






Introduction to Spectral Reflectance (passive sensors)







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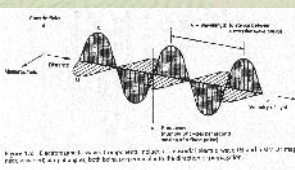
Overview





- Electromagnetic Radiation (light)
- Solar Energy Interactions
- Solar Energy Paths
- Spectral Reflectance and Factors Affecting
- Spectral Reflectance Sensors
- Instrument Calibration Options
- Spectral Data Analysis Options

Electromagnetic Radiation (light)

- Wave-particle duality
- Light behaves as waves
 - Describes light movement
 - $c = v \lambda$: Speed of light = frequency * wavelength
- Light behaves as particles
 - Interaction with matter
 - $Q = h v = h c \lambda^{-1}$
 - Quantum energy = Plank's constant * frequency



The Electromagnetic Spectrum

- Visible Light – 400 – 700 nm
- Near Infrared – 700 – 1000 nm
- Mid Infrared – 1000 – 2500 nm

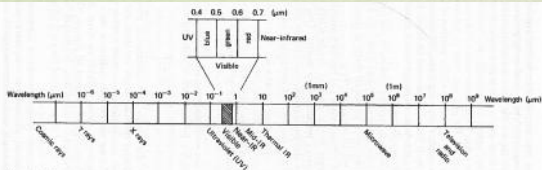


Figure 1.3. Electromagnetic spectrum.



Solar Irradiation

- Solar Energy
 - Light source for passive RS
 - All matter emits radiation
 - Stephan-Boltzman law
 - Radiance ~ (Temperature)⁴
 - Emittance varies with λ
- Earth's atmosphere
 - Scatters solar energy
 - Results in sky color
 - Absorbs solar energy
 - Varies with wavelength
- Sensitivity of detectors

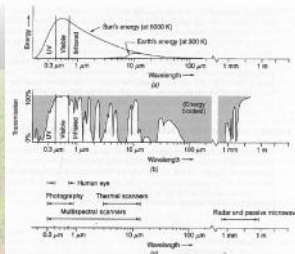


Figure 1.6. Spectral characteristics of (a) energy source, (b) atmospheric transmittance, and (c) common remote sensing systems. (Note that wavelength scale is logarithmic.)



Solar Energy Paths: Source to Sensor

- Incident E
 - Direct “sunlight”
 - “Skylight”
 - Attenuated by atmosphere
- Radiance at sensor
 - Path radiance
 - Reflected radiance

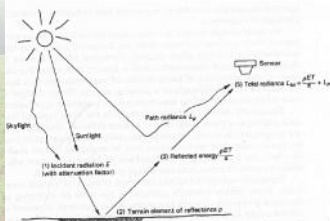


Figure 1.11 Atmospheric effects influencing the measurement of reflected solar energy. Attenuated sunlight and skylight (L_p) is reflected from a terrain element having reflectance ρ. The attenuated skylight reflected from the terrain element (E_{ref}) combines with the path radiance (L_p) to form the total radiance (L_{tot}) recorded by the sensor.



Radiant Energy Interactions

- Incident E = Reflected E + Absorbed E + Transmitted E
- % Reflected E = Reflected E / Incident E * 100
- Analogy to plant canopy with underlying soil background

Figure 1.6 Basic interactions between electromagnetic energy and an earth surface [adapted].

Specular vs. Diffuse Reflectance

- Surface roughness affects reflectance
- Specular reflectance
 - Smooth surfaces
 - Law of reflectance ($\theta_i = \theta_r$)
- Diffuse reflectance
 - Lambertian surface
 - Equal reflectance in all directions

Figure 1.7 Specular and diffuse reflectance. Specular reflection involves reflecting the incident rays at the same angle.

Reflectance of Vegetation and Soil

- Spectral "signatures"
 - Permits object identification
 - Reflectance pattern per wavelength
 - "Average" spectral response
- Vegetative reflectance
 - 450-670nm: Chlorophyll absorption
 - 700-1300nm: NIR scattering due to internal leaf structure
 - 1400,1900,2700nm: Water absorption bands
- Soil reflectance: moisture, texture, roughness, OM, Fe_2O_3
- Partial canopy reflectance

Figure 1.10 Typical spectral response curves for vegetation, soil, and water (adapted from Landsat and Landsat-2000).

Factors Affecting Measurements

- Illumination angle (solar zenith angle)
- Viewer angle
- BRDF: bidirectional reflectance distribution function
 - Summarizes reflectance at all illumination and viewer angles.

