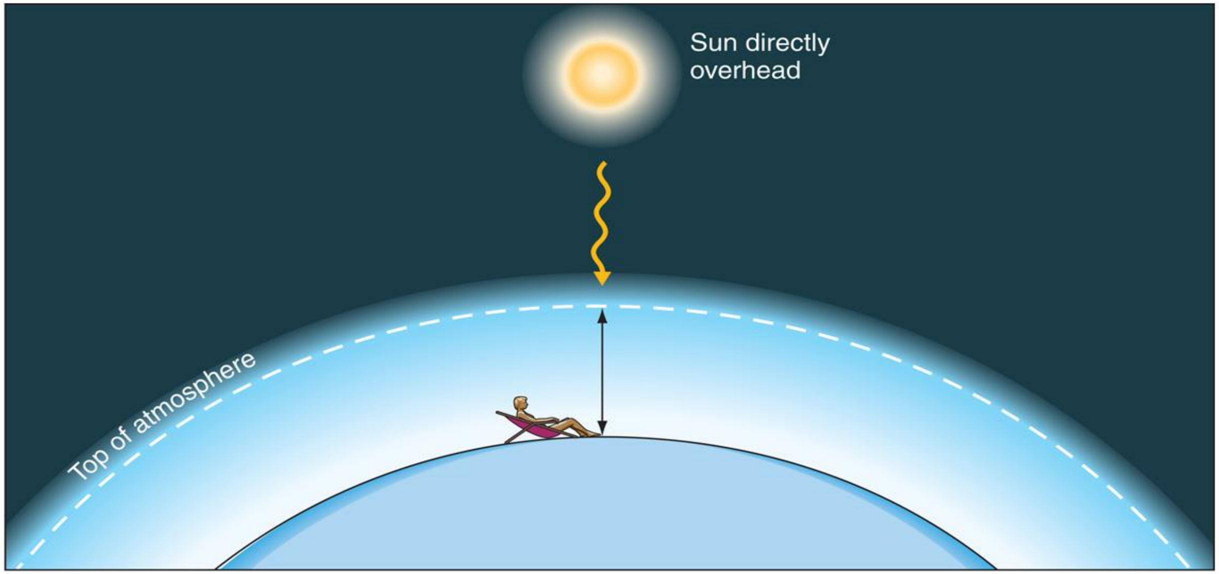
Solar Radiation and the Earth

- 3 factors contribute to the amount of incoming solar radiation (**insolation**):

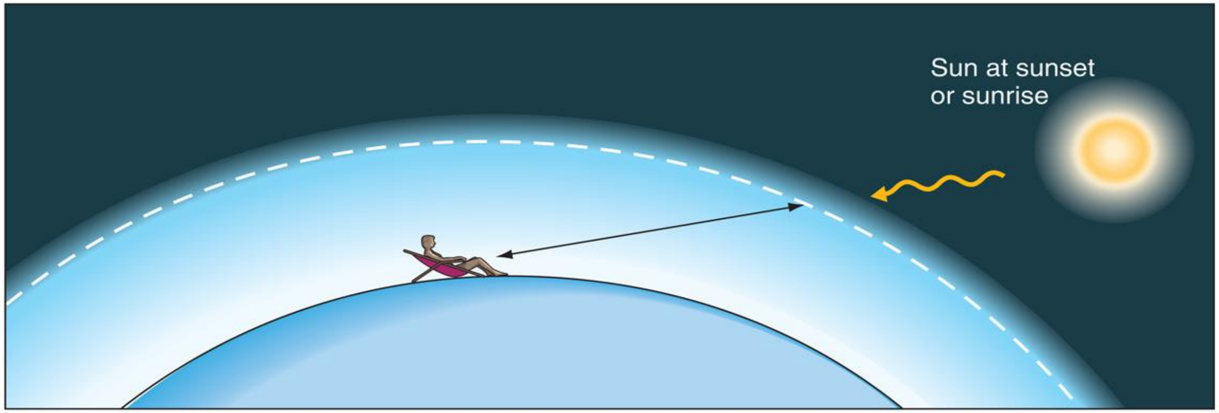
3) Beam depletion



Beam Depletion



(a)



(b)

Planetary Albedo

- A fraction of the incoming solar radiation (S) is reflected back into space, the rest is absorbed by the planet. Each planet has a different reflectivity, or albedo (α):
  - Earth $\alpha = 0.31$ (31% reflected, 69% absorbed)
  - Mars $\alpha = 0.15$
  - Venus $\alpha = 0.59$
  - Mercury $\alpha = 0.1$
- Net incoming solar radiation = $S(1 - \alpha)$
- One possible way of changing Earth's climate is by changing its albedo.

Land has higher albedo than ocean

Clouds have high albedo

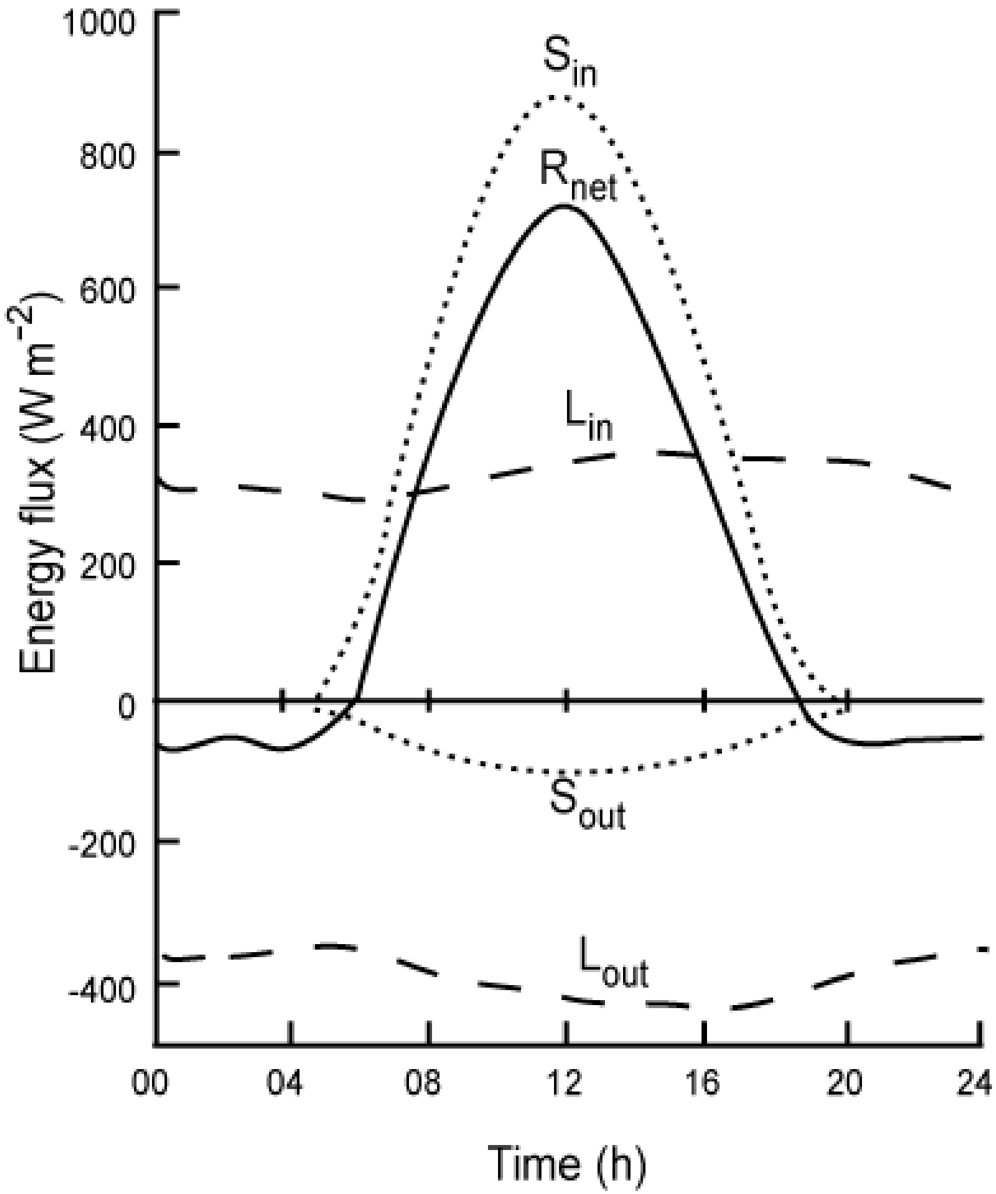
Ice and snow have high albedo

2) Energy balance

Principles of Terrestrial Ecosystem Ecology

Chapin, Matson and Vitousek
2nd edition, 2011

Chapter 4
Water and Energy Balance



Chapin et al., 2011

Fig. 4.2

Energy balance equation

$$K + L + H + LE + G + A_w + \Delta Q / \Delta t = 0$$

where:

K	net shortwave radiation
L	net longwave radiation
LE	latent heat transfer
H	sensible heat transfer
G	soil flux
Aw	advective energy
ΔQ/Δt	change in stored energy

