

Atmospheric optical properties

Atmospheric optical properties

- Optical properties associated with radiative transfer equation
- Optical properties – optical depth, single scattering albedo, phase function – determined by the particles that compose the medium & their properties

Molecular particles

- Molecular particles in atmosphere far smaller than the wavelength, scattering follows Rayleigh scattering law
- Spherical particles
 - Scattering depends on refractive index & the size parameter defined as:
$$\chi = 2 \pi r / \lambda$$
 - where r = radius of the sphere

Rayleigh scattering

- If χ is smaller than 0.01 – Rayleigh scattering formulas are valid
 - Section 2.3.1
- Single scattering albedo ω for Rayleigh particles is 1

Rayleigh scattering

- Main variable is optical depth – stable in a global sense, depends mainly on the elevation
 - Optical depth decreases quickly as wavelength increases (Fig. 2.4)
- Best to take into account at the shorter wavelengths (B-G-R visible spectrum)

Mie scattering

- Particle size close to the wavelength, $0.1 < \chi < 50$, most aerosol particles in the atmosphere
 - Scattering behavior follows Mie theory

Atmospheric aerosols

- Originate from many different sources, mainly from 2 processes
 - Dispersion of materials from Earth's surface
 - Atmospheric chemical reactions or condensation or coagulation processes
- Example aerosols:
 - sea-salt particles from ocean, wind-blown mineral particles (desert dust, sulfate, nitrate aerosols resulting from gas-particle conversion, organic materials, carbonaceous substance from biomass burning, industrial combustions)

Atmospheric aerosols

- Aerosols remain in lower boundary layer of atmosphere, can be transported to higher altitudes

Radiative transfer equation

- To solve radiative transfer eq. – need only the phase function ($P(\mu)$) and the single scattering albedo ω – outputs of Mie code (see CD-ROM)
- Group of particles – need to specify the particle size distribution function $f(r)$

Aerosol particle size distributions

- Aerosol particle sizes are not identical
- Radii represented by:
 - Power-law function, modified gamma distribution function, lognormal distribution function
 - $n(r) dr$ – number of particles per unit volume in the size range r to $r + dr$

Aerosol particle size distributions

- Most aerosol particles are characterized by the lognormal distribution
- Surface fog & mineral dust follow a power-law size distribution

Mie scattering

- Particles much larger than the wavelength ($\chi > 50$), Mie calculation is very time-consuming
- Ray tracing method from geometric optics is appealing – simple & much faster
 - By tracing all the rays – calculate the single scattering albedo and the phase function (fig. 2.6)

Nonspherical particles

- Classified into 3 categories
 - Polyhedral solids
 - Stochastically rough particles
 - Stochastic aggregates
- Soot particles – highly nonspherical, results from biomass burning & human activities

Nonspherical particles

- Calculate scattering properties
- Treat a nonspherical particle as a sphere with an equivalent diameter – use Mie theory
 - Volume diameter
 - Surface diameter
 - Surface volume diameter
- Develop more rigorous computations
 - Small particles – T-matrix algorithm
 - Large particles (ice crystals) – ray-tracing methods

Refractive index for each aerosol type

- Quite variable in space & time
- EOS sensors – MODIS & MISR – are providing answers
- Commonly assign certain values to each individual aerosol type based on airborne observations & other measurements (Tables 2.3, 2.4; Fig. 2.7)
- Coarser the aerosol particles, greater will be the peak of the phase function near the zero phase angle that represents strong forward scattering

Gas absorption

- Caused by atmospheric gases – water vapor, ozone, oxygen, aerosols
- Aerosol absorption accounted for by the single scattering albedo
 - If $\omega = 1$, aerosols not absorptive
- Most gases stable in both time and space
 - Ozone in stratosphere (~20-50 km above surface)
 - CO₂ well mixed with other dry gases, except near sources (big cities, forest fires)
 - Water vapor – most variable – in boundary layer (lowest 1-2 km)

Solving radiative transfer equations

- Sections 2.4.2, 2.4.3
 - Numerical methods (calculate diffuse radiation field)
 - Method of successive orders of scattering
 - Method of discrete ordinates
 - Approximate method (calculate radiant flux – irradiance) to solve radiative transfer equations
 - Two-stream algorithms
- Typical radiative transfer algorithms – Table 2.10

Surface BRDF

- Lambertian surface – isotropic reflectance
- Most surfaces reflect anisotropically
 - Need to make approximations for surfaces characterized by BRDF
 - Section 2.5 – once calculate, surface reflectance matrix can be determined
- Numerical & approximate solutions to radiative transfer equations
 - 6S algorithm



Summary

- Atmosphere modulates surface signals twice
 - Atmosphere affects the distribution of the incoming solar radiation at surface – related to surface reflectance
 - Solar radiation reflected by surface is further scattered & absorbed by the atmosphere before reaching the sensor