ATMS 533. Atmospheric Radiation II Autumn 2013

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COURSE DESCRIPTION

(a) Radiative transfer: methods for solving the radiative transfer equation including scattering.

(b) Scattering and absorption of light by small atmospheric particles: Rayleigh scattering, Mie theory.

A particular application emphasized in the course is the interaction of clouds with solar radiation.

Prerequisite: (1) undergraduate electricity and magnetism.
(2) ATMS 532 is highly desirable.

COURSE OUTLINE

A. Radiative Transfer

1. Definitions and radiation quantities
2. Radiative transfer equation (r.t.e.)
3. Formal solution of r.t.e.
4. Plane-parallel form of r.t.e.
5. Azimuthally-averaged r.t.e.
6. Integral equation for source function
7. Monte-Carlo method
8. Representation of anisotropic phase functions in r.t.e.
9. r.t.e. for plane-parallel atmosphere illuminated by direct solar beam.
10. Two-stream method
11. Eddington method for multi-layer atmosphere
12. Phase function truncation
13. Doubling method
14. Discrete ordinates method

B. Single Scattering

1. Review of electromagnetic theory
2. Polarized light
3. Reflection at an interface
4. Theory of optical constants
5. Rayleigh scattering
6. Mie theory
7. Results of Mie theory
8. Nonspherical particles

TEXTBOOKS

Petty, G.W., 2006: *A First Course in Atmospheric Radiation.* Sundog Publishing.

Thomas, G., and K. Stamnes. *Radiative Transfer in the Atmosphere and Ocean*. Cambridge Univ. Press, 1999.

REFERENCE BOOKS

A. General

Liou, K.N. *An Introduction to Atmospheric Radiation* (second edition). Academic Press, 2002.

Goody and Yung. *Atmospheric Radiation* (second edition). Oxford, 1989.

Bohren, C.F., and E.E. Clothiaux, 2006: *Fundamentals of Atmospheric Radiation.* Wiley.

B. Radiative transfer

Menzel, D.H. (ed.) *Selected Papers on the Transfer of Radiation.* Dover, 1966.

Chandrasekhar, S. *Radiative Transfer*. Dover, 1966.

Mihalas, D. *Stellar Atmospheres.* Freeman, 1978.

Kourganoff. *Basic Methods in Transfer Problems.* 1950.

C. Single Scattering

van de Hulst, H.C. *Light Scattering by Small Particles.* Dover, 1981.

Bohren, D.F., and D.R. Huffman. *Absorption and Scattering of Light by Small Particles.* Wiley, 1983.

Hansen, J.E., and L.D. Travis. "Light Scattering in planetary atmospheres" *Space Science Reviews*, **16**, 527- 610 (1974).

McCartney, E.J. *Optics of the Atmosphere.* Wiley, 1976.

D. Applications

Paltridge, G.W., and C.M.R. Platt. *Radiation Processes in Meteorology and Climatology*. Elsevier, 1976.

JOURNALS

Journal of Quantitative Spectroscopy and Radiative Transfer
Astrophysical Journal
Journal of the Atmospheric Sciences
Applied Optics

ASSIGNMENTS

homework problems (60%)

computer project (30%)

class participation (10%)

Applications

reflection, transmission and absorption of light by clouds, snow, and aerosols
solar albedo of clouds and surfaces
microwave and infrared emissivity of surfaces
radar reflectivity of raindrops and hailstones
remote sensing of Earth's atmosphere and surface by reflected solar radiation
Earth radiation budget: problems of sampling in time and angle
climatic effects of aerosols
parameterization of solar radiation in the atmosphere

Detailed list of topics

A. Multiple Scattering

1. Introduction
   Definition of terms: absorption, emission, scattering, incoherent radiation, plane-parallel atmosphere, direct problems and inverse problems
2. Radiative transfer equation
   Absorption coefficient, optical depth, transmittance, mean-free-path, scattering coefficient, emission coefficient, source function, phase function
   Examples of phase functions
   Single-scattering albedo, examples
   Examples of source function S
3. Formal solution of *r.t.e.*: solution of intensity in terms of source function
4. Plane-parallel form of r.t.e.
   Solutions of emergent intensity for specified source functions
   Limb brightening, limb darkening
5. Azimuthally-averaged r.t.e.
6. Milne's integral equation for source function
   Exponential integrals
   Iterative solution of integral equation (order-of-scattering series)
7. Monte-Carlo method; assign project.
8. Representation of anisotropic phase functions in r.t.e.
   Examples of phase functions for molecules, aerosols, cloud droplets
   Polynomial expansion of phase function
   Moments of phase function
   Henyey-Greenstein phase function
9. R.T.E. for plane-parallel atmosphere illuminated by direct solar beam
   Sign of μ
   Separation of direct and diffuse intensity
   Average over azimuth
   Polynomial expansion of azimuthally-averaged phase function
10. Two-stream method
    Backscattered fraction, relation to asymmetry factor
    Derivation of two-stream equations
    Examples of results
11. Eddington method for multi-layer atmosphere
12. Phase-function truncation
    Delta-Eddington method
    Delta-M
13. Doubling method
14. Discrete Ordinates Method

B. Single Scattering

1. Review of electromagnetic theory
    - Coulomb's law, electric field, Gauss's law, dipole moment, polarizability, polarization, electric displacement, electric susceptibility, permittivity, dielectric constant
    - Magnetic field, Biot-Savart law, current, magnetization, bound currents, displacement current, magnetic susceptibility, magnetic permeability, conductivity
    - Maxwell's equations
    - EM wave solution to Maxwell's equations
        - Complex relative permittivity, complex refractive index
    - Energy stored in EM field, energy transported by EM field
2. Polarized light
3. Reflection at an interface
4. Theory of optical constants: frequency-dependence of permittivity and conductivity
    - Examples of optical constants; variation with wavelength
5. Rayleigh scattering: derivation of dependence on wavelength, angle, polarization
6. Mie theory
    - Outline of derivation
    - Methods of computation
    - Heterogeneous particles; mixing rules
7. Results of Mie theory: examples from van de Hulst, Hansen & Travis
8. Nonspherical particles; representation by "equivalent spheres"