Scattering

Supplemental Reading: Petit 2.1 Kidd & Vonder Haar ch 3.5

Two kinds of treatment of the atmosphere:

1. Crudely treated as a translucent, gray, isothermal "SURFACE"
   - do some simple radiation budget calculations.
   - reflection, refraction, absorption, and emission.

2. Real atmosphere containing various types of particulates ranging from aerosols, water droplets, ice crystals, to raindrops, snowflakes, and hailstones.
   - In real atmosphere, we need to consider Scattering in order to do radiative transfer calculations.

   ![Diagram of scattering](attachment:image.png)

   - Physical processes important for real atmosphere radiative transfer calculations: Emission, Absorption, and Scattering (when we want to calculate transmission).
   - Reflection / Albedo is important when for simple radiation budget calculations and for satellite remote sensing (enstruments).

Scattering:

- is a physical process by which a particle in the path of an EM wave continuously absorb energy from the incident wave and re-emits that energy in all directions.

Examples: cloud, sky, land, water & surfaces.
Size matters: 1) particles that are far smaller than the wavelength will scatter very weakly; (still have absorption though)
2) If the particle is very large compared to the wavelength of the radiator, then only reflection, refraction, and absorption matter.
3) However, many particles in the atmosphere fall in between the above two extremes. For these particles, more complex methods are needed in order to compute their scattering and absorption properties.

Size parameter: \[ \chi = \frac{2 \pi r}{\lambda} \]

where \( r \) is the radius of a spherical particle (for non-spherical particles, \( r_e = \frac{3V}{4 \pi} \), which is the effective radius of a sphere having the same volume); \( \lambda \) is wavelength.
\( \chi \) is non-dimensional.

Three Scattering Regimes (arbitrary boundaries)

Petyt Fig 12.1
Rayleigh Scattering: \( 200 < \chi < 0.2 \) \((x < 1)\)
Mie Scattering: \( 0.2 < \chi < 2000 \) \((x \approx 1)\)
Geometric Optics: \( \chi > 50 \) (Petty) \( \chi > 2000 \) (Wallace & Hobbs)
Angular distribution of scattering:

Rayleigh scattering: back scatter & forward scatter are almost equal.

Mie Scattering: when the particle becomes larger, the scattered energy becomes increasingly concentrated in the forward direction.

Scattering cross section $I_x$:

is defined as the fractional area removed from a pencil radiation through scattering.

This definition is similar to the absorption cross section.

If considering only scattering:

$$\frac{dI_x}{I_x} = -e \sigma_{sa} ds$$

the fractional energy scattered (removed) from a pencil of radiation is proportional to the mass traversed by the radiation.

Combination effects of absorption & scattering:

Extinction = absorption + scattering

Extinction cross section $I_{ext} = \sigma_{sa} + \sigma_{se}$

Extinction coefficient $\beta_{ext} = \Delta I_x / I_x$

Lambert's Law for extinction: (replace $\sigma_{sa}$ with $\sigma_{ext}$)

$$\frac{dI_x}{I_x} = -e \sigma_{ext} ds$$

$$I_x(s) = I_x(0) \exp \left(-\int_0^s e \sigma_{ext} ds' \right)$$

$$= I_x(0) \exp \left(-\int_0^s \beta_{ext} ds' \right)$$