Carleton UNIVERSITY

GEOM 3002 - Lecture 5

The Physical Basis for Remote Sensing

- Electromagnetic Radiation
- Spectral Reflectance

Readings

Lillesand et al. 2015: Ch. 1.2-1.4, 1.6; Appendix A (online)

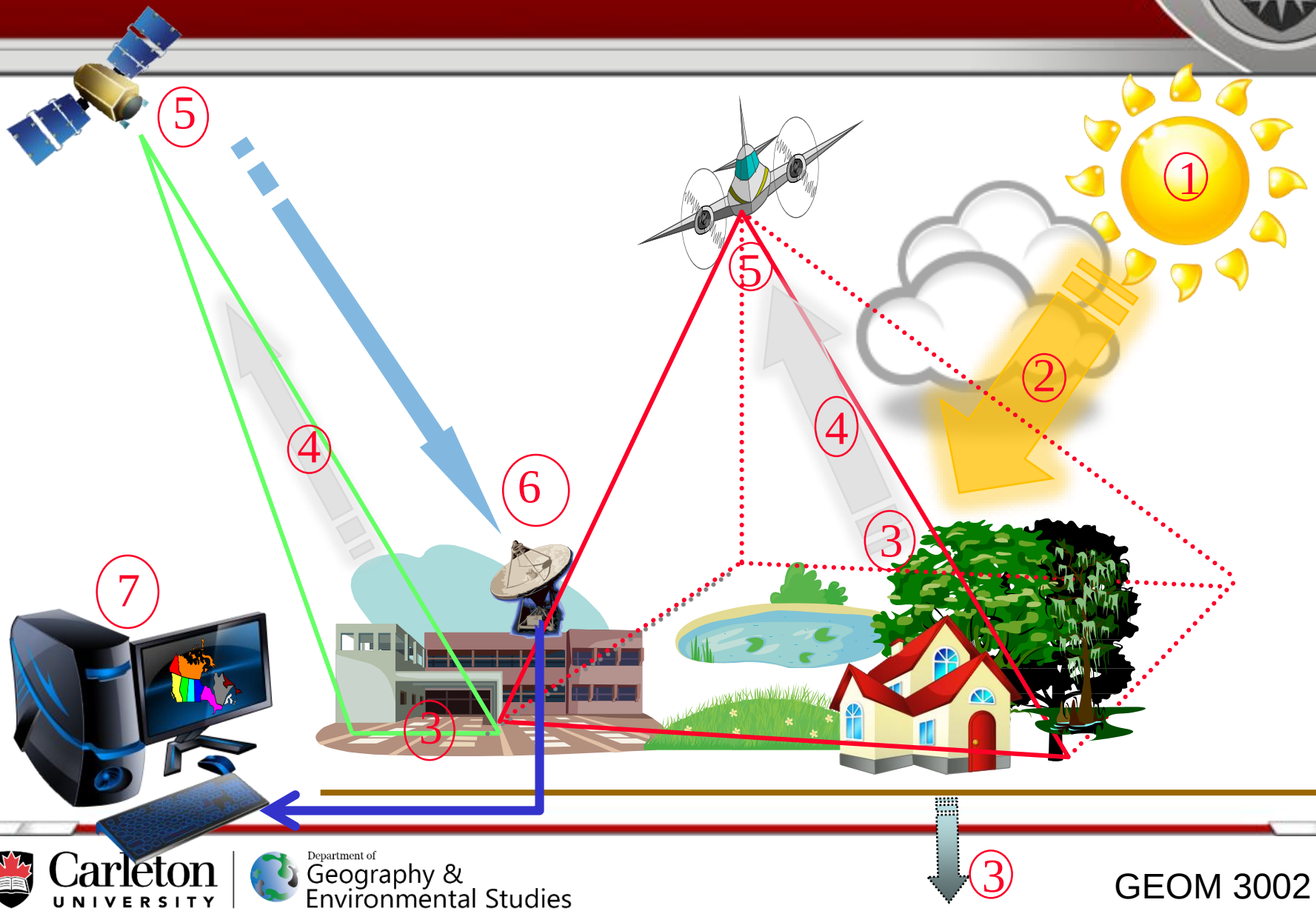
Jensen 2007, Remote Sensing of the Environment

Chapter 2, plus pp. 333-354 (vegetation); 379-392 (water); 401-402 (snow, clouds); 417 (urban); 474-482 (soils, rock minerals; some > detail than covered in lectures)

Jensen, 2015 – Intro to Digital Image Processing

pp. 185-194; 200-204; 315-326

The Remote Sensing Process (again)



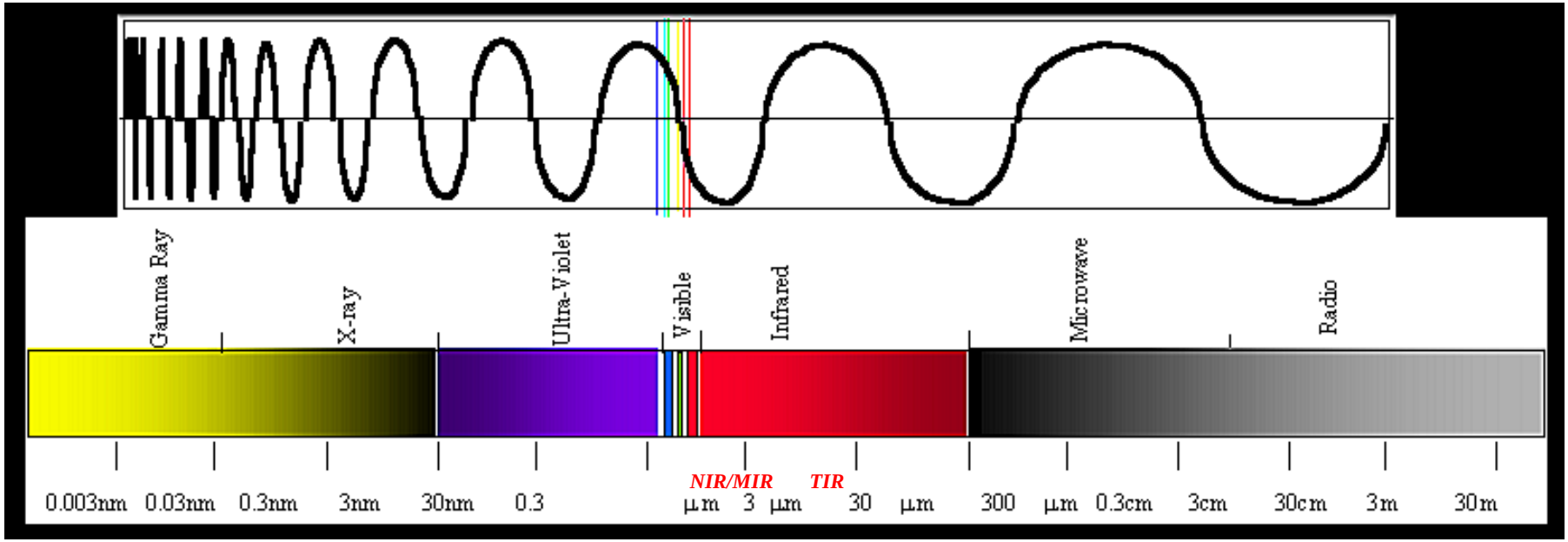
EMR

- Remote sensing images are created by electromagnetic radiation (EMR)
  - Has electric and magnetic fields
  - Propagates as packets of energy (photons) with given frequency, *v* and wavelength, ***λ***
  - Travels at the speed of light, *c* (3 x 10^8 m/s)

    $c = v \lambda$

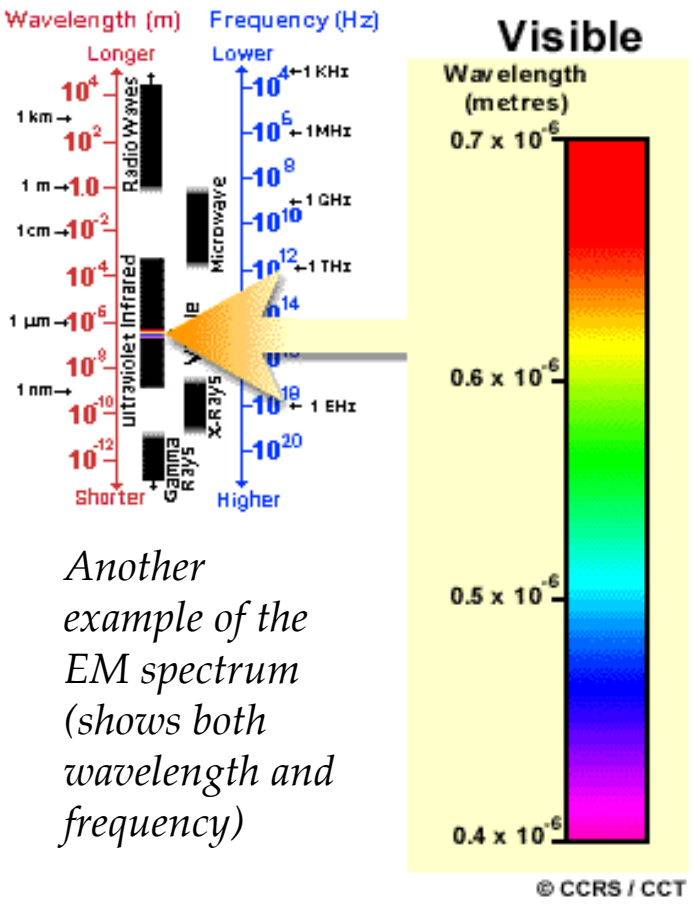
    Frequency or wavelength can be used to characterize a wave, but in remote sensing we generally categorize the EM waves by their wavelength along the electromagnetic spectrum.

Spectrum

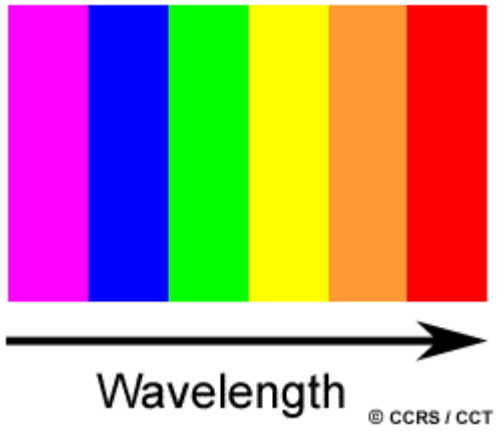


Wavelength

Spectrum (cont'd)
Visible EMR



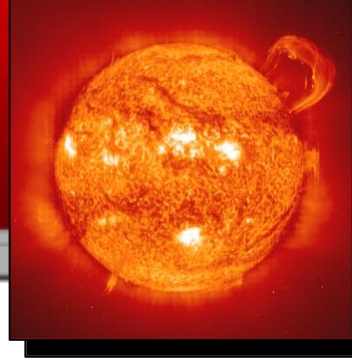
Another example of the EM spectrum (shows both wavelength and frequency)



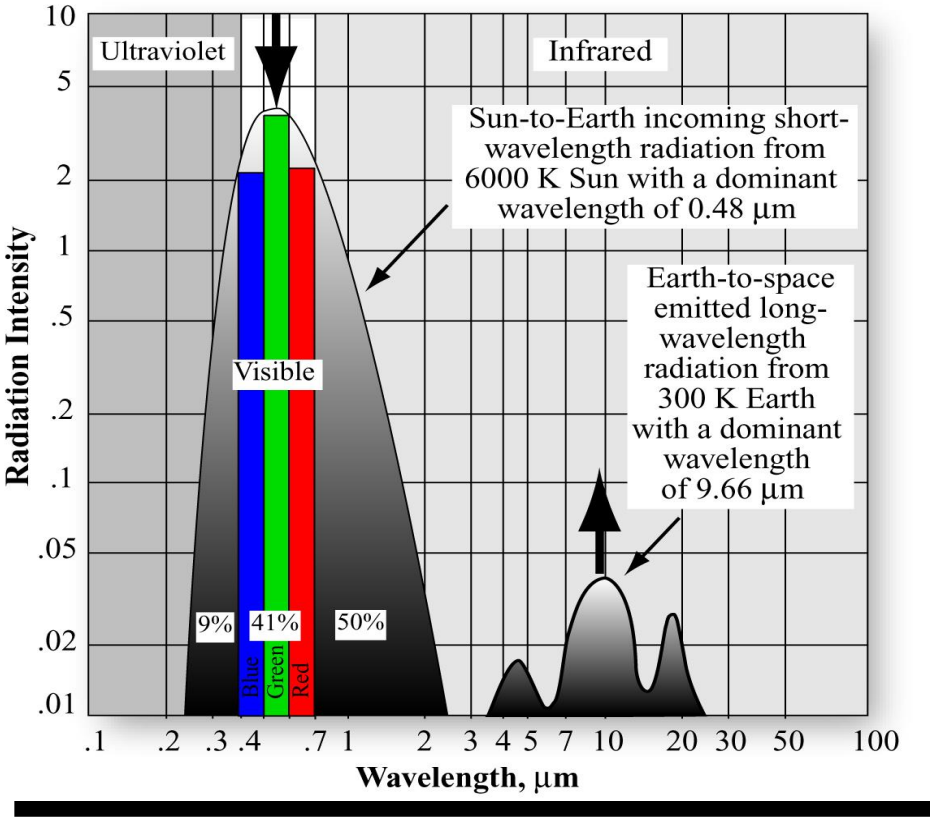
Violet: 0.4 - 0.446 µm
Blue: 0.446 - 0.500 µm
Green: 0.500 - 0.578 µm
Yellow: 0.578 - 0.592 µm
Orange: 0.592 - 0.620 µm
Red: 0.620 - 0.7 µm

http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309

Sun and Earth Emitted EMR



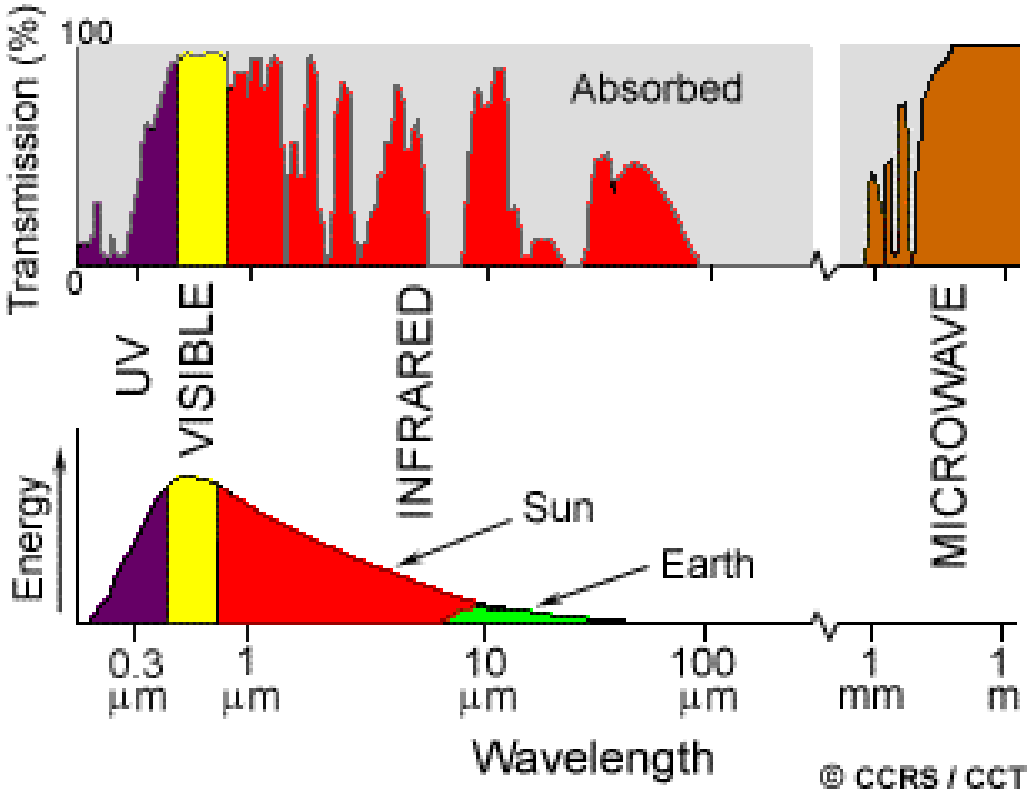
- EMR is emitted by all objects as their temperature is > 0º K (-273 ºC)
- Sun is main source of our EMR
- Emitted EMR is at wavelengths <u>inversely</u> proportional to the object temperature
  - Sun = hot; Wavelength of peak emission is about 0.5µm
  - Earth = cool; Wavelength of peak emission is about 9.7µm



