EMR Response: Soil & Snow

Soil & snow

- Lower boundary condition of vegetation canopies
- Important role in surface radiation budget – high albedo values

Soil

- Physical & chemical properties
  - Soil carbon, nutrition, phosphorus, bulk density & particle size distribution
- Needed in agricultural, ecological & hydrological models

Snow

- Geophysical properties
  - Snow-covered area, water equivalent & grain size
- Modeling soil & snow radiation – helps in developing the advanced algorithms to estimate their properties

Similarities of soils & snow

- Model bidirectional reflectance distribution functions of soils & snow
- Both characterizations of dense particulate media – densely packed
  - Models as spheroids
  - Surface roughness – order of mm to cm
  - Anisotropic diffuse & direct solar illumination irradiance

Single scattering properties of snow & soil

- Single particle scattering & absorbing quantities required for calculating multiple scattering
  - Single scattering albedo, ω, which represents the probability that light incident on a particle will be scattered
  - Particle scattering phase function $P(\theta)$, where θ is the scattering angle

Mie theory

- Mie scattering – large particles
  - Particle size is close to the length of the wavelength – $0.1 < \chi < 50$ – aerosol particles in the atmosphere
- Assume snow & soil particles can be modeled as spheres
  - Know the size distribution & refractive indices of components comprising the particulate media
- Use Mie theory to provide optical parameters of individual particles

Optical properties of snow

- Model as layered particulate medium composed of ice spheres in air
- Use refractive indices of ice and an optically equivalent ice sphere radius – Mie theory used to calculate single particle scattering & absorption

Mie theory

- Snow grains behave as spheres (or optically equivalent spheres)
- Snow grain radii – range in size from 50 μm for fresh, cold snow to 1000 μm representing wet snow or grain clusters

Optical property

- Spectral variation in the reflectance of snow in visible and near-infrared wavelengths – absorption coefficient (imaginary part of the refractive index) varies by 7 orders of magnitude at wavelengths 0.4-2.5 μm (Fig. 4.1)

Optical properties of soils

- Need to know mineral & organic components of the soil, relative fractions estimated
- Mie scattering theory – less successful for soils due to:
  - Particle size – much larger than the visible & near IR wavelengths ($\chi \sim 50$)
  - Particle shape – nonspherical shape of soil particles

Other approaches for soils

- Ray tracing approach
  - considers diffraction, reflection, refraction of a large particle
- Anomalous diffraction theory
- Method of complex angular momentum
- High-energy approximation

Multiple scattering solutions

- 3 categories of solutions
  - Approximate solutions
  - Numerical solutions
  - Geometric optical modeling
    - Can represent soil roughness effects

Approximate solutions

- Radiative transfer equations for snow – Warren & Wiscombe
  - 2-stream approximation – diffuse upwelling flux from either snow or soils

Snow

- Approximation characterizes the strong forward scatting of snow throughout the optical region
  - Physical depth & bulk density of snowpack affects scattering & absorbing properties via the optical depth, τ
  - Optical depth – dimensionless quantity
    - Snow – related to snowpack density, depth, snow grain size, and wavelength of observation

Snow: surface albedo depends

- Snow particle size
  - Increasing grain size affects albedo more in the NIR than visible
  - Albedo sensitive to grain size, 1.0-1.3 μm
- Water equivalence
  - Reflectance reduced as snow water equivalence (depth) decreases
- Solar zenith angle
  - Increased angles result in larger snow reflectance

Soil

- Hapke model of bidirectional reflectance
- Retrieve soil physical properties

Numerical solutions

- Use discrete ordinates & adding-doubling numerical methods – determine bidirectional reflectance quantities of snow & soil

Geometric optical modeling

- Mathematical expressions used to describe the geometry of the surface – soils
- Bidirectional reflectance calculated from parameterizations of reflectance & transmittance of the 3-D objects that make up the scattering medium

Soil surface

- Simulate soil aggregates by cuboids
- Monte Carlo method – soil surface height varies periodically with the cosine function in 1 or more directions
- Opaque spheres in a regularly spaced grid over an isotropically scattered horizontal surface

Inversion of snow parameters

- Estimate snow parameters from RS data – snow albedo, snow grain size, equivalent water content

Snow grain size

- Primary parameter controlling broadband albedo
- Rate of change of grain growth is exponentially proportional to snow temperature
- Changes in grain size
  - Useful indicators of thermodynamic processes in snowpack
  - Can help identify ice sheet surface features
    - Melt areas, snow dunes, blue ice regions, indicates changes in snow energy balance

Snow grain size

- Snow reflectance in NIR wavelengths is sensitive to grain size
- In visible wavelengths, insensitive to grain size
- Snow reflectance strongly affected by the texture of the uppermost layer of the snow surface

Practical issues

- Snow and soil surface roughness
- Soil inversion with ancillary information
- Soil moisture conditions