CTCN
CLIMATE TECHNOLOGY CENTRE & NETWORK

Workshop on

"Technology development for climate resilience and efficient use of resources in the agricultural sector in Thailand"

26-30 September, 2016

Geo-informatics in Precision Agriculture

Juthasinee Thanyapraneedkul, Ph D.

Thammasat University, Faculty of Science and Technology,

Department of Environmental Science.

27 September 2016 @ NSTDA

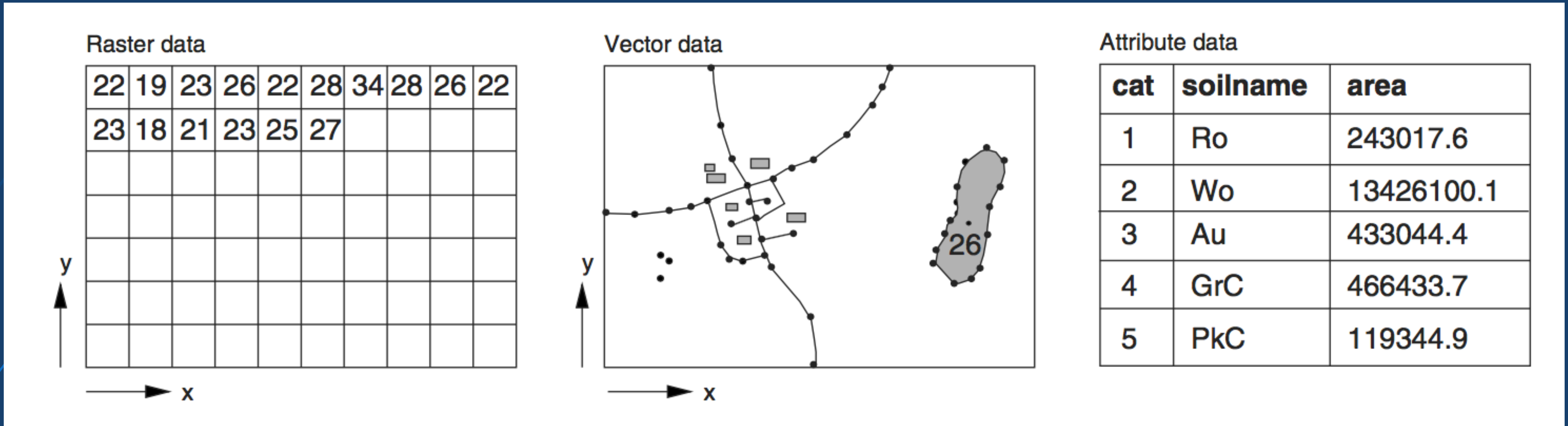
Outline

- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS in precision agriculture
- RS band composite
- Hyperspectral Remote Sensing

Outline

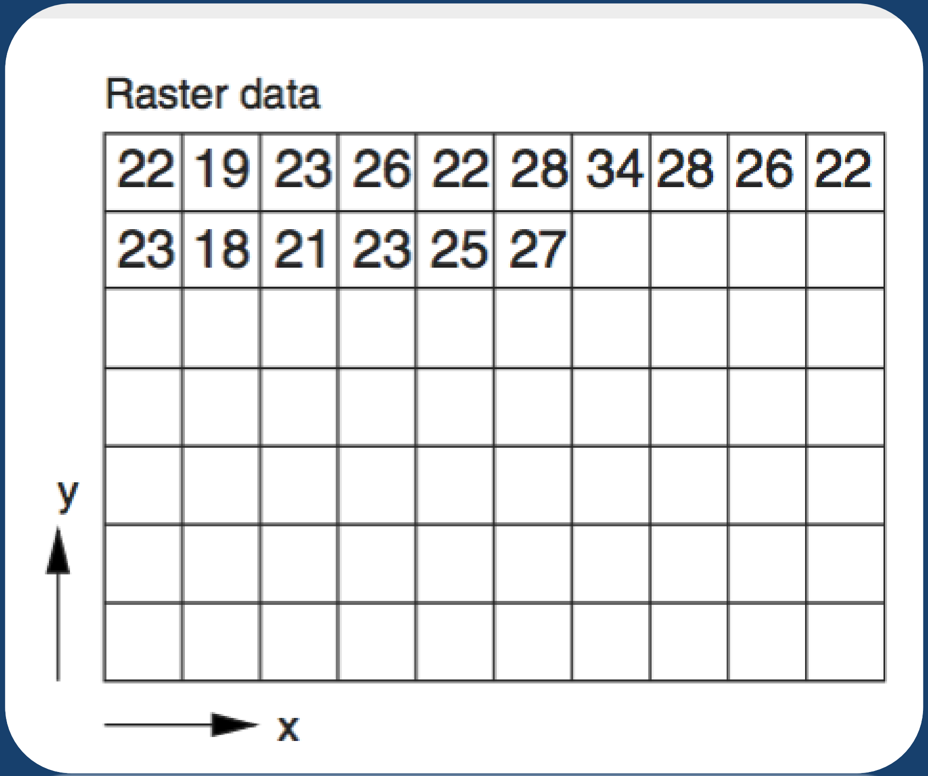
- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS in precision agriculture
- RS band composite
- Hyperspectral Remote Sensing

GIS Data Model



Raster and vector data with attribute table
- Raster data: rows and columns of values representing spatial phenomenon;
- Vector data: representation by points, lines and areas;
Attributes: descriptive data stored in a database table

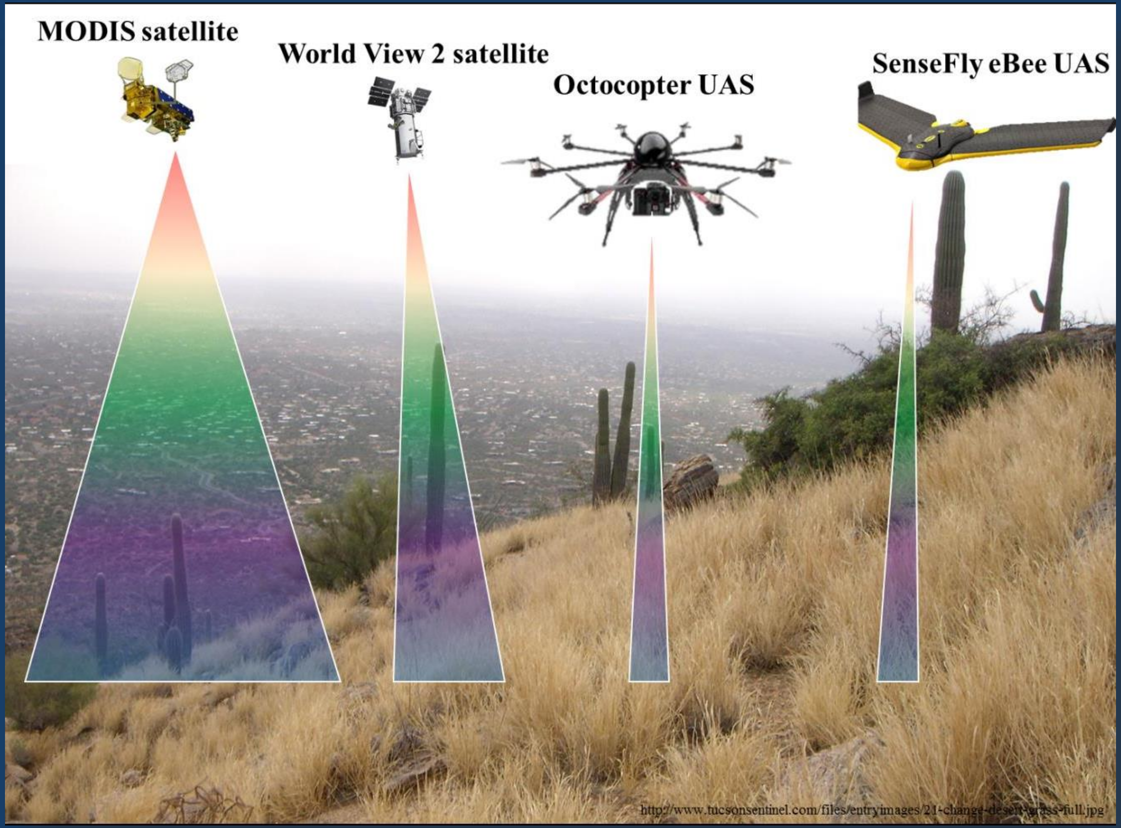
(Remote Sensed) image, photo....



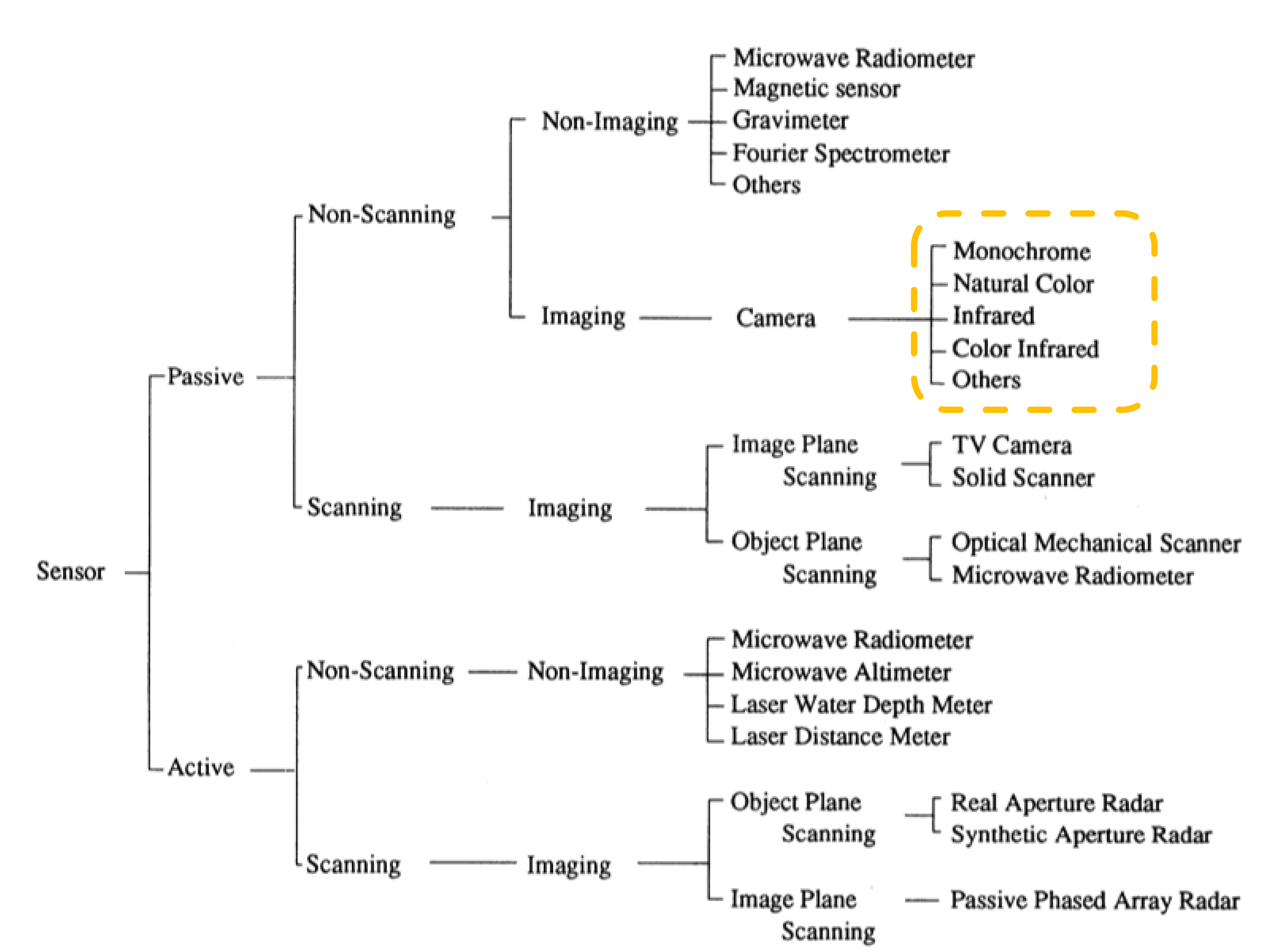
Platform types and observation objects

Table 5.1.1 Platform types and observation objects

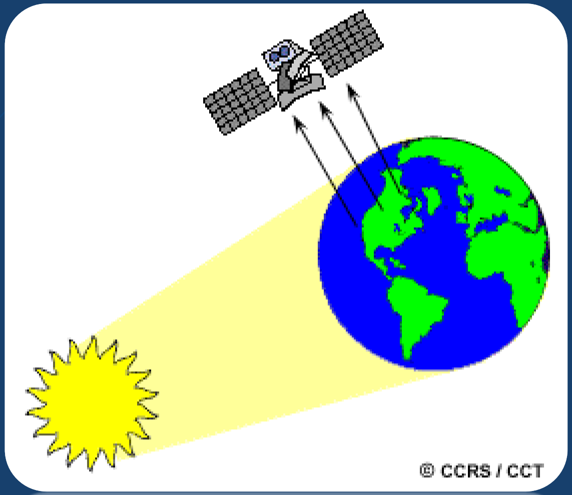
platform	altitude	observation	remarks
geostationary satellite	36,000m	fixed point observation	GMS
circular orbit satellite (earth observation)	500km - 1,000km	regular observation	Landsat,SPOT, MOS-1,etc
space shuttle	240km - 350km	irregular observation space experiment	
radio-sonde	100m - 100km	various investigations (meteorological, etc)	
high altitude jet-plane	10km - 12km	reconnaissance wide area investigations	
low or middle altitude plane	500m - 8,000m	various investigation aero surveys	
aerostat	500m - 3,000m	reconnaissance various investigations	
helicopter	100m - 2,000m	various investigations aero surveys	
radio-controlled plane	below 500m	various investigations aero surveys	aeroplane helicopter
hang-plane	50 - 500m	various investigations aero surveys	hang-glider para-glider
hang-balloon	800m -	various investigations	
cable	10 - 40m	archeologic investigations	
crane car	5 - 50m	close range surveys	
ground measurement car	0 - 30m	ground truth	cherrypicker



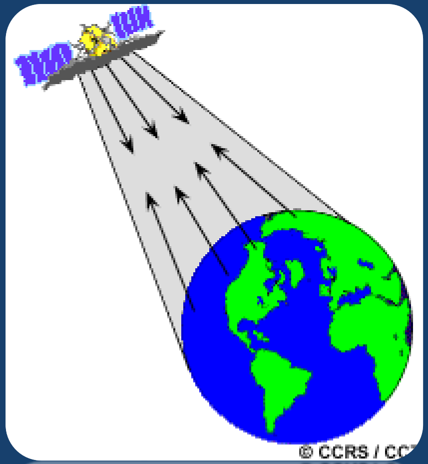
Types of sensor



Passive vs. Active Sensing

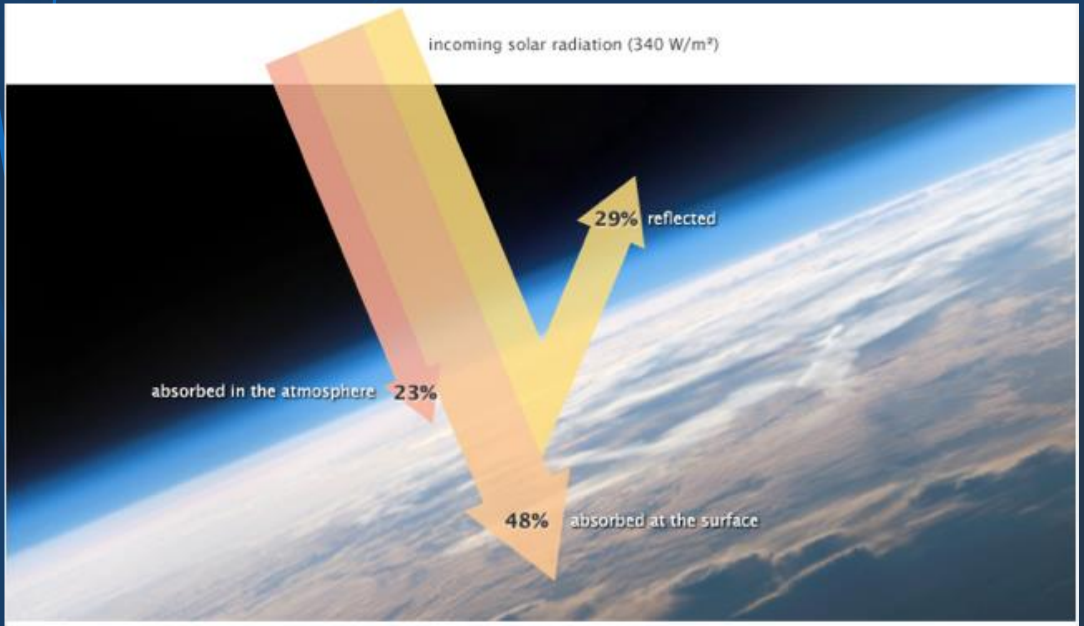


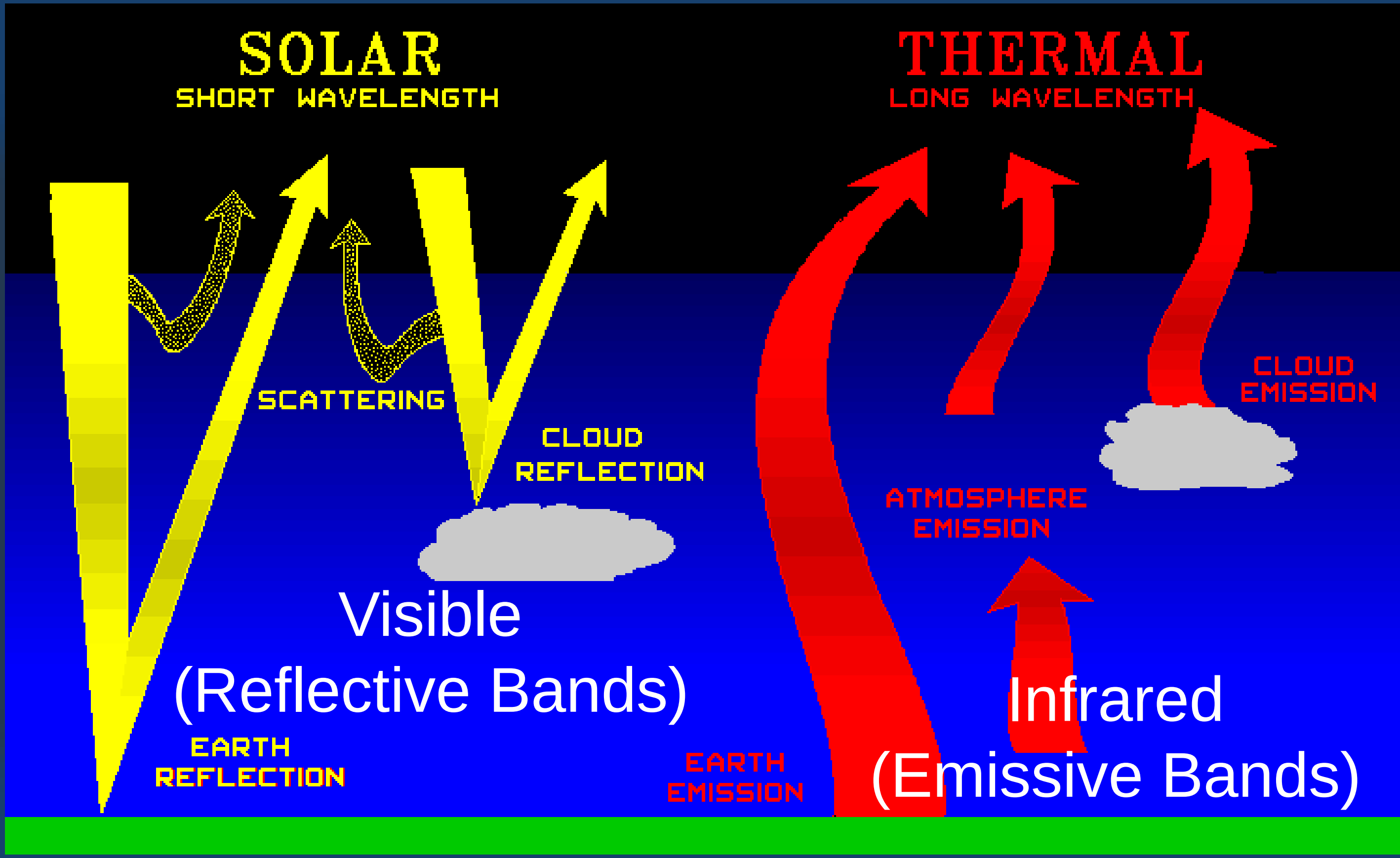
- measure energy that is naturally available.
- The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then re-emitted, as it is for thermal infrared wavelengths.
- can only take place during the time when the sun is illuminating the Earth.



- Provide their own energy source for illumination.
- The sensor emits radiation which is directed toward the target to be investigated.
- The radiation reflected from that target is detected and measured by the sensor.
- Ability to obtain measurements anytime, regardless of the time of day or season.