Jensen, 2015

Atmospheric Windows

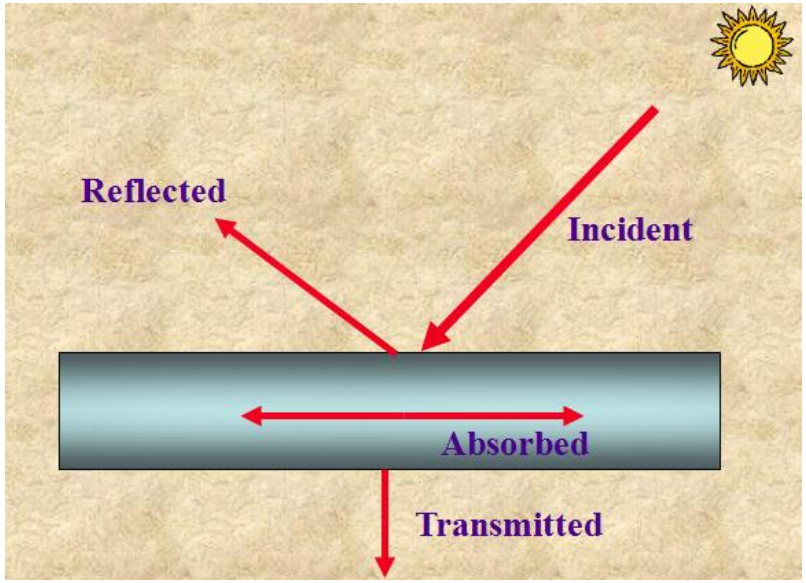
- EMR from Sun or Earth is absorbed by the atmosphere to varying degrees
  - Wavelengths with more atmospheric transmission (atmospheric windows) are used for remote sensing



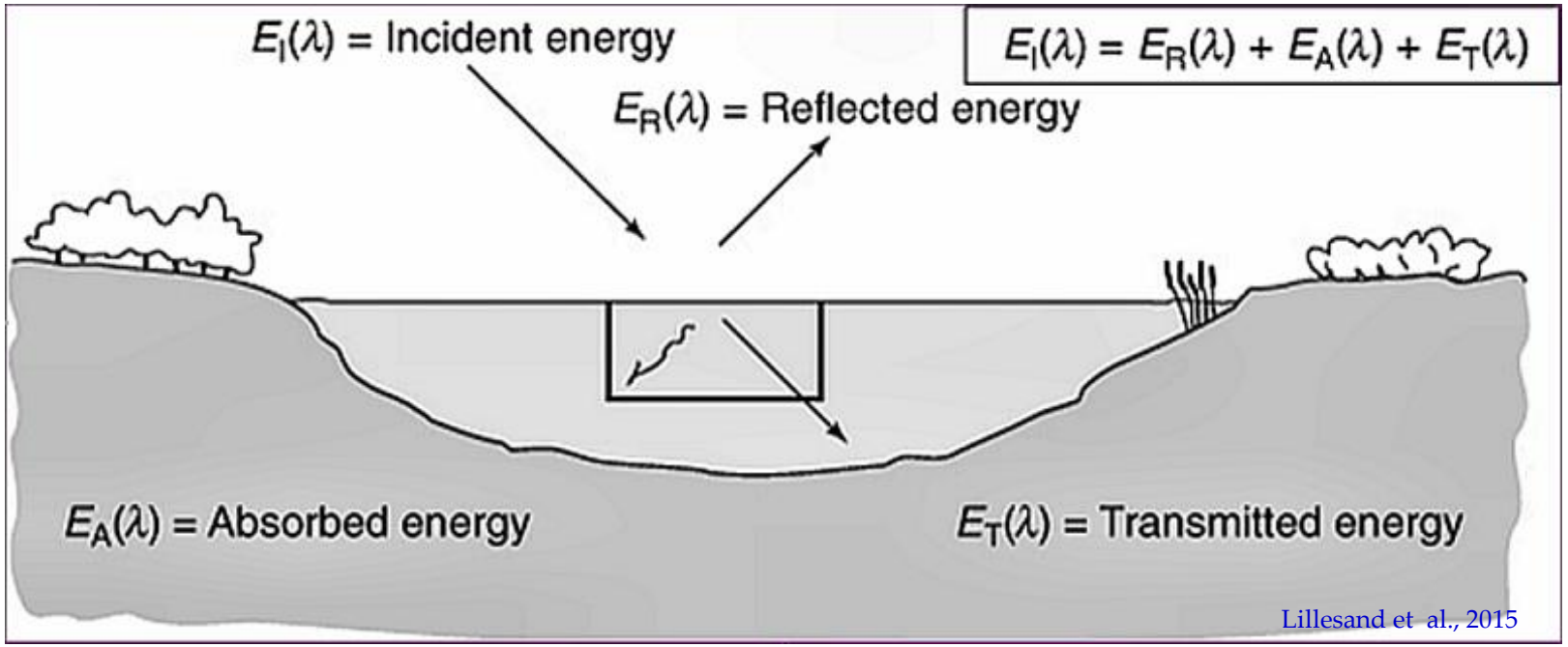
http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309

EMR Interactions with the Earth's Surface

- EMR from the Sun can be reflected or absorbed by the Earth's surface
  - Or, if surface is porous, EMR can be transmitted through the surface (e.g. vegetation, water, some soils, atmosphere) to a certain depth.
  - Multiple interactions are possible (called multiple scattering)
    - E.g. At any level in a forest or crop canopy, incident or reflected EMR may be transmitted through a leaf, absorbed or reflected.



EMR Interactions with the Earth's Surface



- In the UV, Visible, NIR, and MIR (SWIR), the amount of EMR **reflected** from the surface [here $E_R(\lambda)$] that passes through the atmosphere to the sensor determines image brightness.

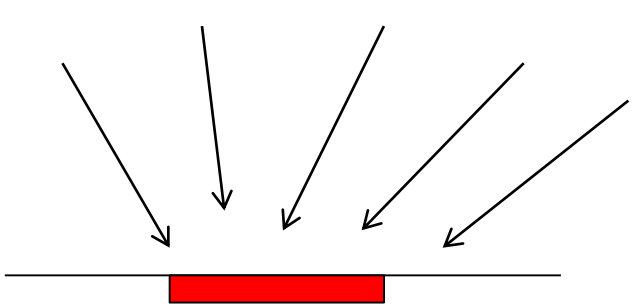
Units for Radiometric Measurement

See Lillesand et al. 2015. Appendix A

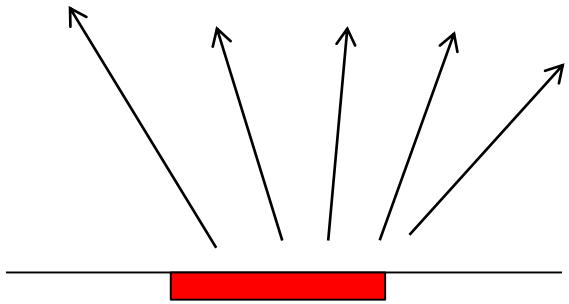
- Radiant Energy (Q): (Joules)
  - EMR energy; energy of the wave
- Radiant Flux (φ): (Watts)
  - Time rate of flow of radiant energy incident to, from, or through a surface – i.e. [Watts] represent [Joules/s]

Units for Radiometric Measurement

- Exitance (M) and Irradiance (E): ($W \cdot m^{-2}$)
  - Irradiance (E) - radiant flux per unit area incident to a surface
  - Radiant Exitance (M) - radiant flux per unit area leaving a surface.



Irradiance

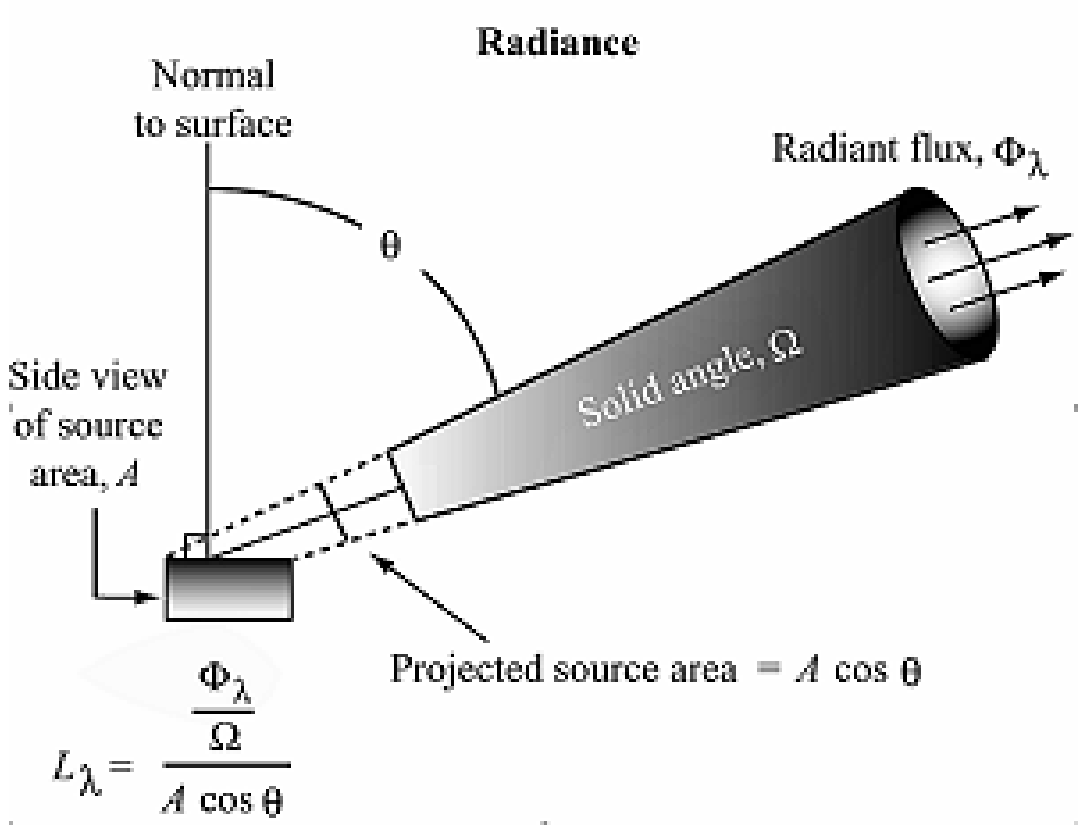


Radiant Exitance

- On average over the globe, E ~ 340 $W \cdot m^{-2}$ Sun irradiance on Earth's atmosphere.
  - ~1/3 is reflected by atmosphere and Earth's surface. Rest is absorbed.

http://earthobservatory.nasa.gov/IOTD/view.php?id=84499&src=eoa-iotd

Radiance



Jensen, 2007

Radiance (L):

$(W \bullet m^{-2} \bullet sr^{-1})$

The radiant exitance in a given solid angle

Spectral Radiance:

$(W \bullet m^{-2} \bullet \mu m^{-1} \bullet sr^{-1})$

- i.e., radiance leaves a specific area on the ground, in a specific wavelength(s), and within a specific solid angle

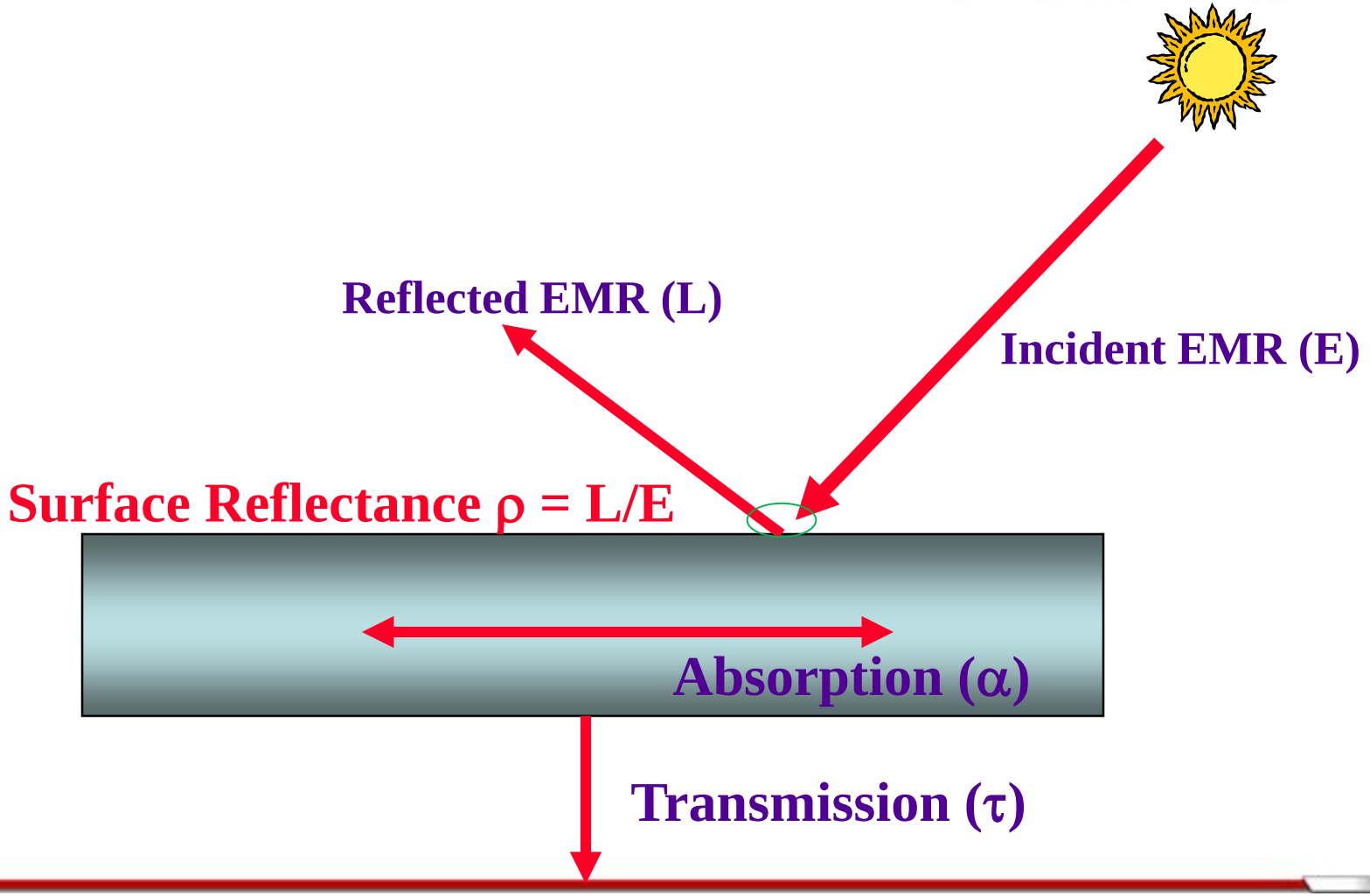
Surface Reflectance

- Reflectance (ρ) is the proportion of EMR (M) that reflects (bounces) off the surface in relation to the amount of EMR (E) that arrived at (was incident to) the surface
  - EMR can be measured in all directions (*radiant exitance, M*) or in one specific direction (e.g. *radiance* (L) in the direction towards the sensor)

In all directions: $M / E = \rho$

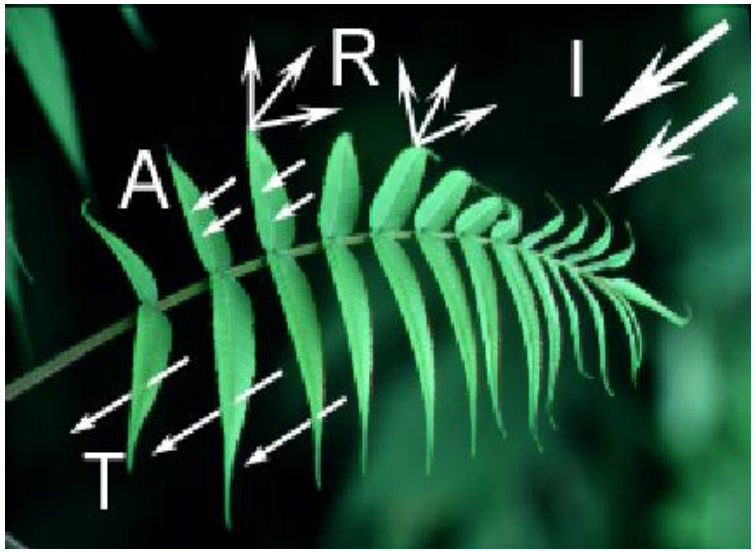
- High reflectance = bright in the image
- Low reflectance = dark in the image

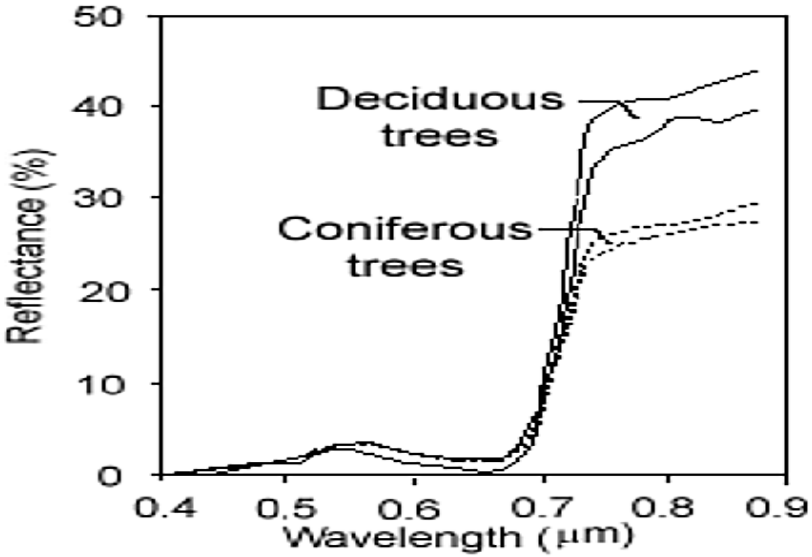
Surface Interactions with Incident EM Radiation



Spectral Reflectance

- For remote sensing in the Visible, NIR, MIR:
  - Reflectance of the surface is the major physical characteristic affecting image brightness.



