Electromagnetic Radiation at the Earth’s Surface
Outline for 4/11/2003

- Scattering and absorption
- Spectral reflectance
- Definitions of radiant quantities
- “Following the energy”
- Photographic vs. Electro-optical systems
EMR at the Earth’s Surface

• Recall that energy can be transmitted, absorbed, or reflected (or some combination of the three)
• For remote sensing purposes, energy is not transmitted through the Earth
• So, at the surface we only consider absorption (and re-radiation) and reflection (scattering)
$E_I(\lambda) = \text{Incident energy}$

$E_R(\lambda) = \text{Reflected energy}$

$E_A(\lambda) = \text{Absorbed energy}$

$E_T(\lambda) = \text{Transmitted energy}$

Basic interactions between electromagnetic energy and an earth surface feature.
Specular Versus Diffuse Reflectance

The nature of specular and diffuse reflectance.
Anisotropic Scattering from Snow
Typical spectral reflectance curves for urban-suburban phenomena in the region 0.4 – 0.9 µm
<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Equation</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiant energy</td>
<td>(Q)</td>
<td></td>
<td>joule</td>
</tr>
<tr>
<td>Radiant energy density</td>
<td>(W)</td>
<td>(W = dQ/dv)</td>
<td>joule/m(^3)</td>
</tr>
<tr>
<td>Radiant flux</td>
<td>(\Phi)</td>
<td>(\Phi = dQ/dt)</td>
<td>watt, watt = joule/sec</td>
</tr>
<tr>
<td>Radiant flux density at a surface</td>
<td>(E) (irradiance)</td>
<td>(E = d\Phi/dA)</td>
<td>watt/m(^2)</td>
</tr>
<tr>
<td></td>
<td>(M) (emittance)</td>
<td>(M = d\Phi/dA)</td>
<td></td>
</tr>
<tr>
<td>Radiant intensity</td>
<td>(I)</td>
<td>(I = d\Phi/d\Phi)</td>
<td>watt/steradian</td>
</tr>
<tr>
<td>Radiance</td>
<td>(L)</td>
<td>(L = dI/(dA \cos\theta))</td>
<td>watt/steradian m(^2)</td>
</tr>
</tbody>
</table>

“d” means “the change in…”
So, \(dQ/dt\) means “the change in energy over time”
Concept of Radiant Flux Density

a. Irradiance
\[ E_\lambda = \frac{\Phi_\lambda}{A} \]

b. Exitance
\[ M_\lambda = \frac{\Phi_\lambda}{A} \]
The concept of radiance leaving a specific projected source area on the ground, in a specific direction, and within a specific solid angle. This is the most precise radiometric measurement used in remote sensing.
Path from Sun-to-Earth

\[ E_0 = \text{Top-of-Atmosphere solar irradiance (Wm}^{-2}) \]

- it passes through the atmosphere and is attenuated based on the atmospheric transmittance, \( t_q \), at a particular solar zenith angle
- it reaches the ground and is reduced by a factor of \( \cos q \), depending on the angle of incidence (solar zenith angle + slope)
- Thus, for a specified wavelength, the irradiance at the ground surface is:

\[ E_{g} = t_q E_0 \cos q \]
The cosine effect
Diffuse Sky Irradiance

- Some of the solar energy is scattered in the atmosphere and makes it down to the surface adding to the direct beam irradiance
- Some of the diffuse sky irradiance never reaches the surface but does reach the sensor
Reflection from the Surface

• Some energy is absorbed by the surface material
• Some is reflected depending on the spectral reflectance of the material
• The direction of reflectance is not uniform (more about this later)
Scattering from nearby terrain

- Some radiation is scattered from nearby surfaces into the field of view of the sensor without interacting with the target of interest.
- Some radiation is scattered from nearby surfaces and is reflected from the target of interest (change in spectral composition of radiation).
Back to the sensor

• Radiation reflected from the target area again passes through the atmosphere and is attenuated by atmospheric transmittance

• Radiation is also added by the components mentioned earlier: from atmospheric scattering and neighboring terrain scattering (neither of which has interacted with the target of interest)
Various Paths of Radiance Received by a Remote Sensing System

Solar irradiance $E_0$

Diffuse sky irradiance $E_d$

Total radiance at the sensor $L_s$

Reflectance from neighboring area, $r_{\lambda,\Omega}$

Reflectance from study area, $r_{\lambda}$

$T_{\theta_0}$

$T_{\theta_V}$

Atmosphere

Remote sensing system

$\theta_0$

$\theta_V$

90°
Why we care about this

• reflectance of the surface tells us about the nature of the material (reflectance, roughness, etc.)
• atmospheric effects obscure our ability to measure surface properties
• surrounding materials can also add some confusion about the nature of the surface
Principles of Detection

• Film (Analog)
• Digital systems
Photographic Systems vs. Electro-optical Systems

- Both can be used to create images
  - photography is non-scanning
  - electro-optical systems can be either scanning or non-scanning
- Both record interactions with radiation
  - film systems detect radiation through a chemical process
  - electro-optical systems detect radiation through an electrical system
- EMR detection capabilities are quite different
  - film is always passive, uses reflected sunlight, only works in the range of 0.4 - 1.0 μm
  - digital systems can be active or passive, can work in all parts of EM spectrum, high spectral resolution is possible, can be non-imaging system (e.g. altimeter)
Film Emulsions

• Black and White
  – Silver halide; grains are typically 1 μm in diameter
  – max. sensitivity from 0.4-0.5 μm
  – pan-chromatic film has a sensitivity range 0.35-0.65 μm

• Color
  – 3 layers of emulsion are used that are sensitive to different portions of the visible spectrum (blue, green, red)

• Color Infrared (CIR)
  – 3 layers of emulsion are used that are sensitive to green, red, near-infrared
  – max. near-infrared sensitivity at about 0.8 μm
Film Properties

• **Speed**
  – refers to length of time film must be exposed to a given irradiance to produce sufficient opacity

• **Contrast**
  – describes effect of changing the irradiance (or exposure time)

• **Resolution**
  – the ability of a photographic system to distinguish an extended object from a point
  – expressed as line pairs per unit length
  – detection vs. identification vs. analysis
a) A normal (natural) color photograph of Tivoli North Bay along the Hudson River in New York. Color aerial photography records blue, green, and red light reflected from the scene. A haze filter (HF3) is usually placed in front of the lens to prevent scattered ultraviolet light from reaching the film plane. Vegetation shows up in green hues because the plants absorb more blue and red incident light than green light. b) A color-infrared aerial photograph records green, red, and near-infrared light reflected from the scene. A yellow (Wratten 12) filter is usually placed in front of the lens to prevent blue light from reaching the film plane. The land-water interface is especially well-delineated because water absorbs most of the incident near-infrared radiant energy causing it to appear dark. Vegetation appears in magenta hues because healthy vegetation reflects substantial amounts of near-infrared radiant flux while absorbing much of the green and red incident energy (after Berglund, 1999).
Electro-Optical Systems

When the input is electromagnetic radiation

- Photons are typically recorded using a charge-coupled device (CCD)
- A CCD is formed from light-sensitive material embedded in a silicon chip (1-D or 2-D arrays)
- Exposure to EMR generates an electrical charge, proportional to the incident energy, at each element in the CCD array
Digital Image

Picture element (pixel) at location Line 4, Column 4, in Band 1 has a Brightness Value of 24, i.e., \( BV_{4,4,1} = 24 \).