Incoming Solar radiation

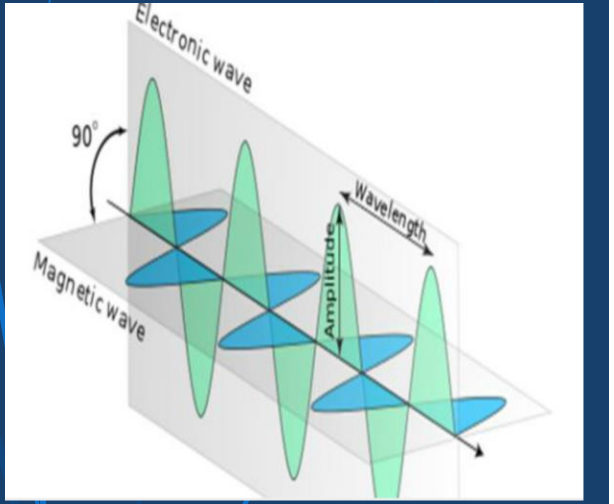


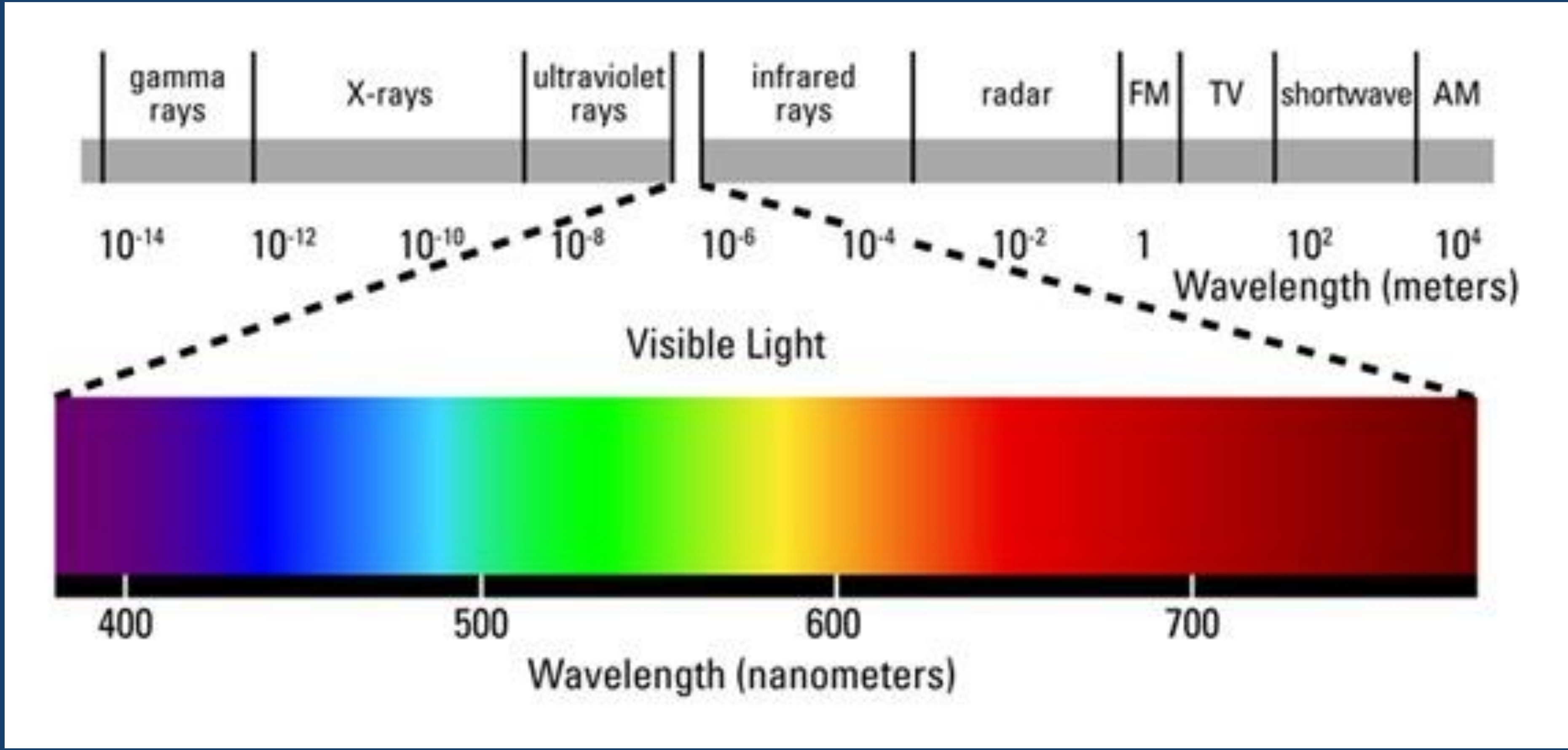


Outline

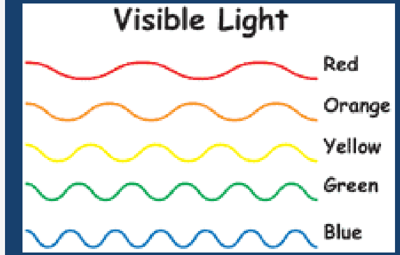
- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS band composite
- RS in precision agriculture
- Hyperspectral Remote Sensing

Electromagnetic wave

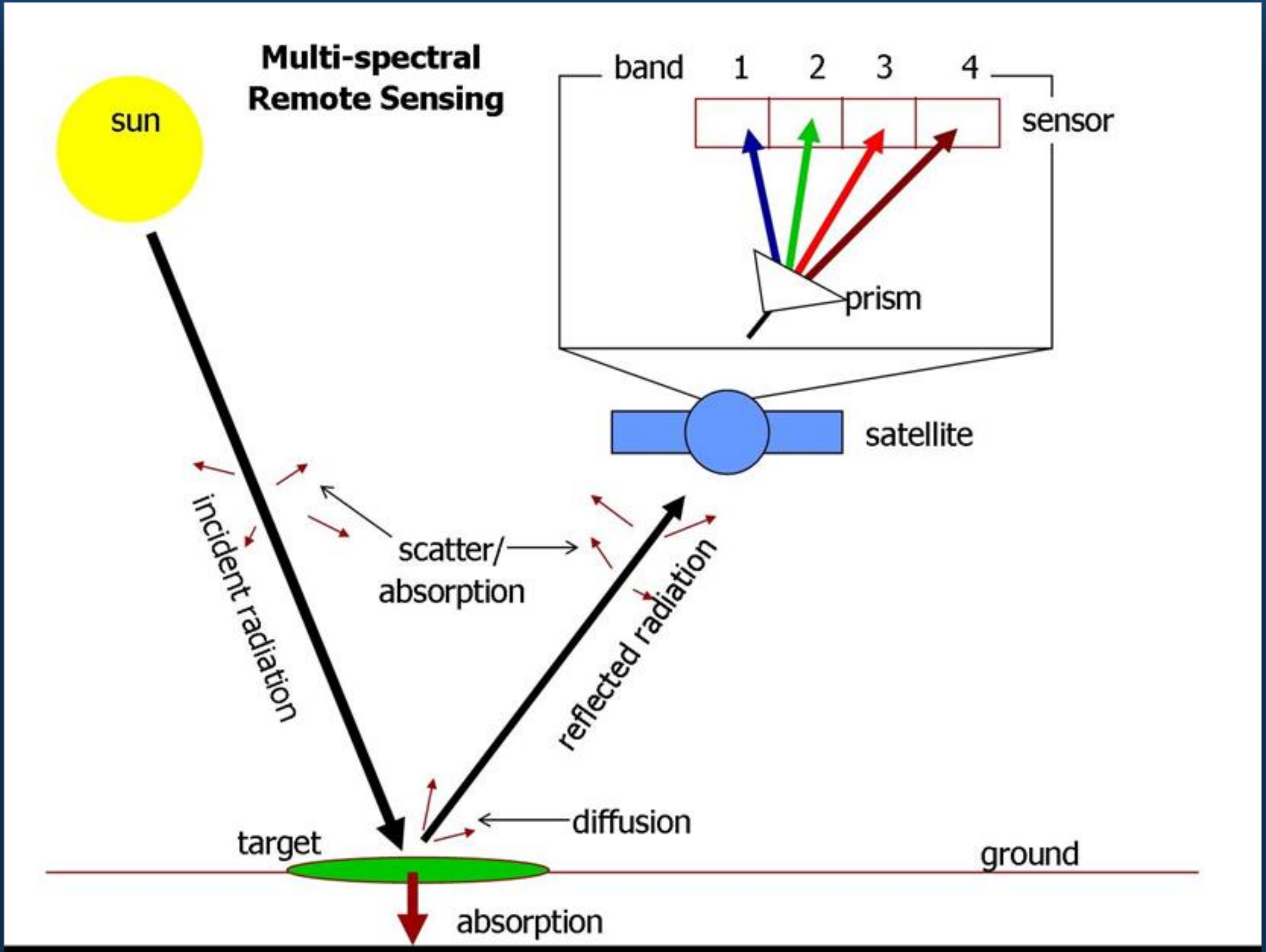




Blue is 0.4 to 0.5 microns (or 400 to 500 nanometers)
Green is 0.5 to 0.6 microns (or 500 to 600 nanometers)
Red is 0.6 to 0.7 microns (or 600 to 700 nanometers)
Near Infrared is 0.7 to 0.9 microns (or 700 to 900 nanometers)

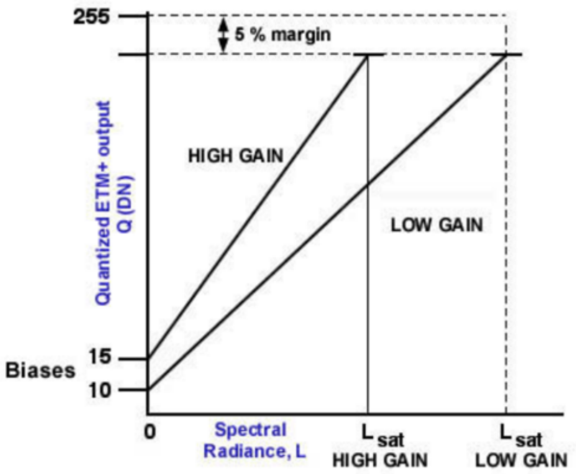


$$\text{Wavelength} = \frac{\text{Speed of Light}}{\text{Frequency}}$$



Multi-spectral
Remote Sensing
sun
band 1 2 3 4
sensor
prism
satellite
incident radiation
scatter/
absorption
reflected radiation
diffusion
target
ground
absorption

- DN is scaled from Radiance measured by sensors



http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter6/chapter6.html

DN (Digital Number)

↓

Radiance

↓

ToA Reflectance

↓ Atmospheric correction

Reflectance

$$L_\lambda = gain \times DN + offset$$

or

$$L_\lambda = \frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN}(QCAL - QCALMIN) + LMIN_\lambda$$

$$gain = \frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN}$$

$$offset = -\frac{LMAX_\lambda - LMIN_\lambda}{QCALMAX - QCALMIN} + LMIN_\lambda$$

$$DN = QCAL, offset = bias$$

$$\rho_\lambda = \frac{\pi L_\lambda}{G_\lambda} = \frac{\pi L_\lambda}{\mu_s E_{s\lambda}}$$

$$E_{s\lambda} = \frac{ESUN_\lambda}{d_s^2}$$

$E_{s\lambda}$: Exo - atmospheric Solar Spectral Irradiance $W/m^2 \cdot \mu m$

$ESUN_\lambda$: Average Exo - atmospheric Solor Spectral Irradiance $W/m^2 \cdot \mu m$

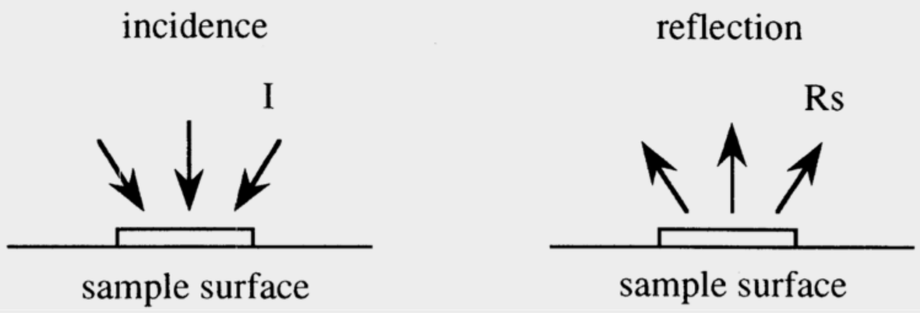
d_s : Earth - Sun distance in astronomical units

$\mu_s = \cos(\theta_s), \theta_s$: Solar zenith angle

Please go to for each satellite calibration

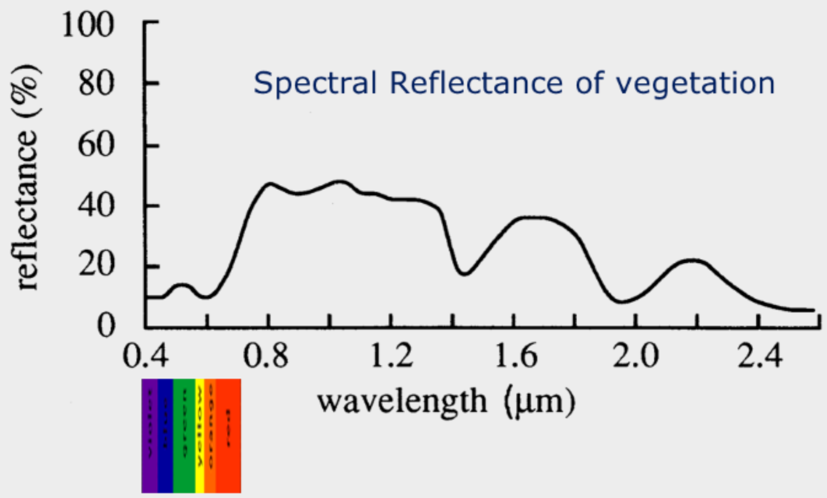
http://landsat.usgs.gov/science_calibration.php

Spectral Reflectance



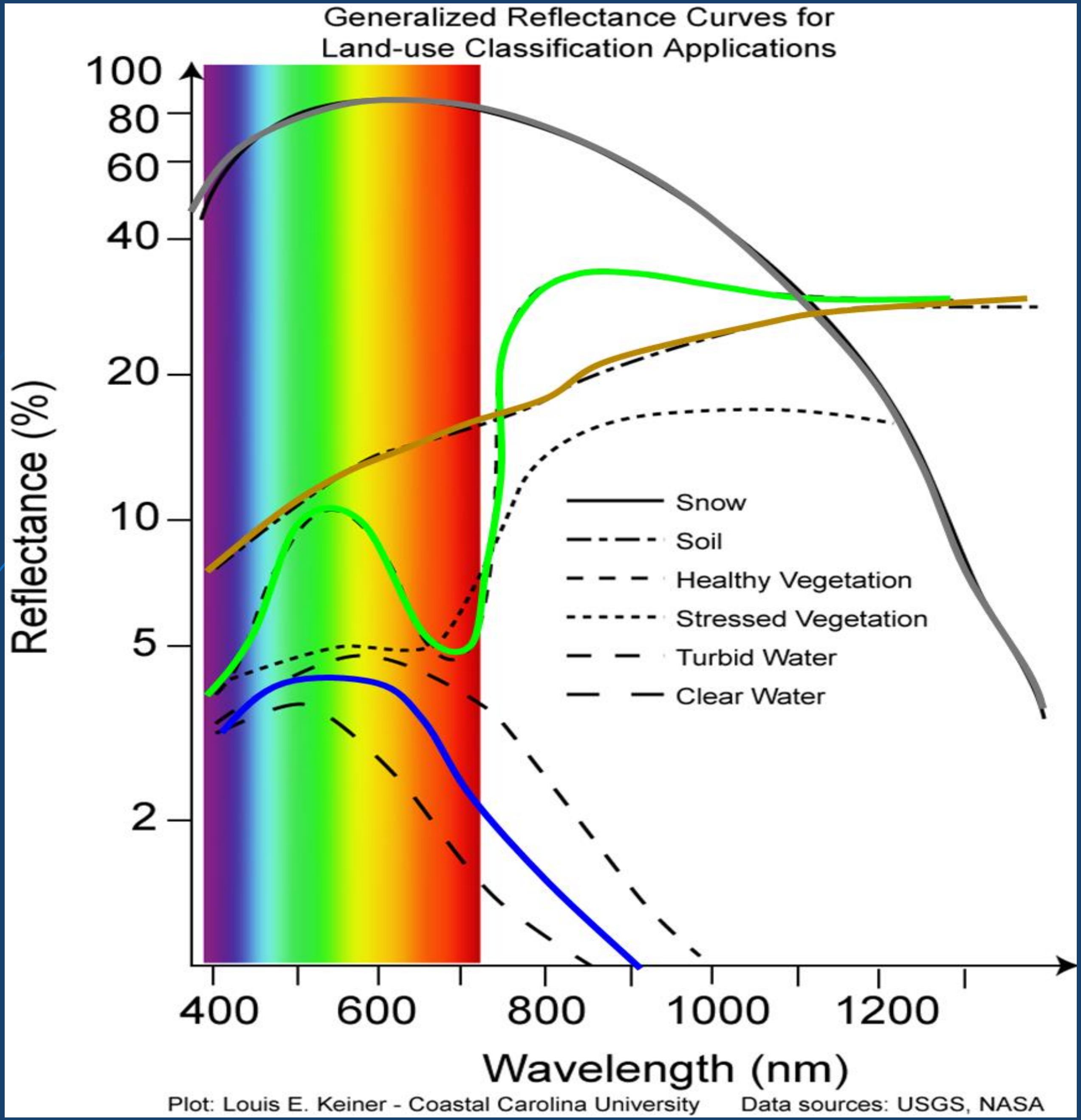
$$\text{reflectance} = \frac{Rs}{I}$$

Reflectance: Ratio of reflected flux from the surface to the incident flux.
Ranges from **0 to 1**.
Equipment: **Spectrometer**



Spectral Reflectance: Reflectance w.r.t. specific wavelength. Spectral Reflectance is unique and different from one object to an unlike object.
Ranges from **0 to 1**.
Equipment: **Spectrophotometer**

Spectral Signature



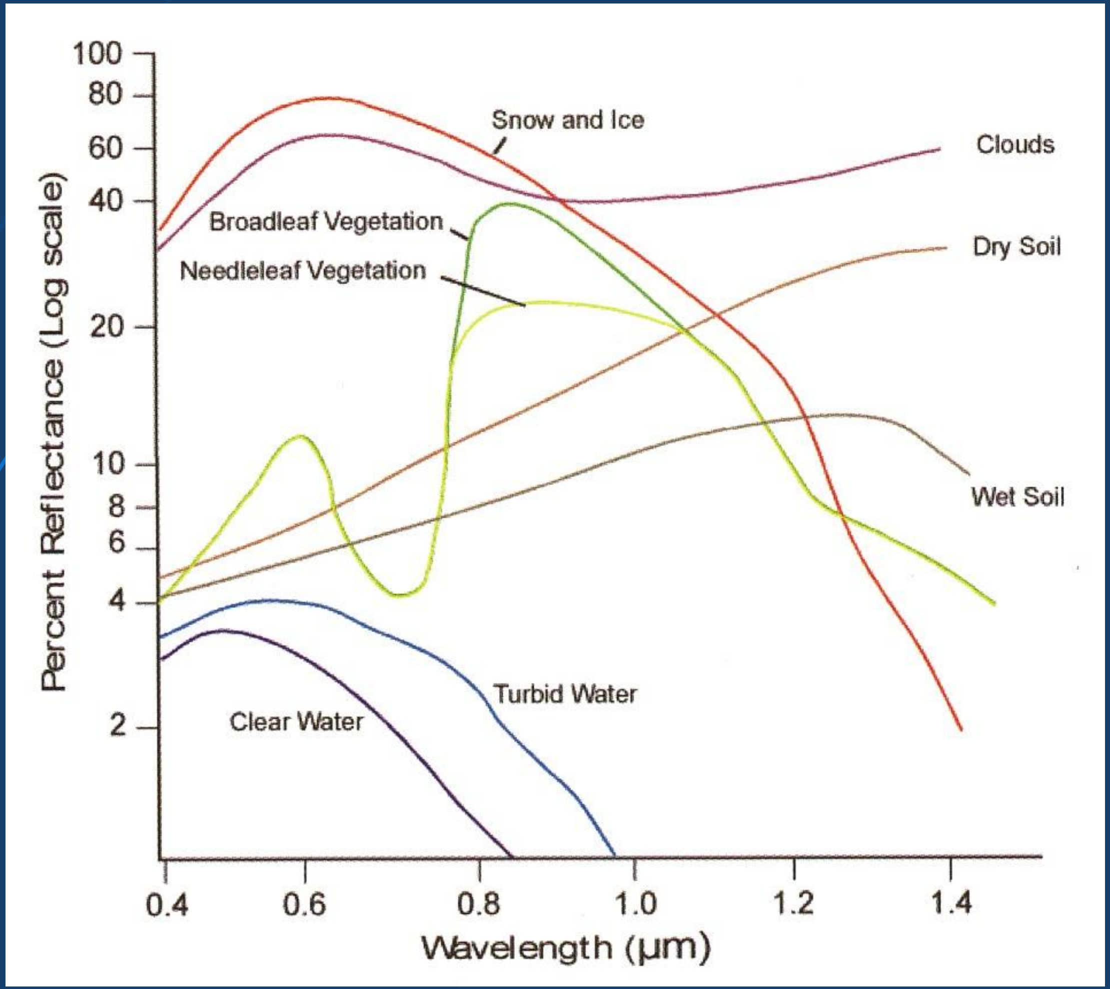
Soil

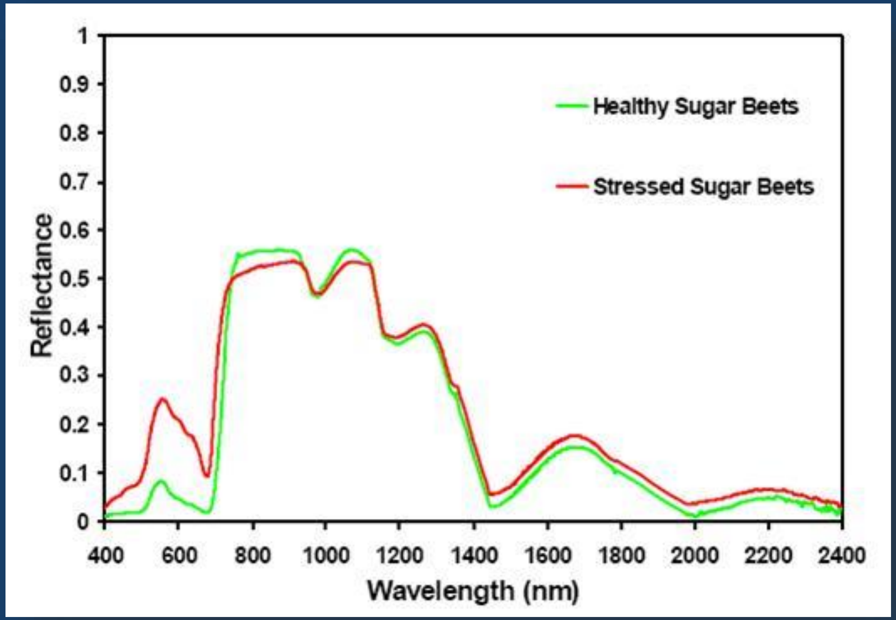
Vegetation

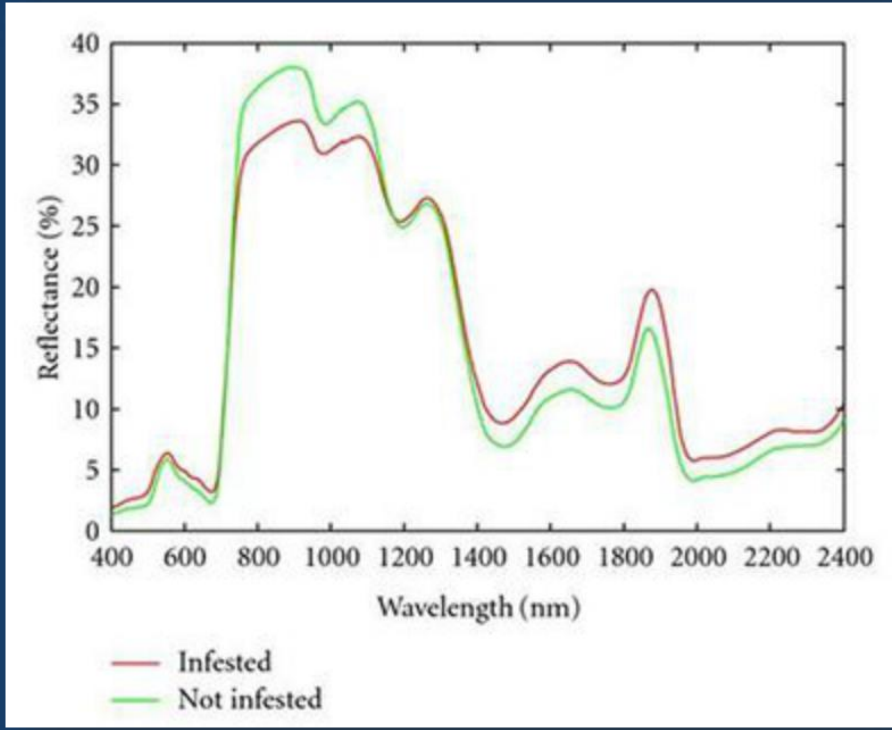
Snow

Ocean

CTCN
CLIMATE TECHNOLOGY CENTRE & NETWORK







CTCN
CLIMATE TECHNOLOGY CENTRE & NETWORK

Quiz

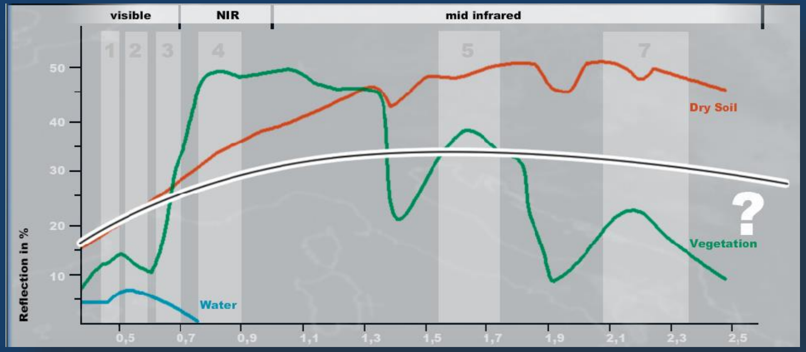
Turbid Water | Clear Water | Dry Sand | Concrete