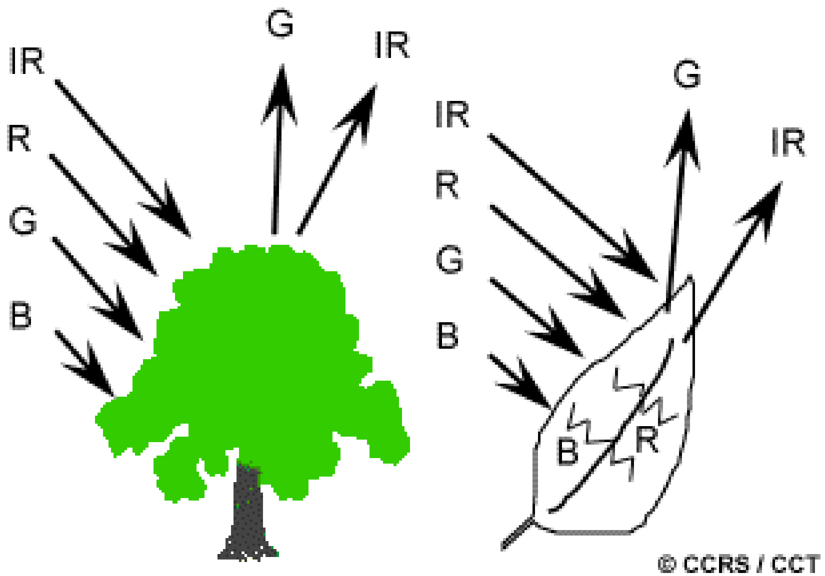
Units: $[EL^{-2}T^{-1}]$

Bowen ratio = H/LE   replace H = B·LE

2) Other relevant biophysics

Reflection of land surface

Seeing (infra)***Red***

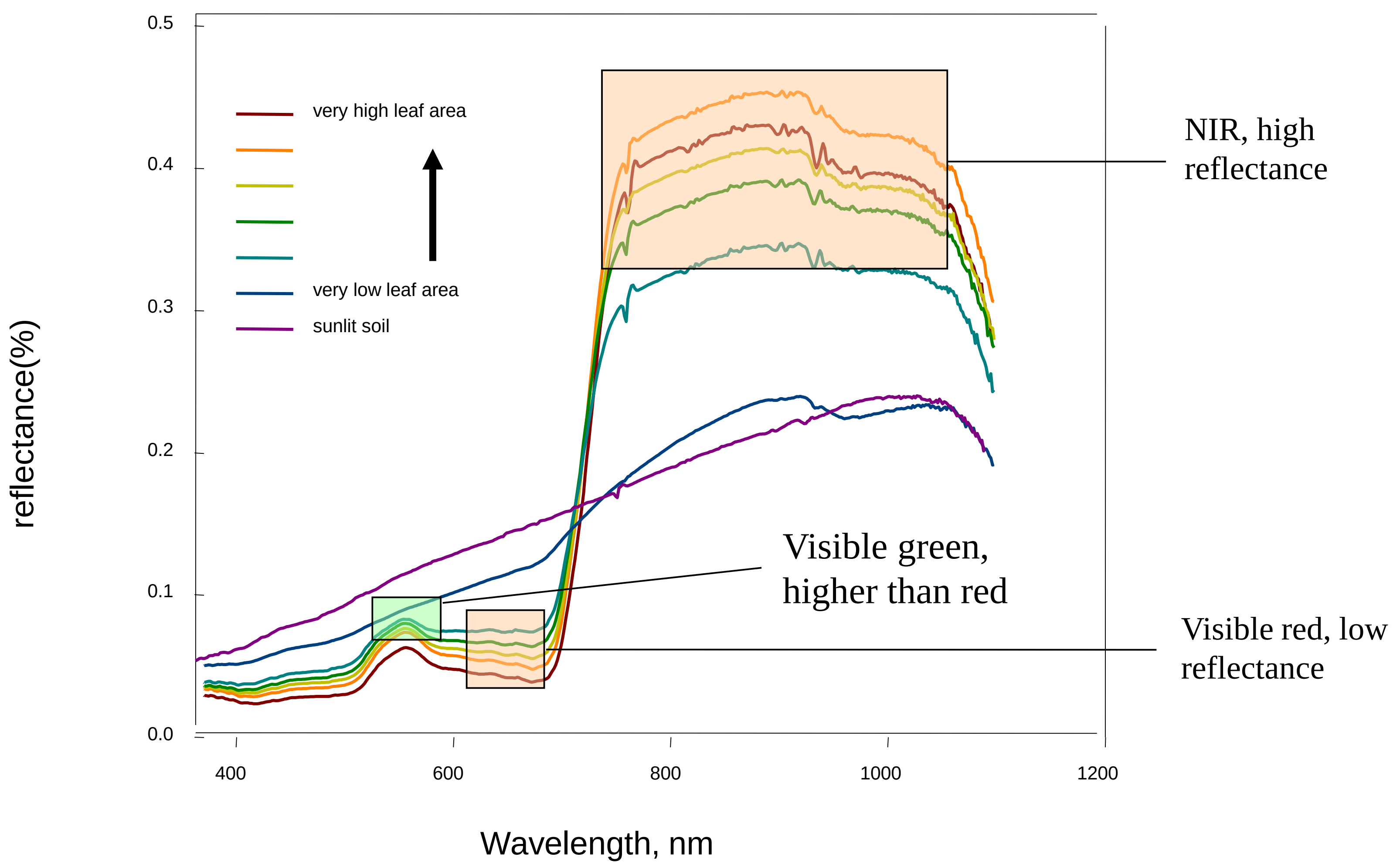


Chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. (This is why healthy vegetation appears green.)

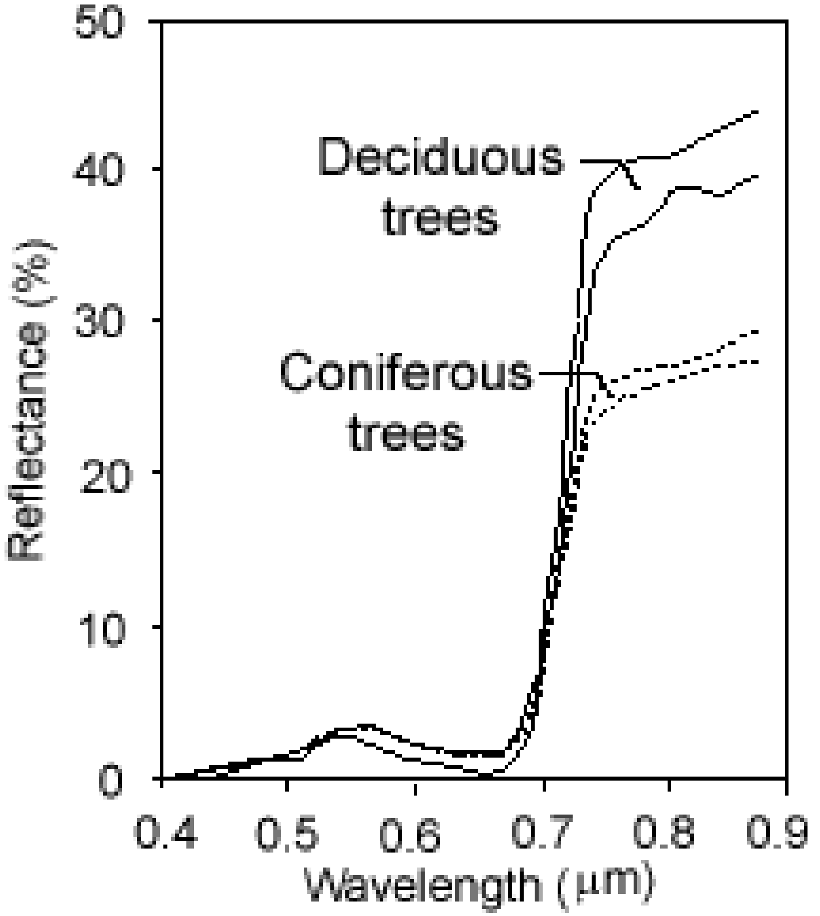
The internal structure of healthy leaves act as excellent diffuse reflectors of near-infrared wavelengths.

Measuring and monitoring the near-IR reflectance is one way that scientists can determine how healthy (or unhealthy) vegetation may be.

