Lecture 2 – Understanding Electromagnetic Radiation (EMR) Interactions

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Bldg Purple 12.3.09

Lecture Outline

• Revision
• Introduction to electromagnetic radiation (EMR)
• Wave and particle theory
• EMR interactions in the atmosphere
• From EMR interactions to imagery
• Spectral band combinations

Revision – What is Remote Sensing?

• The science and art of obtaining information about an object, area, or phenomenon, without being in direct contact with the feature under investigation

Revision - Why Use Remote Sensing?

• Large area coverage
• Synoptic view, continuous spatial coverage
• Information about hard to access areas
• Use sensors to ‘see’ in wavelengths not visible to human eye
• Make quantitative measurements about biogeophysical properties of earth’s surface
• Digital record of features and processes
• Repeat coverage
• Cost (field vs. image)

Resources


What is Electromagnetic Radiation?

• Any object with a temperature > 0 Kelvin emits electromagnetic radiation (EMR)
• Sunlight is a form of EMR
• Thermal energy (heat) is a form of EMR
• All EMR travels at the speed of light, but energy levels are different

http://www.abc.net.au/science/articles/2010/02/18/2817543.htm
The Electromagnetic Spectrum

EMR and Remote Sensing

EMR Interactions

EMR Principles and Properties
- Understanding how EMR interacts with the feature you are interested in is the basis for interpreting remotely sensed data
- This also enables you to select appropriate remotely sensed data
- Leads to visual & quantitative interpretation of images and other data sets to IDENTIFY features and MEASURE biophysical properties of interest

Ocean Colour and Vegetation Density

Ozone Hole Watch
Volcanic Gas & Ash

Sulphur Dioxide

Ash and Aerosols

Source: http://toms.umbc.edu/

EMR – Vegetation Interaction (Global to Leaf Scales)

Source: S. Phinn

EMR Wave and Particle Theories

- Any material with molecular motion (T > 0K) emits radiant energy
- Can earth surface features be differentiated based on the amount of EMR they emit?
- EMR radiates according to wave theory

\[ c = \nu \lambda \]

where

- \( c \) = speed of light (3x10^8 m.sec\(^{-1}\))
- \( \lambda \) = wavelength of EMR (\( \mu \)m = micro-m = 10^{-6} m)
- \( \nu \) = frequency of EMR (sec\(^{-1}\))

As \( c \) remains constant, if \( \nu \) increases, \( \lambda \) must decrease (and vice versa)

Electromagnetic Wave

Regions of the EMR Spectrum

- Wavelengths and the spectrum - EMR units
- Frequencies (instead of wavelengths as units?)
- Energy levels

EMR – Vegetation Interaction (Global to Leaf Scales)

Source: S. Phinn

Particle Theory

- EMR is composed of discrete units (photons or quanta)
- Determines energy level of EMR
- Planck’s equation for the EMR emitted at a specific wavelength and frequency:

\[ Q = h \nu \]

where

- \( Q \) = radiant energy of quanta (joules)
- \( h \) = Planck’s constant (6.626x10^{-34} joules.sec)
- \( \nu \) = frequency of EMR (sec\(^{-1}\))

Remember: \( c = \nu \lambda \)
Energy, Wavelength & Frequency

- Wavelength (inverse) and frequency (direct) relationships with EMR energy levels


Energy & Wavelength

- MIR TIR

EMR Units

- Airborne and satellite imaging systems record the amount of EMR being reflected or emitted from a target
- Amount of EMR reaching a sensor is in one of the following units:

<table>
<thead>
<tr>
<th>TERM</th>
<th>UNIT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>radiant energy</td>
<td>joule</td>
<td>energy per quanta</td>
</tr>
<tr>
<td>radiant flux</td>
<td>watt (joule.second^-1)</td>
<td>energy per unit time</td>
</tr>
<tr>
<td>Radiant flux density</td>
<td>watt.m^-2</td>
<td>incident flux per unit area over all angles</td>
</tr>
<tr>
<td>irradiance</td>
<td>watt.m^-2</td>
<td>incident flux per unit area at specific solid/3-D angle</td>
</tr>
<tr>
<td>radiance</td>
<td>watt.m^-2.sr^-1</td>
<td>incident flux per unit area at specific solid angle over a set range of wavelengths</td>
</tr>
<tr>
<td>spectral radiance</td>
<td>watt.m^-2.sr^-1</td>
<td>incident flux per unit area at specific angle over a set range of wavelengths</td>
</tr>
</tbody>
</table>

