Chapter 2: Solar Radiation and Seasons

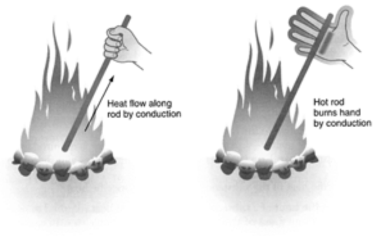
- Spectrum of Radiation
- Intensity and Peak Wavelength of Radiation
- Solar (shortwave) Radiation
- Terrestrial (longwave) Radiations

How to Change Air Temperature?

- **Add (remove) heat to (from) the air parcel (diabatic processes)**

(1) Conduction: requires touching
(2) Convection: Hot air rises
(3) Advection: horizontal movement of air
(4) Radiation: exchanging heat with space
(5) Latent heating: changing the phase of water

Conduction



- Conduction is the process of heat transfer from molecule to molecule.
- This energy transfer process requires contact.
- Air is a poor conductor. (with low thermal conductivity)
- Conduction is not an efficient mechanisms to transfer heat in the atmosphere on large spatial scales.

(from *Meteorology: Understanding the Atmosphere*)

Convection

- Convection is heat transfer by mass motion of a fluid (such as air or water).
- Convection is produced when the heated fluid moves away from the heat source and carries energy with it.
- Convection is an efficient mechanism of heat transfer for the atmosphere in some regions (such as the tropics) but is an inefficient mechanism in other regions (such as the polar regions).

(from *Meteorology: Understanding the Atmosphere*)

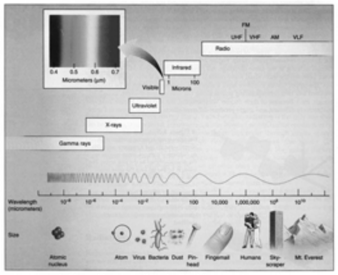
Radiation

- Radiation is heat transfer by the emission of electromagnetic waves which carry energy away from the emitting object.
- The solar energy moves through empty space from the Sun to the Earth and is the original energy source for Earth's weather and climate.

Importance of Radiation Transfer

- Virtually all the exchange of energy between the Earth and the rest of the universe takes place by radiation transfer.
- Radiation transfer is also a major way of energy transfer between the atmosphere and the underlying surface and between different layers of the atmosphere.

Spectrum of Radiation



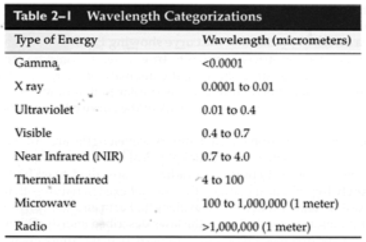


Table 2–1 Wavelength Categorizations

Type of Energy	Wavelength (micrometers)
Gamma	<0.0001
X ray	0.0001 to 0.01
Ultraviolet	0.01 to 0.4
Visible	0.4 to 0.7
Near Infrared (NIR)	0.7 to 4.0
Thermal Infrared	4 to 100
Microwave	100 to 1,000,000 (1 meter)
Radio	>1,000,000 (1 meter)

(from *Understanding Weather & Climate*)

- Radiation energy comes in an infinite number of wavelengths.
- We can divide these wavelengths into a few bands.

Micrometer (μm)

1 micrometer (μm) = 10^{-6} meter (m)

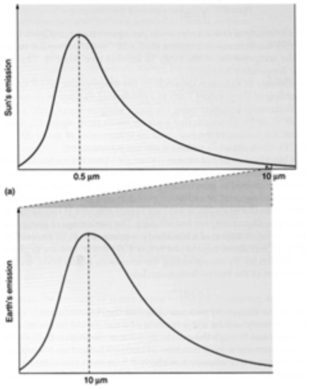
Planetary Energy Balance

Solar Energy Absorbed = Terrestrial Energy Emitted

⇩

Determine Earth's Surface Temperature

Solar and Terrestrial Radiation



(from *Understanding Weather & Climate*)

- ❑ All objectives radiate energy, not merely at one single wavelength but over a wide range of different wavelengths.
- ❑ The sun radiates more energy than the Earth.
- ❑ The greatest intensity of solar energy is radiated at a wavelength much shorter than that of the greatest energy emitted by the Earth.

