Introduction to Spectral Reflectance (passive sensors)

Kelly R. Thorp
Research Agricultural Engineer
USDA-ARS Arid-Land Agricultural Research Center

THE UNIVERSITY OF ARIZONA USDA KANSAS STATE UNIVERSITY

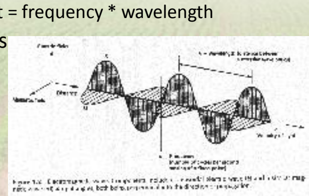
Overview

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

THE UNIVERSITY OF ARIZONA USDA KANSAS STATE UNIVERSITY

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 UNIVERSITY OF ARIZONA USDA KANSAS STATE UNIVERSITY

The Electromagnetic Spectrum

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

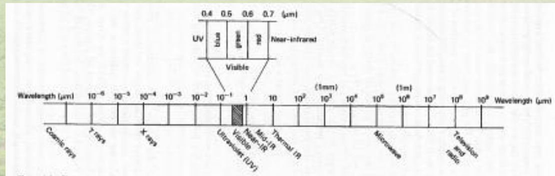


Figure 1.3 Electromagnetic spectrum.

THE UNIVERSITY OF ARIZONA · USDA · KANSAS STATE UNIVERSITY

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

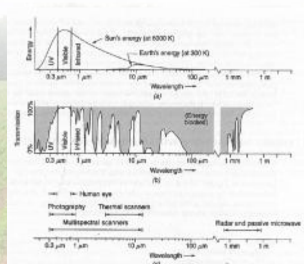


Figure 1.5 Spectral characteristics of (a) energy sources, (b) atmospheric transmittance, and (c) common remote sensing systems. (Note that wavelength scale is logarithmic.)

THE UNIVERSITY OF ARIZONA · USDA · KANSAS STATE UNIVERSITY

Solar Energy Paths: Source to Sensor

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

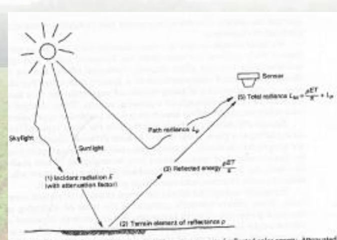


Figure 1.11 Atmospheric effects influencing the measurement of reflected solar energy. Attenuated sunlight and skylight (E) is reflected from a terrain element having reflectance ρ. The attenuated radiance reflected from the terrain element ($\rho ET/\pi$) combines with the path radiance (L_p) to form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

THE UNIVERSITY OF ARIZONA · USDA · KANSAS STATE UNIVERSITY

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

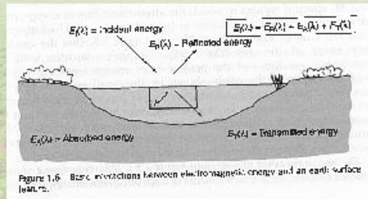
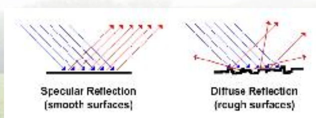


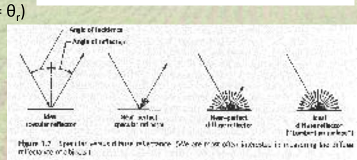
Figure 1.6 Basic interactions between electromagnetic energy and an earth surface feature.

THE UNIVERSITY OF ARIZONA USDA KANSAS STATE UNIVERSITY

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

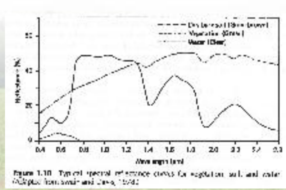




THE UNIVERSITY OF ARIZONA USDA KANSAS STATE UNIVERSITY

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

THE UNIVERSITY OF ARIZONA USDA KANSAS STATE UNIVERSITY

Factors Affecting Measurements

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

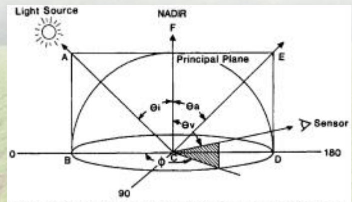
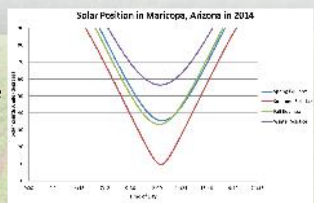


Figure 3. Coordinate system used in bidirectional leaf spectral property measurements. Light source is positioned at zenith angle θ_i defined by angle ACF and azimuth 0° and the sensor is positioned at view zenith θ_v and azimuth φ. ABDE defines the principal plane. FCE defines the specular angle, θ_s.

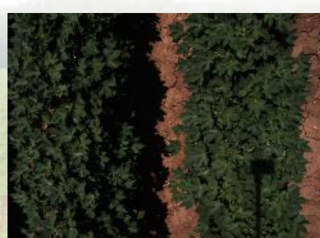
Factors Affecting Measurements

- 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

THE UNIVERSITY OF ARIZONA · USDA · KANSAS STATE UNIVERSITY

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

THE UNIVERSITY OF ARIZONA · USDA · KANSAS STATE UNIVERSITY

Passive Reflectance Sensors

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

THE UNIVERSITY OF ARIZONA · USDA · KANSAS STATE UNIVERSITY

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

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 DNs to radiance at each wavelength

Instrument Calibration Techniques

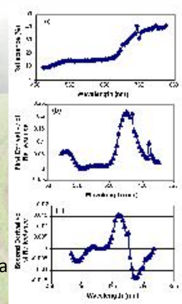
- Field procedures (% reflectance)
- Spectralon panels
  - Labsphere, Inc.
  - Near Lambertian behavior
  - 99% reflectance
  - Must be well maintained
  - Regular panel measurements during field outings
- Cosine receptors
  - Attached to upward facing sensor
  - Requires at least two spectrometers

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_{cr}, C_{bp}
  - Leaf water content: C_w
  - Canopy architecture: C_m, N, LAI, Θ_l
  - 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

THE UNIVERSITY OF ARIZONA USDA KANSAS STATE UNIVERSITY