Spectral information: vegetation



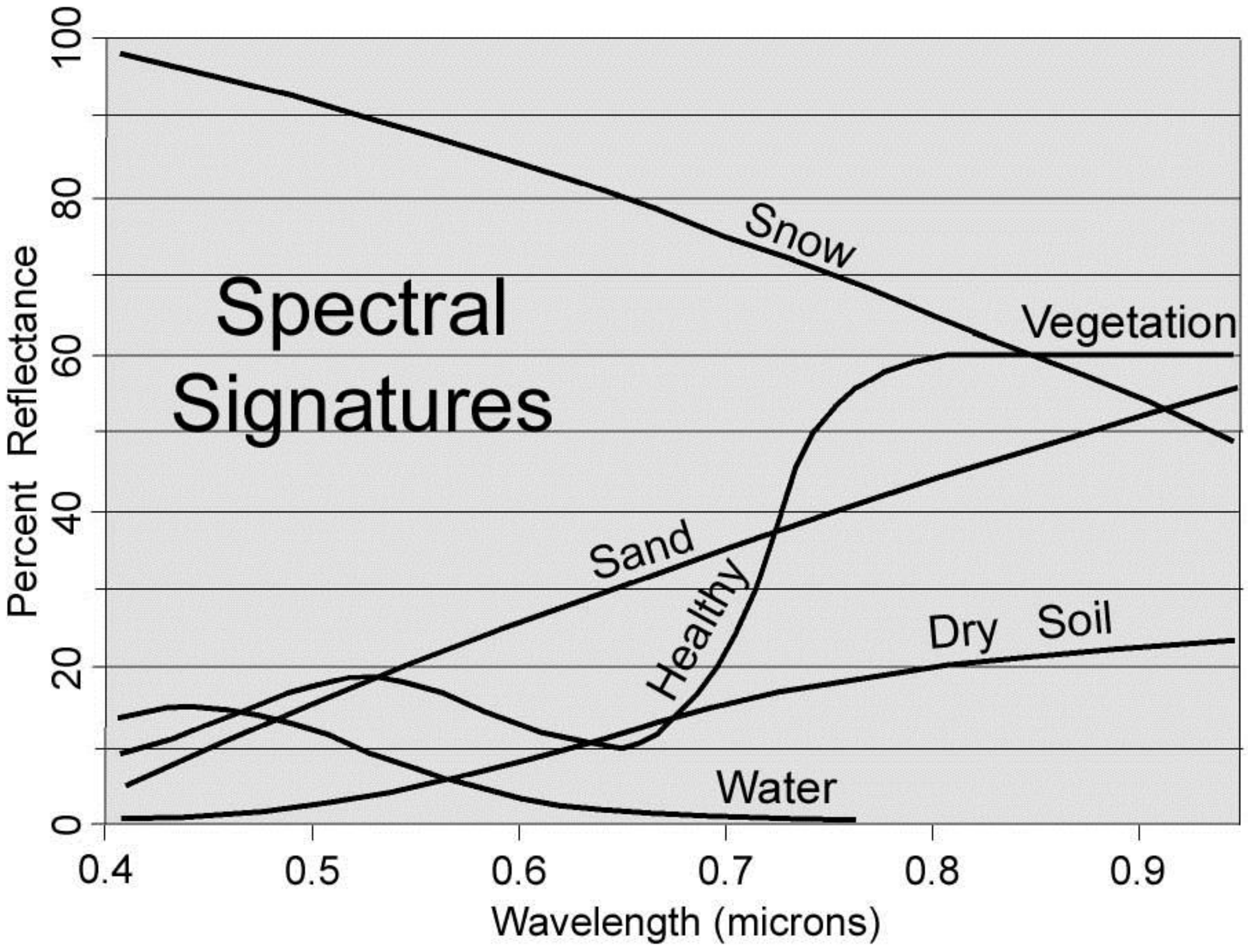
Vegetation characteristics



- high reflectivity in NIR
- - distinguish between vegetation types on basis of spectral reflection curves

Spectral signature

Explain why water looks darkish blue; Explain why vegetation looks greenish; Explain why sand looks reddish yellow



2) Other relevant biophysics

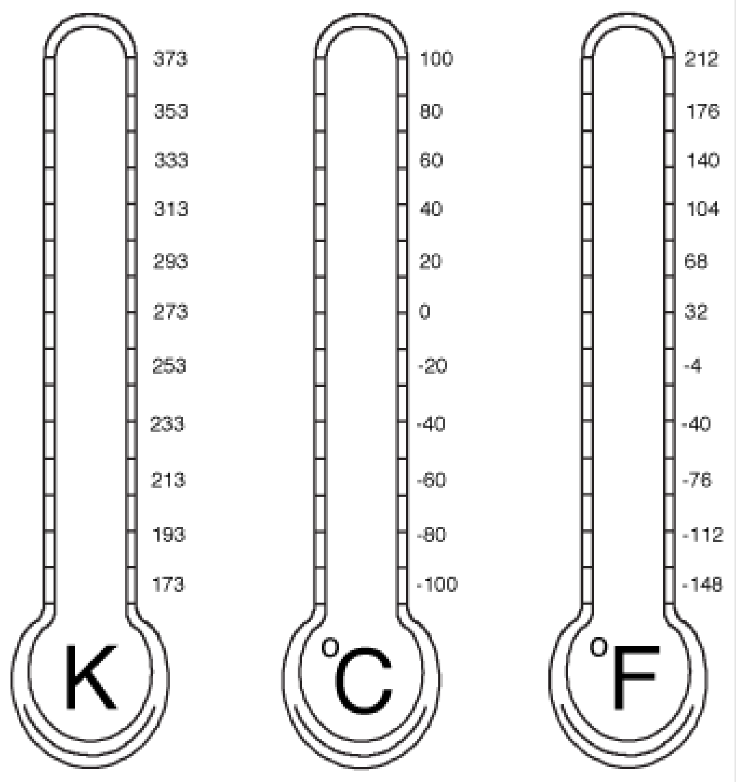
Vertical temperature

Atmospheric temperature

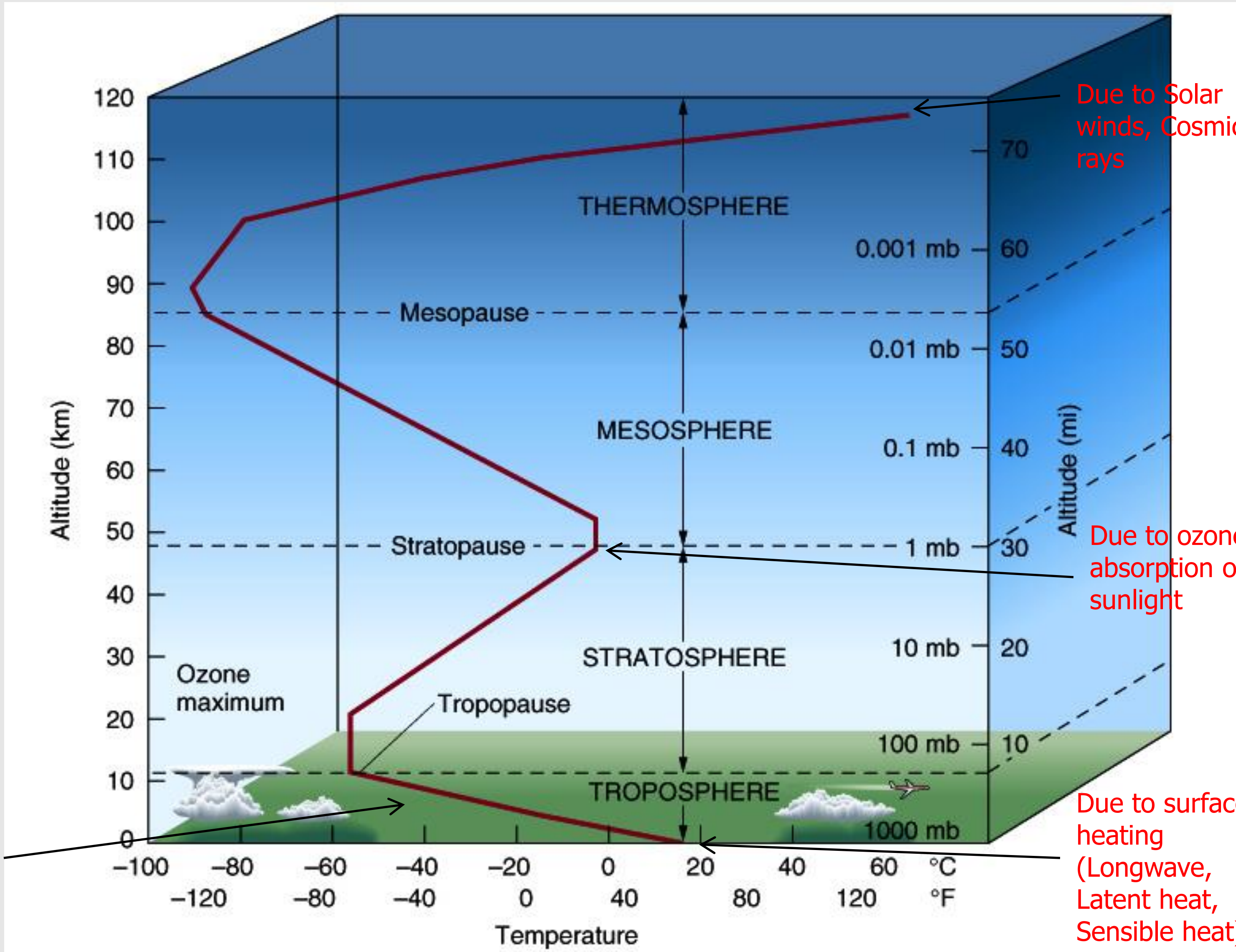
http://lightning.sbs.ohio-state.edu/geog1900/ch4_pressure_wind1.ppt(4 slides)

Temperature Basics

- **Temperature** – measure of average kinetic energy (motion) of individual molecules in matter
- Three temperature scales (units): Kelvin (K), Celsius (C), Fahrenheit (F)
  - All scales are relative
  - degrees F = $\frac{9}{5}$ degrees C + 32
  - degrees K = degrees C + 273.15