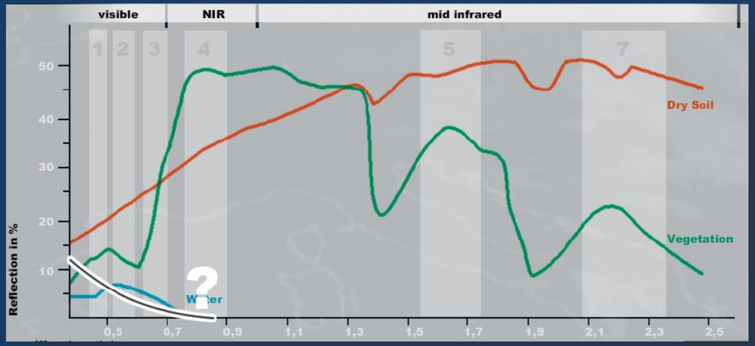
Grasland | Coniferous Forest

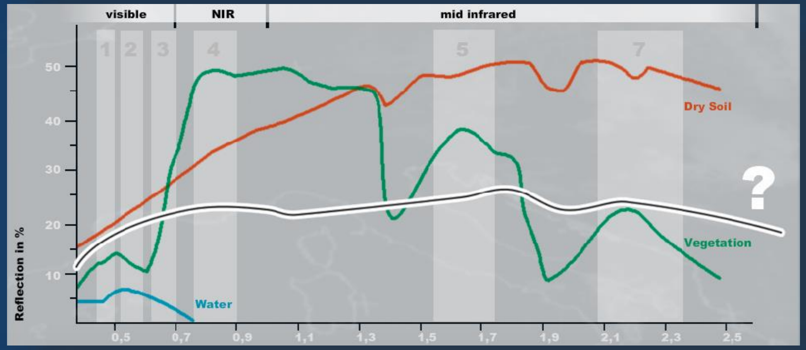
A B

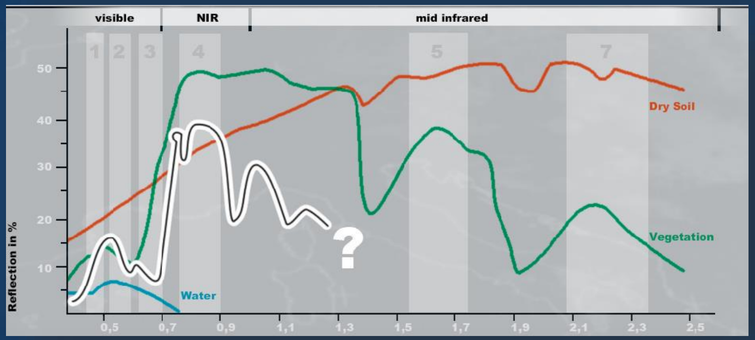
C D

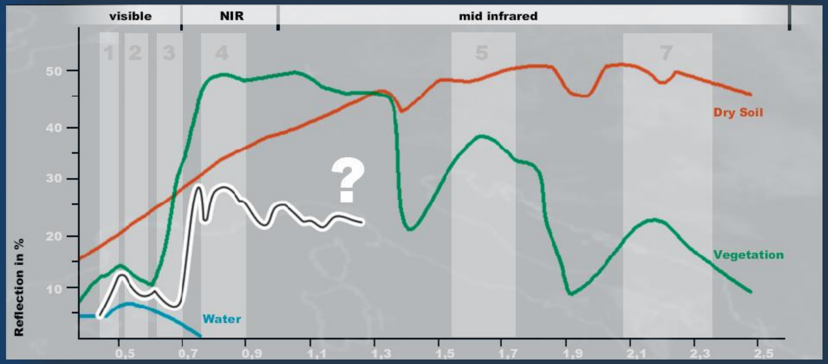
E F

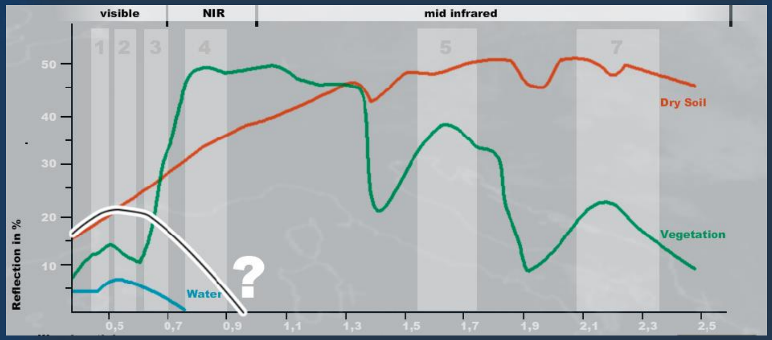












http://www.seos-project.eu/modules/remotesensing/remotesensing-c06-p03.html

Terminology of radiant energy

Energy from the Earth Atmosphere

over time is

Flux

which strikes the detector area

Irradiance

at a given wavelength interval

Monochromatic Irradiance

over a solid angle on the Earth

***Radiance* observed by satellite radiometer**

Emitted

is described by

The Planck function

can be inverted to

Brightness temperature

can be converted to

Surface temperature

Reflected

can be converted to

TOA Reflectance

Atmospheric correction

Reflectance

Radiance *is the "flux of energy (primarily irradiant or incident energy) per solid angle leaving a unit surface area in a given direction"*

Brightness Temperature is the temperature, in Kelvin, of a blackbody that emits the observed radiance

Outline

- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS band composite
- RS in precision agriculture
- Hyperspectral Remote Sensing

Thermal imaging

Emitted

is described by

The Planck function

can be inverted to

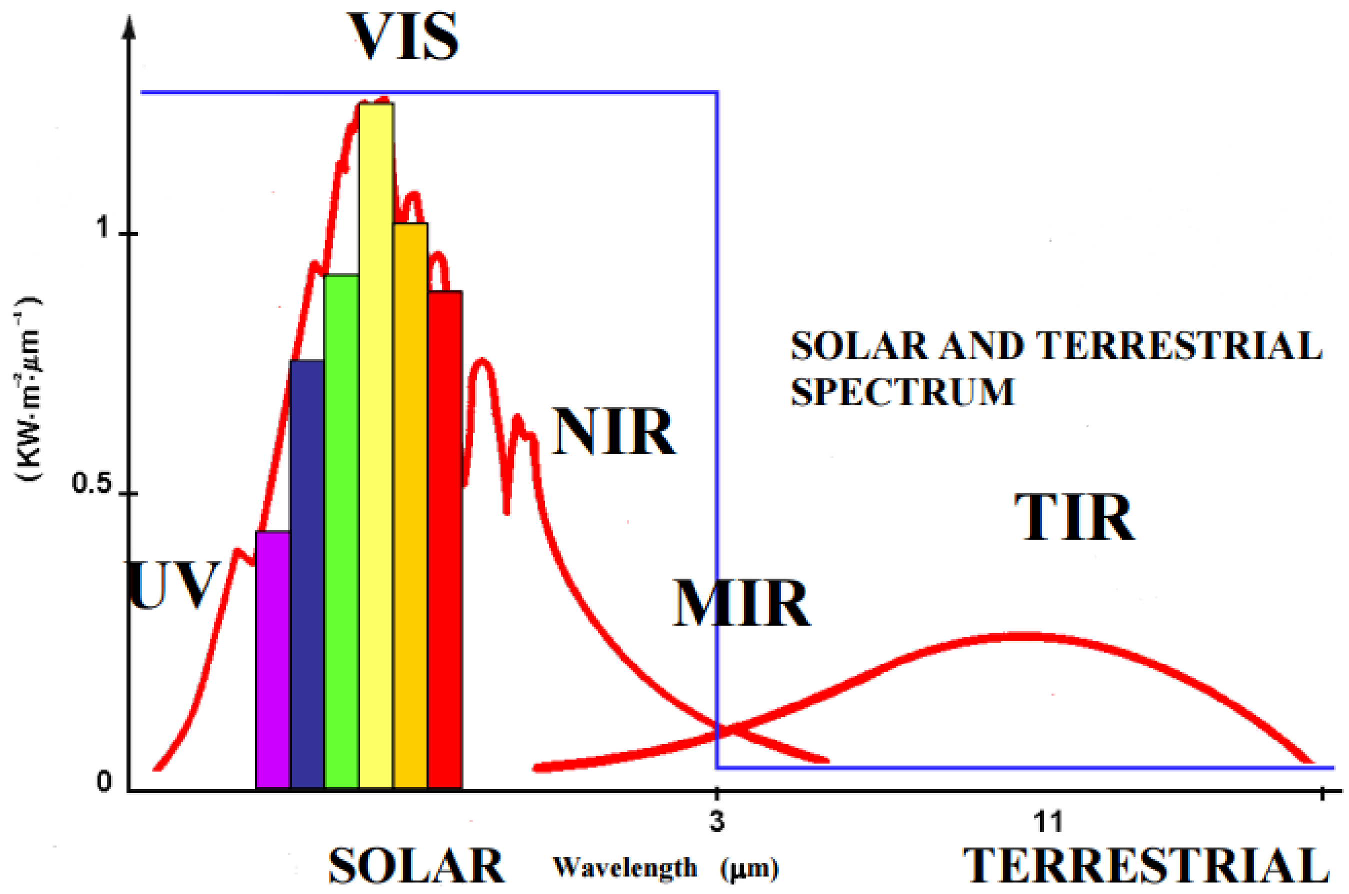
Brightness temperature

can be converted to

Surface temperature

Brightness Temperature is the temperature, in Kelvin, of a blackbody that emits the observed radiance

THERMAL INFRARED RADIATION is a form of electromagnetic radiation with a wavelength between 3 to 14 micrometers (μm). Its flux is much lower than visible flux.



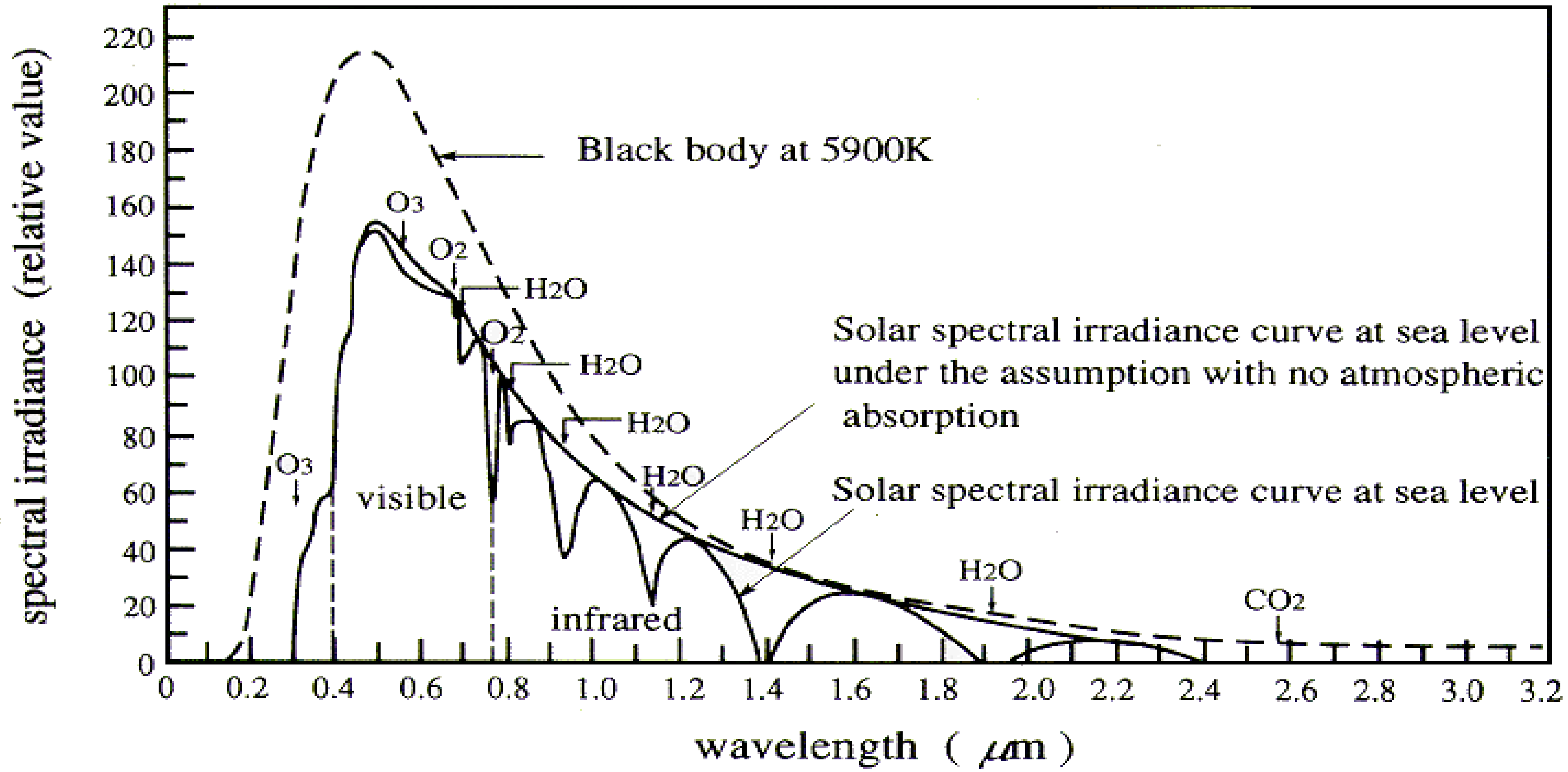
All objects have a temperature above absolute zero (0 K) emit EM energy (in 3.0-100 μm).

- Human being has normal 98.6 ºF (37 ºC)

Our eyes are only sensitive to visible energy (0.4-0.7 μm). Human sense thermal energy through touch. while detectors (sensors) are sensitive to all EM spectrum.

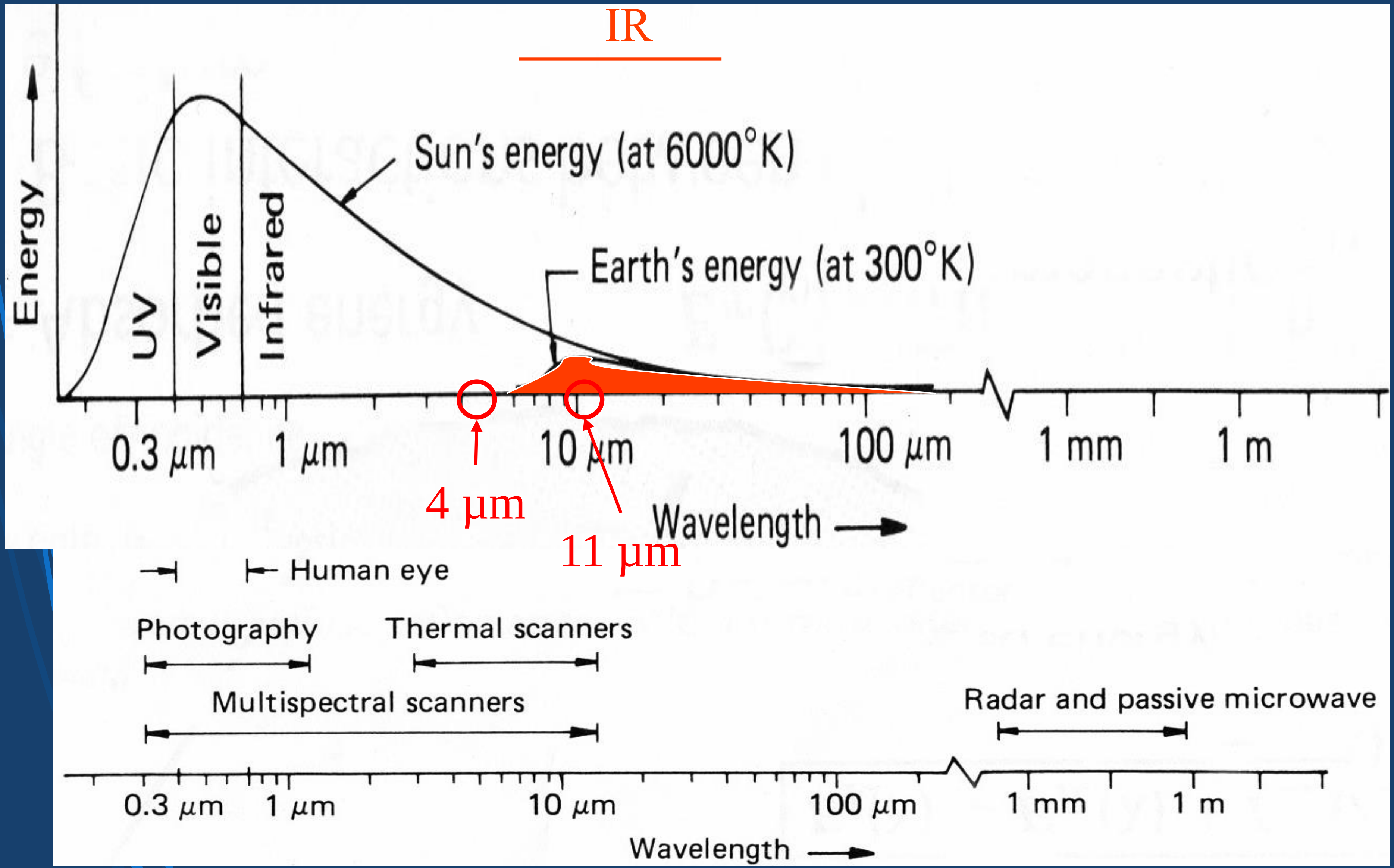
All objects (vegetation, soil, rock, water, concrete, etc) selectively absorb solar short-wavelength energy and radiate thermal infrared energy.

Source: J.-L. Casanova



Comparison of spectral irradiance of solar light at sea level with black body radiation

Spectral Characteristics of Energy Sources and Sensing Systems



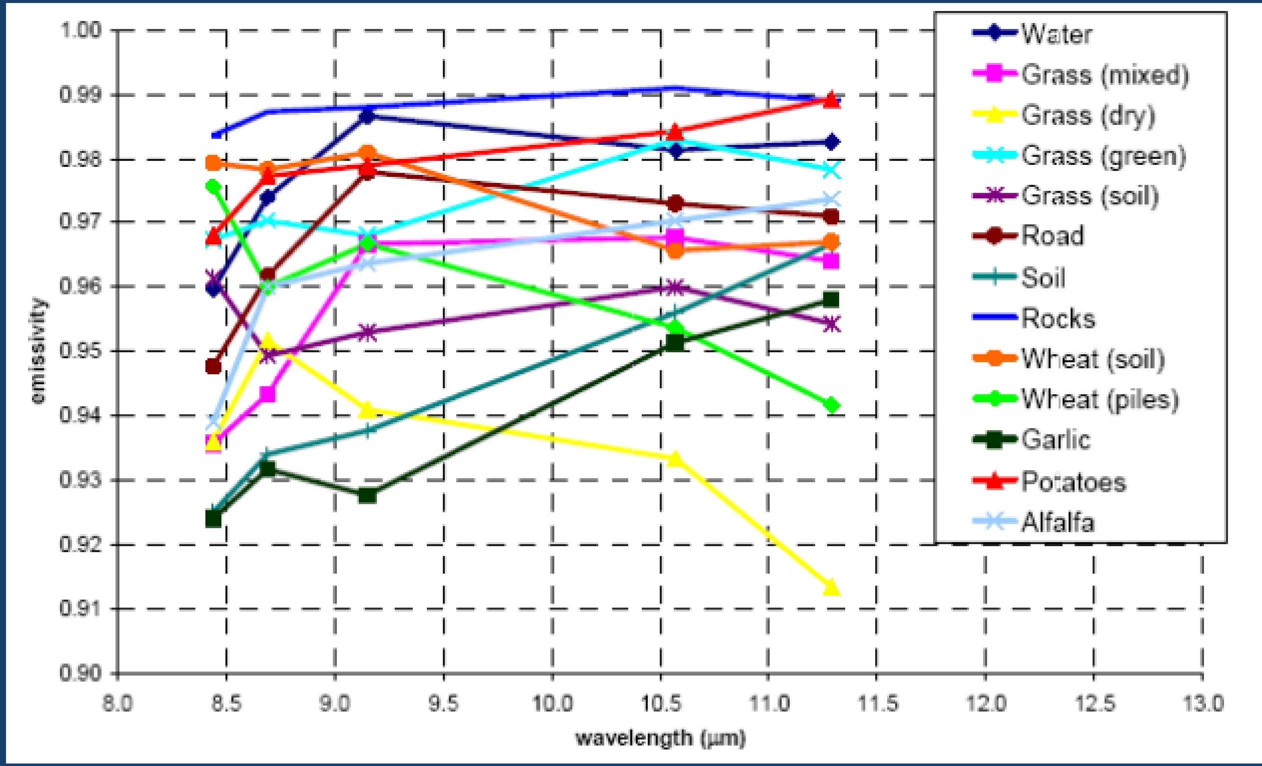
- Used to observe terrestrial energy emitted by the Earth system in the IR between 4 and 15 µm
- About 99% of the energy observed in this range is emitted by the Earth

AST_L1T: ASTER Level 1
Precision Terrain Corrected Registered At-Sensor Radiance

- The amount of thermal radiation emitted at a particular wavelength from a warm object depends on its temperature.
- If the earth's surface is regarded as a blackbody emitter, its apparent temperature (known as the brightness temperature) and the spectral radiance are related by the Planck's blackbody equation, plotted in the above figure for several temperatures.
- For a surface at a brightness temperature around 300 K, the spectral radiance peaks at a wavelength around 10 µm. The peak wavelength decreases as the brightness temperature increases.
- For this reason, most satellite sensors for measurement of the earth surface temperature have a band detecting infrared radiation around 10 µm.

Emissivity (ε)

ε of Blackbody =……



Factors Influencing the Emissivity ε

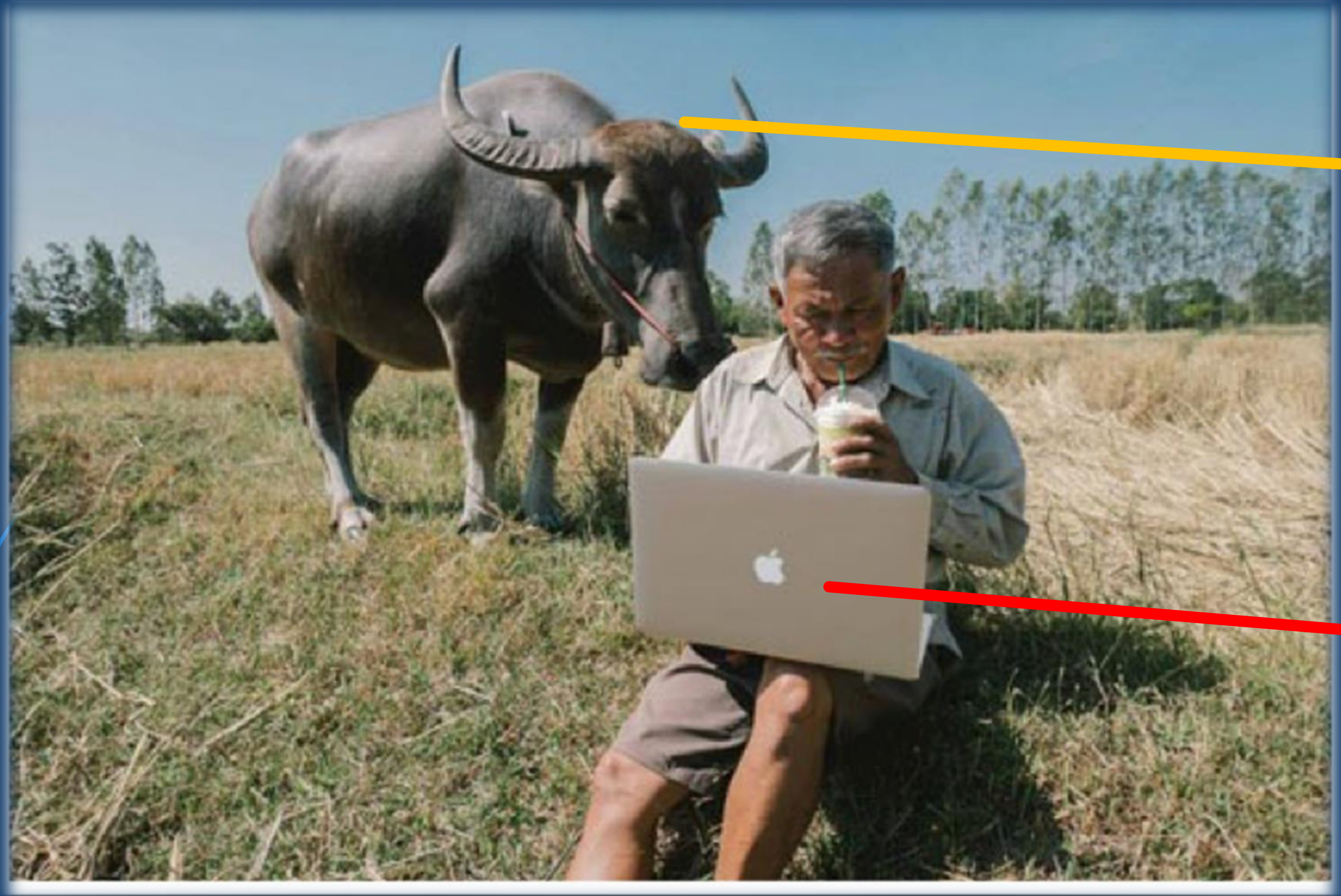
- The material (minerals, water etc.)
- The surface geometry (roughness of the surface)
- The wavelength of the radiation
- The view angle

Sobrino,2005

Outline

- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS in precision agriculture
- RS band composite
- Hyperspectral Remote Sensing

Precision Agriculture??



