ESM186 and 186L: Environmental Remote Sensing Spring 2011

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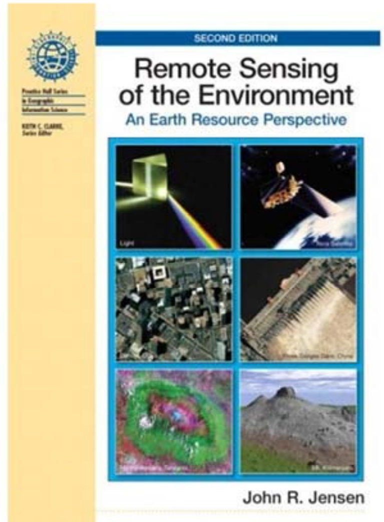
Assigned Text

- Jensen, J.R. 2006. Remote Sensing of the Environment: An Earth Resource Perspective. Prentice-Hall, Inc., Upper Saddle River, NJ.

- All other texts/articles will either be distributed in class or placed on the website.



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Username: **ESM186**
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The door code for 1137 PES is 79715

Course Goals

- **ESM186**: to read, understand, and evaluate environmental literature from a mechanistic understanding of remote sensing principles and technology.

- **ESM18L**: to learn basic techniques in image processing and fundamentals of remote sensing research (project design, data collection, image acquisition, image analysis, presentation of results) that enables you to analyze and interpret environmental data.

Course Topics:
Remote sensing of environmental materials at scales from leaf and lab bench to global

Plants:
Leaves and Canopy Spectra
Plant Canopy and Ecosystem Structure
Plant Functional type/Vegetation/species mapping
spatial & temporal ecosystem patterns & processes

Geology:
minerology, geomorphology

Soils:
soil texture, chemistry

Water:
phases (ice, liquid, vapor states);
Hydrological processes
Precipitation

Change detection:

Disaster prediction/monitoring:
risk, detection, response, recovery:
Wildfires, Weather, Severe storms
Earthquakes, Tsunamis,
Pollution, Contamination

Climate Change:
Sea level rise
Loss glacier, polar ice
Biogeochemical cycle changes:
carbon (CO_2, CH_4), water (H_2O),
Nitrogen (NOx, N_2O)

Urban applications:
planning, monitoring,

A broad survey of remote sensing applications for many environmental disciplines

This course (ESM 186 and 186L) is 5 units

This subject requires broad range of understanding: chemistry, physics, optics, and environmental sciences.

- You should expect to study about 2 hrs outside class for each class hour.
- Take notes, read the assigned reading and review:
- The homework is designed to help you prepare for exams.

Most people learn best using different communication modes: reading, hearing, writing, and speaking

Read assignments
Listen to lecture
Take notes
Talk to your friends!

UCD Smartsite:

- esm186-2012@smartsite.ucdavis.edu
- Ask general interest questions here, but please don't send personal questions through this list!
- We occasionally send information through this listserv, so check your email!

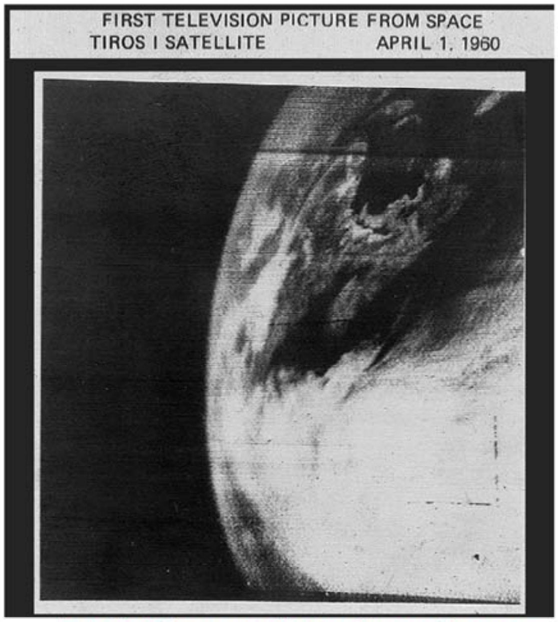
Lecture Grading:

- 2 Midterms worth 25% each
- 4 homework sets worth 5% each
- Comprehensive Final worth 30%

Today: Reading Assignment: chapter 1 and 2

Introduction to Remote Sensing

1. Wavelength, frequency, energy
2. Reflectance, Transmission, Absorption
3. Index of Refraction
4. Target and path radiance



Earth Observations from Space: 1958-2008: The First 50 Years of Scientific Achievements

Explorer 1 on January 31, 1958

What Is Remote Sensing?

ASPRS adopted a combined formal definition from *photogrammetry* and *remote sensing* (Colwell, 1997) as:

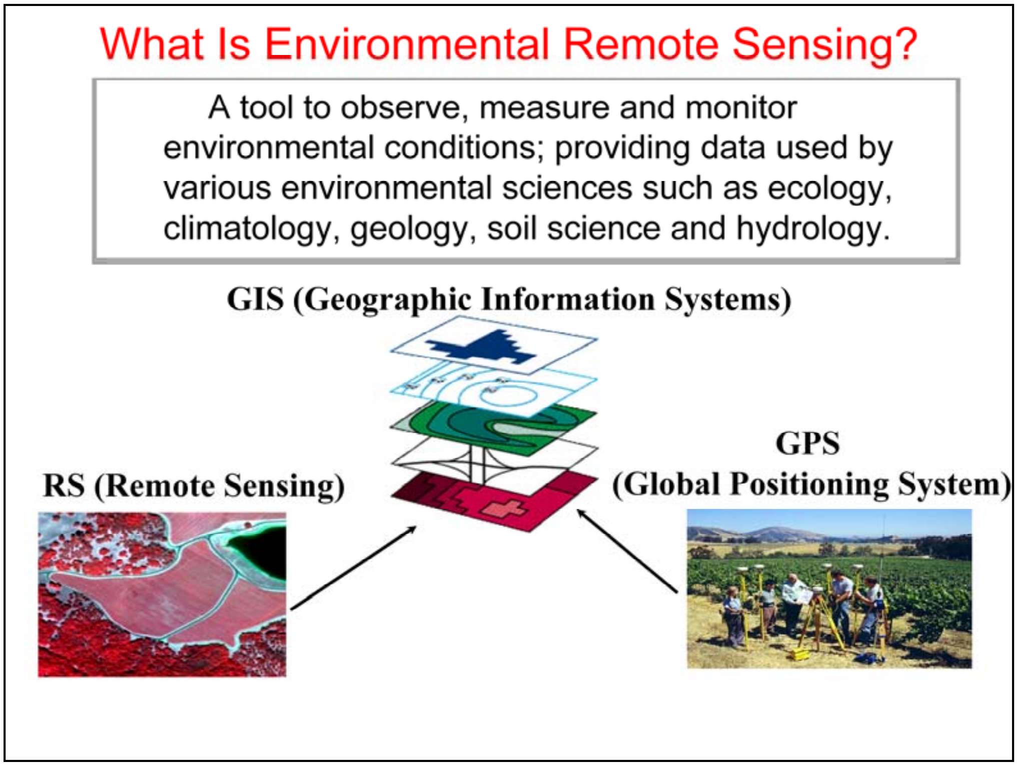
> "the art, science, and technology of obtaining reliable information about physical objects and the environment, through the process of recording, measuring and interpreting imagery and digital representations of energy patterns derived from noncontact sensor systems".

1. First definition is very general and applies to many types of "remote" sensing.

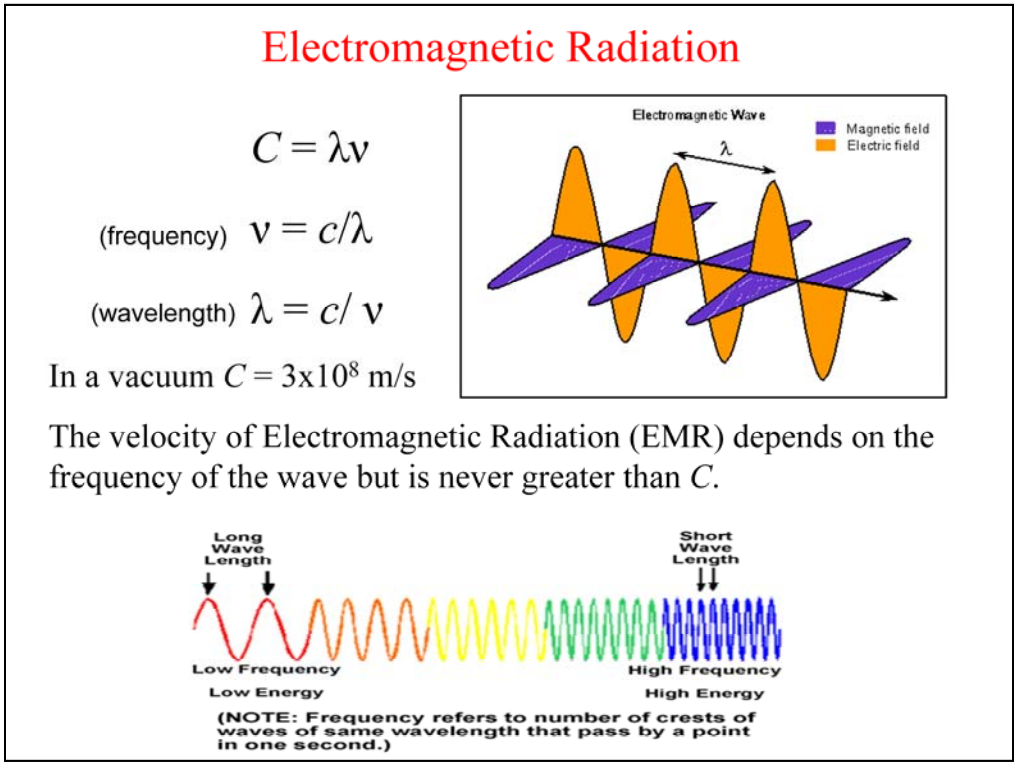
You use your eyes to sense light waves and ears to sense sound waves.