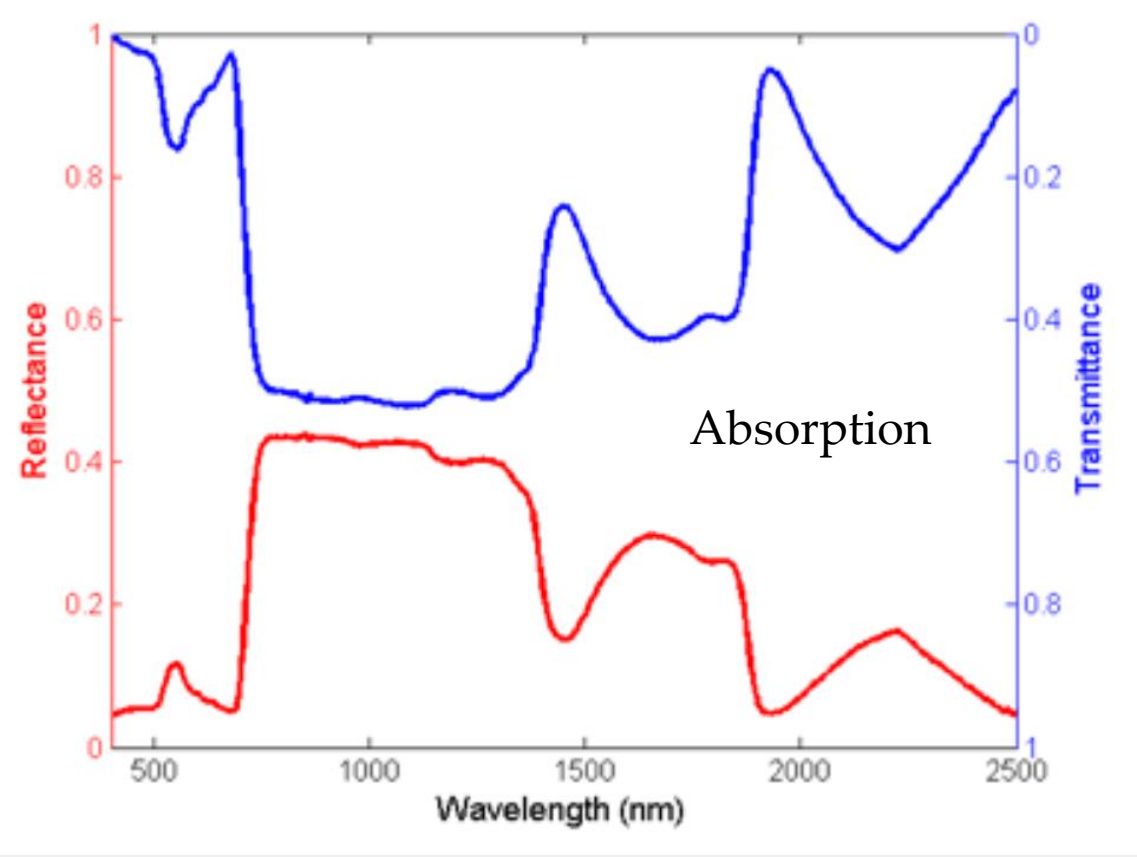


http://www.nrcan.gc.ca/earth-sciences/geomatics/satellite-imagery-air-photos/satellite-imagery-products/educational-resources/9309

Lillesand *et al.*, 2015.

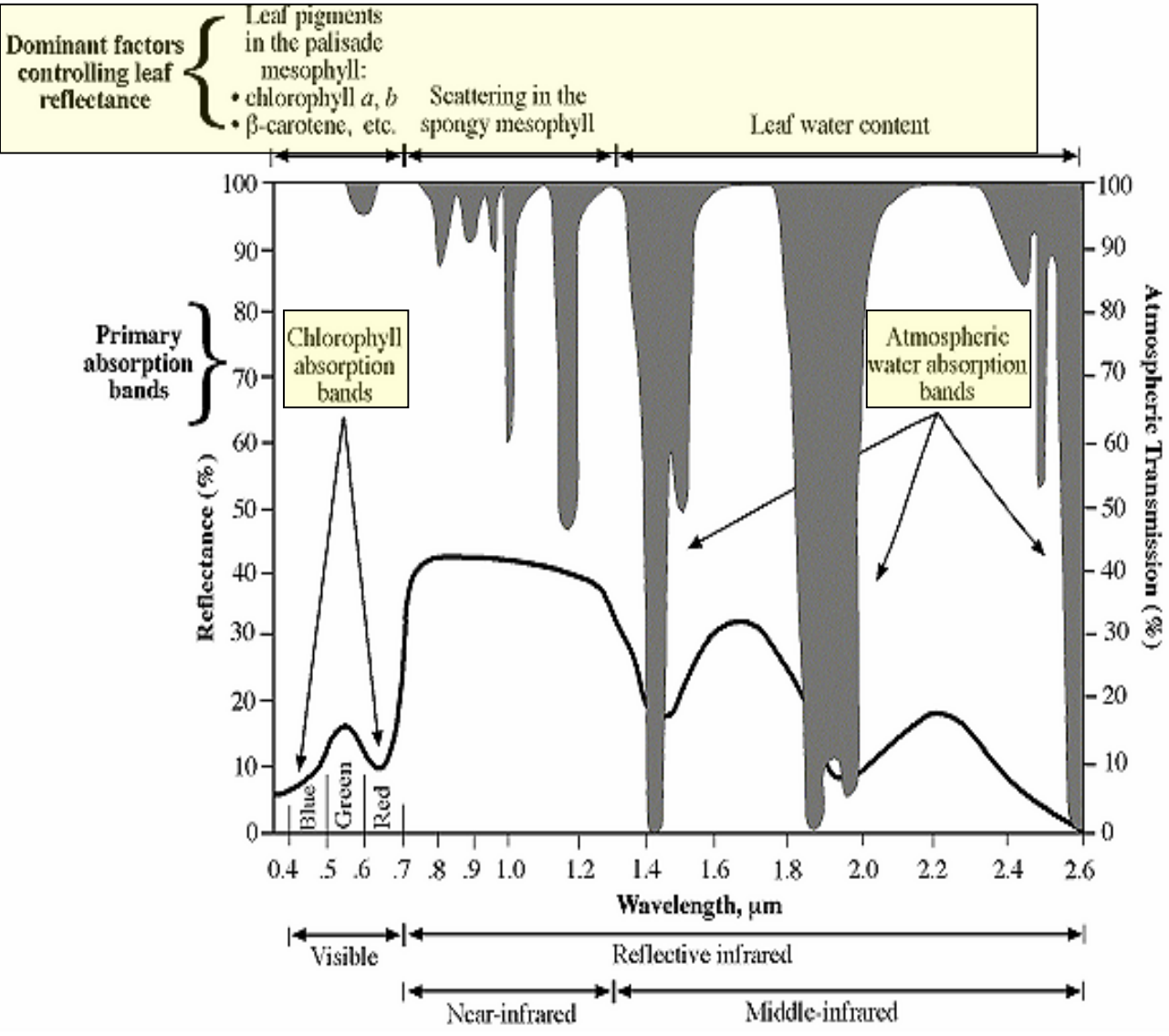
Spectral Reflectance Partitioning

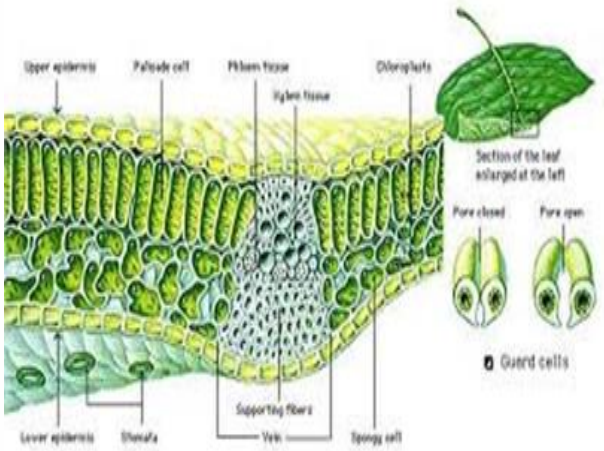
Vegetation



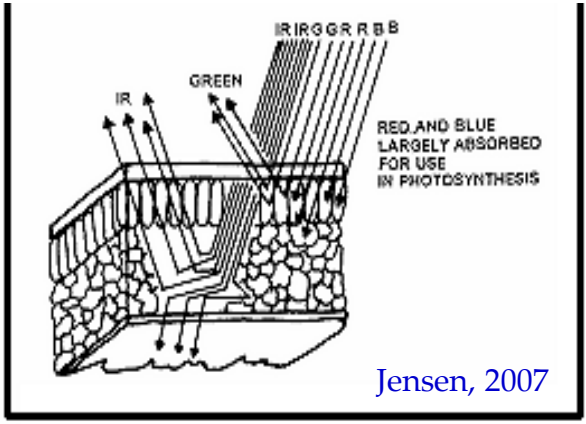
http://photobiology.info/Jacq_Ustin.html