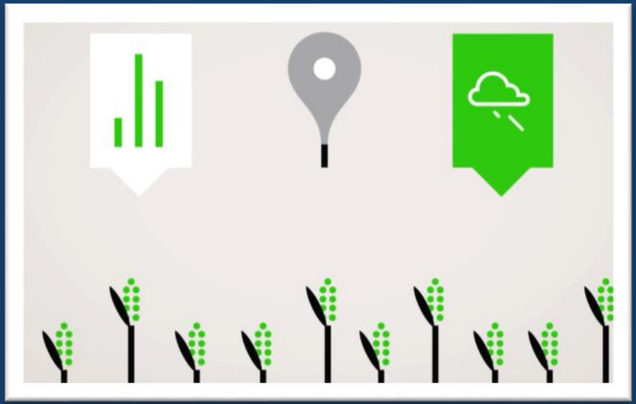
Agricultural Mechanization

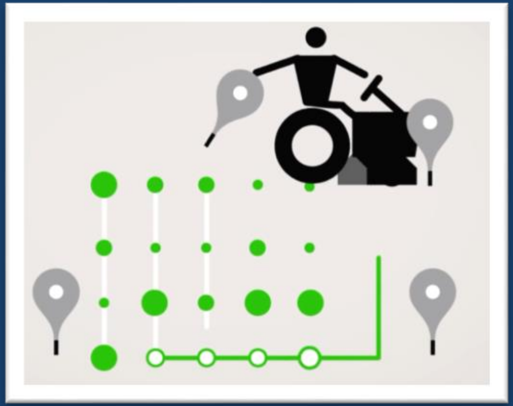
+

Information Technology

Satellite Agriculture Applications

- Identify land cover/ land use/ objects
- Land leveling
- Nutrient
- Pest control
- Soil moisture
- Yield
- etc…

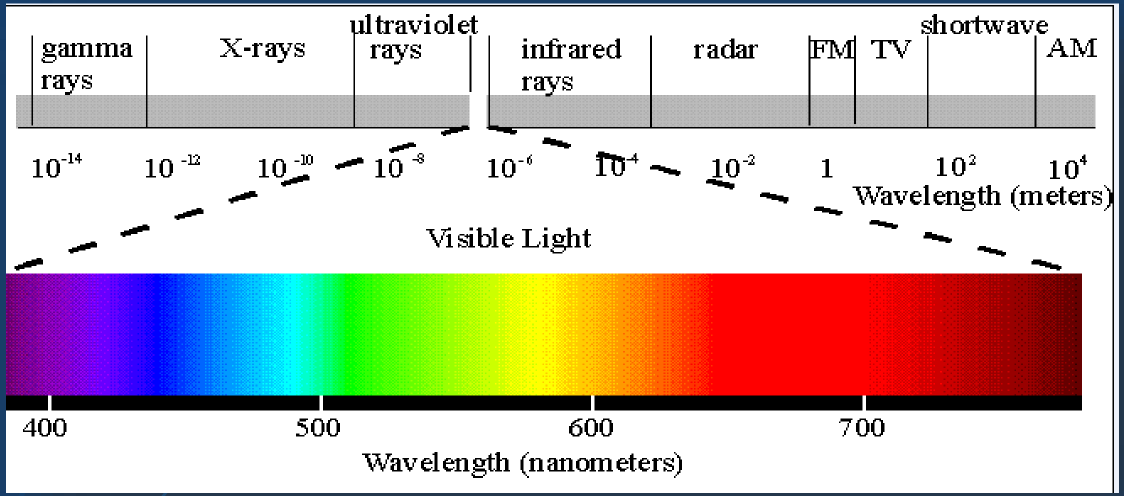




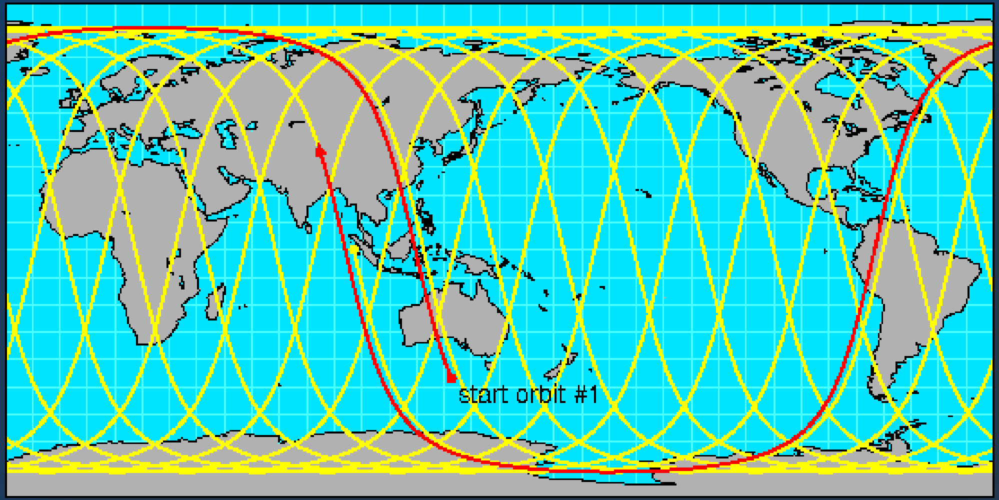
How to start …

Satellite Remote Sensing Systems

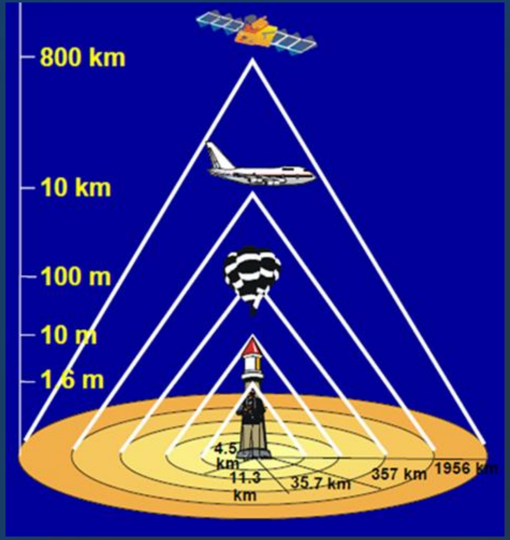
1. Spectral resolution



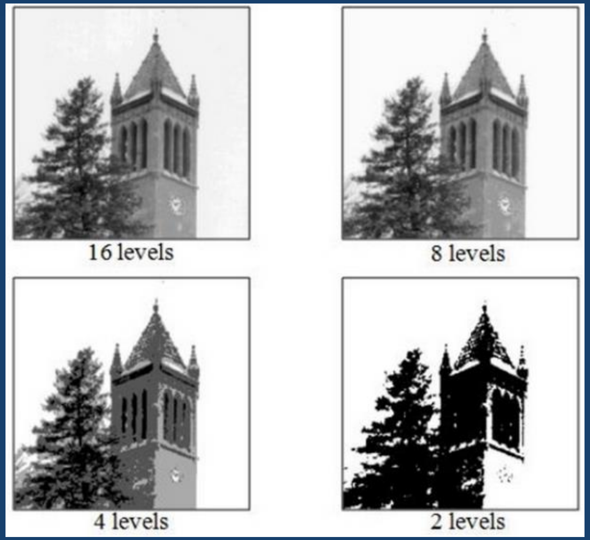
3. Temporal Resolution



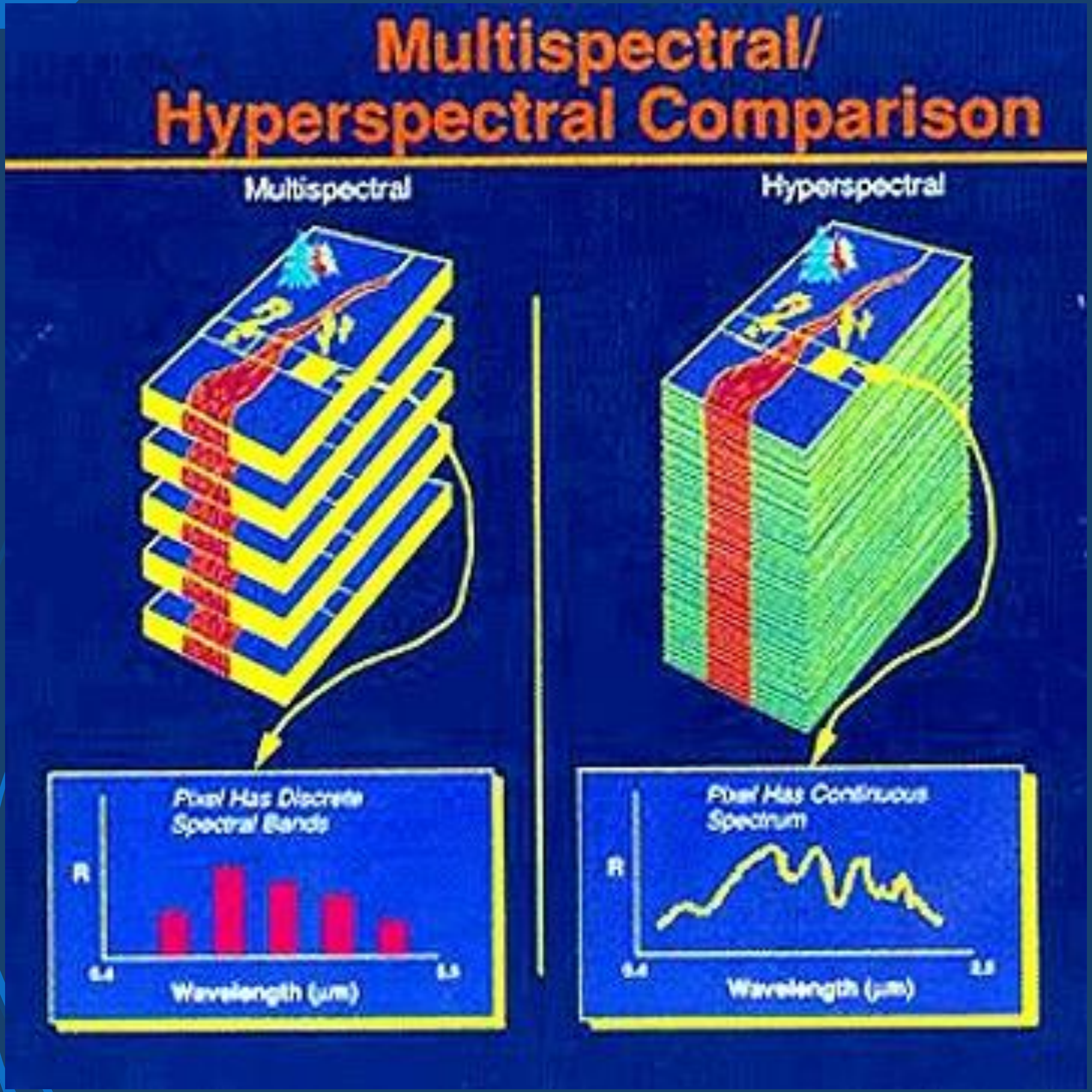
2. Spatial resolution



4. Radiometric Resolution

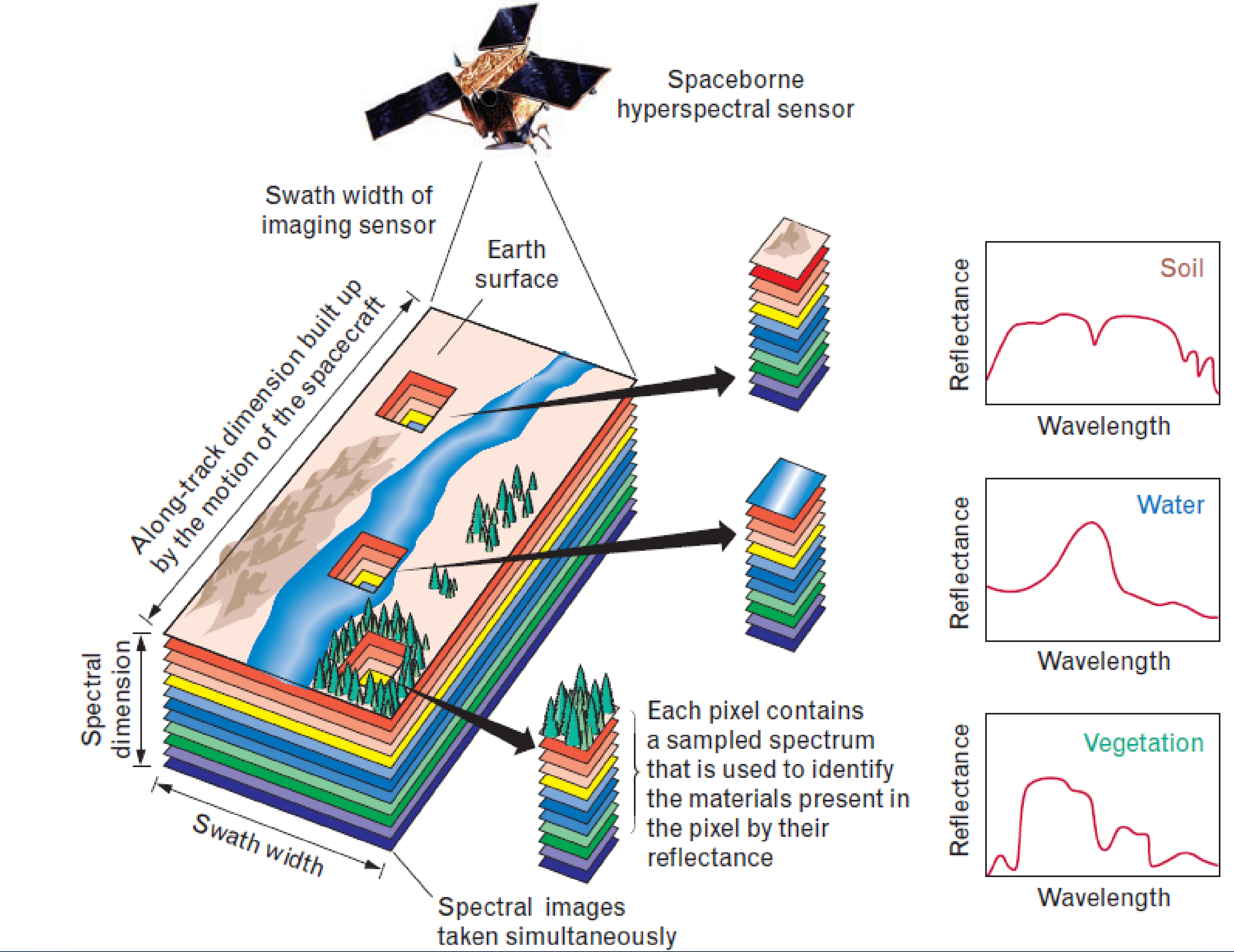


1. Spectral Resolution



Specifies the <u>number of spectral bands</u> in which the sensor can collect reflected radiance. But the number of bands is not the only important aspect of spectral resolution. The <u>position of bands</u> in the electromagnetic spectrum is important, too.

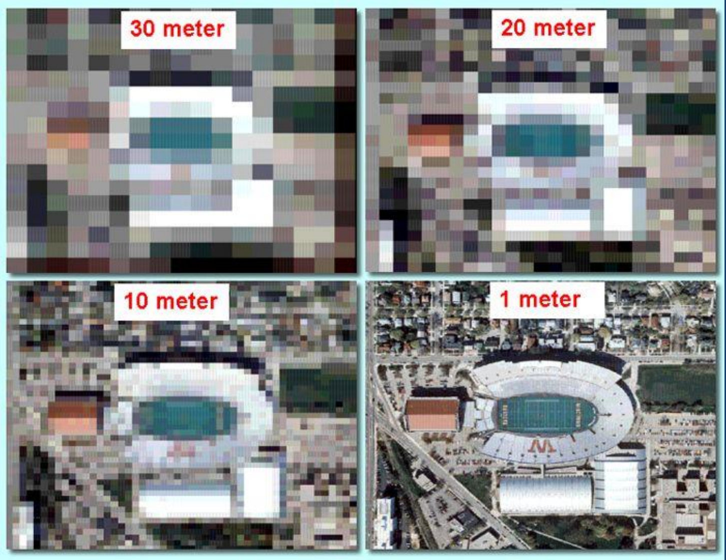
* High spectral resolution: 15 - 220 bands
* Medium spectral resolution: 3 – 15 bands
* Low spectral resolution: < 3 bands

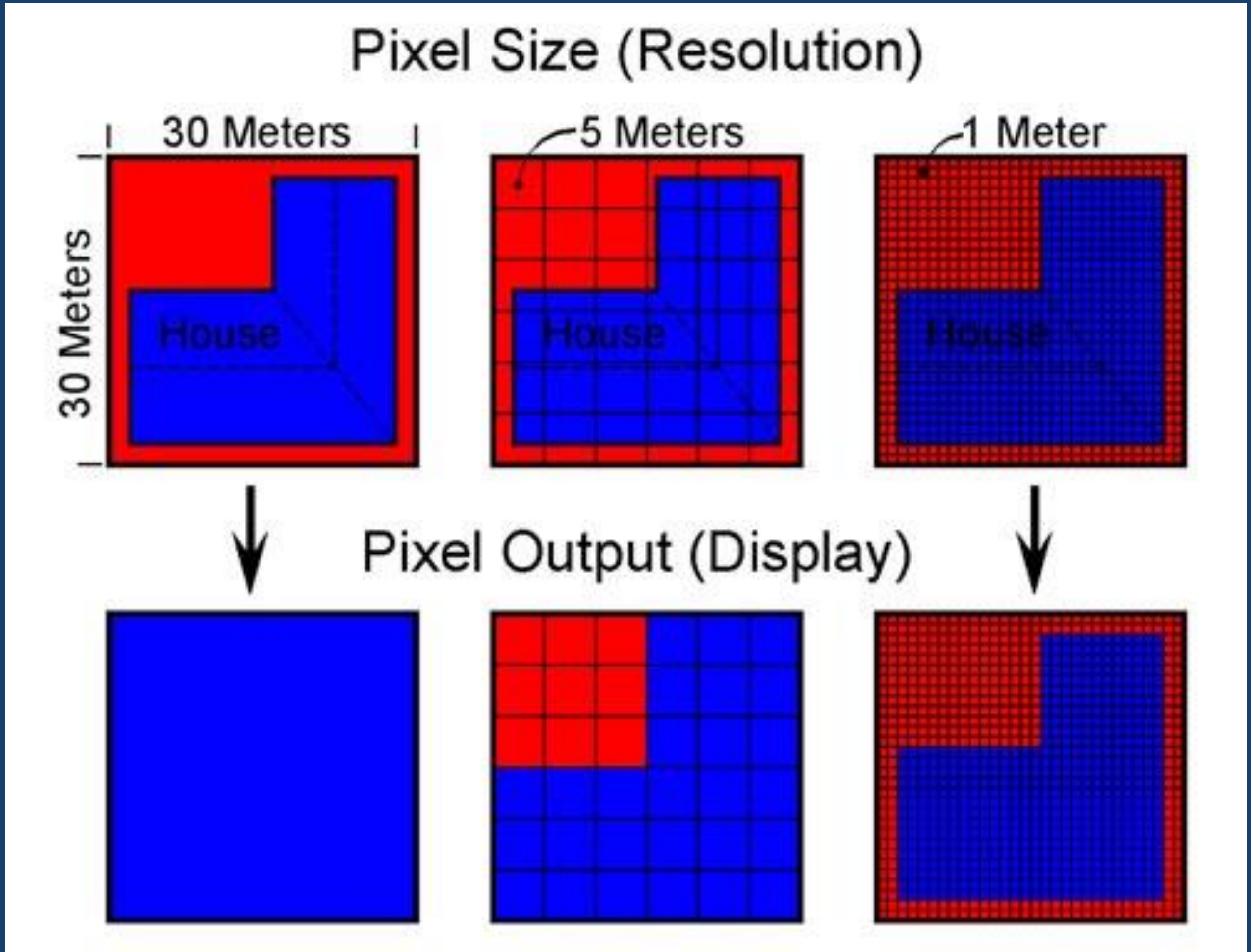

Spaceborne hyperspectral sensor
Swath width of imaging sensor
Earth surface
Along-track dimension built up by the motion of the spacecraft
Spectral dimension
Swath width
Spectral images taken simultaneously
Each pixel contains a sampled spectrum that is used to identify the materials present in the pixel by their reflectance
Reflectance
Soil
Wavelength
Reflectance
Water
Wavelength
Reflectance
Vegetation
Wavelength

2. Spatial Resolution

The spatial resolution specifies the pixel size of satellite images covering the earth surface

- High spatial resolution: 0.41 - 4 m
- Low spatial resolution: 30 - > 1000 m



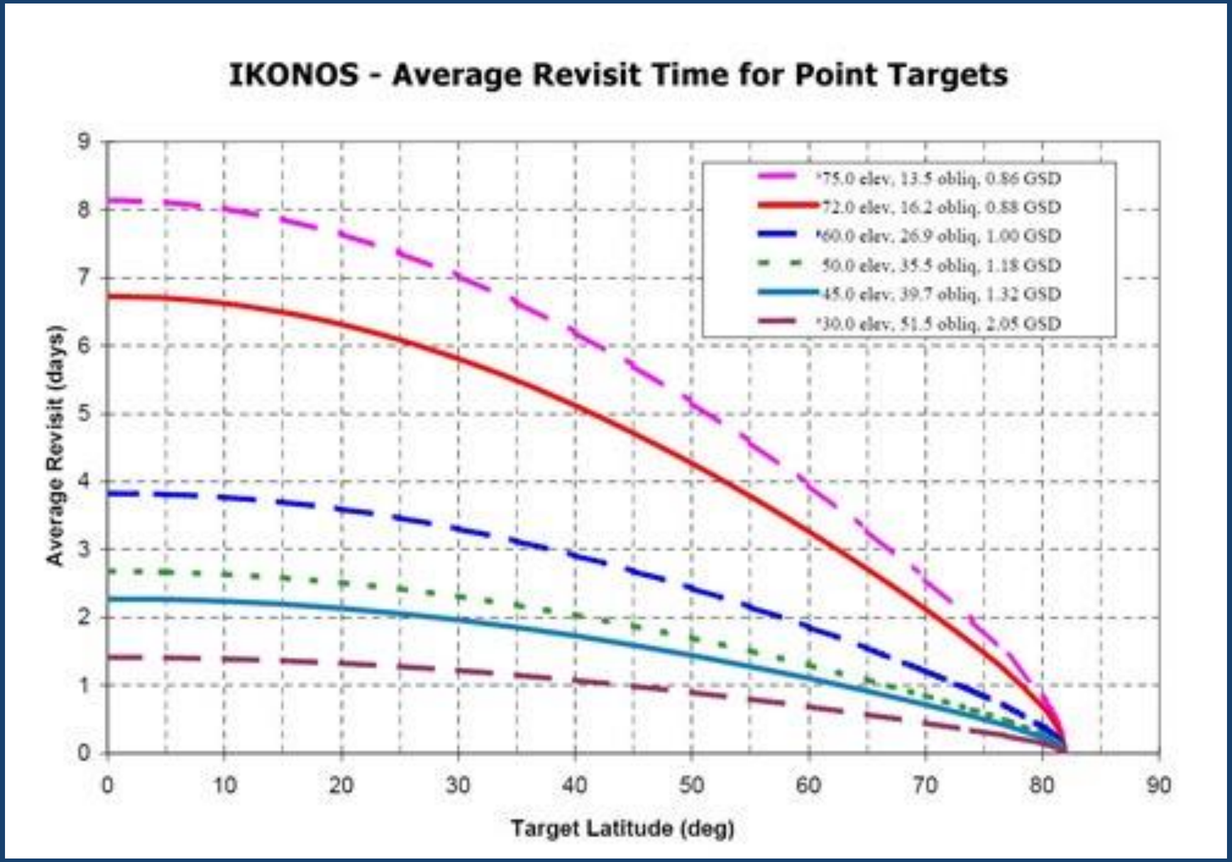


Map scale and raster resolution

Map scale	Detectable size (in meters)	Raster resolution (in meters)
1:1,000	1	0.5
1:5,000	5	2.5
1:10,000	10	5
1:50,000	50	25
1:100,000	100	50
1:250,000	250	125
1:500,000	500	250
1:1,000,000	1,000	500

3. Temporal Resolution (re-visiting time)

The temporal resolution specifies the revisiting frequency of a satellite sensor for <u>a specific location</u>.