2. The second definition is a closer description of this class although we will focus on solar energy in the visible and reflected infared and emitted energy in the thermal infrared, and do little with UV and microwave radiation.

3. Instruments collect data (not pictures) that can be analyzed using mathematical and statistical relationships. Provides synoptic coverage and wall to wall sampling.



Remote sensing instruments are tools that let you measure different parts of the electromagnetic spectrum, generally in a spatial context. As such the data can become part of a GIS database (along with other spatial data e.g., GPS). The purpose is to inform environmental science research.

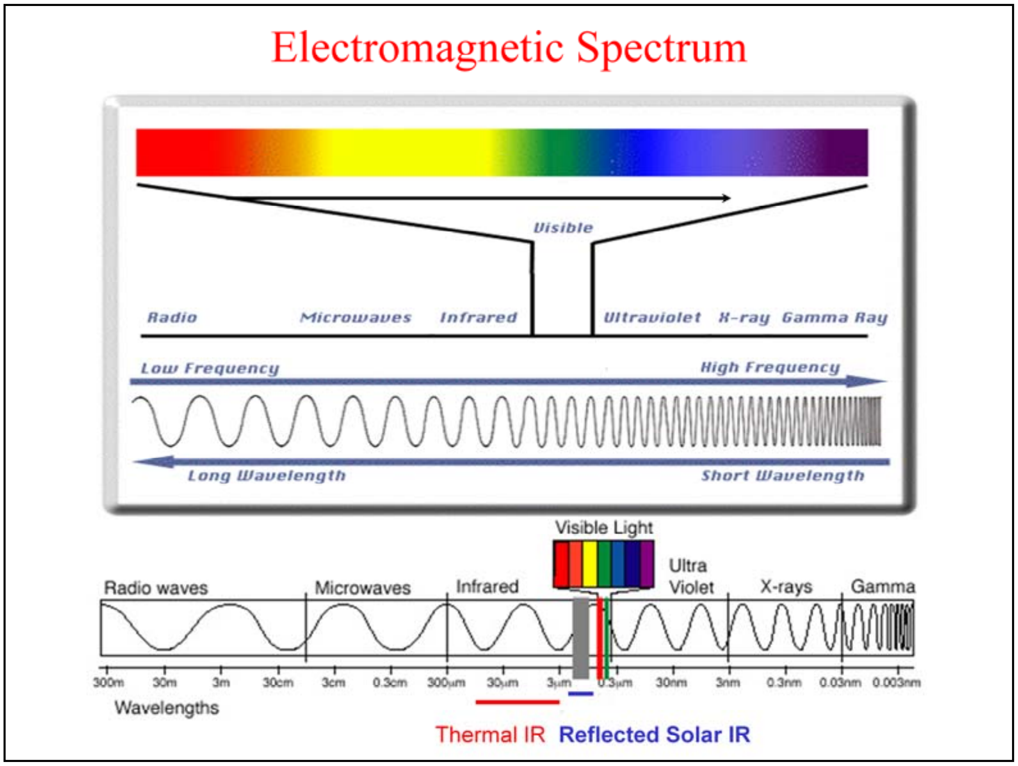


Generated when an electromagnetic particle is accelerated

C = speed of light in a vacuum

Frequency [v =nu] number of accelerations (waves) per second. 1 cycle/sec = 1 Hertz (Hz) (MHz= 10^6, GHz= 10^9)

Wavelength= mean distance peak to peak, usually measured in nanometers (nm= 10^{-9} m) or micrometers (μm, = 10^{-6} m) for environmental remote sensing applications



Naming of EMR regions is arbitrary and different disciplines use different terms:

Visible light = 400nm (blue), 500nm (green), 600nm (red), 700nm-1200nm (NIR), 1200nm-3000nm (Middle-infrared [also Shortwave Infrared, SWIR]), 3000-30000nm = Thermal IR

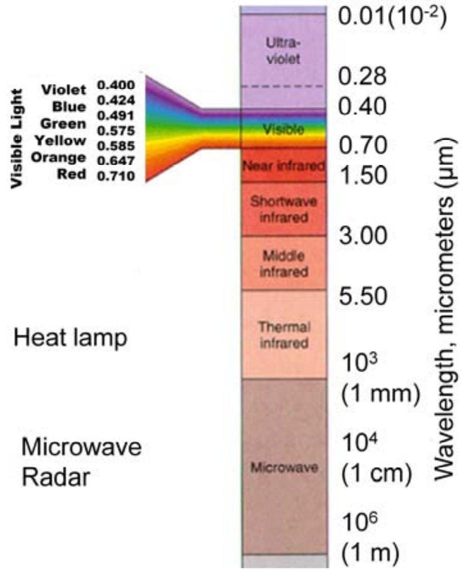
0.4μm, 0.5μm, 0.6μm, 0.7μm-1.2μm, 1.2μm-3.0μm, 3.0μm-30.0 0.4μm

Why use different units?

Introduction

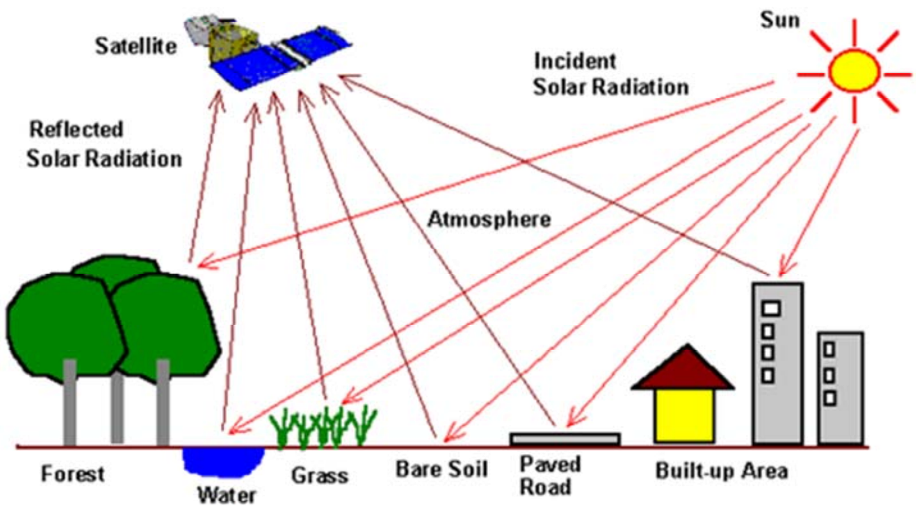
EM Terminology Varies with Discipline

Remote Sensing use generally follows this terminology



Robert W. Christopherson, 2000
Elemental Geosystems

How does light interact with matter to create the measurement?

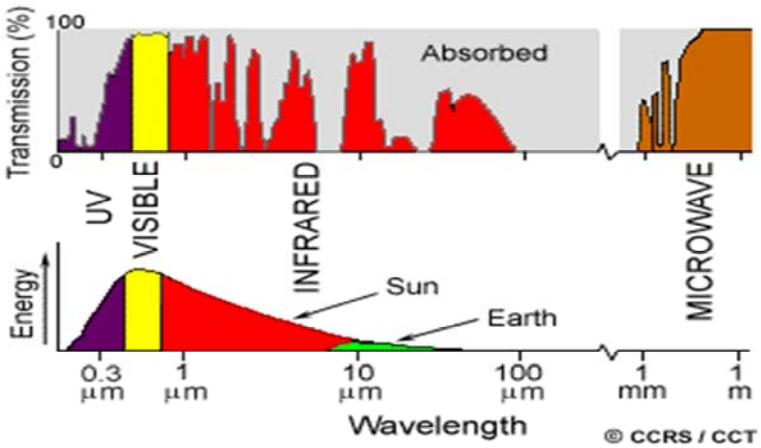


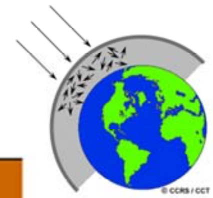
Light from the sun passes through the atmosphere and is absorbed or scattered by gasses and particles in the atmosphere. Light reaching the surface interacts with the ground materials and some energy is absorbed, scattered or transmitted through these materials. The reflected and scattered energy passes back through the atmosphere and some reaches the remote sensing detector on the satellite.

What do you think happens when the sun changes position (over the day or over the year)?

Energy Emission Distribution for Sun and Earth

- Transmission of Light at the Ground Surface





Light Interactions with Surfaces

When energy is incident on a surface

- **Absorption (A):** radiation is absorbed into the target
- **Transmission (T):** radiation passes through a target
- **Reflection (R):** radiation "bounces" off the target and is redirected

- The sum of interactions adds to 100% of the incident energy.
- Proportions depend on the wavelength, the material, and the condition of the material.

