Electromagnetic Radiation: Interactions in the Atmosphere
Outline for 4/7/2003

- EMR interaction with matter
- Atmospheric attenuation
- Atmospheric “windows”
Electromagnetic Radiation Interactions with Matter

- Radiation is
  - transmitted ($t$)
  - reflected ($r$)
  - absorbed ($a$)

Radiation Budget Equation:

$$ F_i = r + t + a $$
– incident radiation passes through the material without attenuation

– change in the direction of radiation is given by the index of refraction of the material

Index of refraction (n) is the ratio of the speed of light in a vacuum relative to the speed of light through the material

\[ n = \frac{c}{c_n} \]

Snell’s Law describes refraction angles:

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]
Absorption
the material is opaque to incident radiation
a portion of EMR is converted to heat (re-radiated)
Reflection

- diffuse reflection (rough surface)
- specular reflection (smooth surface)
Atmospheric Effects

- EMR is attenuated by its passage through the atmosphere

Attenuation = scattering + absorption
- Scattering is the redirection of radiation by reflection and refraction
- Attenuation is wavelength dependent
Atmospheric Scattering

• Rayleigh Scattering (molecular scattering)
  – scattering by molecules and particles whose diameters are << wavelength
  – primarily due to oxygen and nitrogen molecules
  – scattering intensity is proportional to $\lambda^{-4}$
  – responsible for blue sky
A Clear Blue Sky

Blue radiation (\( \lambda = 0.46 \))
Red radiation (\( \lambda = 0.66 \))

\[
\frac{0.66}{0.46}^4 = 4.24
\]

Blue is scattered 4 \( \Box \) more than red radiation
Atmospheric Scattering

• Mie Scattering
  – particles that have a mean diameter 0.1 to 10 times the incident wavelength
  – examples: water vapor, smoke particles, fine dust
  – scattering intensity is proportional to $l^{-4}$ to $l^{0}$
    (depending on particle diameter)

• Clear atmosphere has both Rayleigh and Mie scattering. Their combined influence is between $l^{-0.7}$ to $l^{2}$
Red Sky at Night

- At sunset, solar radiation must traverse a longer path through the atmosphere. Viewing a setting sun, the energy reaching the observer is largely depleted of blue radiation, leaving mostly red wavelengths (Rayleigh). Dust/smoke adds additional scattering with a wavelength dependence that increases the red sky effect (Mie).
• Non-selective Scattering
  – aerosol particles much larger than the wavelength (> 10x)
  – examples: water droplets, ice crystals, volcanic ash, smog
  – independent of wavelength: $\sigma^0$
Atmospheric Scattering

Rayleigh Scattering

a.  Circle Gas molecule

Mie Scattering

b.  Circle Smoke, dust

Non-selective Scattering

c.  Circle Water vapor

Photon of electromagnetic energy modeled as a wave

Types of scattering encountered in the atmosphere. The type of scattering is a function of 1) the wavelength of the incident radiant energy, and 2) the size of the gas molecule, dust particle, and/or water vapor droplet encountered.
Atmospheric Absorption

In the atmosphere EMR is primarily absorbed by

- $\text{H}_2\text{O}$  water vapor, water droplets
- $\text{CO}_2$  carbon dioxide
- $\text{O}_2$  oxygen
- $\text{O}_3$  ozone
- dust
Atmospheric Attenuation Demo
Absorption

- Vibrational process
  - small displacements of the atoms from their equilibrium position
  - N atoms $\rightarrow$ 3N possible vibrational modes

\[
\begin{align*}
\Delta_1 &= 3.106 \text{ m} \\
\Delta_2 &= 6.08 \text{ m} \\
\Delta_3 &= 2.903 \text{ m}
\end{align*}
\]
Water Vapor Absorption

- The water molecule has three classical frequencies \( n_1, n_2, n_3 \) that correspond to the three wavelengths:
  \( n_1 \) 3.106 mm (symmetric OH stretch)
  \( n_2 \) 6.08 (HOH bend)
  \( n_3 \) 2.903 mm (asymmetric OH stretch)

An example of combination: \( \frac{1}{\lambda} = \frac{1}{\lambda_2} + \frac{1}{\lambda_3} \)
\[
\frac{1}{\lambda} = \frac{1}{\lambda_2} + \frac{1}{\lambda_3} = \frac{1}{6.08} + \frac{1}{2.903}
\]
\( \lambda = 1.87 \) m
Gamma Rays, X-Rays and Ultraviolet Light blocked by the upper atmosphere (best observed from space).

Visible Light observable from Earth, with some atmospheric distortion.

Most of the Infrared spectrum absorbed by atmospheric gasses (best observed from space).

Radio Waves observable from Earth.

Long-wavelength Radio Waves blocked.
Atmospheric Windows

• Regions in the EM spectrum where energy can be fully transmitted

0.3-0.7 μm  UV and visible light
3-5 μm  emitted thermal energy from Earth
8-11 μm  emitted thermal energy from Earth
1 mm-1 m  radar and microwave energy