Factors Controlling Vegetation Reflectance



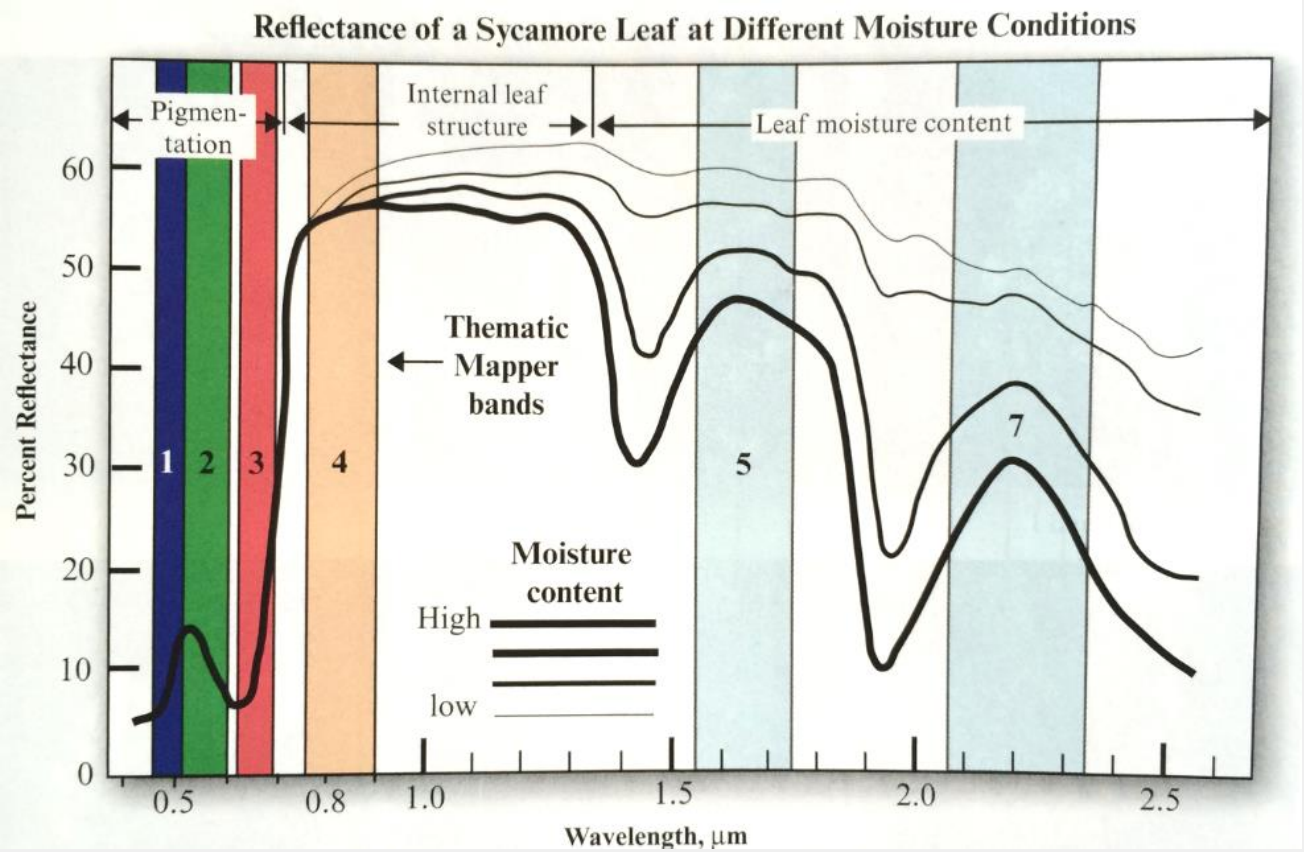


http://www.irwantoshut.net/tree_Chlorophyll.html



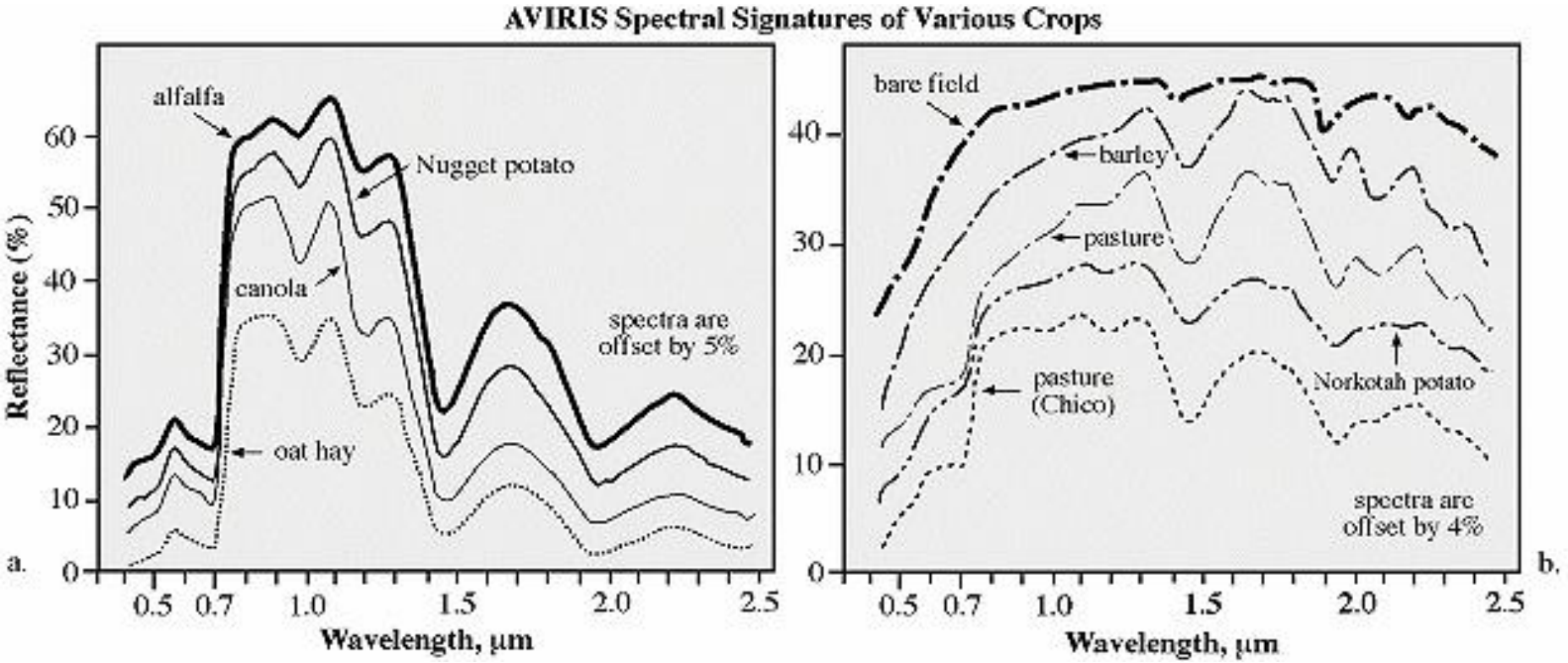
Jensen, 2007

Vegetation Reflectance vs Leaf Water Content



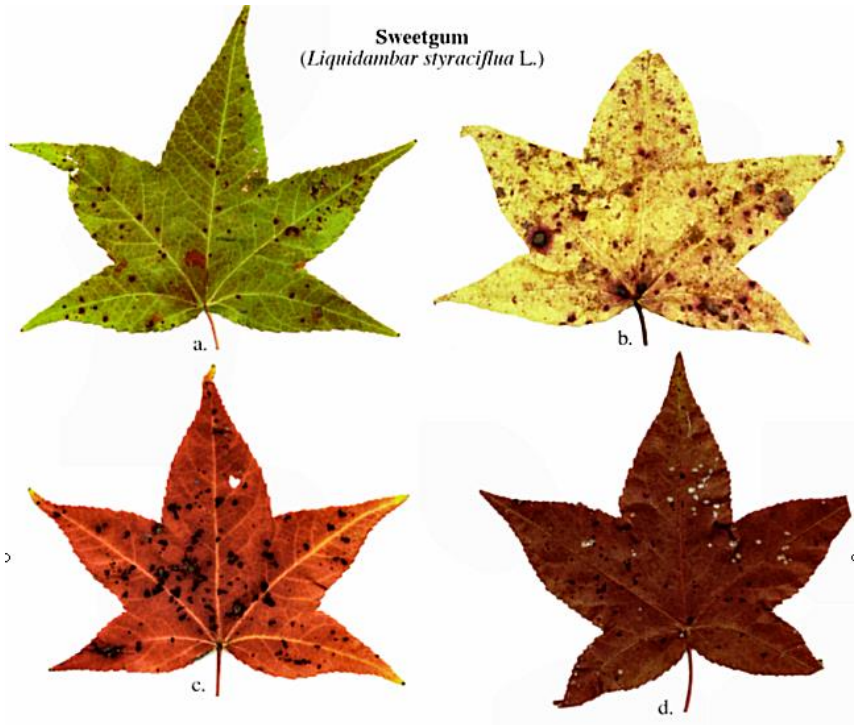
Jensen, 2015

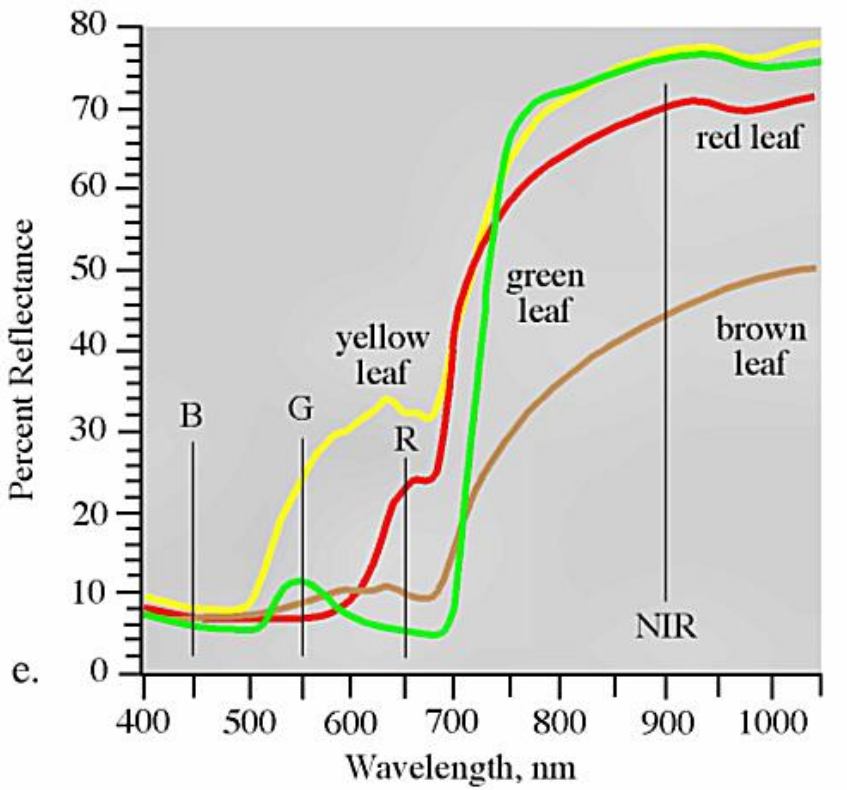
Reflectance of Various Agricultural Vegetation Types



Jensen, 2007

Fall Colours and Leaf Senescence

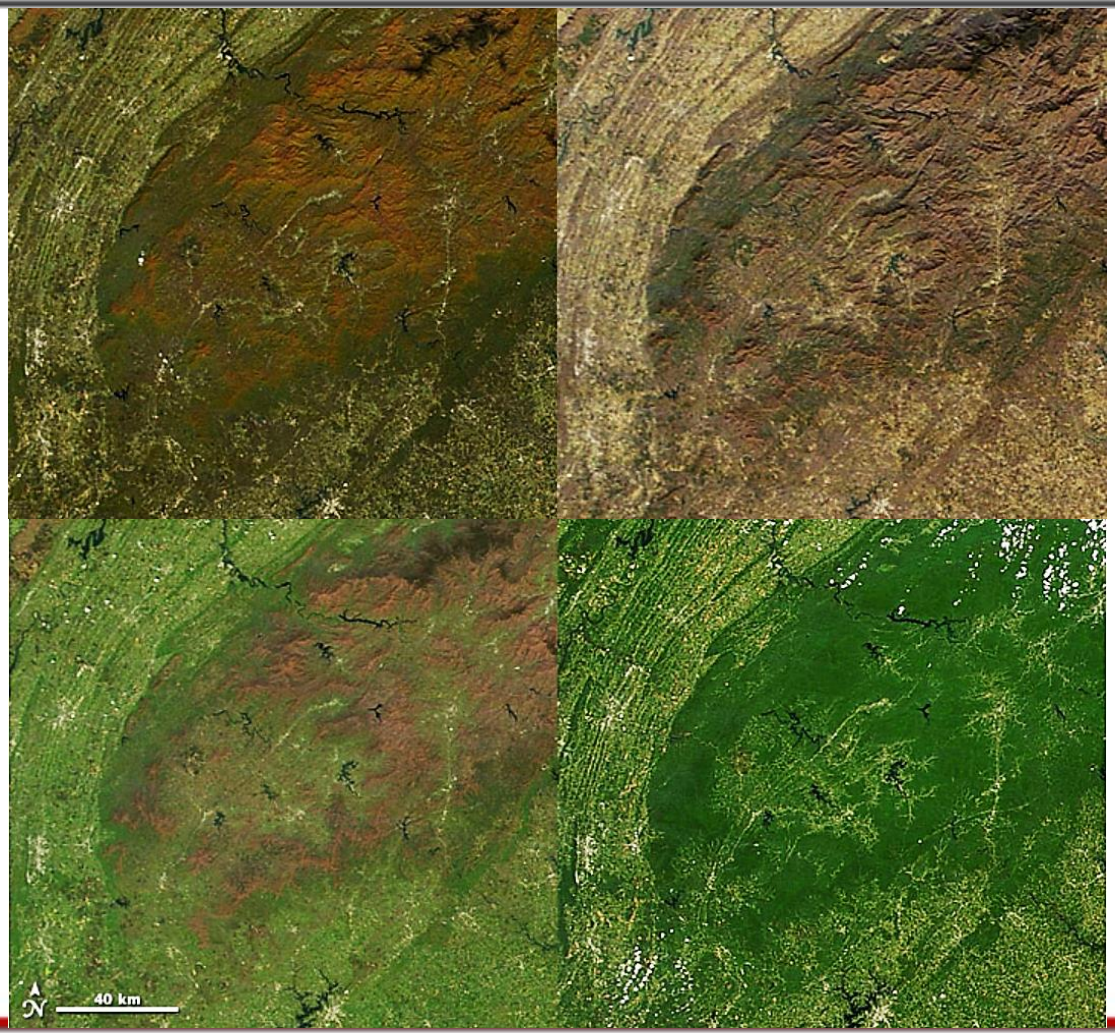




Jensen, 2007

What are the Seasons?

MODIS Natural Colour Composite Smoky Mountains



http://earthobservatory.nasa.gov/IOTD/view.php?id=82828&src=eoa-iotd

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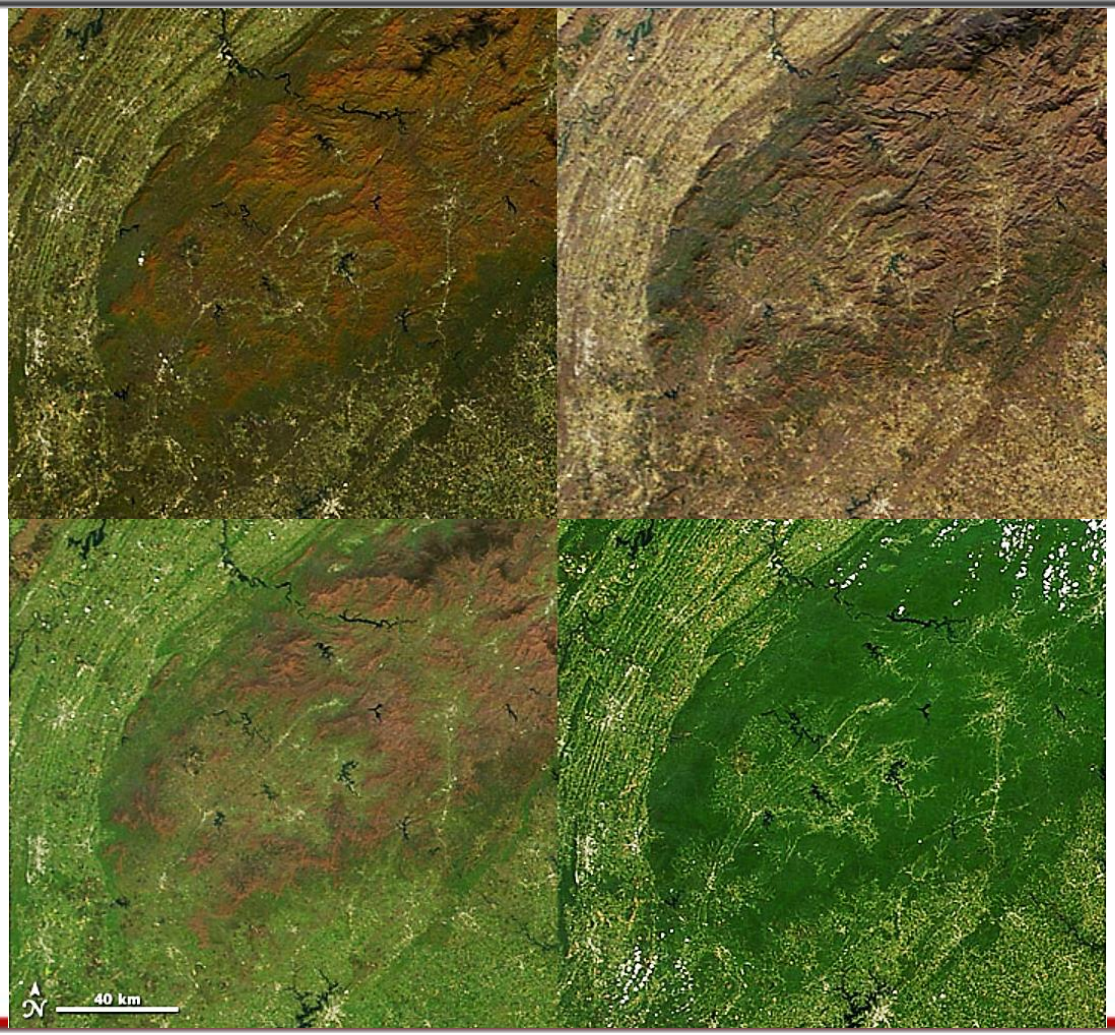