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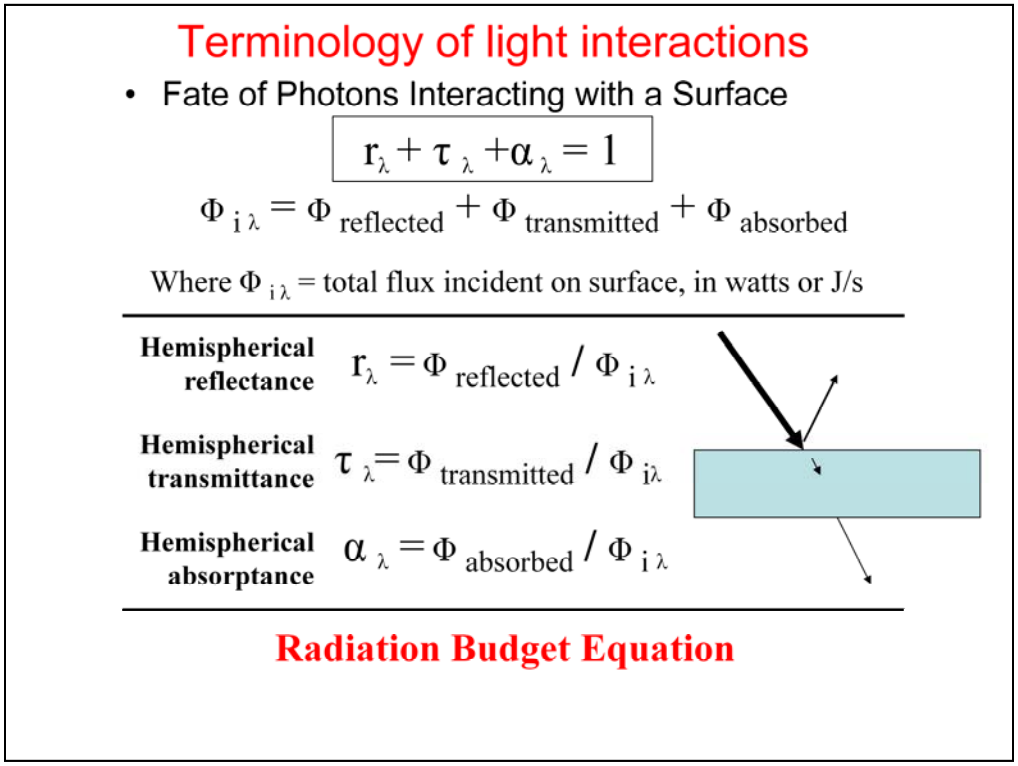


Radiant flux Φ [Phi] is W [or J/s] (but typically, no area is specified) and describes the amount of energy incident on, through, or off a surface.

Energy can be Reflected, Transmitted, or Absorbed. The sum of these equal the incident radiant flux

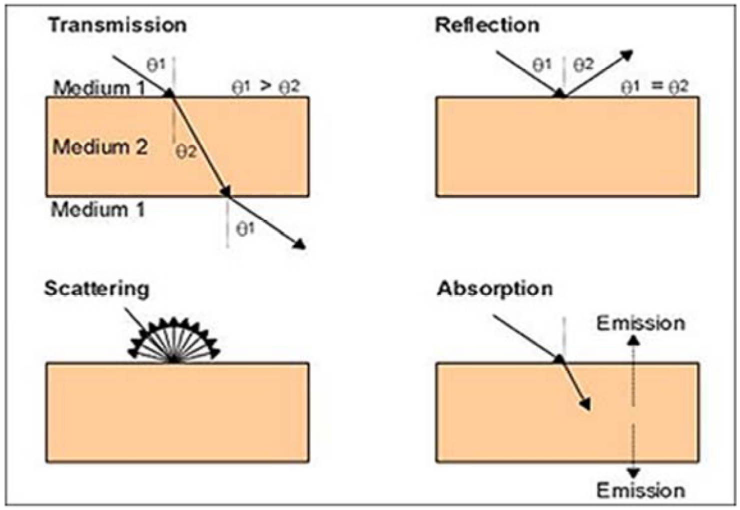
Reflectance (correctly hemispherical) is dimensionless and is the reflected flux/incident flux

Transmittance = transmitted flux

Absorptance= absorbed energy or the ratio of radiant energy absorbed to total incident radiant energy

Absorbance = The ability of a medium to absorb radiation depending on temperature and wavelength. Expressed as the negative logarithm of the transmittance.

Summary of Surface Interactions



α_λ = absorption
ε_λ = emission
τ_λ = transmission
r_λ = reflection

$$\mathbf{r_\lambda + \tau_\lambda + \varepsilon_\lambda + \alpha_\lambda = 1}$$

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Refraction

- Energy Transmission between Media of Different Densities

Refraction: bending of light through media of different density.

$$\eta = C/S$$

The **index of refraction** of the medium:

Where C = speed of light in a vacuum
S = speed of light in a medium

Note: η is always greater than 1

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Note that the light is bent more at shorter wavelengths than longer ones: so the order of visible light, from bottom to top: blue, green, yellow, orange, red.

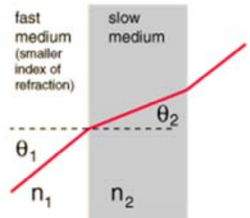
η = eta

Refraction

- Refraction Between Water – Air Interfaces

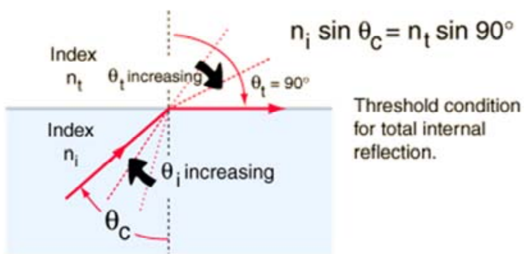
Snell's Law

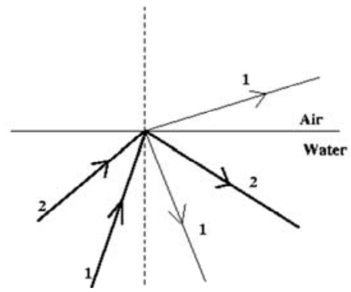
$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1}$$



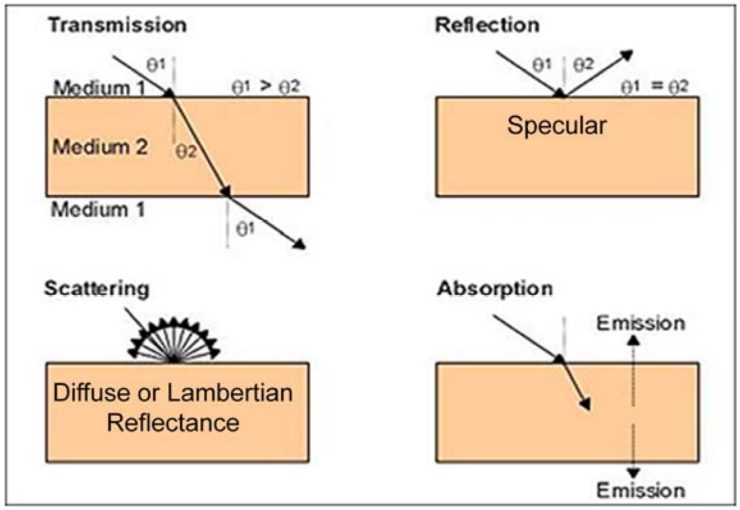
The index of refraction for water is 4/3, indicating that light travels only 3/4 as fast in water as it does in vacuum.

$$n_i \sin\theta_c = n_t \sin 90^\circ$$





Summary of Surface Interactions



α_λ = absorption
ε_λ = emission
τ_λ = transmission
r_λ = reflection

$$\mathbf{r_\lambda + \tau_\lambda + \varepsilon_\lambda + \alpha_\lambda = 1}$$

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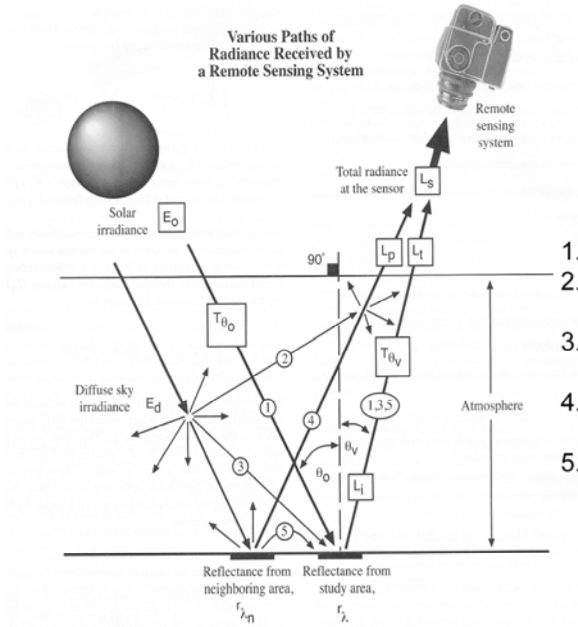


Figure 2-20 *Radiance* (L_t) from paths 1, 3, and 5 contains intrinsic valuable spectral information about the target of interest. Conversely, the *path radiance* (L_p) from paths 2 and 4 includes diffuse sky irradiance or radiance from neighboring areas on the ground. This path radiance generally introduces unwanted radiometric noise in the remotely sensed data and complicates the image interpretation process.

1. Direct Beam Radiation
2. Atmospheric Scattering (sky light)
3. Forward scattering from sky to Ground
4. Scattering from Surroundings to sensor
5. Scattering from Surroundings onto Target

Aerosols are suspensions of fine solid or liquid droplets in a gas. In contrast with smoke which is a suspension of solid particles in a gas.

Aerosol-contamination in North-India and Bangladesh

Anthropogenic aerosols, particularly sulfate aerosols from fossil fuel combustion, exert a cooling influence on the climate. The cooling effect of aerosols, however, does not seem to directly counteract the warming induced by greenhouse gases such as carbon dioxide, methane and water vapor and is accounted for in climate models, despite some claims that "global dimming" by aerosols may counteract global warming.