Temperature Layers



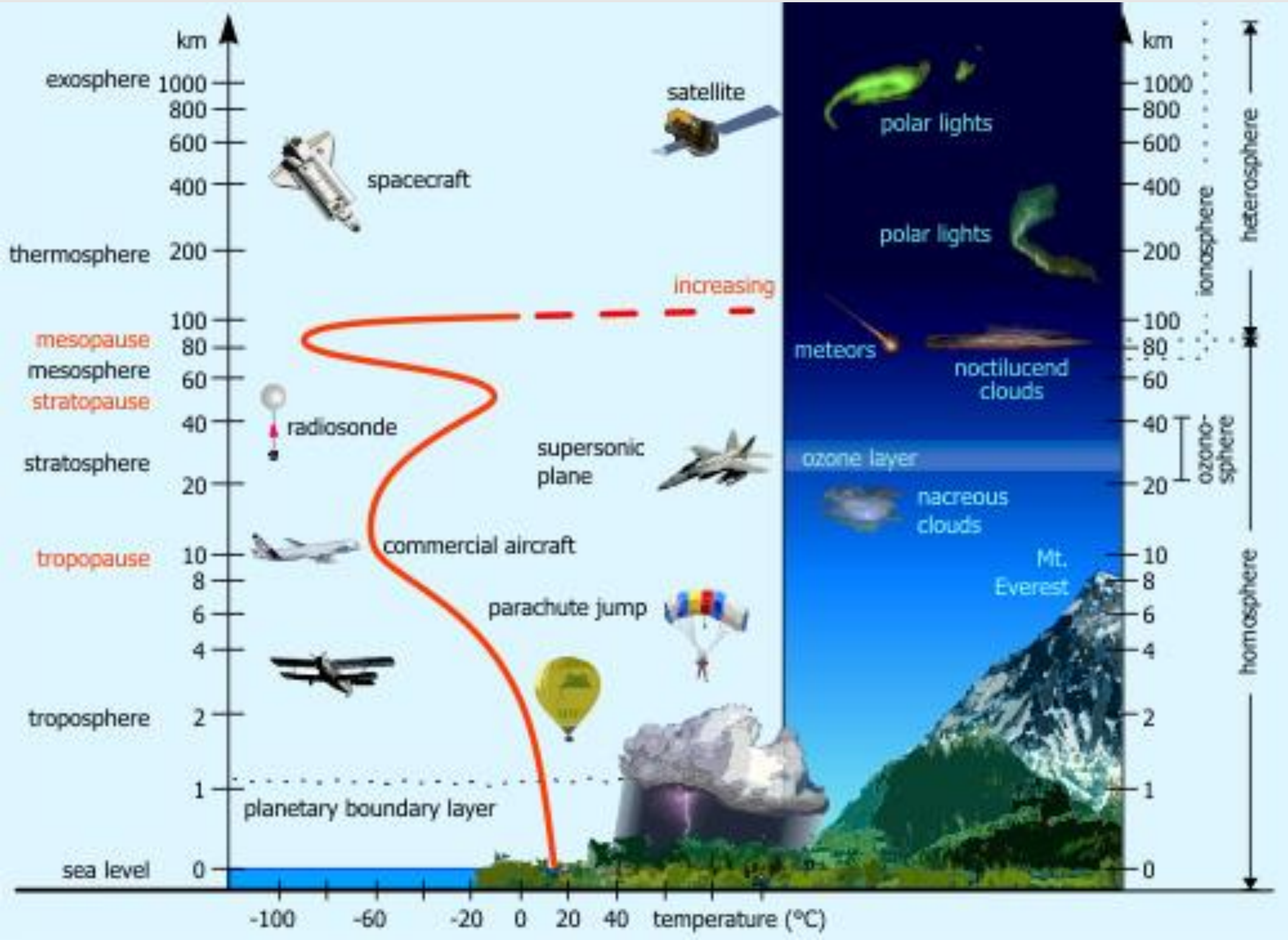
Due to Solar winds, Cosmic rays

Due to ozone absorption of sunlight

Decreasing rate w/ height (Lapse rate): 6.5 °C/km

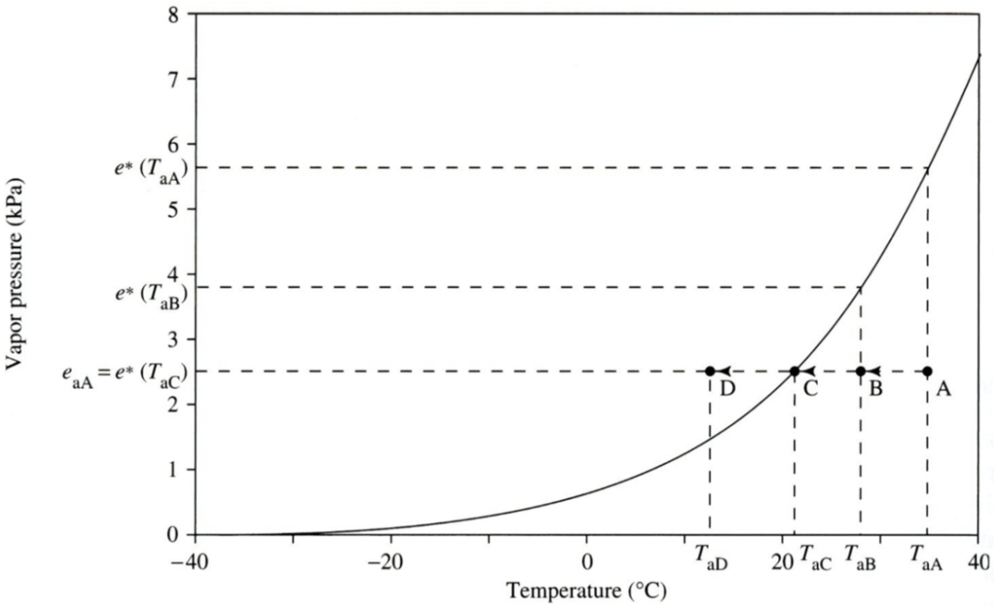
Due to surface heating (Longwave, Latent heat, Sensible heat)

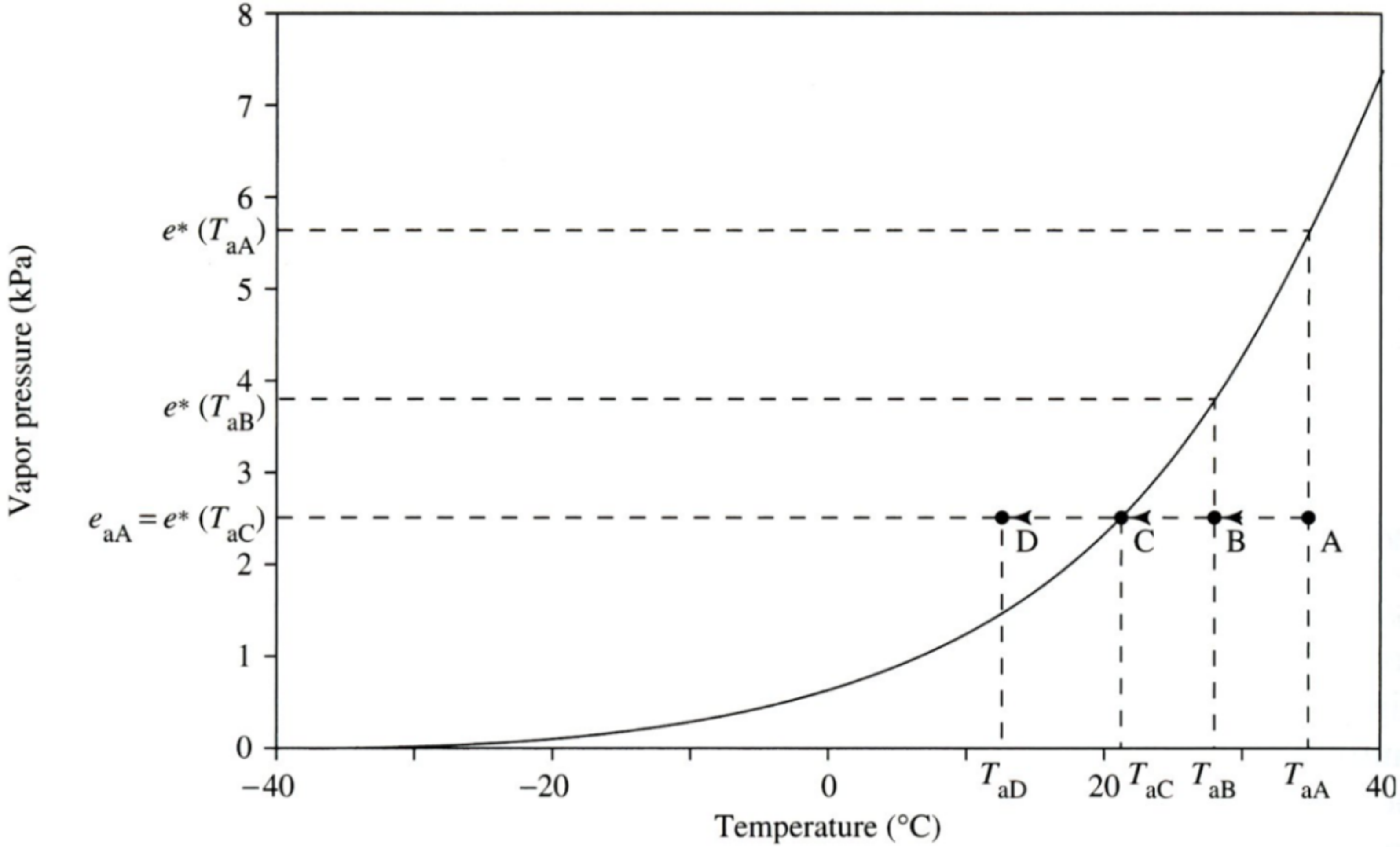
An artist's view



- Pressure-temperature relation (Ideal gas law)
- Adiabatic lapse rate (dry & wet)

- **Vapour**
  - Vapour pressure, e_a
  - Sat. vapour pressure, e_a*
  - Absolute humidity, ρ_v
  - Specific humidity, $q = \rho_a/\rho_v$
  - Relative humidity, $W_a = e_a/e_a$
  - Dew point temperature, T_d





Vapor pressure (kPa)
8
7
6
$e^*(T_{aA})$
5
4
$e^*(T_{aB})$
3
$e_{aA} = e^*(T_{aC})$
2
1
0
D
C
B
A
−40
−20
0
T_{aD}
20
T_{aC}
T_{aB}
T_{aA}
40
Temperature (°C)

4) A few selected applications of RS in ecosystem studies

Landscape Ecology 19: 291–309, 2004.