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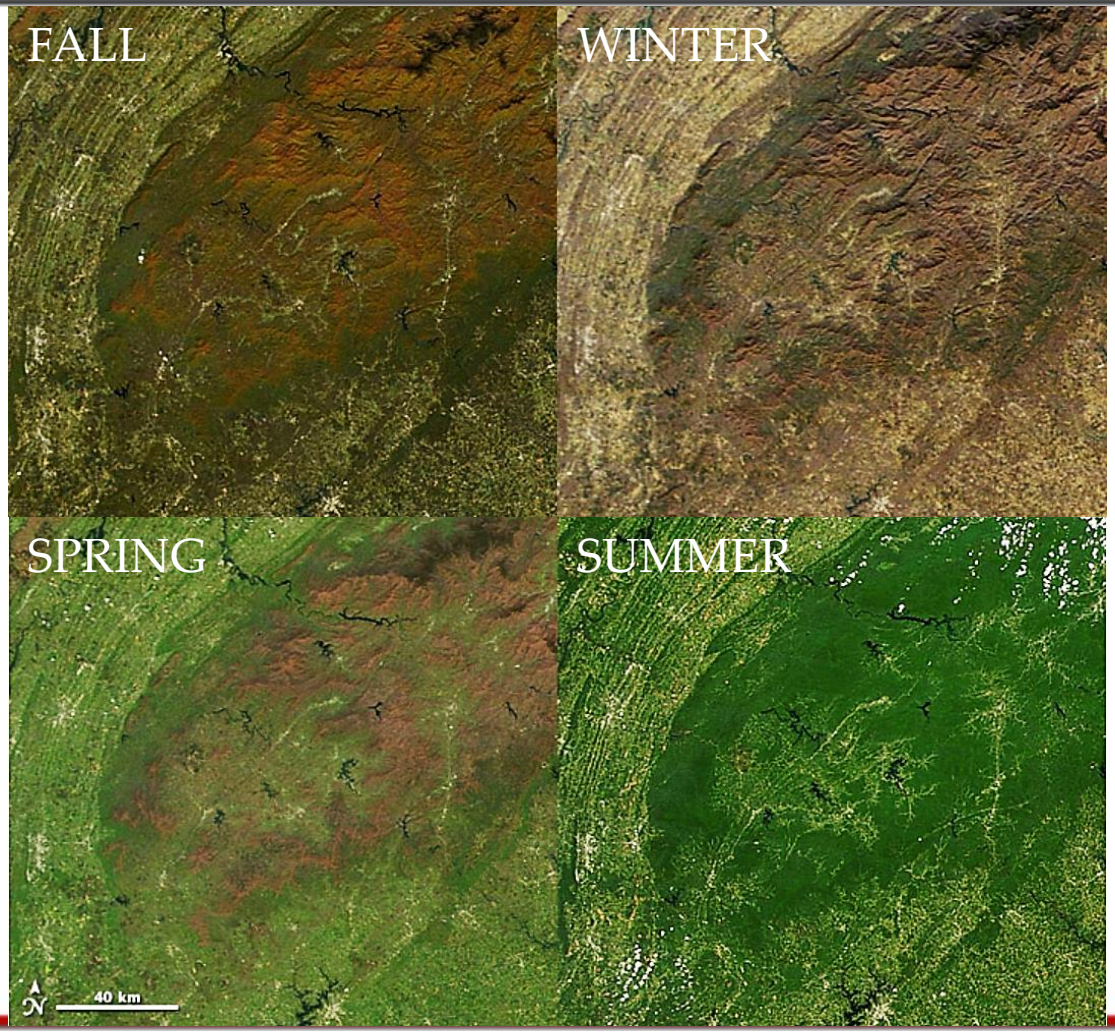
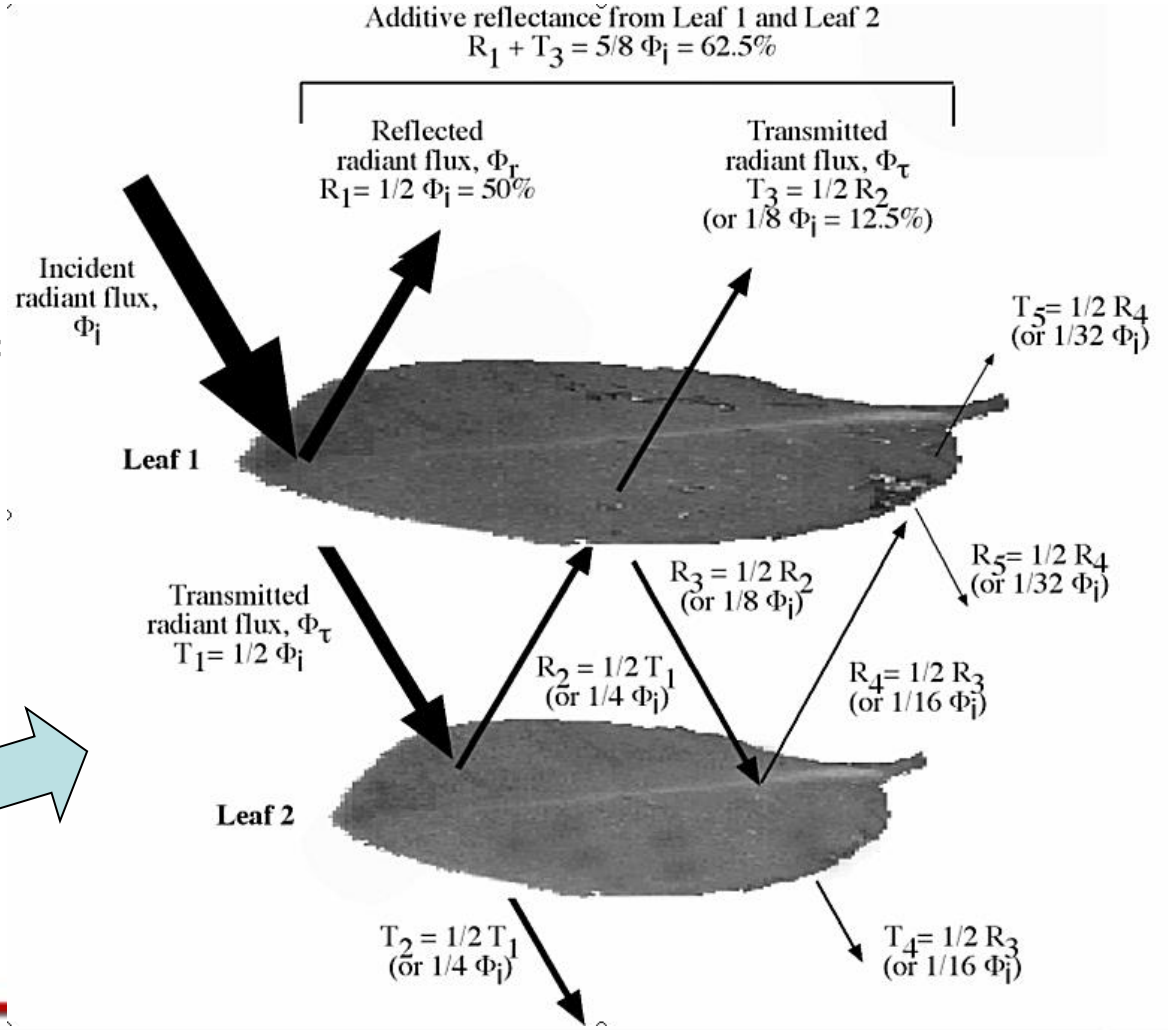


http://earthobservatory.nasa.gov/IOTD/view.php?id=82828&src=eoa-iotd

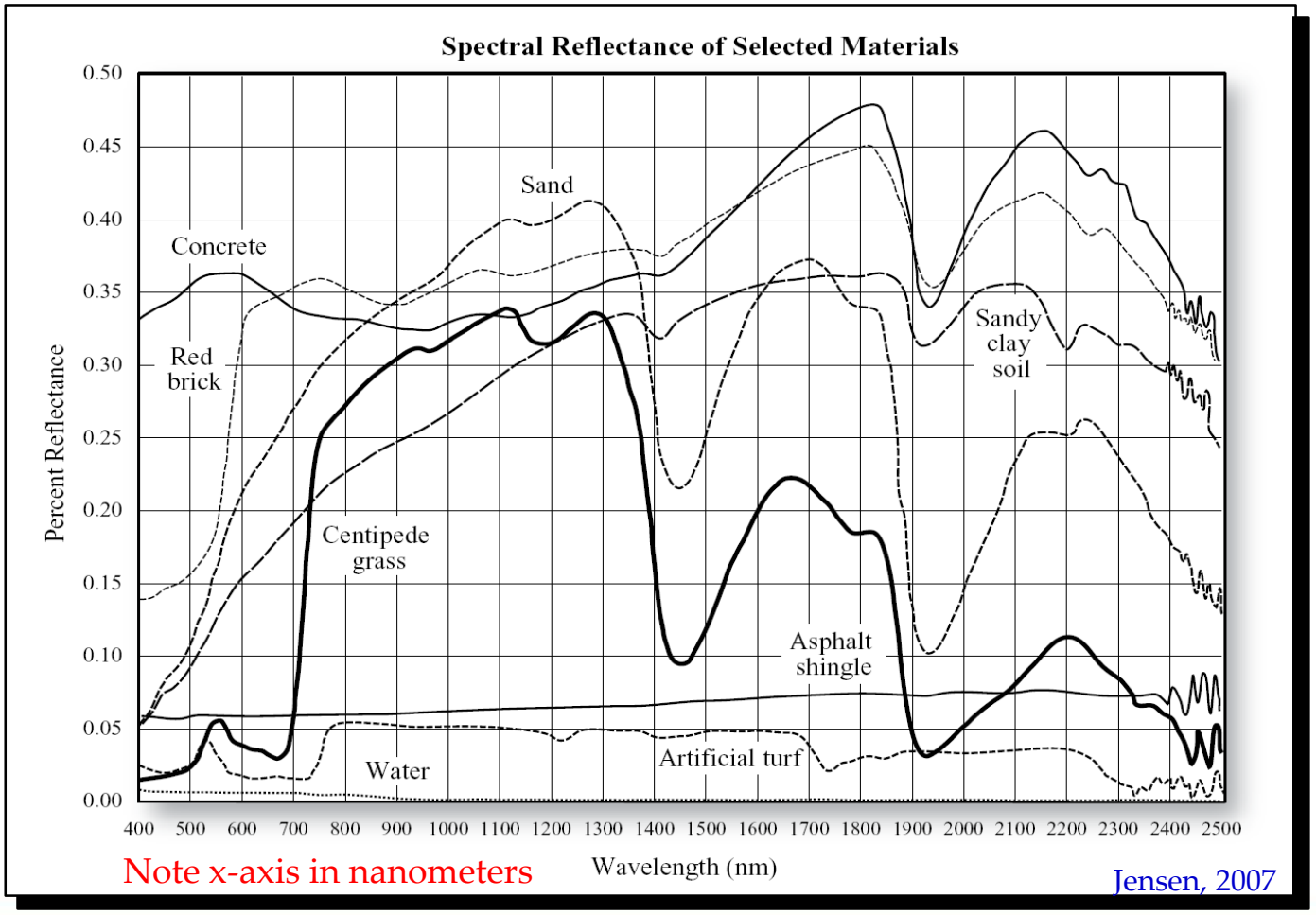
EMR Interaction with Vegetation Canopy

- Downwelling or upwelling radiation may be reflected, transmitted or absorbed at any leaf level.
- E.g. for simple 2-leaf layer canopy with:
  - $\rho_{leaf} = 0.5$
  - $\tau_{leaf} = 0.5$
  - $\alpha_{leaf} = 0.0$



Jensen, 2007

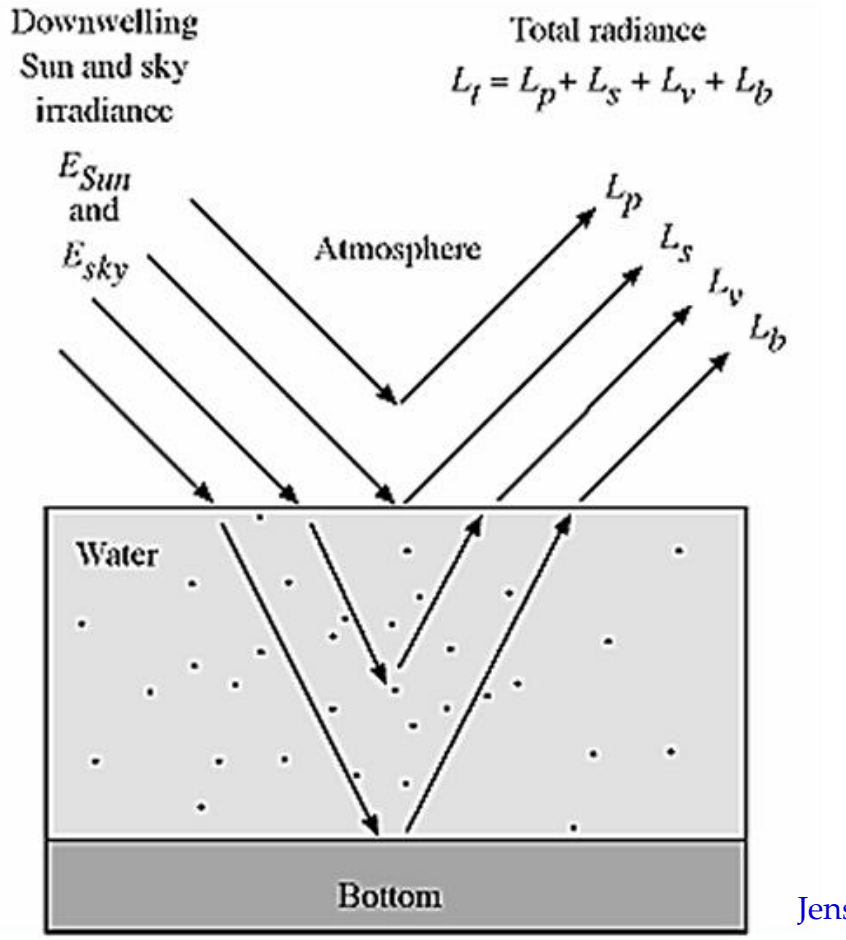
Spectral Reflectance of Common Land Cover Types



Note x-axis in nanometers

Jensen, 2007

Interactions of EMR with Water



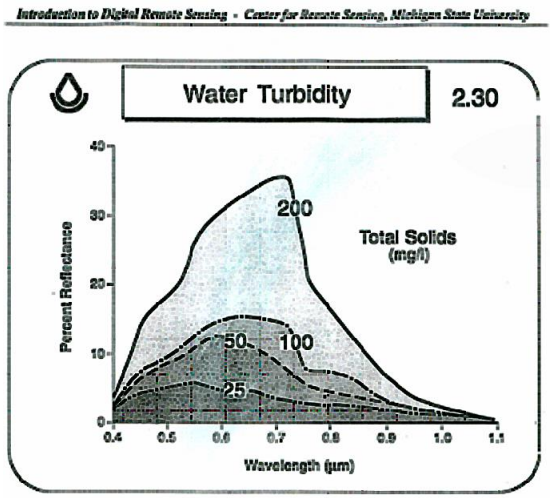
Jensen, 2007

Sediments, Dissolved Organic Matter

Dissolved Organic Matter, Rupert Bay in James Bay

Landsat 8 OLI

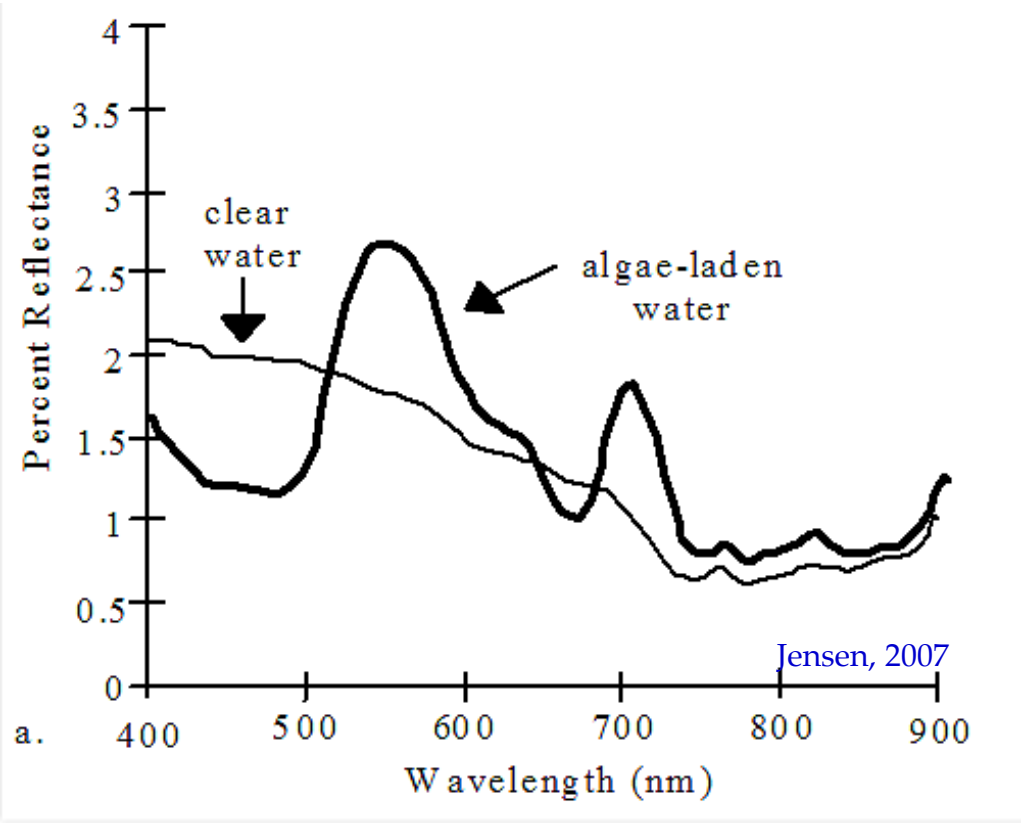
http://earthobservatory.nasa.gov/IOTD/view.php?id=88843&src=eoa-iotd



Advanced Land Imager

http://earthobservatory.nasa.gov/IOTD/view.php?id=79111&src=eoa-iotd

Chlorophyll Affects Water Reflectance



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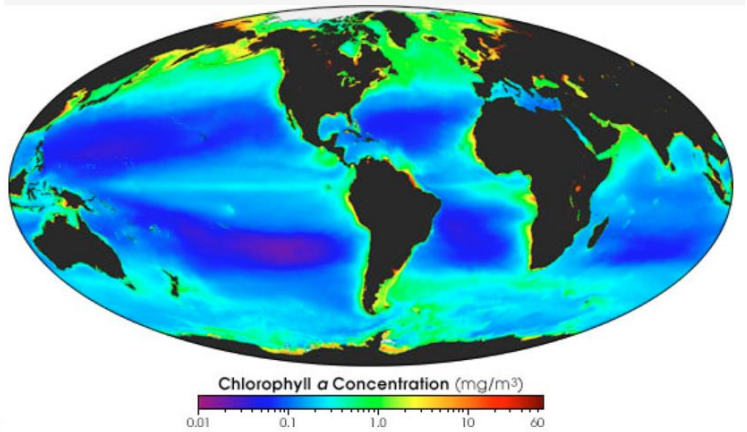


http://earthobservatory.nasa.gov/IOTD/view.php?id=4097

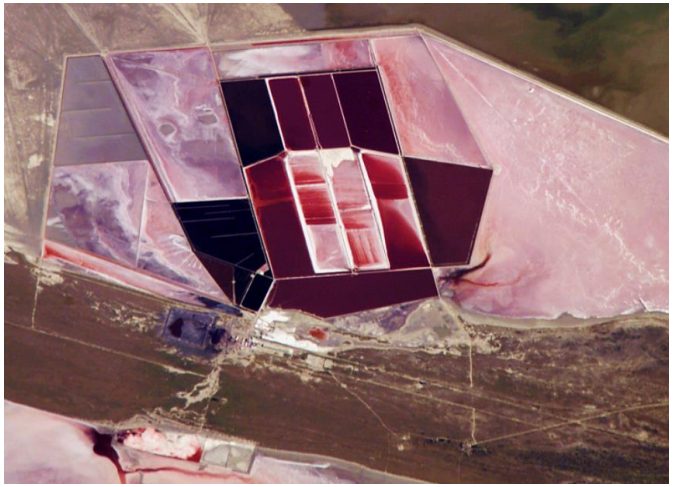
What industry is shown here?