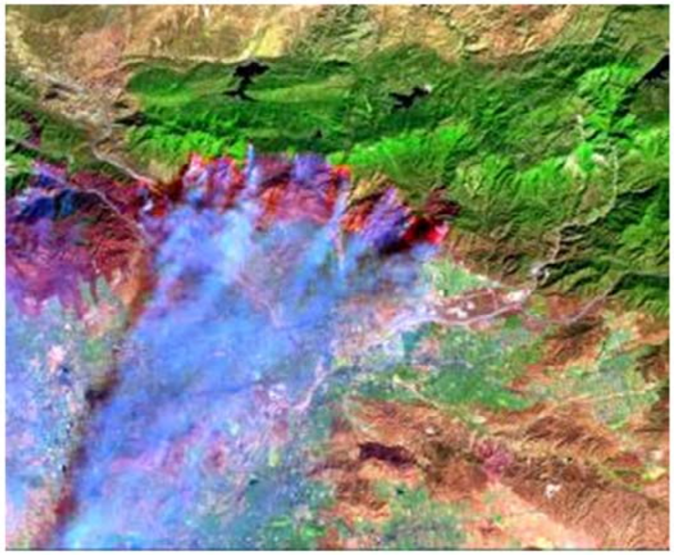
Recent studies of the Sahel drought and major increases since 1967 in rainfall over the Northern Territory, Kimberley, Pilbara and around the Nullarbor Plain have led some scientists to conclude that the aerosol haze over South and East Asia has been steadily shifting tropical rainfall in both hemispheres southward. The latest studies of severe declines in rainfall over southern Australia since 1997 have led climatologists there to consider the possibility that these Asian aerosols have shifted not only tropical but also midlatitude systems southward.

anthropogenic aerosols—those made by human activities—currently account for about 10 percent of the total amount of aerosols in our atmosphere. Increased levels of fine particles in the air are linked to health hazards such as heart disease, altered lung function and lung cancer.

Some occur naturally, originating from volcanoes, dust storms, forest and grassland fires, living vegetation, and sea spray. Human activities, such as the burning of fossil fuels and the alteration of natural surface cover, also generate aerosols. Averaged over the globe, aerosols made by human activities currently account for about 10 percent of the total amount of aerosols in our atmosphere. Most of that 10 percent is concentrated in the Northern Hemisphere, especially downwind of industrial sites, slash-and-burn agricultural regions, and overgrazed grasslands.

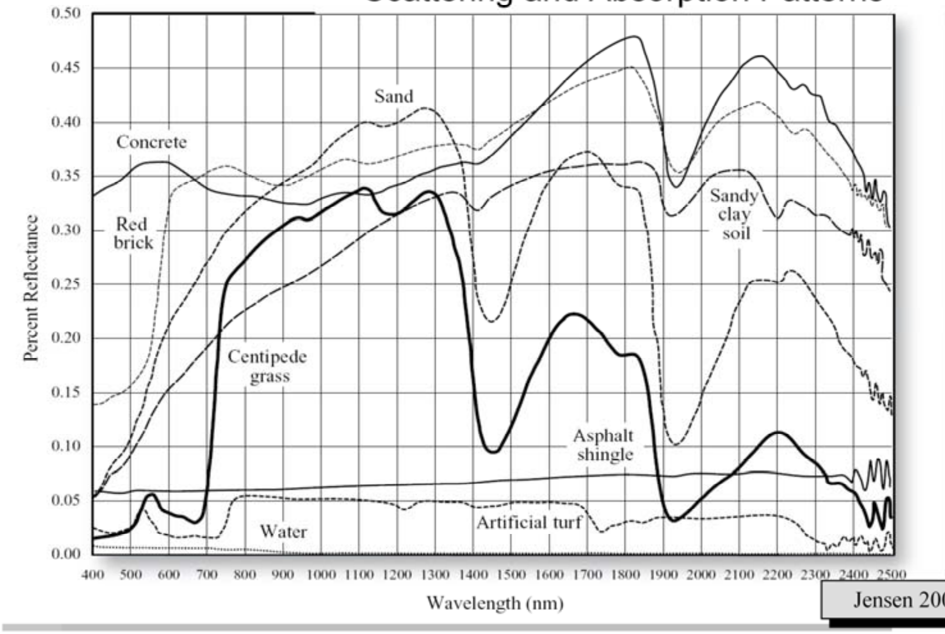
Scientists have much to learn about the way aerosols affect regional and global climate. We have yet to accurately quantify the relative impacts on climate of natural aerosols and those of human origin. Moreover, we do not know in what regions of the planet the amount of atmospheric aerosol is increasing, is diminishing, and is remaining roughly constant. Overall, we are even unsure whether aerosols are warming or cooling our planet.

Applications: Disturbance and Natural Disasters; Detection of Emergencies & Disaster Response



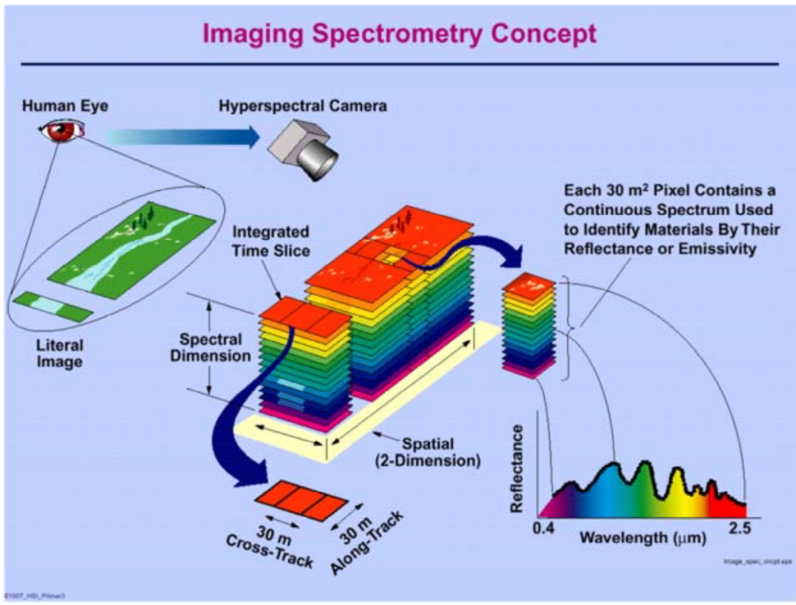
Reflectance of Different Materials

- Scattering and Absorption Patterns

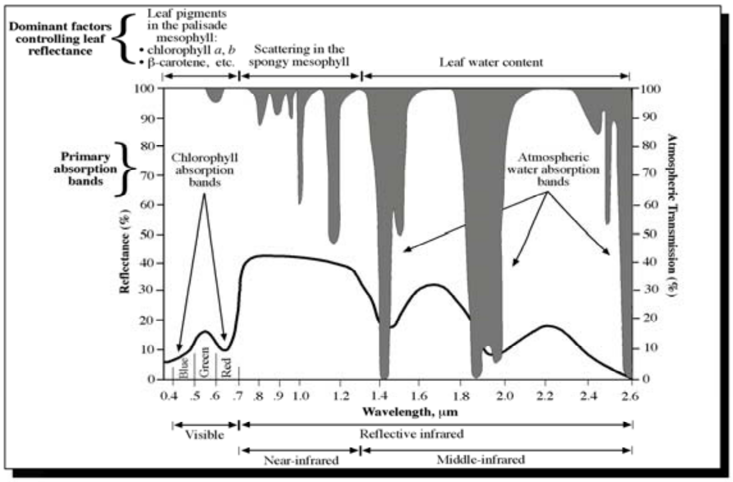


Jensen 2007

Image Data Set: Georegistered Spectral Bands: images of the same location



Reflectance Spectrum of Leaves and Plants



Pigment absorption is the dominant process in **visible**;
Scattering is the dominant process in **near-infrared**;
Water absorption is increasingly important with wavelength in the **mid-infrared**

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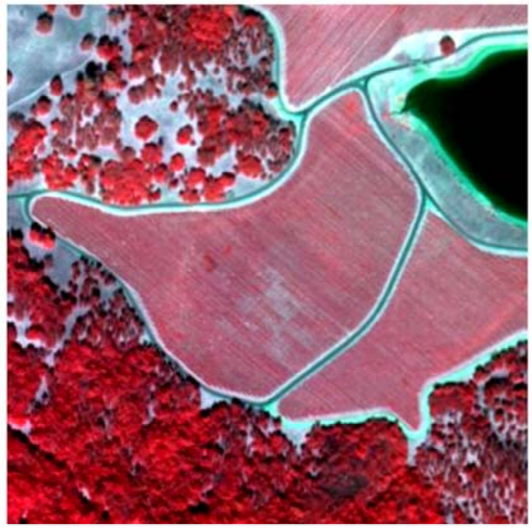
Applications: Agriculture

Color infrared [CIR]
Also called:
False Color IR

Natural color	Display color
Green (0.5-0.6 μm)	Blue
Red (0.6-0.7 μm)	Green
NIR (0.7-0.9 μm)	Red