Figure 2. Coordinate system used in bidirectional leaf spectral property measurements. Light source is positioned at zenith angle θ_i defined by angle ACF and azimuth ϕ_i and the sensor is positioned at view zenith θ_r and azimuth ϕ_r . ABDE defines the principal plane. PCF defines the specular angle θ_s .

Factors Affecting Measurements

- Solar Trajectory
 - Changes with time of year
 - Solar zenith at a given time of day is not constant
- Issues with scheduling data collection time

Factors Affecting Measurements

- Canopy shadowing
 - Depends on solar zenith
 - Depends on leaf size and leaf orientation
- Row direction effects on soil shadows

Factors Affecting Measurements

- Atmospheric conditions
 - Cloud cover
 - Particulate matter
 - Wind
 - Dew
- Background materials
 - Soil color
 - Soil moisture
 - Soil properties
 - Crop residue



Passive Reflectance Sensors

- Exotech radiometer
 - Four broad wavebands
 - 500-600 nm
 - 600-700 nm
 - 700-800 nm
 - 800-1100 nm
 - Analog output (voltage)
 - Passive sensor
 - Mostly Obsolete




Passive Reflectance Sensors

- ASD FieldSpec spectroradiometer
 - 2151 narrow wavebands
 - 350 nm to 2500 nm
 - 1 nm bandwidth
 - \$65,000
 - Risky to mount on vehicles



Passive Reflectance Sensors

- Ocean Optics Jaz spectroradiometers
 - 651 narrow wavebands
 - 350 nm to 1000 nm
 - 1 nm bandwidth
 - Lacks mid infrared bands
 - Expandable system
 - Four-spectrometer system with accessories: ~\$16,000



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Instrument Calibration Options

- Digital spectroradiometers
 - Record data as digital numbers (DNs)
 - Want either radiance ($W\ sr^{-1}\ m^{-2}$) or percent reflectance (%)
- Laboratory procedures
 - Usually performed by the instrument manufacturer
 - ASD: “NIST-traceable, 1000 W quartz-halogen lamp producing a known irradiance on a standardized Spectralon panel”
 - Produces a calibration file with data to convert instrument DN’s to radiance at each wavelength

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Instrument Calibration Techniques





- Field procedures (% reflectance)
- Spectralon panels
 - Labsphere, Inc.
 - Near Lambertian behavior
 - 99% reflectance
 - Must be well maintained
 - Regular panel measurements during field outings
- Cosine receptors
 - Attached to upward facing sensor
 - Requires at least two spectrometers



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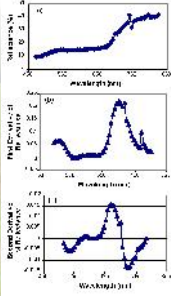
Spectral Data Analysis Options





- Broad band vegetation indices
 - Equations based on reflectance at specific wavelengths
 - Correlated to canopy characteristics: vegetation cover, “greenness”, leaf area index, biomass, and yield.
 - Normalized Difference Vegetation Index (NDVI)
 - Most popular
 - $NDVI = (NIR - RED) / (NIR + RED)$
 - 40 known indices (Bannari et al., 1995)
- Narrow band vegetation indices
 - Since advent of hyperspectral systems
 - Number of two-band combinations for a 2151 band spectroradiometer = 2,312,325

Spectral Data Analysis Options





- Derivative Indices
 - Analyze curvature of hyperspectral data
 - Useful for analysis of “red edge”
- Singular value decomposition methods
 - Principal components regression
 - Partial least squares regression
 - Hyperspectral data reduction
 - Transform reflectance data into a few factors that maximize variability in the data
 - Regress factors with crop variables



Spectral Data Analysis Options

- Physical Modeling of Radiative Transfer
- PROSAIL
 - PROSPECT leaf optical properties model
 - SAIL canopy bidirectional reflectance model
- 14 input parameters
 - Leaf pigment content: C_{ab} , C_{cp} , C_{bp}
 - Leaf water content: C_w
 - Canopy architecture: C_m , N , LAI , θ_i
 - Solar geometry: solar zenith and azimuth, viewer zenith
 - Soil background
 - Hot spot size
- Output
 - Canopy bidirectional reflectance
 - 400 to 2500 nm in 1 nm increments

Active Reflectance Sensors

- Active Sensors
- Active Light Source
- Less sensitive to ambient light conditions
 - Cloud cover
 - Time of day issues
 - Canopy Shadows
- 2-3 bands
- Typically calculate a vegetative index