These two images show the same industry.

- Why does one reflect equally across the visible spectrum (white)

while the other reflects more in the red part of the visible spectrum?

Western Australia
ISS Nikon D4 digital camera with 1150 mm lens
http://earthobservatory.nasa.gov/IOTD/view.php?id=86238&src=eoa-iotd



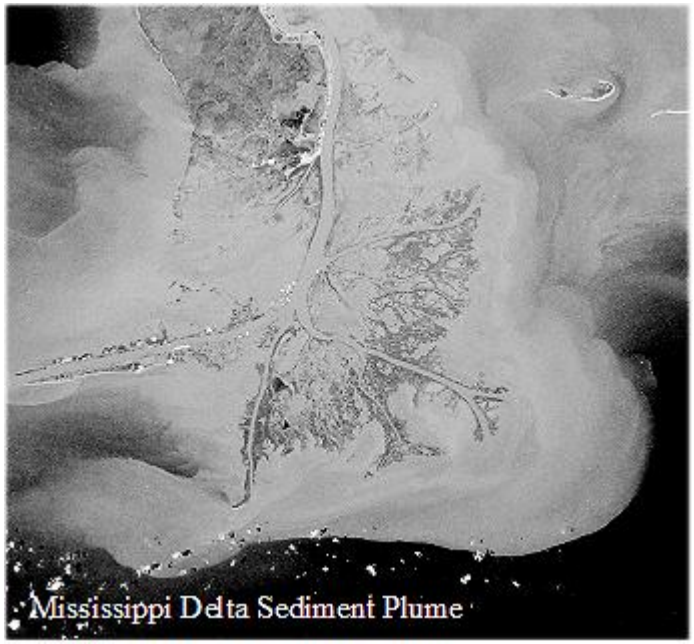
Botswana
ISS Kodak 760C digital camera with 800 mm lens
http://earthobservatory.nasa.gov/IOTD/view.php?id=7676&eocn=image&eoci=related_image

‘Whiting’ Event in Lake Ontario

- Temperature increase in summer leads to:
  - Photosynthesis increase by phytoplankton and other organisms
  - Carbon dioxide in water declines
  - Carbonic acid decreases
  - pH increases (lower acidity)
  - Calcium carbonate $CaCO_3$ molecules form
  - Reflectance across visible spectrum increases leading to "whiting"

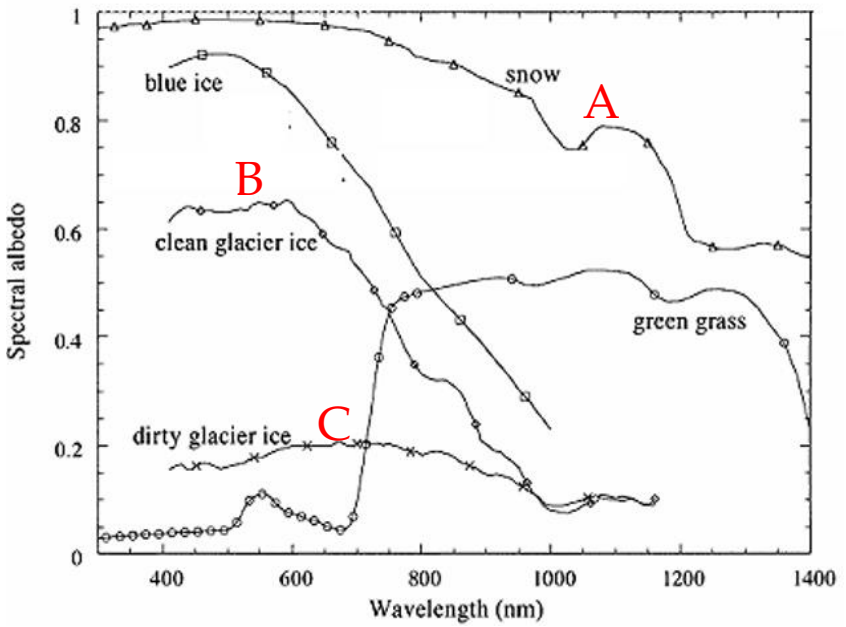
http://earthobservatory.nasa.gov/IOTD/view.php?id=81952&src=eoa-iotd

NIR shows land-water edges well

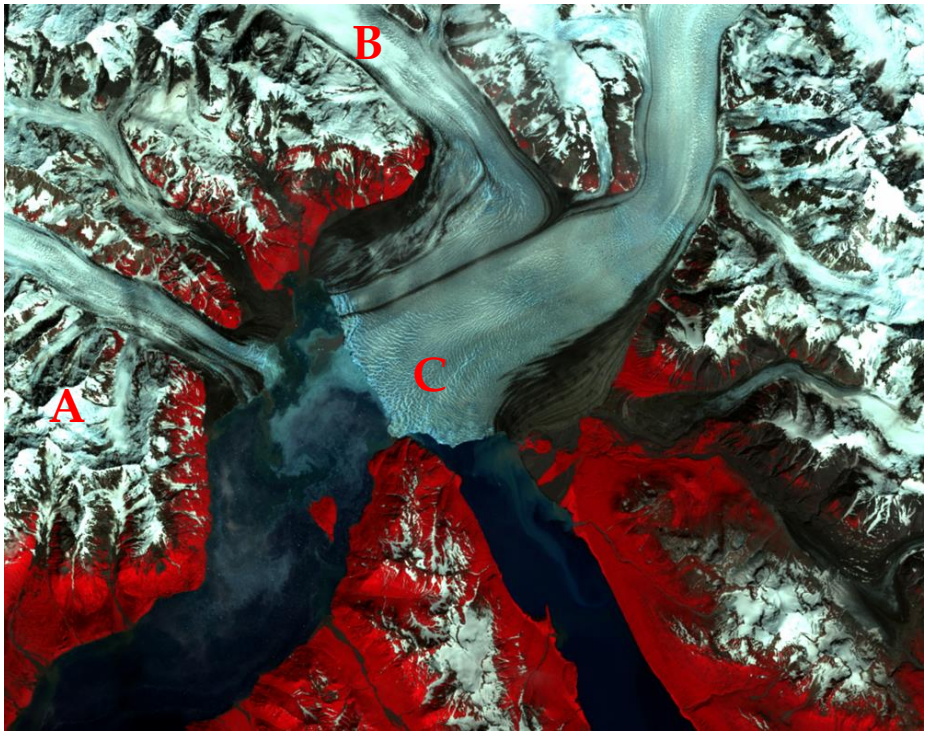


Jensen, 2007

Reflectance of Snow, Ice and Clouds

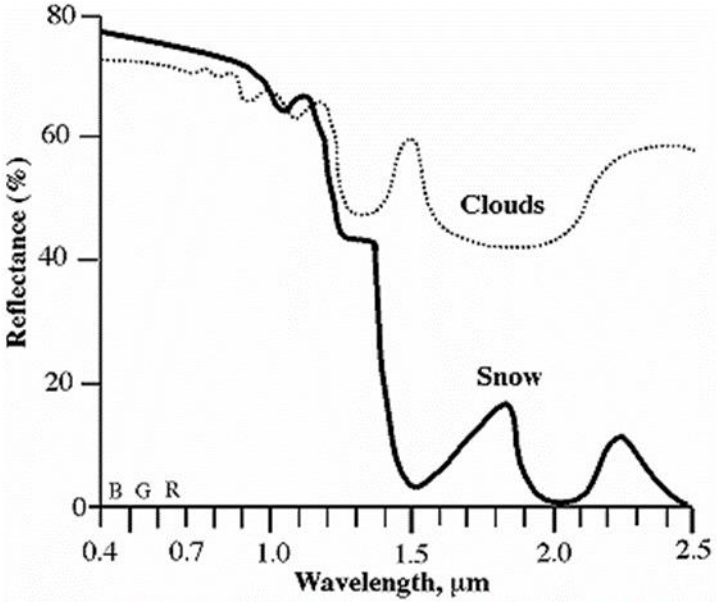


http://www2.hawaii.edu/~jmaurer/albedo/

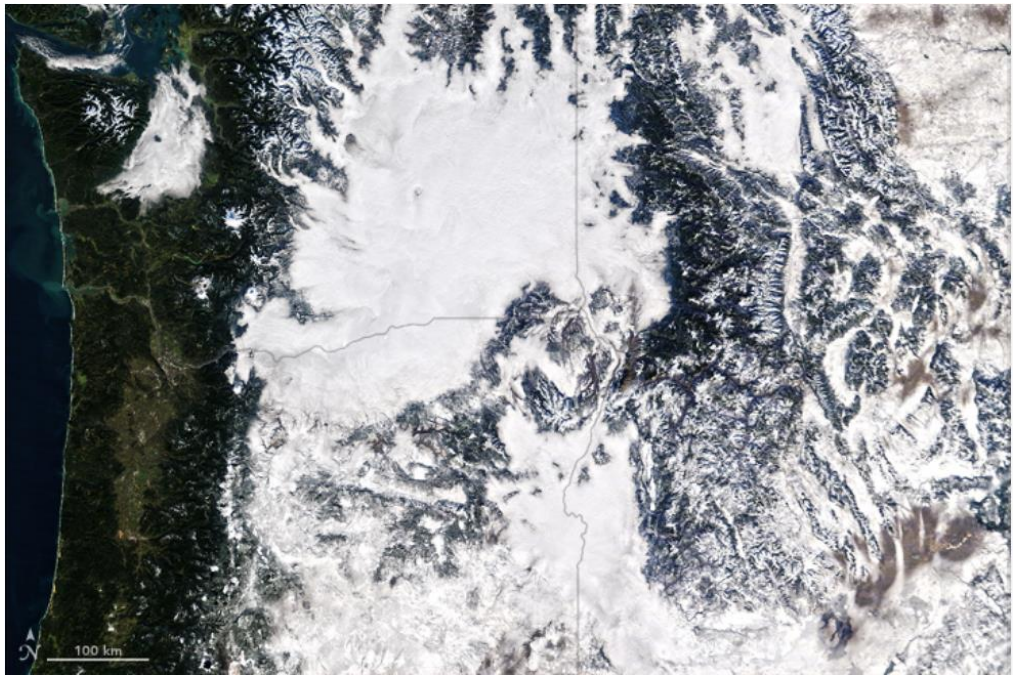


https://earthshots.usgs.gov/earthshots/node/16#ad-image-0-0

Snow vs. Clouds

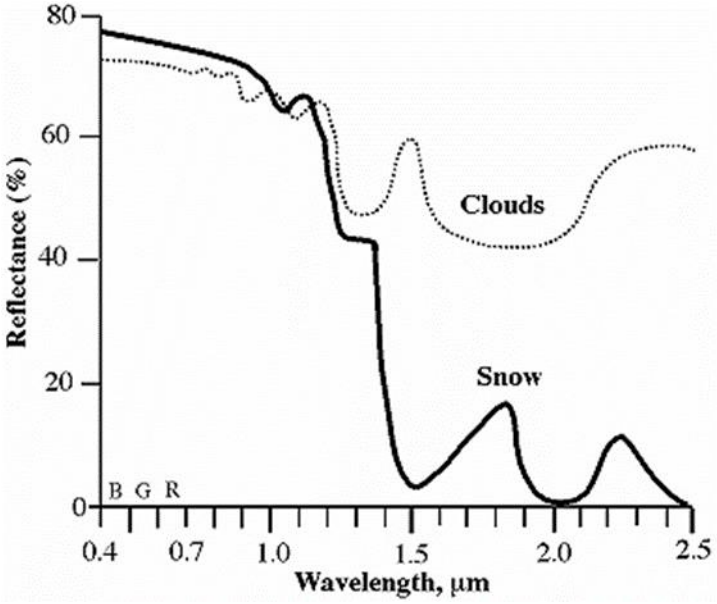


Jensen, 2007

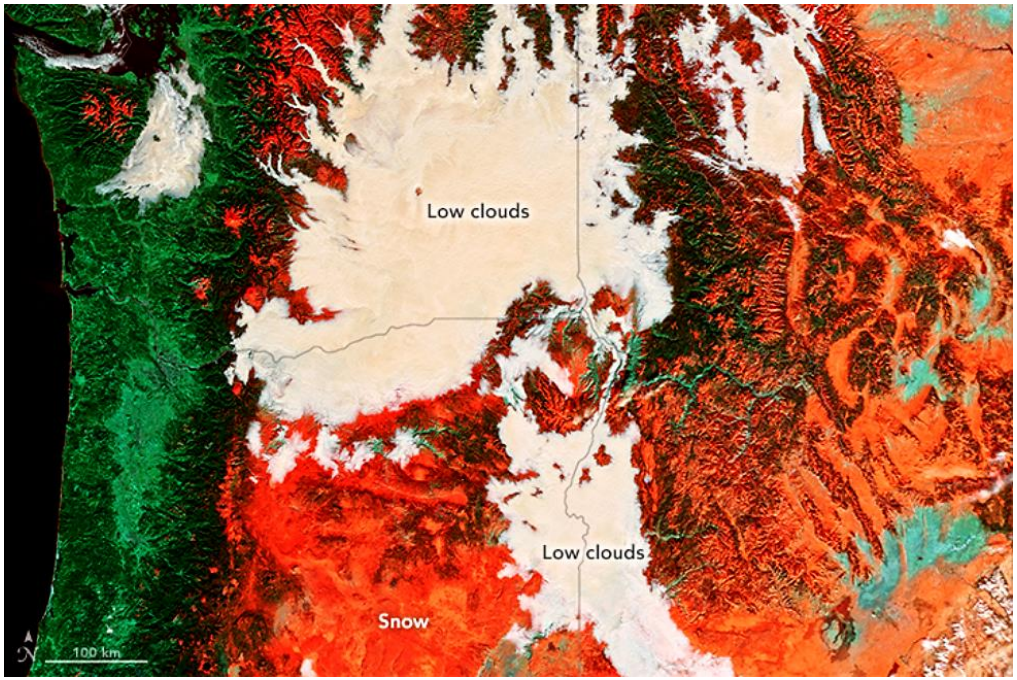


Natural Colour MODIS image:
Where is the snow? Where are the Clouds?