- High temporal resolution:

< 24 hours - 3 days

- Medium temporal resolution:

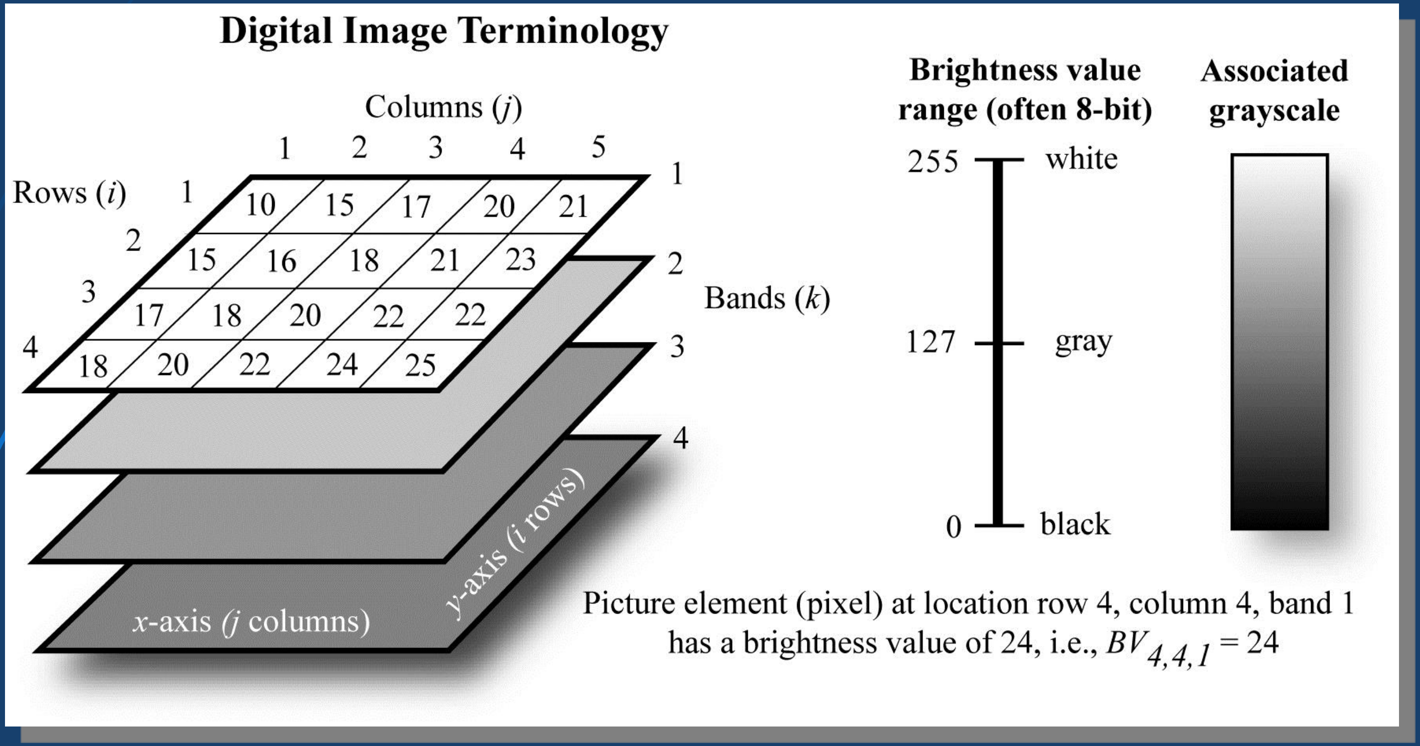
4 - 16 days

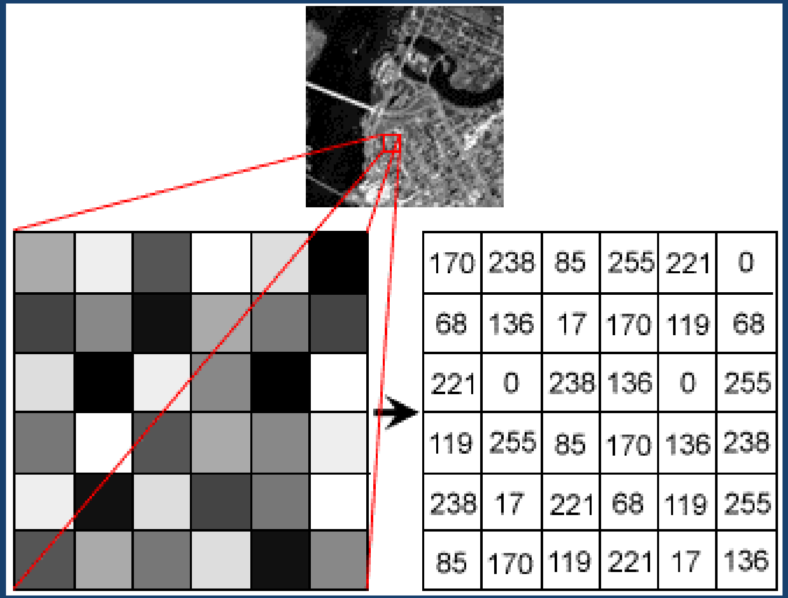
- Low temporal resolution:

> 16 days

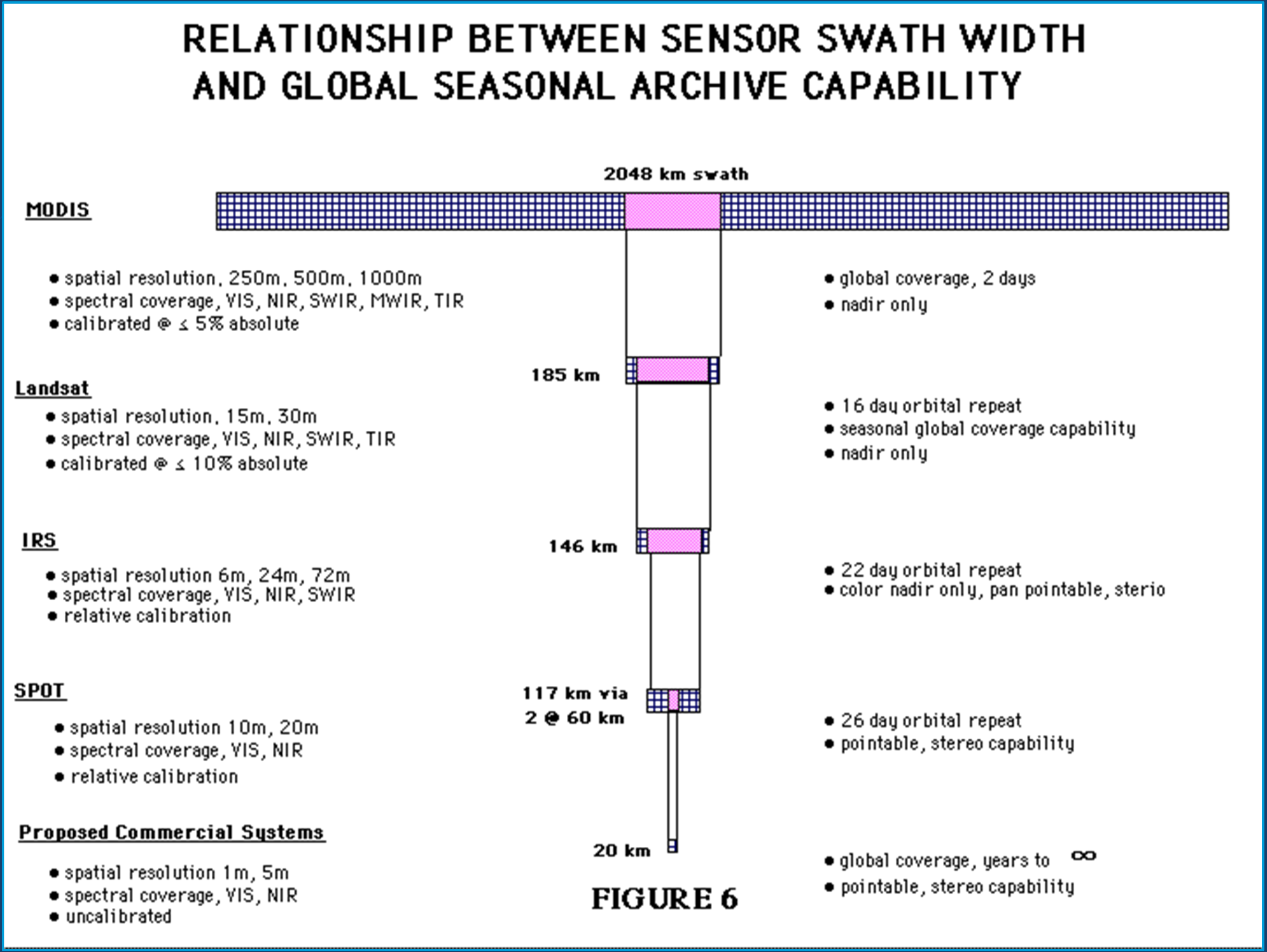
4. Radiometric resolution

- The bit depth is the number of bits used to represent each pixel





http://www.slideshare.net/nidhalelabbadi/image-processing-representing-digital-image


RELATIONSHIP BETWEEN SENSOR SWATH WIDTH
AND GLOBAL SEASONAL ARCHIVE CAPABILITY
2048 km swath
MODIS
• spatial resolution, 250m, 500m, 1000m
• spectral coverage, VIS, NIR, SWIR, MWIR, TIR
• calibrated @ ≤ 5% absolute
• global coverage, 2 days
• nadir only
185 km
Landsat
• spatial resolution, 15m, 30m
• spectral coverage, VIS, NIR, SWIR, TIR
• calibrated @ ≤ 10% absolute
• 16 day orbital repeat
• seasonal global coverage capability
• nadir only
IRS
146 km
• spatial resolution 6m, 24m, 72m
• spectral coverage, VIS, NIR, SWIR
• relative calibration
• 22 day orbital repeat
• color nadir only, pan pointable, sterio
SPOT
117 km via
2 @ 60 km
• spatial resolution 10m, 20m
• spectral coverage, VIS, NIR
• relative calibration
• 26 day orbital repeat
• pointable, stereo capability
Proposed Commercial Systems
20 km
• spatial resolution 1m, 5m
• spectral coverage, VIS, NIR
• uncalibrated
• global coverage, years to ∞
• pointable, stereo capability
FIGURE 6

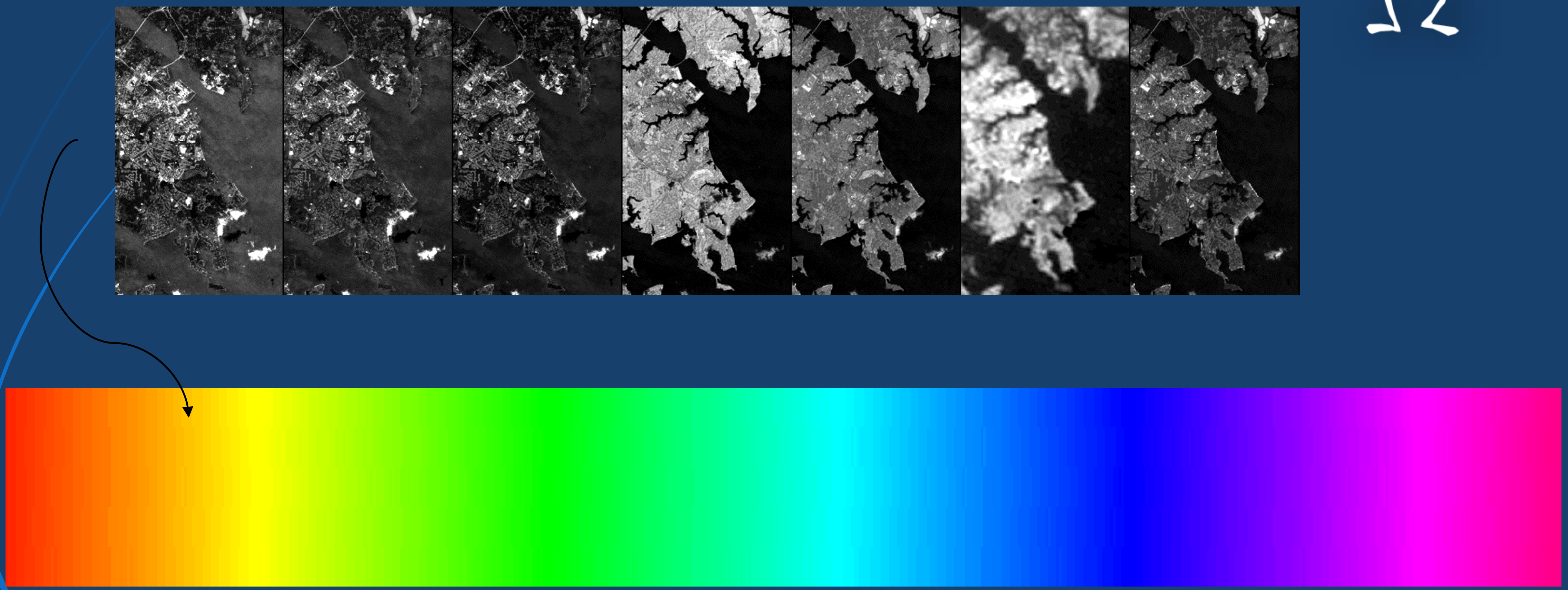
Let's start!
Digital Image Processing

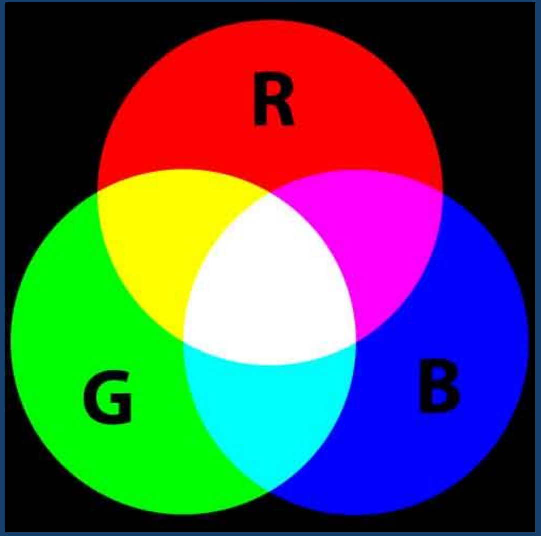
- Download image (Free satellite, Camera, Google earth, ect..)
- Pre-process (Geometric , Radiometric correction)
- Calculate (map algebra, statistics, Veg. Index, ect…)
- Post-process (accuracy assessment, produce printable maps)

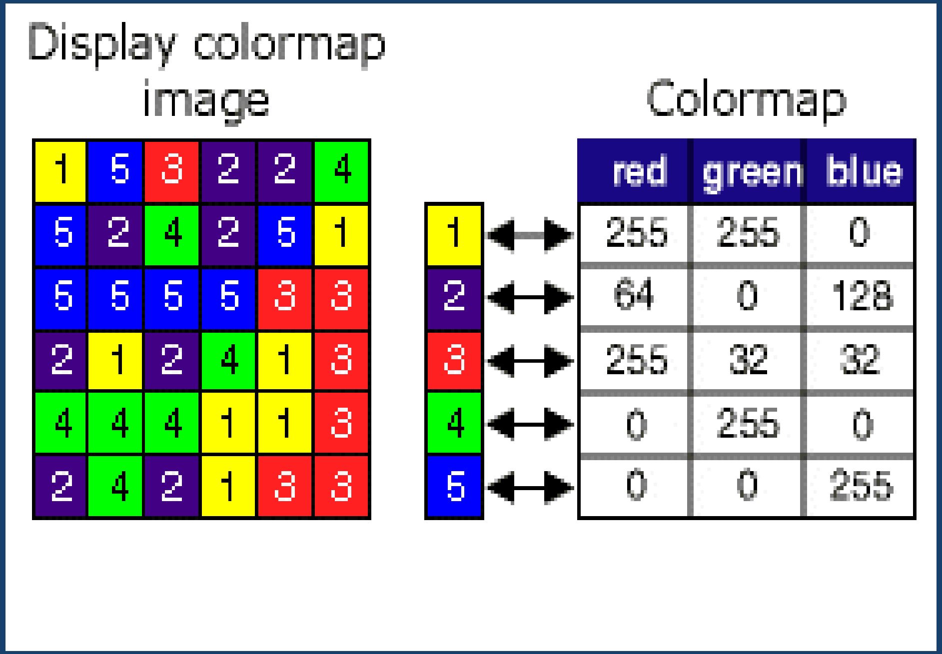
Outline

- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS in precision agriculture
- RS band composite
- Hyperspectral Remote Sensing

Now – how do we make color images of all that grayscale data so we can work with it more easily?



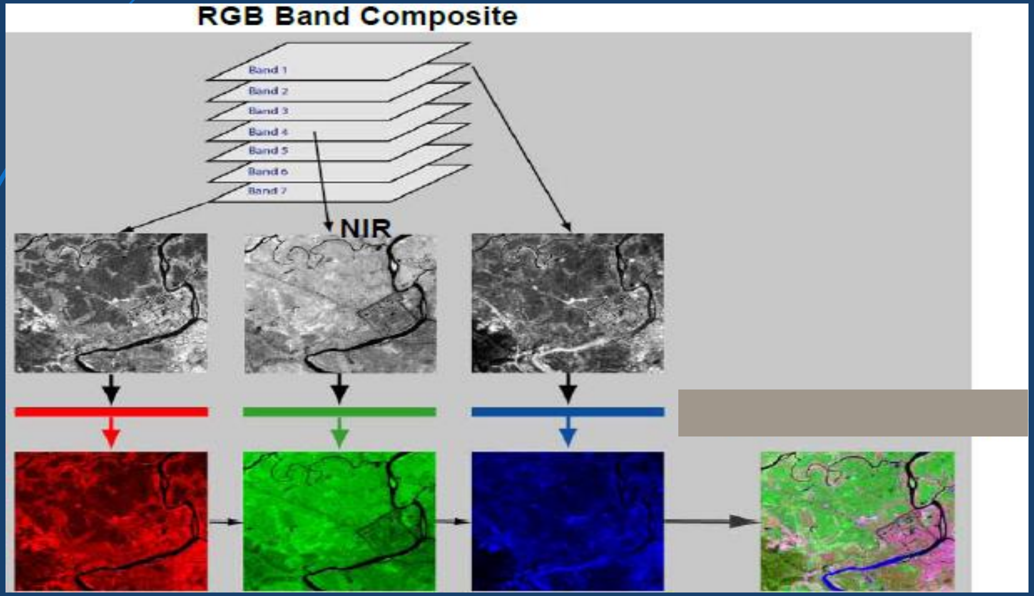


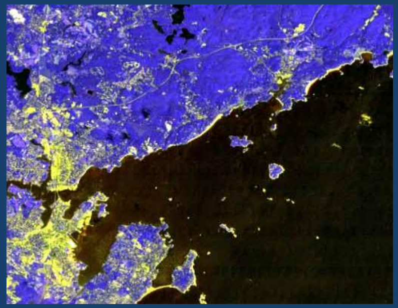


Remember, satelltite uses some bands of ***infrared light.*** And the human eye is ***not sensitive*** to infrared. So to build an image we can see that includes data about infrared light gathered by satellite, we must represent that data with colors we can see: red, green, and blue.

Color Composite

- True color (Natural color)
- False color
- Pseudo color





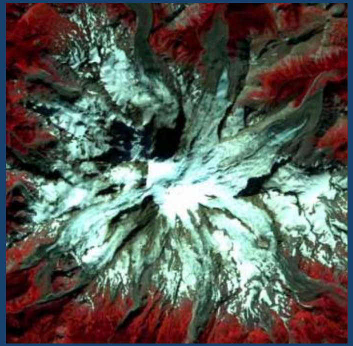
CTCN
CLIMATE TECHNOLOGY CENTRE & NETWORK

True-Color Composite (3,2,1)

True-color composite images approximate the range of vision for the human eye, and hence these images appear to be close to what we would expect to see in a normal photograph. True-color images tend to be low in contrast and somewhat hazy in appearance. This is because blue light is more susceptible than other bandwidths to scattering by the atmosphere. Broad-based analysis of underwater features and landcover are representative applications for true-color composites.

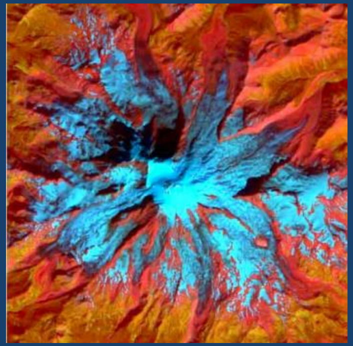
Near Infrared Composite (4,3,2)

Adding a near infrared (NIR) band and dropping the visible blue band creates a near infrared composite image. Vegetation in the NIR band is highly reflective due to chlorophyll, and an NIR composite vividly shows vegetation in various shades of red. Water appears dark, almost black, due to the absorption of energy in the visible red and NIR bands.