Stefan-Boltzmann Law

$$\boxed{E = \sigma T^4}$$

E = radiation emitted in W/m^2

σ= 5.67 x 10^{-8} W/m^2 * K *sec

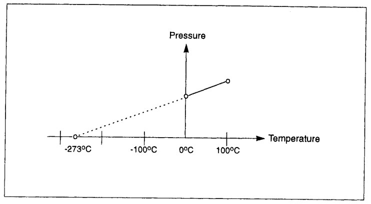
T = temperate (K ← ***Kevin degree***)

- ❑ The single factor that determine how much energy is emitted by a blackbody is its temperature.
- ❑ The intensity of energy radiated by a blackbody increases according to the fourth power of its absolute temperature.
- ❑ This relationship is called the Stefan-Boltzmann Law.

Units of Air Temperature

- ❑ Fahrenheit (ºF)
- ❑ Celsius (ºC) ➔ ºC = (ºF-32)/1.8
- ❑ Kelvin (K): a SI unit ➔ ºK= ºC+273

“*Absolute Zero*” Temperature



(from ***Is The Temperature Rising?***)

- The absolute zero temperature is the temperature that the molecules do not move at all.
- This temperature occurs at –273°C.
- The Kelvin Scale (K) is a new temperature scale that has its “zero” temperature at this absolute temperature:

K = °C + 273

Apply Stefan-Boltzmann Law To Sun and Earth

- **Sun**

  $E_s = (5.67 \times 10^{-8}\ W/m^2\ K^4) * (6000K)^4$

  $= 73{,}483{,}200\ W/m^2$

- **Earth**

  $E_e = (5.67 \times 10^{-8}\ W/m^2\ K^4) * (300K)^4$

  $= 459\ W/m^2$

- Sun emits about 160,000 times more radiation per unit area than the Earth because Sun’s temperature is about 20 times higher than Earth’s temperature.

  ➔ $20^4 = 160{,}000$

Wien’s Law

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

λ_{max} = wavelength (micrometers)

W = 2897 μm K

T = temperate (K)

- Wien’s law relates an objective’s maximum emitted wavelength of radiation to the objective’s temperature.
- It states that the wavelength of the maximum emitted radiation by an object is inversely proportional to the objective’s absolute temperature.

Apply Wien’s Law To Sun and Earth

- **Sun**

  $\lambda_{max} = 2898\ \mu m\ K / 6000K$

  $= 0.483\ \mu m$

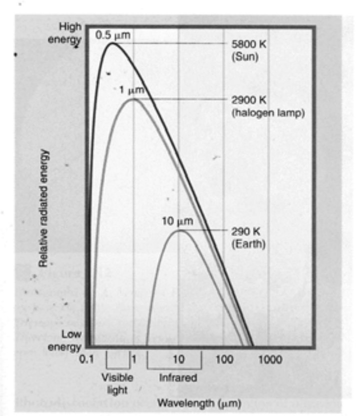
- **Earth**

  $\lambda_{max} = 2898\ \mu m\ K / 300K$

  $= 9.66\ \mu m$

- Sun radiates its maximum energy within the visible portion of the radiation spectrum, while Earth radiates its maximum energy in the infrared portion of the spectrum.

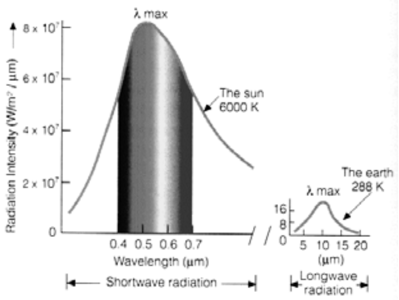
Wavelength and Temperature



- ☐ The hotter the objective, the shorter the wavelength of the peak radiation.

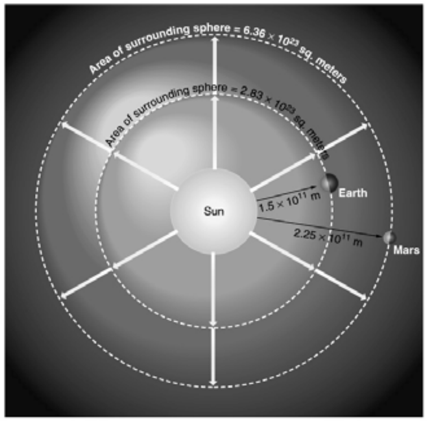
(from *Meteorology: Understanding the Atmosphere*)

Shortwave and Longwave Radiations



(from *Meteorology: Understanding the Atmosphere*)

- ☐ Solar radiation is often referred to as "shortwave radiation".
- ☐ Terrestrial radiation is referred to as "longwave radiation".