Snow vs. Clouds



Jensen, 2007



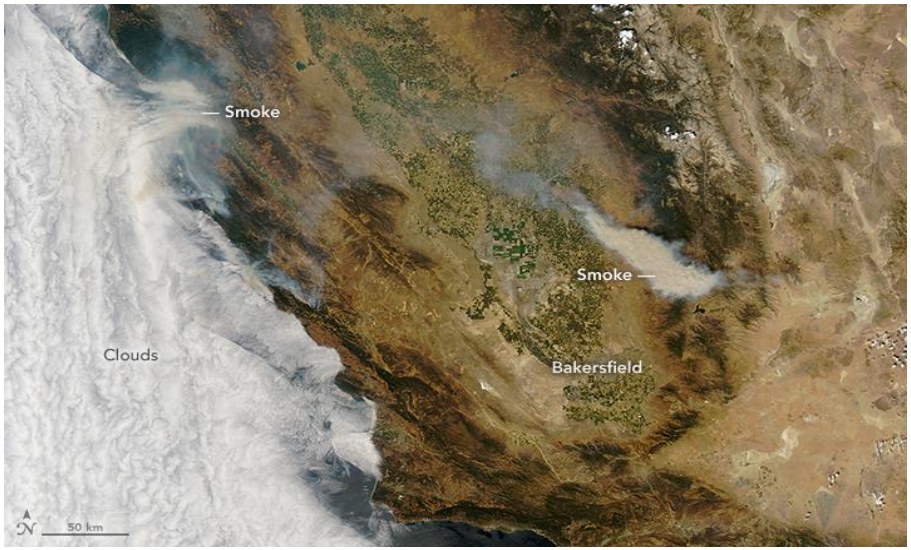
False Colour MODIS image:
B-G band; NIR band; SWIR band

http://earthobservatory.nasa.gov/IOTD/view.php?id=87125&src=eoa-iotd

Clouds vs Smoke

MODIS: Iceland Volcano, April 2010

http://earthobservatory.nasa.gov/IOTD/view.php?id=43670&src=eoa-iotd

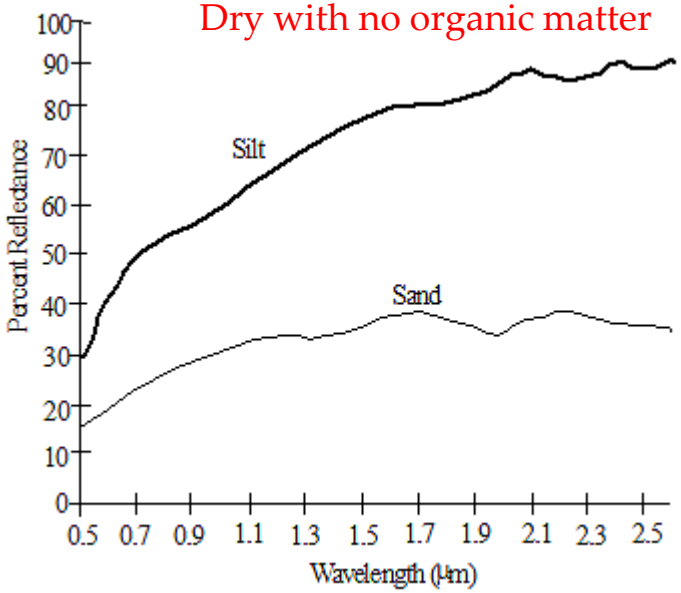


MODIS: California fires, August 2016

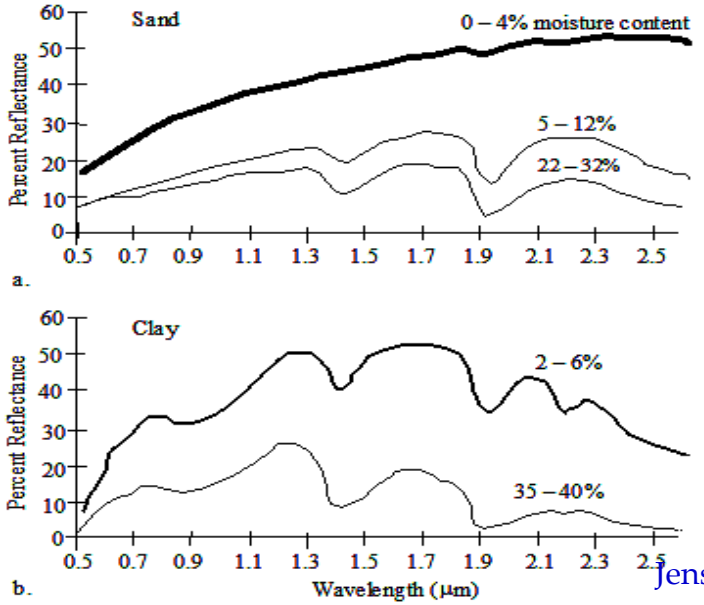
http://earthobservatory.nasa.gov/IOTD/view.php?id=88611&src=eoa-iotd

Soil Reflectance

Dry with no organic matter

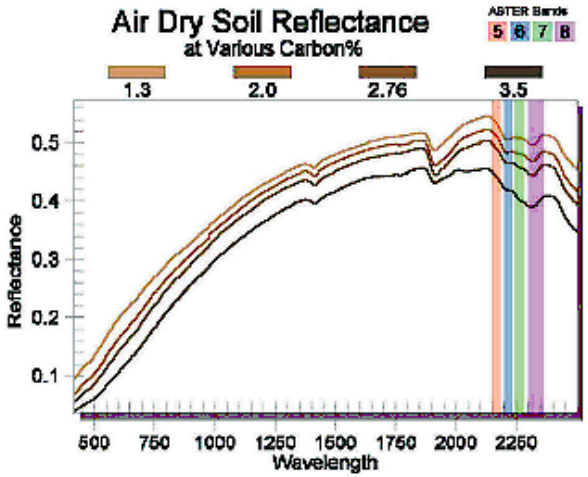


Moisture reduces soil reflectance



Jensen, 2007

Other factors
- Iron oxide
- Salt

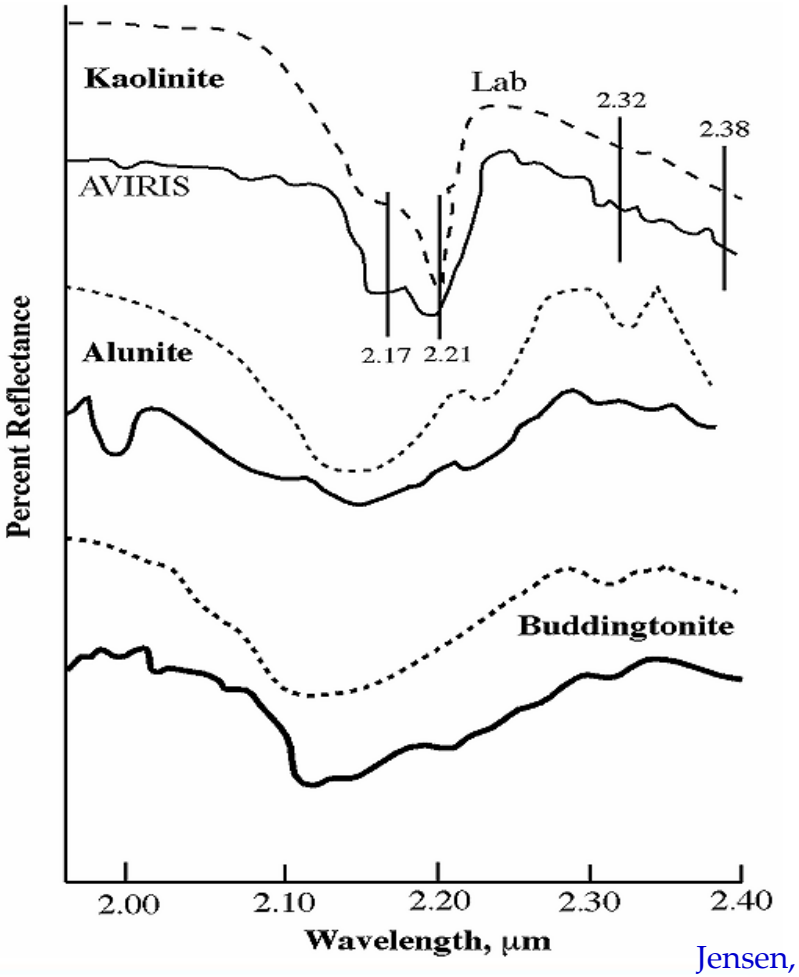


Organic matter reduces soil reflectance

Stephens et al.
(from A. Davidson, AAFC)

Rock Reflectance

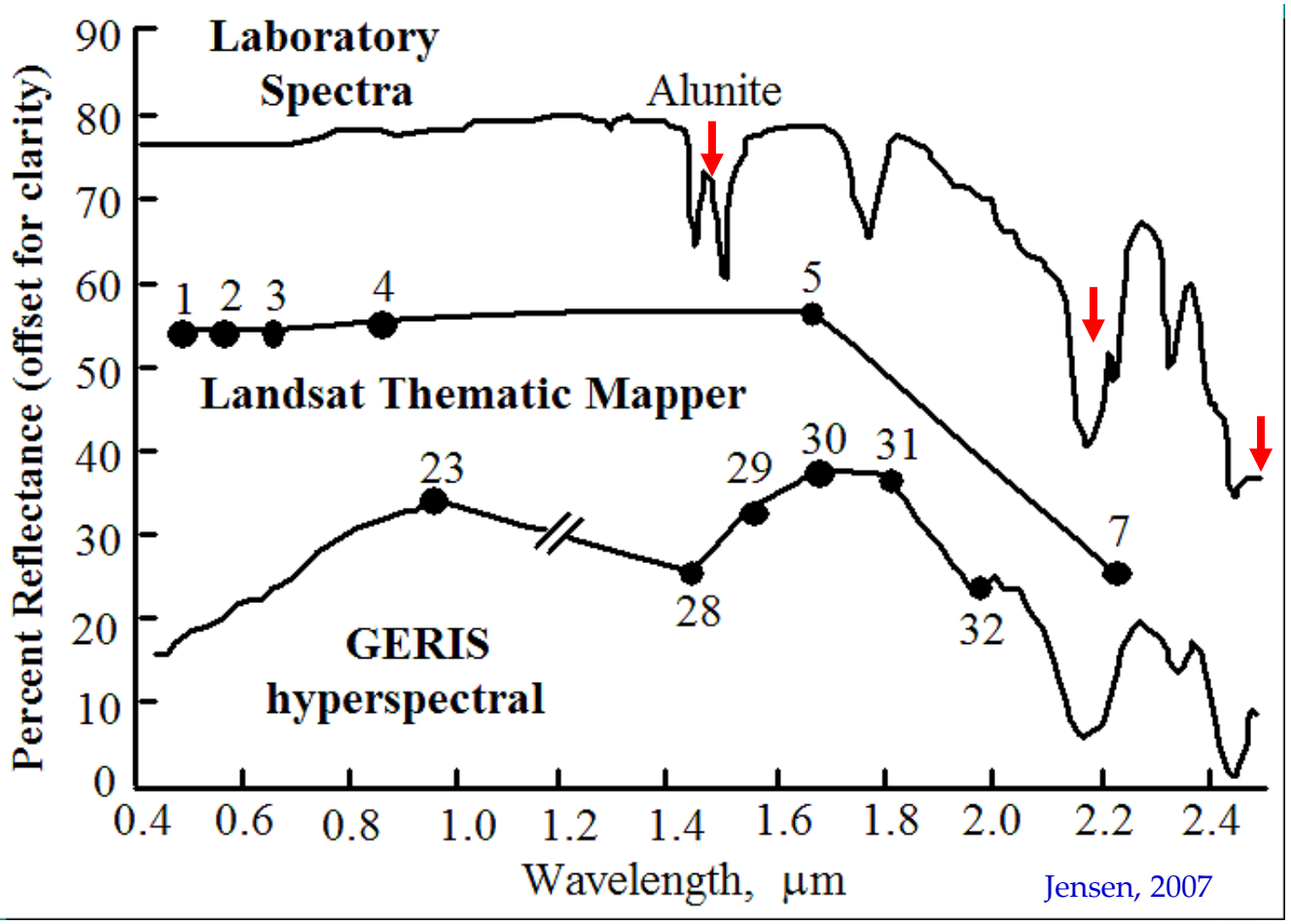
- Depends on mineral composition and exposure
- Most rock mapping done in arid regions
- MIR is very useful as in graph



Jensen, 2007

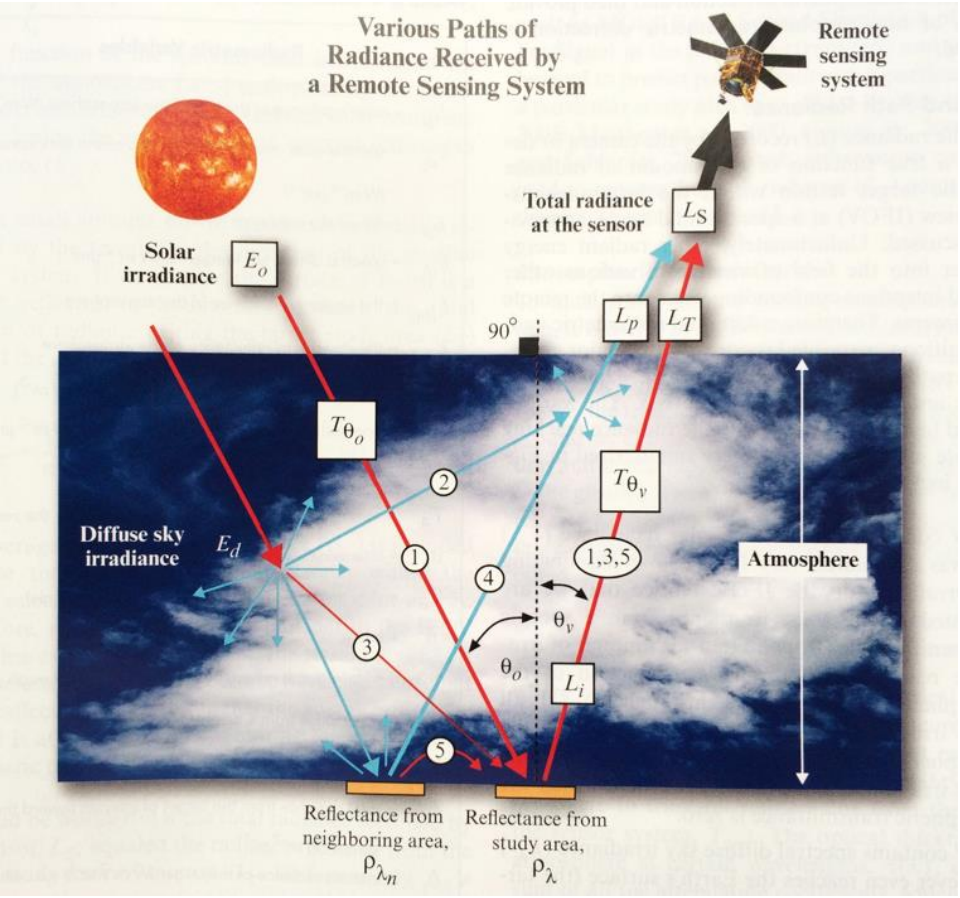
Rock Reflectance

- Sensors with many spectral bands at precisely selected wavelengths detect absorption 'features' better than sensors with a few spectral bands



Jensen, 2007

What Do Remote Sensors Actually Measure in the VIS to MIR?



Jensen, 2015

The total at-sensor radiance (L_S) includes:

1. **Reflected EMR directly from the target (L_T)** that is comprised of:

- Sun irradiance that directly illuminates the target area and reflects directly to the sensor **(Path 1)**
- Diffuse sky irradiance (scattered EMR) that illuminates the target then reflects directly to the sensor **(Path 3)**
- Irradiance reflected from adjacent areas that is scattered back down onto the target and then directly reflected to the sensor **(Path 5)**

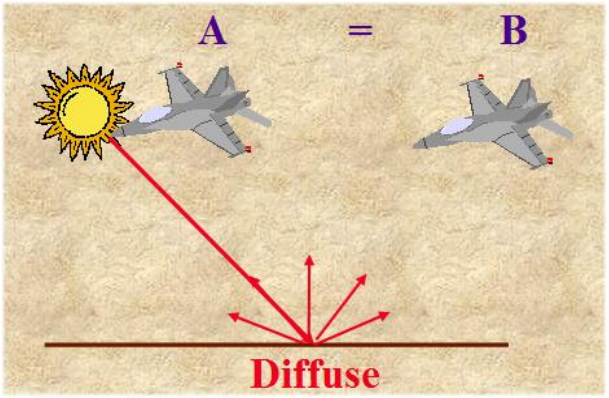
2. **Reflected EMR from other sources (path radiance, L_P):**

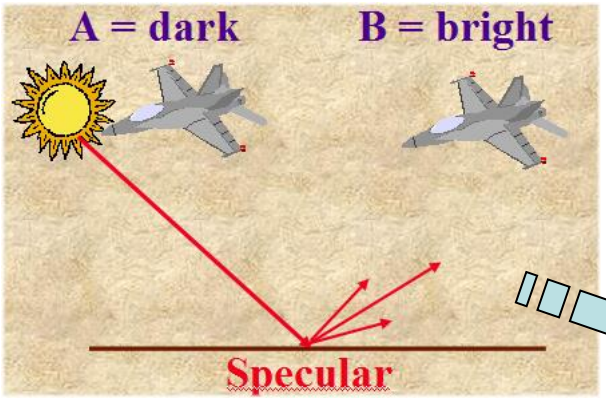
- Sun irradiance reflected directly by the atmosphere into the sensor **(Path 2)**
- Irradiance reflected from adjacent areas directly into the sensor **(Path 4)**
- **Therefore, reflectance curves derived from imagery do not represent exact surface reflectance due to the above factors 2,4,5.**
- Much research has focused on developing methods to correct for these effects and derive actual surface reflectance.