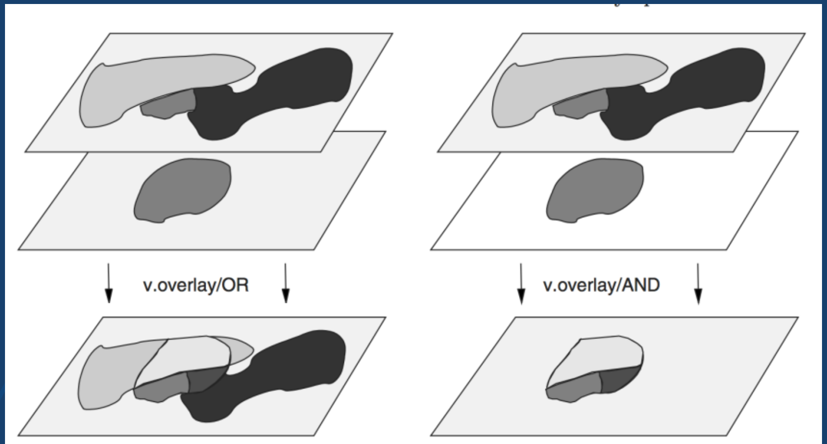
Shortwave Infrared Composite (7,4,3 or 7,4,2)

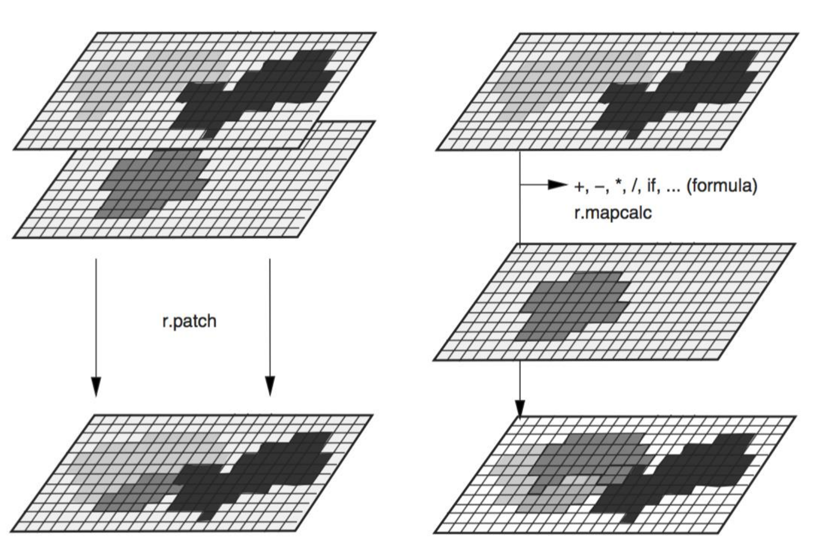
A shortwave infrared composite image is one that contains at least one shortwave infrared (SWIR) band. Reflectance in the SWIR region is due primarily to moisture content. SWIR bands are especially suited for camouflage detection, change detection, disturbed soils, soil type, and vegetation stress.



Mount Rainier

Map Calculation





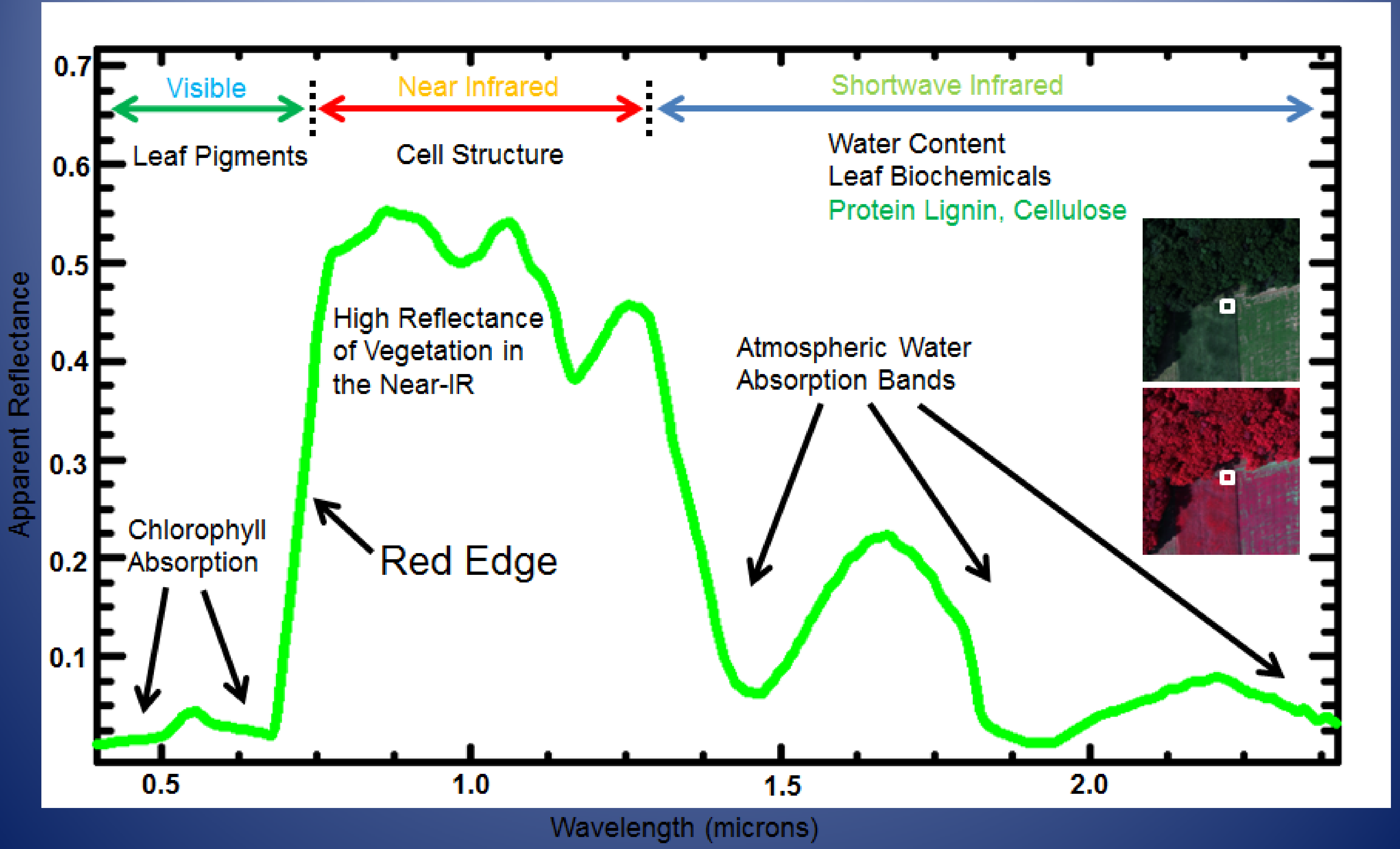
- intersecting vector data using v.overlay with OR and AND operators
- a map merge using r.patch (left) and r.mapcalc (right). The module r.patch patches on basis of overlays, while r.mapcalc combines the raster maps based on a user defined expression

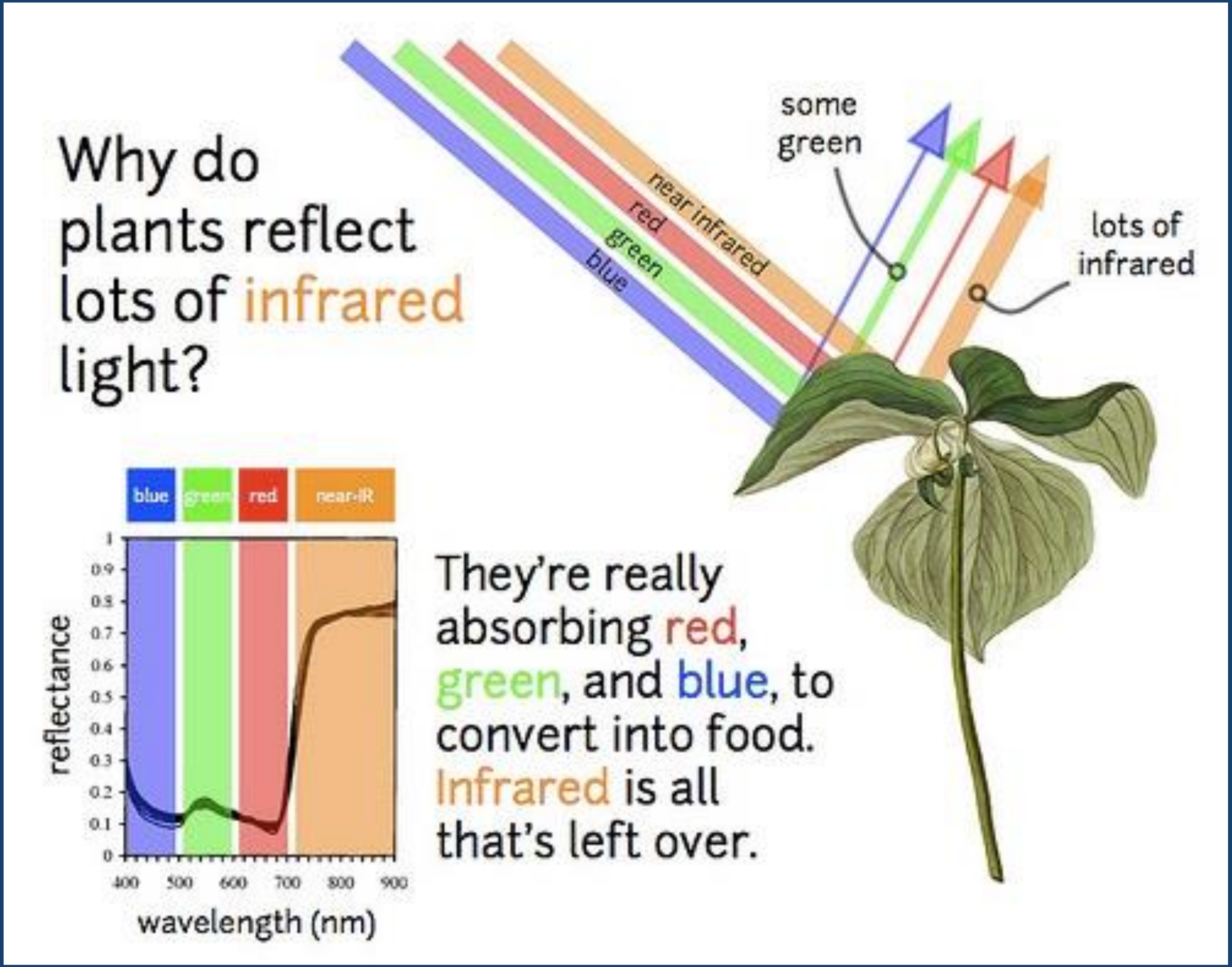
Spectral indices

Indices be grouped by feature type:

- Vegetation Indices
- Geology Indices
- Burn Indices
- Miscellaneous Indices

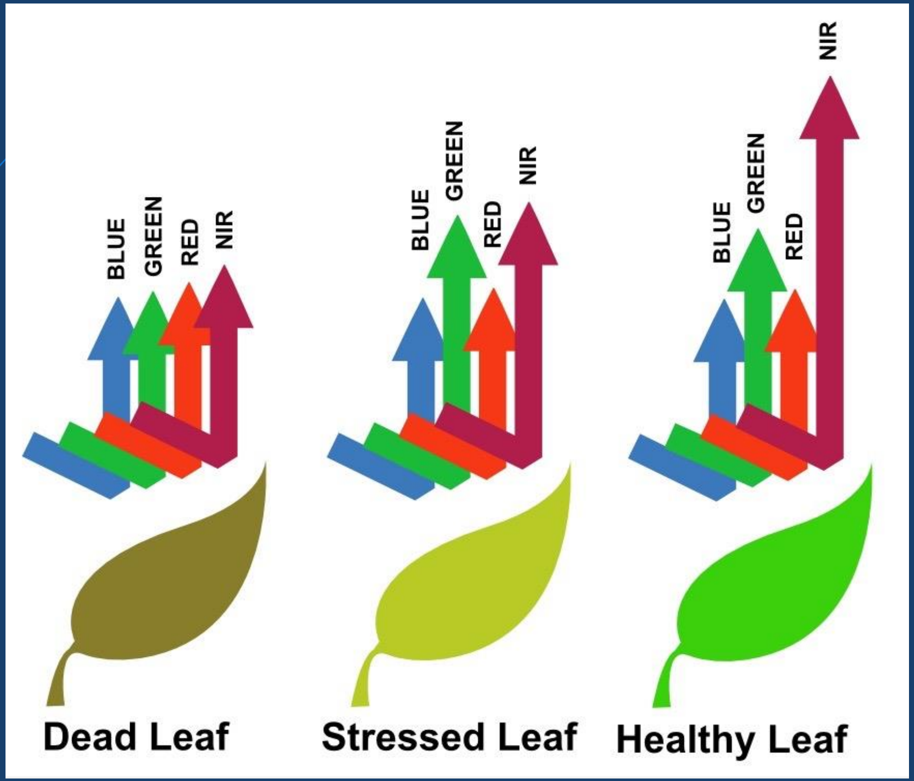
The Vegetation Spectrum in Detail

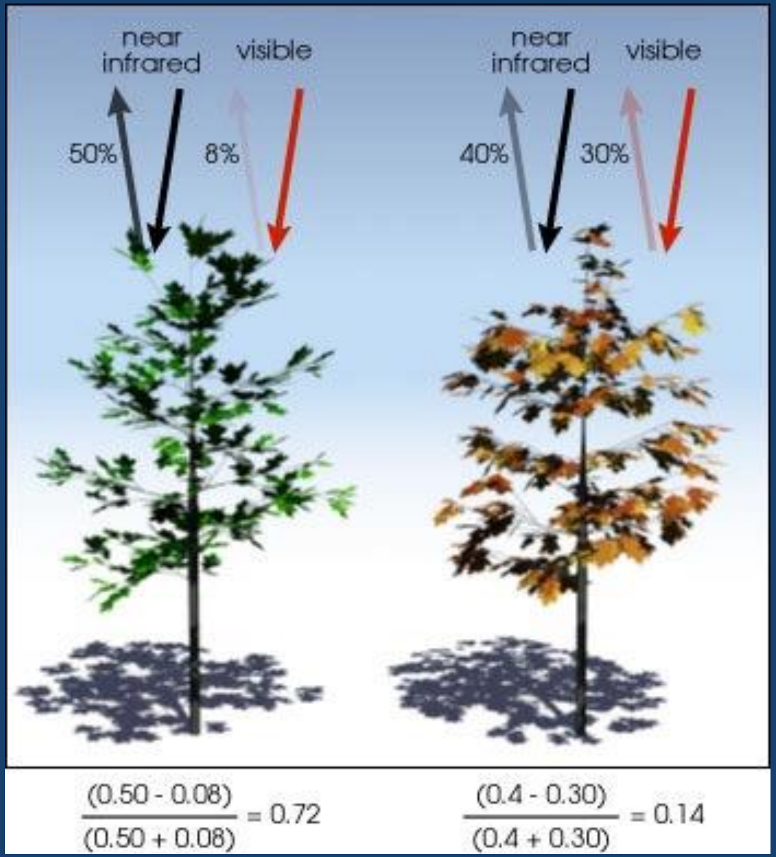



Why do plants reflect lots of infrared light?
near infrared
red
green
blue
some green
lots of infrared
blue
green
red
near-IR
reflectance
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
400
500
600
700
800
900
wavelength (nm)
They're really absorbing red, green, and blue, to convert into food. Infrared is all that's left over.

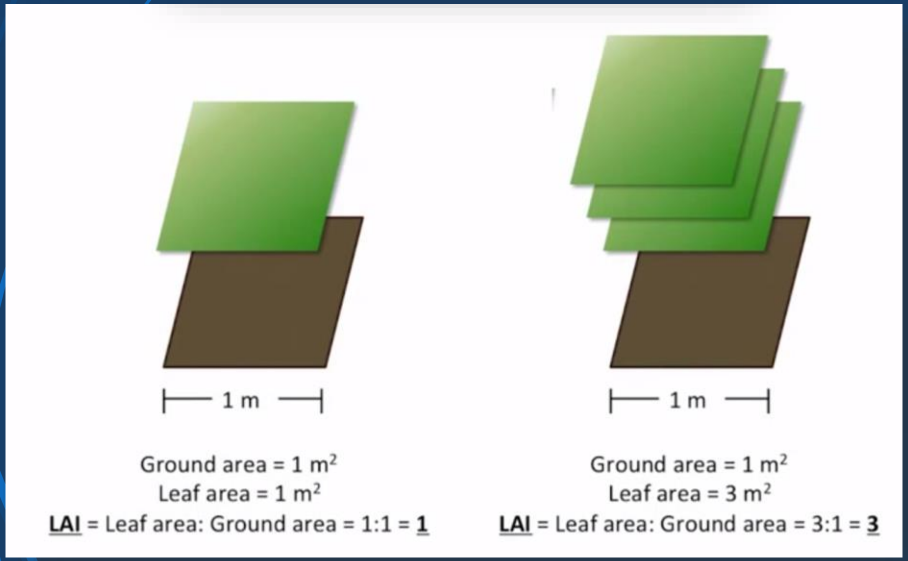
The difference of red and NIR measurements divided by their sum is **normalized difference VI ("NDVI")**

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

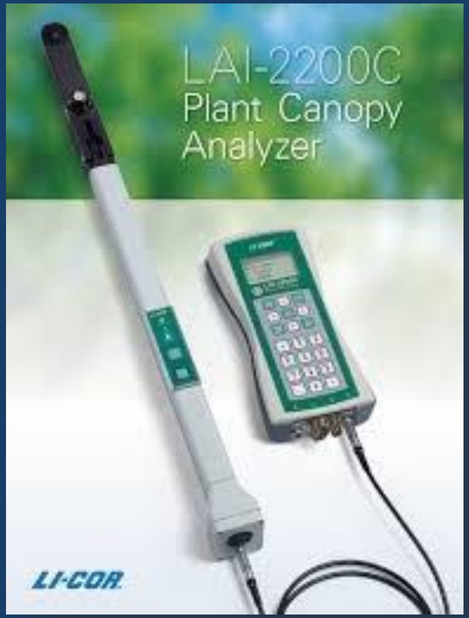




Leaf Area Index (LAI)



- LAI can estimate by remote sensed image!!
- LAI relate to Biomass



Many kinds of Index

- Soil and Vegetation indexes for mineral and biochemical estimation calculated from multispectral and hyperspectral

Structural Vegetation Indexes	**Equation**	**Reference**
Normalized Difference Vegetation Index (NDVI)	$NDVI = (R_{NIR} - R_{red})/(R_{NIR} + R_{red})$	Rouse et al. (1974)[9]
Modified Triangular Vegetation Index (MTVI1)	$MTVI1 = 1.2 * [1.2 * (R_{800} - R_{550}) - 2.5 * (R_{670} - R_{550})]$	Haboudane et al. (2004)[8]
Modified Triangular Vegetation Index (MTVI2)	$MTVI2 = \frac{1.5 * [1.2 * (R_{800} - R_{550}) - 2.5 * (R_{670} - R_{550})]}{\sqrt{(2 * R_{800} + 1)^2 - (6 * R_{800} - 5 * \sqrt{R_{670}}) - 0.5}}$	Haboudane et al. (2004)[8]
Renormalized Difference Vegetation Index (RDVI)	$RDVI = (R_{800} - R_{670}) / \sqrt{(R_{800} + R_{670})}$	Rougean and Breon, (1995)[34]
Simple Ratio Index (SR)	$SR = R_{NIR}/R_{red}$	Rouse et al. (1974)[9]
Modified Simple Ratio (MSR)	$MSR = \frac{R_{NIR}/R_{red} - 1}{(R_{NIR}/R_{red})^{0.5} + 1}$	Chen (1996)[35]
Modified Chlorophyll Absorption in Reflectance Index ($MCARI_1$)	$MCARI1 = 1.2 * [2.5 * (R_{800} - R_{670}) - 1.3 * (R_{800} - R_{550})]$	Daughtry et al. (2000)[36]
Modified Chlorophyll Absorption in Reflectance Index ($MCARI_2$)	$MCARI2 = \frac{1.5 * [2.5 * (R_{800} - R_{670}) - 1.3 * (R_{800} - R_{550})]}{\sqrt{(2 * R_{800} + 1)^2 - (6 * R_{800} - 5 * \sqrt{R_{670}}) - 0.5}}$	Daughtry et al. (2000)[36]
Soil Adjusted Vegetation Index (SAVI)	$SAVI = (1+L) * (R_{800} - R_{670})/(R_{800} + R_{670} + L)$ [L ε (0,1)]	Huete (1988)[10]
Transformed Soil-Adjusted Vegetation Index (TSAVI)	$TSAVI = \frac{a(NIR - aRED - b)}{(NIR + aRED - b)}$	Baret et al. (1989)[37]
Modified SAVI with self-adjustment factor L (MSAVI)	$MSAVI = \frac{1}{2}\left[2 * R_{800} + 1 - \sqrt{(2 * R_{800} + 1)^2 - 8 * (R_{800} - R_{670})}\right]$	Qi et al. (1994)[38]
Optimized Soil-Adjusted Vegetation Index (OSAVI)	$OSAVI = (1 + 0.16) * (R_{800} - R_{670}) / (R_{800} + R_{670} + 0.16)$	Rondeaux et al. (1996)[39]

CTCN
CLIMATE TECHNOLOGY CENTRE & NETWORK

Chlorophyll Indexes	**Equation**	**Reference**
Transformed CARI (TCARI)	$TCARI = 3*[(R_{700} - R_{670}) - 0.2*(R_{700} - R_{550})*(R_{700}/R_{670})]$	Haboudane et al (2002)[40]
Triangular Vegetation Index (TVI)	$TVI = 0.5*[120*(R_{750} - R_{550}) - 200*(R_{670} - R_{550})]$	Broge and Leblanc (2000)[41]
Photochemical Reflectance Index (PRI)	$PRI_1 = (R_{528} - R_{567})/(R_{528} + R_{567})$ $PRI_2 = (R_{531} - R_{570})/(R_{531} + R_{570})$	Gamon et al. (1992)[42]
Cellulose Adsorption Index (CAI)	$CAI = 0.5(R_{2020} + R_{2200}) - R_{2100}$	Daughtry et al.(1995)[43]

Vegetation Water Indexes	**Equation**	**Reference**
Normalized Difference Water Index (NDWI)	$NDWI=(R_{860}-R_{1240})/(R_{860}+R_{1240})$	Gao, (1996)[44]
Simple Ratio Water Index (SRWI)	$SRWI=R_{858}/R_{1240}$	Zarco-Tejada et al., (2003)[45]
Shortwave Infrared Water Stress Index (SIWSI)	$SIWSI = \rho 6 - \rho 2 / \rho 6 + \rho 2 \quad \rho 2 = 0.841 - 0.876; \rho 6 = 1.628 - 1.652$	Fensholt and Sandholt (2003)[46]
Plant Water Index (PWI)	$PWI= R_{970}/R_{900}$	Peñuelas et al. (1997)[47]

Spectral Absorption Metrics	**Equation**	**Reference**
σ = shape parameter as defined by the inverted-Gaussian curve-fit model	$g(\lambda) = R_{\lambda_i} + (R_{\min 500-600} - R_{\max 700-730}) * \exp\left(\frac{-(\lambda_i - \lambda_{\min 500-600})^2}{2\sigma^2}\right)$	Miller et al. (1990)[20]; Bonham-Carter (1988)[19]
Soil Moisture Gaussian Model (SMGM)	$g(\lambda) = R_{\lambda_i} + (R_{2800} - R_{\max 1200-1800}) \exp\left(\frac{-(\lambda_i - \lambda_{2800})^2}{2\sigma^2}\right)$	Whiting et al. (2004)[33]
Continuum Removal Band Depth	$D_B \equiv \frac{R_c - R_b}{R_c}$	Clark and Roush (1984)[15]
Band depth Normalized on Center (BNC)	$D_n = D_B / D_c$	Kokaly and Clark (1999)[17]
Band depth Normalized on Area (BNA)	$D_n = D_B / A$	Curran et al. (2001)[18]

PA applications (narrow-band data)

- soil management zoning,
- weed sensing and control,
- crop nitrogen stress detection,
- crop yield estimation,
- pest and disease detection
- soil properties (e.g., organic matter, moisture, salinity) and/or mineral contents (e.g., Ca, Mg, P, and Zn), and/or other properties (e.g., texture, color).