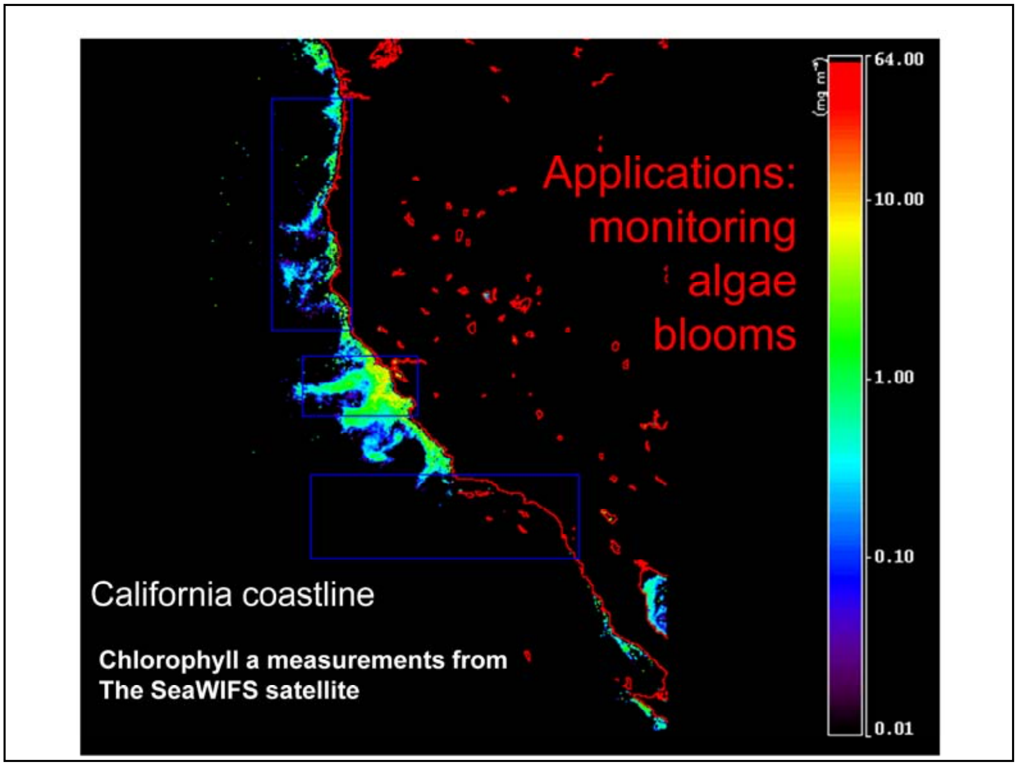


Gallo Vineyards, Sonoma County, ADAR-5500

Parts of the EMR that our eyes can't see can be made visible to us by assigning the bands as red, green or blue colors on computer screen or in a color print.

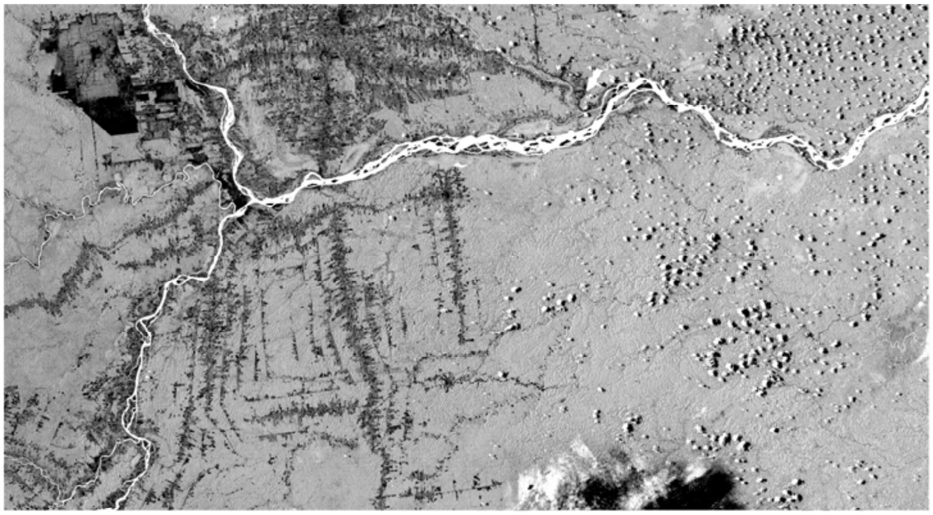
The oldest is to assign the nearinfrared [NIR] band as the red color in a color composite image. In CIR all the bands are shifted to longer wavelengths, so the true "green" is printed as blue, the true "red" becomes green, and the NIR band becomes red.

Plants have high reflectance in the NIR band so they are seen as shades of red. The denser the vegetation the darker the red.



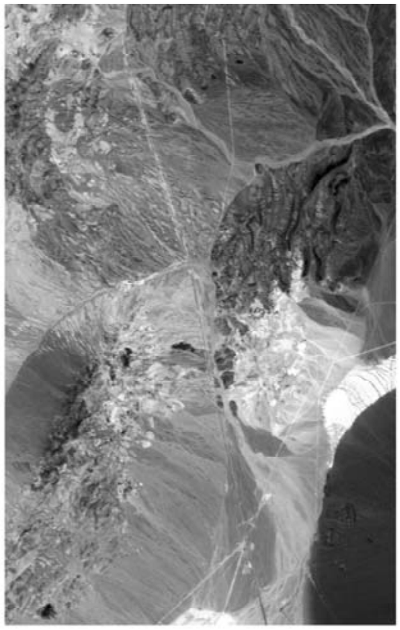
Applications: monitoring algae blooms
California coastline
Chlorophyll a measurements from
The SeaWIFS satellite
(mg m⁻³)
64.00
10.00
1.00
0.10
0.01

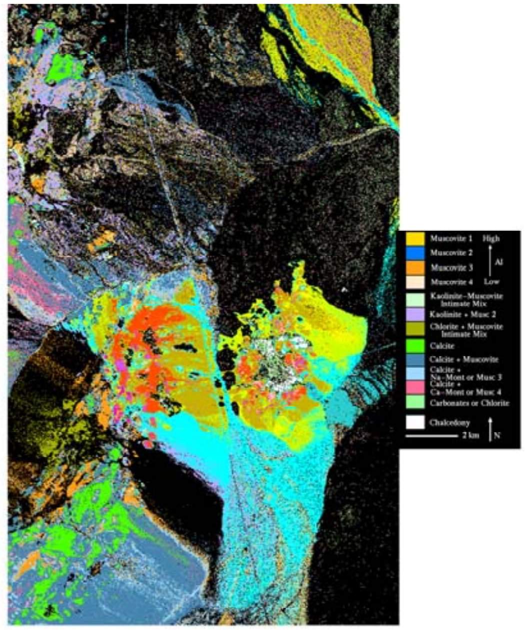
Forest Applications: Detection of Deforestation in Amazon



Yasuni National Park, Ecuador, LANDSAT 1996

Mapping Minerals Based on Spectral Properties



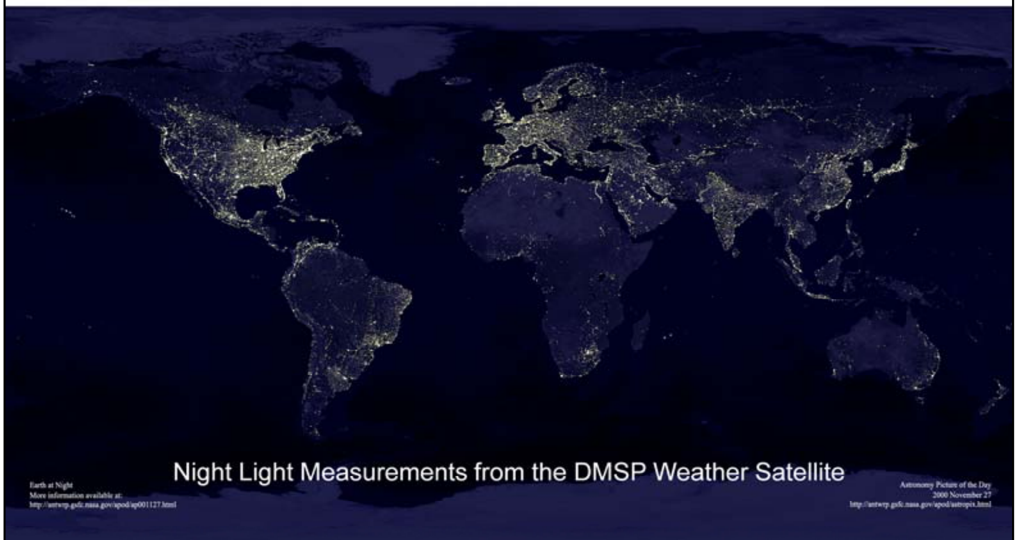


Applications: Monitoring Soil Erosion

Yangtzee River

From Huete, A. 2004
Manual of Remote Sensing
V. 4

Light Emissions Measured at Night



Applications: Observe fires, gas flares, electrical consumption, warfare, etc.