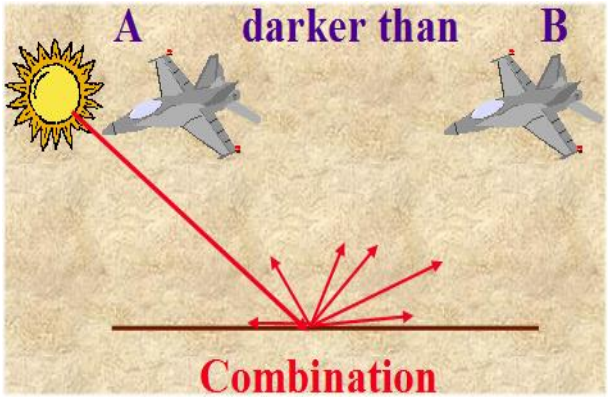
Atmospheric Effects in Natural Colour Images

Selim Erguden

Illumination – View Angle Effects on Reflectance and Image Brightness



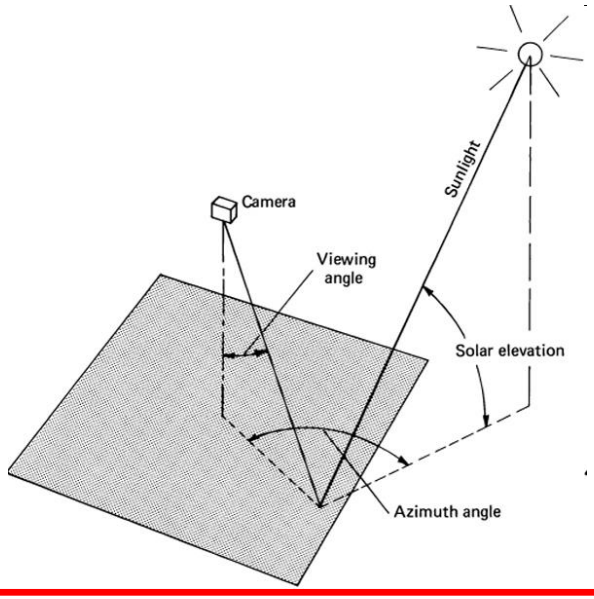


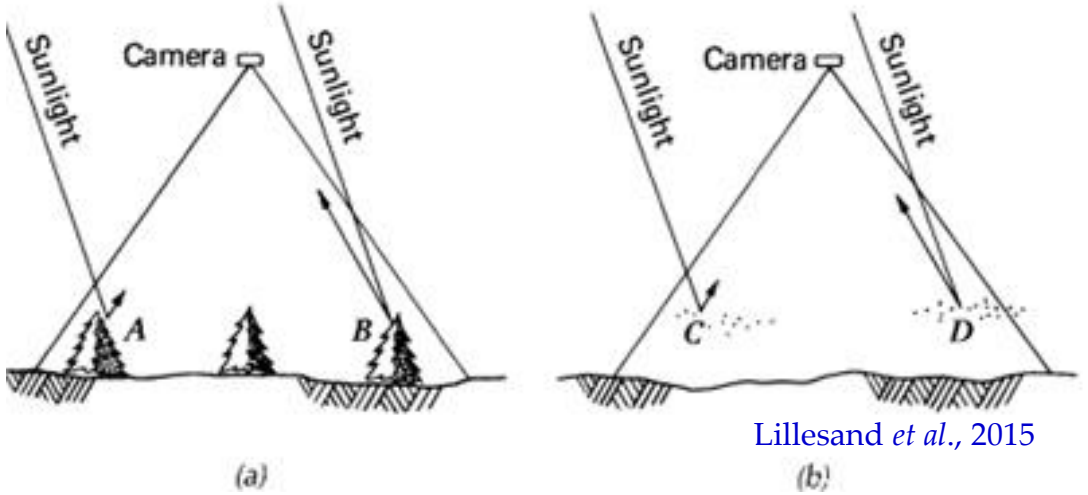


ISS photos 31 seconds apart

http://earthobservatory.nasa.gov/IOTD/view.php?id=85775&src=eoa-iotd

Illumination – View Angle Effects on Reflectance and Image Brightness



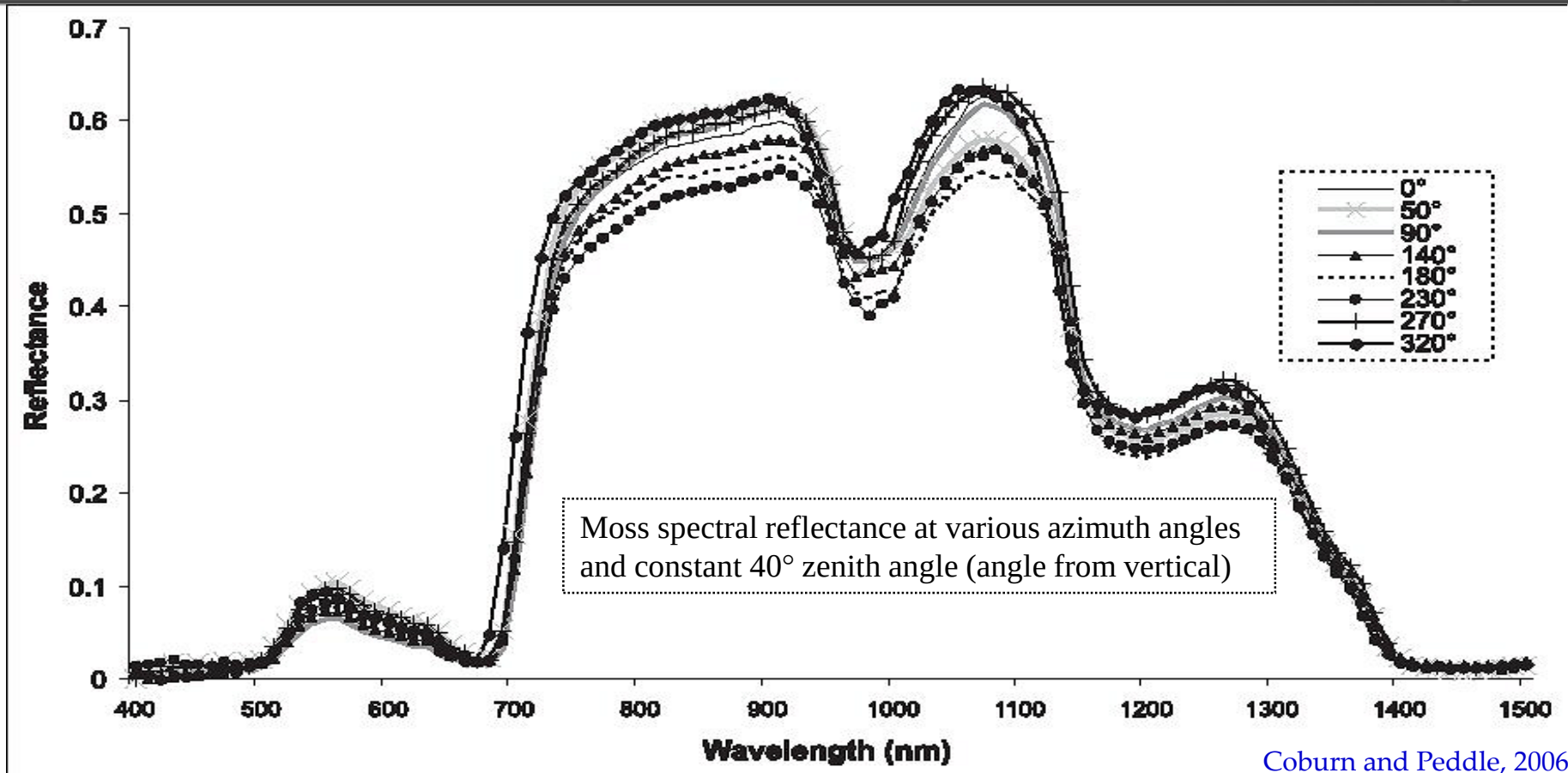


Lillesand *et al.*, 2015

Same sun angle but different view angles

- The Bidirectional Reflectance Distribution Function (BRDF) is the reflectance for a given point on the surface as a function of the sun's illumination angle and the sensor view angle.
  - The sun and sensor are each represented by two angles: elevation and azimuth (e.g.,angle from north) as shown in the left figure.
  - The BRDF for rough surfaces causes increasing brightness across the image as in the right Figure.

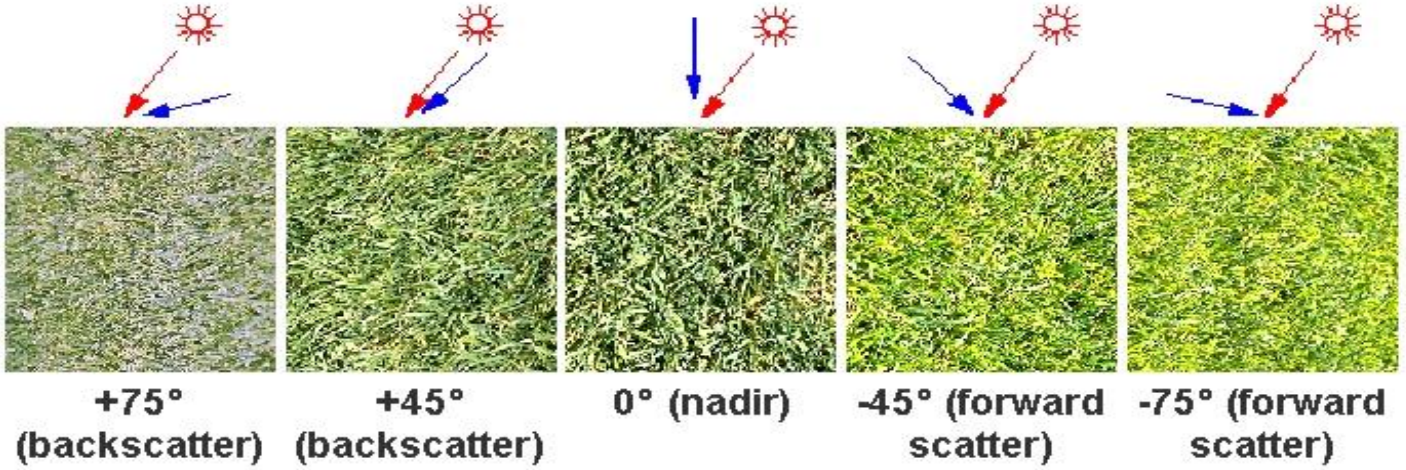
Illumination – View Angle Effects on Spectral Reflectance and Image Brightness



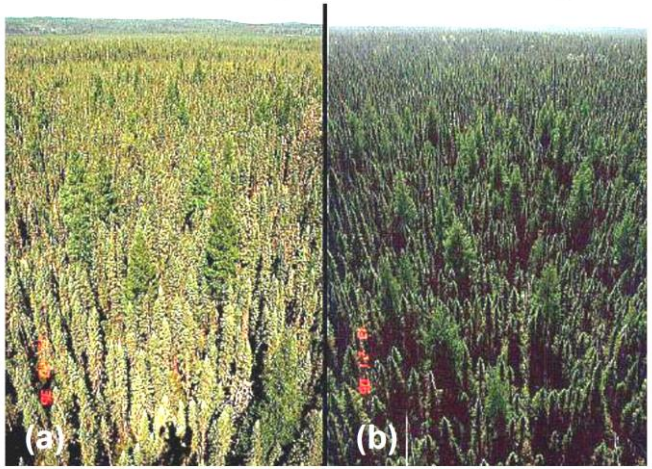
Coburn and Peddle, 2006.

Figure 7. A full-spectrum representation of the pleurozium data at a constant 40° zenith for different azimuths.

Illumination – View Angle Effects on Spectral Reflectance and Image Brightness



Jensen, 2007

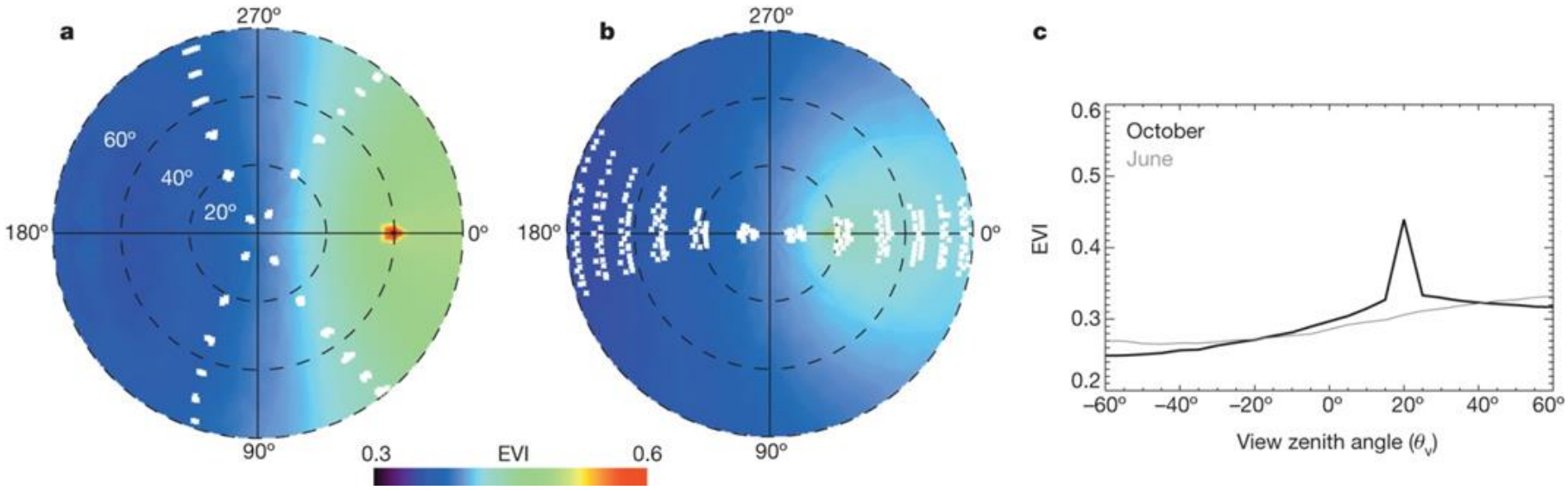


http://www.umb.edu/spectralmass/terra_aqua_modis/modis

Photographs by Don Deering.

Illumination – View Angle Effects Can Impact Scientific Conclusions

- Seasonal changes in sun-sensor geometry generate the appearance of a green-up in dry season (June-October) MODIS images of the Amazon forest.
- For many years, studies falsely concluded that vegetation was greening during the dry season (counter-intuitive). The greening observed in images was actually due to changes in the sun-sensor geometry and BRDF. Once corrected for in this paper, it was shown that greening doesn't occur in the dry season.



DC Morton *et al. Nature* **000**, 1-4 (2014) doi:10.1038/nature13006

Graphics Sources

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Greuell, W., et al. 2002. Narrowband-to-broadband albedo conversion for glacier ice and snow based on aircraft and near-surface measurements. Rem. Sens. Env. 82:48-63.

Stephens, S.C., V.P. Rasmussen, R.D. Ramsey, R.E. Whitesides, G.S. Searle, R.L. Newhall. Remote sensing organic carbon in soil. Utah State University, Logan, Utah.