Research article

Disturbance and landscape dynamics in the Chequamegon National Forest Wisconsin, USA, from 1972 to 2001

Mary K. Bresee[1,*], Jim Le Moine[1], Stephen Mather[1], Kimberley D. Brosofske[2], Jiquan Chen[1], Thomas R. Crow[3] and John Rademacher[1]
*[1]Department of Earth, Ecological, and Environmental Science, University of Toledo, OH 43606, USA; [2]School of Forest Resources and Environmental Science, Michigan Technological University, Houghton, MI 49931, USA; [3]Forestry Sciences Lab, USDA Forest Service, Grand Rapids, MN 55744, USA; *Author for correspondence (e-mail: bres9575@hotmail.com)*

Received 25 September 2002; accepted in revised form 12 May 2003

Key words: Disturbance, Forest management, Fragmentation, GIS, Landscape dynamics, Landscape structure, Landsat MSS, Roads, TM and ETM+, Wisconsin

4) A few selected applications of RS in ecosystem studies

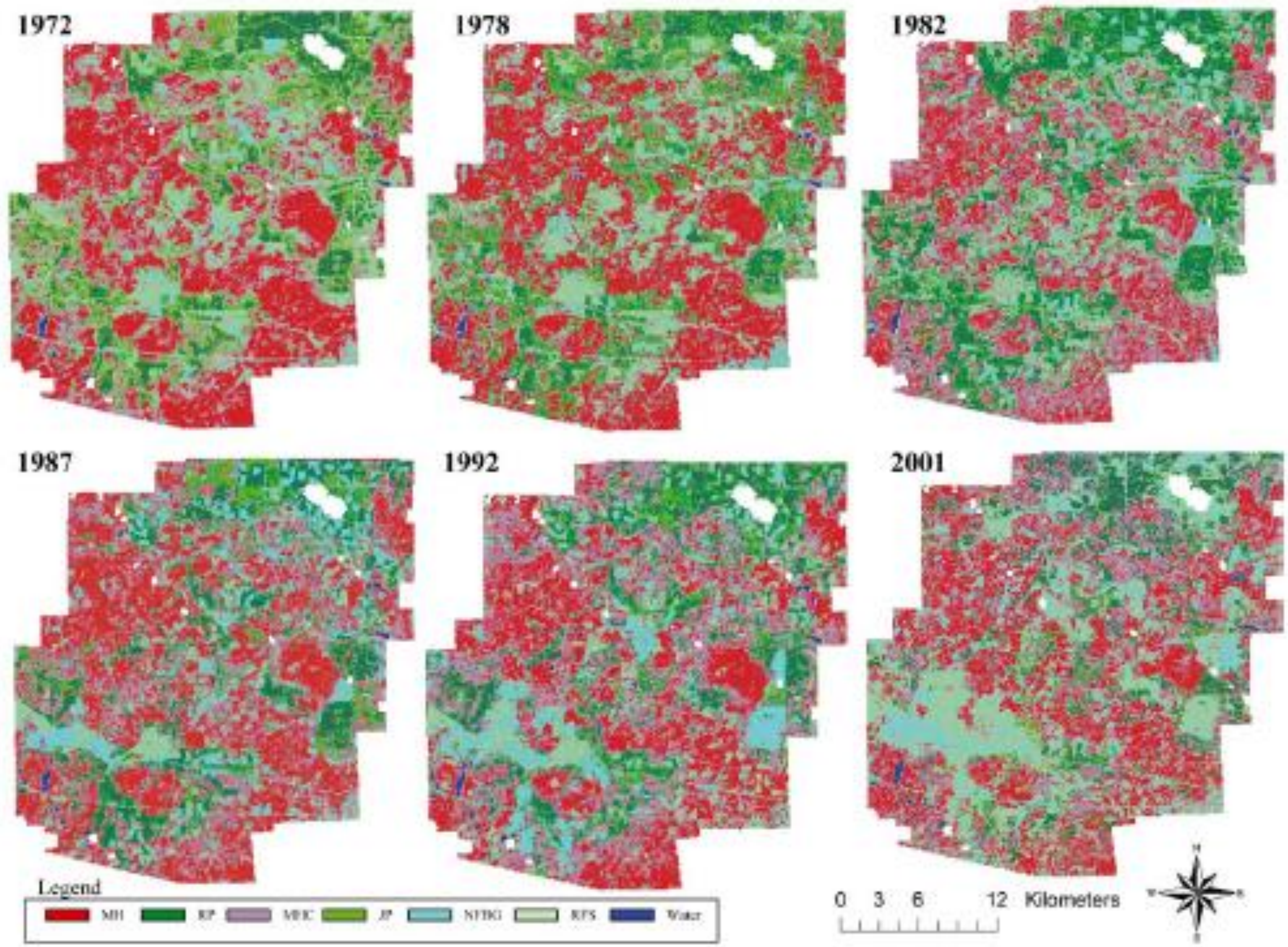


Figure 2. Six classified images (1972-2001) of the landscape. Cover types include mixed hardwood (MH), jack pine (JP), red pine (RP), mixed hardwood/conifer (MHC), regenerating forest or shrub (RFS), and non-forested bare ground (NFBG).

4) A few selected applications of RS in ecosystem studies

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SCIENCE DIRECT

Remote Sensing of Environment 93 (2004) 402–411

Remote Sensing of Environment

www.elsevier.com/locate/rse

Estimating aboveground biomass using Landsat 7 ETM+ data across a managed landscape in northern Wisconsin, USA

Daolan Zheng[a,*], John Rademacher[b], Jiquan Chen[a], Thomas Crow[c], Mary Bresee[a], James Le Moine[d], Soung-Ryoul Ryu[a]

[a] *Department of Earth, Ecological, and Environmental Sciences, University of Toledo, Toledo, OH 43606, USA*
[b] *USDA, Forest Service Ruby Mtn./Jarbidge Ranger District, Wells, NV 89835, USA*
[c] *USDA Forest Service, WFWAR, Arlington, VA 22209, USA*
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Received 7 January 2004; received in revised form 13 July 2004; accepted 5 August 2004

4) A few selected applications of RS in ecosystem studies

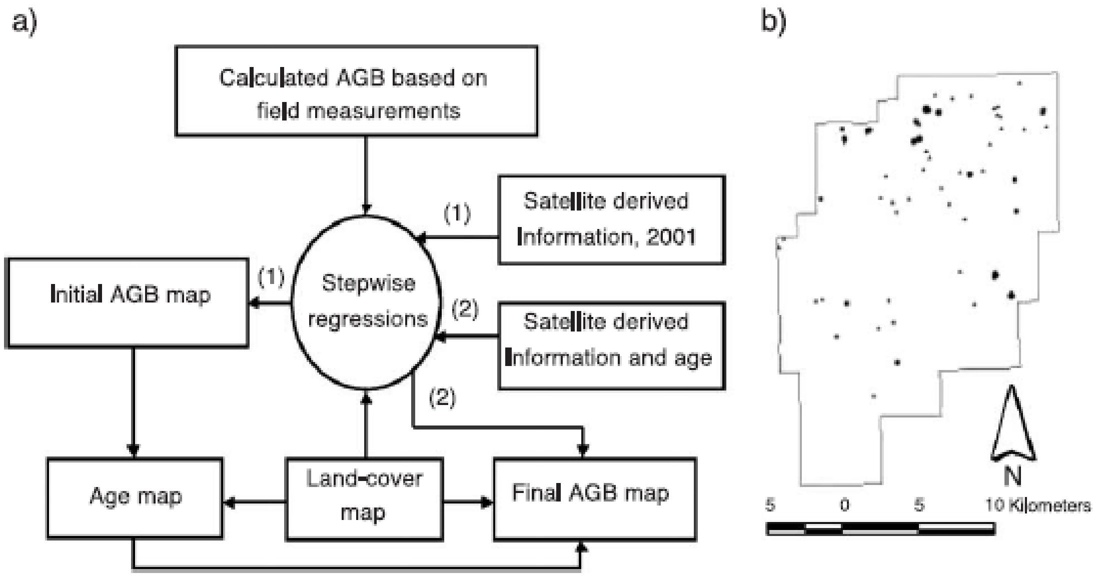

Fig. 1. (a) Framework of estimating AGB (Mg/ha) using Landsat 7 ETM+ data and field measurements in the CNF; and (b) spatial distributions of the plots used for model construction (circles) and validation (triangles).