What you should know:

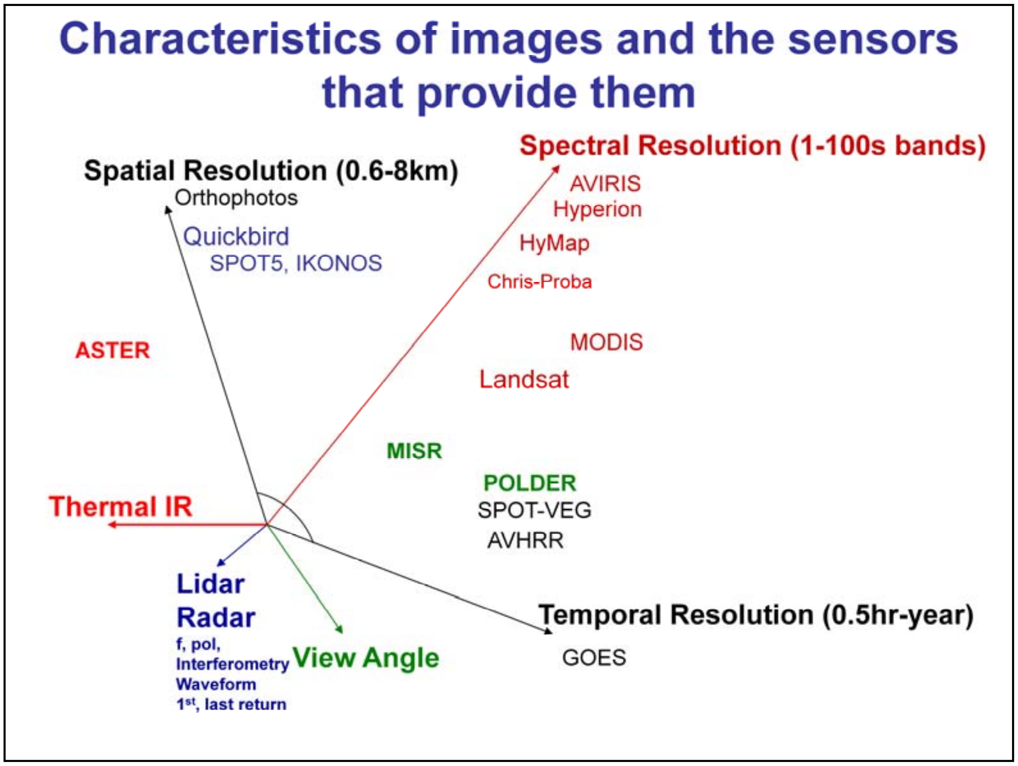
1. Relationship between wavelength and frequency
2. Regions of the electromagnetic spectrum relevant for remote sensing
3. Optical sensors use sunlight for energy; it is transmitted through the atmosphere to the surface and back to the detector (in a plane or satellite). Light can be scattered into or out of the path from the surface.
4. Refraction; Index of refraction; formula to calculate
5. Absorption features; photon absorption; electronic transitions
6. Primary physical unit of radiance; Watts/m^2/Steradian
7. The fate of incident energy: absorption, reflectance, and transmission.
8. Atmospheric windows.

Introduction to Sensors and Image Processing

ESM186L

Environmental Remote Sensing Lab

January 10, 2012



Different data characteristics are required to meet different research needs. Shown here is an ordination of the important traits of image data and examples from the fleet of satellite sensors that span each gradient.

Spatial resolution refers to the pixel size provided. This ranges from 1km MODIS and AVHRR data with very low spatial resolution to aerial orthophotos which can have 15cm spatial resolution or better. Hyperspatial satellite instruments, such as Quickbird, provide 60cm panchromatic data and 2.4 meter color images.

Spectral resolution describes the level of spectral detail provided by a sensor. Low spectral resolution sensors (such as panchromatic or color aerial photography & hyperspatial sensors) have few, wide spectral bands. Sensors with high spectral resolution, or hyperspectral sensors, (such as the Hyperion satellite sensor or airborne imaging spectrometers like AVIRIS and HyMap) have up to several hundred very narrow spectral bands and completely describe the reflectance spectra of objects.

The temporal resolution of a sensor indicates how frequently the sensor images the same location. Weather satellites, such as GOES, have very high temporal resolution and image an area every 30 minutes. MODIS also has quite high temporal resolution, at every 1-2 days. Landsat offers moderate temporal resolution, imaging a site approximately every 16 days.

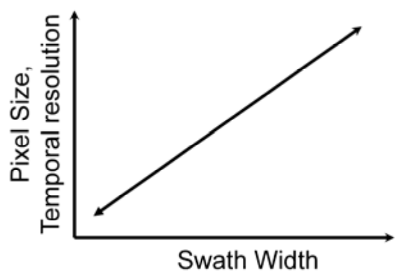
Various sensors exist that provide more specialized information. For example, some satellites detect emitted thermal radiation. Others have variable view angles or LIDAR or RADAR returns.

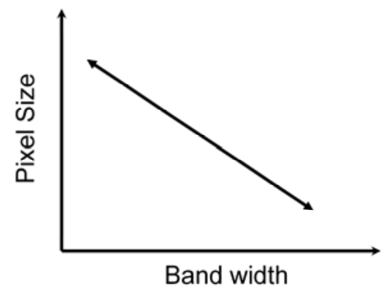
Can you think of different applications that would require different spatial, spectral, or temporal resolutions? How about thermal or structural information as might be provided by different view angles or LIDAR/RADAR returns?

Describing Sensor Properties

- **Resolution**: the smallest difference between two units of measurement that is resolvable by a sensor
- **Extent**: the spatial extent of the measurements that a sensor can resolve

Sensor Tradeoffs



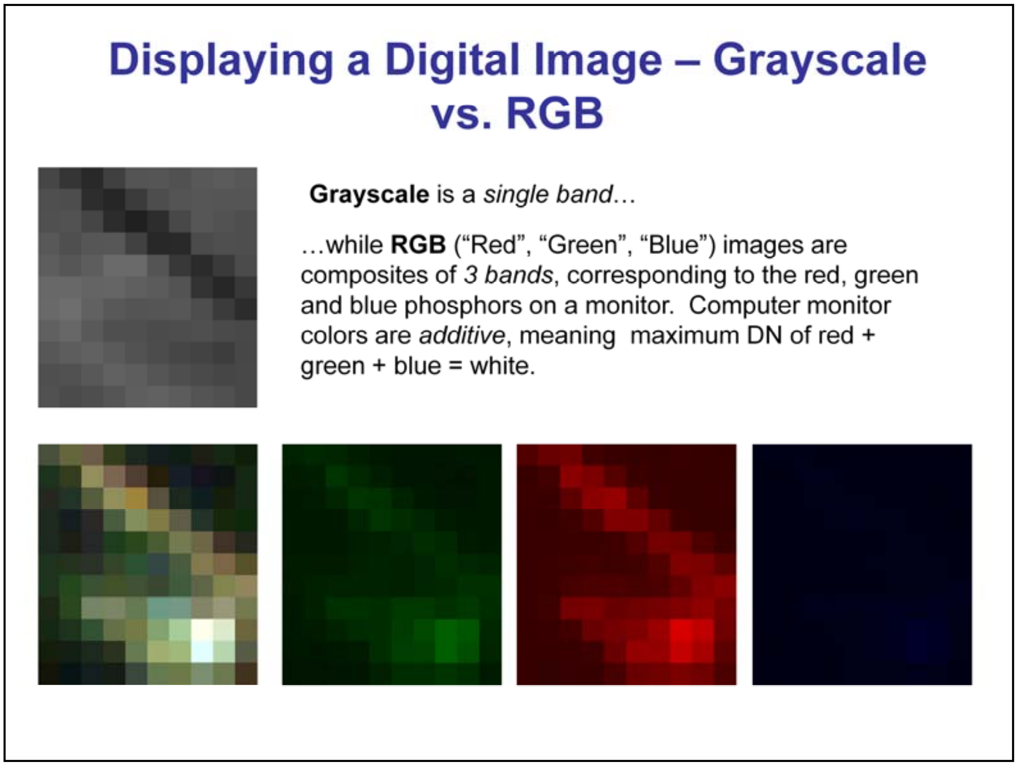


Passive vs. Active Sensors

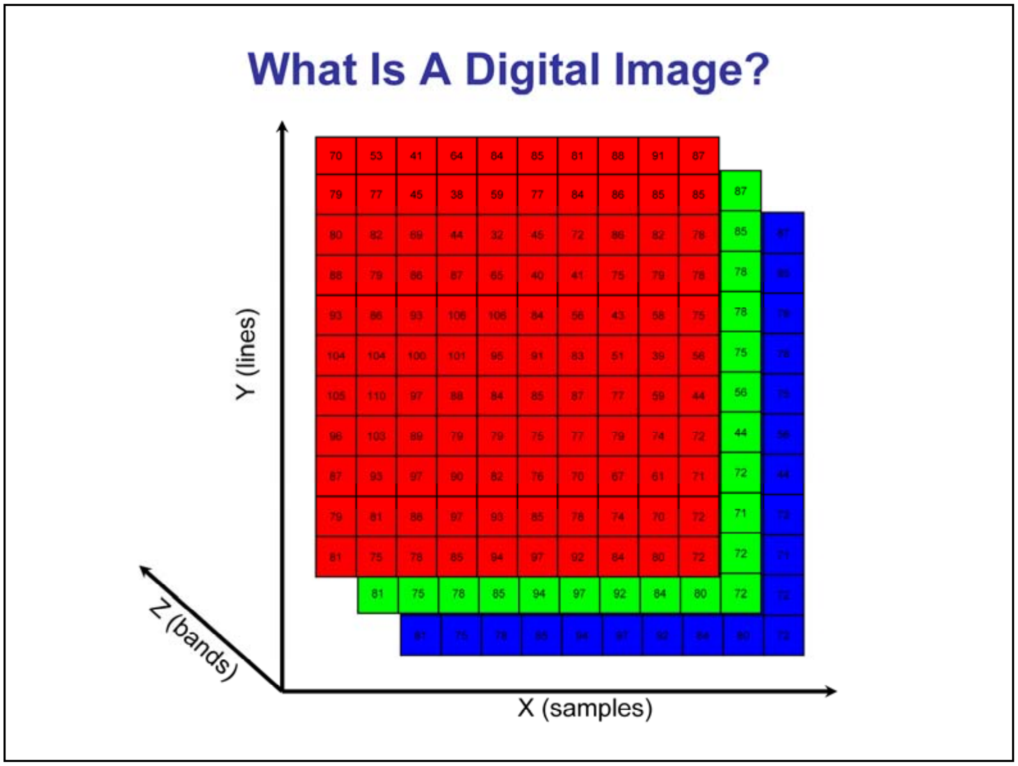
- **Passive sensors** detect and record EMR emitted from an external source [e.g., sunlight or emitted radiance (thermal Infrared)].
- **Active sensors** detect and record EMR emitted from the instrument itself [examples are RADAR and LIDAR].