Source: S. Phinn

Stefan Boltzman Law

- Provides a basis for distinguishing objects based on measurements of emitted energy
- Temperature controls the amount of emitted energy from an object
- The amount of energy a blackbody radiates (M) is a function of its temperature (T)

\[ M = \sigma T^4 \]

- Emitted energy increases very quickly with increases in Temp

where,  
- \( M \) = total spectral radiant exitance (watts.m^-2)
- \( \sigma \) = Stefan-Boltzman constant (5.6697x10^-8 watts.m^-2.K^-4)
- \( T \) = temperature in K

- Note the threshold for reflection/emission is around 3µm, i.e. most EMR beyond this emitted, while EMR at < 3µm is reflected sunlight


Radiant energy

- Area under curves = total radiant energy
- High temperature = large total amount of emitted radiation
- As temp increases, peak emission shifts to shorter wavelengths
- Peak determined by Wien’s displacement law
Wien’s Displacement Law

• Use to select optimum wavelength of EMR for monitoring specific targets
• Wavelength of maximum emitted energy depends on an object’s temperature
• The wavelength (λ) of maximum spectral radiant exitance (M) is inversely related to its temperature (T):

$$\lambda_{\text{max}} = \frac{A}{T}$$

where,

- $\lambda_{\text{max}}$ = wavelength of maximum spectral radiant exitance (µm)
- $A$ = 2898 µm K
- $T$ = temperature in K

Higher temp = Shorter wavelength

Sources: Process Associates of America & Handbook of Chemistry & Physics, 1924

Recap

• As wavelengths decrease,
  – frequency increases (wave theory),
  – energy increases
• Emitted energy increases very quickly with increases in temperature (Stefan Boltzman Law)
• As temperatures increase, wavelength of maximum emitted energy decreases (Wien’s Displacement Law)

Conservation of Energy

• Need to understand this to interpret image data sets and measure processes responsible for absorption, reflection and transmission of EMR
• Controls on elements of image formation
• For any wavelength of EMR and incident amount of EMR ($E$) interacting with a surface:

$$E = E_{\text{Reflected}} + E_{\text{Transmitted}} + E_{\text{Absorbed}}$$

EMR Interactions

• Reflection
  – Re-direction of light striking non-transparent surface
  – Strength of reflection – type of surface
  – Diffuse – smooth
  – Specular (Lambertian) – rough
• Absorption
  – Energy of the photon is taken up by the feature and converted to other forms of energy (eg used for photosynthesis)
• Transmission
  – Light passing through material without much attenuation
  – Water most affected by transmission of light
  – Plant leaves

Reflectance

• Diffuse reflectance - uniform in all directions (Contains information on the characteristics of a target, by the nature of its interactions with EMR)
• Specular reflectance - mirror like / directional with no information on the characteristics of a target
• Accounts for amount of incoming radiation

Reflectance and Geometry

• Reflected EMR depends on angles of incident light and camera position

Reflectance and Geometry
EMR Interactions in the Atmosphere

- How does the atmosphere alter the "quality" of satellite/airborne images and aerial photographs?
- Identification of EMR interactions affecting an airborne or satellite image
- The effect of the atmosphere on the transmission of EMR to and from the earth's surface by scattering and absorption processes is a function of
  - Path length
  - EMR wavelength
  - Atmospheric conditions

Scattering

- Rayleigh
  - Particles smaller in diameter than the EMR wavelength
  - Inversely proportional to 4th power of wavelength
  - Air molecules scatter short wavelengths (blue sky)
- Mie
  - Particles equal in size to wavelength
  - Inversely proportional to 0.6-2nd power of wavelength
  - Water vapour, dust (haze), causes sky to take on reddish appearance
- Non-selective
  - Particles have greater dimensions than wavelength
  - Scatters all wavelengths
  - Water droplets and ice (fog and clouds), causes white appearance
- All scattering produces "additive path radiance"

Absorption

- Reduces the amount of incident solar radiation and reflected or emitted radiation traveling to the sensor
- Loss of EMR energy to atmospheric constituents
- Major absorbers: H₂O, CO₂, O₃, N₂, O, N
- Minor absorbers: NO, N₂O, CO, CH₄

Atmospheric Absorption Effects in Irradiance


Atmospheric Windows

- Regions of the EMR spectrum where there is limited absorption of EMR by atmospheric constituents.
- EMR reflected or transmitted through the atmosphere measured by sensors in these spectral regions.