The best wavebands for specific applications

- **Nitrogen status evaluation** : 430, 550, 670 (or 680), and 780 (or 801) nm
- **LAI and percent green cover** : 674 and 755 nm
- **Biomass and yield** : 680 and 900
- **Crop chlorophyll content prediction** : 550, 670, 700, and 800 nm
- **Vegetation water content :** 1300–2500 nm
- **Pest and disease infestation** : 745 nm or a combination of 531 and 570 nm

To select waveband, a generic approach such as stepwise discriminant analysis, artificial neural networks (ANN), or other multivariate statistical procedures can be used.

Outline

- Introduction
- Basics of remote sensing (RS)
- Electromagnetic wave
- Thermal imaging
- RS in precision agriculture
- RS band composite
- Hyperspectral Remote Sensing

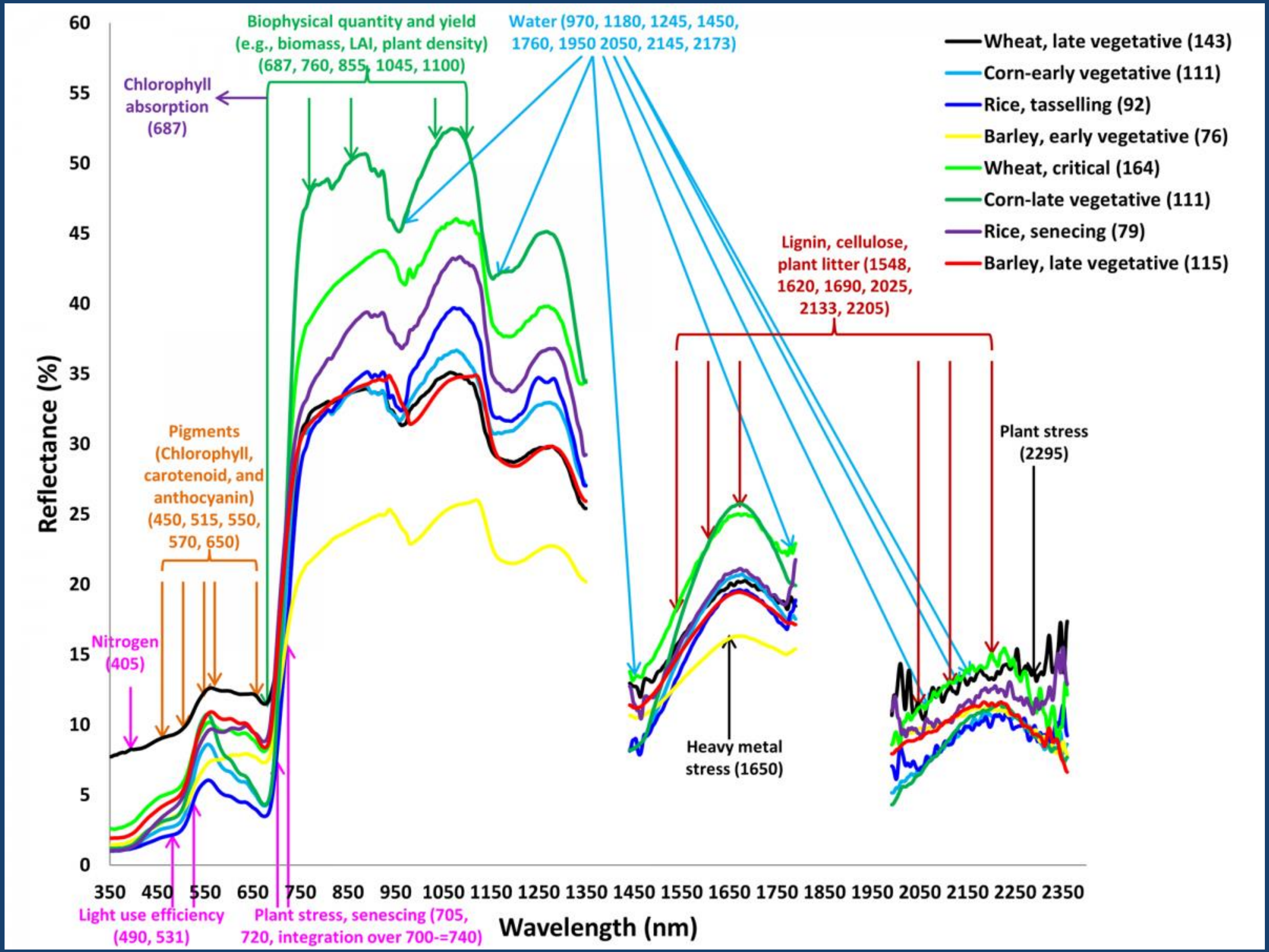
Hyperspectral Remote Sensing

"Hyperspectral data allows us to provide more specific actionable information to our clients who manage high-value crops,"

- Airborne: AVIRIS, HYDICE, AISA, HyMAP, ARES, CASI 1500, MIVIS, AisaEAGLET

- Satellite: Hyperion onboard EO-1, CHRIS onboard PROBA, ARTEMIS onboard TacSat-3

Hyperspectral data & Vegetation



Crop yield estimation in cotton

Michael L. Whiting , SPIE, 2006

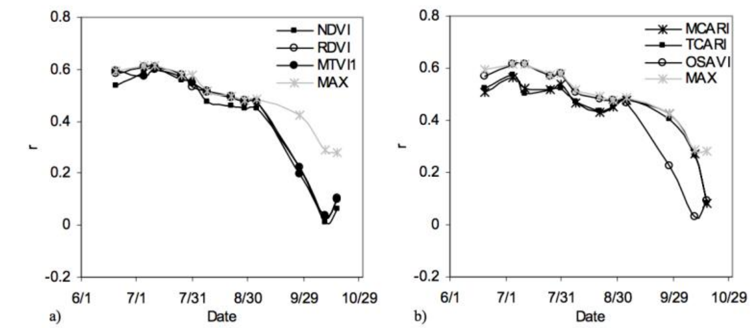


Figure 5. Correlation coefficients (r) obtained between spatial yield data and hyperspectral indices as function of time. The best correlation coefficient for any index is labeled MAX, compared with indices (a) NDVI, RDVI, MTVI1, (b) MCARI, TCARI, OSAVI [11].

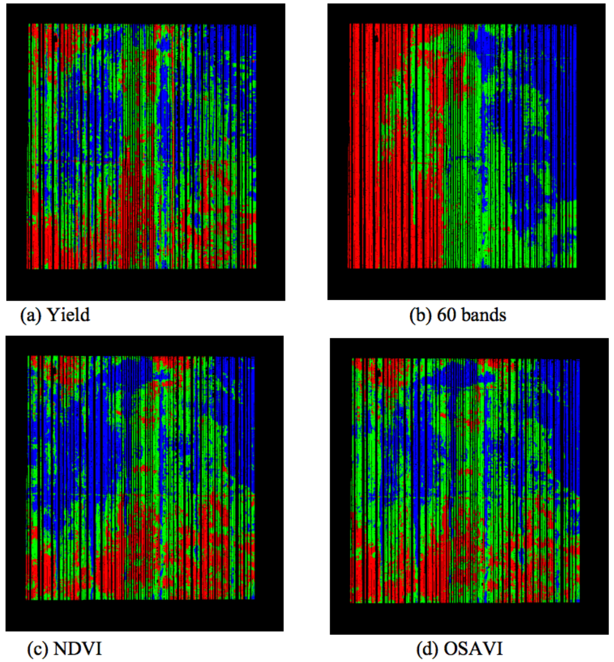


Figure 6. Unsupervised *K-means* clustering method for low (red), medium (green) and high yield (blue) classes calculated from the hyperspectral airborne image that obtained the highest correlation with yield (5 July 2001) [11].

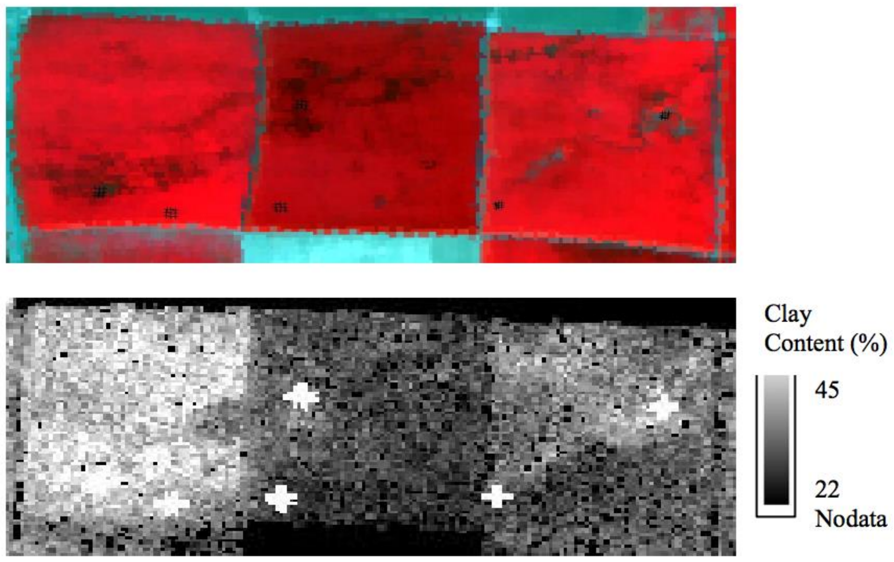
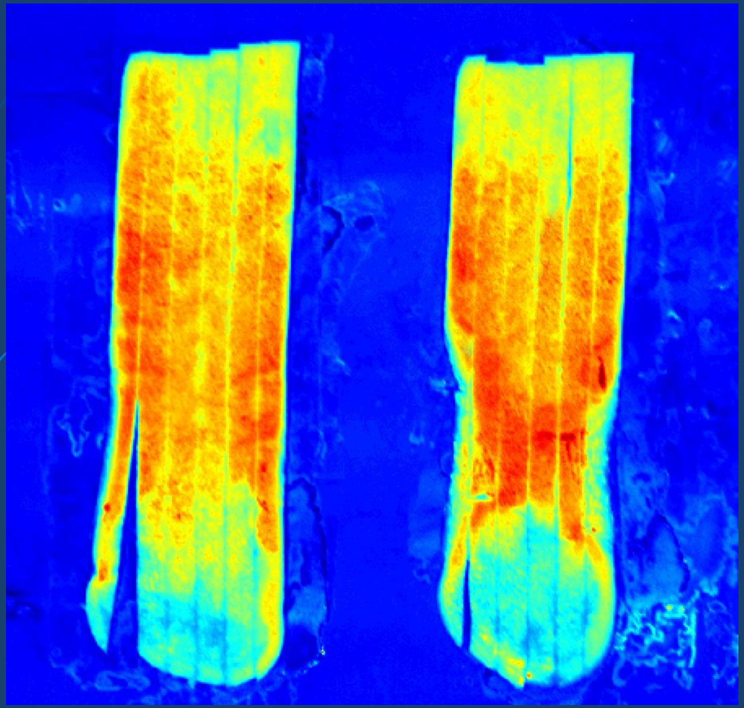


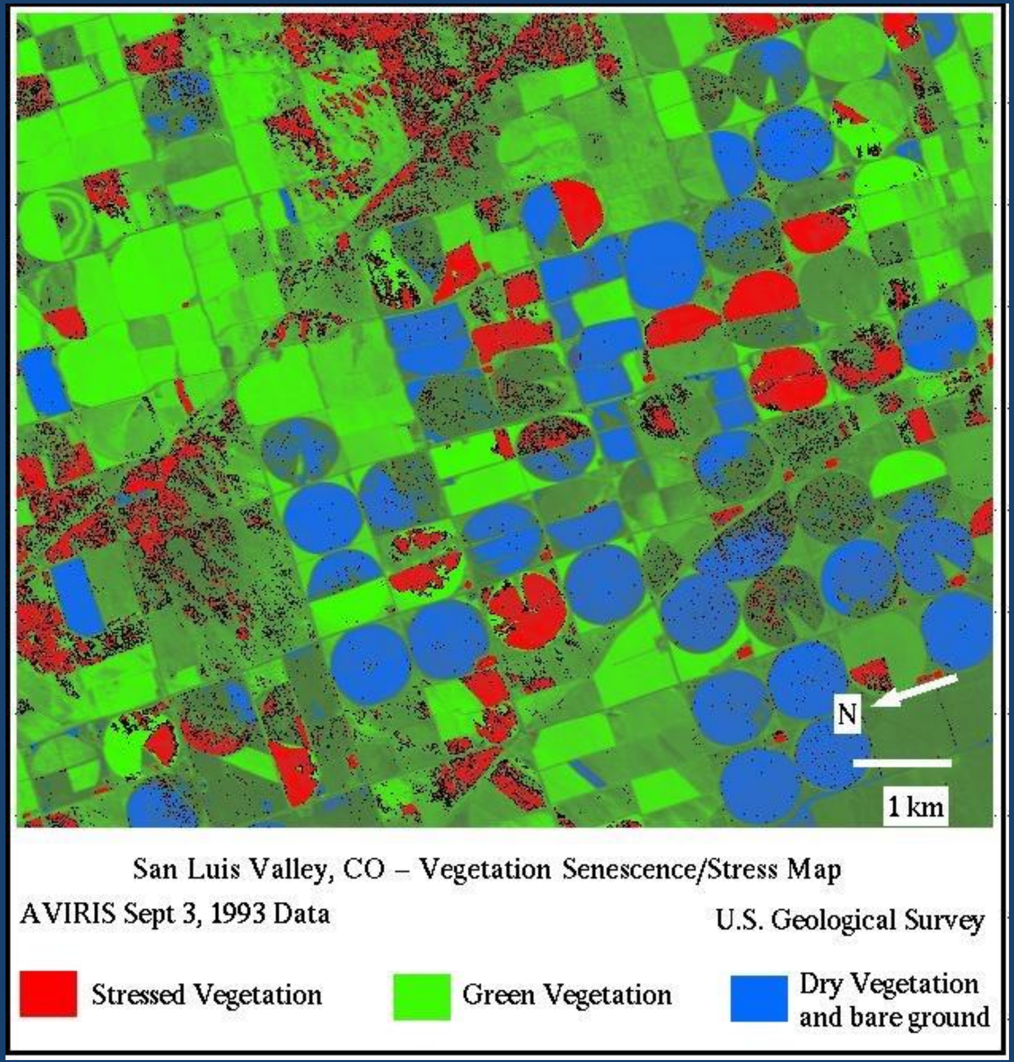
Figure 7 a) AVIRIS, 28 August 1999, false color infrared image (CIR) of full canopy cotton of Lemoore project site, b) AVIRIS image, 5 May 2002, in gray scale of clay contents of bare soil fields [53].

Plant and water indexes provided good predictors of cotton condition as harvest approached. With hyperspectral data, absorption modeling and strength measurements are viable means of estimating plant moisture and nutrient status. Measuring soil mineral abundance can be improved by accounting for the effect of soil moisture on the spectra. Further research in use of imaging spectroscopy will lead to higher precision as producers refine their prescription models and application techniques. Our field data, and collaborators airborne imagery and field data on plant mapping and canopy density, make a tremendous dataset that will take additional time to process. Continued investigations into irrigation scheduling using crop reflectance over a broad range of water contents, readiness for harvest aid chemical applications, and related field measurements will lead to improved accuracy in providing this key management

Detection of Nutrient Deficiencies



Hyperspectral image of "sugar end" potato strips shows invisible defects



Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation *

405	*Nitrogen, senescing*: sensitivity to changes in leaf nitrogen. Significant absorption due to chlorophyll and carotenoids; reflectance changes due to pigments is moderate to low. Sensitive to senescing (yellow and yellow green leaves)
450	*Chlorophyll, carotenoids, senescing*: sensitive to chlorophyll a and b. Significant absorption due to chlorophyll and carotenoids; reflectance changes due to pigments is moderate to low. Sensitive to senescing (yellow and yellow green leaves)
490	*Carotenoid, LUE, stress in vegetation*: Sensitive to senescing and loss of chlorophyll\browning, ripening, crop yield, and soil background effects

515	*Pigments* (*carotenoid, chlorophyll, anthocyanins*), *nitrogen, vigor*: positive change in reflectance per unit change in wavelength of this visible spectrum is maximum around this green waveband
531	*LUE, xanophyll cycle, stress in vegetation, pest and disease*: Senescing and loss of chlorophyll\ browning, ripening, crop yield, and soil background effects
550	*Anthocyanins, chlorophyll, LAI, nitrogen, LUE*: sensitive to numerous vegetation variables
570	*Pigments* (*anthrocyanins, chlorophyll*), *nitrogen*: negative change in reflectance per unit change in wavelength is maximum as a result of sensitivity to vegetation vigor, pigment, and N

* A nominal 5 nm waveband width can be considered optimal for obtaining best results with a forementioned wavebands as band centers. So, for 970 nm waveband center, we can have a band of range of 968–972 nm. Ideal bandwidth is about 3 nm.

But, noise levels in lower bandwidths can be a significant problem.

Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation * (II)

650	*Pigment, nitrogen*: moderate to high sensitivity to changes in pigments (chlorophyll, anthocyanins) and nitrogen
687	*Biophysical quantities, chlorophyll, solar induced chlorophyll fluorescence*: LAI, biomass, yield, crop type\discrimination. Greatest soil-crop contrast. Actively induced emission peaks in red\ far-red 687 and 740 nm

705	*Stress in vegetation detected in red edge, stress, drought*: Nitrogen stress, crop stress, crop growth stage studies. Blueshift in case of stress. Shift toward NIR for healthy vegetation
720	*Stress in vegetation detected in red edge, stress, drought*: Nitrogen stress, crop stress, crop growth stage studies. Blueshift in case of stress. Shift toward NIR for healthy vegetation
700–740	*Chlorophyll, senescing, stress, drought*: first-order derivative index over 700–740 nm has applications in vegetation studies (e.g., blueshift during stress and redshift during healthy growth)

* A nominal 5 nm waveband width can be considered optimal for obtaining best results with aforementioned wavebands as band centers. So, for 970 nm waveband center, we can have a band of range of 968–972 nm. Ideal bandwidth is about 3 nm.

But, noise levels in lower bandwidths can be a significant problem.

Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation * (III)

760	*Biomass, LAI, Solar-induced passive emissions*: NIR reference band for many indices. Solar-induced passive emissions with retrievals made in O_2 atmospheric features at 687 and 760 nm
855	*Biophysical/biochemical quantities, heavy metal stress*: LAI, biomass, yield, crop\discrimination, chlorophyll, anthocyanin, carotenoids. Sensitive to heavy metal stress due to reduction in chlorophyll. High stability in NIR band for developing indices
970	*Water absorption band*: most prominent water absorption trough. Also useful in quantifying most biophysical and biochemical properties
1045	*Biophysical and biochemical quantities*: leaf area index, wet and dry biomass, plant height, grain yield, crop type, crop discrimination, total chlorophyll, anthocyanin, carotenoids

1100	*Biophysical quantities*: sensitive to biomass and leaf area index. A point of most rapid rise in spectra with unit change in wavelength in far near infrared (FNIR)
1180	*Water absorption band*
1245	*Water sensitivity*: water band index, leaf water, biomass. Reflectance peak in 1050–1300 nm

* A nominal 5 nm waveband width can be considered optimal for obtaining best results with aforementioned wavebands as band centers. So, for 970 nm waveband center, we can have a band of range of 968–972 nm. Ideal bandwidth is about 3 nm.

But, noise levels in lower bandwidths can be a significant problem.

Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation * (IV)

1450	*Water absorption band*: very high moisture absorption trough in early short wave infrared (ESWIR). Use as an index with 1548 or 1620 or 1690 nm
1548	*Lignin, cellulose*: plant biochemical properties
1620	*Lignin, cellulose*: plant biochemical properties. Peak reflectance in SWIR 1 for vegetation
1650	*Heavy metal stress, Moisture sensitivity*: Heavy metal stress due to reduction in chlorophyll. Sensitivity to plant moisture fluctuations in ESWIR. Use as an index with 1548 or 1620 or 1690 nm
1690	*Lignin, cellulose, sugar, starch, protein*: plant biochemical properties
1760	*Water absorption band, senescence, lignin, cellulose*: high to moderate moisture absorption in ESWIR for moisture in plant leaves. Use as an index with 1548 or 1620 or 1690 nm

1950	*Water absorption band*: highest moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Affected by noise at times
2025	*Litter (plant litter), lignin, cellulose*: litter-soil differentiation
2050	*Water absorption band*: high moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Not affected by noise
2133	*Litter (plant litter), lignin, cellulose*: typically highest reflectivity in FSWIR for vegetation. Litter-soil differentiation
2145	*Water absorption band*: moderate moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Not affected by noise
2173	*Water absorption band*: moderate to low moisture absorption trough in FSWIR. Use as an index with any one of 2025, 2133, and 2213 nm. Not affected by noise

* A nominal 5 nm waveband width can be considered optimal for obtaining best results with aforementioned wavebands as band centers. So, for 970 nm waveband center, we can have a band of range of 968–972 nm. Ideal bandwidth is about 3 nm.

But, noise levels in lower bandwidths can be a significant problem.

Optimal Hyperspectral Narrow bands in 400–2500 nm to Study Vegetation * (V)

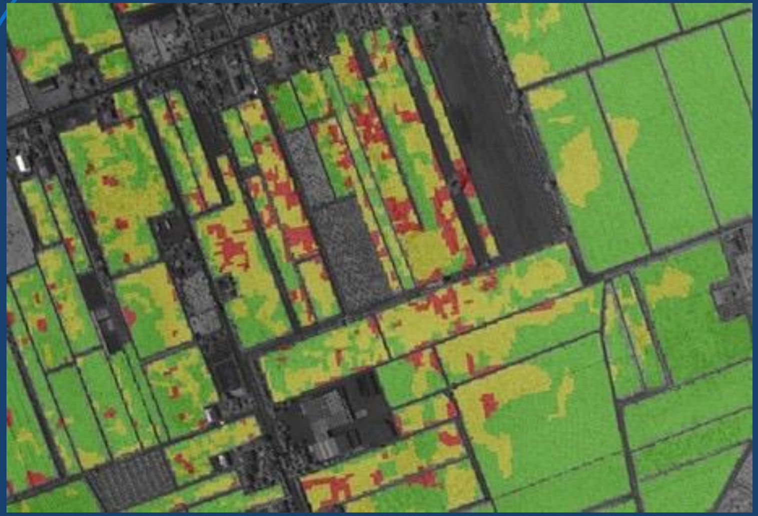
2205	*Litter, lignin, cellulose, sugar, startch, protein; Heavy metal stress*: typically, second highest reflectivity in FSWIR for vegetation. Heavy metal stress due to reduction in chlorophyll
2295	*Stress and soil iron content*: sensitive to soil background and plant stress

* A nominal 5 nm waveband width can be considered optimal for obtaining best results with aforementioned wavebands as band centers. So, for 970 nm waveband center, we can have a band of range of 968–972 nm. Ideal bandwidth is about 3 nm.

But, noise levels in lower bandwidths can be a significant problem.