We will focus on **passive** remote sensing data for these labs.

All sensors detect reflected (or emitted) light. There are two main categories of sensors, however, that differ in the source of the light that is reflected and ultimately detected. Passive sensors depend upon radiation that is emitted from the sun or from the object itself (such as thermal radiation emitted from the earth). Active sensors contain their own light source which they omit and then record its reflection. RADAR emits EMR in the microwave range and LIDAR uses near infrared wavelengths.

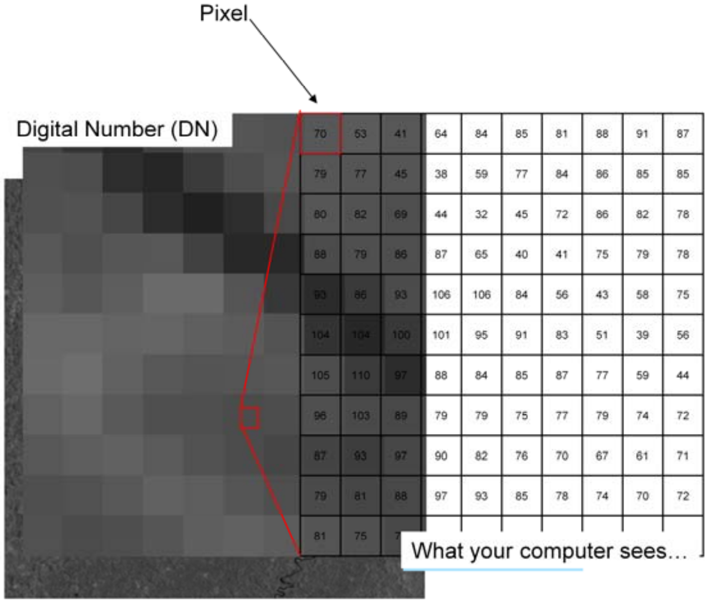


You have two options for displaying digitial image: grayscale or, if you have a multiband image, color!



Now that we've briefly discussed sensors, let's move on to the data that they collect: images. What is an image? In short, an image is a 3-dimensional matrix. The familiar X and Y dimensions are the spatial dimensions (units = meters, kilometers, centimeters, etc.). In remote sensing parlance, the X position is referred to as the sample and the Y position is the line. The Z dimension is the spectral dimension and Z positions are bands (units refer to the wavelength detected = nanometers, micrometers, etc.). So at every X,Y position (every pixel), the sensor detects and records EMR at each of its bands. In this illustration, there are 3 bands; within each X,Y,Z grid cell is a unique value.

What Is A Digital Image?



The range in Digital numbers (DNs) is the Radiometric Resolution

DN typical ranges from 0 to 255; 0 to 511; 0 to 1023, etc.

These ranges are binary scales: 2^8=256; 2^9=512; 2^{10}=1024.

Current instruments typically have 2^{14} or 2^{16} DN

This unique value is a digital number. The range of digital numbers offered by a sensor is the radiometric resolution, and is generally a power of two (from the binary scale) resulting from data storage capacities. When you display an image, your computer assigns a brightness value to each pixel depending upon its digital number. Pixels with high DNs appear bright, pixels with low DNs are portrayed dark.

Data Visualization

- A digital number (DN) has no intrinsic meaning to the display.
- Based on a predefined algorithm, the computer adjusts the brightness of a monitor as a function of the pixel value. This function can take a wide range of forms.
- 0 DN is displayed as black and the highest value [255, 511, 1023, etc.] is displayed white and all in-between values are shades of gray.
- There is no limit to the number of image bands but a monitor can only display three at once.

Displaying a Digital Image – RGB Options

True Color

Bands selected for display are from ***the visible spectrum*** and the RGB display corresponds to the true colors of red, green and blue.

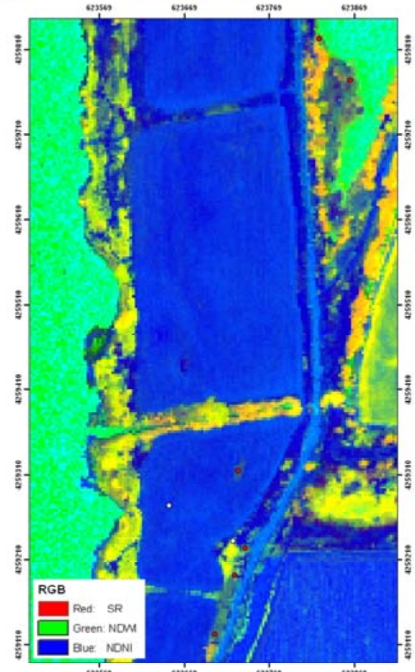
Color Infrared

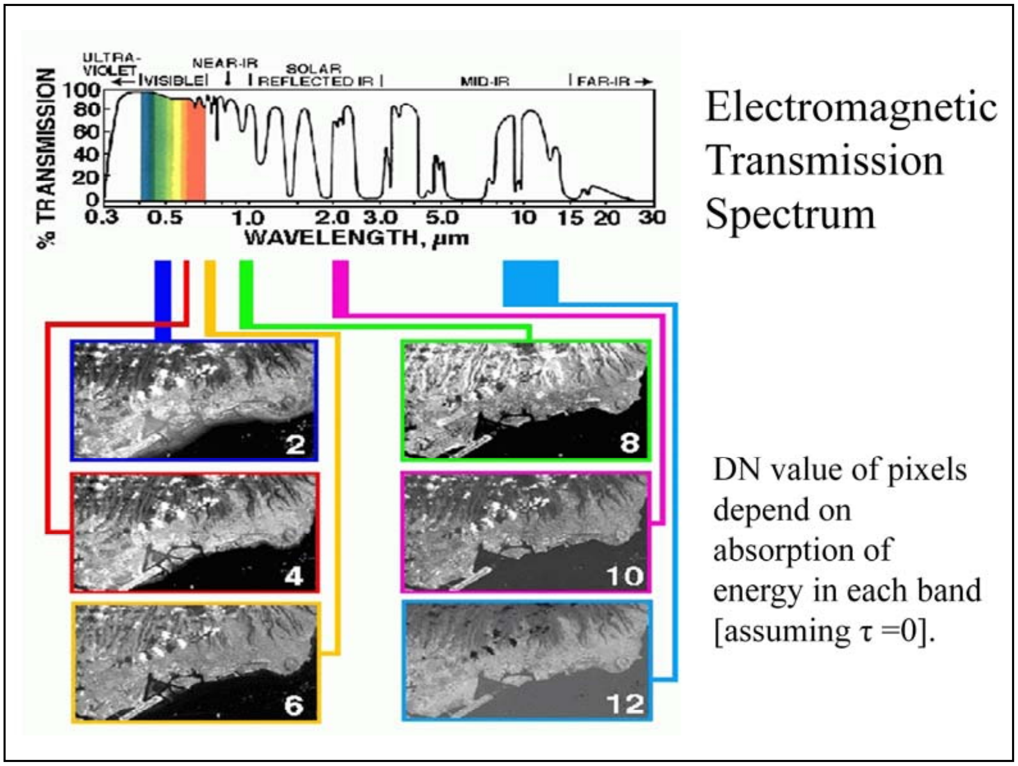
Bands displayed in RGB correspond to the near-infrared, red, and green, R, NIR

“false color IR” can be any IR bands

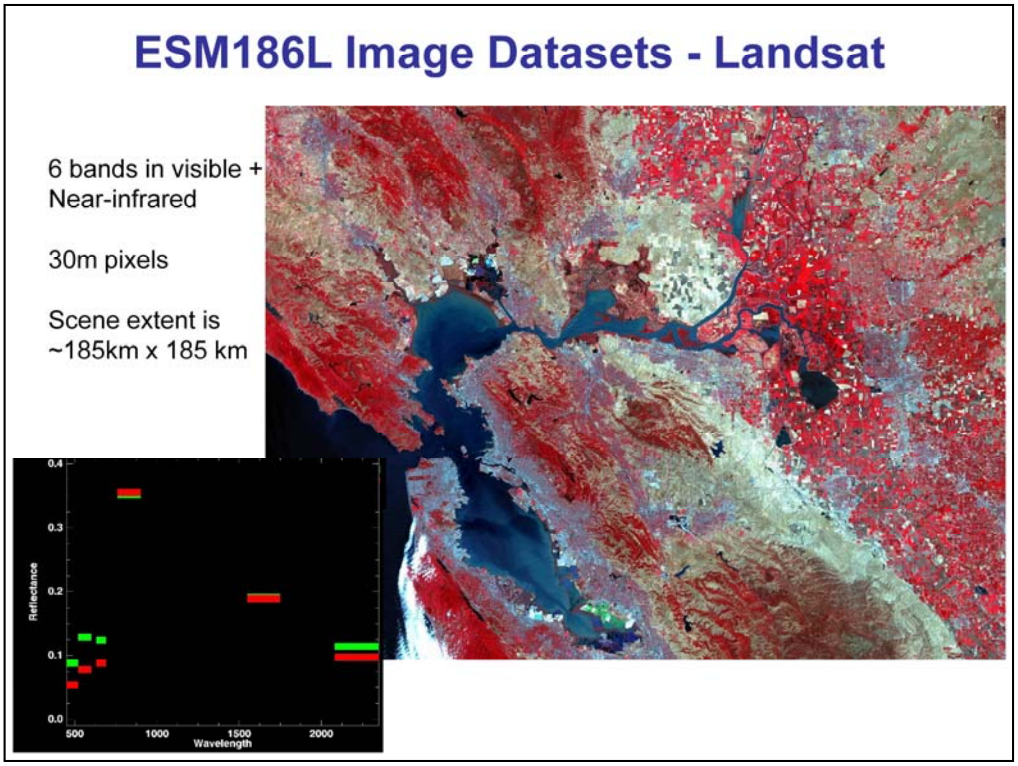
Displaying a Digital Image - False Color RGBs

- A display in which R,G, B do not correspond to the true colors of red, green and blue. This can be any combination of 3 bands or spectral products.
- Examples:
  - False-color infrared:
    Monitor blue = true green
    Monitor green = SWIR
    Monitor red = near infrared
  - Spectral index composite:
    (shown to the right)





Here's another example illustrating the 6 bands of the Landsat sensor. You can see that each band records a complete grayscale image of EMR that is reflected and detected at that wavelength. Also shown on this example are the regions of the electromagnetic spectrum that correspond to each band which are superimposed on the transmission spectrum of earth's atmosphere. All of the molecules in the atmosphere absorb and scatter at specific wavelengths, which influences a sensor's ability to see through the atmosphere and detect the ground surface at those wavelengths. As you can see, the Landsat bands were specifically chosen to be sensitive to regions of the spectrum that have high atmospheric transmission (i.e., wavelengths in which it is able to see through the atmosphere).



