1 Atmospheric optical properties

2 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

3 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

4 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

5 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)

6 Mie scattering

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

7 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

8 Atmospheric aerosols

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

9 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 $f(r)$

10 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 $r + dr$

11 Aerosol particle size distributions

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

12 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)

13 Nonspherical particles

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

14 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

15 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

16 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)
  - CO_2 well mixed with other dry gases, except near sources (big cities, forest fires)
  - Water vapor – most variable – in boundary layer (lowest 1-2 km)

17 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

18 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

19 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