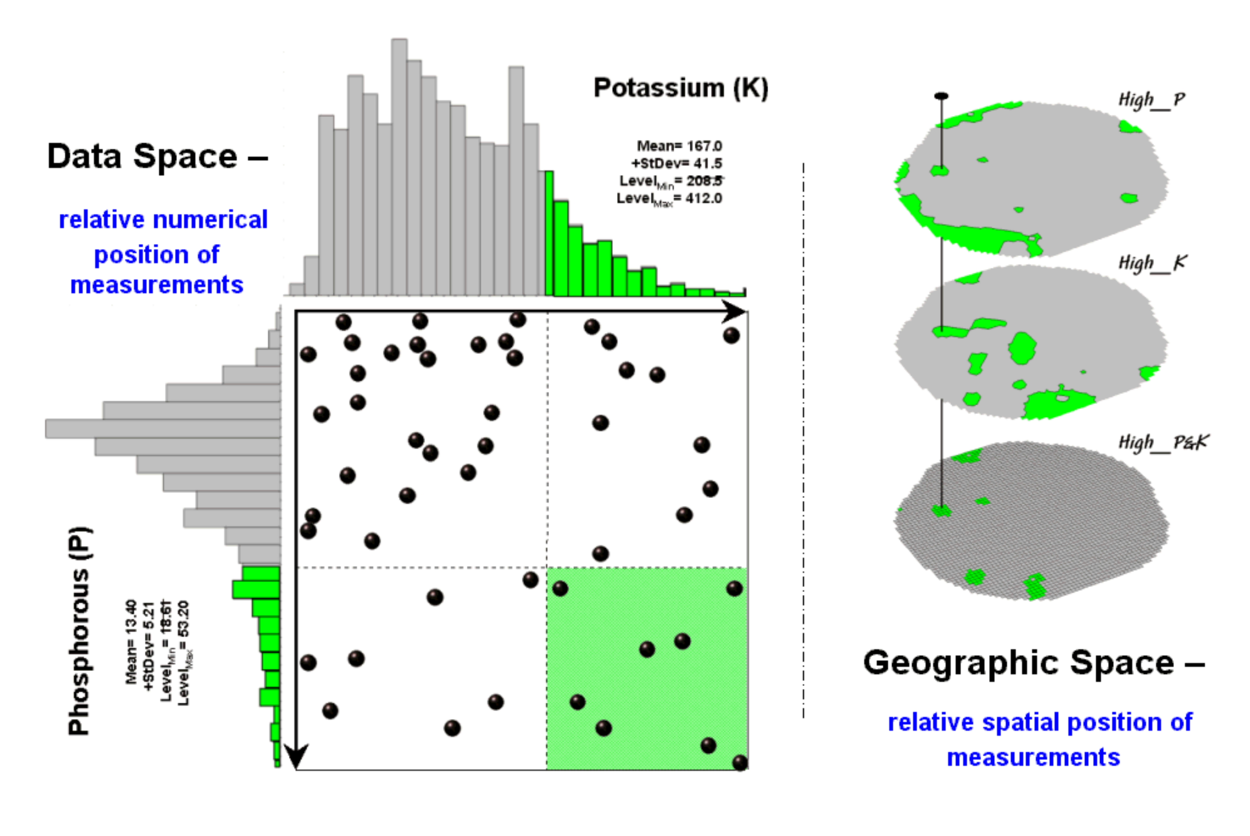
Infestation

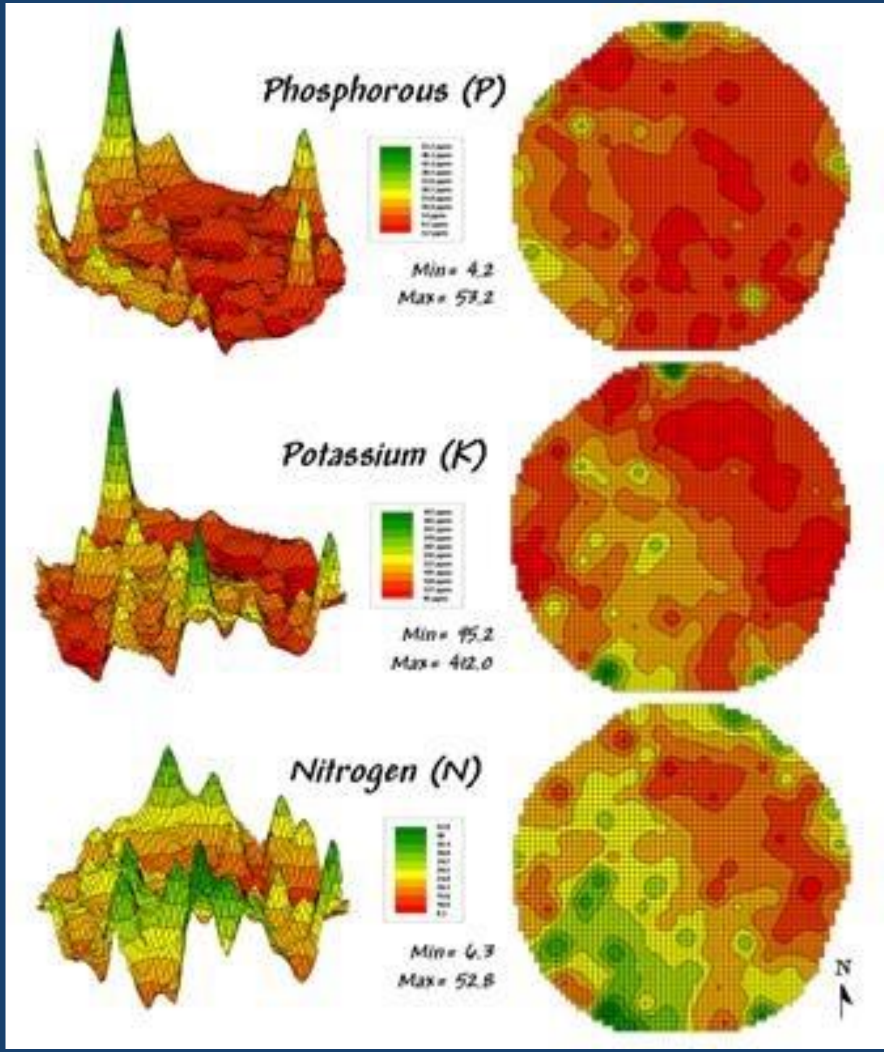
Aerial infra-red image of kiwi fruit areas affected by kiwifruit bacterial canker (Psa)



Geo-referenced map of the study compared the degree of disease previously developed

The spatial distribution N, P and K

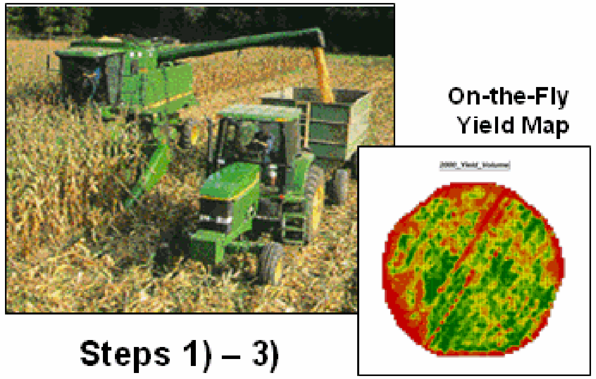




The Precision Ag Process (Fertility)

As a combine moves through a field it…

1) uses GPS to check its location, then
2) checks the yield at that location to
3) create a continuous map of the yield variation every few feet. This map is then…
4) combined with soil, terrain and other maps to
5) derive a "Prescription Map" that is used to
6) adjust fertilization levels every few feet in the field (variable rate application).



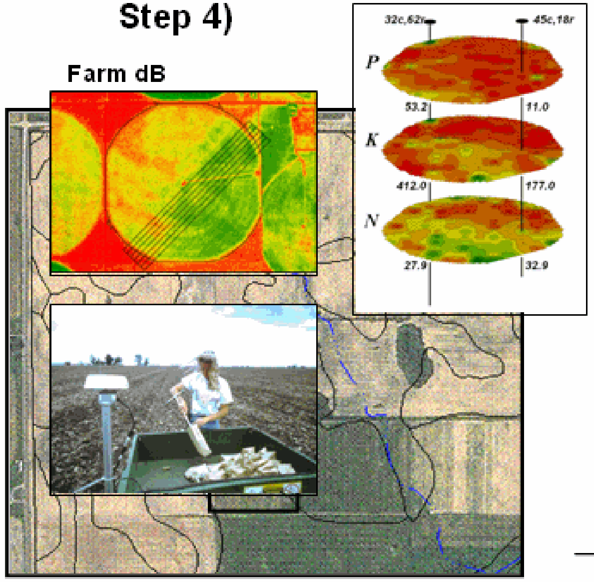
On-the-Fly Yield Map

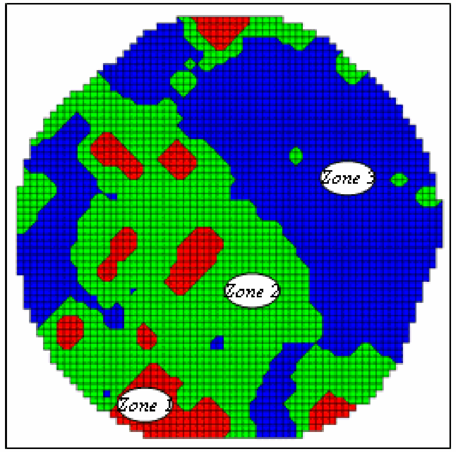
Steps 1) – 3)

Step 4)

Farm dB

Map Analysis





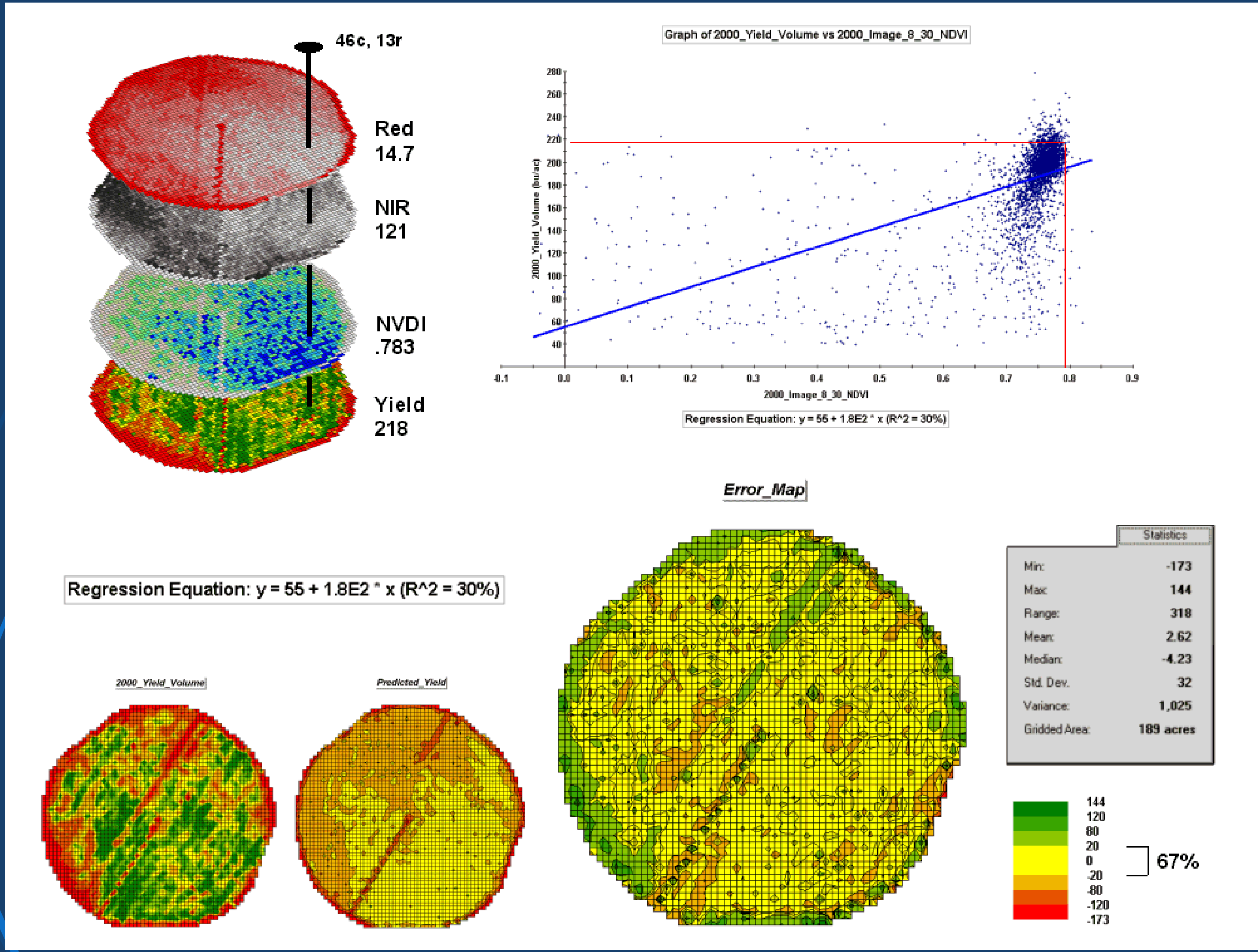
Prescription Map

Step 5)

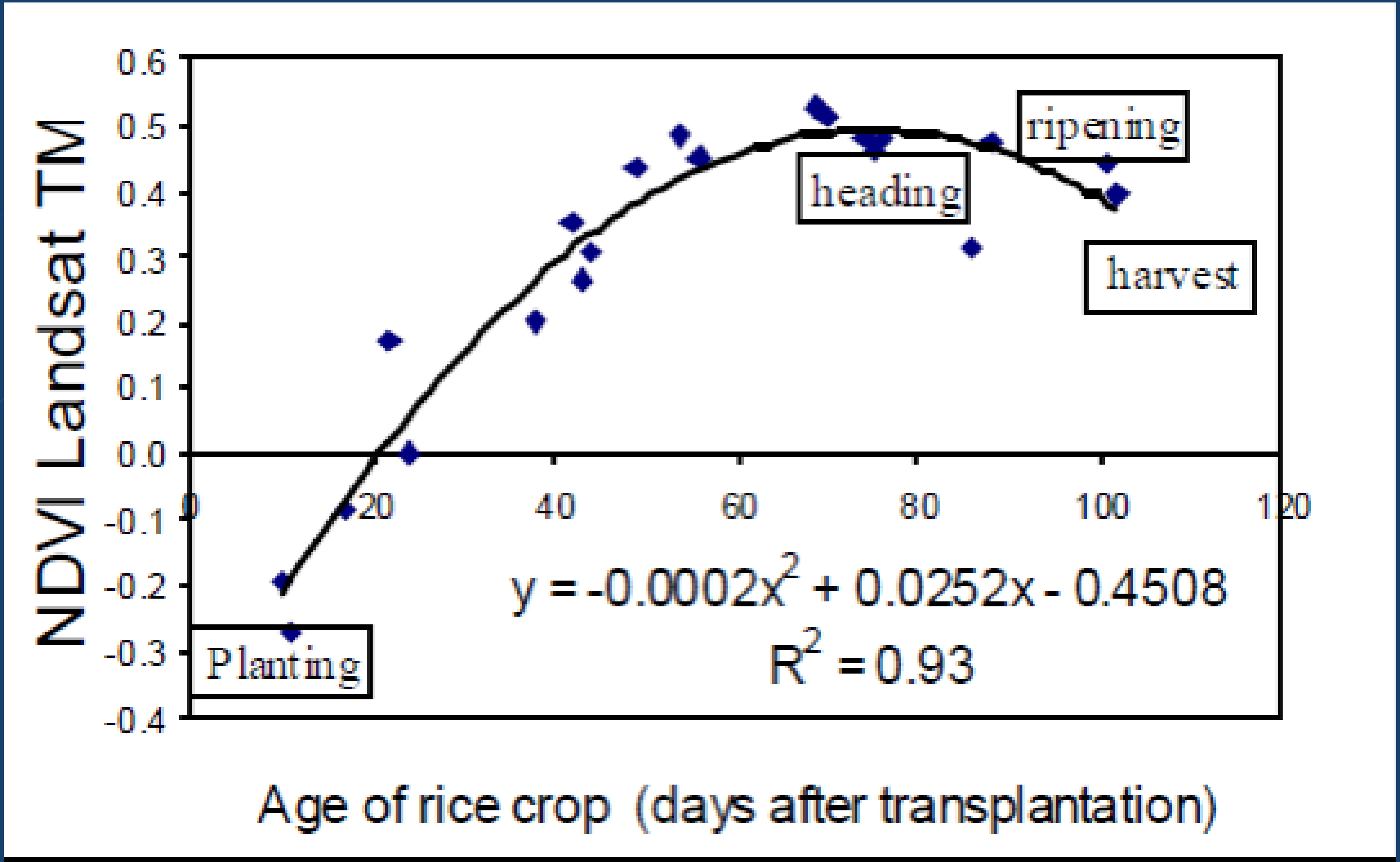
Variable Rate Application

Step 6)

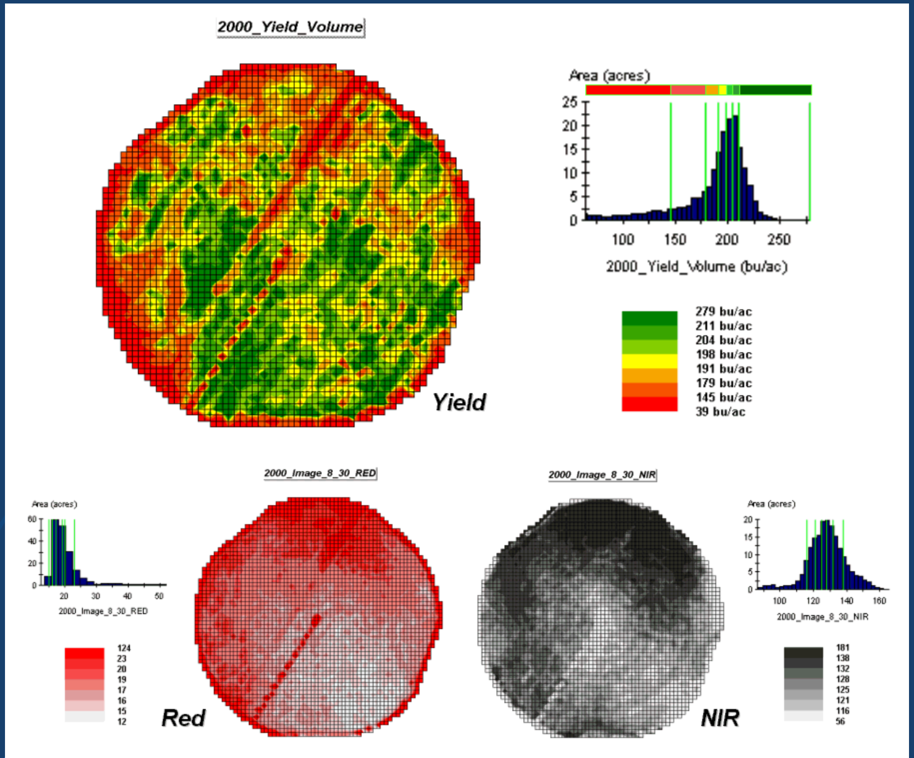
NDVI for Yield Prediction

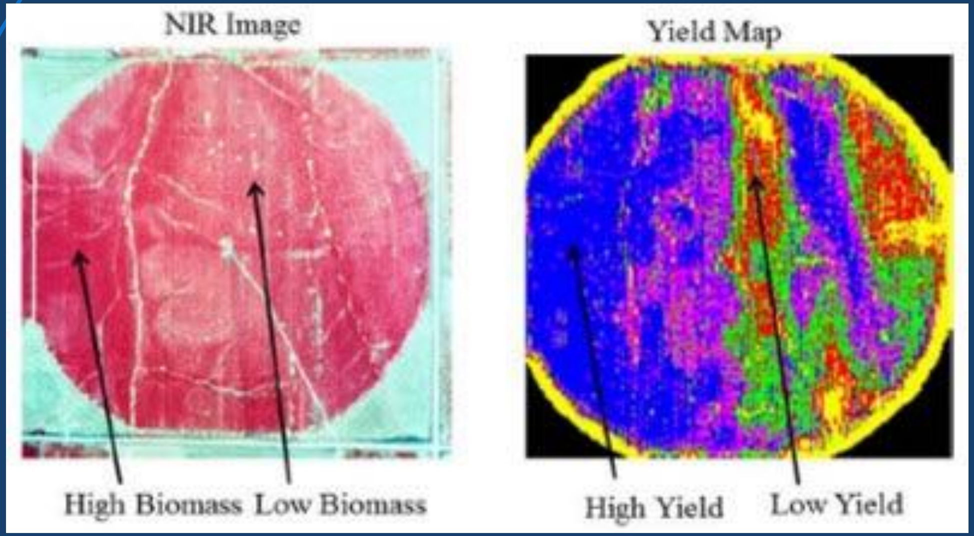


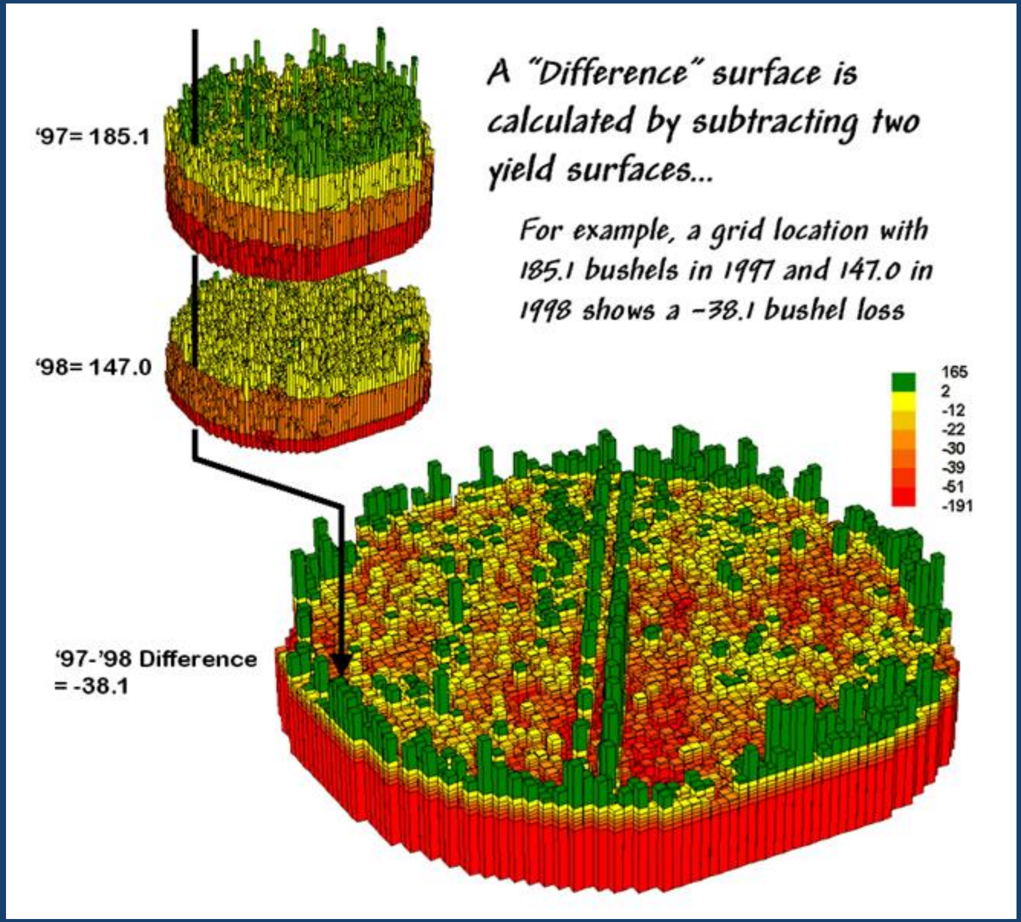
- Regression analysis was used to relate a map of NDVI (derived from remote sensing imagery) to a map of corn yield for a farmer's field. Then the equation was used to derive a map of predicted yield based on the NDVI values and the results evaluated for how well the prediction equation performed



NDVI Landsat TM
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0
20
40
60
80
100
120
ripening
heading
harvest
Planting
y = -0.0002x2 + 0.0252x - 0.4508
R2 = 0.93
Age of rice crop (days after transplantation)







http://www.innovativegis.com/basis/mapanalysis/topic16/topic16.htm

CTCN
CLIMATE TECHNOLOGY CENTRE & NETWORK

Q&A

LAB Session

Please install software before start session!
- QGIS
with openlayers, Semi-Autometic Classification Plugin
- Google Earth pro

Register and login to USGS to download Landsat, sentinel-2