Atmospheric Windows and Absorption Features

Source: A. Held, CSIRO and NASA-JPL
EMR Interactions with the Earth’s Surface

Spectral Radiance
- Spectral radiance or spectral radiant intensity \( L_\lambda \) is the amount of EMR incident on a surface, from a specific direction, in a specific wavelength.

Spectral Reflectance
- Spectral reflectance \( \rho_\lambda \) in a specific wavelength, is the ratio of the amount of EMR reflected from a surface (radiance) to the amount of EMR incident on a surface (irradiance).
\[
\rho_\lambda = \frac{\text{radiance} \_\lambda}{\text{irradiance} \_\lambda}
\]

Spectral Reflectance Curves and Signatures
- “Fingerprints” of different targets that can be used to identify them in remotely sensed images.
- Plot of the reflectance level in discrete wavelengths over all or a portion of the EMR spectrum for specific materials.
- Characteristic absorption, emission, reflectance or transmission levels of a target in specific EMR wavelengths.
- To separate cover types in images their spectral signatures must be different.

Recording EMR – Spectral Signatures

Remote Sensing Images Record EMR
**Layers to Colour Composites**

- **True Colour**: B,G,R
- **False Colour**: G,R,NIR
- **False Natural Colour**: G,NIR,MIR

**Interpreting Colour Composite Images**

- **Primary colours**:
  - Blue
  - Green
  - Red

- **Secondary colours**:
  - Magenta
  - Yellow
  - Cyan

- Bright = High reflection
- Dark = Low reflection (Absorption)

**Interpreting a Standard False Colour Composite Image**

<table>
<thead>
<tr>
<th>Colour</th>
<th>Interpretation (general)</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>Areas of maximum reflectance such as sandy beaches, sand dunes, bare ground, clouds and salt pans etc.</td>
</tr>
<tr>
<td>Yellow</td>
<td>Deserts, areas of minimum vegetation cover, overgrazed areas.</td>
</tr>
<tr>
<td>Red-Magenta</td>
<td>Red colour shades can be used to interpret the vigour and stages of growth of healthy vegetation, sugarcane, pastures, mangoes, pepper plant, rapeseed, rice, wheat. Note: Some vegetation could rapidly change its false colour through season or in response to drought, rain or diseases.</td>
</tr>
<tr>
<td>Pink-Red</td>
<td>Depicts hilly, mountainous areas, early growth stages in crops, grassland, suburban backyards</td>
</tr>
<tr>
<td>Brown</td>
<td>Rangelands, arid woodland and bare rocky areas</td>
</tr>
<tr>
<td>Light Green</td>
<td>Shallow water bodies, sediments in water, shrub land &amp; moist clay soils.</td>
</tr>
<tr>
<td>Dark Green</td>
<td>Shallow but clear water bodies, shallow red soils, burnt land</td>
</tr>
<tr>
<td>Blue to light blue</td>
<td>Shallow water bodies, sediments in water, shrub land &amp; moist clay soils.</td>
</tr>
<tr>
<td>Cyan</td>
<td>Concrete, urban areas, houses, roads, asphalt</td>
</tr>
<tr>
<td>Dark Blue</td>
<td>Areas of vegetation absorption: deep and clear water bodies, oceans, rivers, lakes and reservoirs, shadows of clouds and mountains</td>
</tr>
</tbody>
</table>

**Colour Display**

A

- Satellite Acquisition
- Band 1 - Blue
- Band 2 - Green
- Band 3 - Red
- Band 4 - NIR
- Band 5 - MIR
- Band 6 - MIR

B

- Satellite Acquisition
- Band 1 - Blue
- Band 2 - Green
- Band 3 - Red
- Band 4 - NIR
- Band 5 - MIR
- Band 6 - MIR

**Coming Up**

- Practical this week – Image characteristics and dimensions (Assessable)
- Lecture next week – Radiation transfer theory