4) A few selected applications of RS in ecosystem studies

406 D. Zheng et al. / Remote Sensing of Environment 93 (2004) 402–411

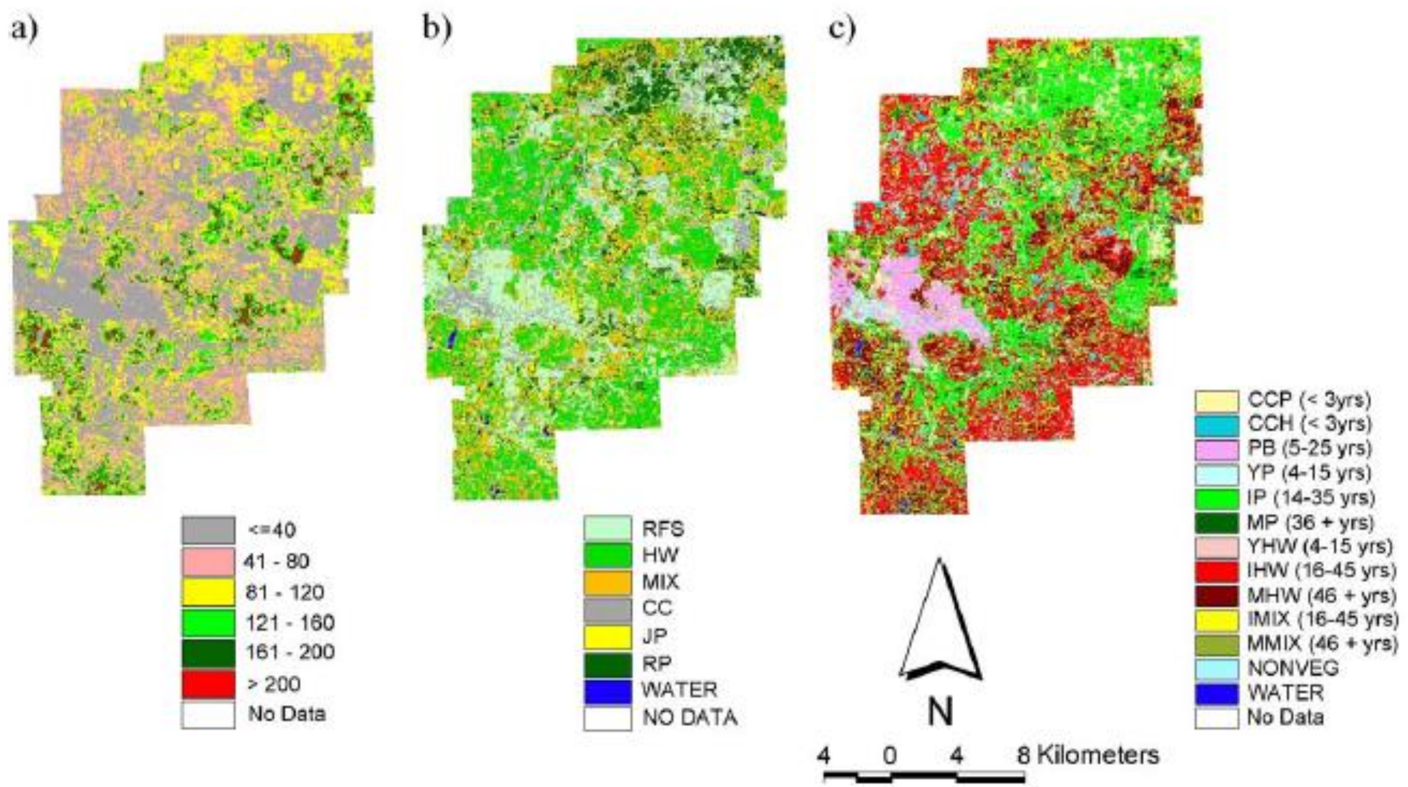

Fig. 3. Maps for (a) AGB (Mg/ha), (b) land cover, and (c) age map (recoded as a category map to increase the readability). All were derived from 2001 Landsat 7 ETM+ data for CNF.

4) A few selected applications of RS in ecosystem studies

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Remote Sensing of Environment 112 (2008) 2018–2032

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Predicting plant diversity based on remote sensing products in the semi-arid region of Inner Mongolia

Ranjeet John [a,*], Jiquan Chen [a,b], Nan Lu [a], Ke Guo [b], Cunzhu Liang [c], Yafen Wei [b], Asko Noormets [d,e], Keping Ma [b], Xingguo Han [b]

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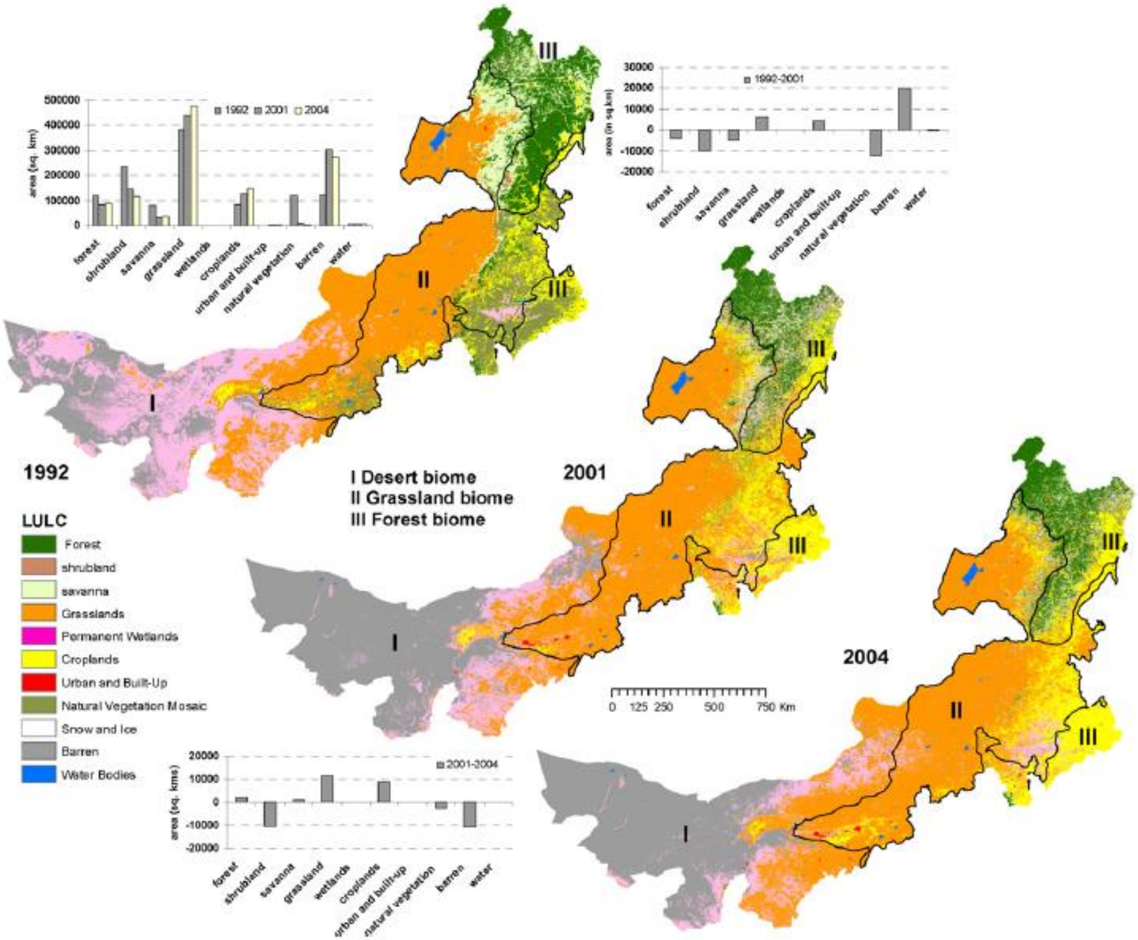

Figure 1. Changes in LCLU in Inner Mongolia between 1992 and 2001/2004 based on AVHHR (1992) and MODIS (2001 and 2004) derived IGBP classification, modified through recoding for forest, shrubland and savanna classes. Graphs denote proportions and changes in LCLU between 1992 to 2001 and 2004.

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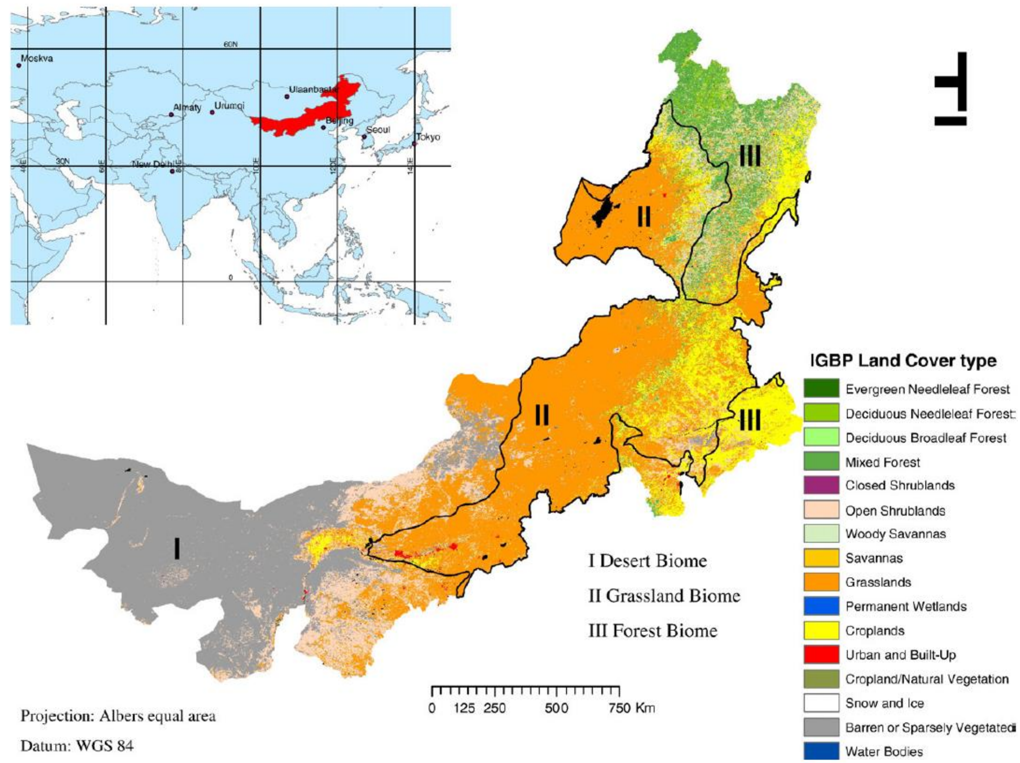