Solar Flux and Flux Density

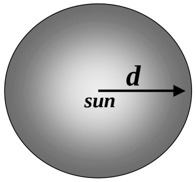
- ☐ Solar Luminosity (***L***)

  the constant flux of energy put out by the sun

$$L = 3.9 \times 10^{26} \quad \mathrm{W}$$

- ☐ Solar Flux Density (***S***)

  the amount of solar energy per unit area on a sphere centered at the Sun with a distance ***d***



$$S_d = L / (4 \pi d^2) \quad \mathrm{W/m^2}$$

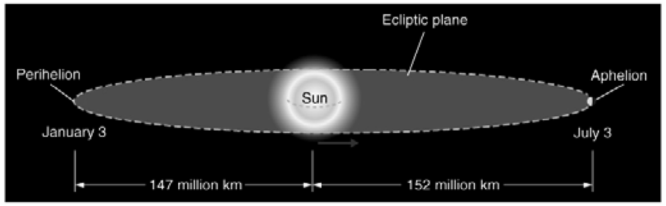
Solar Flux Density Reaching Earth

- ❑ Solar Constant (***S***)

  The solar energy density at the mean distance of Earth from the sun (1.5×10^{11} m)

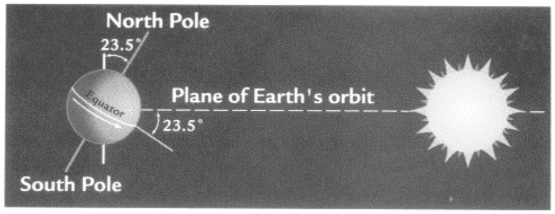
$$S = L / (4 \pi d^2)$$
$$= (3.9 \times 10^{26}\ \mathrm{W}) / [4 \times 3.14 \times (1.5 \times 10^{11}\ \mathrm{m})^2]$$
$$= 1370\ \mathrm{W/m^2}$$

Revolution



- ❑ Revolution
  - Earth revolves about the Sun along an ***ecliptic plane***
  - Total variation is about 3%
  - Using the inverse square law, radiation intensity varies by about 7% between perihelion and aphelion
  - This variation in radiation intensity is small and ***is not the cause of seasons.***

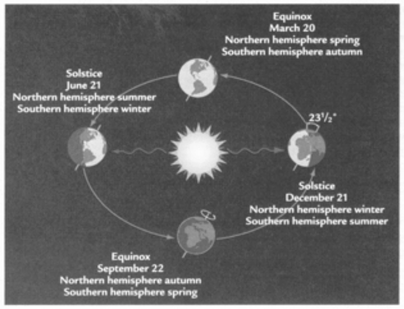
Tilt Produces Seasons



(from *Earth's Climate: Past and Future*)

- ❑ At present-day, the axis is tilted at an angle of 23.5°, referred to as Earth's "obliquity", or "tilt".
- ❑ The Sun moves back and forth through the year between 23.5°N and 23.5°S.
- ❑ Earth's 23.5° tilt also defines the 66.5° latitude of the Artic and Antarctic circles. No sunlight reaches latitudes higher than this in winter day.
- ❑ The tilt produces ***seasons***!!

Seasons and the Elliptical Orbit



Orbital changes All aspects of Earth's present-day orbit have changed with time: the tilt of its axis, the shape of its path around the Sun, and the positions of the seasons on this path. These changes in orbit have driven climatic changes on Earth. (Adapted from F. K. Lutgens and E. J. Tarbuck, *The Atmosphere* [Englewood Cliffs, N.J.: Prentice-Hall, 1992].)

- ❑ Seasons

  Solstices: mark the longest and shortest days of the years (June 21 and December 21 in the northern hemisphere, the reverse in the southern)

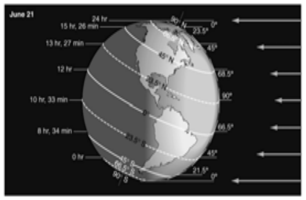
  Equinoxes: the length of night and day become equal in each hemisphere.

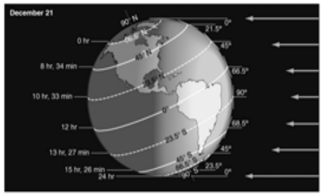
- ❑ At the present-day orbit, the winter and summer solstices differ from the aphelion and perihelion by about 13 days.

