ESCI 241 – Meteorology
Lesson 3 –Radiation

References: ***Meteorology Today*, Ahrens**

Reading: MT – Chapter 2

WAVE BASICS

- **Definitions**
  - ***Wave speed* (c) – speed of an individual trough or crest**
  - ***Wavelength* (λ) – distance between two adjacent troughs or crests**
  - ***Frequency* (ν) – number of troughs or crests which pass a fixed point in a unit of time (s^{-1})**
  - ***Angular frequency* (ω) - $2\pi\nu$ (rad s^{-1})**
  - ***Period* (T) – Time between two adjacent troughs or crest passing a fixed point. ($T = 1/\nu$).**
  - **Wave number (k) – $1/\lambda$ (m^{-1})**
- **Relationship between wave speed, wavelength, and frequency**

$$c = \nu\lambda$$

RADIATION

- **Radiation moves at a speed of $c = 3.0\times10^8$ m/s in a vacuum**
  - **Travels slower through matter**
  - **Index of refraction of a medium is speed in a vacuum divided by speed in the medium**
- **Electromagnetic spectrum**
  - **Visible light – 0.4 – 0.7 μm**
  - **Shortwave radiation – λ < 4μm**
  - **Longwave radiation – λ > 4μm**
- **The shorter the wavelength the greater the energy.**

- **Radiation Laws**
  - ***Planck's Law***

$$E_\lambda = \frac{c_1}{\lambda^5\left[\exp(c_2/\lambda T)-1\right]}$$

c_1 = 3.74×10^{-16} W m^2; c_2 = 1.44×10^{-2} m K

    - **E_λ has units of W-m^{-2} -μm^{-1}**
  - ***Stefan-Boltzmann Law***

$$E = \sigma T^4$$

$$\sigma = 5.67\times10^{-8}\ \text{W-m}^{-2}\text{-K}^{-4}$$

E has units of W-m^{-2}, and is the area under the curve given by Planck's Law

  - **Wien's Displacement Law**

$$\lambda_{\max} = \frac{2897\ \mu m\cdot K}{T}$$

    - **λ_{max} is wavelength where Planck curve is maximum**
- **As radiation passes through a medium it can be**
  - **Scattered**
  - **Reflected**
  - **Absorbed**

SCATTERING

- **There are two extreme scattering regimes**
  - **Rayleigh scattering – scattering particles are small compared to the wavelength of radiation.**
    - **Scattering increases greatly at small wavelengths**
    - **Blue light scattered the greatest (has shortest wavelength)**
    - **This is why sky is blue**
  - **Geometric scattering – scattering particles are large compared to the wavelength of radiation**
    - **Can use geometry and ray tracing to describe scattering.**
    - **Little wavelength dependence, so scattered sunlight appears white.**

        - **This is why clouds appear white.**

SOLAR (SHORTWAVE) RADIATION

- **Sun emits radiation at an emission temperature of 6000 K.**
  - **Maximum emission is in the visible wavelengths.**
  - **88% of energy is emitted at wavelengths less than 1.5 μm**
- **Fate of incoming solar radiation**
  - **30% reflected back to space**
    - **Fraction reflected is known as the albedo**
  - **19% absorbed by atmosphere and clouds**
  - **51% absorbed by ground**
- **Important gases for absorption of solar radiation**
  - **Ozone (O_3)**
  - **Oxygen (O_2)**

TERRESTRIAL (LONGWAVE) RADIATION

- **Earth's surface emits radiation at a temperature of 288 K**
  - **Maximum emission is in the near infrared.**
  - **Almost all emission is between 5 and 25 μm**
- **Fate of outgoing terrestrial radiation**
  - **There is little scattering of LW radiation**
  - **Some is absorbed by atmosphere, and reradiated in all directions (including back toward the ground).**
- **Important gases for absorption of LW radiation**
  - **Ozone (O_3)**
  - **Water vapor (H_2O)**
  - **Carbon dioxide (CO_2)**
  - **Nitrous oxide (N_2O)**

RADIATION BALANCE

- **In order to remain at a constant temperature, an object must emit the same amount of energy that it receives**
- **The amount of solar energy absorbed by the earth and its atmosphere is**

$$E_{solar} = \pi R^2 \times S \times (1-\alpha)$$

  - ***S* is the radiation flux at the top of the atmosphere, and is called the *solar constant*. It has units of W-m^2.**
  - **α is the albedo**

- **The amount of energy radiated by the earth and its atmosphere is**

$$E_{earth} = 4\pi R^2 \times \sigma T^4$$

- **In order to be in equilibrium, E_{solar} must equal E_{earth}**

$$\pi R^2 S\,(1-\alpha) = 4\pi R^2 \sigma T^4$$

which can be solved for *T* to get

$$T = \sqrt[4]{\frac{S(1-\alpha)}{4\sigma}}$$

Radiation temperature of earth

EXERCISES

1. **Blue light has a wavelength of 0.48μm.**
   a. **What is its frequency?**
   b. **What is its angular frequency?**
   c. **What is its wave number?**

2. **The Sun radiates at a temperature of 6000K.**
   a. **Use the Stefan-Boltzmann law to find out how much energy per square meter it radiates?**
   b. **Use Wien's Law to find out at what wavelength it emits its peak radiation? What part of the spectrum is this in?**

3. **The Earth's surface radiates at a temperature of 288K.**
   a. **Use the Stefan-Boltzmann law to find out how much energy per square meter it radiates?**
   b. **Use Wien's Law to find out at what wavelength it emits its peak radiation? What part of the spectrum is this in?**

4. a. **Using the following values for the solar constant and albedo, find the radiation temperature of the Earth.** S **= 1368 W-m^2 and** α **= 0.3**

   b. **If the Earth became cloudier, would the radiation temperature increase or decrease? Why?**

   c. **If the Earth became cloudier, would the surface temperature increase or decrease? Why?**

5. **An increase in greenhouse gasses may cause the Earth's surface temperature to rise, but it won't necessarily change the radiation temperature. Why?**