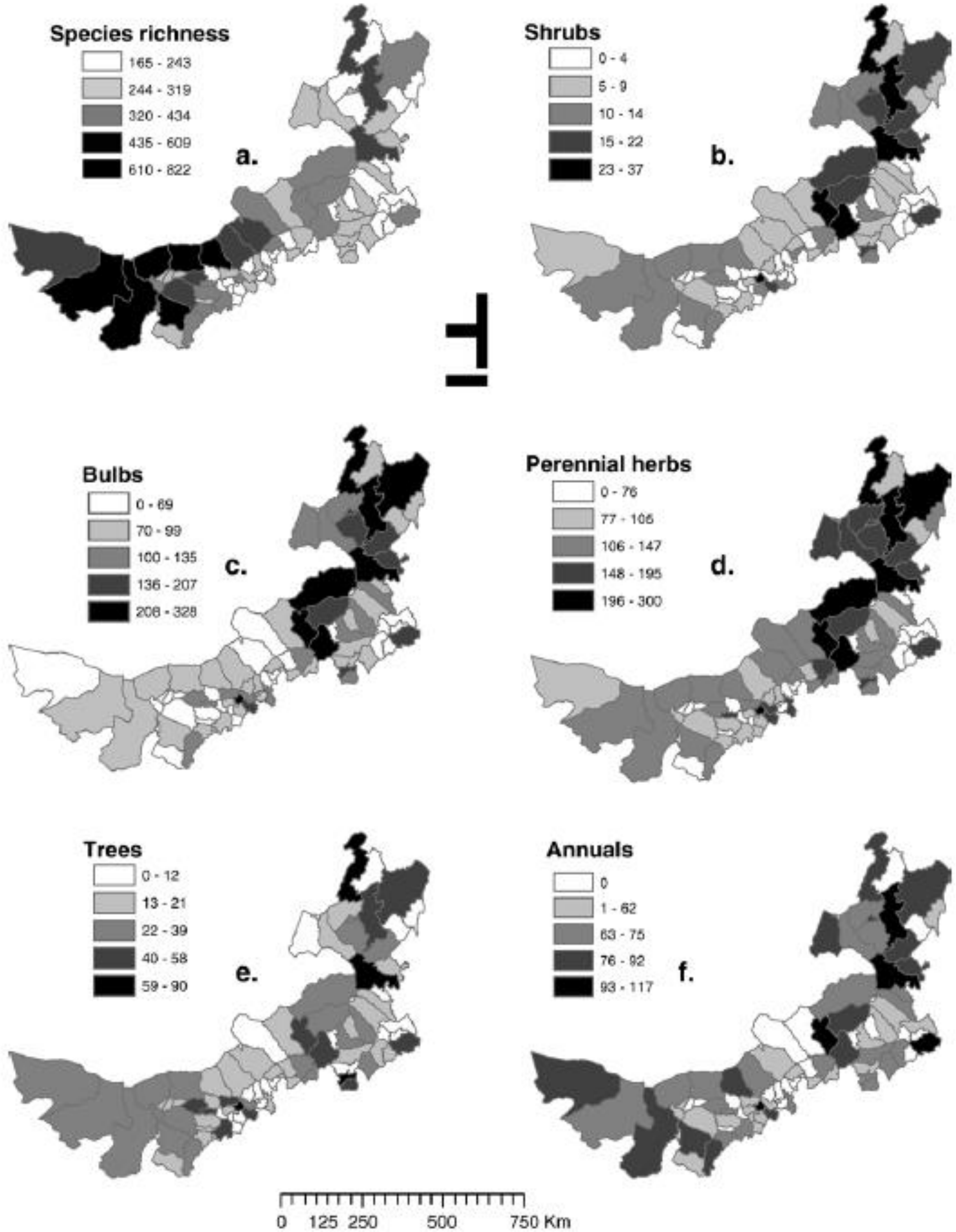

Fig. 2. Species richness distributions at county level include: a) all species, b) shrubs, c) underground bulbs/corms, d) perennial herbs, e) trees, and f) annuals. These maps were developed based on species distribution database at county level from *Flora of Inner Mongolia* (Ma, 1989, 1990, 1993, 1994, 1998).

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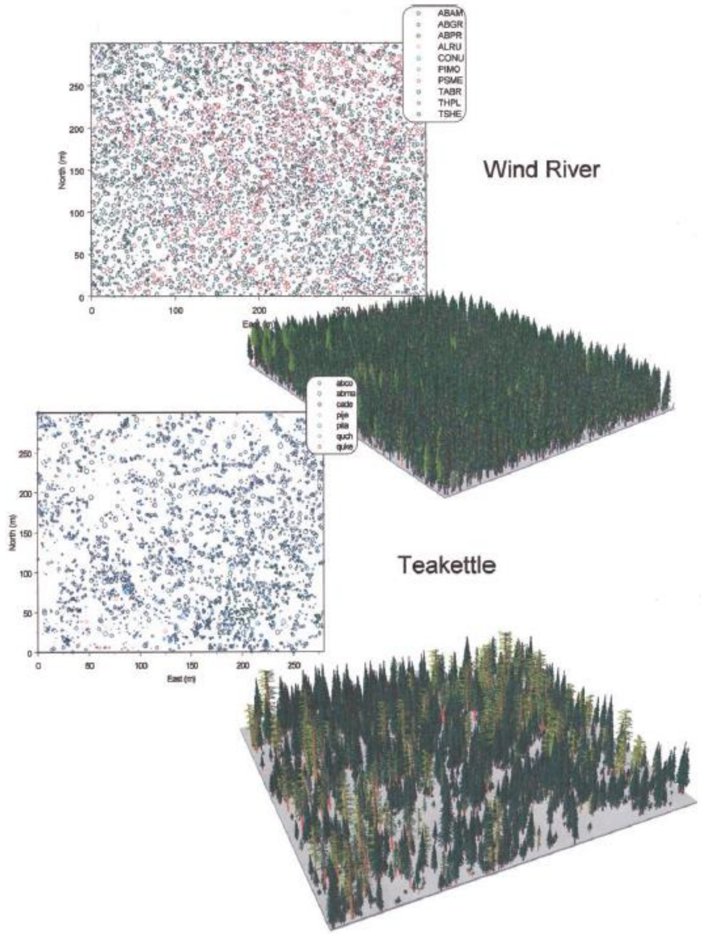

Figure 2. Map and stand visualization simulations (SVS) of all live stems ≥5 cm dbh at Wind River and Teakettle. Circles are proportional to diameter and color coded by species. To facilitate comparison, plots and diameter circle sizes have been scaled to the same dimension. Species codes at Wind River are *Abies amabilis* (ABAM), *A. grandis* (ABGR), *A. procera* (ABPR), *Alnus rubra* (ALRU), *Cornus nuttallii* (CONU), *Pinus monticola* (PIMO), PSME (*Pseudotsuga menziesii*), *Taxus brevifolia* (TABR), *Thuja plicata* (THPL), and *Tsuga heterophylla* (TSHE). Species codes at Teakettle are *Abies concolor* (ABCO), *A. magnifica* (ABMA), *Calocedrus decurrens* (CADE), *Pinus lambertiana* (PILA), *P. jeffreyi* (PIJE), *Quercus chrysolepis* (QUCH), and *Q. kelloggii* (QUKE). Crowns representations of each tree by species were developed from shapes in SVS and drawn over the location of each stem.