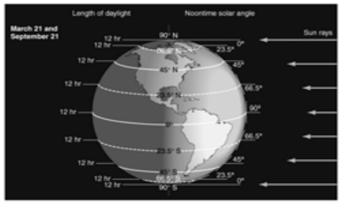
Three Ways the Tilt Affects Solar Heating to Earth

- ☐ Period of Daylight
- ☐ Solar Angle
- ☐ Atmospheric Bean Depletion

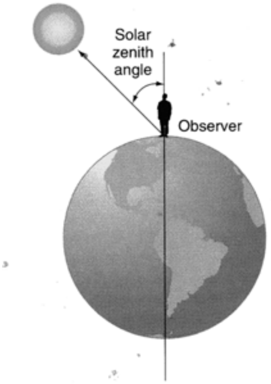
Period of Daylight







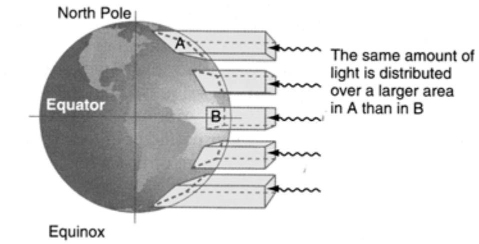
Solar Zenith Angle



- ☐ Solar zenith angle is the angle at which the sunlight strikes a particular location on Earth.
- ☐ This angle is 0° when the sun is directly overhead and increase as sun sets and reaches 90 ° when the sun is on the horizon.

(from *Meteorology: Understanding the Atmosphere*)

Solar Angle and Insolation



The same amount of light is distributed over a larger area in A than in B

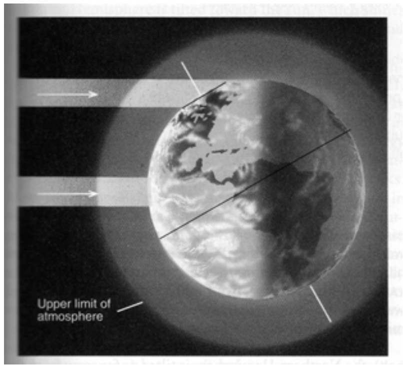
(from *Meteorology: Understanding the Atmosphere*)

- ☐ The larger the solar zenith angle, the weaker the insolation, because the same amount of sunlight has to be spread over a larger area.

How to Calculate Solar Angle?

- ❑ Solar angle = 90° - (solar zenith angle)
- ❑ Solar angle = (90° - latitude of the location) + solar declination
- ❑ Example for Toronto (located at 44°N)
  - In spring equinox (March 21)
    - solar declination = 0°
    - solar angle = (90° - 44°) + 0° = 46°
  - In summer solstice (June 21)
    - solar declination = 23.5°
    - solar angle = (90° - 44°) + 23.5° = 69.5°
  - In winter solstice (December 21)
    - solar declination = -23.5°
    - solar angle = (90° - 44°) + (-23.5°) = 22.5°

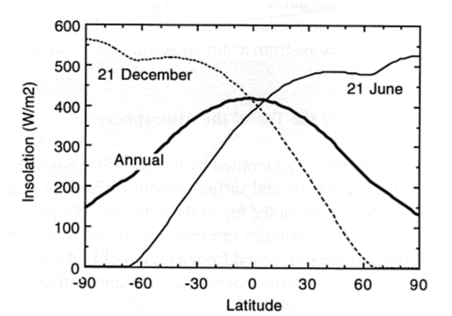
Atmospheric Bean Depletion



(from *Meteorology Today*)

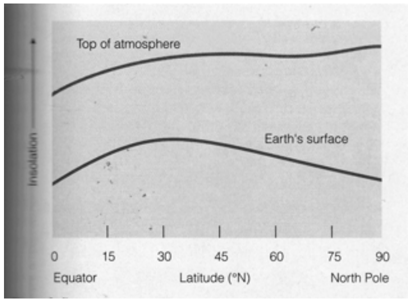
- ❑ When the zenith angle is large, sunlight has to pass through a thicker layer of the atmosphere before it reaches the surface.
- ❑ The thinker the atmospheric layer, more sunlight can be reflected or scattered back to the space.

Insolation at Top of Atmosphere



(from *Global Physical Climatology*)

Insolation in Summer Solstice



(from *Meteorology Today*)