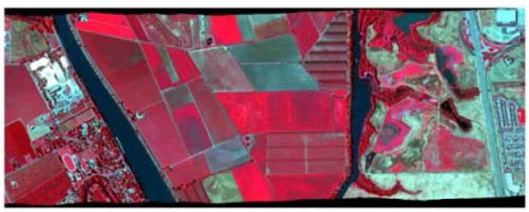
Your lab exercises this quarter will analyze two datasets of a quite local study site: the San Francisco Bay/Sacramento-San Joaquin Delta Region. Look familiar?

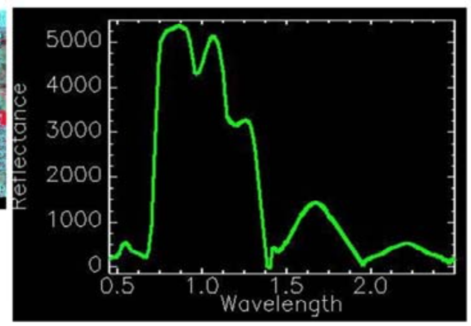
The first dataset you will analyze is from the Landsat TM instrument. Landsat is a multispectral satellite sensor that is very important to remote sensing applications. Seven Landsats have been launched, the first in 1972. This sensor thus has a temporal extent of over 35 years, the longest of continuous satellite dataset. Landsat has 6 bands: 3 in the VIS, one in the NIR, and two in the SWIR. Sample vegetation spectra (that have been modified to display band width) are displayed in the lower left. Bandwidths, as you can see, are variable: from tens of nanometers in the VIS to hundreds in the SWIR.

Landsat has a spatial resolution of 30m. Previous research highlighted the utility of color-infrared imagery for detecting and monitoring vegetation and Landsat's bands were chosen accordingly. Many vegetation indexes taking advantage of visible and near infrared reflectance of vegetation, such as the ubiquitous NDVI which you may already be familiar with and which you will learn about in this class, were originally developed on Landsat data.

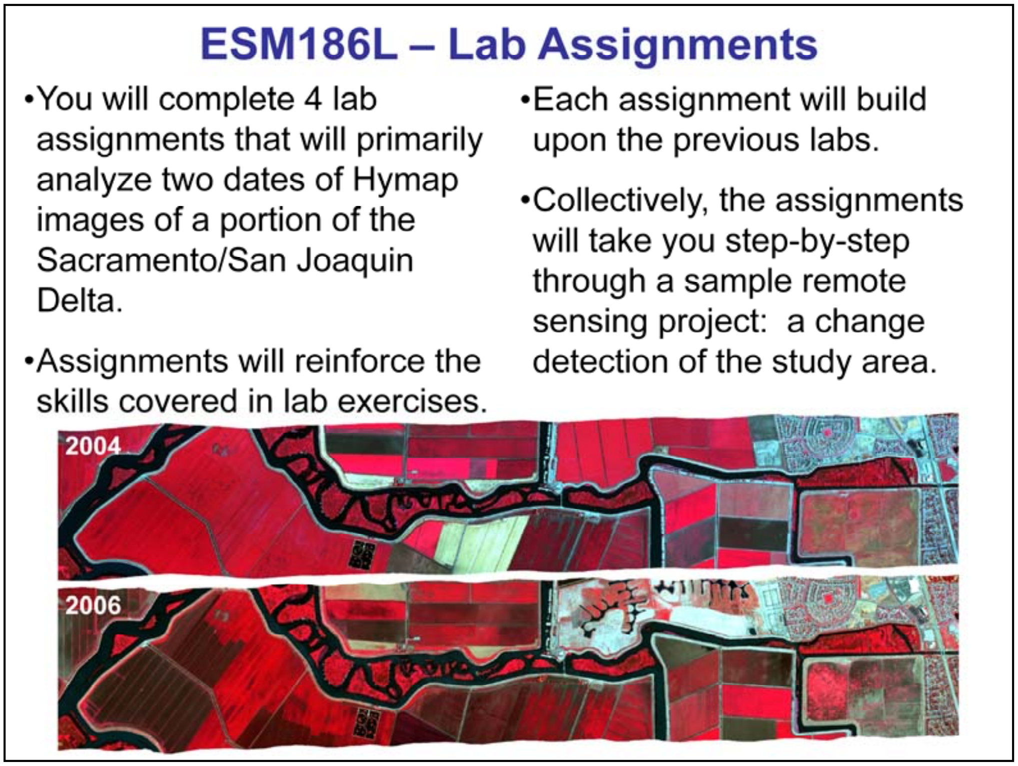
The two SWIR bands have turned out to have numerous ecological applications and have ensured Landsat's importance in ecological remote sensing.

ESM186L Image Datasets - Hymap





The second dataset you will be investigating, from a smaller portion of the Sacramento-San Joaquin Delta, is from the HyMap sensor. HyMap is an airborne hyperspectral sensor. It is an imaging spectrometer that detects visible through shortwave infrared reflectance in 126 bands that are 15-20nm wide. A sample plant spectrum is displayed in the bottom right. This imagery was acquired at an altitude of 1.5 km yielding a 3m pixel resolution.

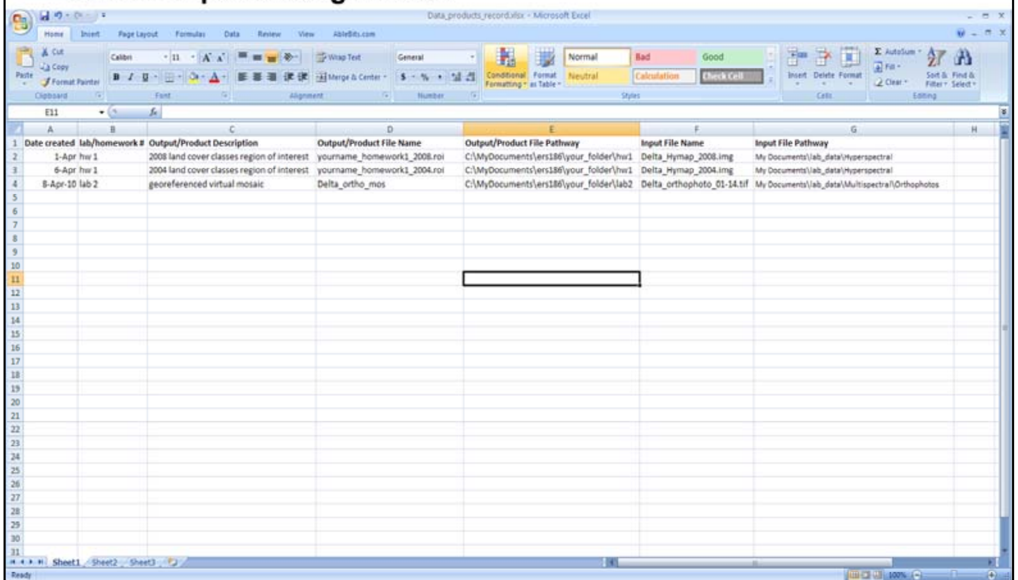


In addition to the lab tutorials, you will complete 4 lab assignments this quarter; each assignment will count as 25% of your grade for the lab class. The tutorials and assignments will analyze two image dates (June 2004 and June 2006) of a different Hymap scene from the Sacramento-San Joaquin Delta. The assignments will all build upon each other and will take you step-by-step through a sample remote sensing project. You will ultimately perform a change detection analysis using the two image dates. Since the assignments build on each other, it is important that perform each assignment with care. Poor work at the beginning of the quarter will undermine your ability to have meaningful results at the end.

You will be given time in class to work on the lab assignments. If you need extra time, you may work on them in this computer lab when no classes are occurring.

A word about data management…

Image processing tends to create large volumes of data, all of which is important. You will need data products you create now for subsequent assignments.



Date created	lab/homework #	Output/Product Description	Output/Product File Name	Output/Product File Pathway	Input File Name	Input File Pathway
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6-Apr	hw 1	2004 land cover classes region of interest	yourname_homework1_2004.roi	C:\MyDocuments\ers186\your_folder\hw1	Delta_Hymap_2004.img	My Documents\lab_data\Hyperspectral
8-Apr-10	lab 2	georeferenced virtual mosaic	Delta_ortho_mos	C:\MyDocuments\ers186\your_folder\lab2	Delta_orthophoto_01-14.tif	My Documents\lab_data\Multispectral\Orthophotos