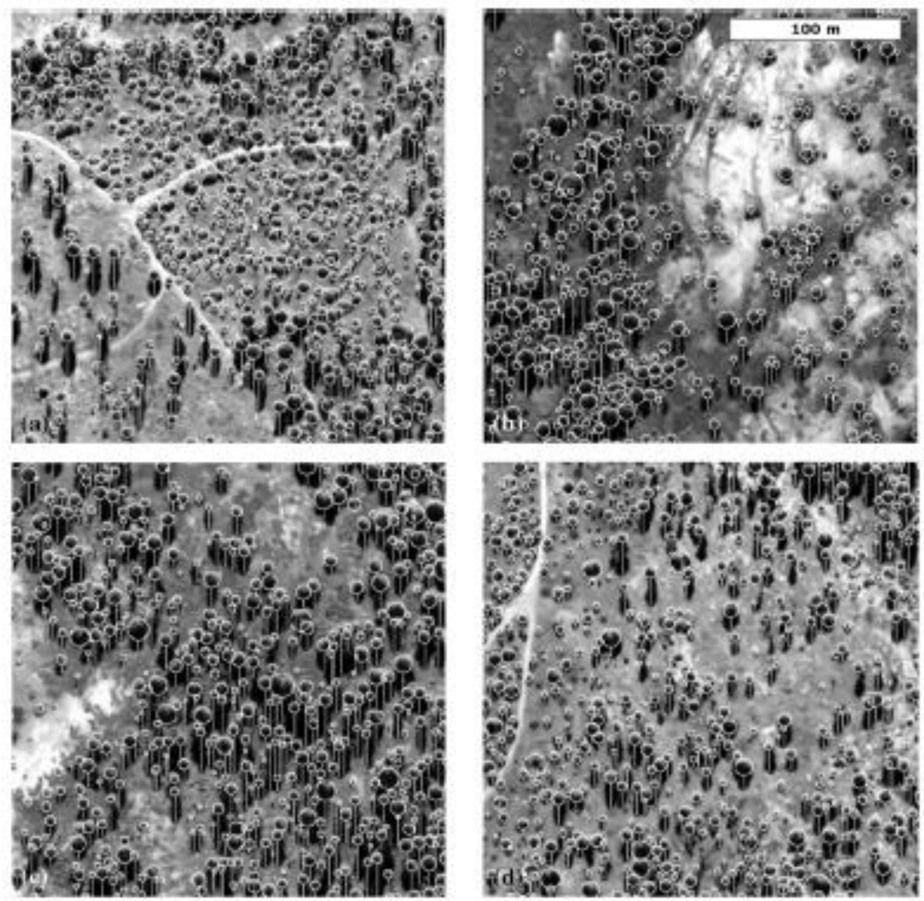

Fig. 3. Typical CANAPI crown (circle) and tree shadow (line) detections over QuickBird 0.6 m panchromatic images in the Teakettle Experimental Forest, Sierra National Forest, California. Shadows that are truncated by tree crowns or the edge of the image are not used in tree height calculation. The imagery was acquired June 25, 2003.

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ECOSYSTEMS

Spectral and Structural Measures of Northwest Forest Vegetation at Leaf to Landscape Scales

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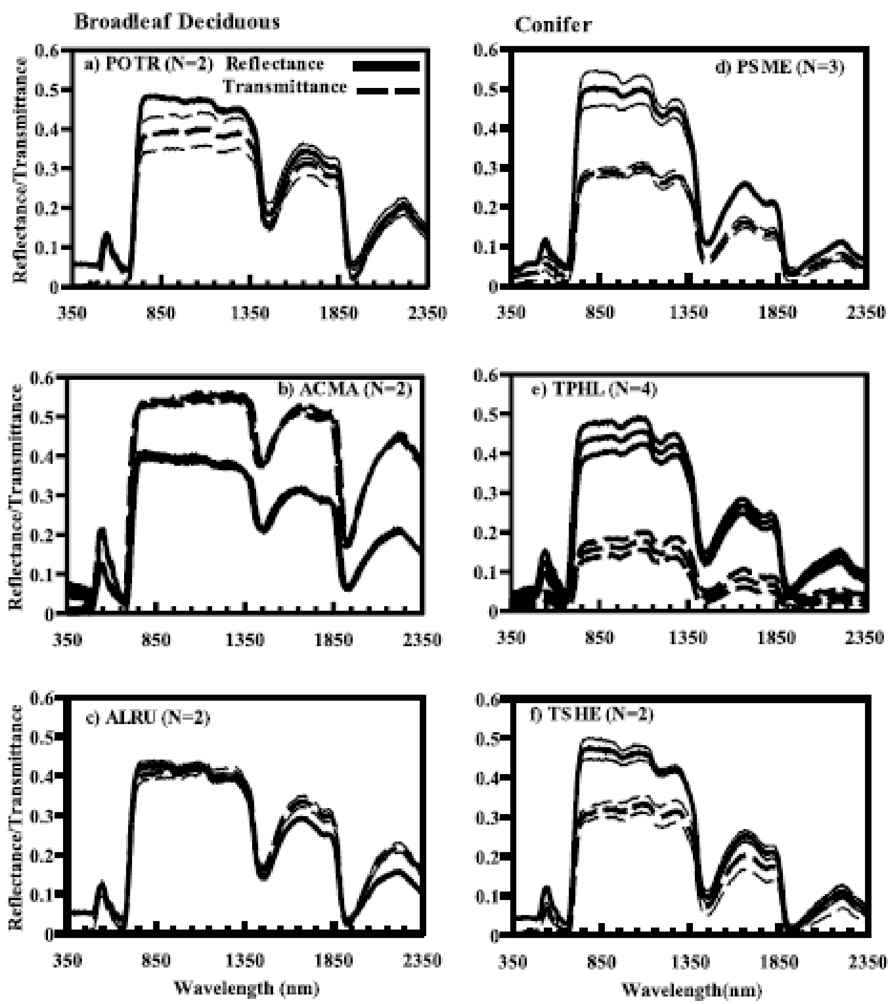

Figure 2. Leaf-level hemispherical reflectance and transmittance spectra of three broadleaf and three conifer dominants. Reflectance is plotted as a solid line; transmittance, as a dashed line. Plots show the mean ± SD. The number of spectra taken is shown in parentheses. Species names follow the codes in the text. POTR, *Populus trichocarpa;* ACMA, *Acer macrophyllum;* ALRU, *Alnus rubra;* PSME, *Pseudotsuga menziesii;* THPL, *Thuja plicata;* TSHE, *Tsuga heterophylla.*

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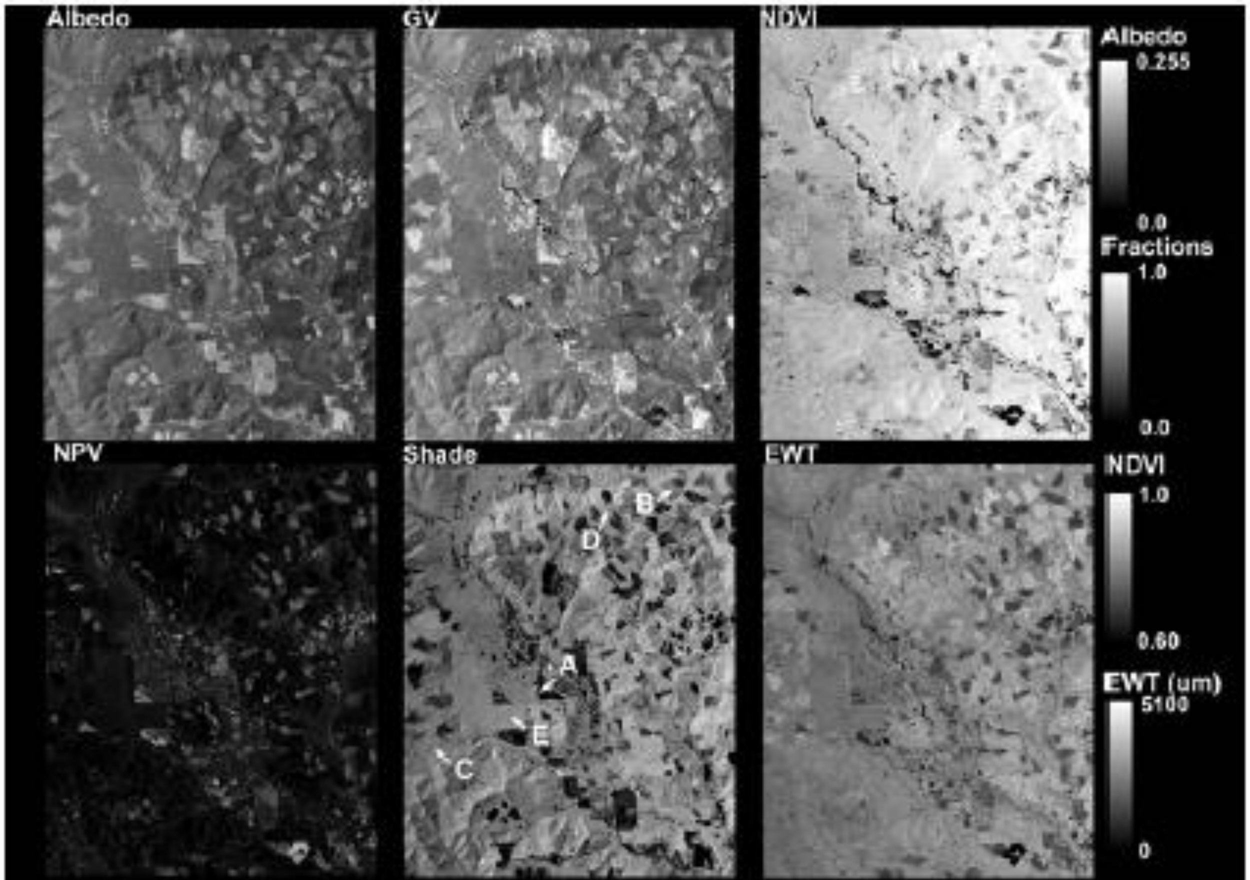

Figure 6. AVIRIS image data from a subset of the study site showing albedo, spectral fractions for non-photosynthetic vegetation (NPV), green vegetation (GV), and shade. The normalized difference vegetation index (NDVI), scaled between 0.6 and 1.0, and equivalent water thickness (EWT), scaled between 0 and 5,100, are shown to the right of spectral fractions. Five locations that represent a diversity of age classes are in the shade image. These stands are A) 8, B) 29, C) 70, D) 132, and E) 461 years old.