ESCI 241 – Meteorology
Lesson 3 –Radiation

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}).**
    - **1 Hertz (Hz) is defined as one cycle or wave per second.**
  - ***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 ($\tilde{\nu}$) – $1/\lambda$ (m^{-1})**
  - **Angular wave number (k) - $2\pi/\lambda$ (rad m^{-1})**
- **Relationship between wave speed, wavelength, and frequency**

$$c = \nu\lambda \qquad (1)$$

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 – $\lambda < 4\mu m$**
  - **Longwave radiation – $\lambda > 4\mu m$**
- **The shorter the wavelength the greater the energy.**

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

$$E_\lambda = \frac{c_1}{\lambda^5\left[\exp(c_2/\lambda T) - 1\right]} \tag{2}$$

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***

$$E = \sigma T^4 \tag{3}$$

where $\sigma = 5.67\times10^{-8}$ W m^{-2} 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**

$$\lambda_{\max} = \frac{2897\,\mu\text{m K}}{T} \tag{4}$$

    - **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 approximately as a black body at a temperature of about 6000K (5778 K is closest fit).**
    - **Maximum emission is in the visible wavelengths.**
    - **Measured peak is at 0.46 μm (blue light)**
    - **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**

$$E_{solar} = \pi R^2 \times S \times (1 - \alpha) \qquad \textbf{(5)}$$

    - ***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**

$$E_{earth} = 4\pi R^2 \times \sigma T^4 \qquad \textbf{(6)}$$

- **In order to be in equilibrium, E_{solar} must equal E_{earth}, so equating (5) and (6) we get**

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

which can be solved for *T* to get

$$T = \sqrt[4]{\frac{S(1 - \alpha)}{4\sigma}} \qquad \textit{Radiation temperature of earth} \qquad \textbf{(7)}$$

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 about 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?